UNIT 10

HUMAN BIOLOGY

CHAPTERS

References to *Scientific American* project ideas are located throughout this unit.

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National Science Teachers Association *sci*LINKS Internet resources are located throughout this unit.

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"The human body is marvelous. It can move freely, act deliberately, and survive under the most variable conditions. Its construction is complex and its requirements many."

From "Exploring Man," from *Behold Man: A Photographic Journey of Discovery Inside the Body,* by Lennart Nilsson in collaboration with Jan Lindberg. English translation copyright © 1974 by Albert Bonniers, Förlag, Stockholm. Reprinted by permission of *Little, Brown and Company.*

Near-perfect coordination of the many organ systems enables humans to play soccer and carry out daily activities.

At six weeks old, this developing human embryo (right) weighs less than 1 g. By eight weeks, all of the major organ systems will be recognizable.

This X ray of a child's hand (below) reveals the hand's many bones.

This researcher, like other scientists around the world, spends many hours in the lab each day searching for safe drugs that can be used to treat human ailments.

Red blood cells within a blood vessel

CHAPTER 45

Skeletal, Muscular, and Integumentary Systems

This X-ray shows a color-enhanced image of the human skull, mandible, teeth, and neck.

SECTION 1

THE HUMAN BODY PLAN

The human body begins to take shape during the earliest stages of embryonic development. While the embryo is a tiny ball of dividing cells, it begins forming the tissues and organs that compose the human body. By the end of its third week, the human embryo has bilateral symmetry and is developing vertebrate characteristics that will support an upright body position.

OBJECTIVES

- **Describe** four types of tissues that make up the human body.
- **Explain** how tissues, organs, and organ systems are organized.
- **Summarize** the functions of the primary organ systems in the human body.
- **Identify** the five human body cavities and the organs that each contains.

VOCABULARY

muscle tissue
skeletal muscle
smooth muscle
cardiac muscle
nervous tissue
neurons
epithelial tissue
connective tissue
matrix
organ
cranial cavity
spinal cavity
diaphragm
thoracic cavity
abdominal cavity
pelvic cavity

BODY TISSUES

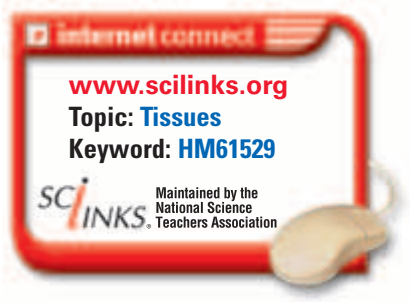
A tissue is a collection of cells that are similar in structure and that work together to perform a particular function. The human body has four main types of tissues: muscle, nervous, epithelial, and connective.

Muscle Tissue

Muscle tissue is composed of cells that can contract. Every function that muscle tissue performs—from creating a facial expression to keeping the eyes in focus—is carried out by groups of muscle cells that contract in a coordinated fashion. The human body has three types of muscle tissue: skeletal, smooth, and cardiac. **Skeletal muscle** moves the bones in your trunk, limbs, and face. **Smooth muscle** handles body functions that you cannot control consciously, such as the movement of food through your digestive system. **Cardiac muscle,** found in your heart, pumps blood through your body. Figure 45-1a, on the following page, shows an illustration of cells of skeletal muscle tissue.

Nervous Tissue

Nervous tissue contains cells that receive and transmit messages in the form of electrical impulses. These cells, called **neurons** (NOO-rahnz), are specialized to send and receive messages throughout the body. Nervous tissue makes up your brain, spinal cord, and nerves. It is also found in parts of sensory organs, such as the retina in your eye. Some nervous tissue senses changes in the internal and external environment. Other nervous tissue interprets the meaning of sensory information. Still other types of nervous tissue cause the body to move in response to sensory information. Coordination of voluntary and involuntary activities and regulation of some body processes are also accomplished by nervous tissue. Figure 45-1b, on the following page, shows an illustration of cells of nervous tissue.



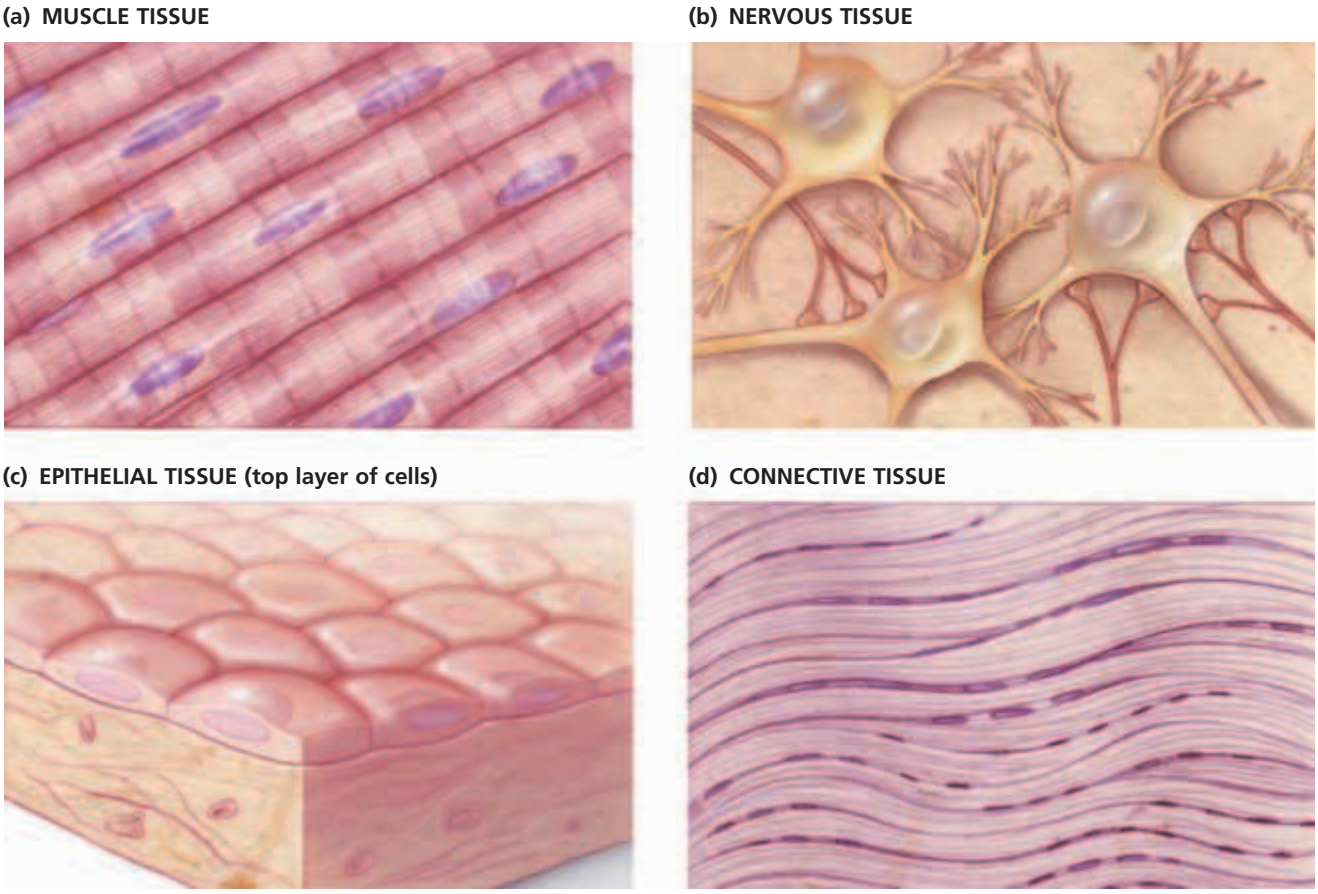


FIGURE 45-1
These four drawings show representative cells of the four main types of tissues in the human body: (a) muscle tissue, (b) nervous tissue, (c) epithelial tissue, and (d) connective tissue.

Epithelial Tissue

Epithelial (ep-uh-THEE-lee-uhl) **tissue** consists of layers of cells that line or cover all internal and external body surfaces. Each epithelial layer is formed from cells that are tightly bound together, often providing a protective barrier for these surfaces. Epithelial tissue is found in various thicknesses and arrangements, depending on where it is located. For example, the epithelial tissue that lines blood vessels is a single layer of flattened cells through which substances can easily pass. But the epithelial tissue that lines the trachea consists of a layer of cilia-bearing cells and mucus-secreting cells that act together to trap inhaled particles. The most easily observed epithelial tissue, the body's outer layer of skin, consists of sheets of dead, flattened cells that cover and protect the underlying living layer of skin. Figure 45-1c shows an illustration of cells of epithelial tissue.

Connective Tissue

Connective tissue binds, supports, and protects structures in the body. Connective tissues are the most abundant and diverse of the four types of tissue, and include bone, cartilage, tendons, fat, and blood. These tissues are characterized by cells that are embedded in large amounts of an intercellular substance called **matrix.** Matrix can be solid, semisolid, or liquid. Bone cells are surrounded by a hard, crystalline matrix containing calcium. The cells in cartilage, tendons, and fat are surrounded by a semisolid fibrous matrix. Blood cells are suspended in a liquid matrix. Figure 45-1d shows an illustration of cells of connective tissue.

ORGANS AND ORGAN SYSTEMS

An **organ** consists of various tissues that work together to carry out a specific function. The stomach, a saclike organ in which food is mixed with digestive enzymes, is composed of the four types of tissues. A single organ, such as the stomach, usually does not function in isolation. Rather, groups of organs interact in an organ system. For example, in the digestive system, the stomach, small intestine, liver, and pancreas all work together to break down food into molecules the body can use for energy. Table 45-1 lists the body's organ systems and names their major structures and functions. As you study the table, think about the ways in which the different organ systems work together to function in an efficient, integrated manner.

TABLE 45-1 ***Summary of Organ Systems***

System	Major structures	Functions
Skeletal	bones	provides structure; supports and protects internal organs
Muscular	muscles (skeletal, cardiac, and smooth)	provides structure; supports and moves trunk and limbs; moves substances through body
Integumentary	skin, hair, nails	protects against pathogens; helps regulate body temperature
Cardiovascular	heart, blood vessels, blood	transports nutrients and wastes to and from all body tissues
Respiratory	air passages, lungs	carries air into and out of lungs, where gases (oxygen and carbon dioxide) are exchanged
Immune	lymph nodes and vessels, white blood cells	provides protection against infection and disease
Digestive	mouth, esophagus, stomach, liver, pancreas, small and large intestines	stores and breaks down food; absorbs nutrients; eliminates waste
Excretory	kidneys, ureters, bladder, urethra, skin, lungs	eliminates waste; maintains water and chemical balance
Nervous	brain, spinal cord, nerves, sense organs, receptors	controls and coordinates body movements and senses; controls consciousness and creativity; helps monitor and maintain other body systems
Endocrine	glands (such as adrenal, thyroid, pituitary, and pancreas); hypothalamus and specialized cells in the brain, heart, stomach, and other organs	maintains homeostasis; regulates metabolism, water and mineral balance, growth, behavior, development, and reproduction
Reproductive	ovaries, uterus, mammary glands (in females), testes (in males)	produces eggs and milk in females, sperm in males, and offspring after fertilization

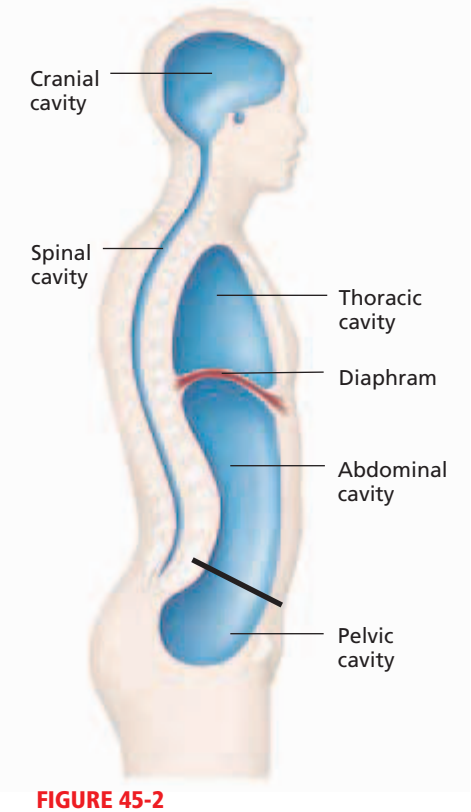


FIGURE 45-2

The human body has five main cavities that house and protect delicate internal organs.

Integration of Organ Systems

An even higher level of organization is the integration of organ systems. Each organ system has organs associated with it according to the organ's primary function. However, the boundaries are not always well defined. For example, nearly all of the juices produced by the pancreas are designed to aid in digestion. But because the pancreas produces vitally important hormones, it is also considered a component of the endocrine system. Each organ system carries out its own specific function, but for the organism to survive, the organ systems must work together. For example, nutrients from the digestive system are distributed by the cardiovascular system. The efficiency of the cardiovascular system depends on nutrients from the digestive system and oxygen from the respiratory system.

BODY CAVITIES

Many organs and organ systems in the human body are housed in compartments called body cavities. These cavities protect internal organs from injuries and permit organs such as the lungs to expand and contract while remaining securely supported. As shown in Figure 45-2, the human body has five main body cavities. Each cavity contains one or more organs. The **cranial cavity** contains the brain. The **spinal cavity** surrounds the spinal cord.

The two main cavities in the trunk of the human body are separated by a wall of muscle called the **diaphragm** (DIE-uh-FRAM). The upper compartment, or **thoracic** (thoh-RAS-ik) **cavity,** contains the heart, the esophagus, and the organs of the respiratory system. The lower compartment, or **abdominal** (ab-DAHM-uh-nuhl) **cavity,** contains organs of the digestive system. The **pelvic cavity** contains the organs of the reproductive and excretory systems.

SECTION 1 REVIEW

1. Name the four types of tissues in the human body, and give an example of each.
2. Explain the difference between muscle tissue and nervous tissue.
3. How are tissues, organs, and organ systems organized in the body?
4. How do the organ systems function together in the human body?
5. Give an example of interaction between the endocrine system and another organ system.
6. Identify the organs each body cavity contains.

CRITICAL THINKING

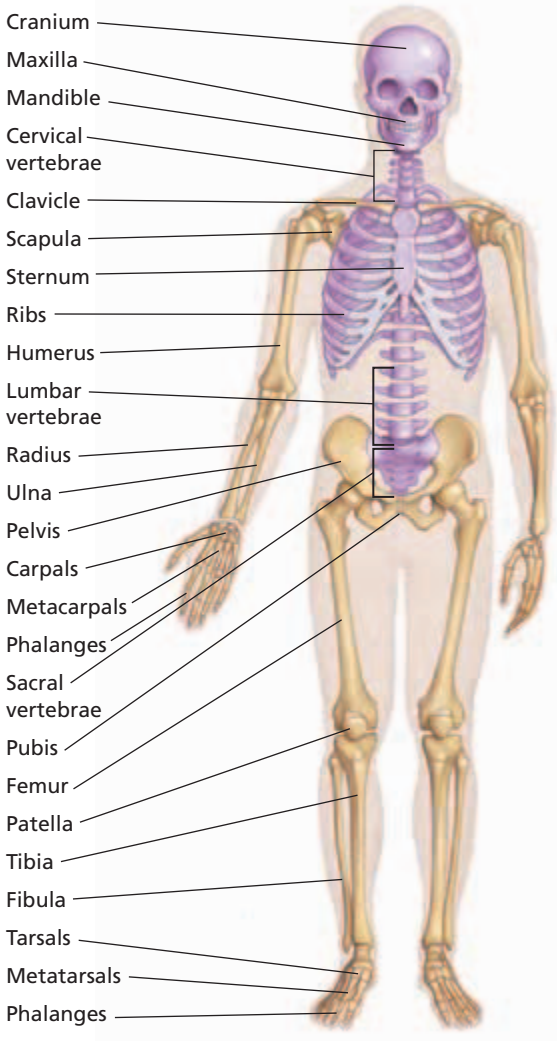
7. **Applying Information** Describe how the skeletal, muscular, nervous, respiratory, and circulatory systems function in a person swimming in a pool.
8. **Analyzing Concepts** Explain how the function of the body's organs might be affected if the body were not divided into cavities?
9. **Forming Reasoned Opinions** The body cavity that protects the brain is encased in bone. Why do you think the abdominal cavity is not encased in bone?

SKELETAL SYSTEM

The adult human body consists of approximately 206 bones, which are organized into an internal framework called the ***skeleton.*** *The variation in size and shape among the bones that make up the skeleton reflects their different roles in the body.*

THE SKELETON

As shown in Figure 45-3, the human skeleton is composed of two parts—the axial skeleton and the appendicular (AP-uhn-DIK-yuh-luhr) skeleton. The bones of the skull, ribs, spine, and sternum form the **axial skeleton.** The bones of the arms and legs, along with the scapula, clavicle, and pelvis, make up the **appendicular skeleton.**



HUMAN SKELETON

FIGURE 45-3

The skeleton is the framework that supports and protects the body. The bones of the axial skeleton are colored purple. The bones of the appendicular skeleton are colored yellow.

SECTION 2

OBJECTIVES

- **Distinguish** between the axial skeleton and the appendicular skeleton.
- **Explain** the function and structure of bones.
- **Summarize** how bones develop and elongate.
- **List** three types of joints, and give an example of each.
- **Describe** a common disorder that affects the skeletal system.

VOCABULARY

skeleton
axial skeleton
appendicular skeleton
periosteum
compact bone
Haversian canal
osteocyte
spongy bone
bone marrow
fracture
ossification
epiphyseal plate
joint
fixed joint
semimovable joint
movable joint
ligament
synovial fluid
rheumatoid arthritis
osteoarthritis

Word Roots and Origins

periostium

from the Greek *peri,* meaning "around," and *osteon,* meaning "bone"

BONE FUNCTION AND STRUCTURE

The bones that make up the skeleton function in a variety of ways. Bones provide a rigid framework against which muscles can pull, give shape and structure to the body, and support and protect delicate internal organs. Notice, for example, that the ribs curve to form a cage that contains the heart and lungs. Similarly, bones in the skull form the cranium, a dome-shaped case that protects the brain. Bones also store minerals, such as calcium and phosphorus, which play vital roles in important metabolic processes. In addition, the internal portion of many bones produces red blood cells, platelets, and white blood cells.

Despite their number and size, bones make up less than 20 percent of the body's mass. The reason for their having relatively little mass can be better understood by looking at bone structure. Bones are not dry, rigid structures, as they may appear in a museum exhibit. They are moist, living tissues.

Long Bone Structure

As shown in Figure 45-4, a long bone consists of a porous central cavity surrounded by a ring of dense material. The bone's surface is covered by a tough membrane called the **periosteum** (PER-ee-AHS-tee-uhm). This membrane contains a network of blood vessels, which supply nutrients, and nerves, which signal pain.

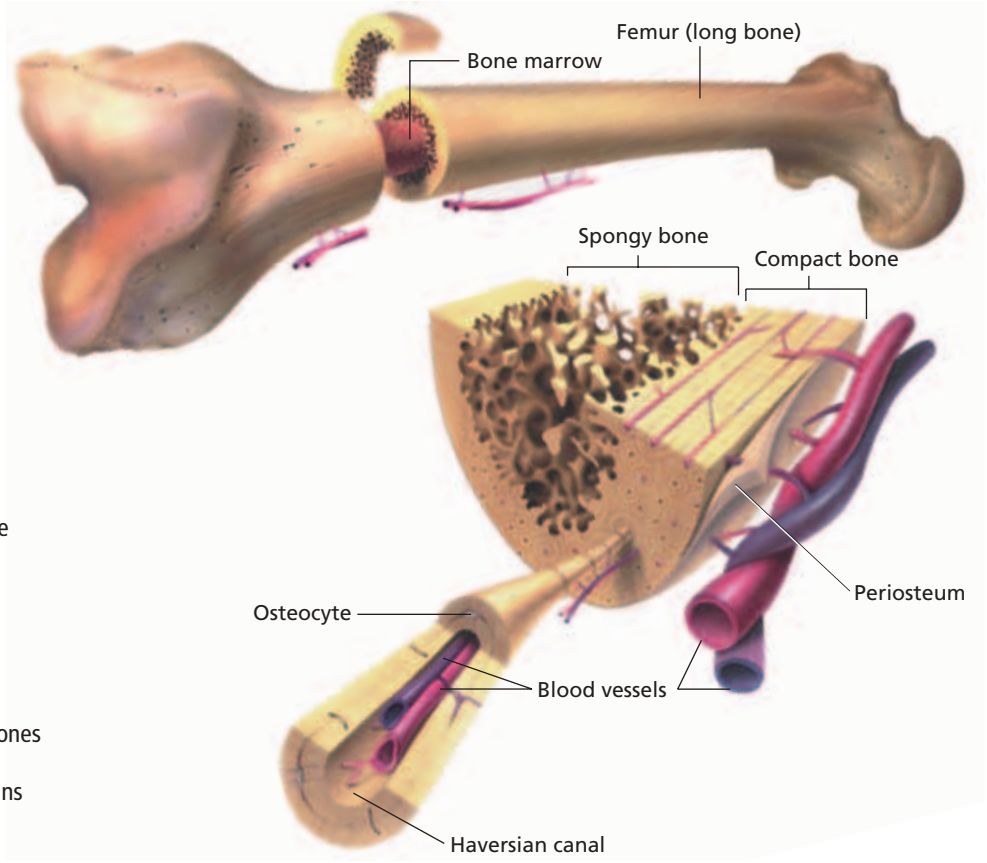


FIGURE 45-4

Long bones, found in the limbs of the body, are hollow and cylindrical. The outer shell of hard compact bone consists of closely packed rings of minerals and protein fibers. Narrow canals running through these rings contain blood vessels and nerves. Spongy bone is found in small flat bones and in the ends of long bones. The central shaft of the long bone contains marrow and blood vessels.

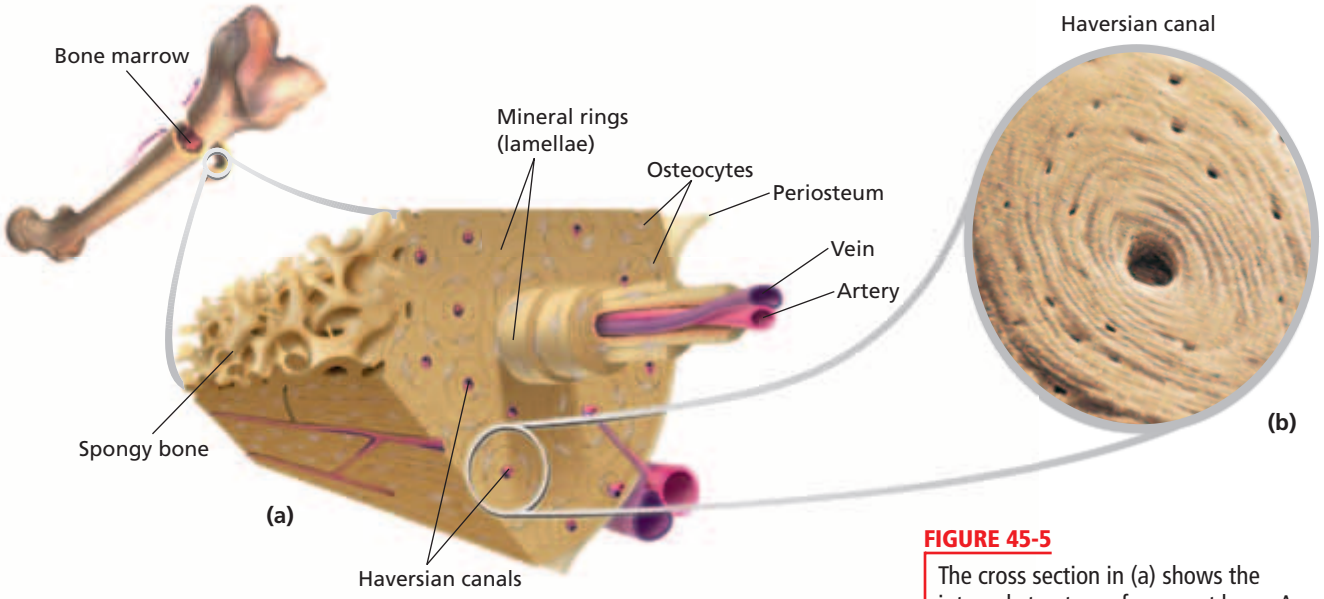


FIGURE 45-5

The cross section in (a) shows the internal structure of compact bone. A micrograph of a Haversian canal (380×) surrounded by lamellae in compact bone is shown in (b).

Under the periosteum is a hard material called **compact bone.** A thick layer of compact bone enables the shaft of the long bone to endure the large amount of stress it receives during activities such as jumping. In the cross section shown in Figure 45-5a, notice that compact bone is composed of cylinders of mineral crystals and protein fibers called *lamellae.* In the center of each cylinder is a narrow channel called a **Haversian** (huh-VER-shuhn) **canal,** as shown in Figure 45-5b. Blood vessels run through interconnected Haversian canals, creating a network that carries nourishment to the living bone tissue. Several layers of protein fibers wrap around each Haversian canal. Embedded within the gaps between the protein layers are bone cells called **osteocytes** (AHS-tee-uh-SIETS).

Beneath some compact bone is a network of connective tissue called **spongy bone.** Although its name suggests that it is soft, this tissue is hard and strong. As shown in Figure 45-4, spongy bone has a latticework structure that consists of bony spikes arranged along points of pressure or stress, making bones both light and strong.

Bone Marrow

Many bones also contain a soft tissue called **bone marrow,** which can be either red or yellow. Red bone marrow—found in spongy bone, the ends of long bones, ribs, vertebrae, the sternum, and the pelvis—produces red blood cells, platelets, and white blood cells. Yellow bone marrow fills the shafts of long bones. It consists mostly of fat cells and serves as an energy reserve. It can also be converted to red bone marrow and produce blood cells when severe blood loss occurs.

Injury and Repair

Despite their strength, bones will crack or even break if they are subjected to extreme loads, sudden impacts, or stresses from unusual directions. The crack or break is referred to as a **fracture.** If circulation is maintained and the periosteum survives, healing will occur even if the damage to the bone is severe.

Eco Connection

Bones of Lead

Millions of Americans have been exposed to lead in the environment. Following exposure to lead, the kidneys excrete most of the metal. But 7 to 10 percent of the remaining lead in the body is stored in bone and can stay there for a lifetime. The rapid bone uptake of lead acts as a detoxifying mechanism. But lead may not be permanently locked in bone. As people age, bone degeneration may occur, releasing lead into the bloodstream. Even very small concentrations of lead in the bloodstream can cause damage to kidneys, and high blood pressure.

The United States has outlawed the addition of lead to gasoline, water pipes, and paint. As a result, people who are now under age 25 may not accumulate as much lead in their bones as people from earlier generations.

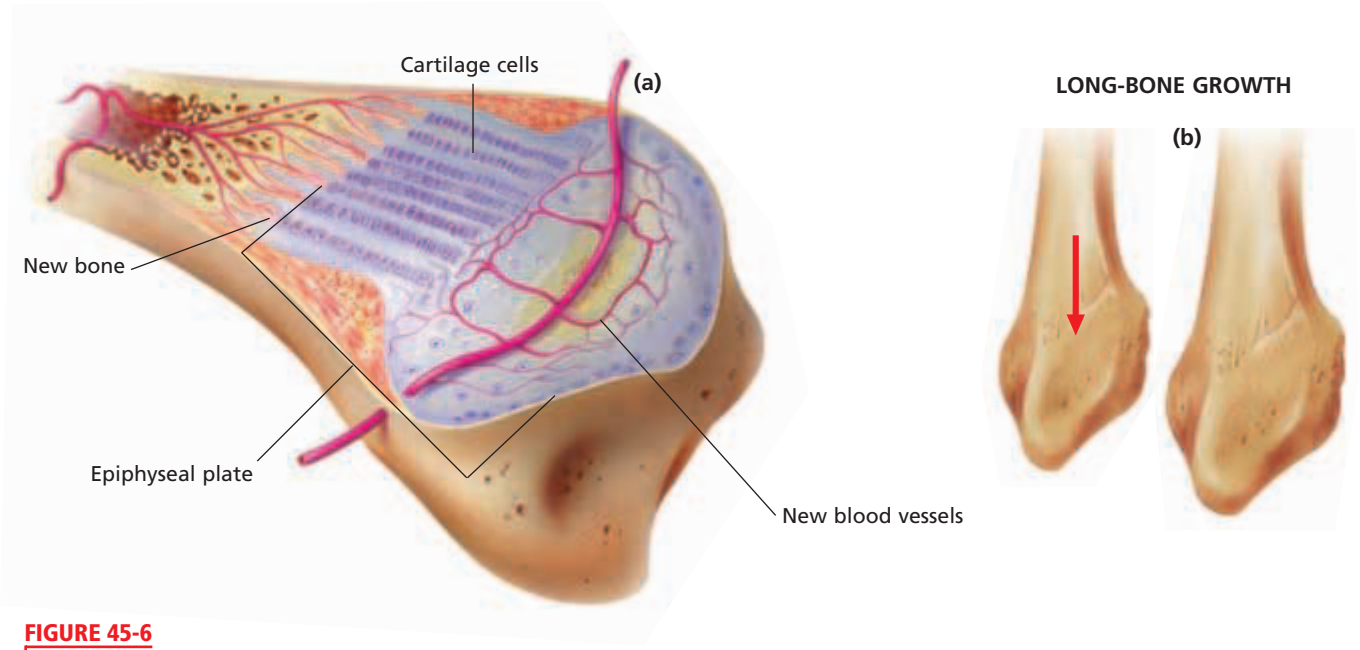


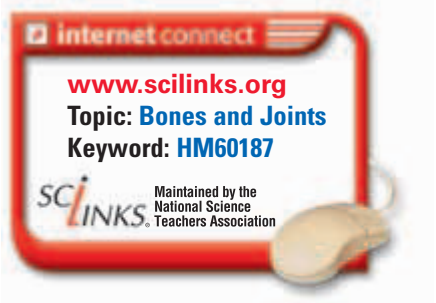
FIGURE 45-6

The epiphyseal plate, found at the ends of immature long bones, such as the fibula shown above, is the site of bone elongation. This region is rich with cartilage cells, which divide, enlarge, and push older cells toward the middle of the bone shaft. As older cells move back, they are replaced by new bone cells, forming new regions of bone. A long bone (a) will grow in length, circumference, and density in this manner, as shown in (b).

BONE DEVELOPMENT

Most bones develop from cartilage, a tough but flexible connective tissue. In the second month of fetal development, much of the skeleton is made of cartilage. During the third month, osteocytes begin to develop and release minerals that lodge in the spaces between the cartilage cells, turning the cartilage to bone. The process by which cartilage is slowly replaced by bone as a result of the deposition of minerals is called **ossification** (AHS-uh-fuh-KAY-shuhn). Most fetal cartilage is eventually replaced by bone. However, some cartilage remains, lending flexibility to the areas between bones, at the end of the nose, in the outer ear, and along the inside of the trachea.

A few bones, such as some parts of the skull, develop directly into hard bone without forming cartilage first. In these cases, the osteocytes are initially scattered randomly throughout the embryonic connective tissue but soon fuse into layers and become flat plates of bone. In the skull, suture lines can be seen where the plates of bone meet.



Bone Elongation

Bones continue to develop after a person's birth. Between early childhood and late adolescence, bone cells gradually replace the cartilage in long bones of limbs, such as the arms and legs. Bone elongation takes place near the ends of long bones in an area known as the **epiphyseal** (EP-uh-FIZ-ee-uhl) **plate.** As shown in Figure 45-6a, the epiphyseal plate is composed of cartilage cells that divide and form columns, pushing older cells toward the middle of the bone. As these older cells die, they are replaced by new bone cells. Growth continues, as shown in Figure 45-6b, until bone has replaced all the cartilage in the epiphyseal plate. At this point, bones no longer elongate and a person has usually reached full height. The epiphyseal plates then become *epiphyseal lines.*

JOINTS

The place where two bones meet is known as a **joint.** Three major kinds of joints are found in the human body—fixed, semimovable, and movable. Examples of these joints are shown in Figure 45-7.

Fixed Joints

Fixed joints prevent movement. They are found in the skull, where they securely connect the bony plates and permit no movement of those bones. A small amount of connective tissue in a fixed joint helps absorb impact to prevent the bones from breaking.

Semimovable Joints

Semimovable joints permit limited movement. For example, semimovable joints hold the bones of the vertebral column in place and allow the body to bend and twist. The vertebrae of the spine are separated by disks of cartilaginous tissue. These tough, springy disks compress and absorb shocks that could damage the fragile spinal cord. Semimovable joints are also found in the rib cage, where long strands of cartilage connect the upper ten pairs of ribs to the sternum, allowing the chest to expand during breathing.

Movable Joints

All other joints in the body are **movable joints.** These joints enable the body to perform a wide range of movements and activities. Movable joints include hinge, ball-and-socket, pivot, saddle, and gliding joints. An example of a *hinge joint* is found in the elbow, which allows you to move your forearm upward and downward, like a hinged door. An example of a *ball-and-socket joint* is the shoulder joint, which enables you to move your arm up, down, forward, and backward, as well as to rotate it in a complete circle. The joint formed by the top two vertebrae of your spine is an example of a *pivot joint*; it allows you to turn your head from side to side, as when shaking your head "no." The *saddle joint*, found at the base of each thumb, allows you to rotate your thumbs and helps you grasp objects with your hand. Finally, *gliding joints* allow bones to slide over one another. Examples are the joints between the small bones of your foot, which allow your foot to flex when you walk.

Joint Structure

Joints, such as the knee, are often subjected to a great deal of pressure and stress, but their structure is well suited to meet these demands. As in all movable joints, the parts of the bones that come in contact with each other are covered with cartilage, which protects the bones' surface from friction. Tough bands of connective tissue, called **ligaments,** hold the bones of the joint in place. The surfaces of the joints that are subjected to a great deal of pressure are lined with tissue that secretes a lubricating substance called **synovial** (sih-NOH-vee-uhl) **fluid.** Synovial fluid helps protect the ends of bones from damage by friction.

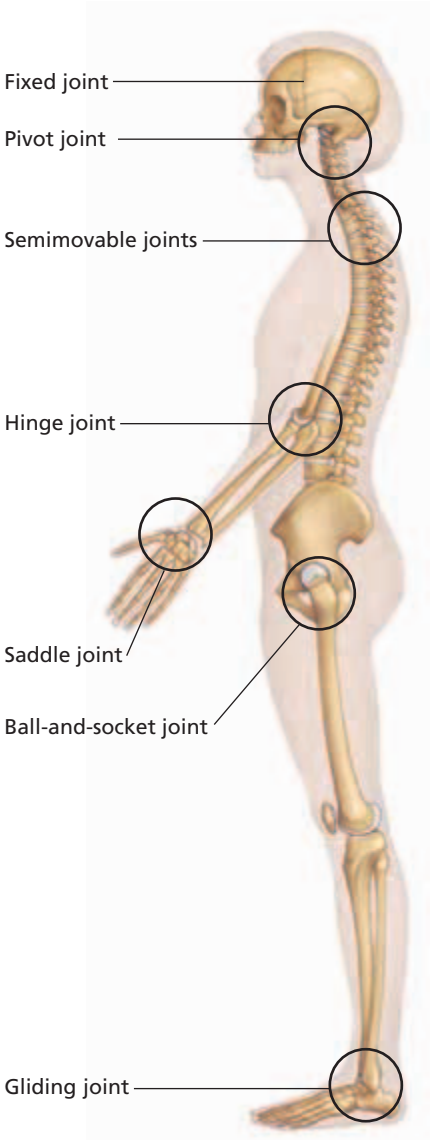
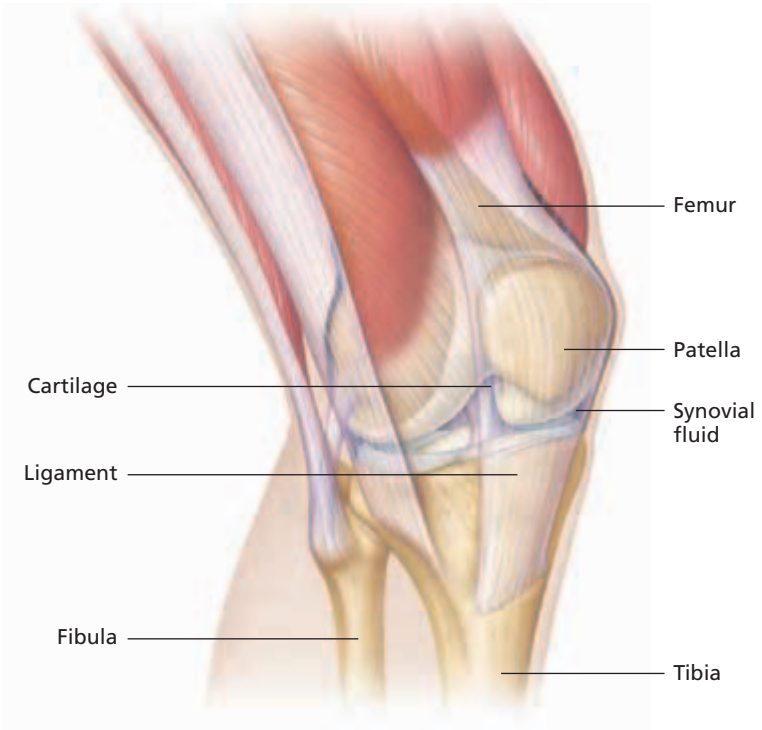


FIGURE 45-7

In addition to fixed joints and semimovable joints, the human body has five types of movable joints: pivot, hinge, saddle, ball-and-socket, and gliding.

FIGURE 45-8

The knee is a movable joint formed by the ends of the femur, the tibia, and the patella. Many cordlike ligaments stabilize the joint, especially during movement. Pads of cartilage protect the ends of bones and act as shock absorbers. Like many joints in the body, the knee is a synovial joint. It contains membranes that secrete synovial fluid, which lubricates and nourishes the tissues inside the joint.



Sometimes these protective structures are not enough to prevent a joint from becoming injured. Of all the joints in the body, the knee joint is the most susceptible to injury because it carries the body's weight and relies on many ligaments for stability. Damage to the knee joint can cause swelling in the compartment that contains the synovial fluid. Figure 45-8 shows the internal structures of the knee joint.

The term *arthritis* is used to describe disorders that cause painful, swollen joints. There are two forms of arthritis that affect joints. **Rheumatoid arthritis** develops when the immune system begins to attack body tissues. The joints become inflamed, swollen, stiff, and deformed. **Osteoarthritis** is a degenerative joint disease in which the cartilage covering the surface of bone becomes thinner and rougher. As a result, bone surfaces rub against each other, which is sensed by the nerves in the periosteum, and causes severe discomfort.

SECTION 2 REVIEW

1. List the major parts of the axial skeleton and the major parts of the appendicular skeleton.
2. Name five functions of bones.
3. Illustrate the structure of a long bone.
4. When does the ossification of most of the bones in the body begin and end?
5. Describe the function of the three major types of joints, and give an example of each.
6. Differentiate between the two types of arthritis.

CRITICAL THINKING

7. **Applying Information** What is the advantage of a cartilaginous skeleton during prenatal development?
8. **Analyzing Information** Which type of arthritis is not related to age?
9. **Relating Concepts** How are the structures of cartilage and bone related to the function each performs in the body?

MUSCULAR SYSTEM

Muscles make up the bulk of the body and account for about one-third of its weight. Their ability to contract and relax not only enables the body to move, but also provides the force that pushes substances, such as blood and food, through the body.

SECTION 3

OBJECTIVES

- **Distinguish** between the three types of muscle tissues.
- **Describe** the structure of skeletal muscle fibers.
- **Explain** how skeletal muscles contract.
- **Describe** how muscles move bones.
- **Explain** the process in which a muscle becomes fatigued.

VOCABULARY

muscle fiber
striation
fascicle
voluntary muscle
involuntary muscle
myofibril
myosin
actin
Z line
sarcomere
tendon
origin
insertion
flexor
extensor
muscle fatigue
oxygen debt

MUSCLE TYPES

A muscle is an organ that can contract in a coordinated fashion and includes muscle tissue, blood vessels, nerves, and connective tissue. Some of the major muscles of the human body are shown in Figure 45-9. Recall that the human body has three types of muscle tissues: skeletal, smooth, and cardiac.

Skeletal muscle is responsible for moving parts of the body, such as the limbs, trunk, and face. Skeletal muscle tissue is made up of elongated cells called **muscle fibers.** Each muscle fiber contains many nuclei and is crossed by light and dark stripes, called **striations,** as shown on the following page in Figure 45-10a. Skeletal muscle fibers are grouped into dense bundles called **fascicles.** A group of fascicles are bound together by connective tissue to form a muscle. Because their contractions can usually be consciously controlled, skeletal muscles are described as **voluntary muscles.**

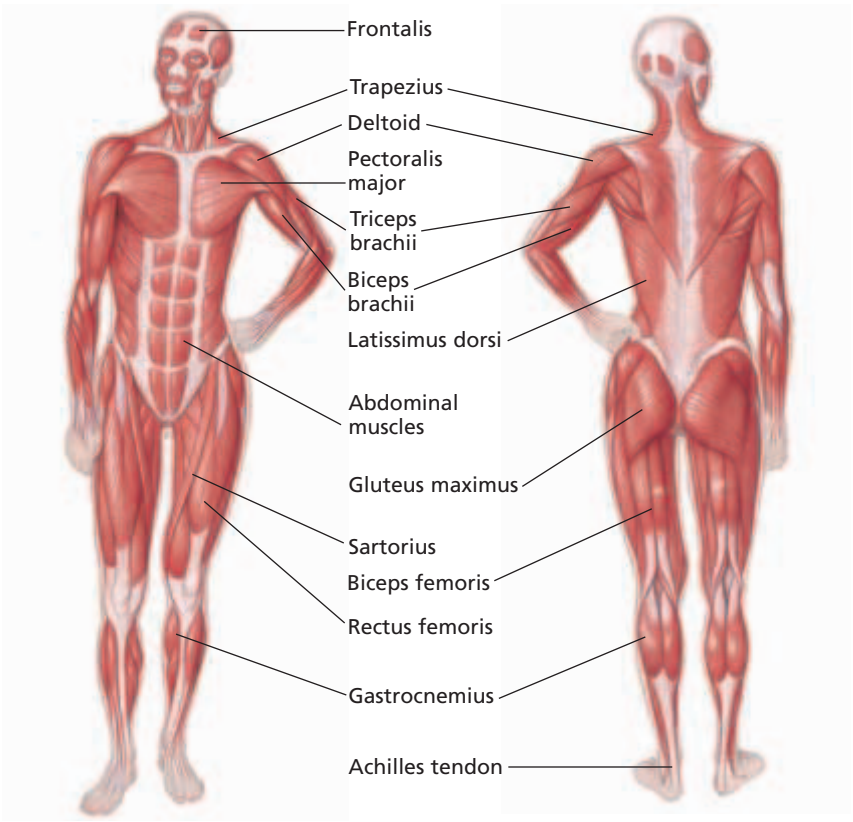


FIGURE 45-9
Skeletal muscle tissue is shown in these diagrams of some of the major muscles in the human body.

Careers in BIOLOGY

Certified Athletic Trainer

Job Description A certified athletic trainer (ATC) is a highly educated and skilled professional who specializes in athletic health care. Certified athletic trainers must have a bachelor's degree, usually in athletic training, health, physical education, or exercise science. In addition, an ATC must pass a certification exam. The job includes the prevention, identification, evaluation, treatment, referral, and rehabilitation of sports-related injuries.

Focus on Certified Athletic Trainer

In high school, Veronica Ampey was interested in science, medicine, rehabilitation, and community service. Today, she has found a career that brings together all of these interests and her love for sports. "I like the fact that I am not tied to a desk," says Ampey. "I get paid to watch athletes practice and compete."

Ampey works as an ATC at a small high school in Washington, D.C. Ampey says "The bonus is using my education and experience to address incidents when they occur. Additionally, there is a great deal of satisfaction in seeing someone you've worked with return to full athletic participation."

Education and Skills

- **High School**—at least three years of science courses and four years of math courses.
- **College**—bachelor's degree from a college with an accredited athletic training curriculum, including course work in biology; a master's degree for some jobs; and certification.
- **Skills**—patience, good organizational skills, and ability to work as a member of a team.

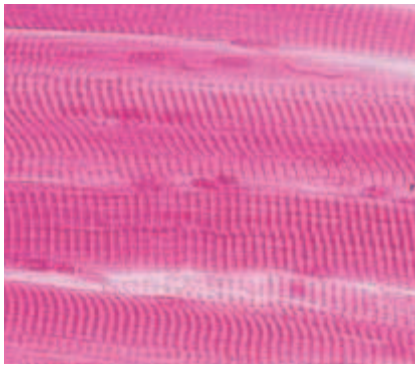
For more about careers, visit **go.hrw.com** and type in the keyword **HM6 Careers.**

Smooth muscle forms the walls of the stomach, intestines, blood vessels, and other internal organs. Individual smooth muscle cells are spindle-shaped, have a single nucleus, and interlace to form sheets, as shown in Figure 45-10b. Notice that smooth muscle lacks the striations found in skeletal muscle tissue. Smooth muscle fibers are surrounded by connective tissue, but the connective tissue does not unite to form tendons as it does in skeletal muscles. Because most of its movements cannot be consciously controlled, smooth muscle is referred to as **involuntary muscle.**

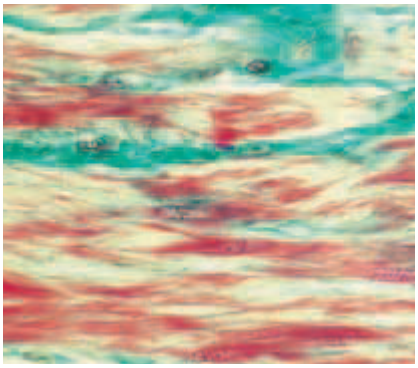
Cardiac muscle, shown in Figure 45-10c, makes up the walls of the heart. Cardiac muscle shares some characteristics with both skeletal muscle and smooth muscle. As with skeletal muscle, cardiac muscle tissue is striated; as with smooth muscle, it is involuntary and each cell has one nucleus.

FIGURE 45-10

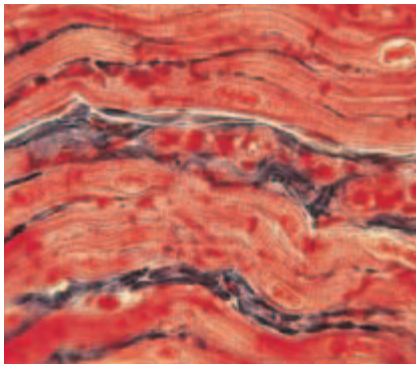
These light micrographs show the three types of muscle tissue. Skeletal muscle tissue (a) has a striped appearance when viewed under a microscope (430×). Smooth muscle tissue (b) is found in the digestive tract, the uterus, the bladder, and the blood vessels (400×). Cardiac muscle tissue (c) is found only in the heart (270×).



(a) SKELETAL MUSCLE TISSUE



(b) SMOOTH MUSCLE TISSUE



(c) CARDIAC MUSCLE TISSUE

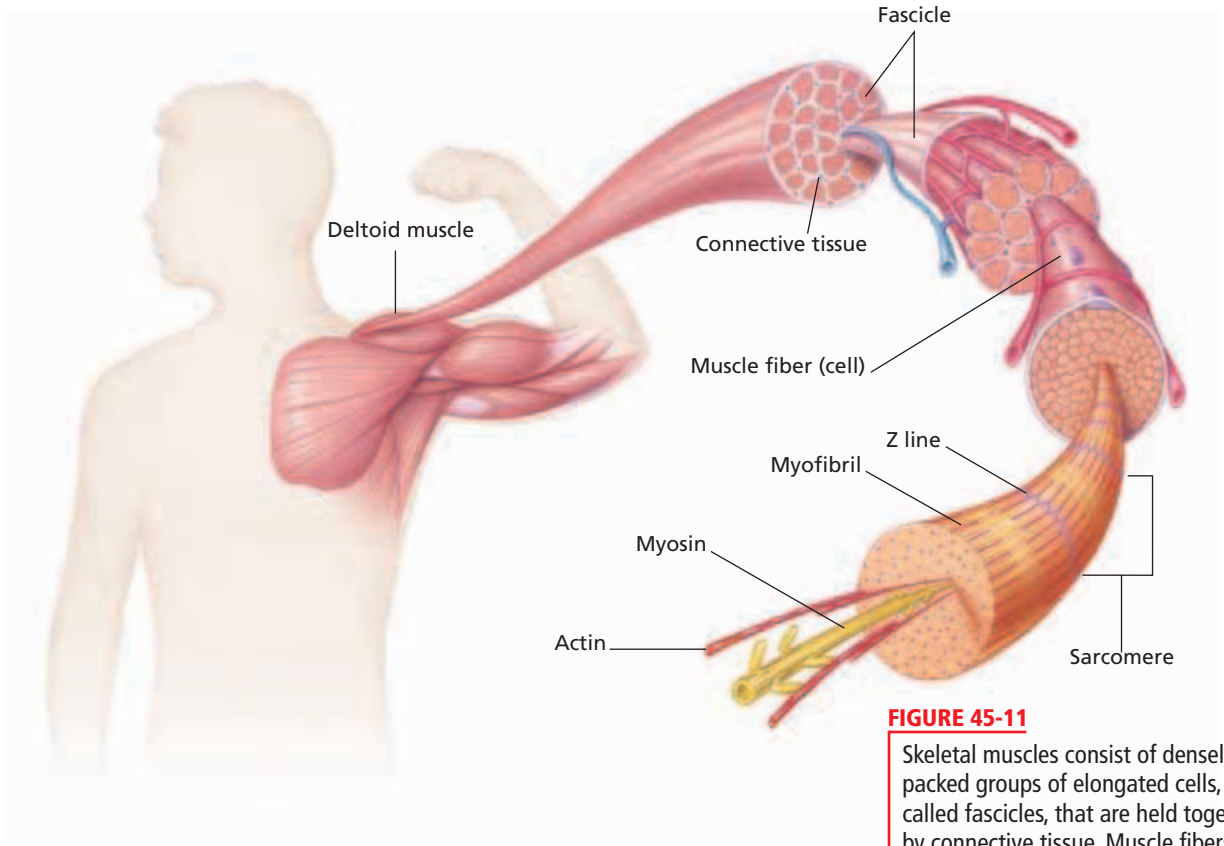


FIGURE 45-11

Skeletal muscles consist of densely packed groups of elongated cells, called fascicles, that are held together by connective tissue. Muscle fibers consist of protein filaments called myofibrils. Two types of filaments are found in muscle fibers—actin and myosin. The complementary structures of actin and myosin interact to contract and relax muscles.

MUSCLE STRUCTURE

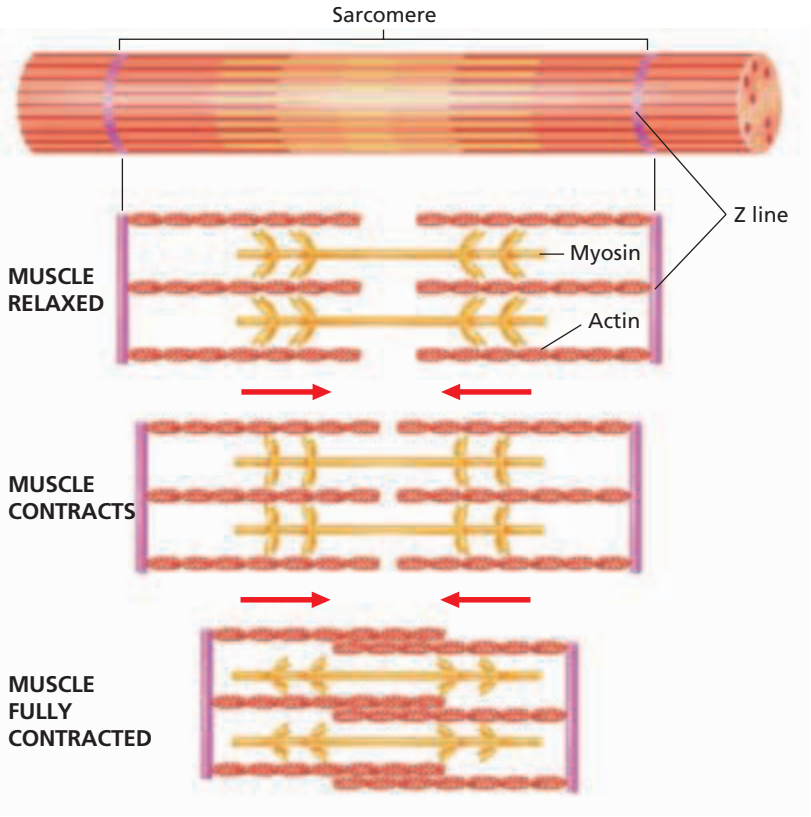
A skeletal muscle fiber is a single, multinucleated muscle cell. A skeletal muscle may be made up of hundreds or even thousands of muscle fibers, depending on the muscle's size. Although muscle fibers make up most of the muscle tissue, a large amount of connective tissue, blood vessels and nerves are also present. Like all body cells, muscle cells are soft and easy to injure. Connective tissue covers and supports each muscle fiber and reinforces the muscle as a whole.

The health of a muscle depends on a sufficient nerve and blood supply. Each skeletal muscle fiber has a nerve ending that controls its activity. Active muscles use a lot of energy and therefore require a continuous supply of oxygen and nutrients, which are supplied by arteries. Muscles produce large amounts of metabolic waste that must be removed through veins.

A skeletal muscle fiber, such as the one shown in Figure 45-11, contains bundles of threadlike structures called **myofibrils** (MIE-oh-FIE-bruhlz). Each myofibril is made up of two types of protein filaments—thick ones and thin ones. Thick filaments are made of the protein **myosin** (MIE-uh-suhn), and thin filaments are made of the protein **actin.** Myosin and actin filaments are arranged to form an overlapping pattern, which gives striated muscle tissue its striped appearance. Thin actin filaments are anchored at their endpoints to a structure called the **Z line.** The region from one Z line to the next is called a **sarcomere** (SAHR-kuh-MIR).

FIGURE 45-12

In a relaxed muscle, the actin and myosin filaments overlap. During a muscle contraction, the filaments slide past each other and the zone of overlap increases. As a result, the length of the sarcomere shortens.



Quick Lab

Testing Muscle Stamina and Strength

Materials bathroom scale, notepad, pencil

Procedure

1. Create a chart that coompares the strength of pectoral muscles at four different time intervals, each 1 minute apart.
2. Press the scale between the palms of your hands. Have your partner record the amount of pressure applied by your pectoral muscles.
3. Set the scale down and press your hands together in front of you for 1 minute. Press the scale between your hands again and have your partner record the pressure.
4. Repeat steps 2 and 3 two more times. Then repeat the experiment with your partner pressing the scale while you record the pressure.

Analysis What trends did you notice, if any, in the amount of pressure recorded? What might be a reason for this trend?

MUSCULAR CONTRACTION

The sarcomere is the functional unit of muscle contraction. When a muscle contracts, myosin filaments and actin filaments interact to shorten the sarcomere. Myosin filaments have extensions shaped like oval "heads." Actin filaments look like a twisted strand of beads. When a nerve impulse stimulates a muscle to contract, the myosin filaments' heads attach to points between the beads of the actin filaments. The myosin heads then bend inward, pulling the actin with them. The myosin heads then let go, bend back into their original position, attach to a new point on the actin filament, and pull again. This action shortens the sarcomere. The synchronized shortening of sarcomeres along the length of a muscle fiber causes the whole fiber, and hence the muscle, to contract. Figure 45-12 shows a sarcomere's structures.

Muscle contraction requires energy, which is supplied by ATP. This energy is used to detach the myosin heads from the actin filaments. Because myosin heads must attach and detach a number of times during a single muscle contraction, muscle cells must have a continuous supply of ATP. Without ATP, the myosin would remain attached to the actin, keeping a muscle permanently contracted.

Muscle contraction is an all-or-none response—either the fibers contract or they remain relaxed. How, then, are you able to contract your muscles tightly enough to lift a dumbbell or gently enough to lift a pen? The force of a muscle contraction is determined by the number of muscle fibers that are stimulated. As more fibers are activated, the force of the contraction increases.

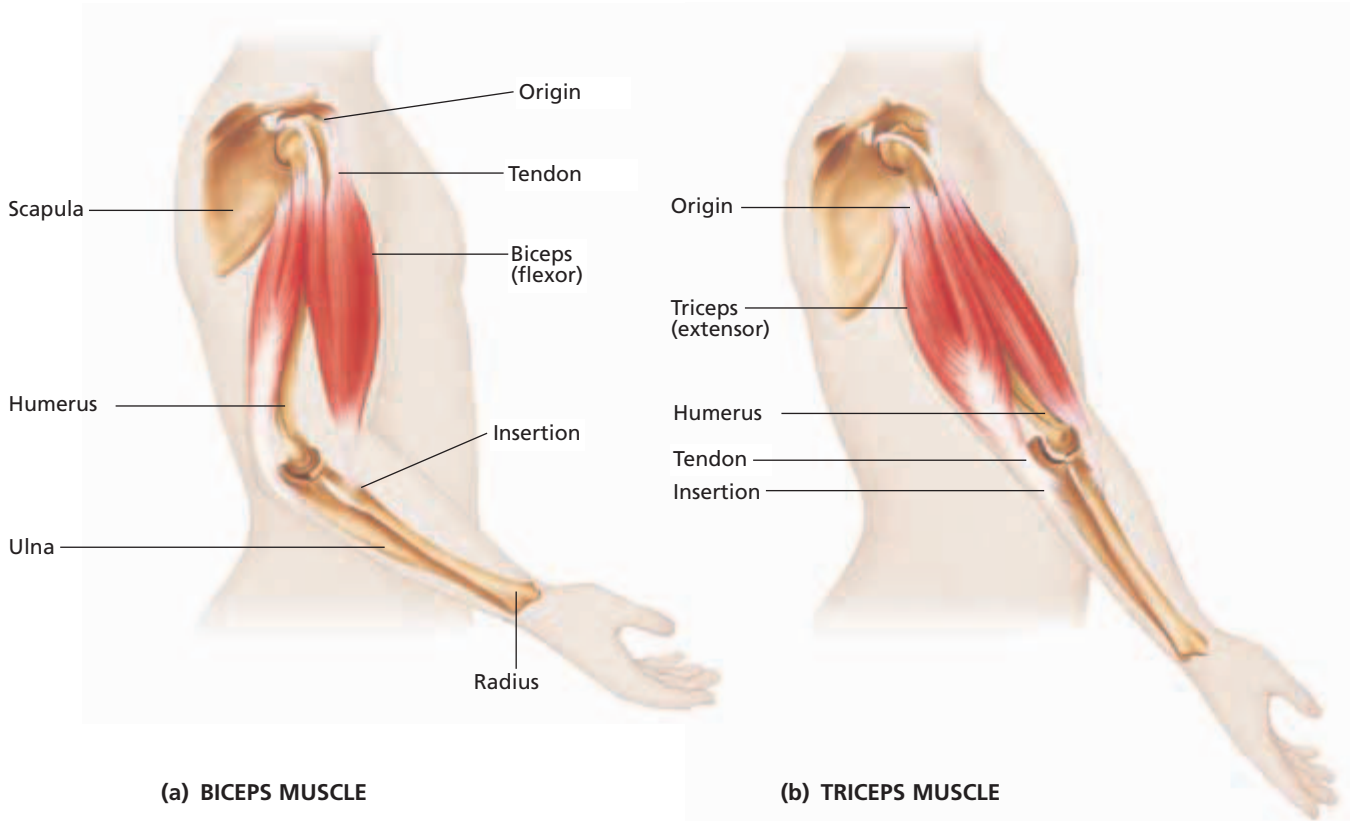
MUSCULAR MOVEMENT OF BONES

Generally, skeletal muscles are attached to one end of a bone, stretch across a joint, and are fastened to a point on another bone. Muscles are attached to the outer membrane of bone, the periosteum, either directly or by a tough fibrous cord of connective tissue called a **tendon.** For example, as shown in Figure 45-13, one end of the large biceps muscle in the arm is connected by tendons to the radius in the forearm, while the other end of the muscle is connected to the scapula in the shoulder. When the biceps muscle contracts, the forearm flexes upward while the scapula remains stationary. The point where the muscle attaches to the stationary bone—in this case, the scapula—is called the **origin.** The point where the muscle attaches to the moving bone—in this case the radius—is called the **insertion.**

Most skeletal muscles are arranged in opposing pairs. One muscle in a pair moves a limb in one direction; the other muscle moves it in the opposite direction. Muscles move bones by pulling them, not by pushing them. For example, when the biceps muscle contracts, the elbow bends. The biceps muscle is known as a **flexor,** a muscle that bends a joint. Contraction of the triceps muscle in the upper arm straightens the limb. The triceps muscle is an example of an **extensor,** a muscle that straightens a joint. To bring about a smooth movement, one muscle in a pair must contract while the opposing muscle relaxes.

FIGURE 45-13

Skeletal muscles, such as the biceps and triceps muscles in the upper arm, are connected to bones by tendons. (a) When the biceps muscle contracts, the elbow bends. (b) When the triceps muscle contracts, the elbow straightens.



(a) BICEPS MUSCLE

(b) TRICEPS MUSCLE

MUSCLE FATIGUE

Muscle cells store glycogen, which is used as a source of energy when the blood cannot deliver adequate amounts of glucose. The breakdown of glycogen releases large amounts of energy, but sometimes even those reserves are used up. During prolonged and vigorous exertion, fat molecules are utilized for energy. Fat molecules contain a greater concentration of potential energy than any other molecule in the body. When energy availability fails to keep pace with its use, muscle fatigue sets in and controlled muscle activity ceases, even though the muscle may still receive nerve stimulation to move. **Muscle fatigue** is the physiological inability of a muscle to contract. Muscle fatigue is a result of a relative depletion of ATP. When ATP is absent, a state of continuous contraction occurs. An example of depletion of ATP is when a marathon runner collapses during a race, suffering from severe muscle cramps.

FIGURE 45-14
These athletes are in the process of repaying their oxygen debts. Oxygen debt occurs frequently after strenuous, sustained exertion.

Oxygen Debt

Oxygen is used during cellular respiration in the synthesis of ATP. Large amounts of oxygen are needed to maintain the rate of maximum ATP production required to sustain strenuous exercise. However, after several minutes of heavy exertion, the circulatory system and the respiratory system are not able to bring in enough oxygen to meet the demands of energy production. Oxygen levels in the body become depleted. This temporary lack of oxygen availability is called **oxygen debt.** Oxygen debt leads to an accumulation of lactic acid as metabolic waste in the muscle fibers. The presence of lactic acid produces the soreness you may experience after prolonged exercise. Oxygen debt causes a person to spend time in rapid, deep breathing after strenuous exercise, as the athletes shown in Figure 45-14 are doing. The oxygen debt is repaid quickly as additional oxygen becomes available, but muscle soreness may persist until all of the metabolic wastes that have accumulated in the muscle fibers are carried away or converted.

SECTION 3 REVIEW

1. Compare the three main types of muscle tissues found in the body.
2. Why is smooth muscle referred to as involuntary muscle?
3. Why do skeletal muscle fibers appear striated?
4. How do skeletal muscles contract?
5. How do muscles work together to move bones?
6. Contrast the functions of flexors and extensors.
7. What causes muscles to become fatigued?

CRITICAL THINKING

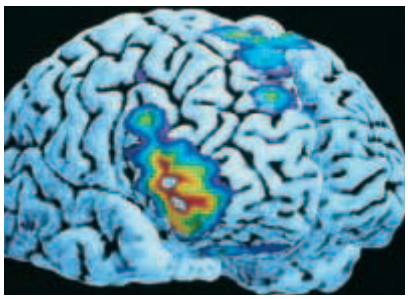
8. **Analyzing Information** Rigor mortis is a condition in which all of the body muscles become rigid shortly after a person dies. Why does rigor mortis develop?
9. **Applying Information** What causes muscle cramping after vigorous exercise or repeated movement?
10. **Applying Information** Why do you think the heart muscle never suffers from fatigue?

Looking Inside the Human Body

In 1895, the development of X-ray equipment provided physicians a way to look at images of dense tissue in the body, such as bones. Modern imaging techniques rely on computers.

Computerized Tomography

Computerized tomography (CT) uses a focused beam of low-dose X-rays to obtain cross-sectional images of structures in the body. Tomography is the technique used to take images of a specific "slice" or plane of tissue. Computerized tomography can differentiate tissues of various densities.



(a)

(b)

(a) A three dimensional PET scan shows the surface detail and cellular activity of the brain. (b) This X-ray shows the bones of the skull, mandible, and neck.

Positrons and Brain Imaging

Still newer imaging technology is positron emission technology, or PET. Positrons are positively charged particles with the same mass as electrons that result from the disintegration of radioisotopes. Michael M. TerPogossian and his colleagues at Johns Hopkins suggested using short-lived radioisotopes in medical research. They developed scanners to detect the positrons released by radioisotopes that had been injected into a patient's bloodstream. As technology improved, biomedical engineers redesigned scanning equipment to create three-dimensional images from the positron emissions. Positron emission technology is used to map areas of the brain that are involved in memory, sensation, perception, speech, and information processing. In addition, positron emission technology provides clues about the causes of psychiatric disorders, such as depression.

Holographic Imaging

A new holographic imaging system combines images obtained by computerized tomography or magnetic resonance scanners and displays an accurate three-dimensional image of anatomical structures. Magnetic resonance imaging (MRI) creates images of soft tissues. MRI uses radio waves emitted by the nuclei of hydrogen atoms that are activated by a magnetic scanner. A holograph is a method of photography that uses laser light to produce a three-dimensional image. The transparent but solid looking image floats in front of the holographic film and can be studied from all sides.

Holograms in Medicine

Physicians can make surgical plans by studying the true appearance of a patient's organs, such as the three dimensional PET scan that highlights the verbal center in the brain (a). Compare the three dimensional PET scan with the X-ray of the same part of the body (b). The X-ray may not be as helpful as the three dimensional PET scan when a physician must diagnose an illness or injury of the brain.

REVIEW

1. How do X-rays differ from PET scans?
2. How might a holograph be more useful than a PET scan?
3. **Justifying Conclusions** If a surgeon had to remove a piece of metal lodged in a patient's skull, which type of imaging would you choose? Support your answer, and give reasons why you did not choose the other imaging techniques.

SECTION 4

OBJECTIVES

- **Describe** the functions of the skin.
- **Distinguish** between the two layers that form the skin.
- **Identify** two types of glands found in the skin, and describe their functions.
- **Describe** the structure of nails.
- **Describe** the structure of hair.

VOCABULARY

epidermis
keratin
melanin
dermis
exocrine gland
sweat gland
oil gland
sebum

INTEGUMENTARY SYSTEM

The integumentary system, consisting of the skin, hair, and nails, acts as a barrier to protect the body from the outside world. It also functions to retain body fluids, protect against disease, eliminate waste products, and regulate body temperature.

SKIN

The skin is one of the human body's largest organs. Subjected to a lifetime of wear and tear, the layers of skin are capable of repairing themselves. Skin contains sensory receptors that monitor the external environment, and mechanisms that rid the body of wastes. The skin is composed of two layers—the epidermis and the dermis.

Epidermis

The **epidermis,** or outer layer of skin, is composed of many sheets of flattened, scaly epithelial cells. Its top layers are made of mostly dead cells. These cells are exposed to the dangers of the external environment. Scraped or rubbed away on a daily basis, they are replaced by new cells made in the rapidly dividing lower layers. The cells of the epidermis are filled with a protein called **keratin,** which gives skin its rough, leathery texture and its waterproof quality.

There is a great variety in skin color among humans. The color of skin is mainly determined by a brown pigment called **melanin** (MEL-uh-nin), which is produced by cells in the lower layers of the epidermis. Melanin absorbs harmful ultraviolet radiation. The amount of melanin produced in skin depends on two factors: heredity and the length of time the skin is exposed to ultraviolet radiation. Increased amounts of melanin are produced in a person's skin in response to ultraviolet radiation. All people, but especially people with light skin, need to minimize exposure to the sun and protect themselves from its ultraviolet radiation, which can damage the DNA in skin cells and lead to deadly forms of skin cancer.

Word Roots and Origins

Epidermis

from the Greek *epi,* meaning "on" or "upon," and *derma,* meaning "skin"

Dermis

The **dermis,** the inner layer of skin, is composed of living cells and specialized structures, such as sensory neurons, blood vessels, muscle fibers, hair follicles, and glands. Sensory neurons make it possible for you to sense many kinds of conditions and signals from the environment, such as heat and pressure. Blood vessels provide nourishment to the living cells and help regulate body temperature.

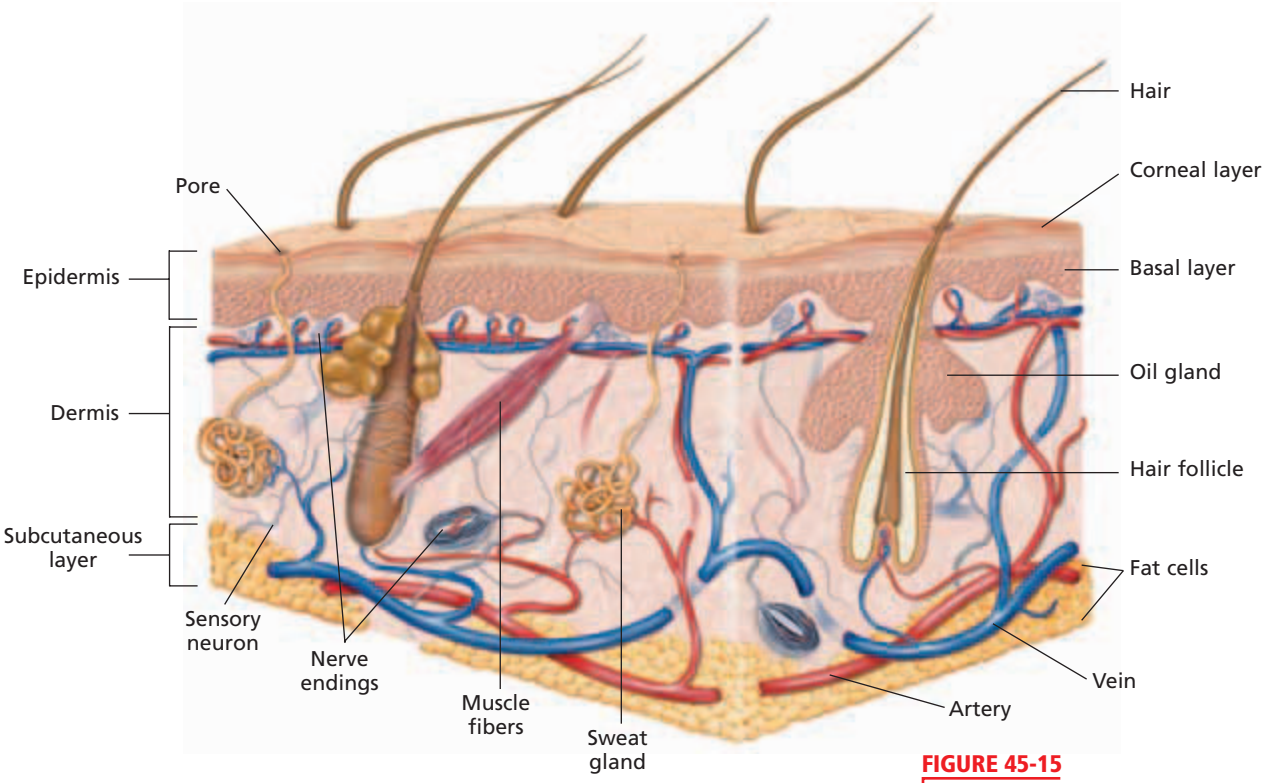


FIGURE 45-15

Skin is composed of two layers: the epidermis and the dermis. The top of the epidermis consists of dead, flattened cells that are shed and replaced every day. The dermis contains specialized structures that protect the body from infectious diseases, regulate body temperature, sense the environment, and secrete oil, sweat, and some wastes.

Tiny muscle fibers attached to hair follicles contract and pull hair upright when you are cold or afraid, producing what are commonly called goose bumps. Glands produce sweat, which helps cool your body, and oil, which helps soften your skin. A layer of fat cells lies below the dermis. These cells act as energy reserves; add a protective, shock-absorbing layer; and insulate the body against heat loss. Study the structures of the skin in Figure 45-15.

Glands

The skin contains **exocrine glands,** glands that release secretions through ducts. The main exocrine glands of the skin are the sweat glands and the oil glands.

The skin functions as an excretory organ by releasing excess water, salts, and urea through the **sweat glands.** By releasing excess water, the skin also helps regulate body temperature. When the body's temperature rises, circulation increases, and the skin becomes warm and flushed, as shown in Figure 45-16. The sweat glands then release more sweat. As the water in sweat evaporates, the skin is cooled.

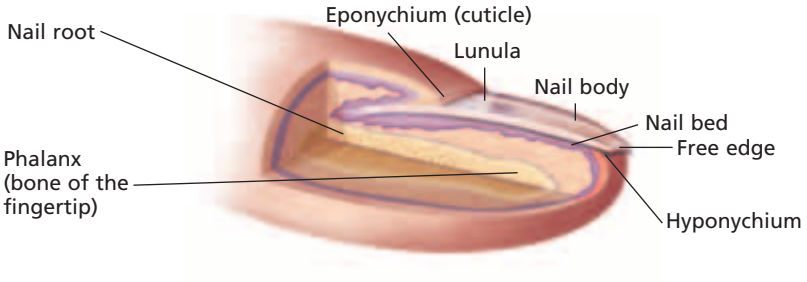
Oil glands, found in large numbers on the face and scalp, secrete the fatty substance **sebum.** Oil glands are usually connected by tiny ducts to hair follicles. Sebum coats the surface of the skin and the shafts of hairs, preventing excess water loss and softening the skin and hair. Sebum is also mildly toxic to some bacteria. The production of sebum is controlled by hormones. During adolescence, high levels of sex hormones increase the activity of the oil glands. If the ducts of oil glands become clogged with excessive amounts of sebum, dead cells, and bacteria, the skin disorder *acne* can result.

FIGURE 45-16

Skin acts as a temperature-controlling device. It contains millions of sweat glands that secrete microscopic droplets of water. The water droplets help cool the body when its temperature rises, such as after a rigorous workout.

FIGURE 45-17

This illustration of the structure of a fingernail shows that the nail root, from which the nail is constantly regenerated, is protected well beneath the surface of the finger, next to the bone of the fingertip.



NAILS

Nails, which protect the ends of the fingers and toes, form from nail roots under skin folds at the base and sides of the nail. As new cells form, the nail grows longer. Like hair, nails are composed primarily of keratin. The nail body is about 0.5 mm (0.02 in.) thick. Nails grow at about 1 mm (0.04 in.) per week. Nails rest on a bed of tissue filled with blood vessels, giving the nails a pinkish color. The structure of a fingernail can be seen in Figure 45-17.

Changes in the shape, structure, and appearance of the nails may be an indicator of a disease somewhere in the body. They may turn yellow in patients with chronic respiratory disorders, or they may grow concave in certain blood disorders.

HAIR

Hair, which protects and insulates the body, is produced by a cluster of cells at the base of deep dermal pits called *hair follicles.* The hair shaft is composed of dead, keratin-filled cells that overlap like roof shingles. Oil glands associated with hair follicles prevent hair from drying out. Most individual hairs grow for several years and then fall out.

Hair color is the result of the presence of the pigment melanin in the hair shaft. Black, brown, and yellow variants of melanin combine to determine an individual's hair color. Hair color is influenced by hereditary factors.

SECTION 4 REVIEW

1. What are the names and functions of the two layers of skin?
2. Identify the reason the dermis is considered the living layer of skin.
3. What are the functions of the two types of exocrine glands found in the dermis?
4. Illustrate and label the structure of a fingernail.
5. Describe the structure of hair.

CRITICAL THINKING

6. **Relating Concepts** Why can sunbathing be considered dangerous?
7. **Analyzing Information** A third-degree burn may be surrounded by painful areas of second- and first- degree burns. However, a third-degree burn is often painless. Why?
8. **Recognizing Relationships** How might muscles in the dermis benefit mammals in cold weather?

CHAPTER HIGHLIGHTS

SECTION 1 The Human Body Plan

- The human body has four main types of tissue: muscle, nervous, epithelial, and connective.
- A tissue is a collection of cells, an organ is a collection of tissues, and an organ system is a collection of organs.
- Some of the primary organ systems in the body include the integumentary, nervous, and cardiovascular systems.
- Many organs are located in the body's five main cavities: abdominal, cranial, spinal, thoracic, and pelvic.

Vocabulary

muscle tissue (p. 907)
skeletal muscle (p. 907)
smooth muscle (p. 907)
cardiac muscle (p. 907)
nervous tissue (p. 907)
neurons (p. 907)
epithelial tissue (p. 908)
connective tissue (p. 908)
matrix (p. 908)
organ (p. 909)
cranial cavity (p. 910)
spinal cavity (p. 910)
diaphragm (p. 910)
thoracic cavity (p. 910)
abdominal cavity (p. 910)
pelvic cavity (p. 910)

SECTION 2 Skeletal System

- The human skeleton is composed of the axial skeleton (skull, ribs, spine, and sternum) and the appendicular skeleton (arms and legs, scapula, clavicle, and pelvis).
- Bones support muscles, give structure to the body, protect organs, store minerals, and make blood cells.
- Bones are made up of minerals, protein fibers, and cells.
- Most bones develop from cartilage through a process called *ossification*.
- The human body has three types of joints: fixed joints, semimovable joints, and movable joints. The joints can be affected by a disease called arthritis.

Vocabulary

skeleton (p. 911)
axial skeleton (p. 911)
appendicular skeleton (p. 911)
periosteum (p. 912)
compact bone (p. 913)
Haversian canal (p. 913)
osteocyte (p. 913)
spongy bone (p. 913)
bone marrow (p. 913)
fracture (p. 913)
ossification (p. 914)
epiphyseal plate (p. 914)
joint (p. 915)
fixed joint (p. 915)
semimovable joint (p. 915)
movable joint (p. 915)
ligament (p. 915)
synovial fluid (p. 915)
rheumatoid arthritis (p. 916)
osteoarthritis (p. 916)

SECTION 3 Muscular System

- The human body has three types of muscle tissues: skeletal, smooth, and cardiac.
- Skeletal muscles consist of groups of fibers. Muscle fibers contain myofibrils made up of protein filaments.
- During a muscle contraction, myosin and actin filaments interact to shorten the length of a sarcomere.
- Most skeletal muscles are arranged in opposing pairs.

Vocabulary

muscle fiber (p. 917)
striation (p. 917)
voluntary muscle (p. 917)
involuntary muscle (p. 918)
myofibril (p. 919)
myosin (p. 919)
actin (p. 919)
Z line (p. 919)
sarcomere (p. 919)
tendon (p. 921)
origin (p. 921)
insertion (p. 921)
flexor (p. 921)
extensor (p. 921)
muscle fatigue (p. 922)
oxygen debt (p. 922)

SECTION 4 Integumentary System

- Skin, hair, and nails act as barriers that protect the body from the environment.
- Skin is composed of two layers, which are the epidermis and the dermis.
- Hair and nails are composed of the protein keratin; they grow from a root of rapidly dividing cells.
- Sweat glands produce sweat, which cools the body. Oil glands secrete sebum, which softens the skin.

Vocabulary

epidermis (p. 924)
keratin (p. 924)
melanin (p. 924)
dermis (p. 924)
exocrine gland (p. 925)
sweat gland (p. 925)
oil gland (p. 925)
sebum (p. 925)

CHAPTER REVIEW

USING VOCABULARY

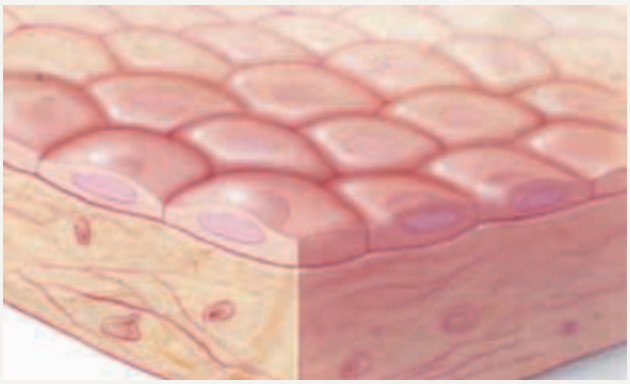
1. Choose the term that does not belong in the following group, and explain why it does not belong: *saddle joint, pivot joint, fixed joint,* and *hinge joint, and ball-and-socket joint*.
2. Distinguish between *compact bone* and *spongy bone*.
3. Use the following key terms in the same sentence: *actin, muscle fiber, myofibrils,* and *myosin*.
4. **Word Roots and Origins** The word *epidermis* is derived from the Greek *derma,* which means "skin." The prefix *epi* means "on." Using this information, explain why the term *epidermis* is a good name for the anatomical structure it describes.

UNDERSTANDING KEY CONCEPTS

5. **Define** epithelial tissue.
6. **Explain** the relationship between cells, tissues, organs, and organ systems.
7. **Summarize** the functions of the primary organ systems in the human body.
8. **Describe** the organs that can be found in the abdominal cavity.
9. **List** all of the bones in the axial skeleton.
10. **Identify** the five functions of the skeletal system.
11. **Explain** the role the Haversian canals play in compact bone.
12. **Define** red bone marrow. Where is it produced, and what is its function?
13. **Summarize** how bones develop and elongate.
14. **State** three types of joints, and give examples of each type.
15. **Describe** the cause and symptoms of the disease rheumatoid arthritis.
16. **Explain** the difference between skeletal muscle, smooth muscle, and cardiac muscle.
17. **Describe** the components of a sarcomere.
18. **Illustrate** how a skeletal muscle contracts.
19. **Explain** how muscles move bones.
20. **Name** the functions of tendons and ligaments.
21. **List** four functions of the skin.
22. **Identify** the difference between the epidermis and the dermis.
23. **Define** melanin. What is its role in the body?
24. **Explain** the similarities and differences between nails and hair.
25. **Identify** the substance that prevents the hair and skin from drying out, and the gland where this substance is produced.
26. **CONCEPT MAPPING** Use the following terms to create a concept map that illustrates the body's four levels of structural organization: *muscle tissue, connective tisue, epithelial tissue, nervous tissue, organ,* and *organ system*.

CRITICAL THINKING

27. **Inferring Relationships** Young thoroughbred horses that are raced too early in life have an increased risk of breaking the bones in their legs. What can you infer about the process of ossification in horses?
28. **Evaluating Information** During a normal birth, a baby passes through the mother's pelvis. A woman's pelvis has a larger diameter and is more oval-shaped than a man's pelvis. In addition, a newborn's skull bones are not completely ossified. How are these skeletal properties advantageous to the birthing process?
29. **Analyzing Concepts** Oil glands secrete an oily substance that helps keep the skin soft and flexible. They also secrete fatty acids, which help kill bacteria. How can the function of oil glands be affected if you wash your skin too frequently?
30. **Interpreting Graphics** Examine the drawing of epithelial cells below. The flat epithelial cells of the skin overlap each other much like shingles on a roof do. How does this arrangement enable these cells to perform their protective function?



Standardized Test Preparation

DIRECTIONS: Choose the letter that best answers the question or completes the sentence.

1. The thoracic cavity contains which organs?
   A. brain
   B. spine
   C. organs of the digestive system
   D. organs of the respiratory system

2. The cells of connective tissue are embedded in what substance?
   F. matrix
   G. keratin
   H. marrow
   J. synovial fluid

3. The periosteum is a membrane that does which of the following?
   A. covers the bone
   B. contains marrow
   C. produces red blood cells
   D. increases the length of long bones

4. Which of the following is true about the dermis?
   F. It is the top layer of skin.
   G. It contains cardiac muscle.
   H. It is made up of dead cells.
   J. It contains nerves and blood vessels.

INTERPRETING GRAPHICS: The graph below shows the relationship between skin type, UV index, and sun burns. Use the table to answer the question that follows.

Relationship of UV Index and Sunburns

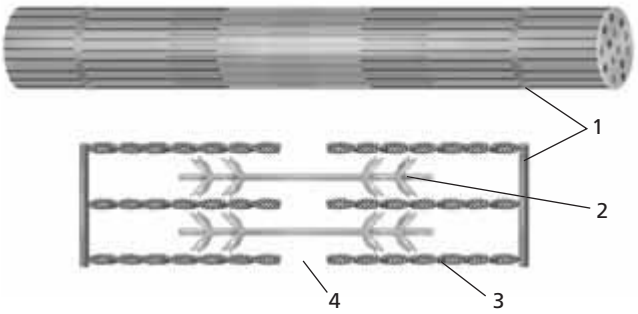
UV index	Minutes before Skin Type 1 burns	Minutes before Skin Type 4 burns
0–2	30	> 120
3	20	90
5	12	60
7	8.5	40
9	7	33

5. Which of the following statements about skin type 1 is true?
   A. Skin type 4 will never sunburn.
   B. Skin type 1 will always burn in less than 20 minutes.
   C. Skin type 1 is less sensitive to UV exposure than skin type 4 is.
   D. Skin type 1 is more sensitive to UV exposure than skin type 4 is.

DIRECTIONS: Complete the following analogy.

6. nerve : neuron :: bone :
   F. marrow
   G. skeleton
   H. osteocyte
   J. Haversian canal

INTERPRETING GRAPHICS: The figure below shows a sarcomere and an enlargement of actin and myosin filaments. Use the figure to answer the question that follows.



7. Which part of the sarcomere represents the Z line?
   A. feature 1
   B. feature 2
   C. feature 3
   D. feature 4

SHORT RESPONSE

Red bone marrow inside spongy bone produces red blood cells, which are specialized cells used to carry oxygen throughout the body.

How are red blood cells transported around the body?

EXTENDED RESPONSE

A single layer of smooth muscle encircles the walls of blood vessels. The walls of the stomach and small intestine have a layer of circular smooth muscle and a layer of longitudinal smooth muscle.

Part A How does the muscle arrangement of blood vessels reflect the function of this structure?

Part B How does the muscle arrangement of the stomach and small intestine reflect the function of these structures?

Test TIP For a question involving experimental data, determine the constants, variables, and control **before** answering the questions.

Dehydrating and Demineralizing Bone

OBJECTIVES

- Determine the amount of water and minerals in bone.
- Identify structures in bone cells.

PROCESS SKILLS

- observing
- identifying
- calculating

MATERIALS

- balance
- beaker, 250 mL
- beakers, 500 mL (2)
- bones (2)
- bone slides, prepared
- drying oven
- gauze, circular piece
- glass plate or parafilm
- hot pad
- hydrochloric acid, 1 M (300 mL)
- lens paper
- marker, permanent
- microscope, compound
- pencil, wax
- plastic bag, resealable
- specimen tag
- tongs

Background

1. Dehydration is the process of removing the water from a substance.
2. Demineralization is the process of removing the minerals from a substance.

PART A Dehydrating a Bone

1. In your lab report, prepare a data table similar to Table A.
2.  Put on safety goggles, a lab apron, and gloves. Wear this protective gear during all parts of this investigation.

TABLE A *DEHYDRATION OF BONE*

Mass before drying	Mass after drying	Percentage of bone mass lost

3. Obtain a bone from your teacher. Test the flexibility of the bone by trying to bend and twist it.
4. Place the bone on a balance. Measure the mass of the bone to the nearest 0.1 g, and record it in your data table. Then, use a permanent marker to write the initials of each member of your group on a specimen tag, and tie the tag to the bone.
5. Place the bone in a drying oven at 100°C for 30 minutes. While the bone is in the oven, complete Part C.
6.  **CAUTION Do not touch hot objects with your bare hands. Use insulated gloves and tongs as appropriate.** Using tongs, remove the bone from the oven and place it on a heat-resistant pad to cool for 10 minutes.
7. Use tongs to place the cooled bone on the balance. Measure the mass of the bone to the nearest 0.1 g, and record it in your data table.
8. Use the equation below to calculate the percentage of the bone's mass that was lost during heating.

$$\text{Percentage mass lost} = \frac{\text{mass before heating} - \text{mass after heating}}{\text{mass before heating}} \times 100$$

PART B Demineralizing a Bone

9. In your lab report, prepare a data table similar to Table B.
10. Obtain a second bone from your teacher. Test the flexibility of the bone by trying to bend and twist it.

TABLE B *DEMINERALIZATION OF A BONE*

Mass before demineralizing	Mass after demineralizing and drying	Percentage of bone mass lost

11. Place the bone on a balance. Measure the mass of the bone, and record it in your data table.
12. **CAUTION Glassware is fragile. Notify your teacher promptly of any broken glass or cuts. Do not clean up broken glass or spills unless your teacher tells you to do so.** Using a wax pencil, label a 500 mL beaker "1 M HCl." Also label the beaker with the initials of all group members. Place a piece of gauze in the bottom of the beaker.
13. **CAUTION If you get an acid on your skin or clothing, wash it off at the sink immediately while calling to your teacher.** Place the bone on top of the gauze in the beaker, and add enough 1 M HCl to cover the bone. Use a glass plate or parafilm to cover the beaker.
14. Place the beaker under a fume hood, and allow the bone to soak in the acid until it softens and becomes spongy. This should take 5 to 7 days. Periodically use tongs to test the hardness of the bone. *Note: Do not touch the bone with your fingers while it is soaking in acid. Rinse the tongs with water thoroughly each time you finish testing the bone.*
15. When the bone becomes spongy, use tongs to carefully remove it from the beaker, and rinse it under running water for two minutes.
16. After the bone has been thoroughly rinsed, test the bone for hardness by twisting and bending it with your fingers. *Note: Be sure you are wearing gloves.*
17. Then, use a permanent marker to write the initials of each member of your group on a specimen tag, and tie the tag to the bone. Place the bone in a drying oven at 100°C for 30 minutes.
18. **CAUTION Do not touch hot objects with your bare hands. Use insulated gloves and tongs as appropriate.** Using tongs, remove the bone from the oven and place it on a heat-resistant pad. Allow the bone to cool for 10 minutes.
19. Use tongs to place the cooled bone on the balance. Measure the mass of the bone to the nearest 0.1 g, and record the measurement in your data table.
20. Use the equation below to calculate the percentage of the bone's mass that was lost through demineralization and dehydration.

$$\text{Percentage of mass lost} = \frac{\text{mass before demineralizing} - \text{mass after demineralizing and drying}}{\text{mass before demineralizing}} \times 100$$

PART C Observing Prepared Slides of Bone

21. **CAUTION Do not use electrical equipment near water or with wet hands or clothing.** Using a compound light microscope, focus on a prepared slide of bone by using low power, and then switch to high power. Locate a Haversian canal, the darkly stained circle in the center of a set of lamellae. Find the darkly stained osteocytes between the lamellae.
22. In your lab report, draw and label the following bone structures: Haversian canal, lamella, and osteocyte.

Analysis and Conclusions

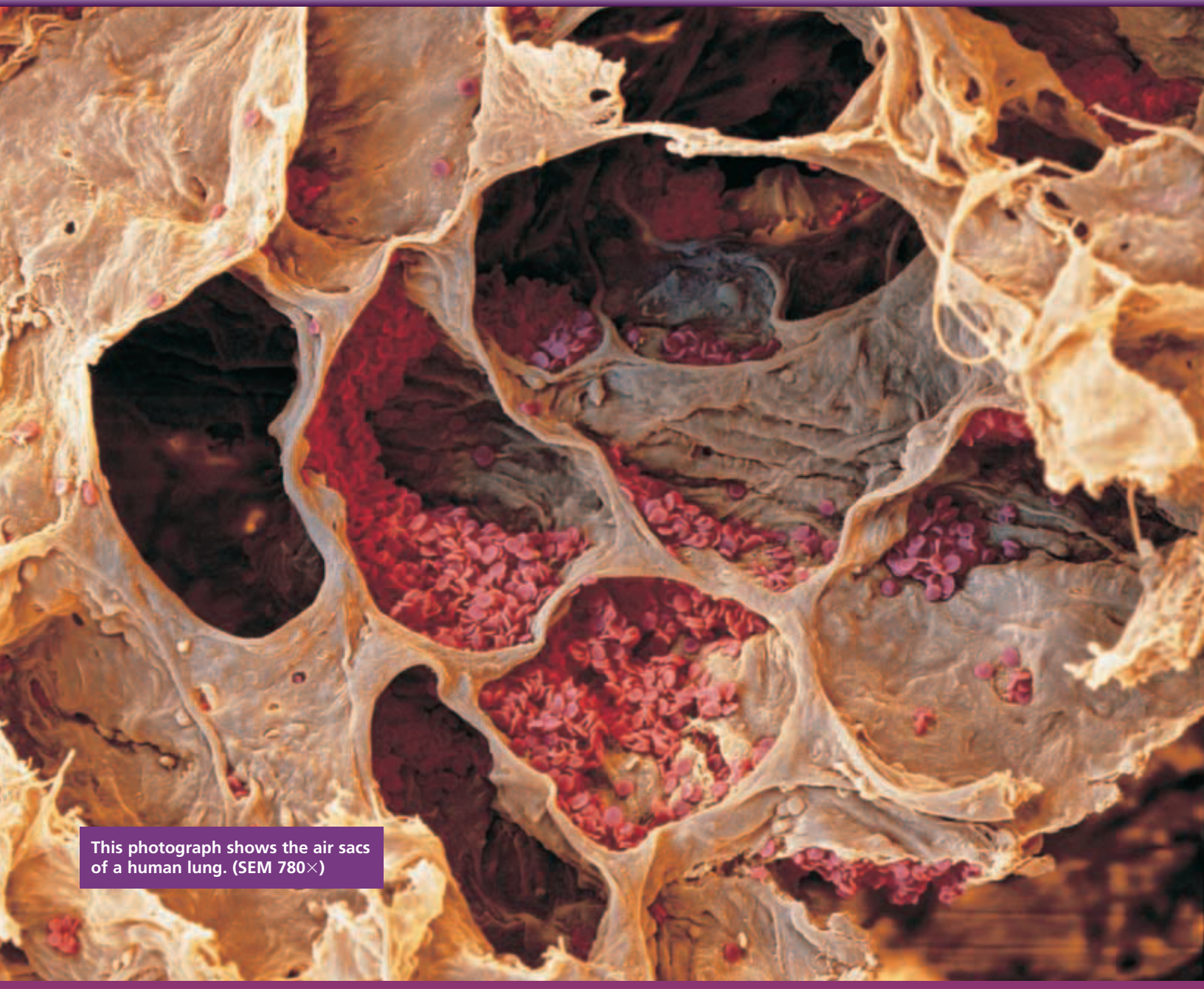
1. What effect did water loss have on the bone? What effect did mineral loss have on the bone?
2. Why did you have to dehydrate the bone before measuring its mass in Part B?
3. What percentage of bone is water? What percentage of bone is made of minerals?
4. If you were to prepare a slide using the dehydrated and demineralized bone, what do you think the bone would look like?
5. What happened when the demineralized bone was dried? Why do you think this happened?
6. If a person's diet lacked calcium, how could this affect his or her bones?

Further Inquiry

Research the differences in the amount and distribution of different bone types from various parts of the human skeleton.

CHAPTER 46

Circulatory and Respiratory Systems



This photograph shows the air sacs of a human lung. (SEM 780×)

THE CIRCULATORY SYSTEM

Most of the cells in the human body are not in direct contact with the external environment. The circulatory system acts as a transport service for these cells. Two fluids move through the circulatory system: blood and lymph.

SECTION 1

OBJECTIVES

- **Describe** the structure and function of the human heart.
- **Trace** the flow of blood through the heart and body.
- **Distinguish** between arteries, veins, and capillaries in terms of their structure and function.
- **Distinguish** between pulmonary circulation and systemic circulation.
- **Summarize** the functions of the lymphatic system.

VOCABULARY

cardiovascular system
lymphatic system
atrium
ventricle
valve
aorta
sinoatrial node
atrioventricular node
pulse
artery
blood pressure
hypertension
capillary
vein
pulmonary circulation
systemic circulation
atherosclerosis
lymph

THE HEART

The blood, heart, and blood vessels form the **cardiovascular system.** The lymph, lymph nodes, and lymph vessels form the **lymphatic system.** The cardiovascular system and lymphatic system collectively make up the *circulatory system.* The circulatory system transports nutrients, hormones, and gases; gets rid of wastes; and helps maintain a constant body temperature.

The central organ of the cardiovascular system is the heart, the muscular organ that pumps blood through a network of blood vessels. The heart beats more than 2.5 billion times in an average life span. Yet this organ is slightly larger than a fist. The heart lies within the thoracic (chest) cavity, behind the sternum (breastbone) and between the two lungs. A tough, saclike membrane called the *pericardium* surrounds the heart and secretes a fluid that reduces friction as the heart beats.

Notice in Figure 46-1 that a *septum* (wall) vertically divides the heart into two sides. The right side pumps blood to the lungs, and the left side pumps blood to the other parts of the body. Each side of the heart is divided into an upper and lower chamber. Each upper chamber is called an **atrium,** and each lower chamber is called a **ventricle.**

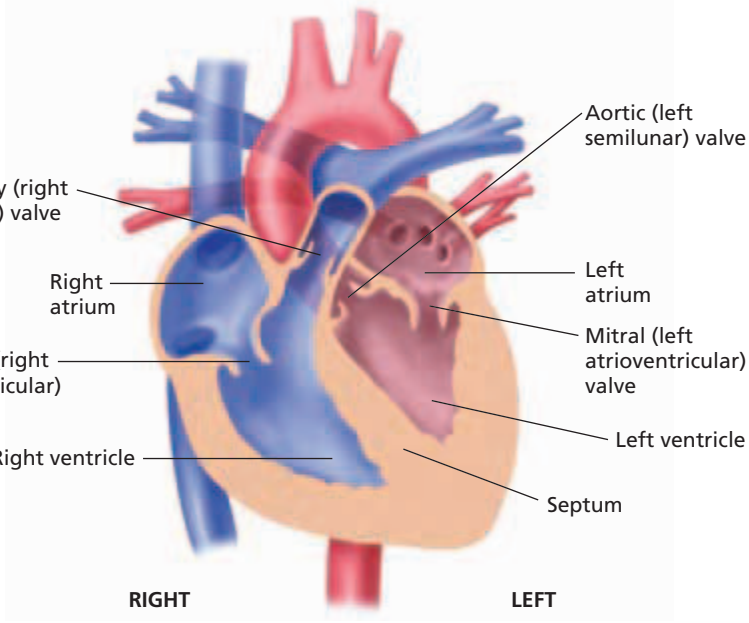


FIGURE 46-1
The septum prevents mixing of blood from the two sides of the heart, and the valves ensure that blood flows in only one direction.

Quick Lab

Determining Heart Rate

Materials stopwatch or clock with second hand

Procedure

1. Have your partner find the pulse in your wrist and count your heartbeats for 15 seconds while you are seated. Calculate your resting heart rate in beats per minute.
2. Have your partner count your heartbeats for 15 seconds while you are standing. Calculate your heart rate in beats per minute.
3. Have your partner count your heartbeats for 15 seconds after you jog or march in place for 1 minute. Calculate your heart rate in beats per minute.

Analysis What causes your pulse? What causes the change in your heart rate in each situation?

Valves are flaps of tissue that open in only one direction. The *atrioventricular* (AY-tree-oh-ven-TRIH-kyuh-luhr) *valve* (AV valve) on the right side of the heart is called the *tricuspid valve*. The *mitral valve*, also called the *bicuspid valve,* is on the left. As the ventricles pump, blood pressure closes the AV valves to prevent blood from flowing backward into the atria. From the ventricles, blood is pumped out of the heart into large vessels. A *semilunar* (SEM-ee-LOON-uhr) *valve* (SL valve) separates the ventricles from these large vessels on each side of the heart. The SL valve on the right side is known as the *pulmonary valve*, and the SL valve on the left side is known as the *aortic valve*. The SL valves prevent blood from flowing back into the ventricles when the heart relaxes.

Circulation in the Heart

Refer to Figure 46-2 to trace the path of the blood as it circulates through the heart. Blood returning to the heart from parts of the body other than the lungs has a high concentration of carbon dioxide and a low concentration of oxygen. (1) Deoxygenated (O_2-poor) blood enters the right atrium.

(2) The right atrium sends deoxygenated blood into the right ventricle. (3) The muscles of the right ventricle contract and force the blood into the pulmonary arteries. (4) The pulmonary artery sends the blood to the lungs. In the lungs, the carbon dioxide diffuses out of the blood, and oxygen diffuses into the blood. (5) The oxygenated blood returns to the left atrium of the heart. Notice in Figure 46-2 that the flow of blood on the left side of the heart is illustrated with a red arrow representing oxygenated blood, which has a bright red color.

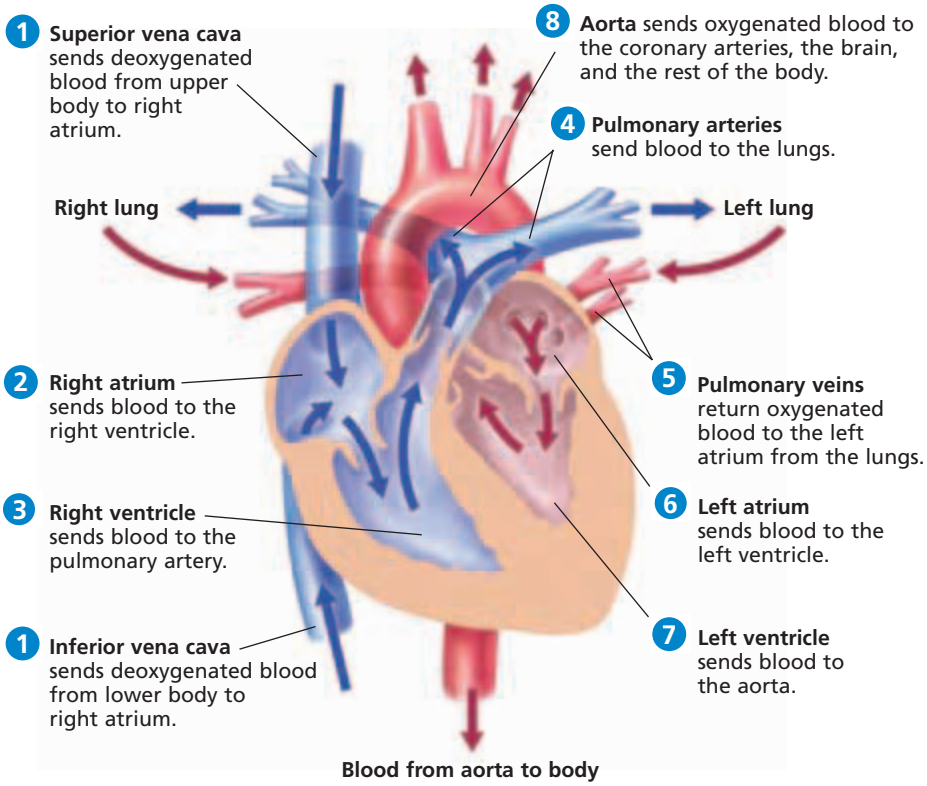


FIGURE 46-2

Trace the path of blood through the heart. Notice that illustrations of a heart are drawn as if the heart were in a person facing you. That is, the left side of the heart is shown on the right as you face the heart, and the right side of the heart is on the left as you face the heart.

6 The oxygenated blood is then pumped into the left ventricle. 7 Contraction of the muscular walls of the left ventricle forces the blood into a large blood vessel called the **aorta.** 8 From the aorta, blood is transported to all parts of the body. The left ventricle is the thickest chamber of the heart because it has to do the most work to pump blood to all parts of the body.

Deoxygenated blood is commonly represented with the color blue. However, it is a misconception that deoxygenated blood is blue. When oxygen is attached to hemoglobin, the blood is bright red. Without oxygen, blood is dark red. The dark red blood in veins appears blue when it shows through the vein walls and skin.

Control of the Heartbeat

The heart consists of muscle cells that contract in waves. When the first group of cells are stimulated, they in turn stimulate neighboring cells. Those cells then stimulate more cells. This chain reaction continues until all the cells contract. The wave of activity spreads in such a way that the atria and the ventricles contract in a steady rhythm. The first group of heart-muscle cells that get stimulated lie in an area of the heart known as the sinoatrial node, shown in Figure 46-3.

The **sinoatrial** (SIEN-oh-AY-tree-uhl) **(SA) node** is a group of specialized heart-muscle cells located in the right atrium. These muscle cells spontaneously initiate their own electrical impulse and contract. The SA node is often called the *pacemaker* because it regulates the rate of contraction of the entire heart. The electrical impulse initiated by the SA node subsequently reaches another special area of the heart, known as the **atrioventricular (AV) node.** The AV node is located in the septum between the atria, as shown in Figure 46-3. The AV node relays the electrical impulse to the muscle cells that make up the ventricles. As a result, the ventricles contract a fraction of a second after the atria, completing one full heartbeat. In an average adult at rest, the heart beats about 70 times each minute.

A heartbeat has two phases. Phase one, called *systole* (SIS-tohl), occurs when the ventricles contract, closing the AV valves and opening the SL valves to pump blood into the two major vessels that exit the heart. Phase two, called *diastole* (DIE-a-stohl), occurs when the ventricles relax, allowing the back pressure of the blood to close the SL valves and opening the AV valves. The closing of these two heart valves results in the characteristic *lub dup* sound we call a heartbeat. If one of the valves fails to close properly, some blood may flow backward, creating a different sound, which is known as a heart murmur.

A person's **pulse** is a series of pressure waves within an artery caused by the contractions of the left ventricle. When the ventricle contracts, blood surges through the arteries, and the elastic walls in the vessels expand and stretch. The most common site for taking a pulse is at a radial artery, on the thumb side of each wrist. The average pulse rate ranges from 70 to 90 beats per minute for adults.

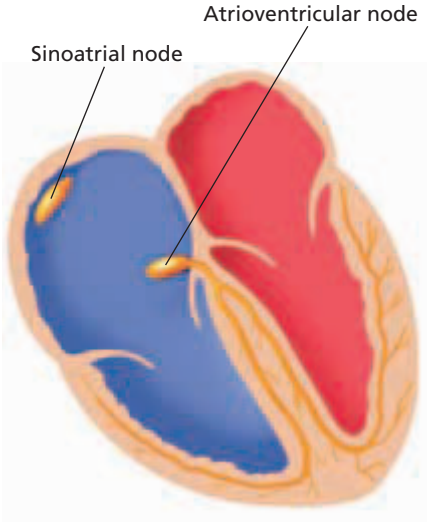
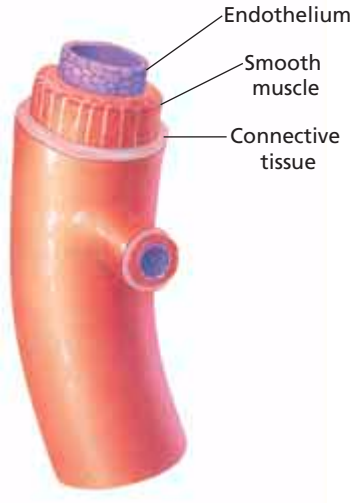


FIGURE 46-3

Two areas of specialized tissue, known as nodes, control the heartbeat. A person whose SA node is defective can have an operation to implant an artificial pacemaker. An artificial pacemaker can also help a defective AV node.



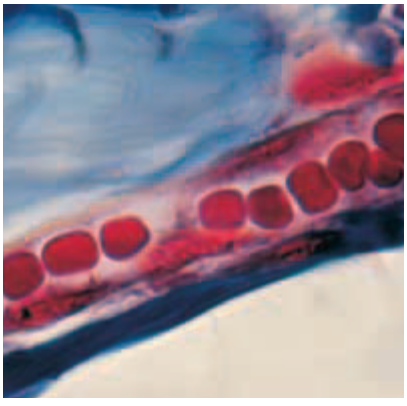
Artery
(carries blood away from the heart)

FIGURE 46-4

Notice the thick muscular layer of an artery. The layers of the artery wall are separated by elastic tissue. This tissue provides strength, preventing systolic pressure from bursting the artery.

FIGURE 46-5

The diameter of a capillary is so small that red blood cells must move single file through these vessels, as shown in this photograph (1,200×). All exchange of nutrients and waste between blood and cells occurs across the thin walls of the capillaries.



BLOOD VESSELS

The circulatory system is known as a closed system because the blood is contained within either the heart or the blood vessels at all times. This type of system differs from an open system, in which blood leaves the vessels and circulates within tissues throughout the organism's body. The blood vessels that are part of the closed circulatory system of humans form a vast network to help keep the blood flowing in one direction.

Arteries and Blood Pressure

The large, muscular vessels that carry blood away from the heart are called **arteries.** As shown in Figure 46-4, the thick walls of the arteries have three layers: an inner endothelial layer, a middle layer of smooth muscle, and an outer layer of connective tissue. This structure gives arteries a combination of strength and elasticity, which allows them to stretch as pressurized blood enters from the heart. You can feel this stretching of arteries—it is your pulse.

Contraction of the heart moves the blood through the arteries with great force. The force that blood exerts against the inside walls of a blood vessel is known as **blood pressure.** Blood pressure is highest in the two main arteries that leave the heart. It is usually measured in the artery that supplies blood to the arm. To measure blood pressure, a trained person inflates a cuff that is placed around a patient's arm, temporarily stopping the flow of blood through the artery. Connected to the cuff is a gauge containing a column of mercury (Hg) that rises as the pressure in the cuff increases. The trained person then releases the air in the cuff slowly while listening to the artery with a stethoscope and watching the column of mercury. The first sounds of blood passing through the artery indicates the *systolic pressure*, or the pressure of the blood when the ventricles contract. In a normal adult, the systolic pressure is about 120 mm of Hg for males and 110 mm of Hg for females. Continuing to release the air in the cuff, the trained person next listens for the disappearance of sound, which indicates a steady flow of blood through the artery in the arm. This indicates the *diastolic pressure*. In a normal adult, the diastolic pressure is about 80 mm of Hg for males and 70 mm of Hg for females.

High blood pressure, or **hypertension,** is a leading cause of death in many countries. Blood pressure that is higher than normal places a strain on the walls of the arteries and increases the chance that a vessel will burst.

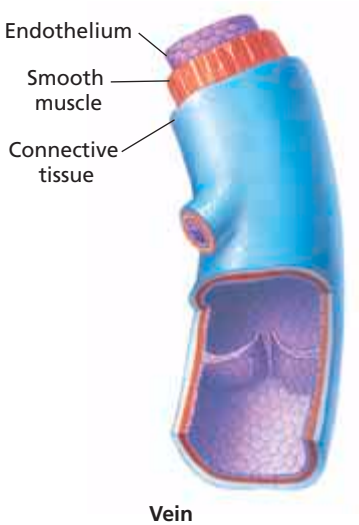
Capillaries and Veins

Recall that when the left ventricle contracts, it forces blood into the aorta, the body's largest artery. From the aorta, blood travels through a network of smaller arteries, which in turn divide and form even smaller vessels, called *arterioles*. The arterioles branch into a network of tiny vessels, called **capillaries.** A capillary is shown in Figure 46-5.

The network formed by capillaries is so extensive that all of the approximately 100 trillion cells in the body lie within about 125 µm of a capillary. This close association between capillaries and cells allows for rapid exchange of materials. Capillary walls are only one cell thick; gases and nutrients can diffuse through these thin walls. Wherever the concentration of oxygen or nutrients is higher in the blood than in the surrounding cells, the substance diffuses from the blood into the cells. Wherever the concentrations of carbon dioxide and wastes are higher in the cells than in the blood, these substances diffuse from the cells into the blood.

Blood flows through capillaries that merge to form larger vessels called *venules* (VEN-yoolz). Several venules in turn unite to form a **vein,** a large blood vessel that carries blood to the heart. Veins returning deoxygenated blood from the lower parts of the body merge to form the *inferior vena cava*. Veins returning deoxygenated blood from the upper parts of the body merge to form the *superior vena cava*. Refer back to Figure 46-2, and locate the inferior vena cava and the superior vena cava.

As you can see in Figure 46-6, although the walls of the veins are composed of three layers, like those of the arteries, they are thinner and less muscular. By the time blood reaches the veins, it is under much less pressure than it was in the arteries. With less pressure being exerted in the veins, the blood could flow backward and disrupt the pattern of circulation. To prevent that, valves in the veins help keep the blood flowing in one direction. Many veins pass through skeletal muscle. When these muscles contract, they are able to squeeze the blood through the veins. When these muscles relax, the valves can close, thus preventing the blood from flowing backward. Figure 46-6 shows the structure of a valve in a vein.



Vein
(returns blood to the heart)

FIGURE 46-6
Like an artery, a vein has three layers: the outer layer of connective tissue, the middle layer of smooth muscle, and the inner layer of endothelial tissue.

PATTERNS OF CIRCULATION

The English scientist William Harvey (1578–1657) first showed that the heart and the blood vessels form one continuous, closed system of circulation, as shown in Figure 46-7. He also reasoned that this system consists of two primary subsystems: **pulmonary circulation,** in which the blood travels between the heart and lungs, and **systemic circulation,** in which the blood travels between the heart and all other body tissues.

Pulmonary Circulation

Deoxygenated blood returning from all parts of the body except the lungs enters the right atrium, where it is then pumped into the right ventricle. When the right ventricle contracts, the deoxygenated blood is sent through the pulmonary artery to the lungs. The pulmonary artery is the only artery that carries deoxygenated blood. The pulmonary artery branches into two smaller arteries, with one artery going to each lung. These arteries branch into arterioles and then into capillaries in the lungs.

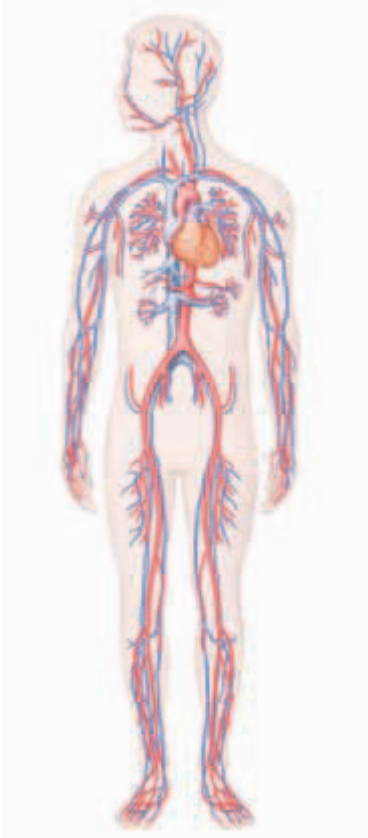
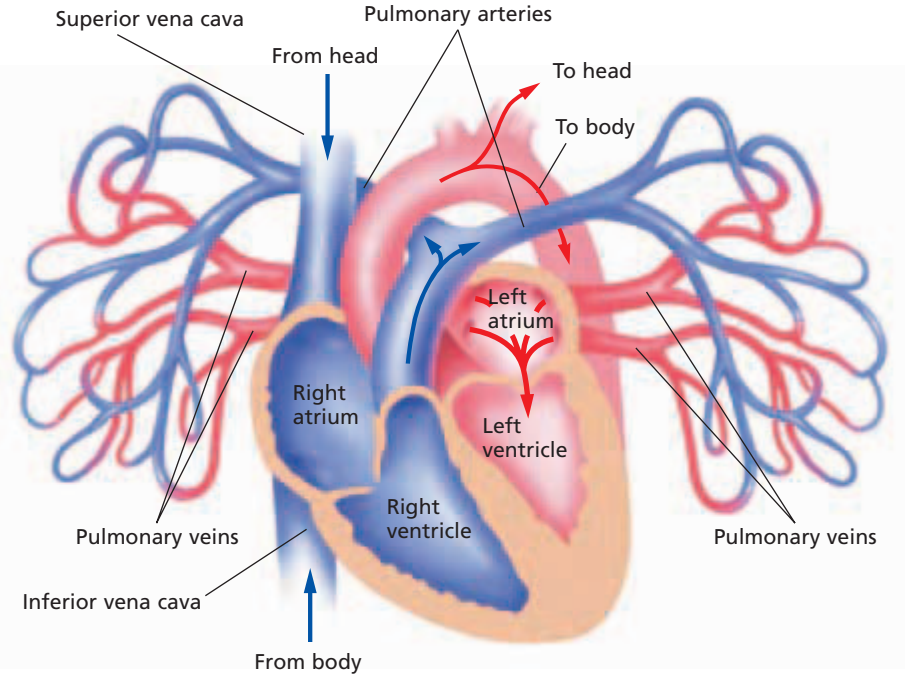


FIGURE 46-7
The cardiovascular system transports materials throughout the body and distributes heat.

FIGURE 46-8

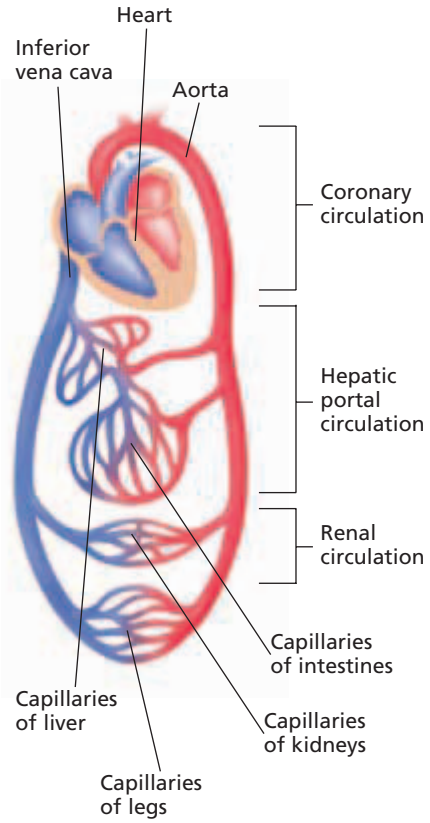
The pulmonary circulation between the heart and the lungs involves the pulmonary arteries and the pulmonary veins. Deoxygenated blood flows from the right side of the heart to the lungs. Oxygenated blood is returned to the left side of the heart from the lungs. This is the opposite of systemic and coronary blood flow, in which oxygen-rich blood flows from the heart and oxygen-poor blood is returned to the heart.



In the lungs, carbon dioxide diffuses out of the capillaries and oxygen diffuses into the capillaries. The oxygenated blood then flows into venules, which merge into the *pulmonary veins* that lead to the left atrium of the heart. From the left atrium, blood is pumped into the left ventricle and then to the body through the aorta. In Figure 46-8, trace the path blood takes as it passes through pulmonary circulation.

FIGURE 46-9

Notice three subsystems of systemic circulation. Other subsystems transport blood between the heart and the head, arms, and other organs.



Systemic Circulation

Systemic circulation is the movement of blood between the heart and all parts of the body except the lungs. Trace the path blood follows in systemic circulation in Figure 46-9. Notice that oxygenated blood is pumped out of the left ventricle and into the aorta. From the aorta, blood flows into other subsystems of systemic circulation.

Coronary circulation is the subsystem of systemic circulation that supplies blood to the heart itself. If blood flow in the *coronary arteries,* which supply blood to the heart, is reduced or cut off, muscle cells will die. This can happen when an artery is blocked by a blood clot or by **atherosclerosis** (ATH-uhr-oh-skler-OH-sis), a disease characterized by the buildup of fatty materials on the interior walls of the coronary arteries. Either type of blockage can lead to a *heart attack*.

Hepatic portal circulation is a subsystem of systemic circulation. Nutrients are picked up by capillaries in the small intestine and are transported by the blood to the liver. Excess nutrients are stored in the liver for future needs. The liver receives oxygenated blood from a large artery that branches from the aorta.

Renal circulation, another subsystem of systemic circulation, supplies blood to the kidneys. Nearly one-fourth of the blood that is pumped into the aorta by the left ventricle flows to the kidneys. The kidneys filter waste from the blood.

LYMPHATIC SYSTEM

In addition to the cardiovascular system, the circulatory system also includes the lymphatic system. One function of the lymphatic system is to return fluids that have collected in the tissues to the bloodstream. Fluids diffuse through the capillary walls just as oxygen and nutrients do. Some of these fluids pass into cells, some return to the capillaries, and some remain in the intercellular spaces.

Excess fluid in the tissues moves into the tiny vessels of the lymphatic system; this fluid is called **lymph.** Lymph vessels merge to form larger vessels. The lymph vessels are similar in structure to capillaries, and the larger lymph vessels are similar in structure to veins. However, an important difference exists between blood vessels and lymph vessels. Blood vessels form a complete circuit so that blood passes from the heart to all parts of the body and then back again to the heart. In contrast, lymph vessels form a one-way system that returns fluids collected in the tissues back to the bloodstream. In addition, the lymphatic system has no pump. Like the blood in veins, lymph must be moved through the vessels by the squeezing of skeletal muscles. Like veins, the larger lymph vessels have valves to prevent the fluid from moving backward.

Notice in Figure 46-10 that lymph vessels form a vast network that extends throughout the body. The lymph that travels in these vessels is a transparent yellowish fluid, much like the liquid part of the blood. As the lymph travels through these vessels on its way to the heart, it passes through small organs known as lymph nodes. Notice in Figure 46-10 that lymph nodes are like beads on a string. These nodes filter the lymph as it passes, trapping foreign particles, microorganisms, and other tissue debris. Lymph nodes also store *lymphocytes*, white blood cells that are specialized to fight disease. When a person has an infection, the nodes may become inflamed, swollen, and tender because of the increased number of lymphocytes.

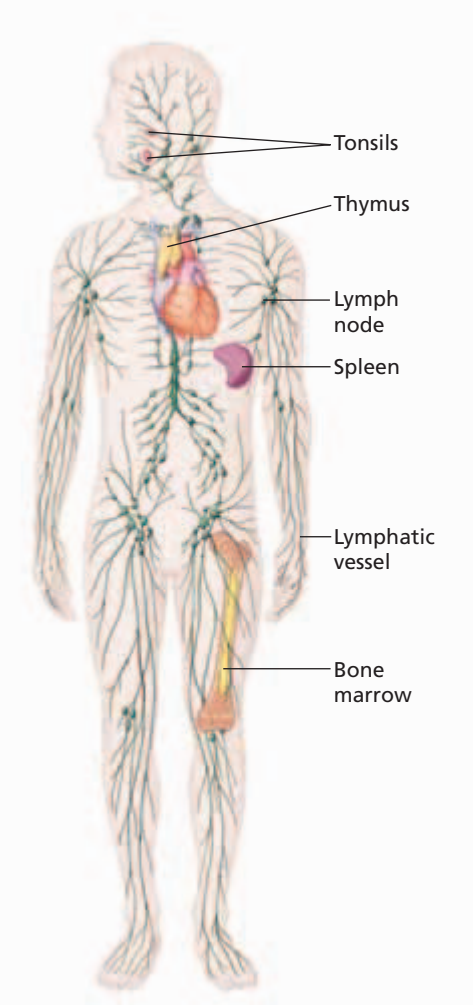


FIGURE 46-10
Like the cardiovascular system, the lymphatic system forms a vast network. Concentrated in certain regions of this network are lymph nodes that contain some of the disease-fighting cells of the immune system.

SECTION 1 REVIEW

1. Describe the structure of the heart.
2. Outline the path that blood follows through the heart and body, starting at the superior vena cava.
3. Describe the process by which the heartbeat is regulated.
4. How are the structures of arteries, veins, and capillaries related to their function?
5. Compare oxygenation levels in pulmonary circulation and systemic circulation.
6. Explain how the lymphatic system works with the cardiovascular system.

CRITICAL THINKING

7. **Analyzing Information** Some babies are born with a hole in the septum between the two atria. Based on what you know about blood flow through the heart, explain why this condition would be harmful to the baby.
8. **Forming Reasoned Opinions** In which blood vessels would you expect to find the lowest average blood pressure? Explain your answer.
9. **Applying Information** A man's arm is cut by a piece of glass. Blood comes out of the wound in rapid spurts. Which type of vessel was cut?

SECTION 2

OBJECTIVES

- **List** the components of blood.
- **Distinguish** between red blood cells, white blood cells, and platelets in terms of their structure and function.
- **Summarize** the process of blood clotting.
- **Explain** what determines the compatibility of blood types for transfusion.

VOCABULARY

plasma
red blood cell (erythrocyte)
hemoglobin
white blood cell (leukocyte)
phagocyte
antibody
platelet
fibrin
blood type
antigen
Rh factor

BLOOD

Blood is a liquid connective tissue. The two main functions of the blood are to transport nutrients and oxygen to the cells and to carry carbon dioxide and other waste materials away from the cells. Blood also transfers heat to the body surface and plays a major role in defending the body against disease.

COMPOSITION OF BLOOD

Blood is composed of a liquid medium and blood solids (formed elements). Formed elements include red blood cells, white blood cells, and platelets. The liquid makes up about 55 percent of the blood, and formed elements make up the remaining 45 percent. A healthy adult has about 4 to 5 L of blood in his or her body.

Plasma

Plasma, the liquid medium, is a sticky, straw-colored fluid that is about 90 percent water and includes metabolites, nutrients, wastes, salts, and proteins. Cells receive nourishment from dissolved substances carried in the plasma. These substances, which may include vitamins, minerals, amino acids, and glucose, are absorbed from the digestive system and transported to the cells. Plasma also carries hormones and brings wastes from the cells to the kidneys or the lungs to be removed from the body.

A variety of proteins are carried in the plasma. The plasma proteins have various functions. Some of the proteins in the plasma are essential for the formation of blood clots. Another protein, called albumin, plays an important role in the regulation of osmotic pressure between plasma and blood cells and between plasma and tissues. Other proteins, called antibodies, help the body fight disease.

FIGURE 46-11

Notice that a mature red blood cell (RBC) is disk-shaped and is concave on both sides. A red blood cell is little more than a cell membrane filled with hemoglobin. How is this structure related to its function?

Red Blood Cells

Red blood cells, or **erythrocytes** (uh-RITH-ruh-siets), shown in Figure 46-11, transport oxygen to cells in all parts of the body. Red blood cells are formed in the red marrow of bones. Immature red blood cells synthesize large amounts of an iron-containing protein called **hemoglobin.** Hemoglobin is the molecule that actually transports oxygen and, to a lesser degree, carbon dioxide. During the formation of a red blood cell, its cell nucleus and organelles disintegrate. The mature red blood cell is little more than a membrane containing hemoglobin.

Because red blood cells lack nuclei, they cannot divide and they have a limited survival period, usually 120 to 130 days. Of the more than 30 trillion red blood cells circulating throughout the body at one time, 2 million disintegrate every second. To replace them, new ones form at the same rate in the red marrow of bones. Some parts of the disintegrated red blood cells are recycled. For example, the iron portion of the hemoglobin molecule is carried in the blood to the marrow, where it is reused in new red blood cells.

White Blood Cells

White blood cells, or **leukocytes** (LOO-kuh-siets), help defend the body against disease. They are formed in the red marrow, but some must travel to lymph nodes, tonsils, the thymus, or the spleen to mature. White blood cells are larger than red blood cells and significantly less plentiful. Each cubic millimeter of blood normally contains about 4 million red blood cells and 7,000 white blood cells. White blood cells can squeeze their way through openings in the walls of blood vessels and into the intercellular fluid. In that way, white blood cells can reach the site of infection and help destroy invading microorganisms.

Word Roots and Origins

leukocyte

from the Greek *leuco*, meaning "white," and *cyte*, meaning "cell"

Notice in Figure 46-12 that a white blood cell has a very different structure from that of a red blood cell. For instance, a white blood cell may be irregularly shaped and may have a rough outer surface. There are other differences between red blood cells and white blood cells as well. In contrast with the short-lived red blood cells, white blood cells may function for years. And while there is only one type of red blood cell, there are several types of white blood cells.

The white blood cell shown in Figure 46-12 is the type of white blood cell known as a **phagocyte** (FA-guh-siet). Phagocytes are cells that engulf invading microorganisms. Locate the microorganisms that are being engulfed by the phagocyte in Figure 46-12. Another type of white blood cell produces **antibodies.** Antibodies are proteins that help destroy substances, such as bacteria and viruses, that enter the body and can cause disease. When a person has an infection, the number of white blood cells can double.

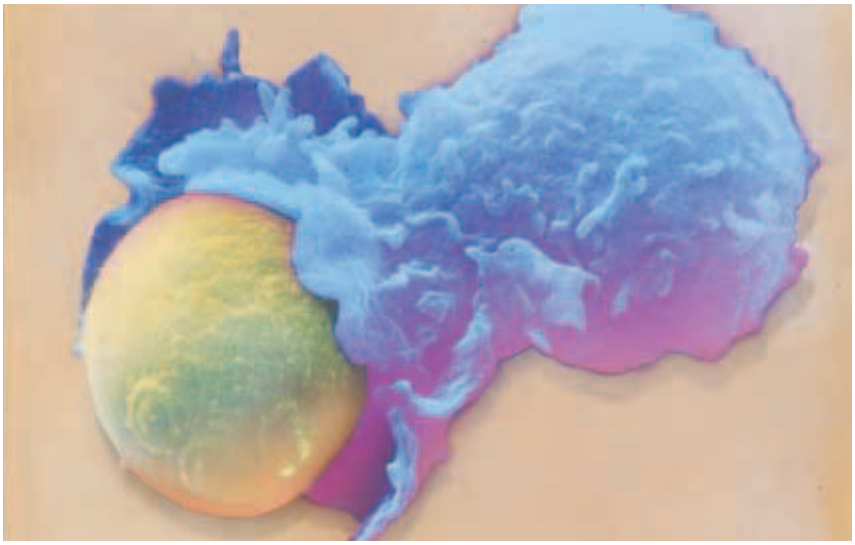
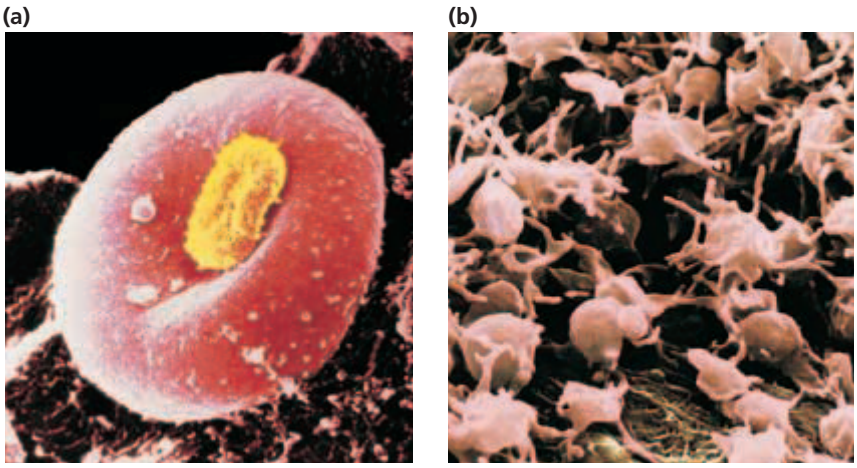


FIGURE 46-12
Some white blood cells, like the phagocyte shown in blue, engulf and destroy invading microorganisms.

FIGURE 46-13

Inactive platelets, such as the yellow object shown in (a), derive their name from the fact that they look like little plates. Platelets are colorless and contain chemicals that are involved in the clotting process. (b) The platelets change shape during the clotting process. When activated, the platelets settle and spread on the substrate.



Eco Connection

Vampire Bats Help Save Stroke Victims

Vampire bats have an anticoagulant in their saliva that prevents blood clotting when it flows from a wound. In 1995, this enzyme was isolated and named *Draculin*.

Researchers have developed a clot-dissolving agent called *Desmodus rotundus salivary plasminogen activator* (DSPA), which is based on the salivary enzyme Draculin. DSPA targets and destroys fibrin. The current treatment must be given within three hours of the onset of a stroke (a sudden loss of consciousness or paralysis that occurs when the blood flow to the brain is interrupted). Otherwise, brain-cell death and brain damage may occur. According to research, DSPA could be a safe treatment for longer periods of time and appears to have no detrimental effect on brain cells.

Platelets

Platelets are essential to the formation of a blood clot. A blood clot is a mass of interwoven fibers and blood cells that prevents excess loss of blood from a wound. Platelets are not whole cells. They are fragments of very large cells that were formed in the bone marrow. As you can see in Figure 46-13a, platelets get their name from their platelike structure. Platelets lack a nucleus and have a life span of 7 to 12 days. A cubic micrometer of blood may contain as many as half a million platelets.

When a blood vessel tears or rips, platelets congregate at the damaged site, sticking together and forming a small plug. The vessel constricts, slowing blood flow to the area. Then, special clotting factors are released from the platelets and the damaged tissue. These factors begin a series of chemical reactions that occur at the site of the bleeding. The last step in this series brings about the production of a protein called **fibrin.** Fibrin molecules consist of long, sticky chains. As you can see in Figure 46-14, these chains form a net that traps red blood cells, and the mass of fibrin and red blood cells hardens into a clot, or scab.

Hemophilia is a disorder caused by the absence of one or more of the proteins required for blood clotting. When a person with hemophilia is injured, bleeding continues for much longer than it would in a person without hemophilia. Large cuts or internal injuries can be life threatening. Today, people with hemophilia are treated with injections of the missing clotting factors.

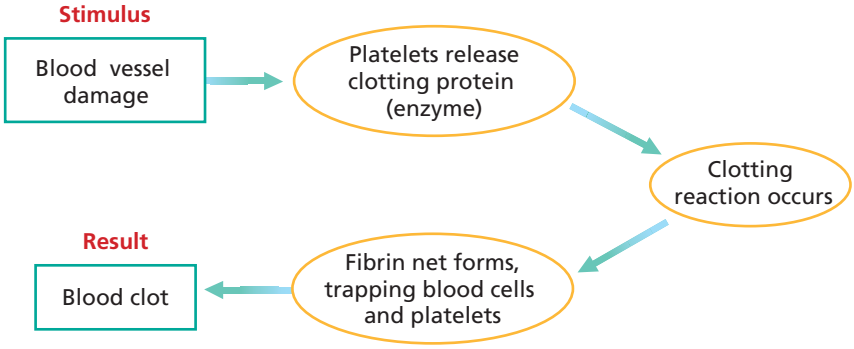


FIGURE 46-14

The release of enzymes from platelets at the site of a damaged blood vessel initiates a "clotting cascade."

BLOOD TYPES

Blood type is determined by the type of antigen present on the surface of the red blood cells. An **antigen** is a substance that stimulates an immune response. Antigens that are normally present in a person's body provoke no response. However, when foreign antigens enter the body, cells respond by producing antibodies. In fact, the word *antigen* is an abbreviation for "antibody-generating substance."

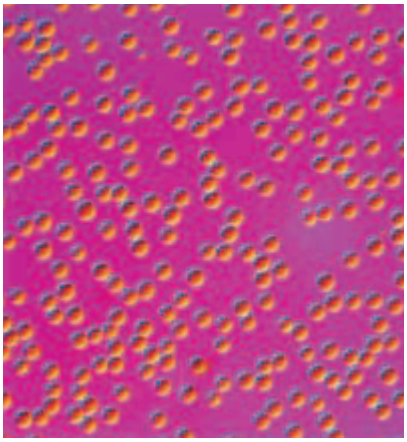
In the early 1900s, Karl Landsteiner used blood taken from his laboratory workers and made observations similar to those you see in Figure 46-15. He noticed that mixing blood samples from two people sometimes resulted in the cells clumping together, or *agglutinating*. When samples of two different blood types are mixed together, reactions occur between the antigens on the red blood cells and the antibodies in the plasma, causing the cells to agglutinate. When samples of the same blood type are mixed, no reaction occurs, and the blood cells do not agglutinate.

Landsteiner's observations led to the classification of human blood by blood types. Three of the most important human antigens are called A, B, and Rh. The A-B-O system of blood typing, described below, is based on the A and B antigens.

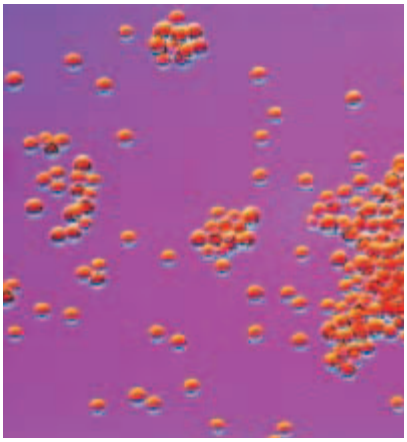
A-B-O System

The A-B-O system is a means of classifying blood by the antigens located on the surface of the red blood cells and the antibodies circulating in the plasma. As shown in Table 46-1, an individual's red blood cells may carry an A antigen, a B antigen, both A and B antigens, or no antigen at all. These antigen patterns are called blood types A, B, AB, and O, respectively.

Notice in Table 46-1 that an individual with type A blood also has anti-B antibodies against type B blood. If type B blood is given to a recipient with type A blood, the recipient's anti-B antibodies will react with the B antigens on the donated red blood cells and the blood will agglutinate. In addition, the donor's type B blood has anti-A antibodies. Their presence will compound the antigen-antibody reaction. The result will be agglutinated blood that will block the flow of blood through the vessels. For this reason, transfusion recipients must receive blood that is compatible with their own.



(a)



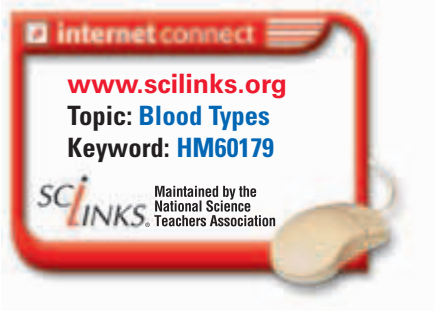
(b)

FIGURE 46-15

Notice that there is no agglutination of red blood cells in the slide in (a), where blood samples from two people with the same blood type were mixed. Compare this with the slide in (b), where blood samples from two people with different blood types were mixed.

TABLE 46-1 *Blood Types, Antigens, and Antibodies*

Blood types	Antigen on the red blood cells	Antibodies in the plasma	Can get blood from	Can give blood to
A	A	anti-B	O, A	A, AB
B	B	anti-A	O, B	B, AB
AB	A and B	none	A, B, AB, O	AB
O	none	anti-A, anti-B	O	A, B, AB, O



People who have type AB blood are *universal recipients.* They can receive A, B, AB, or O blood because they do not have anti-A or anti-B antibodies. People who have type O blood are *universal donors.* They can donate blood to people who have A, B, AB, or O blood because the blood cells of people who have type O blood do not have A or B antigens.

Rh System

An antigen that is sometimes present on the surface of red blood cells is the **Rh factor,** named after the rhesus monkey in which it was first discovered. Eighty-five percent of the United States' population is Rh-positive (Rh^+), meaning that Rh antigens are present. People who do not have Rh antigens are called Rh-negative (Rh^-).

If an Rh^- person receives a transfusion of blood that has Rh^+ antigens, antibodies may react with the antigen and agglutination will occur. The most serious problem with Rh incompatibility occurs during pregnancy. If the mother is Rh^- and the father is Rh^+, the child may inherit the dominant Rh^+ allele from the father. During delivery, a small amount of the fetus's Rh^+ blood may reach the mother's bloodstream. If this happens, the mother will develop antibodies to the Rh factor. If a second Rh^+ child is conceived later, the mother's antibodies can cross the placenta and attack the blood of the fetus. This condition is called *erythroblastosis fetalis.* The fetus may die as a result of this condition, or if the child is born alive, he or she may need an immediate transfusion of Rh^+ blood.

To prevent this condition, an Rh^- mother of an Rh^+ child can be given antibodies to destroy any Rh^+ cells that have entered her bloodstream from the fetus. The mother is, in effect, immunized against the Rh antigen before her immune system has a chance to develop its own antibodies. The antibody treatment prevents Rh sensitization in Rh^- women only if their bodies have not already produced Rh antibodies. If an Rh^- mother has not yet been sensitized, she receives the antibody treatment in the 28th week of pregnancy and again immediately after delivery.

SECTION 2 REVIEW

1. Identify the four main components of blood.
2. Explain how the structure of red blood cells, white blood cells, and platelets relates to the function of these cells.
3. Identify the stages and structures involved in the clotting process.
4. What factors determine the compatibility of blood types for transfusion?
5. Which blood types, in terms of the A-B-O and Rh antigens, can be donated to somebody with type AB^- blood?

CRITICAL THINKING

6. **Analyzing Information** Hemophilia is a disorder in which there is a failure in one of the steps of clot formation. What might be some advantages and disadvantages of this disorder?
7. **Evaluating Results** A patient's blood has an elevated count of leukocytes. What does this most likely indicate?
8. **Relating Concepts** Explain why a pregnant woman should know her blood type and the blood type of her baby's father.

MILESTONES IN Blood Transfusions

Timeline

1628 William Harvey describes the circulation of blood.

1667 Jean-Baptiste Denis successfully transfuses blood from a lamb to a human.

1818 First human-to-human blood transfusion.

1901 Karl Landsteiner determined three of four blood types (A, B, and O).

1914 Blood is stored for the first time.

1937 Bernard Fantus formed the first blood bank.

1939 Charles Drew set up collection centers for blood to fill World War II needs.

1950 Carl Walter and W.P. Murphy, Jr. introduced the plastic bag to collect blood.

1985 Blood is screened for HIV and other diseases.

Every three seconds someone needs a blood transfusion—blood, plasma, or saline is introduced into the body. Blood and blood products are used to treat accident and burn victims, cancer patients, and patients undergoing surgeries and medical treatments. The development of safe blood transfusion techniques was an important achievement in modern medicine.

In 1665, Richard Lower, an English physician, transferred blood between two dogs. Jean-Baptiste Denis, a French physician and astrologer, transfused blood from a lamb to a human in 1667. The first successful human-to-human blood transfusions were performed in 1818 by James Blundell, a British physician, but these were followed by many failures.

In 1901, Austrian-born American physiologist Karl Landsteiner determined the first three blood types—A, B, and O—and that incompatible types will clot. This discovery explained why the outcome of transfusions had been so unpredictable in the past. For his work, Landsteiner received the Nobel Prize in medicine or physiology in 1930.

During World War I, scientists began to study how to preserve and transport blood for wounded soldiers. They found that the addition of sodium citrate prevented clotting, making the storage of blood possible for the first time.

In 1937, Bernard Fantus, a physician, established the first nonprofit blood bank at Cook County Hospital in Chicago. The next year, Charles Drew, a medical doctor, found that blood plasma (the liquid component of blood) could substitute for whole blood in emergency situations.

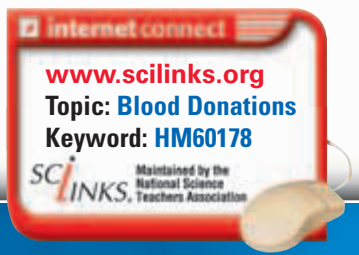
Germany's attack on France in 1940 created a great need for blood. Based on Drew's findings, the United States began to provide liquid plasma and whole blood for France. Working with the National Research Council and the American Red Cross, Drew set up blood collection centers.

Early in the 1980s, some transfused blood was found to carry the human immunodeficiency virus (HIV), the virus that causes acquired immune deficiency syndrome (AIDS). Since 1985, careful screening for HIV, hepatitis, and other diseases has almost entirely removed the risk of receiving contaminated blood.

Today, many people 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. Several companies have begun testing blood substitutes from chemically treated animal blood and outdated human blood.

Review

1. What type of patients can benefit from blood transfusions?
2. **Critical Thinking** How might safe blood transfusion techniques affect you?
3. **Critical Thinking** Use the Web site below to research the latest progress on creating artificial blood. Write a short report to describe your findings.



SECTION 3

OBJECTIVES

- **Differentiate** external respiration from internal respiration.
- **Trace** the path of air from the atmosphere to the bloodstream.
- **Describe** how gases are exchanged in the lungs and transported in the bloodstream.
- **Summarize** the skeletal and muscular changes that occur during breathing.
- **Describe** how the rate of breathing is controlled.

VOCABULARY

respiratory system
external respiration
internal respiration
lung
pharynx
epiglottis
trachea
larynx
bronchus
bronchiole
alveolus
inspiration
diaphragm
expiration

THE RESPIRATORY SYSTEM

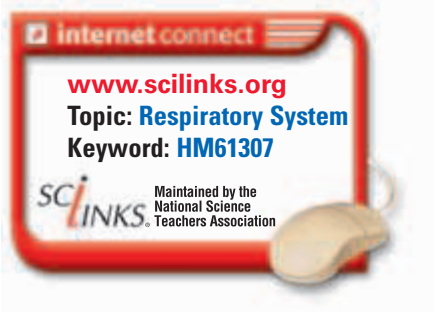
The blood transports oxygen from the lungs to cells and carries carbon dioxide from the cells to the lungs. It is the function of the ***respiratory system*** *to exchange gases with the cardiovascular system.*

RESPIRATION

The respiratory system involves both external respiration and internal respiration. **External respiration** is the exchange of gases between the atmosphere and the blood. **Internal respiration** is the exchange of gases between the blood and the cells of the body. Once oxygen is in the cells, the cells use it to break down glucose and make ATP by the process of aerobic respiration. Without oxygen, the body could not obtain enough energy from food to survive. Excess carbon dioxide produced as a waste product of aerobic respiration is toxic to cells and is removed from the cells by internal respiration.

THE LUNGS

The **lungs** are the site of gas exchange between the atmosphere and the blood. Notice in Figure 46-16 that the right lung has three divisions, or lobes. It is slightly heavier than the two-lobed left lung. The lungs are located inside the *thoracic cavity*, bounded by the rib cage and the diaphragm. Lining the entire cavity and covering the lungs are *pleura*, membranes that secrete a slippery fluid that decreases friction from the movement of the lungs during breathing.



The Path of Air

Refer to Figure 46-16 to trace the path air follows from the atmosphere to the capillaries in the lungs. External respiration begins at the mouth and at the nose. Air filters through the small hairs of the nose and passes into the nasal cavity, located above the roof of the mouth. In the nasal cavity, mucous membranes warm and moisten the air, which helps prevent damage to the delicate tissues that form the respiratory system. The walls of the nasal cavity are also lined with cilia. These cilia trap particles that are inhaled and are eventually swept into the throat, where they are swallowed.

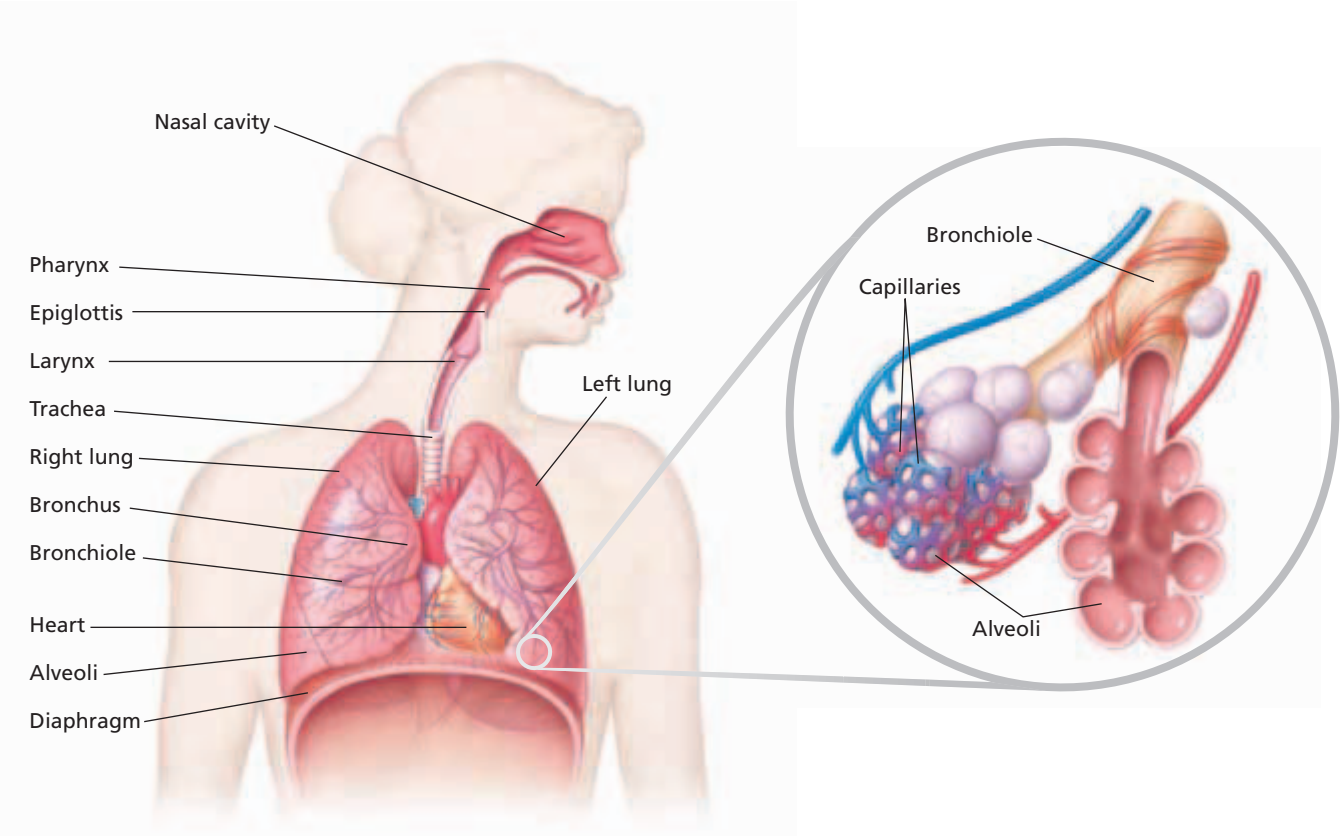


FIGURE 46-16

Trace the passage of air from the atmosphere to the lungs. Oxygen in the air finally reaches the alveoli, the functional units of the respiratory system. All exchange of gases between the respiratory system and the cardiovascular system occurs in the alveoli.

The moistened, filtered air then moves into the throat, or **pharynx** (FER-inks), a tube at the back of the nasal cavities and the mouth. The pharynx contains passageways for both food and air. When food is swallowed, a flap of cartilage, called the **epiglottis,** presses down and covers the opening to the air passage. When air is being taken in, the epiglottis is in an upright position, allowing air to pass into a cartilaginous tube called the windpipe, or **trachea** (TRAY-kee-uh). The trachea is about 10 to 12 cm long and has walls lined with ciliated cells that trap inhaled particles. The cilia sweep the particles and mucus away from the lungs toward the throat.

At the upper end of the trachea is the voicebox, or **larynx** (LER-inks). Sounds are produced when air is forced past two ligaments—the *vocal cords*—that stretch across the larynx. The pitch and volume of the sound produced varies with the amount of tension on the vocal cords and on the amount of air being forced past them.

The trachea then branches into two **bronchi** (BRAHN-kie) (singular, bronchus), each of which leads to a lung. The walls of the bronchi consist of smooth muscle and cartilage and are lined with cilia and mucus. Within the lungs, the bronchi branch into smaller and smaller tubes. The smallest of these tubes are known as **bronchioles,** which are also lined with cilia and mucus. Eventually the bronchioles end in clusters of tiny air sacs called **alveoli** (al-VEE-oh-LIE) (singular, alveolus). A network of capillaries surrounds each alveolus, as you can see in the detailed view shown in Figure 46-16. All exchange of gases in the lungs occurs in the alveoli. To facilitate this exchange, the surface area of the lungs is enormous. A healthy lung contains nearly 300 million alveoli and has a total surface area of about 70 m^2—about 40 times the surface area of the skin.

GAS EXCHANGE AND TRANSPORT

In the lungs, gases are exchanged between the alveoli and the blood in the capillaries. Oxygen (O_2) to be transported throughout the body moves into the bloodstream, and carbon dioxide (CO_2) to be eliminated from the body moves into the alveoli.

Gas Exchange in the Lungs

Figure 46-17 illustrates the direction in which oxygen and carbon dioxide move in the alveoli. When air moves into the lungs, the oxygen in the air crosses the thin alveolar membranes as well as the capillary walls and dissolves in the blood. Carbon dioxide moves in the opposite direction, crossing the capillary walls and thin alveolar membranes and entering the alveoli.

Air moving into the alveoli is rich in oxygen and contains little carbon dioxide. In contrast, blood in the capillaries surrounding the alveoli is low in oxygen and contains high levels of carbon dioxide. Substances diffuse from an area of higher concentration to an area of lower concentration. Consequently, oxygen diffuses from the alveoli into the blood, and carbon dioxide diffuses from the blood into the alveoli. The enormous surface area of the alveoli increases the rate of diffusion of these two gases.

Transport of Oxygen

When oxygen diffuses into the blood, only a small amount remains dissolved in the plasma. Most of the oxygen—95 to 98 percent—moves into the red blood cells, where it combines with hemoglobin, an iron-containing protein. Each hemoglobin molecule contains four iron atoms. Each iron atom can bind to one oxygen molecule. Thus, one hemoglobin molecule can carry up to four molecules of oxygen. There are about 250 million hemoglobin molecules in each red blood cell. When oxygenated blood reaches body tissues, the oxygen concentration is higher in the blood than in the body tissues. Thus, oxygen is released from hemoglobin and diffuses out of the capillaries and into surrounding cells.

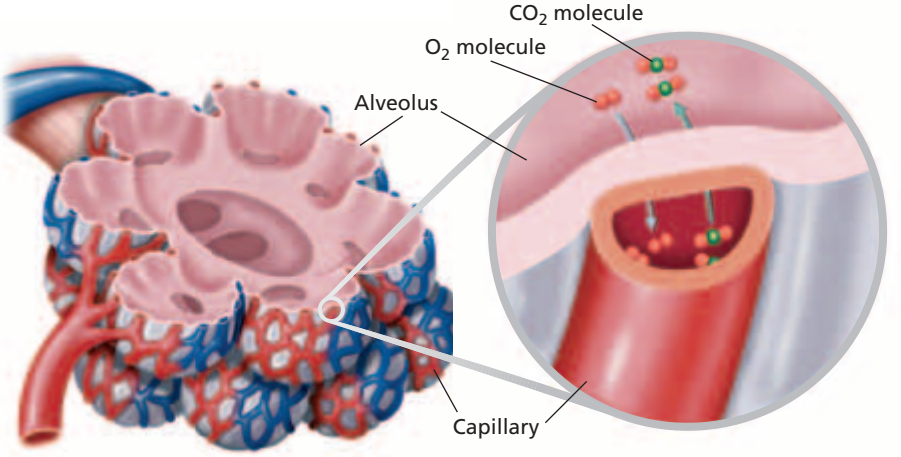


FIGURE 46-17
Because of concentration gradients, oxygen and carbon dioxide diffuse across the alveoli and capillary walls.

Transport of Carbon Dioxide

Because the concentration of carbon dioxide (CO_2) is higher in the cells, it diffuses out of the cells and into the blood. Only about 7 percent of the carbon dioxide dissolves in the plasma. Approximately 23 percent binds to hemoglobin. The remaining 70 percent is carried in the blood as bicarbonate ions (HCO_3^-). As shown in the equation below, CO_2 reacts with water in the plasma to form carbonic acid (H_2CO_3). In turn, the carbonic acid disassociates into bicarbonate ions and hydrogen ions (H^+):

$$H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

Thus, most of the CO_2 travels in the blood as bicarbonate ions. When the blood reaches the lungs, the reactions are reversed:

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3 \rightleftharpoons H_2O + CO_2$$

Bicarbonate ions combine with hydrogen ions to form carbonic acid, which in turn forms carbon dioxide and water. The carbon dioxide diffuses out of the capillaries into the alveoli and is exhaled into the atmosphere.

MECHANISM OF BREATHING

Breathing is the process of moving air into and out of the lungs. **Inspiration,** shown in Figure 46-18, is the process of taking air into the lungs. When you take a deep breath, your chest expands as muscles contract to move the ribs up and outward. At the same time, your **diaphragm,** a large skeletal muscle that separates the thoracic cavity from the abdominal cavity, flattens and pushes down on the abdomen. Muscles in the abdominal wall in turn relax. This action provides room for the flattened diaphragm.

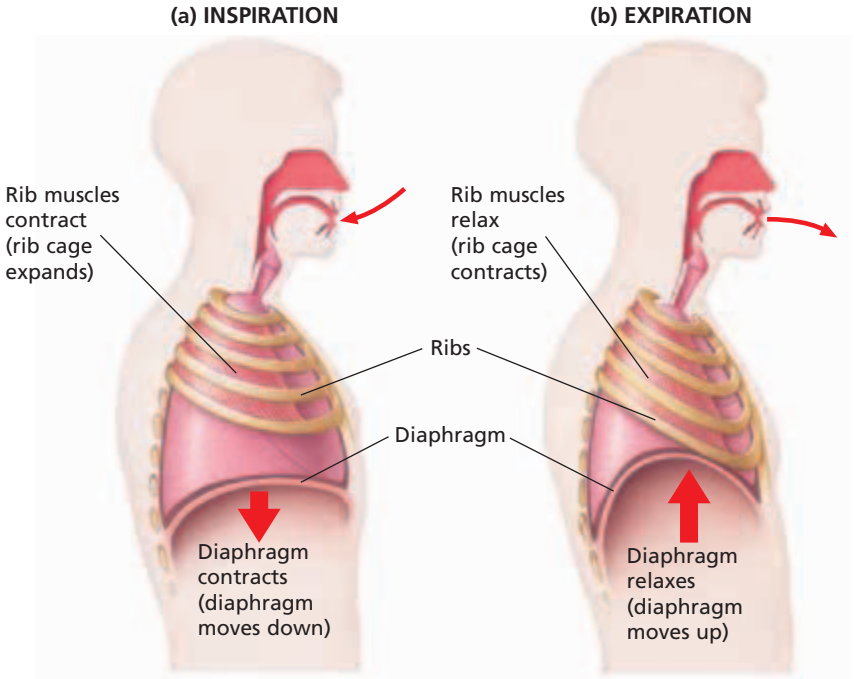


FIGURE 46-18

The diaphragm, a large skeletal muscle that separates the thoracic cavity from the abdominal cavity, and the muscles between the ribs control the movement of the thoracic cavity during breathing. If these muscles were paralyzed, then inspiration and expiration would not occur.

When the diaphragm flattens and the ribs are lifted up and out, the volume of the lungs increases. An increased volume reduces the air pressure within the lungs. At this point, the air pressure inside the lungs is lower than the air pressure outside the body. As a result, air from the atmosphere moves into the lungs.

During **expiration,** the process of releasing air from the lungs, the reverse movements take place, as shown in Figure 46-18. As the diaphragm and rib muscles relax, the elastic tissues of the lungs recoil, deflating the lungs. The volume of the lungs decreases. Because the volume is smaller, the air pressure inside the cavity becomes greater than the air pressure outside the body. This pressure difference forces air out of the lungs until the pressures are again equal.

Word Roots and Origins

expiration

from the Latin *expir*, which means "to breathe out"

Regulation of Breathing

The rate at which oxygen is used depends on the activity of the cells. The greater their activity, the more oxygen they need and the faster the body needs to breathe. The slower their activity, the slower the body needs to breathe. Both rate and depth of breathing change in order to provide oxygen and eliminate carbon dioxide.

The rate of breathing is controlled by the brain and brain stem, which monitors the concentration of carbon dioxide in the blood. As activity increases, high levels of carbon dioxide in the blood stimulate nerve cells in the brain. The brain stem in turn stimulates the diaphragm to increase the breathing rate and depth. When the carbon dioxide concentration in the blood returns to lower levels, the sensors in the brain send a message to the respiratory muscles to return to a slower breathing rate. All this is controlled subconsciously by control centers in the brain. However, a person can temporarily override the respiratory control system at any time, holding his or her breath until losing consciousness. Then the brain stem takes control, and normal breathing resumes. This mechanism allows humans to swim underwater for short periods and to sleep without concern for breathing.

SECTION 3 REVIEW

1. How does internal respiration differ from external respiration?
2. Outline the path of oxygen from the atmosphere to the bloodstream.
3. Explain the process of gas exchange in the lungs.
4. Differentiate between oxygen transport and carbon dioxide transport in the bloodstream.
5. Sequence the skeletal and muscular changes that take place when a person inhales.
6. What factors regulate the rate of breathing?

CRITICAL THINKING

7. **Relating Concepts** Predict the effect that increasing altitude would have on blood-oxygen saturation.
8. **Applying Information** Why does a single-celled organism not need a respiratory system?
9. **Predicting Results** Normally, arterial blood is about 98 percent saturated with oxygen. What are two conditions that could result in lower oxygen saturation?

CHAPTER HIGHLIGHTS

SECTION 1 The Circulatory System

- The human circulatory system is made up of the cardiovascular system and the lymphatic system.
- The heart is a muscular organ that pumps blood through an intricate network of blood vessels.
- Blood flows from the body into the heart, which then pumps blood to the lungs. After oxygenation, blood returns to the heart, which pumps blood to the rest of the body.
- Arteries carry blood away from the heart. Materials are exchanged at the capillaries. Veins contain valves and carry blood back to the heart.
- In pulmonary circulation, blood travels between the heart and lungs. In systemic circulation, blood travels between the heart and all other body tissues.
- The lymphatic system returns lymph, fluid that has collected in the tissues, to the bloodstream.

Vocabulary

cardiovascular system (p. 933)
lymphatic system (p. 933)
atrium (p. 933)
ventricle (p. 933)
valve (p. 934)
aorta (p. 935)
sinoatrial node (p. 935)
atrioventricular node (p. 935)
pulse (p. 935)
artery (p. 936)
blood pressure (p. 936)
hypertension (p. 936)
capillary (p. 936)
vein (p. 937)
pulmonary circulation (p. 937)
systemic circulation (p. 937)
atherosclerosis (p. 938)
lymph (p. 939)

SECTION 2 Blood

- Blood is composed of plasma (water, metabolites, wastes, salts, and proteins), red blood cells, white blood cells, and platelets.
- Red blood cells transport oxygen. White blood cells help defend the body against disease. Platelets are essential to the formation of a blood clot.
- Blood clotting occurs when platelets release a clotting protein, which causes a clotting reaction to occur. A fibrin net forms, trapping blood cells and platelets.
- Human blood can be grouped into four types—A, B, AB, and O—based on proteins on the surface of red blood cells. Another antigen called *Rh factor,* is sometimes present on red blood cells.

Vocabulary

plasma (p. 940)
red blood cell (erythrocyte) (p. 940)
hemoglobin (p. 940)
white blood cell (leukocyte) (p. 941)
phagocyte (p. 941)
antibody (p. 941)
platelet (p. 942)
fibrin (p. 942)
blood type (p. 943)
antigen (p. 943)
Rh factor (p. 943)

SECTION 3 The Respiratory System

- External respiration is the exchange of gases between the atmosphere and the blood. Internal respiration is the exchange of gases between the blood and the cells of the body.
- The lungs are the site of gas exchange between the atmosphere and the blood.
- Air enters through the mouth or nose, passes through the pharynx, larynx, trachea, bronchi and bronchioles and into alveoli. A network of capillaries surrounds each alveolus. All exchange of gases in the lungs occurs at the alveoli.
- Most oxygen is carried attached to hemoglobin. Some carbon dioxide is carried bound to hemoglobin. A small amount is dissolved in plasma. Most carbon dioxide is carried as bicarbonate ions.
- During inspiration, the diaphragm and rib muscles contract, the thoracic cavity expands, and air is pulled into the lungs. During expiration, the diaphragm and rib muscles relax, the thoracic cavity contracts, and air is forced out of the lungs.
- The rate of breathing is controlled by nerve centers in the brain that monitor the level of carbon dioxide in the blood.

Vocabulary

respiratory system (p. 946)
external respiration (p. 946)
internal respiration (p. 946)
lung (p. 946)
pharynx (p. 947)
epiglottis (p. 947)
trachea (p. 947)
larynx (p. 947)
bronchus (p. 947)
bronchiole (p. 947)
alveolus (p. 947)
inspiration (p. 949)
diaphragm (p. 949)
expiration (p. 950)

CHAPTER REVIEW

USING VOCABULARY

1. Distinguish between *systolic pressure* and *diastolic pressure.*
2. Choose the term that does not belong in the following group: *erythrocyte, hemoglobin, leukocyte,* and *platelet.* Explain why it does not belong.
3. For each pair of terms, explain the relationship between the terms.
   a. *atrioventricular valve* and *semilunar valve*
   b. *artery* and *vein*
   c. *expiration* and *inspiration*
4. **Word Roots and Origins** The word *phagocyte* is derived from the Greek word *phagein,* which means "to eat." The suffix *cyte* means "cell." Using this information, explain why the term *phagocyte* is a good name for the biological process that the term describes.

UNDERSTANDING KEY CONCEPTS

5. **Identify** the parts of the human heart, and describe the function of each part.
6. **Outline** the route that blood takes through the heart, lungs, and body.
7. **Relate** the structure of arteries, veins, and capillaries to the function of each.
8. **Compare** the pulmonary arteries and the aorta.
9. **Compare** the pulmonary veins and the inferior vena cava.
10. **Summarize** the roles of the lymphatic system.
11. **Discuss** the function of each of the components of blood.
12. **Identify** the structure that red blood cells lack that limits their life span.
13. **Describe** three differences between white blood cells and red blood cells.
14. **Sequence** the process of blood-clot formation that occurs after a vessel is injured.
15. **Explain** the A-B-O blood-typing system.
16. **Identify** the role of the Rh factor in determining blood compatibility for transfusion.
17. **Compare** external respiration with internal respiration.
18. **Sequence** the path oxygen travels from the environment into the blood.
19. **Compare** the transport and exchange of oxygen and carbon dioxide.
20. **Describe** the movement of the diaphragm and the rib muscles during inspiration and expiration.
21. **Name** the factor that stimulates the brain stem to increase the breathing rate.
22.  **CONCEPT MAPPING** Use the following terms to create a concept map that shows the relationship between the cardiovascular, lymphatic, and respiratory systems: *artery, capillary, vein, lymphatic system, pulmonary circulation, systemic circulation, atrium, ventricle, aorta,* and *vena cava.*

CRITICAL THINKING

23. **Inferring Relationships** A person with anemia can have too few red blood cells or low hemoglobin levels. The most common symptom is a lack of energy. Why would anemia cause this symptom?
24. **Applying Information** Explain how the lymphatic system moves lymph through the body without the aid of a pumping organ like that of the cardiovascular system.
25. **Analyzing Concepts** One function of the cardiovascular system is to help maintain a uniform body temperature. Explain how the constant circulation of blood throughout the body can accomplish this task.
26. **Interpreting Graphics** Copy the blood-type table below on a sheet of paper. Fill in the missing information for each type.

TABLE 1 *Blood Type*

Blood type	Antigen on the red blood cell	Antibodies in plasma	Can receive blood from	Can donate blood to
A		B	O, A	A, AB
B	B		O, B	B, AB
AB	A, B	Neither A nor B	O, A, B, AB	
O	Neither A nor B	A, B		O, A, B, AB

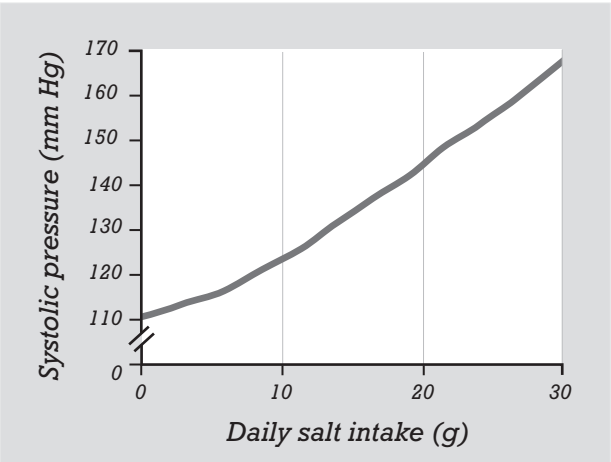
27. **Calculating Data** Calculate the number of times a person's heart will beat if the person lives 75 years. Assume that the average heart beats 70 times per minute.
28. **Recognizing Relationships** Assuming that the heart of an overweight person beats an additional 10 times per minute, explain why being overweight can put additional strain on the heart.

Standardized Test Preparation

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

1. In what direction does blood move during ventricular systole?
   - **A.** from the atria to the veins
   - **B.** from the ventricles to the atria
   - **C.** from the atria to the ventricles
   - **D.** from the ventricles to the arteries
2. What is the function of the lymphatic system?
   - **F.** It opens two-way vessels.
   - **G.** It helps the body fight infections.
   - **H.** It interacts with the respiratory system.
   - **J.** It transports intercellular fluid away from the heart.
3. Fibrin is a protein that does which of the following?
   - **A.** transports oxygen
   - **B.** helps form a blood clot
   - **C.** destroys invading microorganisms
   - **D.** stimulates the production of antibodies

INTERPRETING GRAPHICS: The graph below shows how systolic pressure is affected by salt intake. Use the graph to answer the question that follows.

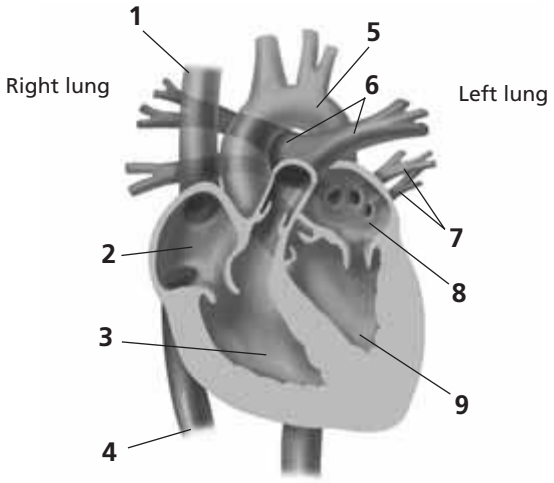


4. What is the relationship between salt intake and blood pressure?
   - **F.** As salt intake increases, blood pressure increases.
   - **G.** As salt intake increases, blood pressure decreases.
   - **H.** Salt intake of 20 g per day results in stable blood pressure.
   - **J.** Salt intake of 30 g per day results in stable blood pressure.

DIRECTIONS: Complete the following analogy.

5. superior vena cava : deoxygenated blood :: pulmonary veins :
   - **A.** type A blood
   - **B.** type B blood
   - **C.** oxygenated blood
   - **D.** deoxygenated blood

INTERPRETING GRAPHICS: The model below shows a cross section of the heart. Use the model to answer the question that follows.



6. Which numbers point to vessels that bring blood into the heart?
   - **F.** 1, 4, and 7
   - **G.** 1, 5, and 6
   - **H.** 4, 5, and 6
   - **J.** 5 and 6 only

SHORT RESPONSE

Even a small increase or decrease in blood volume has an effect on blood pressure. When an accident victim suffers significant blood loss, the person is transfused with plasma rather than whole blood.

Why is plasma effective in meeting the immediate threat to life?

EXTENDED RESPONSE

Polio is a disease that paralyzes muscles by affecting the nerves that make the muscles move.

Part A List muscles involved in breathing.

Part B Explain how polio might affect breathing.

Test TIP Slow, deep breathing helps a person relax. If you suffer from test anxiety, focus on your breathing in order to calm down.

INQUIRY LAB

Measuring Lung Volumes and CO_2 Production

OBJECTIVES

- Use indirect measurement to determine lung capacity.
- Determine the effect of exercise on breathing rate and CO_2 production.

PROCESS SKILLS

- measuring
- hypothesizing
- collecting data
- analyzing data
- experimenting

MATERIALS

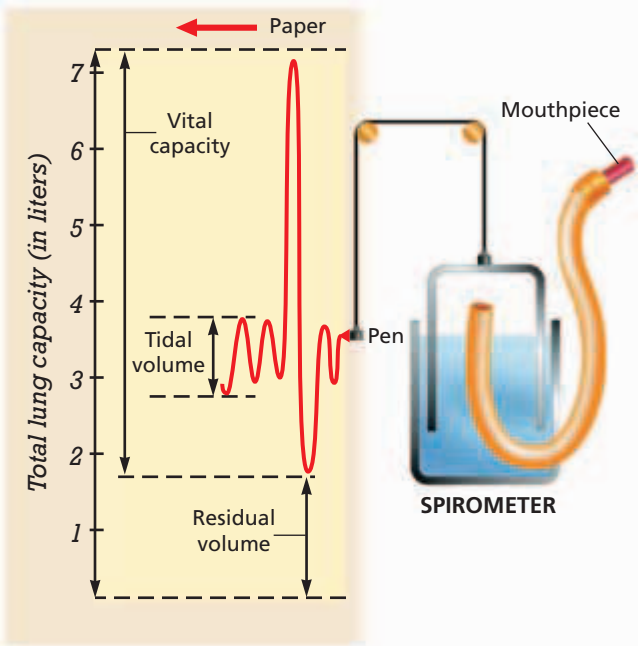
- safety goggles
- lab apron
- disposable gloves
- 1 L bromothymol indicator solution
- drinking straws
- 100 mL Erlenmeyer flasks, 2 per group
- 100 mL graduated cylinders
- marker
- plastic wrap
- spirometer
- stopwatch or clock with second hand

Background

1. A spirometer is an instrument used to measure the volume of air a person can breathe.
2. Compare the diagram of a spirometer on the right with the spirometer you will be using to complete this investigation. The marking pen creates a line that can be compared with the scale on the left side to measure liters of air.
3. Tidal volume is the volume of air inhaled or exhaled during a normal breath.
4. Lung capacity is the total volume of air that the lungs can hold. Total lung capacity is 5 to 6 L. What factors might increase or reduce lung capacity?
5. Expiratory reserve volume is the amount of air that can be forcefully exhaled after a normal exhalation.
6. Vital capacity is the maximum amount of air that can be inhaled or exhaled.
7. Carbon dioxide is soluble in water. You can determine the relative amount of CO_2 in your breath by using an indicator to react with the CO_2. Higher CO_2 levels will react with the indicator solution faster.

PART A Tidal Volume, Expiratory Volume, and Vital Capacity

1. Make a data table in your notebook like the one shown on the next page (Part A Lung Volumes).
2. Place a clean mouthpiece in the end of the spirometer. **CAUTION** **Many diseases are spread by body fluids, such as saliva. Do NOT share a mouthpiece with anyone.** Inhale a normal breath. Hold your nose, then exhale a normal breath into the spirometer. Record your data in the table.
3. Measure your expiratory reserve volume by first breathing a normal breath and exhaling normally. Then put the spirometer tube to your mouth as you forcefully exhale whatever air is left in your lungs. Be sure to force out as much air as possible. Record your data in the table.



PART A *Lung Volumes*

	Average for young adult males	Average for young adult females	Average for athletes	Your readings
Tidal volume	**500 mL**			
Expiratory reserve volume	**100 mL**			
Vital capacity	**4,600 mL**			

4. The table includes values for young adult males. The average volumes for young adult females are 20–25 percent lower than those of males. Calculate the average volumes for young adult females. Athletes can have volumes that are 30–40 percent greater than the average for their gender. Calculate the average volumes for athletes.
5. Dispose of your mouthpiece in the designated waste container.

PART B Breathing Rate and CO_2 Production

6. Discuss with your partners the use of bromothymol blue as an indicator of CO_2. Develop a hypothesis that describes a relationship between air volume exhaled during rest or exercise and the volume of CO_2 exhaled.
7. Make a data table in your notebook like the one on this page, titled "Part B CO_2 Production".
8. Label two flasks as 1 and 2.
9. CAUTION **Wear safety goggles at all times during this procedure. If you get the indicator solution on your skin or clothing, wash it off at the sink while calling to your teacher. If you get the indicator solution in your eyes, immediately flush it out at the eyewash station while calling to your teacher.**
10. Add 100 mL of indicator solution to each flask. Cover the mouth of each flask with plastic wrap.
11. Remove the plastic wrap from flask 1. Begin the stopwatch. Blow gently through one straw into flask 1 until the solution turns a yellowish color, exhaling slowly so that the solution does not bubble up. CAUTION **Be careful not to inhale the solution or get it in your mouth.** Stop the stopwatch.
12. Record in your data table the time in seconds that it took to see a color change in flask 1.
13. Exercise by jogging in place or doing jumping jacks for 2 min. Begin the stopwatch immediately. Blow gently through a new straw into flask 2 until the solution becomes the same yellowish color as the solution in flask 1. Stop the stopwatch.
14. In your data table, record the amount of time in seconds that it took to get the same yellow color in flask 2 as you got in flask 1.
15. Calculate the difference in the amount of time it took to see a color change in the two flasks. What can you infer about the amount of CO_2 you exhaled before and after exercise?
16. Clean up your materials. Pour the solutions down the sink, and rinse the sink thoroughly with water. Wash your hands before leaving the lab.

Analysis and Conclusions

1. How did your tidal volume compare with that of your classmates?
2. What are the independent and dependent variables in Part B? How did you vary the independent variable and measure changes in the dependent variable?
3. Why were the flasks covered with plastic wrap?
4. Do your data support your hypothesis from Part B? Explain your answers.
5. How do you know whether you produced more carbon dioxide before or after you exercised?
6. What were some of the possible sources of error in your experiment?

PART B *CO_2 Production*

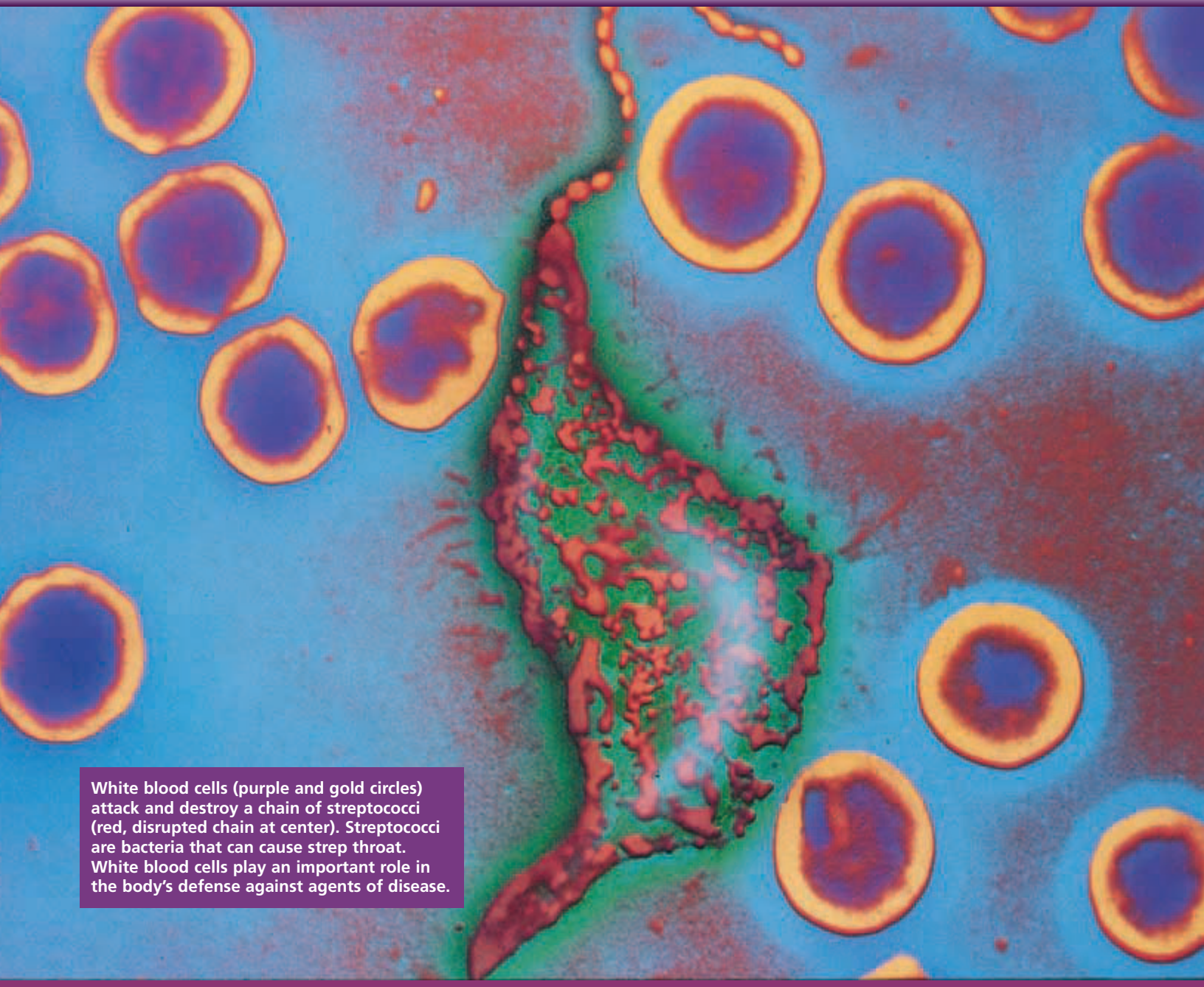
Time for color change in flask 1	
Time for color change in flask 2	
Difference in time between flask 1 and flask 2	

Further Inquiry

Design an experiment to determine whether exercise affects heart rate in the same way it affects breathing rate and tidal volume.

CHAPTER 47

THE BODY'S DEFENSE SYSTEMS



White blood cells (purple and gold circles) attack and destroy a chain of streptococci (red, disrupted chain at center). Streptococci are bacteria that can cause strep throat. White blood cells play an important role in the body's defense against agents of disease.

SECTION 1

NONSPECIFIC DEFENSES

When a type of virus called a rhinovirus enters the human body, it can cause the common cold. Diseases, such as colds, that are caused by agents that have invaded the body are called ***infectious diseases.*** *This section explains how the human body identifies the agents that cause infectious diseases and defends itself against these agents.*

OBJECTIVES

- **Summarize** Koch's postulates for identifying a disease-causing agent.
- **Describe** how the skin and mucous membranes protect the body against pathogens.
- **Describe** the steps of the inflammatory response.
- **Analyze** the roles of white blood cells in fighting pathogens.
- **Explain** the functions of fever and proteins in fighting pathogens.

VOCABULARY

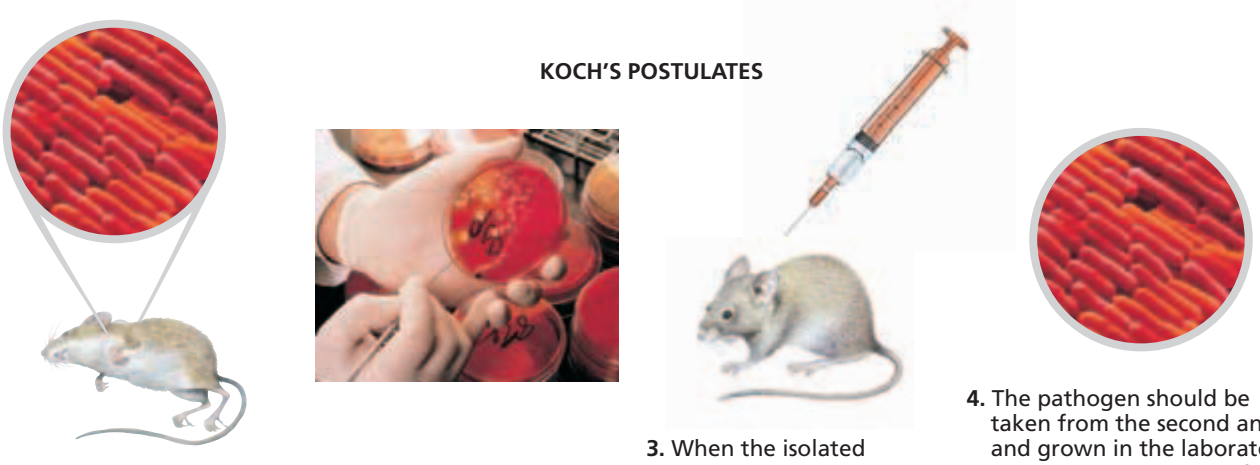
infectious disease
pathogen
Koch's postulates
mucous membrane
inflammatory response
histamine
phagocyte
neutrophil
macrophage
natural killer cell
complement system
interferon

IDENTIFYING PATHOGENS

A **pathogen** is any agent that causes disease. Robert Koch (KAWHK) (1843–1910), a German doctor, was the first person to establish a step-by-step procedure for identifying the particular pathogen that causes an infectious disease. In the 1870s, Koch studied anthrax, a disease of cattle that can spread to people. Koch observed that cattle with the illness had swarms of bacteria in their blood. He hypothesized that these bacteria caused anthrax.

To test his hypothesis, Koch isolated rod-shaped bacteria from a cow with anthrax and grew colonies of the bacteria to be sure he had isolated a single species. Then, he injected healthy cows with these bacteria. The cows developed anthrax. Koch found that the blood of these cows contained the same rod-shaped bacteria as the first cow. Furthermore, healthy cows that he had not injected lacked this type of bacteria. Koch concluded that the isolated species of bacterium causes anthrax. Through these studies, he developed **Koch's postulates,** which are "rules" for determining the cause of a disease. Figure 47-1 illustrates these postulates.

FIGURE 47-1
By applying the four principles of Koch's postulates, scientists can identify the pathogen that causes an infectious disease.



1. The pathogen must be present in an animal that has the disease and absent in healthy animals.

2. The pathogen must be isolated from the sick animal and grown in a laboratory.

3. When the isolated pathogen is injected into a healthy animal, the animal must develop the disease.

4. The pathogen should be taken from the second animal and grown in the laboratory. The pathogen cultured from the second animal should be the same as the pathogen cultured from the first animal.

TABLE 47-1 *Pathogens Responsible for Some Human Diseases*

Disease	Pathogen	Method of transmission
Botulism	*Clostridium botulinum* (bacterium)	contaminated food
Lyme disease	*Borrelia burgdorferi* (bacterium)	tick bites
AIDS	HIV (human immunodeficiency virus)	sexual contact, contaminated needles, contact with contaminated fluids from a mother to a fetus or infant
Severe acute respiratory syndrome (SARS)	coronavirus (virus)	person-to-person contact, indirect contact through pathogens in air or on objects (from coughs or sneezes)
Amebic dysentery	*Entamoeba histolytica* (protist)	contaminated food and water
Athlete's foot	*Tinea* (fungus)	contact with contaminated surfaces, person-to-person contact
Head lice	Lice (invertebrate parasite)	person-to-person contact, sharing personal items

Scientists have used Koch's postulates to identify thousands of pathogens. Many human diseases are caused by bacteria, viruses, protists, fungi, and invertebrates. Pathogens can spread to humans in five main ways—through air, food, water, person-to-person contact, and the bites of animals. Table 47-1 lists examples of pathogens that cause different human diseases and the means by which each is commonly transmitted.

FIGURE 47-2

The passages of the respiratory system are lined with cells that are covered with beating cilia (purplish strands). Pathogens (bluish circles) that become trapped in mucus secreted by these cells are swept upward, away from the lungs. (5,325×)

FIRST LINE OF DEFENSE: BARRIERS

The body's nonspecific defenses help protect the body against any pathogen, regardless of the pathogen's identity. Nonspecific defenses include the skin and mucous membranes. **Mucous** (MYOO-kuhs) **membranes** are epithelial tissues that protect the interior surfaces of the body that may be exposed to pathogens.

Most pathogens must enter the body to cause disease. The skin serves as a physical barrier to pathogens. Any break in the skin may allow pathogens to enter the body. In addition, the skin also releases sweat, oils, and waxes. These substances contain chemicals that are toxic to many pathogens. For example, sweat contains *lysozyme,* an enzyme that destroys some bacteria.

Mucous membranes serve as a barrier and secrete *mucus,* a sticky fluid that traps pathogens. Mucous membranes line the respiratory and digestive systems, the urethra, and the vagina. The passages of the respiratory tract are lined with cells that are covered with beating cilia, as shown in Figure 47-2. These cilia sweep mucus and pathogens up to the pharynx, where they are swallowed. Most swallowed pathogens are destroyed in the stomach by acids.

SECOND LINE OF DEFENSE: NONSPECIFIC IMMUNITY

If a pathogen gets past the skin and the mucous membranes, there is a second line of nonspecific defense inside the body—nonspecific immunity. Nonspecific immunity includes the inflammatory response, the temperature response, and proteins. Like the barriers of the first line of defense, these second-line defenses are nonspecific—they work the same way against any pathogen.

Inflammatory Response

Any pathogen that gets past the skin or mucous membranes will stimulate the **inflammatory response,** a series of events that suppress infection and speed recovery. An example is shown in Figure 47-3. When cells are damaged, whether through a cut on the skin or invasion by pathogens, some of the damaged cells release histamine (HIS-tuh-MEEN), as described in step 1. **Histamine** is a substance that increases blood flow to the injured area and increases the permeability of surrounding capillaries. The changes caused by histamine result in redness, swelling, warmth, and pain. If blood vessels have been damaged, platelets begin the blood-clotting process, sealing off surrounding tissues and stopping pathogens from entering the rest of the body.

White blood cells fight pathogens that have entered the body. In step 2, fluids and white blood cells called *phagocytes* pass through the capillary walls to the injured area. **Phagocytes** ingest and destroy pathogens and foreign matter, as shown in step 3. Phagocytes and some other types of white blood cells are attracted to the site of injury by histamine.

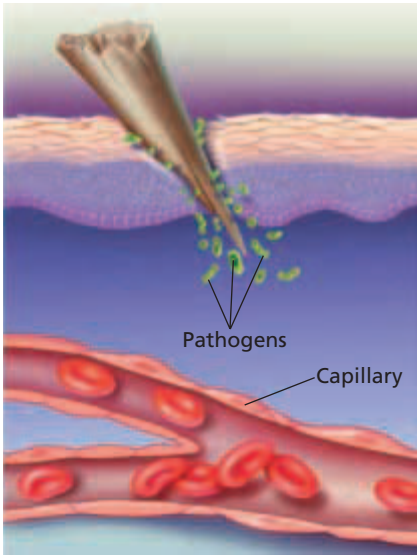
Eco Connection

Agriculture and Human Diseases

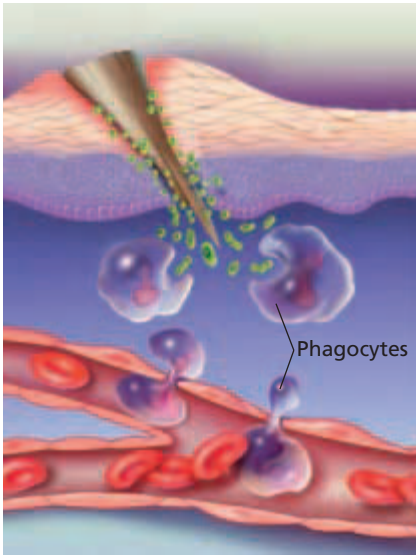
The beginning of farming and herding about 10,000 years ago changed the nature of human diseases. When humans began to keep herds of domesticated animals, such as cattle and sheep, humans were exposed to the pathogens that infect these animals. Some of these pathogens then began infecting humans. Measles, tuberculosis, smallpox, and flu are among the diseases that may have been transmitted to humans from domesticated animals.

FIGURE 47-3

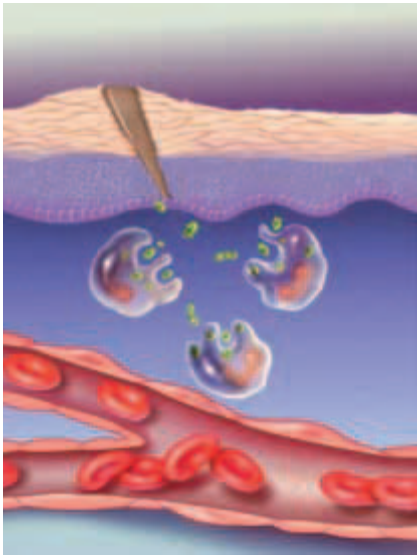
Injury to cells triggers an inflammatory response.



1 An injury may allow pathogens to get past the barrier of the skin. Injured cells release chemical messengers, such as histamine.



2 Nearby capillaries respond by swelling and leaking fluid. Phagocytes pass through capillary walls and attack the pathogens.



3 Phagocytes destroy the pathogens, and the injury begins to heal.

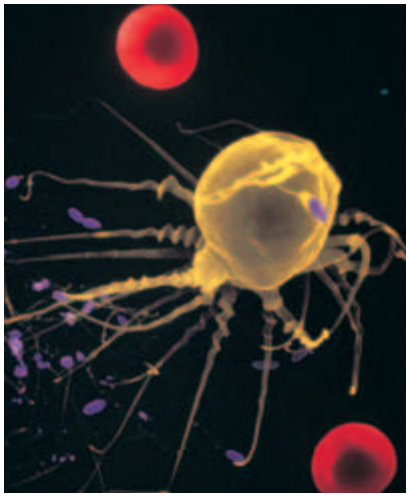


FIGURE 47-4

This macrophage (shown in yellow) is using cytoplasmic extensions to capture bacteria (shown in purple). (SEM 17,400×)

The **neutrophil** (NOO-troh-fil) is the most abundant type of phagocyte in the body. Neutrophils circulate through blood vessels, and they can squeeze through capillary walls to reach the infection site. Once there, neutrophils ingest pathogens they encounter. Another type of phagocyte is the **macrophage** (MAK-roh-FAYJ), shown in Figure 47-4. Macrophages engulf pathogens and cellular debris. Some are stationed in body tissues, waiting for pathogens, while others seek out pathogens.

Natural killer cells are large white blood cells that attack pathogen-infected cells—not the pathogens themselves. Natural killer cells are effective at killing cancer cells and virus-infected cells. A natural killer cell pierces the cell membrane of its target cell, allowing water to rush in and causing the cell to burst.

Temperature Response

When the body begins to fight pathogens, body temperature may increase several degrees. A rise in body temperature above the normal 37°C (98.6°F) is called a *fever.* Fever is a symptom of illness that shows the body is responding to an infection. Some pathogens trigger fever, as do chemicals released by macrophages. A moderate fever may slow bacterial and viral growth and promote white blood cell activity. However, very high fever is dangerous because extreme heat can destroy important cellular proteins. Temperatures greater than 39°C (103°F) can be dangerous, and those greater than 41°C (105°F) can lead to death.

Word Roots and Origins

macrophage

from the Greek *makros,* meaning "large," and *phagein,* meaning "to eat"

Proteins

Proteins also provide nonspecific defenses. About 20 different proteins make up the **complement system.** Complement proteins circulate in the blood and become active when they encounter certain pathogens. Some of these proteins form a ring-shaped structure that punctures the membranes of infected cells, causing the cells to die. Another nonspecific defense is **interferon,** a protein released by cells infected with viruses. Interferon causes nearby cells to make a protein that helps them resist viral infection.

SECTION 1 REVIEW

1. Explain how Koch tested his hypothesis about the cause of anthrax.
2. How does the body's first line of defense function?
3. What role does greater permeability of capillaries play in the inflammatory response?
4. How do natural killer cells differ from macrophages?
5. What is the role of interferon?

CRITICAL THINKING

6. **Analyzing Information** Scientists can't always apply all of Koch's postulates to determine the cause of a disease. Explain why.
7. **Forming Reasoned Opinions** Should a fever always be treated? Why or why not?
8. **Inferring Relationships** Explain how cold symptoms show that the body is using both lines of nonspecific defenses to fight pathogens.

SECTION 2

SPECIFIC DEFENSES: THE IMMUNE SYSTEM

Although the nonspecific defenses usually keep pathogens from harming the body, a pathogen sometimes breaks through. In response, the body begins its third line of defense—a response aimed specifically at the pathogen.

OBJECTIVES

- **Identify** and describe the parts of the immune system.
- **Explain** how the immune system recognizes pathogens.
- **Compare** the actions of T cells and B cells in the immune response.
- **Relate** vaccination to immunity.
- **Distinguish** between allergy, asthma, and autoimmune disease.

VOCABULARY

immune system
lymphocyte
thymus
spleen
B cell
T cell
antigen
immune response
helper T cell
cell-mediated immune response
cytotoxic T cell
humoral immune response
plasma cell
antibody
memory cell
immunity
vaccination
allergy
asthma
autoimmune disease

THE IMMUNE SYSTEM

The **immune system,** the cells and tissues that recognize and attack foreign substances in the body, provides the body's specific defenses. The immune system fights pathogens and helps to stop the growth and spread of cancers. The immune system is made up of several tissues and white blood cells. The components of the immune system, shown in Figure 47-5, are found throughout the body. The tissues include the bone marrow, thymus, lymph nodes, spleen, tonsils, and adenoids. The white blood cells of the immune system are called **lymphocytes** (LIM-foh-sietz).

Each part of the immune system plays a special role in defending the body against pathogens. *Bone marrow,* the soft material found inside long bones, such as the femur, makes the billions of new lymphocytes needed by the body every day. The **thymus,** a gland located above the heart, helps produce a special kind of lymphocyte.

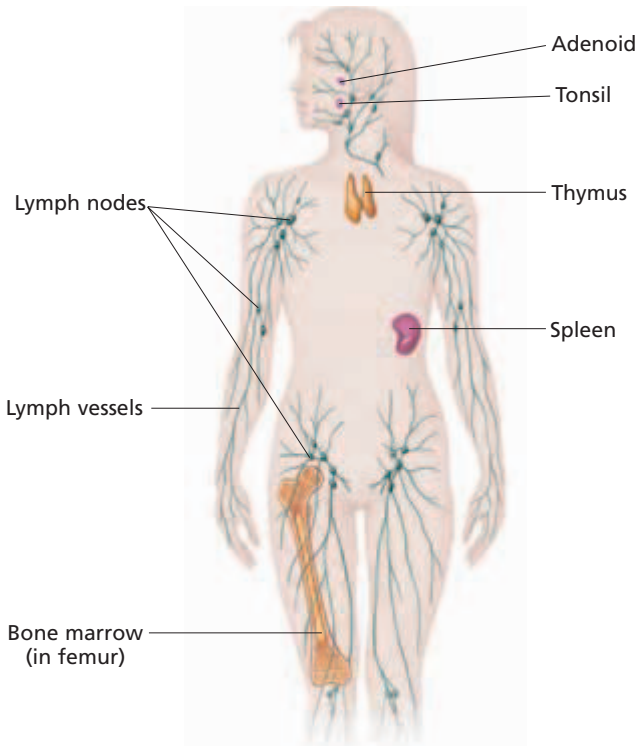


FIGURE 47-5
The cells and tissues of the immune system recognize and attack foreign substances in the body.

Lymph nodes, located throughout the body along the vessels of the lymphatic system, contain lymphocytes. (Recall that the lymphatic system gathers and filters the fluid, called *lymph,* that leaks from the circulatory system.) Lymph nodes collect pathogens from the lymph and expose them to lymphocytes. The **spleen,** the largest lymphatic organ in the body, stores healthy blood cells, breaks down aging red blood cells, and helps develop lymphocytes and other types of white blood cells. The spleen also collects pathogens from the blood, and the lymphocytes in the spleen attack these trapped pathogens. The *adenoids* and *tonsils* are masses of lymph tissue found in the nose and throat.

There are two types of lymphocytes: B cells and T cells. **B cells** are made in the bone marrow and complete their development there. **T cells** are also made in the bone marrow but complete their development only after traveling to the thymus.

Word Roots and Origins

antigen

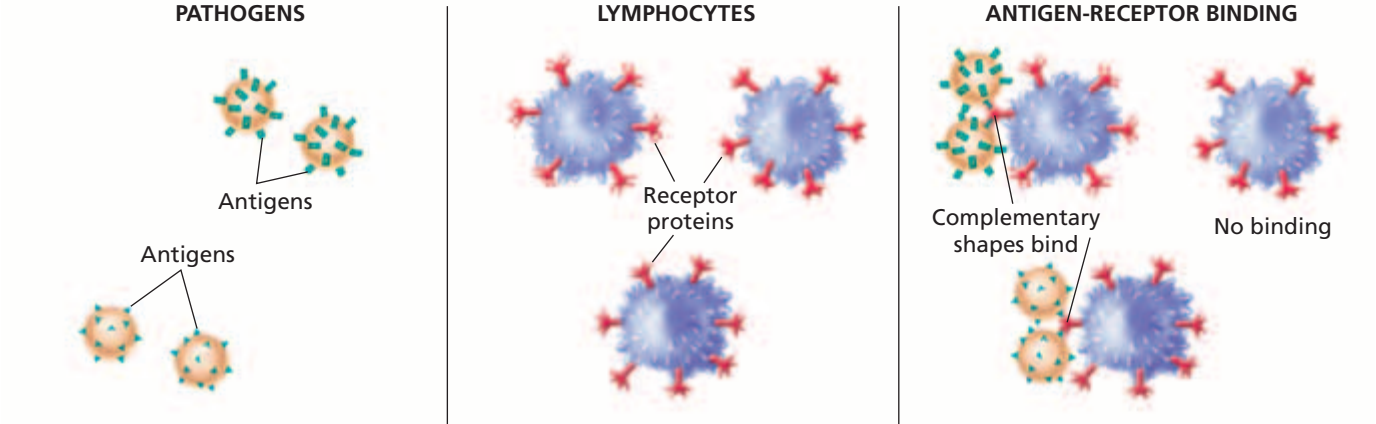
from the Greek *anti,* meaning "against," and *gen,* meaning "producing"

RECOGNIZING PATHOGENS

Lymphocytes can provide specific defenses because they recognize foreign invaders. An **antigen** (AN-tuh-juhn) is any substance that the immune system can recognize and react with. Antigens, as shown in Figure 47-6a, cause lymphocytes to react. A wide variety of substances can be antigens, including pathogens or parts of pathogens, bacterial toxins, insect venom, and pollen. In addition, almost any molecule that is not a natural part of an individual's body, such as that from transplanted tissue or transfused blood of an incompatible type, can act as a foreign antigen. When lymphocytes recognize an antigen, they bind to the antigen to start a specific attack. The reaction of the body against an antigen is known as an **immune response.**

FIGURE 47-6

(a) Antigens are found on a pathogen's surface. (b) The receptor proteins on the surface of lymphocytes (such as B cells, shown here) have a complex, three-dimensional structure. (c) The receptors can bind to antigens that have a complementary shape.



(a) Many pathogens are covered with molecules that function as antigens and cause lymphocytes to react.

(b) A lymphocyte has receptor proteins all over its surface. Note the different shapes of receptor proteins on the different lymphocytes. All of the receptor proteins on an individual lymphocyte are the same unique shape.

(c) The receptor proteins on each lymphocyte bind to antigens with complementary shapes. If a lymphocyte does not have a complementary receptor protein, it will not bind to an antigen (upper right).

How do lymphocytes identify antigens? A lymphocyte has unique receptor proteins all over the surface of its cell membrane, as shown in Figure 47-6b. These receptor proteins recognize and bind to antigens that match their three-dimensional shape, as shown in Figure 47-6c. The surface of a bacterial cell, for instance, can be covered with many different kinds of molecules, each of which can function as an antigen and cause lymphocytes to react. All of the receptors on an individual lymphocyte are the same shape or type and thus bind to the same type of antigens.

The body can defend itself against an enormous number of different pathogens, because the immune system makes billions of different kinds of lymphocytes. Each kind of lymphocyte carries unique receptors. The specificity of the immune response is due to the specificity of the antigen receptors on the lymphocytes. For example, when a cold virus enters the body, lymphocytes with receptors that match the antigens of that cold virus respond. Lymphocytes with other kinds of receptors, such as those that bind to a flu virus, do not respond.

IMMUNE RESPONSE

An immune response is a two-part assault on a pathogen. Both parts, the cell-mediated immune response and the humoral immune response, occur at the same time and require a specialized lymphocyte called a **helper T cell.** Steps ❶, ❷, and ❸ of Figure 47-7 on the next page show how an immune response is initiated. The first step occurs when a macrophage engulfs a pathogen. The macrophage then displays fragments of the pathogen's antigens on the surface of its own cell membrane. When the macrophage binds to a helper T cell with a receptor matching this antigen, the macrophage releases a cytokine called *interleukin-1* (in-tuhr-LOO-kin). *Cytokines* are proteins that can affect the behavior of other immune cells. The release of interleukin-1 by the macrophage activates more helper T cells, which then release a second cytokine, interleukin-2.

Word Roots and Origins

cytokine

from the Greek *kytos,* meaning "hollow vessel" or "cell," and *kinesis,* meaning "movement"

Cell-Mediated Immune Response

More than one type of T cell carries out the **cell-mediated immune response.** Interleukin-2 stimulates the further production of helper T cells. The increase in helper T cells produces an increase in interleukin-2, which allows T cells to divide even faster. Interleukin-2 is also responsible for stimulating the production of **cytotoxic** (siet-oh-TAHKS-ik) **T cells** (sometimes called killer T cells), which recognize and destroy cells that have been infected by the pathogen. Invaded cells are recognizable because they usually have some of the pathogen's antigens on their surface, as shown in Figure 47-7. The cytotoxic T cells produced have receptors that match the antigen. Cytotoxic T cells usually kill by making a hole in the cell membrane of their target. Cytotoxic T cells can also kill cancer cells and attack parasites and foreign tissues.

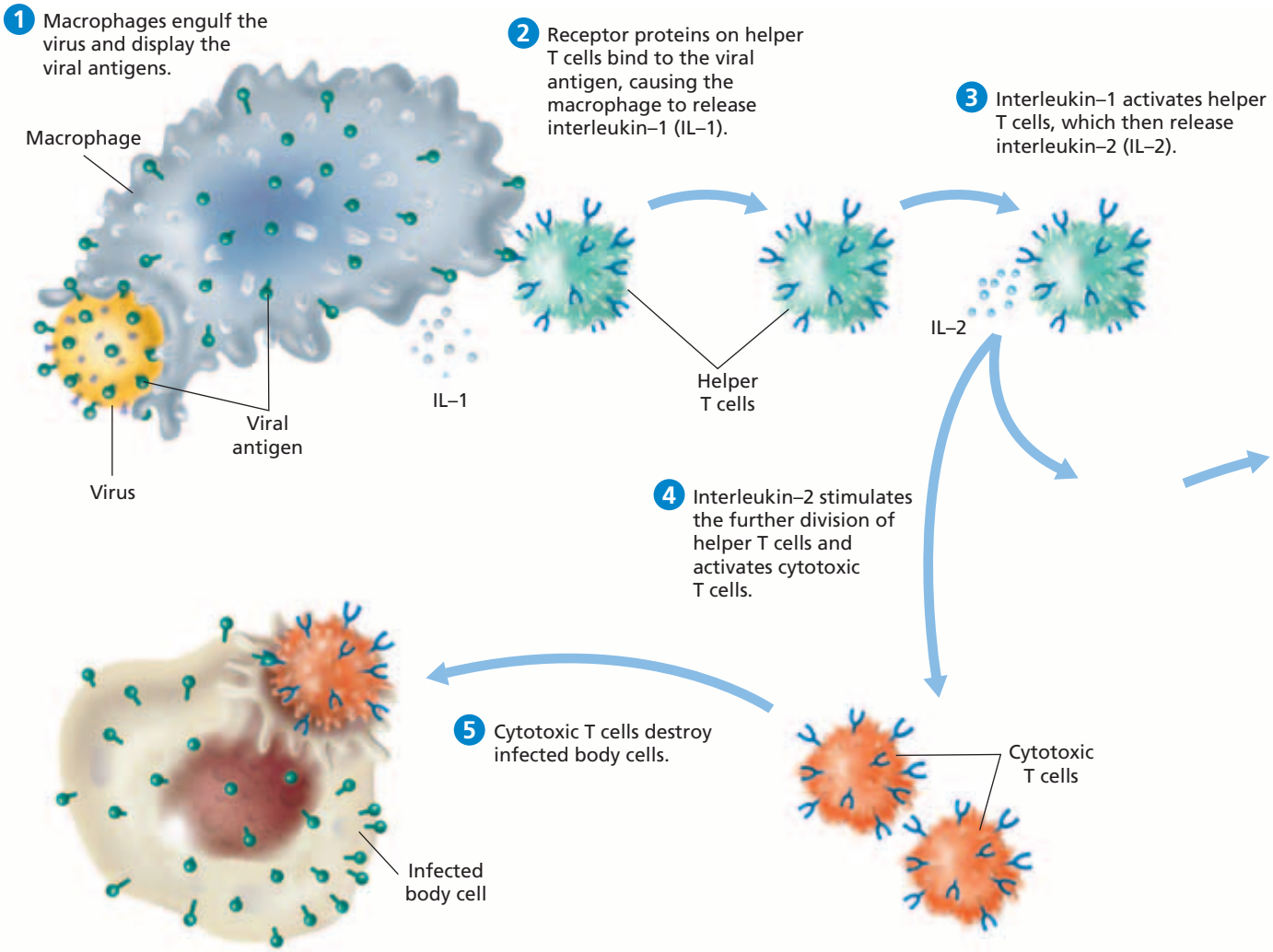


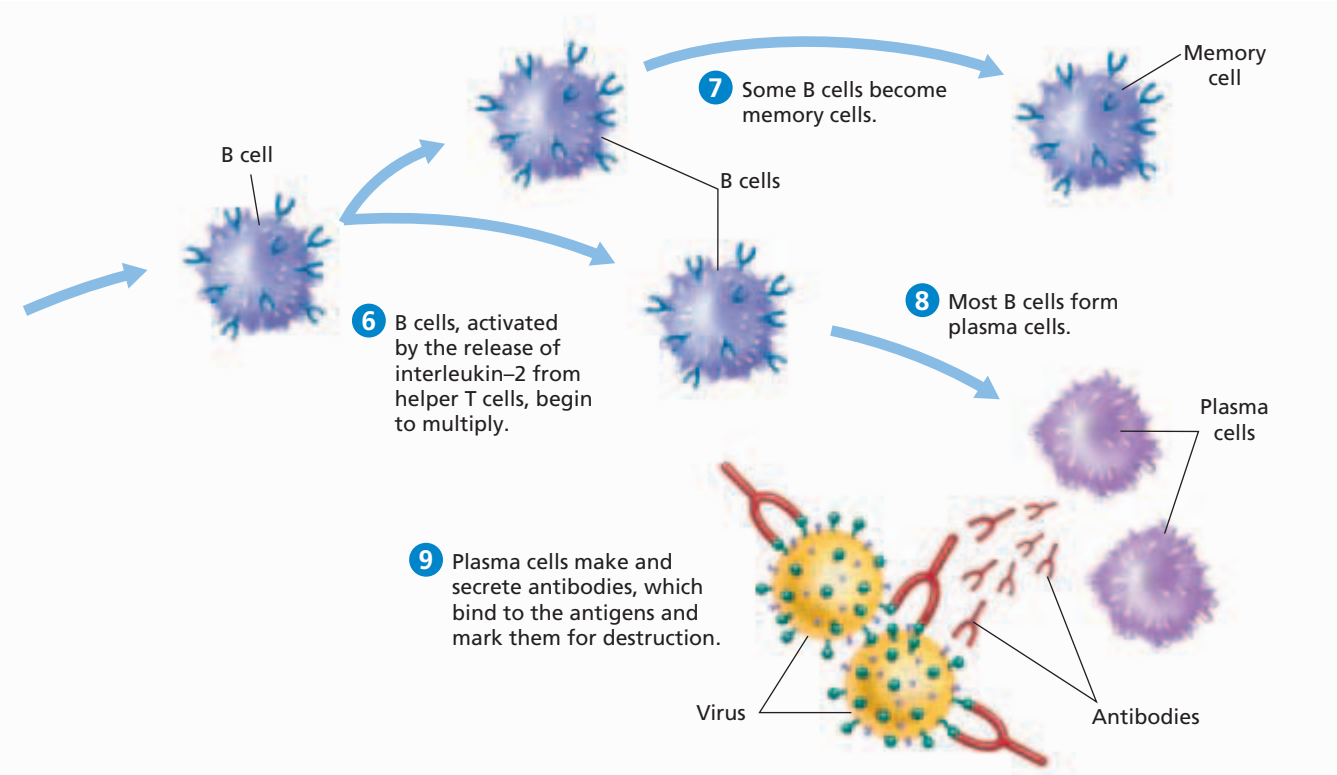
FIGURE 47-7

The immune response is a two-part assault on a pathogen: the cell-mediated immune response and the humoral immune response. Both responses occur at the same time and are triggered when a macrophage engulfs a pathogen, thus activating helper T cells (steps 1 through 3). The cell-mediated immune response is shown in steps 4 and 5, and the humoral immune response is shown in steps 6 through 9 on the next page.

One other type of T cell that plays a part in cell-mediated immunity is *suppressor T cells*. Suppressor T cells are not well understood but are thought to help shut down the immune response after the pathogen has been cleared from the body. The cell-mediated immune response is shown in steps 4 and 5 in Figure 47-7 above.

Humoral Immune Response

The **humoral** (HYOO-muhr-uhl) **immune response** involves the action of B cells and occurs at the same time the cell-mediated immune response occurs. Like the cell-mediated immune response, the humoral immune response is triggered when macrophages engulf pathogens, stimulating helper T cells. The release of interleukin-2 stimulates B cells that have receptors that are complementary to the antigen to divide and change into plasma cells. **Plasma cells** are highly specialized cells that make defensive proteins called *antibodies* that are released into the blood. An **antibody** binds to a specific antigen or inactivates or destroys toxins. Antibodies are Y-shaped molecules. The two arms of each Y are identical, and each arm has a receptor that can attach to a specific antigen. A plasma cell can make up to 30,000 antibody molecules per second.



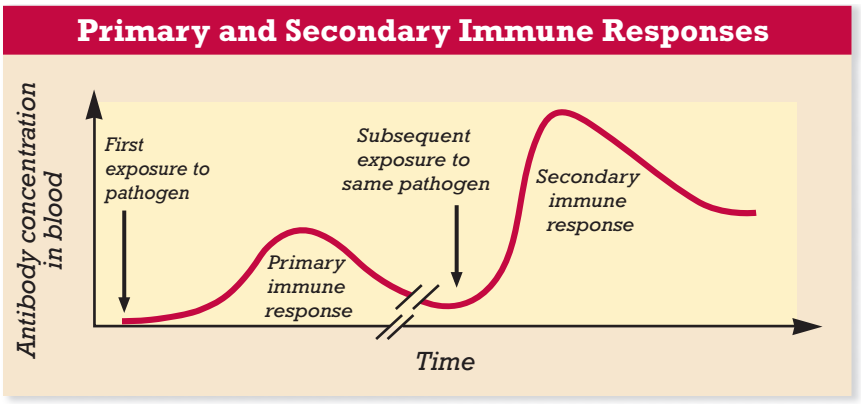
Antibodies bind to pathogens but do not destroy them directly. Instead, antibodies either inactivate the pathogen or cause its destruction by the nonspecific defenses. For example, by attaching to the surface proteins of a virus, antibodies prevent the virus from entering a cell, thereby blocking its reproduction. Antibodies also cause pathogens to clump together, which helps macrophages to engulf the pathogens. Antigen-antibody binding also activates the complement system. The complement proteins can then create holes in the membranes of the pathogen's cells, causing them to burst. The humoral immune response is shown in steps 6 through 9 in Figure 47-7 above.

Primary and Secondary Immune Responses

Although the immune response stops once the body has overcome an infection, some memory cells remain in the body. **Memory cells** are lymphocytes that will not respond the first time that they meet with an antigen or an invading cell but will recognize and attack that antigen or invading cell during later infections.

Memory cells are the body's long-term protection against reinfection by a pathogen. Memory cells often remain effective throughout an individual's life. Because of memory cells, a person will get most diseases only once. When exposed to a pathogen a second time, memory cells immediately recognize it and begin to divide rapidly. They eliminate the pathogen before it can produce serious illness.

(a)



(b)

FIGURE 47-8

(a) Vaccinations take advantage of the production of memory cells and the secondary immune response. (b) Compare the production of antibodies during the primary and secondary immune responses that are shown on the graph.

The first time the body encounters an antigen, the immune response is called a *primary immune response*. The response of memory cells to a later infection by the same pathogen is called a *secondary immune response*. The secondary immune response is much faster and more powerful, producing many more antibodies, as shown in the graph above. Recall that memory cells protect only against pathogens already encountered. Colds and flu are an exception, because rhinoviruses and flu viruses mutate at a high rate. Therefore, these viruses are always presenting new antigens.

IMMUNITY AND VACCINATION

Immunity is the ability to resist an infectious disease. A person who is resistant to a pathogen is said to be immune to it. One way for the body to gain immunity to a pathogen is to be infected by it, undergo a primary immune response, and survive the disease it causes. Another, safer way is through **vaccination** (vak-suh-NAY-shuhn), the introduction of antigens into the body to cause immunity. Vaccination usually involves an injection of a vaccine under the skin, as shown in Figure 47-8a.

Vaccines

A *vaccine* is a solution that contains a dead or weakened pathogen or material from a pathogen. However, the antigens are still present, so the body produces a primary immune response to the antigens in the vaccine. The memory cells that remain after the primary immune response can provide a quick secondary immune response if the antigen ever enters the body again.

Some of the diseases that have been controlled through the use of vaccines are polio, measles, mumps, tetanus, and diphtheria. An intensive worldwide vaccination campaign has eliminated smallpox. Sometimes, the protection provided by vaccines wears off over time. So, doctors recommend *booster shots* to restore immunity against some diseases, such as tetanus and polio.

Quick Lab

Organizing the Immune Response

Materials paper, pencil

Procedure Create a diagram or a flowchart that outlines the steps involved in an immune response. Label the cells and the steps.

Analysis What are helper T cells? How is a cell-mediated response different from a humoral response?

MILESTONES IN Vaccine Development

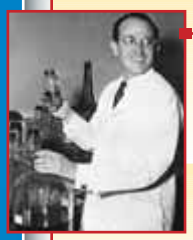
Timeline

Before 1700 Asian physicians use variolation.

1796 Jenner uses cowpox to immunize against smallpox.

1885 Pasteur treats rabies with vaccination.

1940s Vaccines for diphtheria, pertussis, tetanus, and smallpox are used routinely.

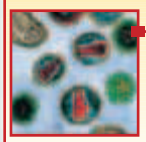


1955 An injectable polio vaccine is introduced by Jonas Salk.

1964 A vaccine for measles is released.

1967 A mumps vaccine is introduced.

1986 Recombinant vaccines are developed.



1990s and later Researchers seek an effective vaccine for HIV and other pathogens.

Centuries ago, Asian physicians sought to understand immunity by exposing healthy people to material from the sores of smallpox victims. This technique, called variolation, *had limited success but a huge historical impact. In the early 1700s, a British woman saw the technique being used in Turkey and described it to British doctors, who tried it on children. One of those children was Edward Jenner, the inventor of vaccination.*

As a country doctor in the late 1700s, Edward Jenner was investigating cowpox, a relatively harmless disease. He knew that milkmaids often contracted cowpox from cows. He had also heard that milkmaids who had cowpox were immune to smallpox. Jenner saw a connection, and he hypothesized that exposure to the pathogen that causes cowpox would give a person immunity to the smallpox pathogen also. In 1796, Jenner tested his hypothesis.

Jenner took matter from the cowpox sore of a milkmaid and injected it into an 8-year-old boy. Two months later, Jenner injected material from a sore of a smallpox patient. The boy remained healthy, even after several more injections. Jenner's experiment would be considered unethical today, but his observations led to millions of lives being saved through vaccination.

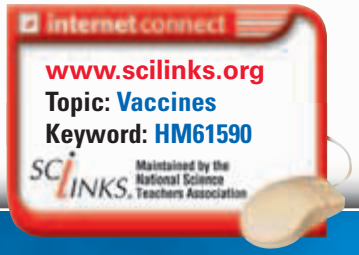
Science and medicine advanced slowly before the 20th century, and vaccination caught on only after scientists understood that germs cause disease. Louis Pasteur succeeded in vaccinating sheep against anthrax in 1881. In 1885, he injected a boy with killed rabies virus to save him from contracting the disease. This event helped explain vaccination, and soon scientists around the world began searching for the agents of disease and creating vaccines. By the early 1970s, vaccines had been developed for diphtheria, pertussis, tetanus, mumps, polio, measles, and rubella. In the United States, these illnesses have been virtually eliminated through vaccination.

Researchers soon discovered that the immune system can recognize a tiny piece of a pathogen and still form antibodies. By 1986, scientists had developed a recombinant hepatitis B vaccine by using harmless organisms altered to make a protein from the virus. The new vaccine cannot actually cause the disease, a rare but dangerous side effect of previous vaccines.

Vaccine research now focuses on conquering pathogens that have caused new outbreaks of disease around the world. These pathogens include HIV, the West Nile virus, the Ebola virus, and the coronavirus that causes SARS. In addition, researchers are working to improve existing vaccines, such as those for smallpox and anthrax.

Review

1. Why is it unnecessary for a vaccine to contain a whole pathogen?
2. **Critical Thinking** How can a person be immune to smallpox after exposure to cowpox?
3. **Critical Thinking** Do you think Pasteur's injection of rabies virus into a child would be considered unethical today?



PROBLEMS OF THE IMMUNE SYSTEM

Sometimes, the immune system reacts to otherwise harmless antigens in ways that can be harmful. Three examples of such problems of the immune system are allergies, asthma, and autoimmune diseases.

Allergies

An **allergy** is a physical response to an antigen. The antigen can be a common substance that produces little or no response in the general population. Antigens that can trigger allergic reactions include pollen, animal dander (flakes of skin), dust mites, food, and fungal spores. Allergic symptoms are generally mild, including a runny nose, sneezing, watery eyes, or itchy swellings of the skin. However, some people have extreme and life-threatening reactions to allergies. Many of the symptoms of allergy result from the release of histamine by cells that are exposed to the antigen. Drugs called *antihistamines* help counteract the effects of histamine and can relieve some symptoms of allergies.

Asthma

Allergies can also trigger **asthma,** a respiratory disorder that causes the bronchioles (airways of the lungs) to narrow. Asthma attacks occur when the muscles covering the bronchioles overreact to substances in the air, as shown in Figure 47-9. Substances that can cause asthma attacks include cigarette smoke and allergens such as animal dander. During an asthma attack, the lining of the bronchioles and other respiratory tissues may also swell and become inflamed, making breathing difficult. Other symptoms of asthma include shortness of breath, wheezing, and coughing. Asthma attacks are serious. Thousands of people in the United States die from asthma each year.

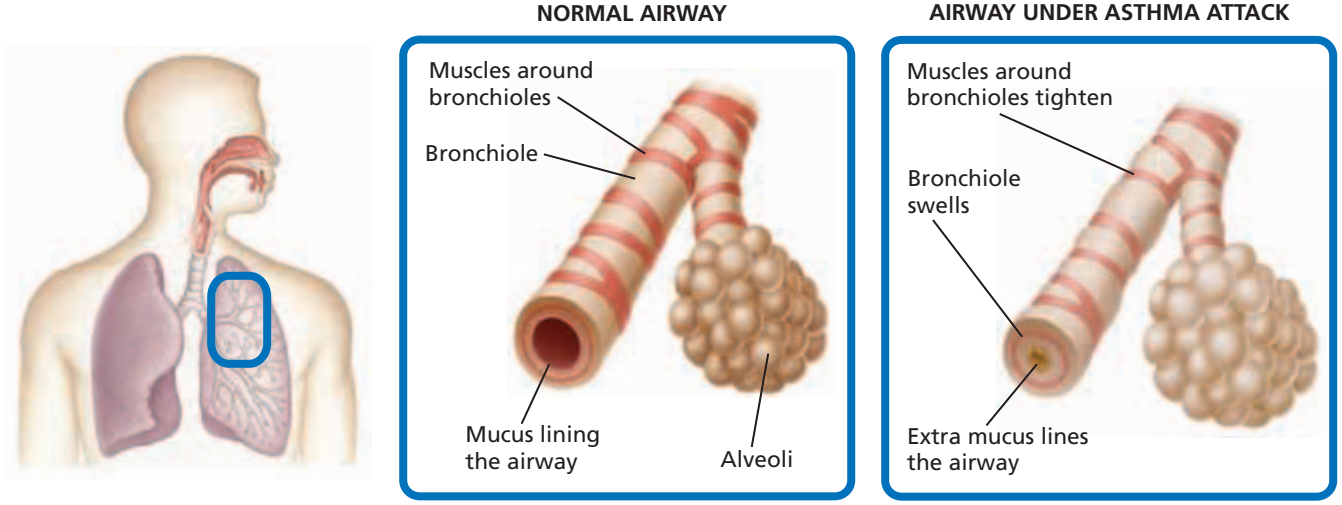


FIGURE 47-9

During an asthma attack, the muscles that encircle the airways of the lung (bronchioles) constrict, and inflammation of the respiratory tissues causes swelling and extra mucus to be produced in the airways. These reactions can make breathing difficult.

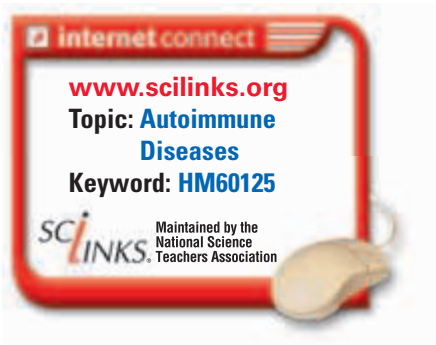
TABLE 47-2 *Autoimmune Diseases, Target Tissues, and Symptoms*

Disease	Tissues affected	Symptoms
Systemic lupus erythematosus	Connective tissue throughout the body	Facial rash, painful joints, fever, fatigue, kidney problems, weight loss
Type 1 diabetes	Insulin-producing cells in pancreas	Excessive urine production, excessive thirst, weight loss, fatigue, confusion
Rheumatoid arthritis	Joints	Painful, crippling inflammation of the joints
Psoriasis	Skin	Dry, scaly, red skin patches
Scleroderma	Multiple organs	Hardening and stiffening of the skin
Crohn's disease	Digestive system	Abdominal pain, nausea, vomiting, weight loss

Autoimmune Diseases

A disease in which the immune system attacks the organism's own cells is called an **autoimmune** (awt-oh-i-MYOON) **disease.** Lymphocytes that recognize and react to the body's own cells are usually eliminated during development, before they become functional. This removal of certain lymphocytes prevents an attack directed at the body's own tissues. However, in rare cases the immune system does respond to the body's own cells, attacking them as if they were pathogens. An autoimmune disease results.

Autoimmune diseases affect organs and tissues in various areas of the body. Multiple sclerosis is an autoimmune disease of the nervous system that affects mainly young adults. In this disease, T cells attack and slowly destroy the insulating material surrounding nerve cells in the brain, in the spinal cord, and in the nerves leading from the eyes to the brain. Symptoms include weakness, unsteadiness, tingling or burning sensations, and blurred vision. In severe cases, paralysis, blindness, and even death can result. Scientists are still searching for the causes of multiple sclerosis and other autoimmune diseases. Table 47-2 lists some other autoimmune diseases and describes their effects on the body.



SECTION 2 REVIEW

1. Describe the functions of the spleen and of the bone marrow.
2. What is an antigen?
3. How does the role of B cells in the immune response differ from that of helper T cells?
4. Explain how vaccination stimulates immunity to a disease.
5. Name one similarity and one difference between autoimmune diseases and allergies.

CRITICAL THINKING

6. **Recognizing Relationships** Explain how B cells depend on T cells.
7. **Evaluating an Argument** "A person who has just recovered from a cold cannot get the flu." Is this statement true? Explain your reasoning.
8. **Forming Reasoned Opinions** Would vaccine research be useful in preventing autoimmune diseases? Explain your reasoning.

SECTION 3

OBJECTIVES

- **Describe** the relationship between HIV and AIDS.
- **Distinguish** between the three phases of HIV infection.
- **Identify** the two main ways that HIV is transmitted.
- **Determine** how the evolution of HIV affects the development of vaccines and treatment.

VOCABULARY

AIDS
HIV
opportunistic infection

HIV AND AIDS

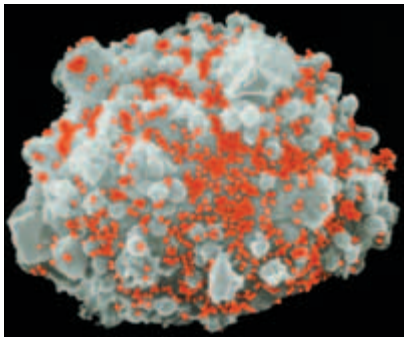
The immune system normally provides protection against infectious diseases. The importance of the immune system can be seen in diseases in which the immune system does not function properly. One of the deadliest of these diseases is ***AIDS*** *(acquired immunodeficiency syndrome), in which the immune system loses its ability to fight off pathogens and cancers. AIDS was recognized as a disease in 1981. Since then, it has killed more than 22 million people worldwide.*

THE COURSE OF HIV INFECTION

AIDS results from infection by the human immunodeficiency virus, or **HIV.** Once HIV has entered the bloodstream, HIV binds to CD4, a receptor protein on the surface of some cells. To enter a cell, HIV must also bind to an associated protein, or co-receptor. Macrophages, which have the CD4 receptor and a co-receptor called CCR5, are often the first cells of the immune system infected with HIV. The virus replicates inside the macrophages, and new viruses are released through "budding." This process does not destroy the macrophages. Viral replication of HIV results in many mutations. Eventually, a mutation may enable the virus to recognize other co-receptors, such as those found on helper T cells.

After release from macrophages, HIV attaches to and enters helper T cells. After viral replication, the new viruses are released from the T cell, as shown in Figure 47-10. These viruses then attach to other helper T cells, where the process repeats. Unlike macrophages, helper T cells are destroyed. Eventually, HIV kills enough helper T cells to cripple the immune system, leading to AIDS. HIV infection doesn't progress to AIDS on a specific timetable, but people tend to go through three phases of infection.

FIGURE 47-10
An HIV-infected helper T cell (grey mass) releases hundreds of new virus particles (red dots). (SEM 5,600×)



Phase I

Phase I of HIV infection is called the *asymptomatic stage,* because there are few or no symptoms. However, the amount of virus increases due to replication, as shown in Figure 47-11. The immune system begins an attack, and plasma cells make antibodies to fight the virus. However, it may take several weeks for the amount of anti-HIV antibodies to become large enough to result in a positive HIV test. HIV-infected people may feel well during phase I but can still infect other people. Phase I can last for up to 10 years or more.

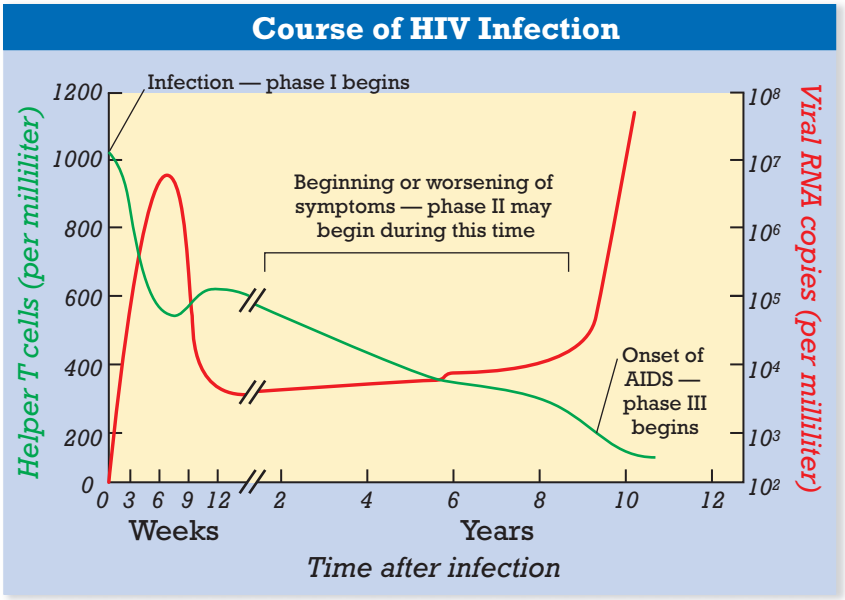


FIGURE 47-11

This graph shows an example of how the course of HIV infection can proceed. The course of HIV infection depends on both the numbers of virus particles and the numbers of helper T cells in the blood.

Phase II

The beginning or worsening of symptoms marks the start of the second phase of HIV infection. B cells continue to make a large amount of antibody against HIV. However, as shown in Figure 47-11, the number of T cells drops steadily as the virus continues to replicate. As the immune system fails, lymph glands become swollen, and fatigue, weight loss, fever, or diarrhea develop or worsen. Some infected people may notice mental changes, such as forgetfulness and abnormal thinking patterns.

Phase III

In phase III, the number of helper T cells drops so low that they can no longer stimulate B cells and cytotoxic T cells to fight invaders. As a consequence, the amount of anti-HIV antibody falls, and HIV levels rise dramatically. The virus continues destroying the few helper T cells remaining. AIDS is diagnosed when the helper T-cell count drops to 200 cells per milliliter of blood or lower (a normal amount is 600 to 700 helper T cells per milliliter).

AIDS may also be diagnosed if an opportunistic infection has developed. **Opportunistic infections** are illnesses caused by pathogens that produce disease in people with weakened immune systems. These organisms usually do not create problems in people with a healthy immune system. Opportunistic infections include pneumocystis pneumonia, tuberculosis, and a rare infection of the brain called *toxoplasmosis*. Rare cancers such as Kaposi's sarcoma, which causes purplish-red blotches on the skin, can also signal the onset of AIDS.

Drug therapy can slow the progress from HIV infection to AIDS. But AIDS is fatal. Few individuals live more than two years after an AIDS diagnosis. It is important to note that HIV itself does not cause death. Rather, death results from the weakened immune system's inability to fight opportunistic infections and cancers.

TRANSMISSION OF HIV

HIV is transmitted by the transfer of body fluids containing HIV or HIV-infected cells. The most common means of infection is sexual contact with an infected person. The second most common means is the use of syringes and hypodermic needles that have been contaminated with blood containing HIV. People who inject intravenous drugs and who share needles are at very high risk of infection. HIV can also be transmitted from an infected mother to her infant before or during birth or through breast-feeding.

HIV is not transmitted through casual contact, such as shaking hands. HIV is apparently not transmitted through the air, in water, on toilet seats, or through insect bites. The likelihood of infection through a blood transfusion is extremely low.

VACCINES AND TREATMENTS

FIGURE 47-12

A scientist studies blood samples as part of the search for a treatment or vaccine for HIV.

Scientists trying to create vaccines and treatments for HIV, such as the scientist shown in Figure 47-12, must contend with its rapid rate of evolution. The genes that code for the virus's surface proteins mutate frequently. As a result, new variants of the virus with slightly different surface proteins are constantly appearing. To produce effective immunity, a vaccine against HIV must stimulate the immune system to respond to many variants of the virus. Although researchers are developing and testing several vaccines against HIV, none has yet proven effective.

In addition, HIV can quickly become resistant to drugs. Scientists now treat patients with a combination of three drugs. Because mutations are random, mutations that create resistance to all three drugs are not likely to occur. However, this therapy often requires patients to take 50 or more pills a day. Many HIV-infected patients find the plan difficult and expensive. Nevertheless, the multidrug treatment is the most effective plan currently available. Because there is not yet a vaccine or cure for HIV infection, the only way to prevent HIV infection is to avoid high-risk behaviors.

SECTION 3 REVIEW

1. Describe the relationship between HIV and AIDS.
2. State the developments during the course of HIV infection that can lead to a diagnosis of AIDS.
3. List two ways that HIV can be transmitted and two ways that it cannot.
4. Why have scientists been unable to develop an effective vaccine for HIV?

CRITICAL THINKING

5. **Recognizing Factual Accuracy** Evaluate the statement "HIV infection causes death."
6. **Analyzing Current Research** Explain how research on co-receptor blocking might affect the search for a treatment for HIV infection.
7. **Comparing Concepts** Identify one similarity and one difference between HIV and a cold virus.

CHAPTER HIGHLIGHTS

SECTION 1 Nonspecific Defenses

- A pathogen is any agent that causes a disease. Robert Koch developed four basic steps, or postulates, for identifying the pathogen responsible for a disease.
- The skin and mucous membranes are nonspecific defenses that keep pathogens out of the body.
- The skin acts as an external barrier to pathogens and also releases substances that are toxic to pathogens.
- The mucous membranes protect the interior surfaces of the body and secrete mucus, a sticky fluid that traps pathogens.
- Injury to cells triggers an inflammatory response. Injured cells release chemical messengers that attract phagocytes through the capillary walls. Phagocytes then destroy the pathogens.
- White blood cells fight pathogens. Two types of phagocytes (neutrophils and macrophages) ingest pathogens. Natural killer cells pierce the cell membranes of infected cells.
- Nonspecific defenses also include an elevation in temperature (fever) and the activation of proteins such as the complement system and interferon.

Vocabulary

infectious disease (p. 957)
pathogen (p. 957)
Koch's postulates (p. 957)
mucous membrane (p. 958)
inflammatory response (p. 959)
histamine (p. 959)
phagocyte (p. 959)
neutrophil (p. 960)
macrophage (p. 960)
natural killer cell (p. 960)
complement system (p. 960)
interferon (p. 960)

SECTION 2 Specific Defenses: The Immune System

- The immune system consists of the cells and tissues that recognize and attack foreign substances in the body.
- Lymphocytes must be able to recognize foreign invaders and tell them apart from the cells of the body. Receptor proteins on a lymphocyte's plasma membrane allow the lymphocyte to recognize the invaders' antigens.
- The reaction of the body against an antigen is called an *immune response.* An immune response is a two-part assault on a pathogen: the cell-mediated immune response and the humoral immune response.
- Memory cells that remain after a primary response to an antigen allow a rapid secondary immune response if that antigen appears again. Vaccinations take advantage of the production of memory cells and the secondary immune response.
- An allergy is a physical response to an antigen that causes little or no response in the general population. Allergies can trigger asthma, a respiratory disorder that causes the bronchioles to narrow. An autoimmune disease is a disease in which the immune system attacks the organism's own cells.

Vocabulary

immune system (p. 961)
lymphocyte (p. 961)
thymus (p. 961)
spleen (p. 962)
B cell (p. 962)
T cell (p. 962)
antigen (p. 962)
immune response (p. 962)
helper T cell (p. 963)
cell-mediated immune response (p. 963)
cytotoxic T cell (p. 963)
humoral immune response (p. 964)
plasma cell (p. 964)
antibody (p. 964)
memory cell (p. 965)
immunity (p. 966)
vaccination (p. 966)
allergy (p. 968)
asthma (p. 968)
autoimmune disease (p. 969)

SECTION 3 HIV and AIDS

- AIDS results from infection by HIV. HIV can replicate inside macrophages and helper T cells.
- The course of HIV infection usually has three phases: phase I, the asymptomatic phase; phase II, the beginning or worsening of symptoms; and phase III, AIDS.
- HIV is transmitted mainly through sexual contact and the use of HIV-contaminated needles.
- Because its genes mutate often, HIV can quickly become resistant to medication. The rapid evolution of HIV also makes it difficult to develop an effective vaccine.

Vocabulary

AIDS (p. 970)
HIV (p. 970)
opportunistic infection (p. 971)

CHAPTER REVIEW

USING VOCABULARY

1. For each pair of terms, explain how the meanings of the terms differ.
   a. *macrophage* and *natural killer cell*
   b. *B cell* and *T cell*
   c. *antigen* and *antibody*
   d. *allergy* and *asthma*
2. Explain the relationship between HIV and AIDS.
3. Use the following terms in the same sentence: *cell-mediated immune response, helper T cell, cytotoxic T cell,* and *interleukin-2*.
4. **Word Roots and Origins** The word *pathogen* is derived from the Greek *pathos,* which means "suffering" or "disease," and *-gen,* which means "to produce." Using this information, explain why the term *pathogen* is a good name for an infectious agent.

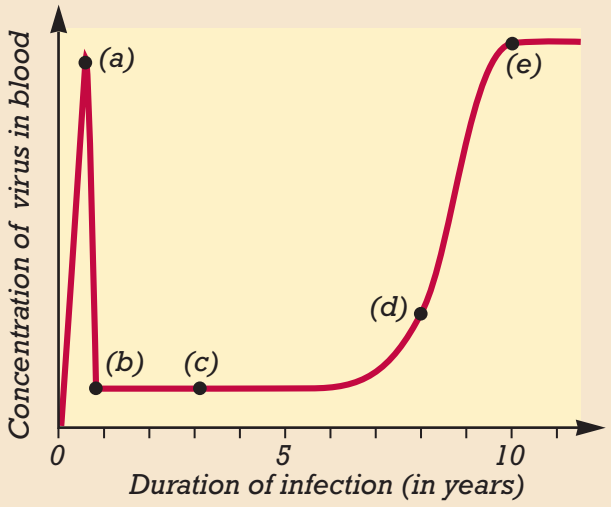
UNDERSTANDING KEY CONCEPTS

5. **Describe** the steps that must be followed to prove that a particular pathogen is responsible for a disease.
6. **Compare** the function of the mucous membranes with that of the skin.
7. **Summarize** the steps of the inflammatory response.
8. **Name** the chemical messenger that increases the permeability of the capillaries surrounding an injury.
9. **Identify** the roles that white blood cells play in the second line of nonspecific defenses.
10. **Explain** how fever and protein production help defend against infection.
11. **Name** one function of the thymus.
12. **Describe** how lymphocytes recognize and bind to pathogens.
13. **Explain** the role that helper T cells play in the immune response.
14. **Name** the type of cell that produces antibodies and releases them into the blood.
15. **Explain** the function of antibodies.
16. **State** the role that memory cells play in providing immunity against disease.
17. **Relate** vaccination to immunity.
18. **Describe** the cause of autoimmune diseases.
19. **Name** the point at which phase III in the course of HIV infection begins.
20. **List** two main ways HIV is usually transmitted.
21. **Identify** the problem scientists have encountered when trying to develop a vaccine against HIV.
22.  **CONCEPT MAPPING** Use the following terms to create a concept map: *pathogen, macrophage, helper T cell, cytotoxic T cell, B cell, plasma cell,* and *antibody*.

CRITICAL THINKING

23. **Making Comparisons** Scientists created an effective vaccine for smallpox but have not been able to do so for HIV. What does this suggest about the rate of evolution of the smallpox virus?
24. **Relating Concepts** Cytotoxic T cells attack and destroy some kinds of cancer cells. What can you conclude about the surface proteins of these cancer cells?
25. **Interpreting Graphics** The graph below shows the amount of HIV in the blood of an infected person over time. Use the graph to answer the following questions:
   a. What caused the peak in viral concentration at point a?
   b. Why did the level of virus drop between points a and b?
   c. Describe what is happening to both the virus and the immune system at points c and d.

Virus Concentration in HIV Infection



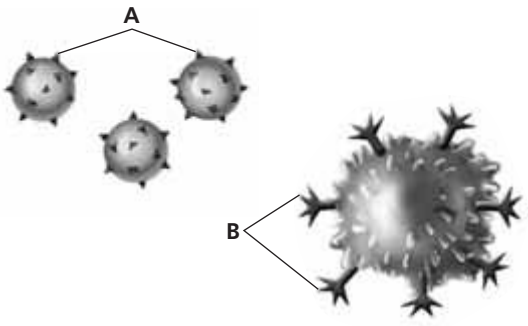
26. **Inferring Relationships** People who are severely burned often die from infection. Use what you know about disease transmission to explain why this situation is common.

Standardized Test Preparation

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

1. Which of the following is part of the nonspecific defenses?
   - **A.** the inflammatory response
   - **B.** the primary immune response
   - **C.** the humoral immune response
   - **D.** the secondary immune response
2. Which of the following statements is false?
   - **F.** Autoimmune diseases can be fatal.
   - **G.** Autoimmune diseases are a type of cancer.
   - **H.** Multiple sclerosis is an autoimmune disease.
   - **J.** Autoimmune diseases target the body's cells.
3. Which of the following is the most common means of HIV transmission?
   - **A.** receiving a blood transfusion
   - **B.** performing experiments with HIV
   - **C.** shaking hands with a person who has AIDS
   - **D.** having sexual contact with an HIV-infected person

INTERPRETING GRAPHICS: The image below shows two kinds of structures involved in an immune response. Use the image to answer the questions that follow.

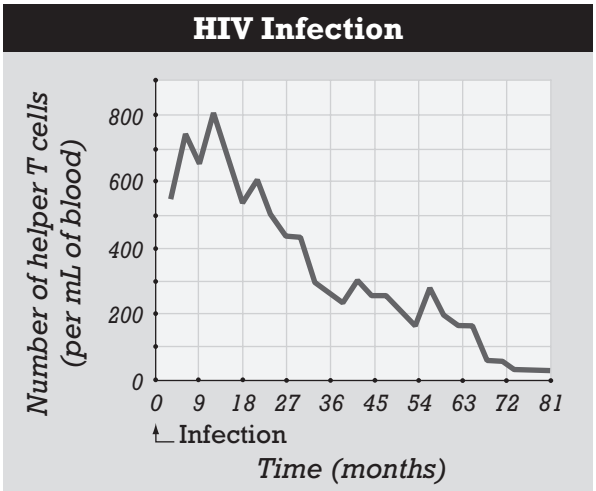


4. What are the structures labeled *A*?
   - **F.** antigens
   - **G.** interferons
   - **H.** interleukins
   - **J.** receptor proteins
5. What are the structures labeled *B*?
   - **A.** antigens
   - **B.** interferons
   - **C.** interleukins
   - **D.** receptor proteins
6. Why do structures *A* and *B* interact with each other?
   - **F.** Both are viral proteins.
   - **G.** Both are "nonself" structures.
   - **H.** They are complementary shapes.
   - **J.** They are produced by the same cells.

DIRECTIONS: Complete the following analogy.

7. T cell : cell-mediated :: B cell :
   - **A.** humoral
   - **B.** infectious
   - **C.** secondary
   - **D.** inflammatory

INTERPRETING GRAPHICS: The graph below shows the number of helper T cells over time from the onset of HIV infection. Use the graph to answer the question that follows.



8. About how many months after infection did the number of T cells first drop below 200/mL?
   - **F.** 18
   - **G.** 39
   - **H.** 51
   - **J.** 58

SHORT RESPONSE

A person infected with HIV today might not test positive for HIV antibodies for up to 6 months.

Explain why an HIV antibody test may not be positive until several weeks after a person's exposure to HIV.

EXTENDED RESPONSE

The inflammatory response results from cell injury.

Part A Explain the role of histamine in the inflammatory response.

Part B Explain the usefulness of having more than one type of white blood cell respond in the inflammatory response.

Test TIP Whenever possible, highlight or underline numbers or words that are critical to correctly understanding a question.

Simulating Disease Transmission

OBJECTIVES

- Simulate the transmission of a disease.
- Determine the original carrier of the disease.

PROCESS SKILLS

- organizing data
- analyzing data
- identifying
- modeling

MATERIALS

- lab apron
- safety goggles
- disposable gloves
- dropper bottle of unknown solution
- large test tube
- indophenol indicator

Background

1. What are the five main ways that human diseases can be transmitted?
2. How does a cold or flu spread from person to person?
3. How does the body fight invading viruses?
4. Why has the transmission of HIV become a great concern worldwide?
5. Why is a person with AIDS less able to combat infections than a person who does not have AIDS?

PART A Simulating the Transmission of a Disease

1. This investigation will involve the class in a simulation of disease transmission. After the simulation, you will try to identify the original infected person in the closed class population.
2. In your lab report, construct a data table similar to Table A.
3.  **CAUTION Put on a lab apron, goggles, and disposable gloves.**
4.  **CAUTION If you get any solution used in this investigation on your skin or clothing, wash it off at the sink while calling to your teacher. If you get any solution used in this investigation in your eyes, immediately flush your eyes with water at the eyewash station while calling to your teacher.** You have been given a dropper bottle of unknown solution and a clean test tube. The solution in the dropper bottle represents the pathogens that you carry. Handle the unknown solution with care because it is not simply water.
5. When your teacher says to begin, transfer three dropperfuls of your solution to your clean test tube. Then, replace the lid on the dropper bottle, and do not re-open it until Part B of this investigation.
6. Select one person to be your partner. Let one partner pour the contents of his or her test tube into the other partner's test tube. Then, pour half the solution back into the first test tube. You and your partner now share pathogens of any possible transmittable disease that either of you might have had. Record the name of your first partner (Round 1) in your data table in your lab report.
7. For Round 2, wait for your teacher's signal, and then find a different partner and exchange solutions in the same manner as you did in step 6. Record the name of your second partner (Round 2) in your lab report. Do not exchange solutions with the same person more than once. Repeat this procedure again for Round 3.
8. After all rounds are finished, your instructor will ask you to add one dropperful of indophenol indicator to your test tube to see if the fluids in your test tube have become infected. Infected solutions will be colorless or light pink. All uninfected solutions will appear blue. Record the outcome of your tests in your lab report.

TABLE A *LIST OF PARTNERS' NAMES*

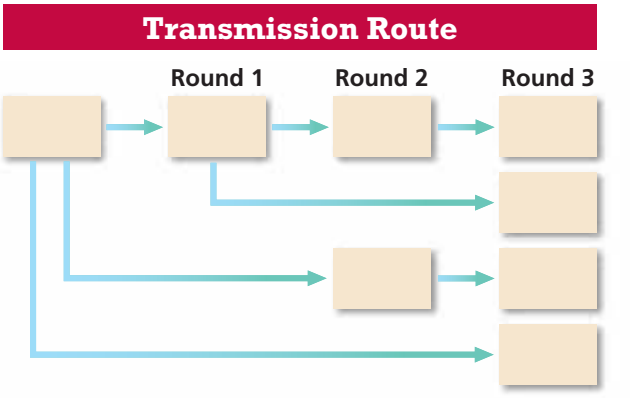
Round number	Partner's name
1	
2	
3	

TABLE B *PATH OF DISEASE TRANSMISSION*

Name of infected person	Names of infected person's partners		
	Round 1	Round 2	Round 3

PART B Tracing the Source of the Disease

9. If you are an infected person, give your name to your teacher. As names of infected people are written on the chalkboard or on the overhead projector, record them in your lab report in a table similar to Table B shown above.
10. Try to trace the original source of the infection, and then determine the transmission route of the disease. In your table, cross out the names of all the uninfected partners in Rounds 1, 2, and 3. There should be only two people in Round 1 who were infected. One of these people was the original carrier.
11. Draw a diagram that shows the transmission route of the disease through all three rounds. Your diagram may look something like the chart below. Include your diagram in your lab report.



12. In your diagram, insert the names of the two people in Round 1 who were infected and the names of their partners in Rounds 2 and 3.
13. To test whether a person was the original disease carrier, pour a sample from his or her dropper bottle into a clean test tube, and add indophenol indicator.
14.  Clean up your materials, and wash your hands before leaving the lab.

Analysis and Conclusions

1. What might the clear fluid in each student's dropper bottle represent?
2. Does the simulated disease have any apparent symptoms?
3. What chemical is added to the test tubes when the rounds are completed?
4. What color indicates a positive result?
5. What color indicates a negative result?
6. Who was the original disease carrier?
7. After the three rounds, how many students were infected? Express this as a percentage of the number of students in the class.
8. If an epidemic occurred in your community, how might public-health officials work to stop the spread of the disease?

Further Inquiry

A public-health official is sent to investigate an outbreak of a new disease. Devise an experiment to allow the official to determine whether the disease has been caused by the passing of pathogens from person to person or by environmental conditions.

CHAPTER 48

Digestive and Excretory Systems

This is a scanning electron micrograph of a filtration membrane in the human kidney. (SEM 3060×)

SECTION 1

NUTRIENTS

Carrots, fish, eggs, hamburgers, blackberries, cow's milk—the human body is able to convert each of these foods into nutrients that body cells need to function, grow, and replicate. In this section, you will learn what nutrients the human body needs and how it uses those nutrients to carry out life processes.

OBJECTIVES

- **Relate** the role of each of the six classes of nutrients in maintaining a healthy body.
- **Describe** each of the parts of the USDA Food Guide Pyramid.
- **Identify** foods containing each of the organic nutrients.
- **Explain** the importance of vitamins, minerals, and water in maintaining the body's functions.
- **Identify** three disorders associated with improper nutrition.

VOCABULARY

nutrient
vitamin
mineral
dehydration

SIX CLASSES OF NUTRIENTS

Organisms that do not carry out photosynthesis must obtain energy from nutrients in the food they consume. A **nutrient** is a substance required by the body for energy, growth, repair, and maintenance. All foods contain at least one of six basic nutrients: carbohydrates, proteins, lipids, vitamins, minerals, and water. Few foods contain all six nutrients. Most foods contain a concentration of just one or two.

Nutritionists classify foods into six groups—meat, milk, fruits, vegetables, breads and cereals, and fats, oils, and sweets—based on nutrient similarity. Each nutrient plays a different role in keeping an organism healthy. The USDA Food Guide Pyramid, shown in Figure 48-1, shows the number of servings from each food group needed for a balanced diet.

Some nutrients provide energy for powering cellular processes. The energy available in food is measured in kilocalories, or Calories, which is equal to 1,000 calories. A *calorie* is the amount of heat energy required to raise the temperature of 1 g of water 1°C (1.8°F). The greater the number of calories in a quantity of food, the more energy the food contains.

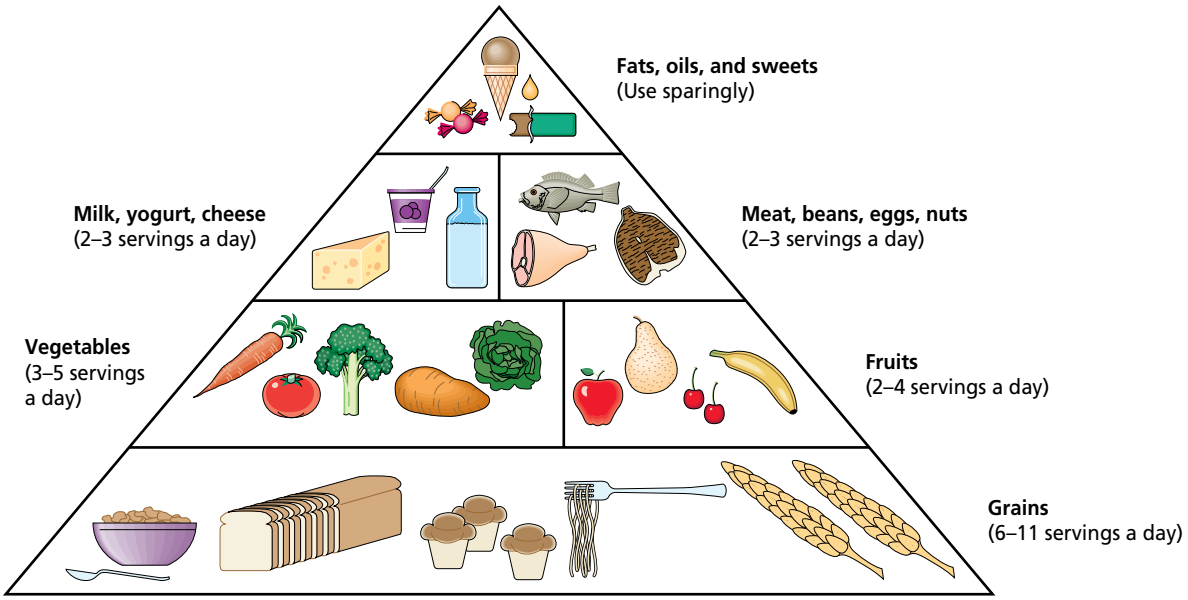


FIGURE 48-1
The USDA Food Guide Pyramid lists the daily number of servings needed from each food group to obtain a variety of nutrients and maintain a healthy diet.

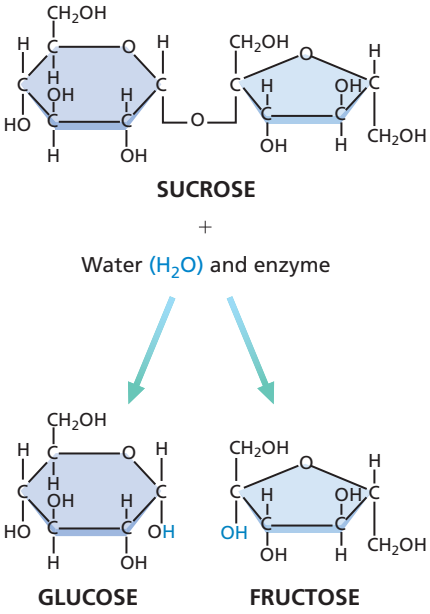


FIGURE 48-2

The hydrolysis of a disaccharide requires water and an enzyme. When sucrose is hydrolyzed, two monosaccharides are formed—glucose and fructose. These monosaccharides are then transported through cell membranes to be used by cells.

CARBOHYDRATES, PROTEINS, AND LIPIDS

The three nutrients needed by the body in the greatest amounts—carbohydrates, proteins, and lipids—are organic compounds. *Organic compounds* are compounds containing the elements carbon, hydrogen, and oxygen.

Carbohydrates

Carbohydrates are organic compounds composed of carbon, hydrogen, and oxygen. Carbohydrates are broken down in aerobic respiration to provide most of the body's energy. Although proteins and fats also supply energy, the body most easily uses the energy provided by carbohydrates. Carbohydrates contain sugars that are quickly converted into the usable energy ATP, but proteins and fats must go through many chemical processes before the body can use them to make ATP.

The fructose and glucose (also known as dextrose) in fruit and honey are simple sugars, or *monosaccharides.* These sugars can be absorbed directly into the bloodstream and made available to cells for use in cellular respiration. Sucrose (table sugar), maltose, and lactose (milk sugar) are *disaccharides.* Disaccharides are sugars that consist of two chemically linked monosaccharides. Before disaccharides can be used by the body for energy they must be split into two monosaccharides in a process called *hydrolysis.* Figure 48-2 shows how sucrose is hydrolyzed to produce glucose and fructose.

Polysaccharides are complex molecules that consist of many monosaccharides bonded together. The starch found in many grains and vegetables is a polysaccharide made up of long chains of glucose molecules. During digestion, the enzymes hydrolyze these long chains into individual glucose units.

Many foods we get from plants contain cellulose, a polysaccharide that forms the walls of plant cells. The body cannot break down cellulose into individual component sugars. Nevertheless it is an extremely important part of the human diet. Cellulose and other forms of fiber help move the food along by stimulating contractions of the smooth muscles that form the walls of the digestive organs.

Proteins

The major structural and functional material of body cells are *proteins.* Proteins consist of long chains of amino acids. Proteins from food must be broken down into amino acids in order for the body to grow and to repair tissues. The human body uses 20 different amino acids to build the proteins it needs. The body can make many of these amino acids, but it cannot produce all of them in the quantities that it needs. Amino acids that must be obtained from food are called *essential amino acids*. Ten amino acids are essential to children and teenagers for growth. Only eight are essential to adults.

Word Roots and Origins

hydrolysis

from the Greek *hydro,* meaning "water," and *lysis,* meaning "dissolve"

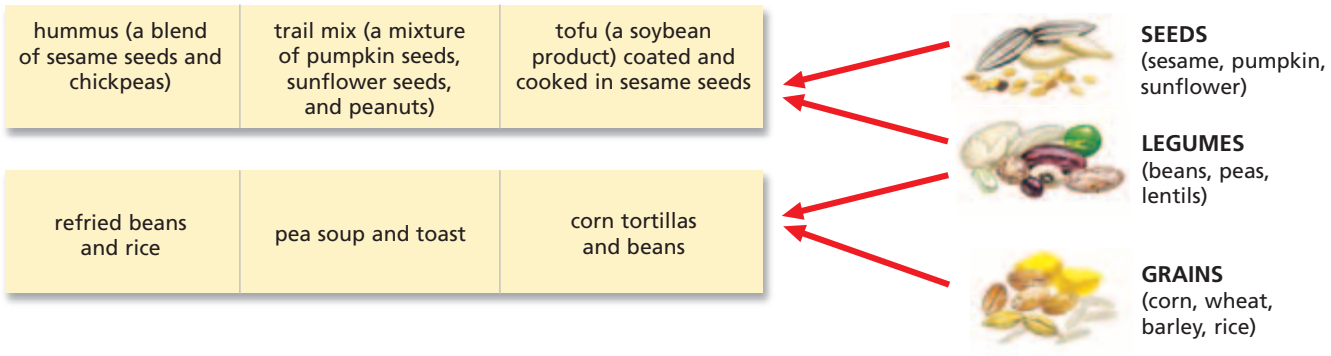


FIGURE 48-3
The combination of legumes, seeds, and grains furnishes all the essential amino acids.

Most of the foods we get from plants contain only small amounts of certain essential amino acids. Eating certain combinations of two or more plant products, such as those shown in Figure 48-3, can ensure an adequate supply of all the essential amino acids. Most animal products, such as eggs, milk, fish, poultry, and beef, contain larger amounts of all the essential amino acids.

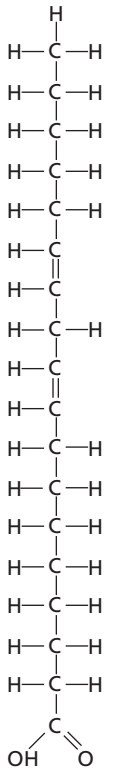
Lipids

Lipids are organic compound that are insoluble in water. They include fats, oils, and waxes. Lipids are used to make cell membranes and steroid hormones and to store energy.

The most common fats are *triglycerides* which are used for energy and to build cell membranes and other cell parts. The body stores excess fat from the diet. Excess carbohydrates and protein may also be converted to fat for storage. Stored fats are beneficial unless they are excessive. A light layer of body fat beneath the skin provides insulation in cold weather. Fat surrounding vulnerable organs, such as the kidneys and liver, acts as protective padding. Most important, fat reserves are a concentrated source of energy.

To use fats, the body must first break down each fat molecule into *glycerol* and *fatty acids.* The glycerol molecule is the same in all fats, but the fatty acids differ in both structure and composition. The body converts some fatty acids to other fatty acids, depending on which one the body needs at the time.

Scientists classify fats as saturated or unsaturated, based on structural differences in their fatty acids. A *saturated fatty acid* has all its carbon atoms connected by single bonds and thus contains as many hydrogen atoms as possible. An *unsaturated fatty acid* has at least one double bond between carbon atoms. If there are two or more double bonds, as shown in Figure 48-4, the fatty acid is called *polyunsaturated*. Although lipids are essential nutrients, too much fat in the diet is known to harm several body systems. A diet high in saturated fats is linked to heart disease and to high levels of blood-cholesterol. High cholesterol contributes to atherosclerosis, or build-up of fatty deposits within vessels. A diet high in fat also contributes to obesity, and can lead to late-onset diabetes. Diabetes is the leading cause of kidney failure, blindness, and amputation in adults.



Linoleic acid

FIGURE 48-4
The structure of linoleic acid, a fatty acid in margarine, is shown in this figure. Notice the two double bonds between carbon atoms.

VITAMINS, MINERALS, AND WATER

Vitamins, minerals, and water are nutrients that do not provide energy but are required for proper functioning of the body. **Vitamins** work as *coenzymes* to enhance enzyme activity. **Minerals** are necessary for making certain body structures, for normal nerve and muscle function, and for maintaining osmotic balance. Water transports gases, nutrients, and waste; is a reagent in some of the body's chemical reactions; and regulates body temperature. Table 48-1 summarizes the sources of vitamins and their functions.

TABLE 48-1 *Food Sources of Vitamins*

Vitamins	Best sources	Essential for	Deficiency diseases and symptoms
Vitamin A (carotene; fat soluble)	fish-liver oils, liver and kidney, green and yellow vegetables, yellow fruit, tomatoes, butter, egg yolk	growth, health of the eyes, and functioning of the cells of the skin and mucous membranes	retarded growth, night blindness, susceptibility to infections, changes in skin, defective tooth formation
Vitamin B_1 (thiamin; water soluble)	meat, soybeans, milk, whole grains, legumes	growth; carbohydrate metabolism; functioning of the heart, nerves, muscles	beriberi—loss of appetite and weight, nerve disorders, and faulty digestion
Vitamin B_2 (riboflavin; water soluble)	meat, fowl, soybeans, milk, green vegetables, eggs, yeast	growth, health of the skin, eyes, and mouth, carbohydrate metabolism, red blood cell formation	retarded growth, dimness of vision, inflammation of the tongue, premature aging, intolerance to light
Vitamin B_3 (niacin; water soluble)	meat, fowl, fish, peanut butter, potatoes, whole grains, tomatoes, leafy vegetables	growth; carbohydrate metabolism; functioning of the stomach, intestines, and nervous system	pellagra—smoothness of the tongue, skin eruptions, digestive disturbances, and mental disorders
Vitamin B_6 (pyridoxine; water soluble)	whole grains, liver, fish 	protein metabolism, production of hemoglobin, health of the nervous system	dermatitis, nervous disorders
Vitamin B_{12} (cyanocobalamin; water soluble)	liver, fish, beef, pork, milk, cheese	red blood cell formation, health of the nervous system	a reduction in number of red blood cells, pernicious anemia
Vitamin C (ascorbic acid; water soluble)	fruit (especially citrus), tomatoes, leafy vegetables	growth, strength of the blood vessels, development of teeth, health of gums	scurvy—sore gums, hemorrhages around the bones, and tendency to bruise easily
Vitamin D (calciferol; fat soluble)	fish-liver oil, liver, fortified milk, eggs, irradiated foods	growth, calcium and phosphorus metabolism, bones and teeth	rickets—soft bones, poor development of teeth, and dental decay
Vitamin E (tocopherol; fat soluble)	wheat-germ oil, leafy vegetables, milk, butter	normal reproduction	anemia in newborns
Vitamin K (naphthoquinone; fat soluble)	green vegetables, soybean oil, tomatoes	normal clotting of the blood, liver functions	hemorrhages

Vitamins

Vitamins are small organic molecules that act as coenzymes. Coenzymes activate enzymes and help them function. Because vitamins generally cannot be synthesized by the body, a diet should include the proper daily amounts of all vitamins. Like enzymes, coenzymes can be reused many times. Thus, only small quantities of vitamins are needed in the diet.

Vitamins dissolve in either water or fat. The fat-soluble vitamins include vitamins A, D, E, and K. The water-soluble vitamins are vitamin C and the group of B vitamins. Because the body cannot store water-soluble vitamins, it excretes surplus amounts in urine. Fat-soluble vitamins are absorbed and stored like fats. Unpleasant physical symptoms and even death can result from storing too much or having too little of a particular vitamin.

The only vitamin that the body can synthesize in large quantities is vitamin D. This synthesis involves sunlight converting cholesterol to vitamin D precursors in the skin. People who do not spend a lot of time in the sun can get their vitamin D from food.

Minerals

Minerals are naturally occurring inorganic substances that are used to make certain body structures, to carry out normal nerve and muscle function, and to maintain osmotic balance. Some minerals, such as calcium, magnesium, and iron, are drawn from the soil and become part of plants. Animals that feed on plants extract the minerals and incorporate them into their bodies. Table 48-2 lists the primary sources and functions of a few of the minerals considered most essential to human beings. Iron, for example, is necessary for the formation of red blood cells, and potassium maintains the body's acid-base balance and aids in growth. Both are found in certain fruits and vegetables. Excess minerals are excreted through the skin in perspiration and through the kidneys in urine.

TABLE 48-2 *Food Sources of Minerals*

Minerals	Source	Essential for
Calcium	milk, whole-grain cereals, vegetables, meats	deposition in bones and teeth; functioning of heart, muscles, and nerves
Iodine	seafoods, water, iodized salt	thyroid hormone production
Iron	leafy vegetables, liver, meats, raisins, prunes	formation of hemoglobin in red blood cells
Magnesium	vegetables	muscle and nerve action
Phosphorus	milk, whole-grain cereals, vegetables, meats	deposition in bones and teeth; formation of ATP and nucleic acids
Potassium	vegetables, citrus fruits, bananas, apricots	maintaining acid-base balance; growth; nerve action
Sodium	table salt, vegetables	blood and other body tissues; muscle and nerve action

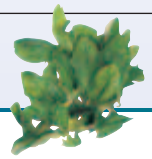


FIGURE 48-5

Athletes drink water to replace water lost through perspiration. Excess water loss can lead to a condition called dehydration.

Water

Water accounts for over half of your body weight. Most of the reactions that maintain life can take place only in water. Water makes up more than 90 percent of the fluid part of the blood, which carries essential nutrients to all parts of the body. It is also the medium in which waste products are carried away from body tissues.

Water also helps regulate body temperature. It absorbs and distributes heat released in cellular reactions. When the body needs to cool, perspiration—a water-based substance—evaporates from the skin, and heat is drawn away from the body. Usually, the water lost through your skin, lungs, and kidneys is easily replaced by drinking water or consuming moist foods. People, like the athletes in Figure 48-5, must drink water to avoid **dehydration**—excess water is lost and not replenished. Water moves from intercellular spaces to the blood by osmosis. Eventually, water will be drawn from the cells themselves. As a cell loses water, the cytoplasm becomes more concentrated until the cell can no longer function.

SECTION 1 REVIEW

1. Summarize the major role of each of the organic nutrients in the body's function.
2. Describe the type of information the USDA Food Guide pyramid provides.
3. Identify a food that is high in carbohydrates, another that is high in proteins, and a third that is high in lipids.
4. Identify the role that minerals play in maintaining a healthy body.
5. Explain the importance of water to the body.
6. Identify disorders caused by a diet high in saturated fats.

CRITICAL THINKING

7. **Predicting Results** What might be the health consequences of a diet consisting of only water and rice?
8. **Justifying Conclusions** Why would large doses of vitamin B_2 be less harmful than large doses of vitamin A?
9. **Applying Information** Caffeine tends to increase the discharge of urine. Should an athlete drink a caffeinated beverage before a big game? Explain your answer.

SECTION 2

DIGESTIVE SYSTEM

Before your body can use the nutrients in the food you consume, the nutrients must be broken down physically and chemically. The nutrients must be absorbed, and the wastes must be eliminated.

OBJECTIVES

- **List** the major organs of the digestive system.
- **Distinguish** between mechanical digestion and chemical digestion.
- **Relate** the structure of each digestive organ to its function in mechanical digestion.
- **Identify** the source and function of each major digestive enzyme.
- **Summarize** the process of absorption in both the small and large intestine.

VOCABULARY

digestion
gastrointestinal tract
saliva
pharynx
epiglottis
peristalsis
gastric fluid
ulcer
cardiac sphincter
chyme
pyloric sphincter
gallbladder
villus
colon

THE GASTROINTESTINAL TRACT

The process of breaking down food into molecules the body can use is called **digestion.** Digestion occurs in the **gastrointestinal tract,** or digestive tract, a long, winding tube which begins at the mouth and winds through the body to the anus. The gastrointestinal tract, shown in Figure 48-6, is divided into several distinct organs. These organs carry out the digestive process. Along the gastrointestinal tract are other organs that are not part of the gastrointestinal tract, but that aid in digestion by delivering secretions into the tract through ducts.

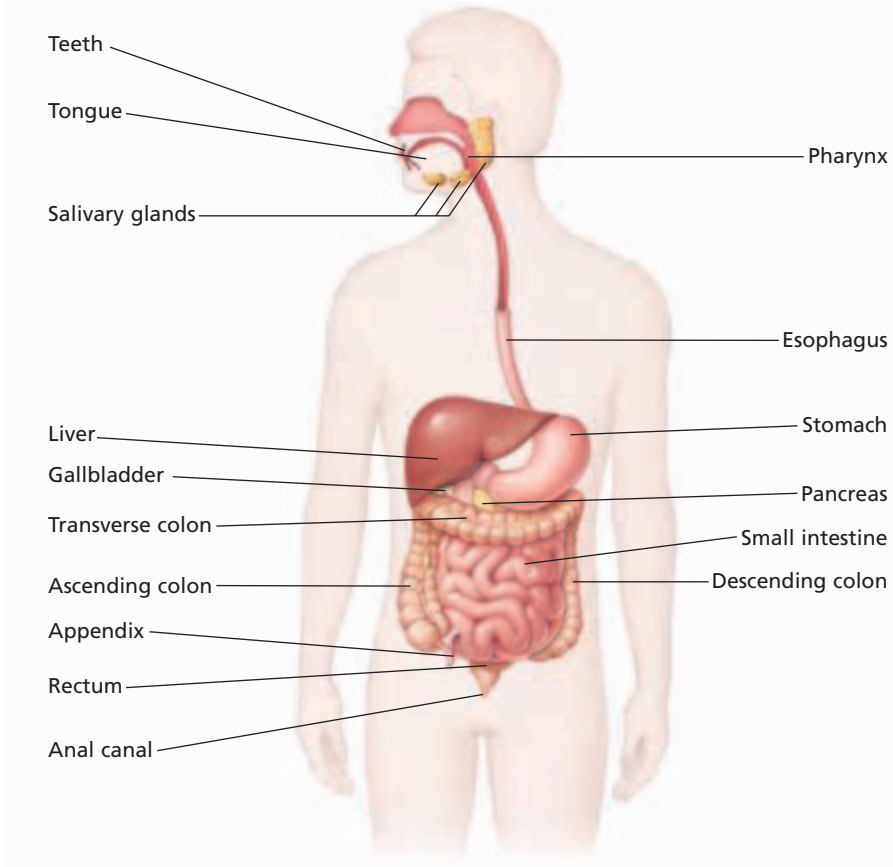


FIGURE 48-6
The digestive system is made up of the gastrointestinal tract, salivary glands, the liver, gallbladder, and pancreas. These organs break down food into nutrients that can be absorbed into the bloodstream.

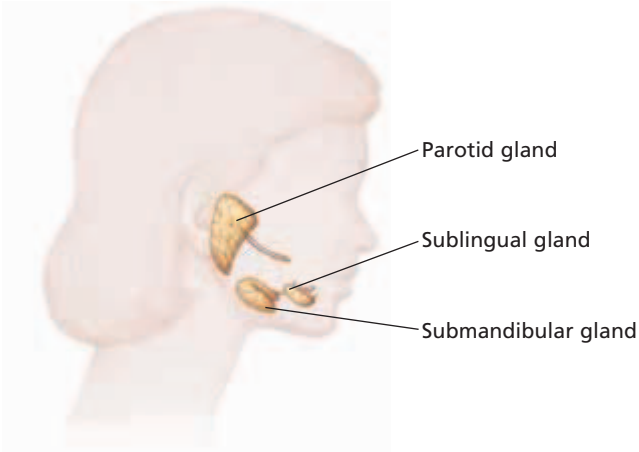


FIGURE 48-7
Saliva is produced by three sets of glands located near the mouth. The set closest to the ear is the target of the virus that causes mumps.

THE MOUTH AND ESOPHAGUS

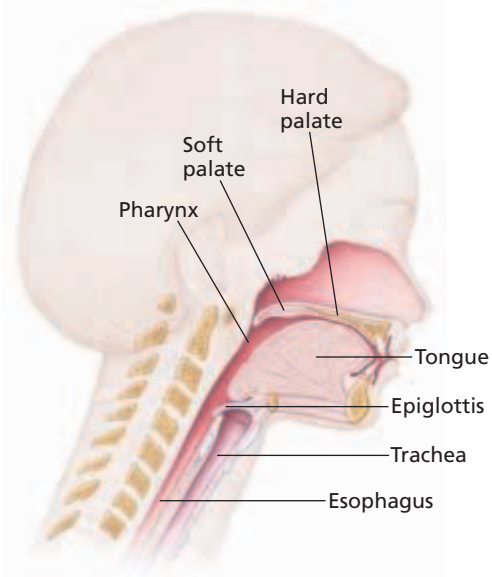
Digestion includes the mechanical and chemical breakdown of food into nutrients, the absorption of nutrients, and the elimination of waste. In the mechanical phase, the body physically breaks down chunks of food into small particles. Mechanical digestion increases the surface area on which digestive enzymes can act.

Mouth

When you take a bite of food, you begin the mechanical phase of digestion. *Incisors*—sharp front teeth—cut the food. Then, the broad, flat surfaces of *molars,* or back teeth, grind it up. The tongue helps keep the food between the chewing surfaces of the upper and lower teeth by manipulating it against the *hard palate,* the bony, membrane-covered roof of the mouth. This structure is different from the *soft palate,* an area located just behind the hard palate. The soft palate is made of folded membranes and separates the mouth cavity from the nasal cavity.

Chemical digestion involves a change in the chemical nature of the nutrients. Salivary glands produce **saliva** (suh-LIE-vuh), a mixture of water, mucus, and a digestive enzyme called *salivary amylase*. Besides the many tiny salivary glands located in the lining of the mouth, there are three pairs of larger salivary glands, as shown in Figure 48-7. The salivary amylase begins the chemical digestion of carbohydrates by breaking down some starch into the disaccharide maltose.

FIGURE 48-8
The pharynx is the only passage shared by the digestive and respiratory systems. Notice how the epiglottis can close off the trachea so that food can pass only down the esophagus.



Esophagus

After food has been thoroughly chewed, moistened, and rolled into a *bolus,* or ball, it is forced into the pharynx by swallowing action. The **pharynx,** an open area that begins at the back of the mouth, serves as a passageway for both air and food. As Figure 48-8 shows, a flap of tissue called the **epiglottis** (EP-uh-GLAHT-is) prevents food from entering the trachea, or windpipe, during swallowing. Instead, the bolus passes into the esophagus, a muscular tube approximately 25 cm long that connects the pharynx with the stomach.

The esophagus has two muscle layers: an inner circular layer that wraps around the esophagus and an outer longitudinal layer that runs the length of the tube. As you can see in Figure 48-9, alternating contractions of these muscle layers push the bolus through the esophagus and into the stomach. This series of rhythmic muscular contractions and relaxations is called **peristalsis.**

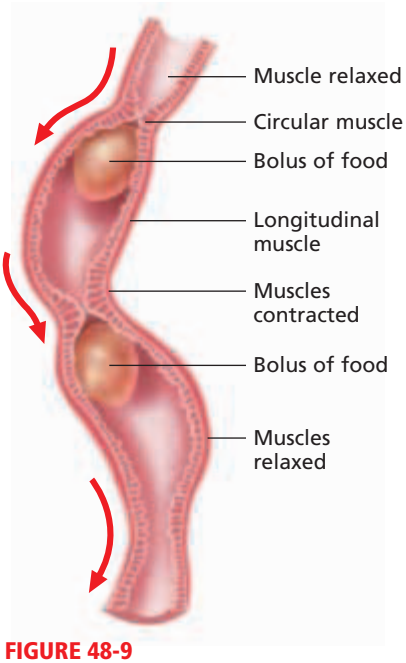


FIGURE 48-9
Peristalsis is so efficient at moving materials down the esophagus that you can drink while standing on your head. The smooth muscles move the water "up" the esophagus, against the force of gravity.

STOMACH

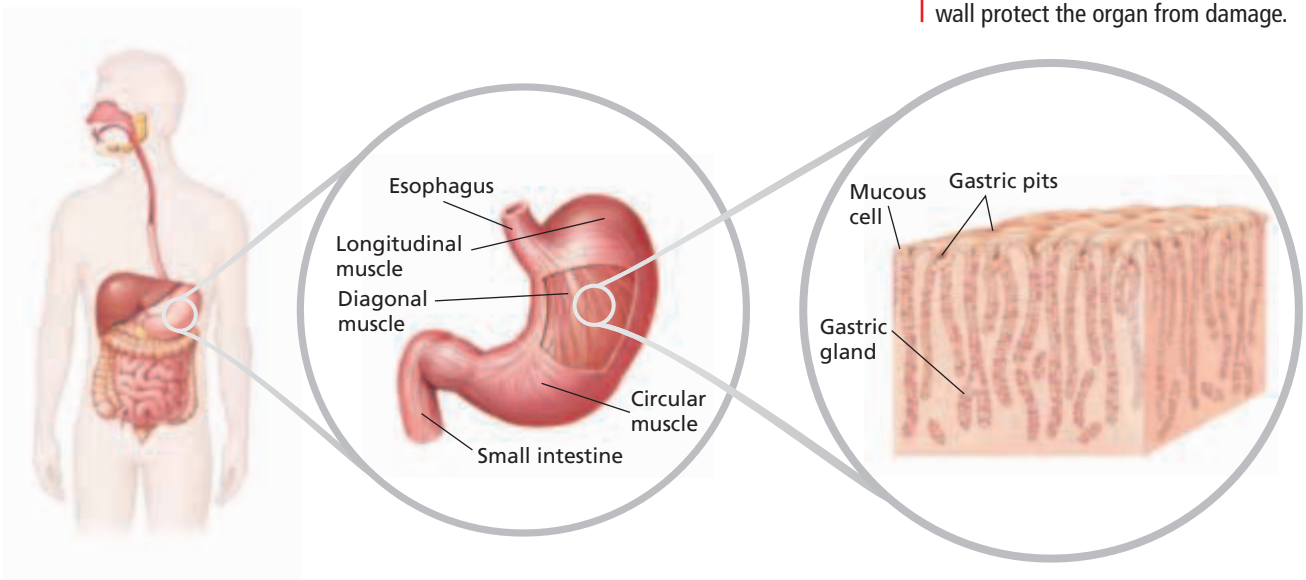
The stomach, an organ involved in both mechanical and chemical digestion, is located in the upper left side of the abdominal cavity, just below the diaphragm. It is an elastic bag that is J-shaped when full and that lies in folds when empty. You have probably heard your stomach "growl" when it has been empty for some time. These sounds are made by the contraction of smooth muscles that form the walls of the stomach.

Mechanical Digestion

The walls of the stomach have several layers of smooth muscle. As you can see in Figure 48-10, there are three layers of muscle—a circular layer, a longitudinal layer, and a diagonal layer. When food is present, these muscles work together to churn the contents of the stomach. This churning helps the stomach carry out mechanical digestion.

The inner lining of the stomach is a thick, wrinkled mucous membrane composed of epithelial cells. This membrane is dotted with small openings called gastric pits. *Gastric pits,* which are shown in Figure 48-10, are the open ends of gastric glands that release secretions into the stomach. Some of the cells in gastric glands secrete mucus, some secrete digestive enzymes, and still others secrete hydrochloric acid. The mixture of these secretions forms the acidic digestive fluid.

FIGURE 48-10
Each of the muscle layers of the stomach is oriented in a different direction. The pH of the stomach is normally between 1.5 and 2.5, making it the most acidic environment in the body. Mucous cells lining the stomach wall protect the organ from damage.



Chemical Digestion

Gastric fluid carries out chemical digestion in the stomach. An inactive stomach secretion called *pepsinogen* is converted into a digestive enzyme called *pepsin* at a low pH. Chemical digestion of proteins starts in the stomach when pepsin splits complex protein molecules into shorter chains of amino acids called *peptides*. Hydrochloric acid in the stomach not only ensures a low pH but also dissolves minerals and kills bacteria that enter the stomach along with food.

Mucus secreted in the stomach forms a coating that protects the lining from hydrochloric acid and from digestive enzymes. In some people, the mucous coating of the stomach tissue breaks down, allowing digestive enzymes to eat through part of the stomach lining. The result is called an **ulcer.** The breakdown of the mucous layer is often caused by bacteria that destroy the epithelial cells, which form the mucous layer.

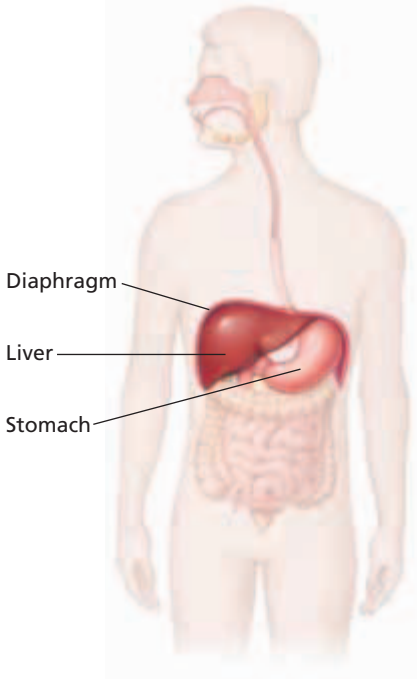
Formation of Chyme

The **cardiac sphincter** (SFINGK-tuhr) is a circular muscle located between the esophagus and the stomach. After the food enters the stomach, the cardiac sphincter closes to prevent the food from reentering the esophagus. Food usually remains in the stomach for three to four hours. During this time, muscle contractions in the stomach churn the contents, breaking up food particles and mixing them with gastric fluid. This process forms a mixture called **chyme** (KIEM).

Peristalsis forces chyme out of the stomach and into the small intestine. The **pyloric** (pie-LOHR-ik) **sphincter,** a circular muscle between the stomach and the small intestine, regulates the flow of chyme. Each time the pyloric sphincter opens, about 5 to 15 mL (about 0.2 to 0.5 oz) of chyme moves into the small intestine, where it mixes with secretions from the liver and pancreas.

FIGURE 48-11

The liver is the body's largest internal organ, weighing about 1.5 kg (3 lb). If a small portion is surgically removed because of disease or injury, the liver regenerates the missing section.

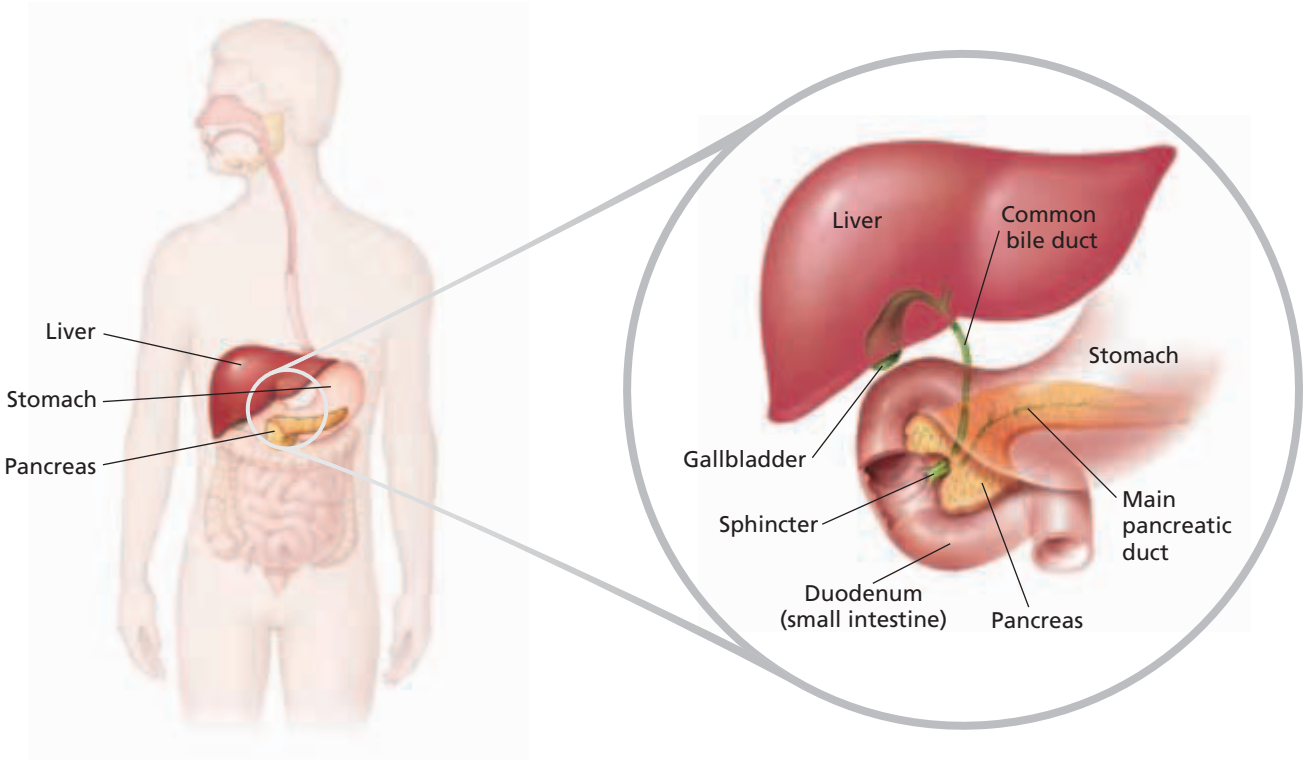


THE LIVER, GALLBLADDER, AND PANCREAS

Several of the organs involved in digestion do not come directly in contact with food. The liver, gallbladder, and pancreas work with the digestive system to perform several important functions.

Liver

The liver is a large organ located to the right of the stomach, as shown in Figure 48-11. The liver performs numerous functions in the body, including storing glucose as glycogen, making proteins, and breaking down toxic substances, such as alcohol. The liver also secretes bile, which is vital to the digestion of fats. Bile breaks fat globules into small droplets, forming a milky fluid in which fats are suspended. This process exposes a greater surface area of fats to the action of digestive enzymes and prevents small fat droplets from rejoining into large globules.



Gallbladder

The bile secreted by the liver passes through a Y-shaped duct, as shown in Figure 48-12. The bile travels down one branch of the Y-shaped duct and then up the other branch to the **gallbladder,** a saclike organ that stores and concentrates bile. When chyme is present in the small intestine, the gallbladder releases bile through the common bile duct into the small intestine.

FIGURE 48-12

Cholesterol deposits known as *gallstones* can form in the ducts leading from the liver and gallbladder to the small intestine. If the gallstones interfere with the flow of bile, they must be removed, along with the gallbladder in some cases.

Pancreas

As shown in Figure 48-12, the pancreas is an organ that lies behind the stomach, against the back wall of the abdominal cavity. The pancreas is a gland that serves several important functions. The pancreas acts as an endocrine gland, producing hormones that regulate blood sugar levels. As part of the digestive system, the pancreas serves two roles. It produces sodium bicarbonate, which neutralizes stomach acid. The pH of stomach acid is about 2. Pancreatic fluid raises the pH of the chyme from an acid to a base.

Neutralizing stomach acid is important in order to protect the interior of the small intestine and to ensure that the enzymes secreted by the pancreas can function. Many enzymes in the pancreatic fluid are activated by the higher pH. The pancreas produces enzymes that break down carbohydrates, proteins, lipids, and nucleic acids. These enzymes hydrolyze disaccharides into monosaccharides, fats into fatty acids and glycerol, and proteins into amino acids. Pancreatic fluid enters the small intestine through the pancreatic duct, which joins the common bile duct just before it enters the intestine.

SMALL INTESTINE

If the small intestine were stretched to its full length, it would be nearly 7 m (about 21 ft) long. The *duodenum,* the first section of this coiled tube, makes up only the first 25 cm (about 10 in.) of that length. The *jejunum* (jee-JOO-nuhm), the middle section, is about 2.5 m (about 8 ft) long. The *ileum,* which makes up the remaining portion of the small intestine, is approximately 4 m (about 13 ft) in length. As shown in Figure 48-13, the entire length of the small intestine lies coiled in the abdominal cavity.

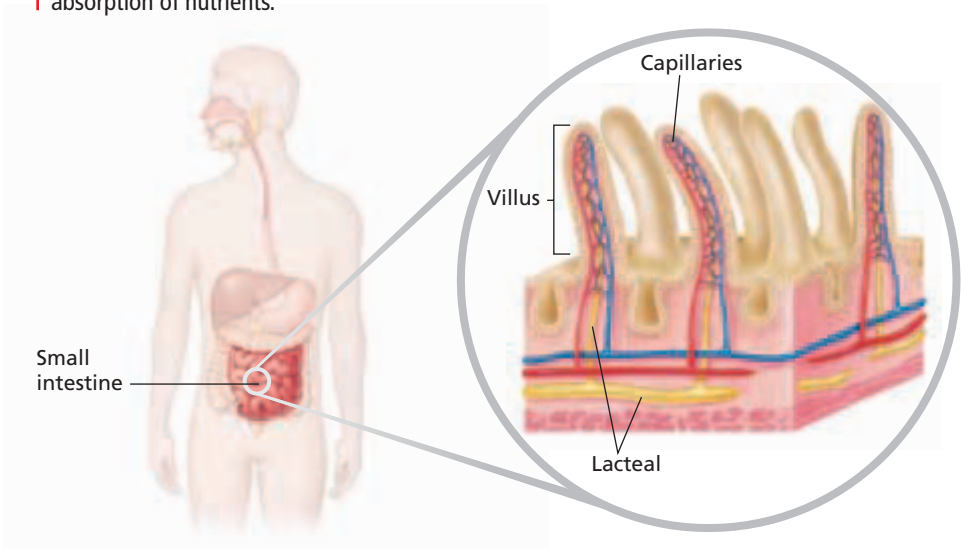
Secretions from the liver and pancreas enter the duodenum, where they continue the chemical digestion of chyme. When the secretions from the liver and pancreas, along with the chyme, enter the duodenum, they trigger intestinal mucous glands to release large quantities of mucus. The mucus protects the intestinal wall from protein-digesting enzymes and the acidic chyme. Glands in the lining of the small intestine release enzymes that complete digestion by breaking down peptides into amino acids, disaccharides into monosaccharides, and fats into glycerol and fatty acids.

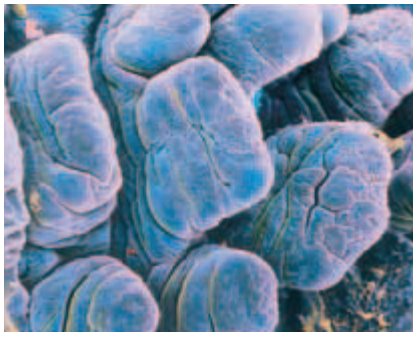
Absorption

During *absorption,* the end products of digestion—amino acids, monosaccharides, glycerol, and fatty acids—are transferred into the circulatory system through blood and lymph vessels in the lining of the small intestine. The structure of this lining provides a huge surface area for absorption to take place. The highly folded lining of the small intestine is covered with millions of fingerlike projections called **villi** (singular, *villus*), which are shown in Figure 48-13. The cells covering the villi, in turn, have extensions on their cell membranes called *microvilli*. The folds, villi, and microvilli give the small intestine a surface area of about 250 m^2 (about 2,685 ft^2), or roughly the area of a tennis court. Nutrients are absorbed through this surface by means of diffusion and active transport.

FIGURE 48-13

Although the small intestine is nearly 7 m long, only the first 25 cm are involved in digesting food. The rest is involved in the absorption of nutrients. Villi, as shown in the SEM (137×) and the diagram, expand the surface area of the small intestine to allow greater absorption of nutrients.





SEM of intestinal villi

Inside each of the villi are capillaries and tiny lymph vessels called *lacteals* (LAK-tee-uhlz). The lacteals can be seen in Figure 48-13. Glycerol and fatty acids enter the lacteals, which carry them through the lymph vessels and eventually to the bloodstream through lymphatic vessels near the heart. Amino acids and monosaccharides enter the capillaries and are carried to the liver. The liver neutralizes many toxic substances in the blood and removes excess glucose, converting it to glycogen for storage. The filtered blood then carries the nutrients to all parts of the body.

LARGE INTESTINE

After absorption in the small intestine is complete, peristalsis moves the remaining material on to the large intestine. The large intestine, or **colon,** is the final organ of digestion. Study Figure 48-14 to identify the four major parts of the colon: *ascending colon, transverse colon, descending colon,* and *sigmoid colon.* The sigmoid colon leads into the very short, final portions of the large intestine called the *rectum* and the *anal canal.*

Most of the absorption of nutrients and water is completed in the small intestine. About 9 L (9.5 qt) of water enter the small intestine daily, but only 0.5 L (0.53 qt) of water is present in the material that enters the large intestine. In the large intestine, only nutrients produced by bacteria that live in the colon, as well as most of the remainder of the water, are absorbed. Slow contractions move material in the colon toward the rectum. Distension of the colon initiates contractions that move the material out of the body. As this matter moves through the colon, the absorption of water solidifies the mass. The solidified material is called *feces.*

As the fecal matter solidifies, cells lining the large intestine secrete mucus to lubricate the intestinal wall. This lubrication makes the passing of the feces less abrasive. Mucus also binds together the fecal matter, which is then eliminated through the anus.

FIGURE 48-14

This X ray shows the large intestine, or colon. The ascending colon is on the left. The transverse colon crosses the abdominal cavity. The descending colon can be seen on the right. The sigmoid colon is the small section that leads to the anal canal.

SECTION 2 REVIEW

1. Sequence the organs that are involved in each step of digestion.
2. Explain the difference between mechanical digestion and chemical digestion.
3. Describe the processes involved in mechanical digestion.
4. Identify the source and function of each class of digestive enzymes.
5. Explain how the small intestine and large intestine are related to the function of absorption.

CRITICAL THINKING

6. **Applying Information** Which of the six basic nutrients might a person need to restrict after an operation to remove the gallbladder? Why?
7. **Predicting Results** Explain how the gastrointestinal tract would be affected if the pancreas were severely damaged.
8. **Forming Reasoned Opinions** Considering the stomach's role in the digestive system, is it possible for a person to digest food without a stomach? Explain your answer.

Science in Action

Can Saris Prevent Cholera?

Health authorities in Bangladesh urge villagers to boil surface water before drinking it, but a severe shortage of wood makes this process impossible for most people. Millions of people therefore must still use surface water and are at risk of cholera. However, scientist Rita Colwell came up with a method to filter out disease-causing organisms with an item available even in the poorest homes.

Dr. Rita Colwell

HYPOTHESIS: Simple Filtration Methods Will Reduce the Incidence of Cholera

Cholera is a severe disease that causes thousands of deaths each year. Symptoms of cholera include abdominal cramps, nausea, vomiting, dehydration, and shock. If untreated, death may occur after severe fluid and electrolyte loss. The responsible agent is a comma-shaped bacterium called *Vibrio cholerae.* In certain developing regions around the world where people must obtain untreated drinking water from streams and lakes, *V. cholerae* infection can occur.

Dr. Colwell, one of the world's leading cholera researchers, observed that *V. cholerae* lives in association with microscopic copepods, which are a type of zooplankton. Dr. Colwell also showed that cholera outbreaks occurred seasonally in association with temperature changes and blooms of the copepod organisms.

Dr. Colwell and her colleagues knew that villagers often strained flavored beverages through a piece of fine cloth cut from an old, discarded sari, a woman's long flowing garment. Colwell came up with a hypothesis: Straining drinking water through an old piece of sari cloth could remove copepods and the associated cholera bacteria and prevent cases of cholera.

METHODS: Compare Filtration Methods

Colwell's team chose 142 villages in Bangladesh where people use untreated river or pond water for drinking and have high rates of cholera. They assigned over 45,000 participants to three groups. The control group would continue to use unfiltered, untreated water. One experimental group would collect water in jars by tying four layers of sari cloth over the opening. The other experimental group would collect water in containers covered by filter fabric designed to remove copepod-sized organisms. Field workers collected medical data on cholera cases during the study period.

RESULTS: Cholera Cases Are Reduced

The team compared the incidence of cholera for the control group with that of the two experimental groups. They found that the control group had the usual number of cholera cases (about 3 per 1,000 people per year). However, using either nylon filtration cloth or sari cloth cut the number of cases in half. Interestingly, old cloth worked better than new cloth because older fibers soften, the pore size is reduced, and more copepods and attached bacteria are trapped in the pores.

CONCLUSION: Saris Can Reduce the Incidence of Cholera

Rita Colwell and her team concluded that saris are a simple, practical solution to a serious global problem. They are currently looking at ways to expand this filtration idea to other parts of the world. Women don't wear saris everywhere, but old cloth is available in virtually every home.

REVIEW

1. Identify the relationship between copepods, *V. cholerae,* and drinking water.
2. Explain the reason that the age of the saris made a difference in filtration.
3. **Critical Thinking** If the *V. cholerae* bacteria were not associated with copepods, would this filtration have been successful? Explain your reasoning.

URINARY SYSTEM

The body must rid itself of the waste products of cellular activity. The process of removing metabolic wastes, called ***excretion,*** *is just as vital as digestion in maintaining the body's internal environment. Thus, the urinary system not only excretes wastes but also helps maintain homeostasis by regulating the content of water and other substances in the blood.*

SECTION 3

OBJECTIVES

- **Identify** the major parts of the kidney.
- **Relate** the structure of a nephron to its function.
- **Explain** how the processes of filtration, reabsorption, and secretion help maintain homeostasis.
- **Summarize** the path in which urine is eliminated from the body.
- **List** the functions of each of the major excretory organs.

VOCABULARY

excretion
renal cortex
renal medulla
renal pelvis
urea
ammonia
urine
nephron
Bowman's capsule
glomerulus
renal tubule
filtration
reabsorption
secretion
loop of Henle
ureter
urinary bladder
urethra

KIDNEYS

The main waste products that the body must eliminate are carbon dioxide, from cellular respiration, and nitrogenous compounds, from the breakdown of proteins. The lungs excrete most of the carbon dioxide, and nitrogenous wastes are eliminated by the kidneys. The excretion of water is necessary to dissolve wastes and is closely regulated by the kidneys, the main organs of the urinary system.

Humans have two bean-shaped kidneys, each about the size of a clenched fist. The kidneys are located one behind the stomach and the other behind the liver. Together, they regulate the chemical composition of the blood.

Structure

Figure 48-15 shows the three main parts of the kidney. The **renal cortex,** the outermost portion of the kidney, makes up about a third of the kidney's tissue mass. The **renal medulla** is the inner two-thirds of the kidney. The **renal pelvis** is a funnel-shaped structure in the center of the kidney. Also, notice in Figure 48-15 that blood enters the kidney through a renal artery and leaves through a renal vein. The renal artery transports nutrients and wastes to the kidneys. The nutrients are used by kidney cells to carry out their life processes. One such process is the removal of wastes brought by the renal artery.

The most common mammalian metabolic waste is **urea** (yoo-REE-uh), a nitrogenous product made by the liver. Nitrogenous wastes are initially brought to the liver as **ammonia,** a chemical compound of nitrogen so toxic that it could not remain long in the body without harming cells. The liver removes ammonia from the blood and converts it into the less harmful substance urea. The urea enters the bloodstream and is then removed by the kidneys.

NEPHRONS

The substances removed from the blood by the kidneys—toxins, urea, water, and mineral salts—form an amber-colored liquid called **urine.** Urine is made in structures called **nephrons** (NEF-RAHNZ), the functional units of the kidney. Nephrons are tiny tubes in the kidneys. One end of a nephron is a cup-shaped capsule surrounding a tight ball of capillaries that retains cells and large molecules in the blood and passes wastes dissolved in water through the nephron. The cup-shaped capsule is called **Bowman's capsule.** Within each Bowman's capsule, an arteriole enters and splits into a fine network of capillaries called a **glomerulus** (gloh-MER-yoo-luhs).

Take a close look at the structure of the nephron, shown in Figure 48-15. Notice the close association between a nephron of the kidney and capillaries of the circulatory system. Initially, fluid passes from the glomerulus into a Bowman's capsule of the nephron. As the fluid travels through the nephron, nutrients that passed into the Bowman's capsule are reabsorbed into the bloodstream. What normally remains in the nephron are waste products and some water, which form urine that passes out of the kidney.

Each kidney consists of more than a million nephrons. If they were stretched out, the nephrons from both kidneys would extend for 80 km (50 mi). As you read about the structure of a nephron, locate each part in Figure 48-15.

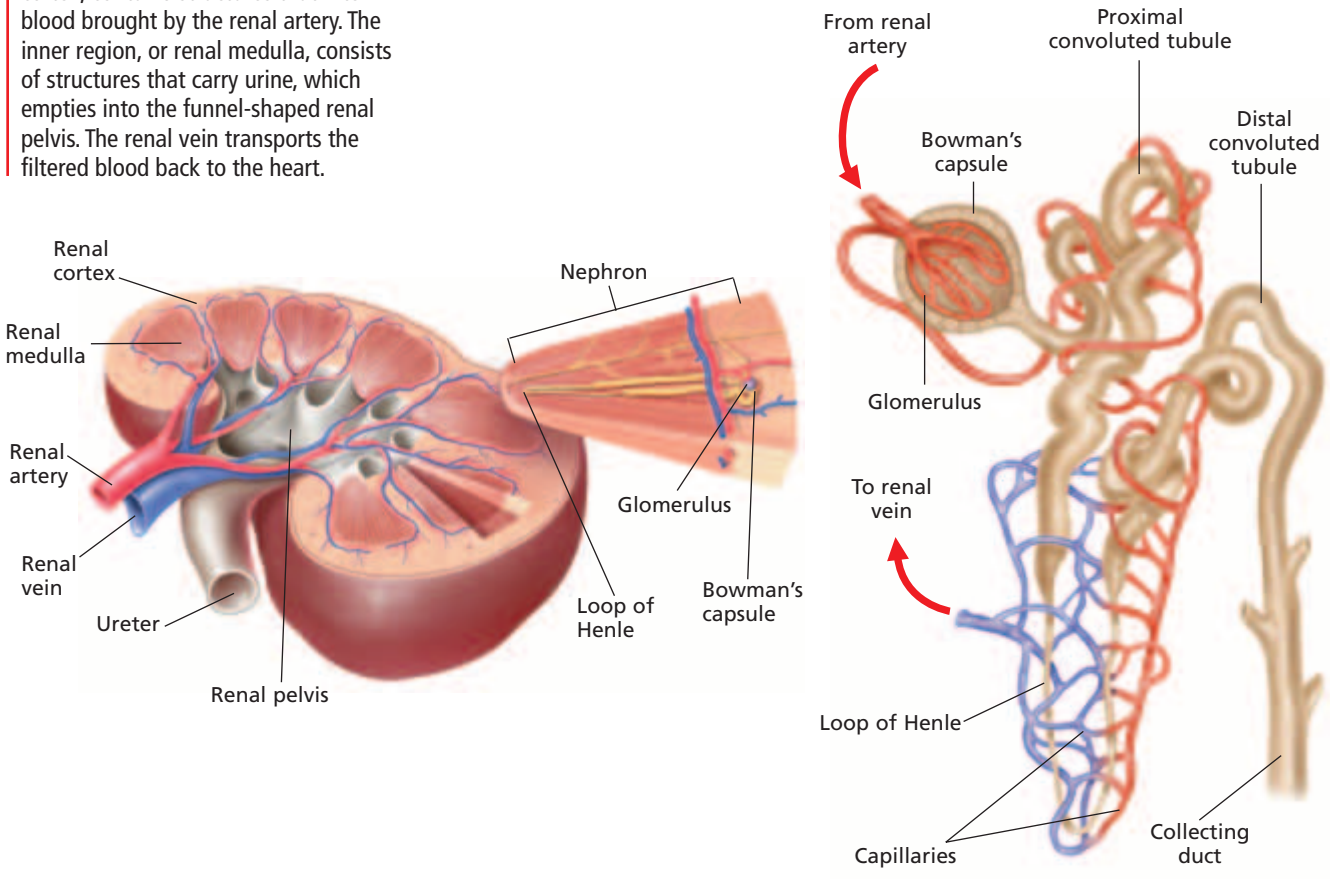


FIGURE 48-15
The outer region of the kidney, the renal cortex, contains structures that filter blood brought by the renal artery. The inner region, or renal medulla, consists of structures that carry urine, which empties into the funnel-shaped renal pelvis. The renal vein transports the filtered blood back to the heart.

Each nephron has a cup-shaped structure, called a Bowman's capsule, that encloses a bed of capillaries. This capillary bed, called a glomerulus, receives blood from the renal artery. Fluids are forced from the blood through the capillary walls and into the Bowman's capsule. The material filtered from the blood then flows through the **renal tubule,** which consists of three parts: the proximal convoluted tubule, the loop of Henle, and the distal convoluted tubule. Blood remaining in the glomerulus then flows through a network of capillaries. The long and winding course of both the renal tubule and the surrounding capillaries provides a large surface area for the exchange of materials.

As the filtrate flows through a nephron, its composition is modified by the exchange of materials among the renal tubule, the capillaries, and the extracellular fluid. Various types of exchanges take place in the different parts of the renal tubule. To understand how the structure of each part of the nephron is related to its function, we will examine the three major processes that take place in the nephron: filtration, reabsorption, and secretion. Figure 48-16 shows the site of each of these processes in the nephron.

Word Roots and Origins

glomerulus

from the Latin *glom,* meaning "little ball of yarn"

FILTRATION

Materials from the blood are forced out of the glomerulus and into the Bowman's capsule during a process called **filtration.** Blood in the glomerulus is under relatively high pressure. This pressure forces water, urea, glucose, vitamins, and salts through the thin capillary walls of the glomerulus and into the Bowman's capsule. About one-fifth of the fluid portion of the blood filters into the Bowman's capsule. The rest remains in the capillaries, along with proteins and cells that are too large to pass through the capillary walls. In a healthy kidney, the filtrate—the fluid that enters the nephron—does not contain large protein molecules.

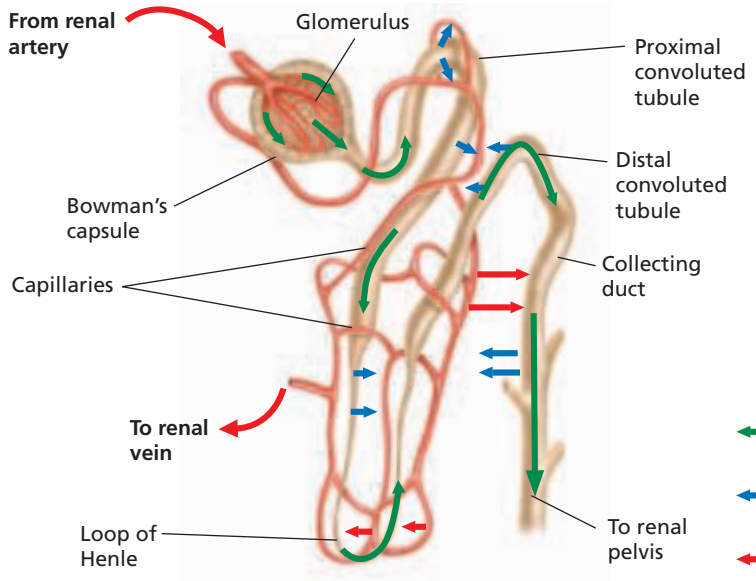


FIGURE 48-16
Color-coded arrows indicate where in the nephron the filtrate travels, and where reabsorption and secretion occur.

Eco Connection

Kidneys and Pollution

According to data from the U.S. Environmental Protection Agency, indoor areas, where we spend up to 90 percent of our time, contain substances that may be hazardous to our health. Because of their function in excretion, kidneys often are exposed to hazardous chemicals that have entered the body through the lungs, skin, or gastrointestinal tract. Household substances that, in concentration, can damage kidneys include paint, varnishes, furniture oils, glues, aerosol sprays, air fresheners, and lead.

Many factors in our environment are difficult to control, but the elimination of pollutants from our indoor living areas is fairly simple. The four steps listed below may help reduce the effects of many indoor pollutants.

1. Identify sources of pollutants in your home.
2. Eliminate the sources, if possible.
3. Seal off those sources that cannot be eliminated.
4. Ventilate to evacuate pollutants and bring in fresh air.

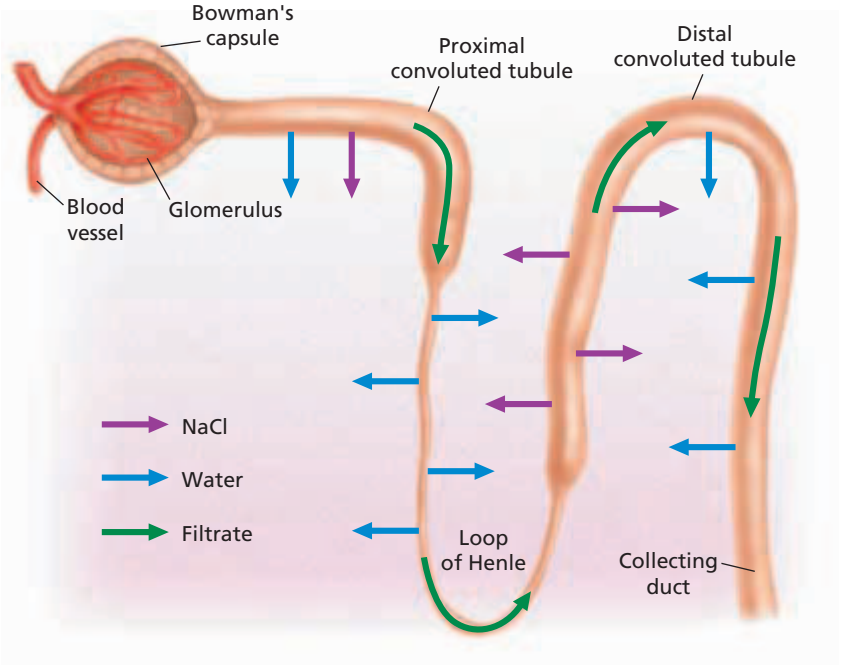
REABSORPTION AND SECRETION

The body needs to retain many of the substances that were removed from the blood by filtration. Thus, as the filtrate flows through the renal tubule, these materials return to the blood by being selectively transported through the walls of the renal tubule and into the surrounding capillaries. This process is called **reabsorption.** Most reabsorption occurs in the proximal convoluted tubule. In this region, about 75 percent of the water in the filtrate returns to the capillaries by osmosis. Glucose and minerals, such as sodium, potassium, and calcium, are returned to the blood by active transport. Some additional reabsorption occurs in the distal convoluted tubule.

When the filtrate reaches the distal convoluted tubule, some substances pass from the blood into the filtrate through a process called **secretion.** These substances include wastes and toxic materials. The pH of the blood is adjusted by hydrogen ions that are secreted from the blood into the filtrate.

Formation of Urine

The fluid and wastes that remain in the distal convoluted tubule form urine. The urine from several renal tubules flows into a collecting duct. Notice in Figure 48-17 that the urine is further concentrated in the collecting duct by the osmosis of water through the wall of the duct. This process allows the body to conserve water. In fact, osmosis in the collecting duct, together with reabsorption in other parts of the tubule, returns to the blood about 99 of every 100 mL (about 3.4 oz) of water in the filtrate.



FORMATION OF URINE

FIGURE 48-17

The sodium chloride that is actively transported out of the loop of Henle makes the extracellular environment surrounding the collecting duct hypertonic. Thus, water moves out of the collecting duct by osmosis into this hypertonic environment, increasing the concentration of urine.

The Loop of Henle

The function of the **loop of Henle** (HEN-lee) is closely related to that of the collecting duct. Water moves out of the collecting duct because the concentration of sodium chloride is higher in the fluid surrounding the collecting duct than it is in the fluid inside the collecting duct. This high concentration of sodium chloride is created and maintained by the loop of Henle. Cells in the wall of the loop transport chloride ions from the filtrate to the fluid between the loops and the collecting duct. Positively charged sodium ions follow the chloride ions into the fluid. This process ensures that the sodium chloride concentration of the fluid between the loops and the collecting duct remains high and thus promotes the reabsorption of water from the collecting duct.

ELIMINATION OF URINE

Urine from the collecting ducts flows through the renal pelvis and into a narrow tube called a **ureter** (yoo-REET-uhr). A ureter leads from each kidney to the **urinary bladder,** a muscular sac that stores urine. Muscular contractions of the bladder force urine out of the body through a tube called the **urethra** (yoo-REE-thruh). Locate the ureters, urinary bladder, and urethra in Figure 48-18.

At least 500 mL (17 oz) of urine must be eliminated every day because this amount of fluid is needed to remove potentially toxic materials from the body and to maintain homeostasis. A normal adult eliminates from 1.5 L (1.6 qt) to 2.3 L (2.4 qt) of urine a day, depending on the amount of water taken in and the amount of water lost through respiration and perspiration.

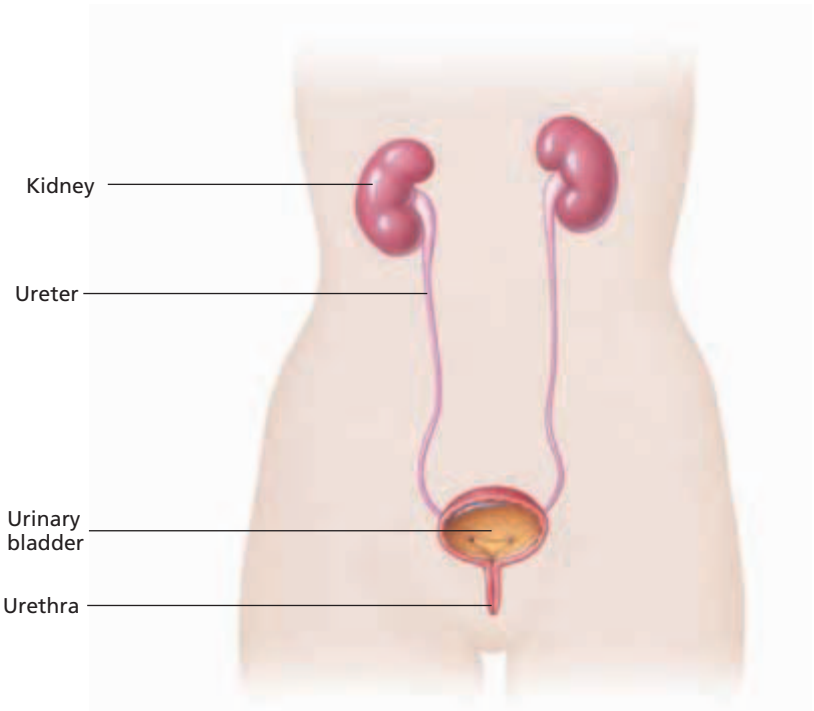


FIGURE 48-18
Urine travels from each kidney through a ureter to the urinary bladder, where it is stored until it is eliminated from the body through the urethra.

Quick Lab

Analyzing Kidney Filtration

Materials disposable gloves, lab apron, safety goggles, 20 mL of test solution, 3 test tubes, filter, beaker, 15 drops each of biuret and Benedict's solution, 2 drops IKI solution, 3 pipets, wax marker pen

Procedure

1. Put on your gloves, lab apron, and safety goggles.
2. Put 15 drops of the test solution into each of the test tubes. Label the test tubes "Protein," "Starch," and "Glucose."
3. Add 15 drops of biuret solution to the test tube labeled "Protein." Record your observations.
4. Add 15 drops of Benedict's solution to the test tube labeled "Glucose." Record your observations.
5. Add two drops of IKI solution to the test tube labeled "Starch." Record your observations.
6. Discard the tested solutions, and rinse your test tubes as your teacher directs.
7. Pour the remaining test solution through a filter into a beaker. Using the test solution from the beaker, repeat steps 3–5.

Analysis Which compounds passed through the filter paper? If some did not, explain why. How does the filtration of this activity resemble the activity of the kidney?

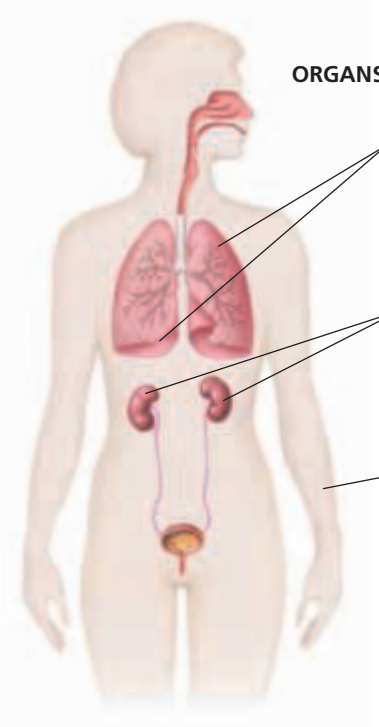


FIGURE 48-19

The lungs, the kidneys, and the skin all function as excretory organs. The main excretory products are carbon dioxide, nitrogen wastes (urea), salts, and water.

THE EXCRETORY ORGANS

Although the kidneys, lungs, and skin belong to different organ systems, they all have a common function: waste excretion.

The kidneys are the primary excretory organs of the body. They play a vital role in maintaining the homeostasis of body fluids.

The lungs are the primary site of carbon dioxide excretion. The lungs carry out detoxification, altering harmful substances so that they are not poisonous. The lungs are also responsible for the excretion of the volatile substances in onions, garlic, and other spices.

The skin helps the kidneys control the salt composition of the blood. Some salt, water, nitrogen waste and other substances are excreted through perspiration. A person working in extreme heat may lose water through perspiration at the rate of 1 L per hour. This amount of perspiration represents a loss of about 10 to 30 g of salt per day. Both the water and salt must be replenished to maintain normal body functions.

Figure 48-19 summarizes some waste substances and the organ(s) that excrete them. Notice that undigested food is not in the figure. Undigested food is not excreted in the scientific sense; it is eliminated, meaning it is expelled as feces from the body without ever passing through a membrane or being subjected to metabolic processes. The term *excretion* correctly refers to the process during which substances must pass through a membrane to leave the body.

SECTION 3 REVIEW

1. Illustrate and label the major parts of the kidney.
2. Explain how the structure of a nephron relates to its function.
3. Describe three processes carried out in the kidney that help maintain homeostasis.
4. Identify five of the structures through which urine is eliminated.
5. Explain the function of each of the organs involved in excretion.

CRITICAL THINKING

6. **Relating Concepts** Explain why a high concentration of protein in the urine may indicate damaged kidneys.
7. **Recognizing Relationships** Why would there be a decrease in urine output if a person had lost a large amount of blood?
8. **Analyzing Concepts** Given the definition of *excretion,* why do you think the large intestine is not classified as a major excretory organ?

CHAPTER HIGHLIGHTS

SECTION 1 Nutrients

- The human body needs six nutrients—carbohydrates, proteins, lipids, vitamins, minerals, and water—to grow and function.
- Carbohydrates, found in foods such as breads, provide most of the body's energy. The body quickly processes monosaccharides. Cellulose cannot be digested but is needed for fiber.
- Proteins, found in foods such as meats, help the body grow and repair tissues. Essential amino acids must be obtained from foods.
- Lipids, found in foods such as oils, are used to build cell membranes.
- Vitamins act as coenzymes to enhance enzyme function.
- Minerals are inorganic substances used to build red blood cells and bones and for muscle and nerve functions.
- Water helps regulate body temperature and transports nutrients and wastes.

Vocabulary

nutrient (p. 979)
vitamin (p. 982)
mineral (p. 982)
dehydration (p. 984)

SECTION 2 Digestive System

- Mechanical digestion involves the breaking of food into smaller particles. Chemical digestion involves changing the chemical nature of the food substance.
- The mouth, teeth, and tongue initiate mechanical digestion. Chemical digestion of carbohydrates begins in the mouth.
- The esophagus is a passageway through which food passes from the mouth to the stomach by peristalsis.
- The stomach has layers of muscles that churn the food to assist in mechanical digestion. Pepsin in the stomach begins the chemical digestion of proteins.
- Bile assists in the mechanical digestion of lipids. Enzymes secreted by the pancreas complete the digestion of the chyme.
- The digested nutrients are absorbed through the villi of the small intestine.
- The large intestine absorbs water from the undigested mass. The undigested mass is eliminated as feces through the anus.

Vocabulary

digestion (p. 985)
gastrointestinal tract (p. 985)
saliva (p. 986)
pharynx (p. 986)
epiglottis (p. 986)
peristalsis (p. 987)
gastric fluid (p. 988)
ulcer (p. 988)
cardiac sphincter (p. 988)
chyme (p. 988)
pyloric sphincter (p. 988)
gallbladder (p. 989)
villus (p. 990)
colon (p. 991)

SECTION 3 Urinary System

- Excretion is the removal of metabolic wastes from the body.
- The kidneys are the main organs of excretion and of the urinary system.
- Nephrons are the functional units of the kidneys. Through filtration, reabsorption, and secretion, they remove wastes and return nutrients and water to the blood.
- The urine passes through a ureter and is stored in the urinary bladder until it is eliminated through the urethra.
- Urine must be eliminated from the body to remove toxic materials and to maintain homeostasis.
- The lungs and the skin also play an important role in the excretion of wastes.

Vocabulary

excretion (p. 993)
renal cortex (p. 993)
renal medulla (p. 993)
renal pelvis (p. 993)
urea (p. 993)
ammonia (p. 993)
urine (p. 994)
nephron (p. 994)
Bowman's capsule (p. 994)
glomerulus (p. 994)
renal tubule (p. 995)
filtration (p. 995)
reabsorption (p. 996)
secretion (p. 996)
loop of Henle (p. 997)
ureter (p. 997)
urinary bladder (p. 997)
urethra (p. 997)

CHAPTER REVIEW

USING VOCABULARY

1. For each set of terms, choose the one that does not belong, and explain why it does not belong.
   a. *carbohydrate, protein, lipid,* and *mineral*
   b. *pharynx, epiglottis, bolus,* and *esophagus*
   c. *cardiac sphincter, gastric pits, renal medulla,* and *pyloric sphincter*
   d. *absorption, filtration, secretion,* and *reabsorption*
2. Use the following terms in the same sentence: *gallbladder, gastric fluid, pepsin,* and *saliva.*
3. **Word Roots and Origins** The word *protein* is derived from the Greek *proteios,* which means "of prime importance." Using this information, explain why the term *protein* is a good name for the nutrient it describes.

UNDERSTANDING KEY CONCEPTS

4. **Identify** which of the six nutrients needed by the body are organic and which are inorganic.
5. **State** the daily number of servings needed from each food group in the USDA Food Guide pyramid in order to maintain a healthy diet.
6. **Propose** a vegetarian diet that includes all of the nutrients needed by the human body.
7. **Explain** the role of inorganic nutrients in keeping the body healthy.
8. **Name** the nutrient that makes up more than 90 percent of the fluid part of blood.
9. **Name** the nutrient associated with heart disease when it is consumed in high levels.
10. **List** the organs of the digestive system and their functions.
11. **Contrast** the processes involved in mechanical and chemical digestion.
12. **Describe** how the stomach carries out mechanical digestion.
13. **Identify** the source and function of each major digestive enzyme.
14. **Predict** the problems a person might have if his or her small intestine were not functioning properly.
15. **Identify** the function of the large intestine.
16. **Identify** the major parts of the kidney.
17. **Explain** the relationship between Bowman's capsule, the proximal tubule, the loop of Henle, and the distal tubule.
18. **Identify** the processes that occur in the nephron that maintain homeostasis.
19. **Summarize** how urine is stored and eliminated from the body.
20. **Describe** the function of two organs other than kidneys that are also involved in excretion.
21. **CONCEPT MAPPING** Use the following terms to create a concept map that shows the process of digestion: *bile, chemical digestion, chyme, digestion, liver, mechanical digestion, molar, pancreas, saliva, small intestine,* and *stomach.*

CRITICAL THINKING

22. **Applying Information** In some countries, many children suffer from a type of malnutrition called *kwashiorkor.* They have swollen stomachs and become increasingly thin until they die. Even when given rice and water, these children still die. What type of nutritional deficiency might these children have?
23. **Analyzing Concepts** Why is it important that the large intestine reabsorb water and not eliminate it?
24. **Predicting Patterns** The loop of Henle functions to conserve water by aiding in reabsorption. Its length varies among mammal species. Would you expect the loop of Henle of an animal such as the beaver, which lives in a watery environment, to be longer or shorter than that found in humans? Explain your answer.
25. **Recognizing Relationships** Look at the pictures of the teeth of different animals. What can you tell about the human diet by comparing the teeth of humans with those of other animals shown here?

Standardized Test Preparation

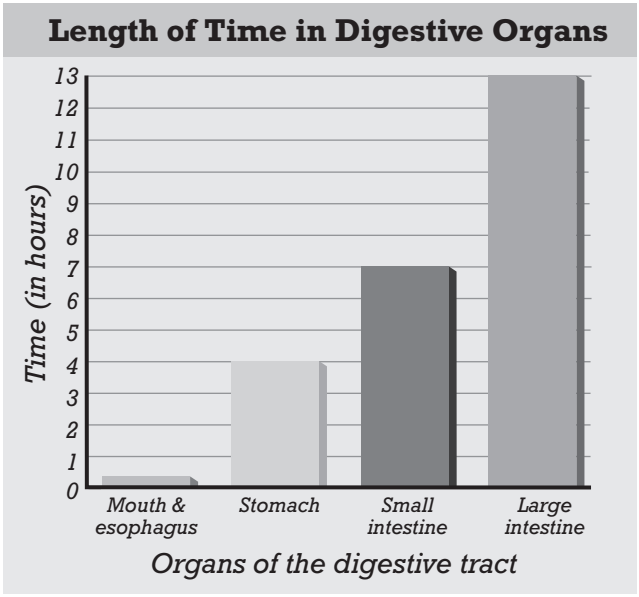
DIRECTIONS: Choose the letter of the answer choice that best answers the question.

1. What is the primary function of carbohydrates?
- **A.** to aid in digestion
- **B.** to break down molecules
- **C.** to regulate the flow of chyme
- **D.** to supply the body with energy

2. How can dehydration best be prevented?
- **F.** by perspiring
- **G.** by inhaling air
- **H.** by drinking water
- **J.** by not drinking water

3. Why is the epiglottis important?
- **A.** It regulates the flow of chyme.
- **B.** It prevents food from going down the trachea.
- **C.** It separates the pharynx from the nasal cavity.
- **D.** It is the passage through which food travels to the stomach.

INTERPRETING GRAPHICS: The graph below shows the approximate length of time food spends in each digestive organ. Use the graph below to answer the following question.

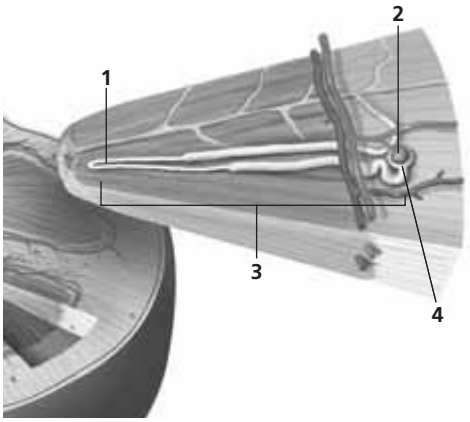


4. Bile breaks up large fat droplets. Approximately how long is the food in the digestive tract before it comes into contact with bile?
- **F.** 4 hours
- **G.** 7 hours
- **H.** 11 hours
- **J.** 13 hours

DIRECTIONS: Complete the following analogy.

5. lung : alveolus :: kidney :
- **A.** ureter
- **B.** nephron
- **C.** microvillus
- **D.** glomerulus

INTERPRETING GRAPHICS: The figure below shows a cross section of a kidney. Use the figure to answer the question that follows.



6. Which part of the model represents the loop of Henle?
- **F.** 1
- **G.** 2
- **H.** 3
- **J.** 4

SHORT RESPONSE

The liver and pancreas are accessory organs of the gastrointestinal tract.

In what two ways do the liver and pancreas differ from other digestive organs?

EXTENDED RESPONSE

When a person's kidneys stop functioning, urea builds up in the blood. For the urea to be removed, the person must be attached to a mechanical kidney, also called a dialysis machine.

Part A What would happen if the person did not have the urea removed from his or her blood?

Part B Using your understanding of how a normal kidney functions, suggest a design for the major components of a dialysis machine.

Test TIP Study of the digestive and urinary systems is often aided by drawing flowcharts of the processes described.

Modeling Human Digestion

OBJECTIVES

- Test a model of digestion in the human stomach.

PROCESS SKILLS

- modeling
- hypothesizing
- observing
- predicting
- inferring

MATERIALS

- safety goggles
- lab apron
- glass-marking pencil
- 5 test tubes with stoppers
- test-tube rack
- scalpel
- cooked egg white
- balance
- 10 mL graduated cylinder
- 1% pepsin solution
- 0.2% hydrochloric acid
- 1% sodium bicarbonate
- distilled water
- red and blue litmus paper
- lined paper
- disposable gloves

Background

1. How is food changed from the chunks you chew with your teeth to the chyme absorbed in your small intestine?
2. What type of organic compound does the enzyme pepsin digest?

PART A Setting Up

1. Label five test tubes 1, 2, 3, 4, and 5, and place them in a test-tube rack.
2. CAUTION **Always cut in a direction away from your body.** Use a scalpel to cut a firm, cooked egg white into fine pieces.
3. Using the balance, measure and place equal amounts (about 6 g) of the fine egg white sample into each test tube, as shown in the illustration above.
4. CAUTION **Put on safety goggles and a lab apron. If you get hydrochloric acid solution on your skin or clothes, wash it off at the sink while calling to your teacher. If you get any solutions in this investigation in your eyes, immediately flush them out at the eyewash station while calling to your teacher.** Use a clean graduated cylinder to add the solutions listed below to the test tubes. Rinse the cylinder between additions so that you do not contaminate the samples.
   - test tube 1—10 mL of water
   - test tube 2—10 mL of pepsin solution
   - test tube 3—10 mL of hydrochloric acid
   - test tube 4—5 mL of pepsin solution and 5 mL of sodium bicarbonate solution
   - test tube 5—5 mL of pepsin and 5 mL of hydrochloric acid

DEGREE OF DIGESTION OF EGG WHITE UNDER VARYING CONDITIONS

Test-tube number	Contents	pH	Degree of digestion
1	egg white 10 mL water		
2	egg white 10 mL 1% pepsin solution		
3	egg white 10 mL 0.2% hydrochloric acid solution		
4	egg white 5 mL 1% pepsin solution 5 mL 1% sodium bicarbonate solution		
5	egg white 5 mL 1% pepsin solution 5 mL 0.2% hydrochloric acid solution		

5. Stopper and gently shake each test tube.
6. In your lab report, make a data table like the one shown above.
7. In your lab report, write a hypothesis which predicts which test tube will show the most digestion after 48 hours. Explain your reasoning.
8. Label your test-tube rack with your initials. Store the test-tube rack for 48 hours at room temperature. Leave a note on the rack cautioning others not to spill the acids or bases.
9.  Clean up your lab materials, and wash your hands before leaving the lab.

PART B Recording the Results

10. After 48 hours, measure the pH of each solution with red and blue litmus paper. Record your results in the data table you created in your lab report.
11. Look for the egg white in each test tube. In your data table, describe the degree to which the egg white has broken down and dissolved in each test tube.
12.  Clean up your lab materials, and wash your hands before leaving the lab.

Analysis and Conclusions

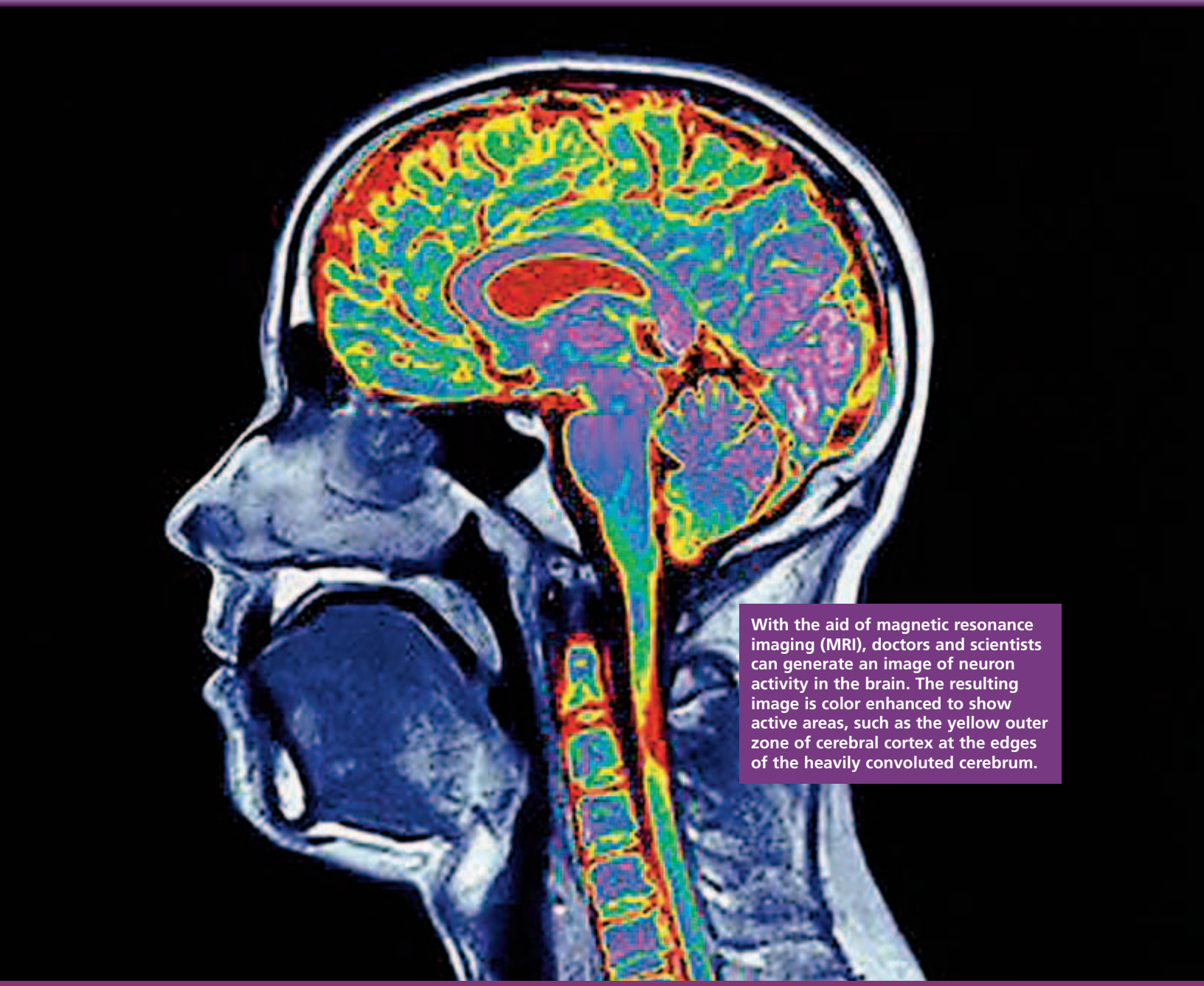
1. What conditions caused the greatest digestion of cooked egg white?
2. Which test tube best modeled the chemical composition in the human stomach?
3. What information do test tubes 1, 2, and 3 give you? What do they control?
4. Compare test tubes 4 and 5. What can you conclude about the effects of the chemical environment on the activity of pepsin?
5. List some other foods that pepsin is likely to digest.
6. Do you think that pepsin would digest butter? Explain your answer.

Further Inquiry

Design an experiment to test the digestion of a food containing carbohydrates, such as a potato or an apple.

CHAPTER 49

Nervous System and Sense Organs



With the aid of magnetic resonance imaging (MRI), doctors and scientists can generate an image of neuron activity in the brain. The resulting image is color enhanced to show active areas, such as the yellow outer zone of cerebral cortex at the edges of the heavily convoluted cerebrum.

For project ideas from *Scientific American,* visit go.hrw.com and type in the keyword **HM6SAM**.

SECTION 1

NEURONS AND NERVE IMPULSES

*The **nervous system,** a complex network of cells that communicate with one another, controls mental and physical activities and maintains homeostasis. The ability of the nervous system to monitor and respond to the environment, both external and internal, depends on the transmission of signals within a neuron and from a neuron to another cell.*

OBJECTIVES

- **Describe** the structure of a neuron.
- **Summarize** the electrical and chemical conditions that characterize a resting potential.
- **Outline** the electrical and chemical changes that occur during an action potential.
- **Explain** the role of neurotransmitters in transmitting a signal across a synapse.

VOCABULARY

nervous system
neuron
dendrite
axon
action potential
axon terminal
myelin sheath
synapse
neurotransmitter
membrane potential
resting potential
refractory period

NEURON STRUCTURE

A **neuron** is a nerve cell. The nucleus of a neuron and most of its organelles are located in the *cell body*. Extending from the cell body in different directions are membrane-covered extensions of the cell called **dendrites.** Dendrites receive information from other neurons or other cells and carry the information toward the cell body. Another cell extension, the **axon,** is a long, membrane-bound projection that transmits information away from the cell body in the form of electrical signals called **action potentials.** A neuron may have a single axon or branching axons that contact several other cells. The end of an axon is called the **axon terminal.** It may contact and communicate with a muscle cell, a gland cell, or another neuron.

The axons of many neurons are covered with a lipid layer known as the **myelin** (MIE-uh-lin) **sheath.** The myelin sheath insulates the axon much as a rubber coating insulates an electrical cord. The myelin sheath speeds up transmission of action potentials along the axon. In neurons that are not part of the brain or spinal cord, cells called *Schwann cells* surround the axon and produce myelin. Gaps in the myelin sheath along the length of the axon are called *nodes of Ranvier* (RAHN-vee-ay).

Neurons communicate with other neurons and other cells at special junctions called **synapses.** Neurons usually do not touch each other or other cells. Instead, a small gap, called a *synaptic cleft,* is present between the axon terminal and the receiving cell. At a synapse, the transmitting neuron is called a *presynaptic neuron*. The receiving cell is called a *postsynaptic cell*.

Electrical activity in the neuron usually causes the release of chemicals called **neurotransmitters** into the synaptic cleft. Often, neurotransmitters cause electrical activity in another neuron. Thus, the signaling activity of the nervous system is made up of electrical activity within neurons and chemical flow between neurons.

Word Roots and Origins

synapse

from the Greek *synaptein,* meaning "to fasten together"

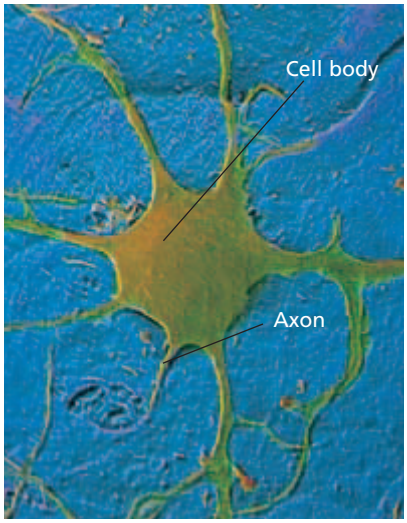


FIGURE 49-1

Neurons transmit information throughout the body via chemical and electrical signals. This stellate neuron is named for its starlike shape. (SEM, 26,000×)

FIGURE 49-2

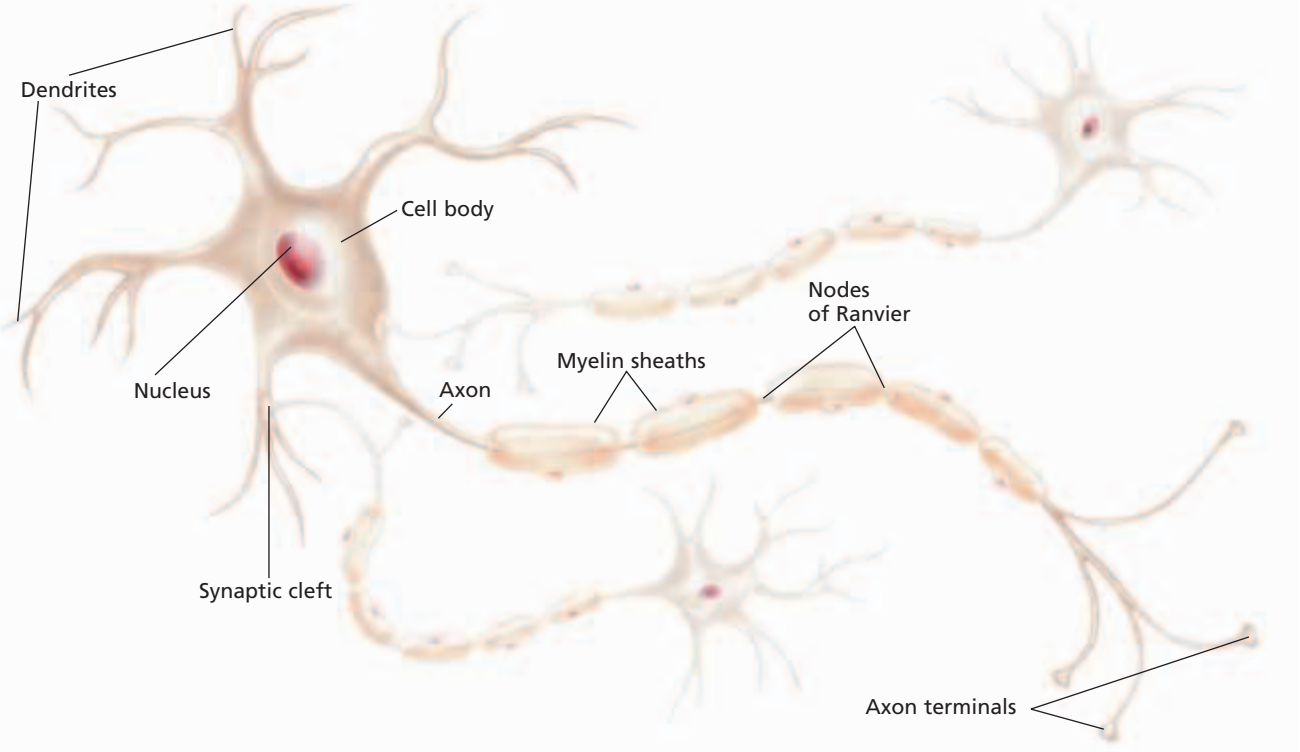
Neurons consist of dendrites, which bring signals toward the cell body, and axons, which carry signals away from the cell body. At the tip of the axon, the axon terminal makes contact with a target cell, such as a muscle cell, gland cell, or other neuron, at a synapse.

NERVE IMPULSES

About 200 years ago, scientists removed muscle from dead animals and passed electric current through it. The scientists discovered that the current caused the muscle to contract just as it did in life. Since then, scientists have learned a great deal about neuron structure, shown in Figure 49-1 and Figure 49-2, and how neurons affect other parts of the body, such as muscles. Scientists have also learned that neuron function is dependent on electrical activity.

All cells, including neurons, have an electrical charge inside the cell that is different from the electrical charge outside the cell. A difference in the electrical charge across the cell membrane is called a **membrane potential.** Membrane potentials are produced by the movement of ions across the cell membrane. The movement of ions depends on the ability of the ions to diffuse through the cell membrane, the concentrations of ions inside and outside the cell, and the electrical charge of the ions. As with batteries, membrane potential is expressed as voltage.

Ions diffuse across a neuron's cell membrane by passing through proteins that act as ion channels. Each type of channel allows only specific ions to pass. Certain channels are voltage gated—that is, whether these channels are open or closed depends on the membrane potential. Even a small change in membrane potential can affect the permeability of the cell membrane to certain ions. As ions move into or out of the neuron, they, in turn, affect the membrane potential.



Resting Potential

A neuron is at rest when it is not receiving or sending a signal. In a neuron at rest, the concentration of negatively charged proteins and positively charged potassium ions, K^+, is greater inside the cell than outside. In contrast, the concentration of sodium ions, Na^+, is greater outside the cell than inside. The concentrations of Na^+ and K^+ ions are partly due to the action of the *sodium-potassium pump,* which actively moves Na^+ out of cells while moving K^+ in.

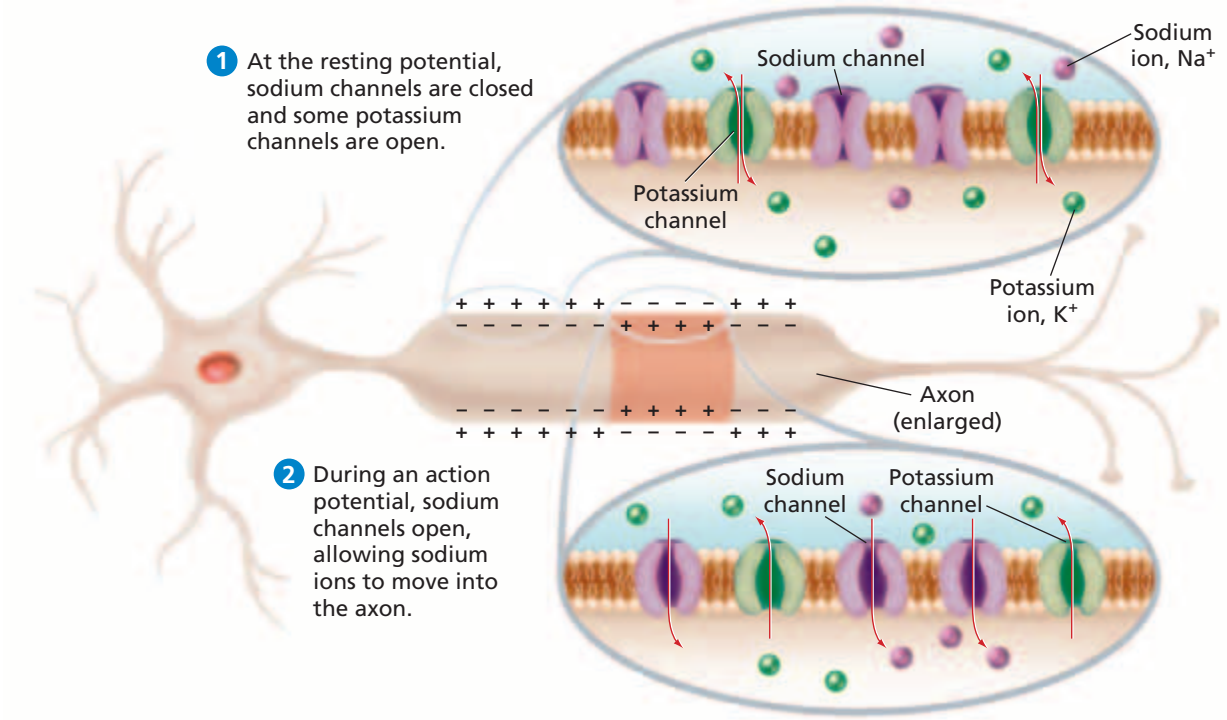
The cell membrane is permeable to some ions but not to others. Na^+ ions do not readily diffuse through the membrane. So, they accumulate outside the cell. Negatively charged proteins remain inside the cell because they are too large to exit. K^+ ions, however, pass freely through the membrane and tend to diffuse out of the cell. This exit of positively charged K^+ ions and the retention of negatively charged proteins eventually cause the interior of the neuron to become negatively charged with respect to the exterior. This charge difference is called the **resting potential** of the membrane. In most neurons, the resting potential is about –70 millivolts.

Action Potential

When a dendrite or cell body is stimulated, the permeability of the neuron's membrane changes suddenly. At the point of stimulation, the cell membrane becomes permeable to Na^+ ions. The rush of Na^+ ions into the cell opens voltage-gated channels in the membrane that allow even more Na^+ ions into the neuron. As a result, the interior of the neuron's cell body becomes more positively charged than the exterior. This reversal of polarity across the membrane begins an action potential, shown in Figure 49-3. The action potential starts where the cell body joins the axon.

FIGURE 49-3

1 At resting potential, a neuron's interior is negatively charged with respect to the extracellular fluid around the cell. 2 The passage of an action potential over the membrane of the axon reverses this polarity, and the interior of the axon becomes more positively charged for a brief time.



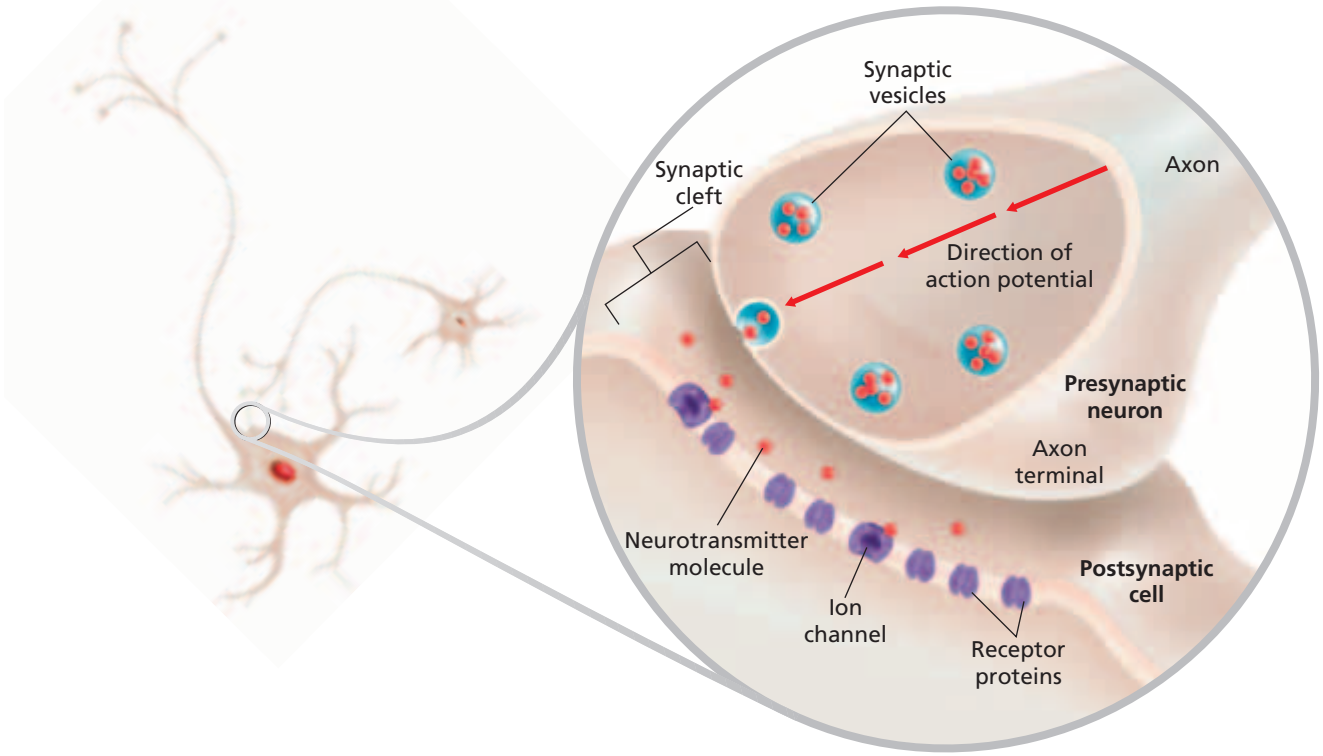
Voltage-gated channels exist along the length of the axon. As a neuron is stimulated and the first small segment of the axon becomes more positively charged, the change in voltage opens channels in the next segment of axon membrane. As before, Na^+ ions enter, driving the voltage in a positive direction and opening channels in the next segment of axon. In this way, positive charges pass down the axon membrane like dominoes falling in a row. Axon potentials usually travel in one direction only—away from the cell body, where they begin, and toward the axon terminal.

Shortly after they open, the voltage-gated channels for Na^+ ions close. Then, voltage-gated channels for K^+ ions open. The result is an abrupt outward flow of K^+ ions. The exterior of the cell again becomes positively charged with respect to the interior of the cell. This change in charge signals the end of the action potential. However, the neuron cannot generate another action potential until resting potential is restored. This period, during which the neuron cannot send a signal, is called the **refractory period.**

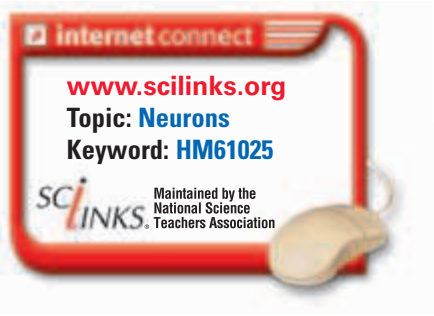
After the action potential, the concentration of Na^+ ions inside the cell is higher than when the cell is at rest, and the concentration of K^+ ions inside the cell is lower. Ion channels and the sodium-potassium pump help reestablish the resting concentrations of Na^+ ions and K^+ ions. Na^+ ions are moved out across the cell membrane, while K^+ ions are moved in across the membrane. Once the original ion concentrations are restored, the neuron is ready for the next action potential. Restoration of resting potential comes at a price. Neurons need a continuous supply of ATP to keep the sodium-potassium pump operating. In fact, neurons consume a great deal of the body's daily energy.

FIGURE 49-4

The presynaptic neuron releases neurotransmitter molecules into the synaptic cleft. These molecules bind to receptor proteins in the postsynaptic membrane, opening ion channels. Positive ions entering through these channels cause the membrane potential of the postsynaptic neuron to become more positive. If the membrane potential becomes sufficiently positive, the postsynaptic neuron will generate an action potential, continuing the signal.



COMMUNICATION BETWEEN NEURONS



A neuron can communicate with another cell across the synaptic cleft only after an action potential reaches the axon terminal. Vesicles that contain neurotransmitters are stored in the axon terminal. When an action potential reaches the axon terminal of the presynaptic neuron, the vesicles fuse with the presynaptic membrane. This fusion releases neurotransmitters into the synaptic cleft. The neurotransmitters quickly diffuse across the synaptic cleft and bind to receptor proteins embedded in the membrane of the postsynaptic cell. This process is shown in Figure 49-4 on the previous page.

The interaction of neurotransmitter and receptor molecules changes the permeability of the postsynaptic membrane by affecting chemically gated ion channels. The opening of Na^+ channels in the postsynaptic membrane causes the membrane potential of the neuron to become more positive. If this change in membrane potential is great enough, a new action potential is generated in the receiving neuron. So, the electrical signal continues. However, the release of neurotransmitters may cause the opening of too few Na^+ channels in the postsynaptic membrane or may cause the opening of other channels that allow negatively charged ions into the cell. As a result, the membrane potential of the receiving neuron will not become positive enough or may become more negative. No action potential will be generated in the receiving neuron, and the nervous signal will terminate.

Neurotransmitters do not remain in the synaptic cleft indefinitely. Instead, most neurotransmitters are cleared from the synaptic cleft shortly after they are released. Many presynaptic neurons reabsorb neurotransmitters and use them again. At other synapses, neurotransmitters are broken down by enzymes. The reabsorption or breakdown of neurotransmitters ensures that their effect on postsynaptic cells is not prolonged.

SECTION 1 REVIEW

1. Describe the structure of a neuron.
2. Define the resting potential of a neuron membrane, and give its typical voltage.
3. What is an action potential?
4. How does a nerve signal transmit from one neuron to the next?
5. Why does the nervous system consume a large amount of energy?
6. Describe two possible effects that neurotransmitters may have at a synapse.

CRITICAL THINKING

7. **Applying Information** What functional advantage does a neuron with several dendrites have over a neuron with only one dendrite?
8. **Analyzing Models** Examine the model for synapse function in Figure 49-4. Predict what would happen if excess neurotransmitters were not removed from the synaptic cleft.
9. **Calculating Information** What is the difference in voltage between a 9V battery and the resting potential of a single human neuron, −70mV?

SECTION 2

OBJECTIVES

- **Identify** the two main parts of the central nervous system.
- **Summarize** the functions of the major parts of the brain.
- **Describe** the roles of the sensory and motor divisions of the peripheral nervous system.
- **Distinguish** between the somatic and autonomic nervous systems.

VOCABULARY

central nervous system
peripheral nervous system
cerebrum
cerebral cortex
brain stem
thalamus
hypothalamus
medulla oblongata
cerebellum
nerve
sensory receptor
motor neuron
interneuron
somatic nervous system
reflex
autonomic nervous system

STRUCTURE OF THE NERVOUS SYSTEM

The nervous system is a highly organized network of cells that detect changes, communicate with each other, and control physical activity, brain function, and metabolic processes. The nervous system includes two major divisions: the central nervous system and the peripheral nervous system.

ORGANIZATION OF THE NERVOUS SYSTEM

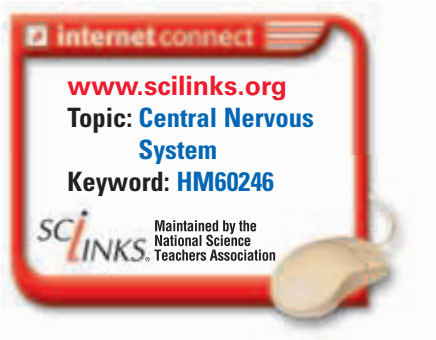
As shown in Figure 49-5, the brain and spinal cord make up the **central nervous system.** The *brain* is the control center of the nervous system, and the *spinal cord* carries nerve signals between the body and the brain. The brain interprets nerve signals from the body and sends response signals that pass through the spinal cord to the body.

The **peripheral nervous system** consists of neurons that have cell bodies that are not included in the brain and spinal cord. Some peripheral neurons collect information from the body and transmit it toward the central nervous system. These neurons are called *afferent neurons.* Other peripheral neurons transmit information away from the central nervous system. These neurons are known as *efferent neurons.*

BRAIN

The brain oversees daily operations of the body and interprets vast amounts of information. The average adult human brain weighs 1.4 kg (about 3.1 lb), or about 2 percent of total body weight. Despite its relatively small mass, the brain contains about 100 billion neurons. Functioning as a unit, these neurons make up one of the most complex structures on Earth. Scientists have learned a great deal about the brain, but because the brain is so complex, much remains to be discovered.

The brain is responsible for many of the qualities that make each person unique—thoughts, feelings, memories, talents, and emotions. However, much of the brain is dedicated to running the body and maintaining homeostasis.



Cerebrum

Through painstaking study, scientists have established how and where various functions are localized in the brain. The largest portion of the human brain is the **cerebrum** (SER-ee-bruhm). The cerebrum is easily identified by its highly folded outer layer. It is composed of two *cerebral hemispheres,* as shown in Figure 49-6. The two cerebral hemispheres are connected by the *corpus callosum* (KAWR-puhs kuh-LOH-suhm). The corpus callosum is a band of axons that lies deep in the central groove that separates the right hemisphere from the left hemisphere. Other grooves separate each hemisphere into four lobes: the frontal, parietal (puh-RIE-uh-tuhl), temporal, and occipital (ahk-SIP-i-tuhl) lobes.

The folded outer layer of the cerebrum is the **cerebral cortex,** which contains 10 to 20 percent of the brain's total number of neurons. The many folds allow the surface area of the cortex to fit within the skull. As shown in Figure 49-6, different parts of the cerebral cortex control information and sensations from the body and motor responses. For example, the area of the cortex that interprets touch information lies in the parietal lobe.

Some functions are not symmetrically localized in the cerebrum. Brain centers involved in speech and language reside primarily in the left hemisphere. Brain centers involved in processing spatial information and certain kinds of reasoning are located primarily in the right hemisphere. These functions are located variably in left-handed people.

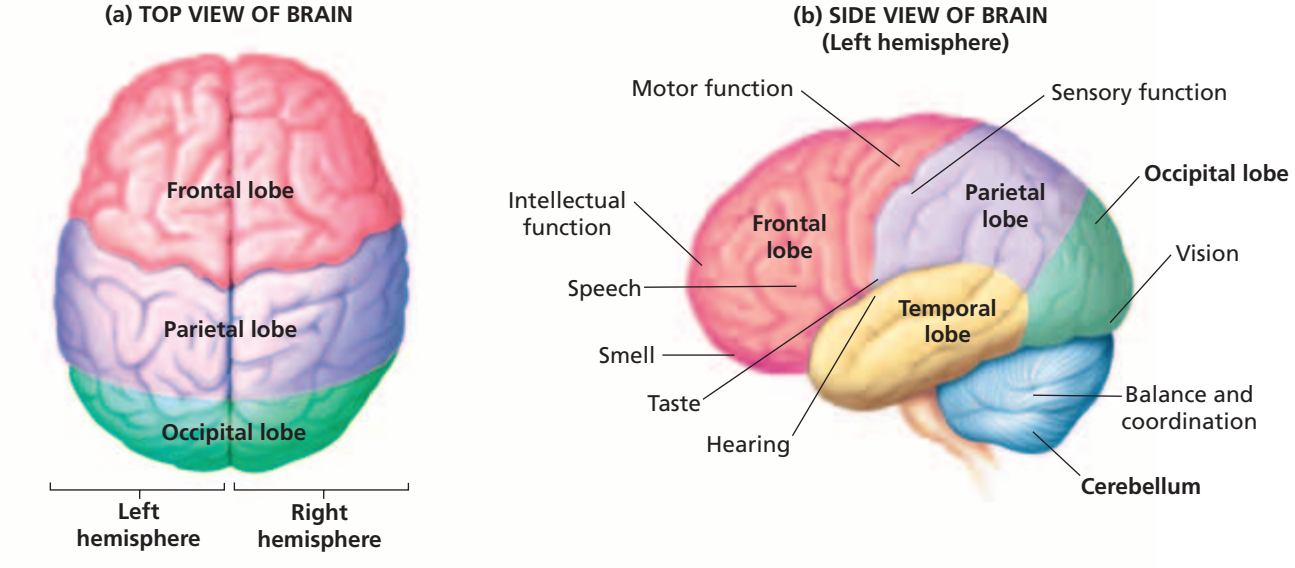
Below the folded surface of the cerebral cortex lies the *white matter,* which is composed of myelinated axons. These axons link specific regions of the cortex with each other and with other neural centers. Because of the crossover of these axons as they enter the brain from the body, many impulses originating in the right half of the body are processed in the left half of the brain, and vice versa.

FIGURE 49-5

The central nervous system includes the brain and spinal cord, shown in orange. The peripheral nervous system, shown in violet, includes all other nervous tissue in the body.

FIGURE 49-6

(a) A view of the top of the brain shows the left and right cerebral hemispheres. (b) Each cerebral hemisphere of the brain has four lobes. Control centers for various functions are located in different areas of the brain.



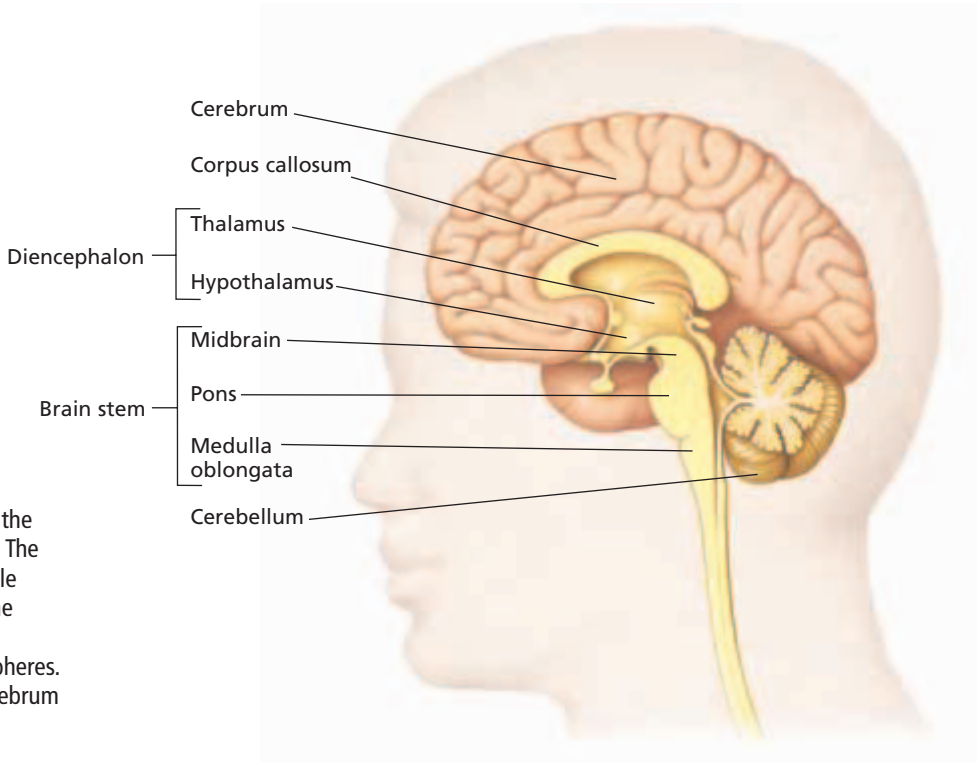


FIGURE 49-7

A side view through the center of the brain shows the right hemisphere. The convoluted cerebral cortex is visible along the front, rear, and top of the brain, where it folds into the deep groove separating the two hemispheres. The structures lying below the cerebrum are shown in cross section.

Diencephalon

The **brain stem,** shown in Figure 49-7, lies below the cerebrum and links it to the spinal cord. The *diencephalon* (DIE-uhn-SEF-uh-lahn) lies between the cerebrum and the brain stem and contains relay centers for information entering and exiting the brain. The uppermost relay center is the **thalamus** (THAL-uh-muhs). It directs most incoming sensory signals to the proper region of the cerebral cortex. The **hypothalamus** helps maintain homeostasis. It also directly and indirectly controls much of the body's hormone production.

A set of brain structures called the *limbic system* includes parts of the thalamus and hypothalamus, centers in the temporal lobes, and some deeper parts of the cerebral cortex. The limbic system helps govern emotion, memory, and motivation.

Brain Stem

Below the diencephalon, the brain stem narrows. This region has three main divisions: midbrain, pons, and medulla oblongata. The *midbrain* relays visual and auditory information. The *pons* relays communications between the cerebral hemispheres and the cerebellum. The **medulla oblongata** (mi-DUHL-uh AHB-lahn-GAHT-uh) serves as both a relay center and a control center for heart rate, respiration rate, and other homeostatic activities.

Lying throughout the brain stem is a diffuse network of neurons called the *reticular formation*. The reticular formation helps control respiration and circulation and helps separate signals that demand attention from those that are unimportant. Learning can modify some functions of the reticular formation. For example, a person can learn to sleep through the noise of a radio but awaken at the sound of a doorbell.

Cerebellum

Below and behind the cerebral hemispheres lies the **cerebellum** (SER-uh-BEL-uhm), which helps coordinate muscle action. The surface of the cerebellum is highly folded. The cerebellum receives sensory impulses from muscles, tendons, joints, eyes, and ears, as well as input from other brain centers. It processes information about body position and controls posture by keeping skeletal muscles in a constant state of partial contraction. The cerebellum coordinates rapid and ongoing movements. It acts with the brain stem and with the cerebral cortex to coordinate skeletal muscles.

SPINAL CORD

The spinal cord, shown in Figure 49-8, is a column of nervous tissue that starts at the medulla oblongata. The spinal cord runs down through the vertebral column, carrying nerve signals back and forth like a superhighway. The spinal cord has an outer sheath of white matter. The rigid inner core is made up of *gray matter,* which is composed of dendrites, unmyelinated axons, and the cell bodies of neurons.

PERIPHERAL NERVOUS SYSTEM

The central nervous system constantly interacts with the peripheral nervous system via 12 pairs of cranial nerves that connect the brain with the head and neck and 31 pairs of spinal nerves that connect the central nervous system with the rest of the body. **Nerves** are the bundled axons and dendrites of neurons found outside the central nervous system. Each spinal nerve has a *dorsal root* and a *ventral root*. The dorsal roots carry signals into the central nervous system from various **sensory receptors.** These neurons are specialized to detect a stimulus such as light, pressure, or heat. The ventral roots contain the axons of **motor neurons,** which carry information from the central nervous system to muscles and glands. The spinal cord has **interneurons,** which relay information between other neurons.

SENSORY DIVISION

The sensory division of the peripheral nervous system contains sensory receptors and the interneurons that connect them to the central nervous system. Sensory receptors receive information from the body's external and internal environments. Spinal and cranial nerves send sensory information to the central nervous system.

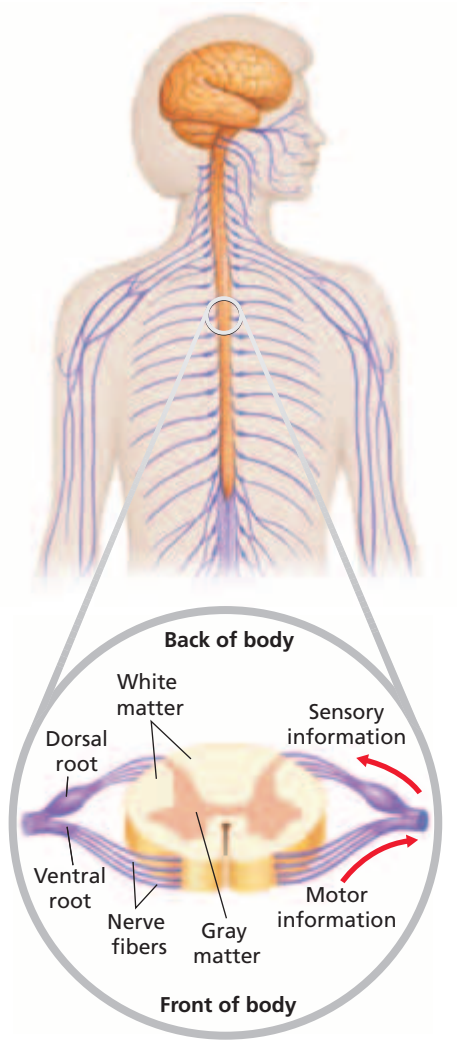


FIGURE 49-8

The spinal cord, shown in cross section, carries information toward and away from the brain. Sensory information from the body enters the spinal cord through the dorsal roots. Instructions to the body's muscles and many glands come from motor neurons that exit the spinal cord through the ventral roots.

Word Roots and Origins

somatic

from the Greek *somatikos,* meaning "of the body"

MOTOR DIVISION

The motor division of the peripheral nervous system lets the body react to sensory information. The motor division is made up of two independent systems—the somatic nervous system and the autonomic nervous system.

Somatic Nervous System

Within the peripheral nervous system's motor division, the **somatic nervous system** contains motor neurons that control the movement of skeletal muscles. The somatic system is voluntary—that is, skeletal muscles can be moved at will. The somatic system can also operate without conscious control, as it does when helping to maintain balance.

The peripheral nervous system relays signals in **reflexes,** which are involuntary and often self-protective movements. The patellar reflex is shown in Figure 49-9. A tap on the tendon below the patella stimulates sensory receptors in the quadriceps muscle. The receptors send impulses to the spinal cord. These impulses activate motor neurons that lead back to the quadriceps. As a result, the quadriceps contracts. The impulses also activate interneurons that have an inhibitory, or calming, effect on the motor neurons of the hamstring muscles in the rear thigh. The contraction of the quadriceps coupled with the relaxation of the hamstrings extends the lower leg. This type of reflex is a *spinal reflex*. It involves only neurons in the body and bypasses the brain.

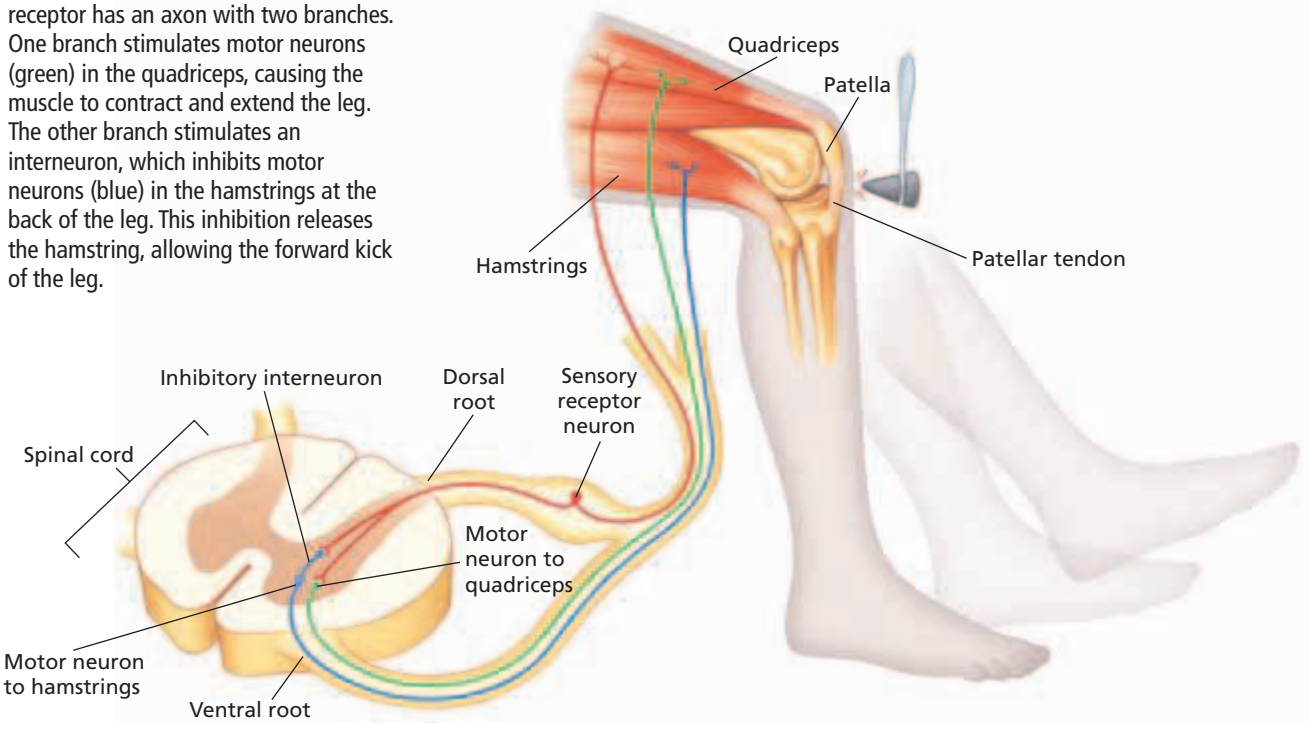


FIGURE 49-9

In the patellar, or knee-jerk, reflex, a sensory receptor (red) that detects stretch in the quadriceps muscle sends signals to the spinal cord. The sensory receptor has an axon with two branches. One branch stimulates motor neurons (green) in the quadriceps, causing the muscle to contract and extend the leg. The other branch stimulates an interneuron, which inhibits motor neurons (blue) in the hamstrings at the back of the leg. This inhibition releases the hamstring, allowing the forward kick of the leg.

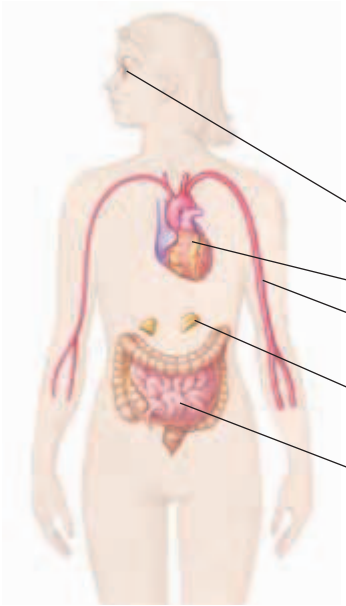


TABLE 49-1 *Effects of Sympathetic and Parasympathetic Divisions on Various Organs*

Organ	Effect of sympathetic division	Effect of parasympathetic division
Eyes	Pupils dilate	Pupils constrict
Heart	Heart rate increases	Heart rate decreases
Blood vessels	Blood vessels to skeletal muscles dilate	Little or no effect
Adrenal glands	Glands secrete hormones	Glands inactive
Intestines	Gastric secretions decrease	Gastric secretions increase

Autonomic Nervous System

Also within the peripheral nervous system's motor division is the **autonomic nervous system.** This system controls internal body conditions by regulating smooth muscles in blood vessels and organs. The autonomic nervous system controls respiration, heartbeat, digestion, and other aspects of homeostasis.

The autonomic system has two subdivisions—the *sympathetic division* and the *parasympathetic division*. These subdivisions stimulate or inhibit body systems, as shown in Table 49-1. Physical or emotional stress can activate the sympathetic division. For example, the threat of a physical attack causes the sympathetic division to redirect blood away from the digestive organs and toward the heart and skeletal muscles. The parasympathetic division controls the internal environment during routine conditions. After a threat has passed, the parasympathetic division signals organs to resume normal activity. Blood flow to the heart and skeletal muscles decreases. Under normal conditions, both systems are usually activated to some degree.

SECTION 2 REVIEW

1. Name the two main organs of the central nervous system.
2. Draw a cross section of the human brain, and label the structures and functions of the cerebrum, diencephalon, brain stem, and cerebellum.
3. Name two divisions of the peripheral nervous system, and describe their roles.
4. How do the somatic nervous system and the autonomic nervous system differ?
5. Describe the two divisions of the autonomic nervous system.

CRITICAL THINKING

6. **Applying Information** One division of the autonomic nervous system increases energy use, and the other division conserves energy. Which division does each? Explain your answer.
7. **Analyzing Models** Examine the patellar reflex shown in Figure 49-9, and determine what would happen if the hamstring neuron were damaged.
8. **Making Inferences** Strokes damage neurons in the brain. How can a doctor tell which areas of the brain have been affected by a stroke?

SECTION 3

OBJECTIVES

- **List** the stimuli to which each of the five types of sensory receptors respond.
- **Identify** the parts of the ear responsible for hearing and for maintaining balance.
- **Describe** the structure of the eye and the roles of rods and cones in vision.
- **Discuss** how taste and smell are detected.
- **Compare** the detection of touch, temperature, and pain.

VOCABULARY

sense organ
auditory canal
tympanic membrane
Eustachian tube
cochlea
semicircular canal
retina
cornea
pupil
iris
lens
rod
cone
taste bud
papilla
olfactory receptor

SENSORY SYSTEMS

Humans are affected by both internal and external stimuli. Humans are able to distinguish among the many different types of stimuli by means of a highly developed system of organs. Sensory systems integrate the functions of the peripheral nervous system and the central nervous system to respond to stimuli.

PERCEPTION OF STIMULI

To survive, organisms must detect changes in the environment and react appropriately to the changes. To detect changes in the environment, humans and other organisms have highly developed **sense organs**—eyes, ears, nose, mouth, and skin—that receive stimuli. The sensory division of the peripheral nervous system gathers information about the body's internal and external environment.

Receptors and Sense Organs

A sensory receptor is a neuron that detects stimuli. There are many kinds of sensory receptors. These receptors can be categorized based on the type of stimuli to which they respond.

- *Mechanoreceptors* respond to movement, pressure, and tension.
- *Photoreceptors* respond to variations in light.
- *Chemoreceptors* respond to chemicals.
- *Thermoreceptors* respond to changes in temperature.
- *Pain receptors* respond to tissue damage.

Sensory receptors are found in higher concentrations in the sense organs than in other parts of the body. When the sensory receptors of a particular sense organ receive appropriate stimulation, they convert the stimulus into electrical signals, or action potentials. These electrical signals are sent to specific regions of the brain. The action potentials generated by the different sense organs are electrically similar. So, how can a person know if the stimulation is a blue sky or a loud noise? The regions of the brain where the action potentials are interpreted vary according to the type of stimulus.

The brain has a specific region for each sense. Thus, signals received by the vision region of the occipital lobe are interpreted by the brain as images, even if the actual stimulus was something else. For example, a blow to the eye makes a person "see stars." The pressure of the blow stimulates visual neurons. The brain interprets this pressure as an image.

HEARING AND BALANCE

The ear performs two main functions: detecting sound and maintaining balance. The fleshy structure of the external ear directs sound vibrations into the ear. As Figure 49-10 shows, the **auditory canal** connects the external ear with the **tympanic** (tim-PAN-ik) **membrane,** or *eardrum*. Vibrations in the air of the auditory canal cause the tympanic membrane to vibrate. Air pressure in the chamber beyond the tympanic membrane, the middle ear, is regulated by the amount of air passing through the Eustachian tube to the middle ear. The **Eustachian** (yoo-STAY-kee-uhn) **tube** is an opening to the throat that equalizes the pressure on both sides of the tympanic membrane during a sudden change in atmospheric pressure, such as occurs when an airplane takes off or lands.

The vibrating tympanic membrane sets in motion three small bones of the middle ear: the hammer, the anvil, and the stirrup. The stirrup transfers vibrations to a membrane called the *oval window.* The oval window separates the middle ear from the inner ear. The inner ear contains the **cochlea** (KAHK-lee-uh), a coiled tube consisting of three fluid-filled chambers that are separated by membranes. The middle chamber contains the *organ of Corti,* which is the organ of hearing. The organ of Corti rests on the bottom membrane in the cochlea and contains mechanoreceptors known as *hair cells*. Vibrations of fluid in the cochlea move the bottom membrane and cause the hair cells to bend against a second membrane, which covers the hair cells. The bending of hair cells activates ion channels. The resulting change in the electric potential of the hair cells causes the release of neurotransmitters. The neurotransmitters stimulate neurons in the auditory nerve. Action potentials are sent to the auditory region of the brain stem, then to the thalamus, and finally to the auditory cortex, which interprets sound.

Word Roots and Origins

tympanic

from the Greek *tympanon,* meaning "drum"

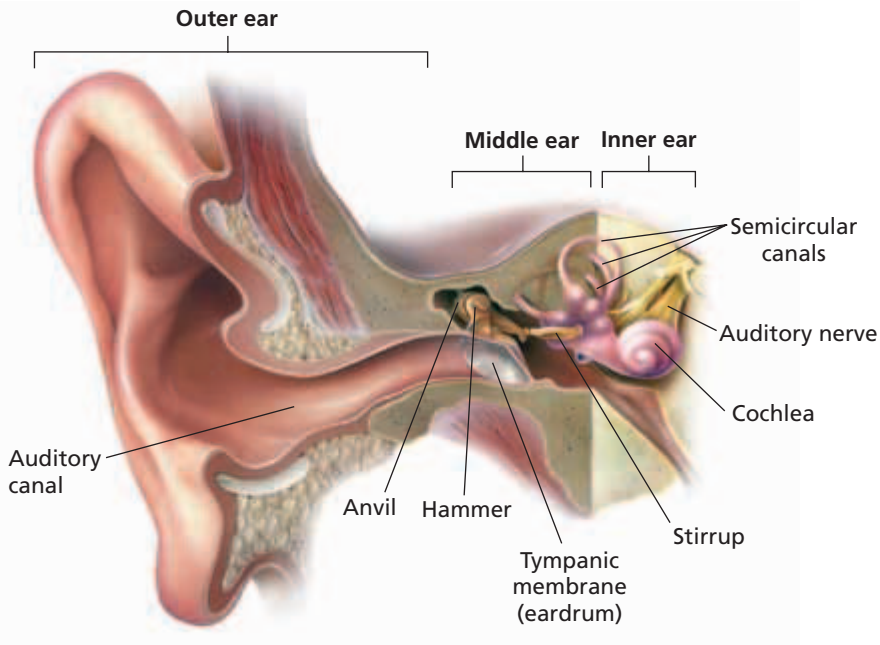


FIGURE 49-10

Sound waves, which are vibrations in the air, cause the tympanic membrane to move back and forth. This motion causes the small bones of the middle ear to move as well, transferring vibrations to the oval window. Mechanoreceptors in the inner ear translate these vibrations to action potentials. These, in turn, travel through the auditory nerve to auditory processing centers in the brain.

FIGURE 49-11

Hair cells are arranged in orderly rows inside the organ of Corti in the middle chamber of the cochlea. In the damaged section shown here, the hair cells in the top and center rows are relatively intact. Many of the hair cells of the bottom row, however, are frayed and bent. The cluster of hair cells in the middle of the bottom row has been completely destroyed.

The hair cells that line the cochlea are delicate and vulnerable. Repeated or sustained exposure to loud noise destroys hair cells in the organ of Corti. Once destroyed, hair cells do not generally regenerate, and the sound frequencies they interpret are no longer heard. Figure 49-11 shows rows of hair cells in a damaged section of the organ of Corti. Hair cells that respond to high-frequency sound are especially vulnerable to destruction. The loss of these cells typically leads to difficulty understanding human voices. Much of this type of permanent hearing loss is avoidable by reducing exposure to loud noises, such as machine noise and loud music.

Besides detecting sound, the ear also helps maintain balance. Balance is maintained by mechanoreceptors in the three **semicircular canals** of the inner ear. The semicircular canals are filled with fluid. Their interiors are lined with hair cells that have tiny particles of calcium carbonate on top of them. When the head moves, the hair cells are bent by the action of gravity or inertia on the calcium carbonate particles. The brain decodes how far and in what direction the hair cells bend. It interprets the head's motion and orientation in space and sends out the proper orders to help the body maintain balance.

VISION

The eyes are specialized organs that detect light and transmit signals to visual processing areas of the brain. The eye is basically a hollow sphere filled with a clear fluid. The structures of the eye act together to focus light on the **retina,** the light-sensitive inner layer of the eye.

Light passes first through a clear, protective layer called the **cornea.** Light then passes through the **pupil,** the opening to the interior of the eye. The pupil becomes larger when light is dim and smaller when light is bright. Muscles in the pigmented **iris** that surrounds the pupil control these involuntary responses.

After light passes through the pupil, it travels through a crystalline structure called the **lens.** Muscles attached to the lens adjust the shape of the lens to bend the rays of the incoming light. This bending focuses the image formed by the light onto the retina.

Lying within the retina are rods and cones, photoreceptors that translate light energy into electrical signals that can be interpreted by the brain. **Rods** contain rhodopsin, a light-sensitive pigment that allows the rods to respond to dim light. **Cones** in the retina are stimulated by bright light. The cones initiate the production of sharp images and respond to different colors. Humans have three kinds of cones. Each kind of cone contains a pigment that absorbs different wavelengths of light. When the brain integrates signals from these three kinds of cones, a person perceives all the colors in the visible spectrum. Colorblindness, which is the inability to distinguish certain colors, is caused by faulty or missing cones.

Quick Lab

Observing a Lens

Materials beaker, water, newspaper, 4 drops cooking oil

Procedure Observe the newspaper through the sides of an empty beaker. Fill the beaker with water, and observe the newspaper through the water. Add four drops of oil to the top of the water. Observe the newspaper through the oil drops and water. Note any difference in print size.

Analysis Infer why the print size changes when the newspaper is viewed through water. Which structure of the eye does the oil on the water represent?

Each photoreceptor responds to light from a single location in the visual field. Signals from the stimulated photoreceptors in the deepest layer of the retina travel to neurons on the surface of the retina. From these neurons, millions of axons, which form the optic nerve, exit the eye. The optic nerve carries visual information in the form of action potentials from the retina to the thalamus. The cortex of the occipital lobe ultimately processes visual information into meaningful patterns of shape and color. Figure 49-12 shows the structure of the eye.

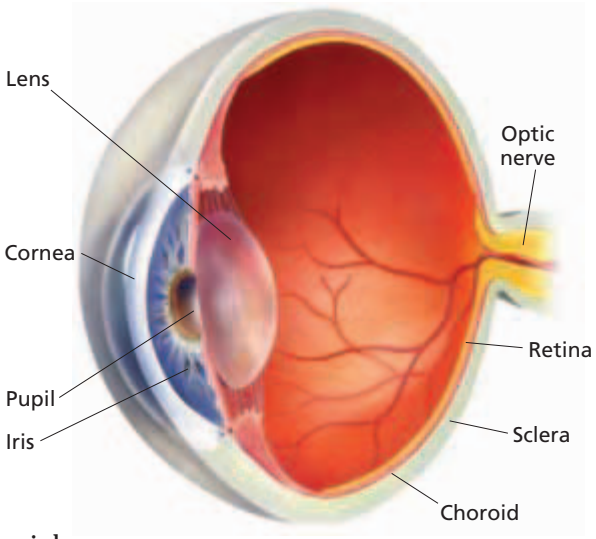


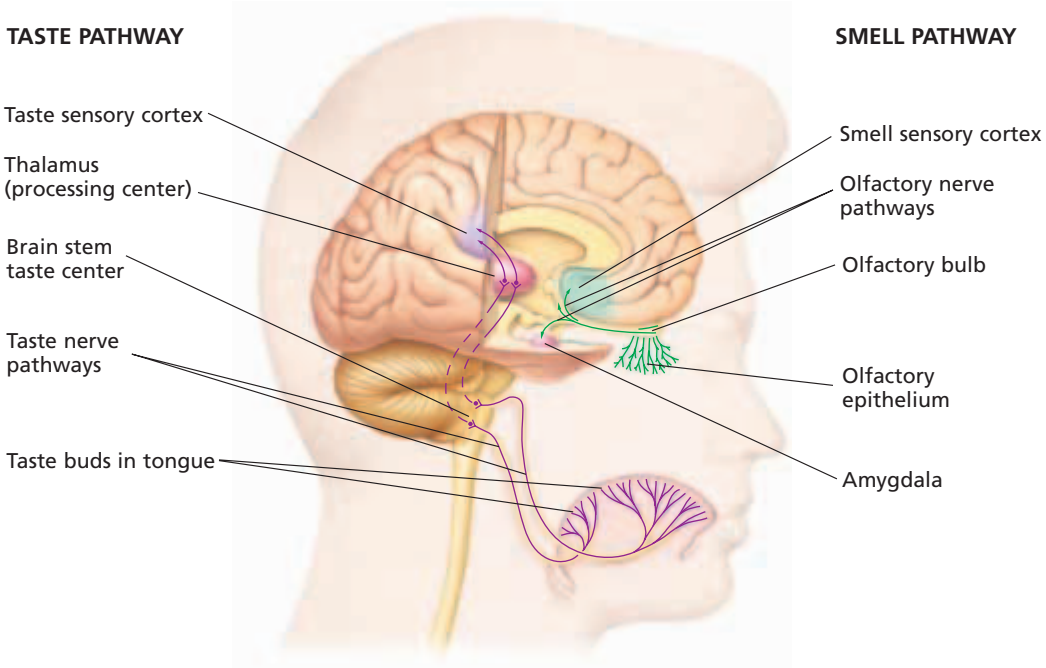
FIGURE 49-12
Light entering the eye travels through the cornea, the pupil, and the lens to the retina, which contains millions of photoreceptors. Activation of these specialized sensory receptors sends a signal through the optic nerve to the optic centers of the brain—first to the thalamus and eventually to the visual cortex in the occipital lobe.

TASTE AND SMELL

People perceive variations in tastes and odors because of specialized chemoreceptors. The chemoreceptors for taste are clustered in **taste buds.** Most of the 10,000 taste buds are embedded between bumps called **papillae** (puh-PIL-ee) on the tongue. Additional taste buds are found in the throat and on the roof of the mouth. Chemicals from food dissolved in saliva enter a taste bud through a small opening. The chemicals bind to receptors and stimulate the neurons that line the inner surface of the taste buds. As shown in Figure 49-13, taste signals travel through a relay in the brain stem, to the thalamus, and finally to the cortex for interpretation.

Receptors in the nasal passages detect chemicals in the air. Specialized chemoreceptors called **olfactory** (ahl-FAK-tuh-ree) **receptors** are located in the mucous lining of the epithelium in the nasal passages. The binding of odor molecules to specific receptor molecules in the olfactory receptors stimulates the receptors. Signals from olfactory receptors travel to the olfactory bulb, a structure of the limbic system. Then, signals travel to olfactory areas of the cortex and to the *amygdala,* another limbic structure.

FIGURE 49-13
Taste and smell are chemical senses. Sensory receptors in the mouth and nasal passages bind to molecules from the environment, initiating neural signals that travel to the brain.



PRESSURE AND TEMPERATURE

Mechanoreceptors located throughout the skin make it possible to sense touch, pressure, and tension. In humans, touch receptors are concentrated in the face, tongue, and fingertips. Body hair also helps humans sense touch because bending a hair stimulates large numbers of mechanoreceptors found at the base of hair follicles in the skin.

Two types of specialized thermoreceptors in skin monitor temperature. Cold receptors are most sensitive to temperatures below 20°C. Heat receptors respond to temperatures between about 30°C and 45°C.

Pain receptors are sensory neurons located in the base of the epidermis and throughout the interior of the body. Mechanical, thermal, electrical, and chemical energy stimulate pain receptors. The type and number of pain receptors vary at different locations throughout the body. For example, the hands and mouth have high concentrations of pain receptors.

Sensory input from the surface of the body travels to the spinal cord in an orderly way. For example, sensory input from the shoulders enters dorsal root sections of the upper spinal cord. Input from the lower body enters the dorsal root sections of the lower spinal cord. Damage to a specific portion of the spinal cord results in sensory problems limited to a well-defined area of the body. This isolation of sensory problems illustrates how function is mapped throughout the nervous system. Specific areas of the brain's sensory cortex and motor cortex likewise correspond to specific body parts. Damage to specific areas of the cortex can result in isolated problems, such as numbness in part of one hand.

SECTION 3 REVIEW

1. Distinguish between the five types of sense receptors.
2. How does the sensory perception system distinguish between different types of stimuli?
3. Draw the structures of the ear. Label the structures, and identify the role of each in hearing or balance.
4. Describe the detection of light.
5. What are the roles of rods and cones in vision?
6. Which mechanisms do the senses of taste and smell have in common?
7. What is the role of skin in sensing the external environment?

CRITICAL THINKING

8. **Applying Information** Why might an injury to the lower spinal cord cause a loss of sensation in the legs?
9. **Analyzing Models** Experiments show that peripheral vision, or the ability to see to the side without turning the head, is greater in deaf people than in hearing people. Suggest a hypothesis to explain this observation.
10. **Making Inferences** What is the importance of a high concentration of pain receptors in the hands and mouth?

DRUGS AND THE NERVOUS SYSTEM

Drugs *are substances that cause a change in a person's physical or psychological state. Though many drugs are legal and available to the public, other drugs are illegal. Drugs, whether legal or illegal, can be misused or abused.*

SECTION 4

OBJECTIVES

- **Define** the relationship between addiction and tolerance.
- **Explain** the physical basis of cocaine addiction.
- **Identify** six types of psychoactive drugs.
- **List** the effects of alcohol and tobacco on the body.

VOCABULARY

drug
psychoactive drug
dependence
addiction
tolerance
withdrawal
stimulant
depressant
blood alcohol concentration
nicotine
emphysema

PSYCHOACTIVE DRUGS

Natural or human-made chemical compounds can alter nervous system function. A **psychoactive drug** is a drug that alters the functioning of the central nervous system. The psychoactive drug cocaine comes from the plant shown in Figure 49-14. Many prescribed medications are psychoactive drugs, as is caffeine, which is found in coffee and many soft drinks.

Addiction and Tolerance

The abuse of psychoactive drugs alters the normal functioning of neurons and synapes. Psychoactive drug abuse often leads to **dependence.** Dependence is a state in which a person relies on a drug physically or emotionally in order to function. Dependence often results in **addiction,** a condition in which a person can no longer control his or her drug use.

With repeated exposure to a drug, a person addicted to the drug develops tolerance to the drug. **Tolerance** is a characteristic of drug addiction in which larger and larger amounts of the drug are needed to achieve the desired sensation. This increase in the *effective dose,* the dose that causes the desired feeling, can be a deadly situation for the users of some drugs. As tolerance increases and the effective dose rises, the addict approaches a *lethal dose*—the amount of drug that will kill the user.

Without the drug, addicts go through **withdrawal,** a physical and emotional response to the drug's absence. The severity of drug dependence is evident in recovering addicts who experience withdrawal when they stop taking an addictive drug. Withdrawal symptoms vary depending on which type of drug was abused and how long it was abused. Symptoms may include vomiting, headache, insomnia, breathing difficulties, depression, mental instability, and seizures. Withdrawal from some drugs, such as alcohol and barbiturates, can be life threatening. Addicts undergoing withdrawal from these drugs are often hospitalized so that doctors can monitor their responses.

FIGURE 49-14
The psychoactive and highly addictive drug cocaine comes from the coca plant, *Erythroxylum coca.*

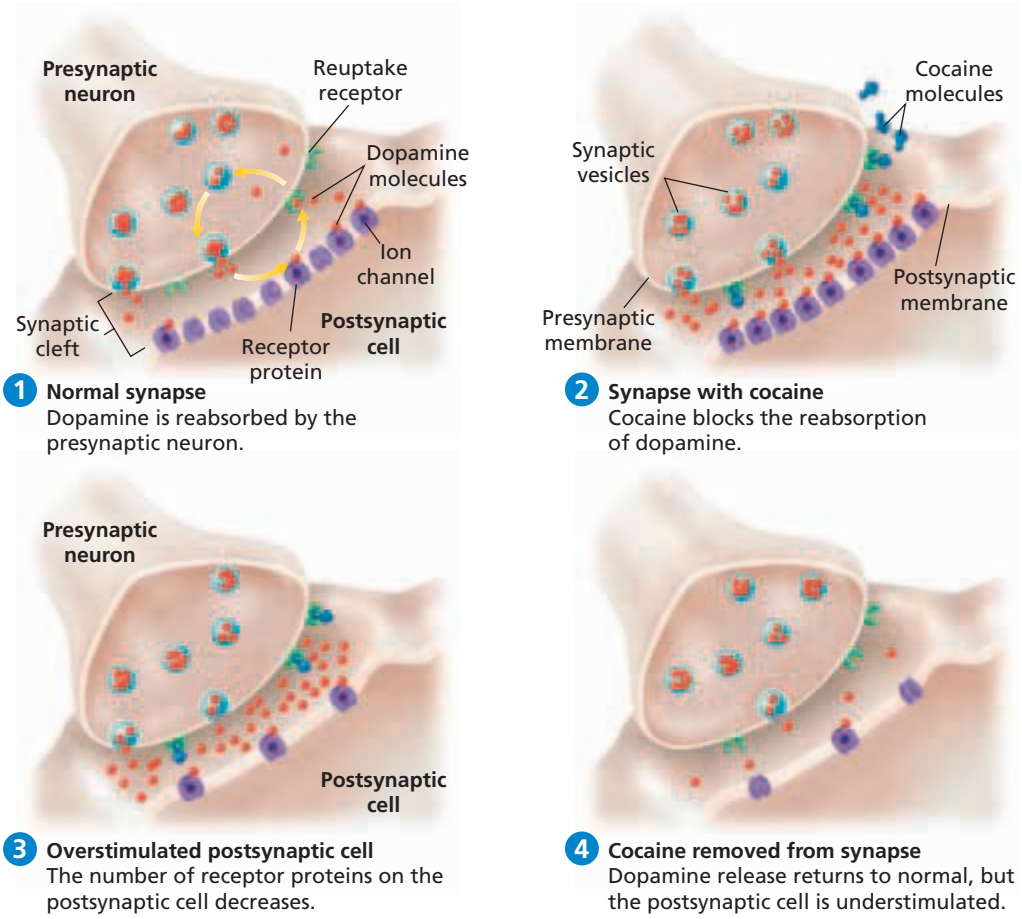


FIGURE 49-15

1 At a normal synapse, dopamine is reabsorbed by reuptake receptors. 2 Cocaine binds and blocks reuptake receptors, causing dopamine molecules to remain longer in the synaptic cleft. 3 The excess dopamine overstimulates the postsynaptic neuron, which responds by reducing its number of receptor proteins. 4 In the absence of the drug, dopamine release returns to normal, but the postsynaptic cell is understimulated due to a lack of receptors.

Neural Changes

Cocaine is a highly addictive **stimulant,** a drug that generally increases the activity of the central nervous system. Though illegal, cocaine is still abused by many people. The excitatory effect sought by cocaine users is due to the drug's action on neurons in the brain.

Figure 49-15 summarizes the effect cocaine addiction has on the brain. Cocaine affects dopamine (DOH-pah-MEEN) receptors in the limbic system. The receptors play an important role in the sensation of pleasure. Recall that neurotransmitters secreted into the synaptic cleft send signals from one neuron to the next. In many kinds of neurons, *reuptake receptors* bind, or reabsorb, the neurotransmitter molecules in the synaptic cleft and move them back into the presynaptic cell for later use. Cocaine molecules bind to these presynaptic reuptake receptors. As a result, the reabsorption of neurotransmitter molecules is blocked. Rather than being removed, the neurotransmitter molecules remain for a long time in the synaptic cleft. The excess neurotransmitters abnormally excite the postsynaptic neurons, providing the sensation cocaine abusers seek.

In response to the surplus neurotransmitter molecules that cocaine causes, postsynaptic neurons make fewer neurotransmitter receptors. As a result, normal levels of neurotransmitter molecules are no longer sufficient to stimulate the postsynaptic neuron in the absence of cocaine because this neuron has reduced numbers of receptors.

TABLE 49-2 *Psychoactive Drugs of Abuse*

Type of drug	Examples	Psychoactive effects	Risks of use
Depressants	alcohol, barbiturates (sedatives), tranquilizers	decreased activity of the central nervous system, impaired judgment, loss of motor control, confusion, sedation	drowsiness, depression, liver damage, brain or nerve damage, respiratory failure, coma
Stimulants	amphetamines, cocaine, crack, nicotine	increased activity of the central nervous system, temporary feeling of exhilaration, irritability, anxiety, elevated blood pressure, increased heart rate	insomnia, paranoia, delusions, loss of coordination, brain damage, respiratory paralysis, irregular heartbeat, cardiac arrest
Narcotics	codeine, heroin, morphine, opium	temporary feeling of euphoria, impaired reflexes, impaired sensory perception, sedation	coma, respiratory failure
Hallucinogens	LSD, MDMA (Ecstasy), PCP, peyote (mescaline), psilocybe mushroom	sensory distortion, hallucinations, delusions, anxiety, slurred speech, numbness, bizarre or violent behavior	depression, paranoia, aggressive behavior, brain damage
Tetrahydro-cannabinol (THC)	hashish, marijuana	temporary feeling of euphoria, short-term memory loss, impaired judgment, hallucinations	lung damage, loss of motivation
Inhalants	aerosols, ether, glue, nitrous oxide, paint thinner	disorientation, confusion, memory loss, sedation	brain damage, spasms, liver and kidney damage, cardiorespiratory failure

DRUGS AND ABUSE

The possession of psychoactive drugs is often illegal. Table 49-2 lists types of abused psychoactive drugs.

Alcohol

For people age 21 and older, alcohol is a legal drug. Alcohol is a **depressant,** a drug that decreases the activity of the central nervous system. Alcohol increases circulation to the skin, decreases blood flow to internal organs, and lowers body temperature. Alcohol causes the kidneys to excrete more water, which can cause dehydration. As drinking continues, judgment and coordination become impaired, speech slurs, and reaction time lengthens. Respiration rate slows after an initial increase. High doses of alcohol can cause death by respiratory failure. The severity of these effects depends largely on **blood alcohol concentration** (BAC), a measurement of the amount of alcohol in the blood. A BAC of 0.30 or greater can cause unconsciousness, and a BAC of 0.50 can be fatal.

Alcohol is a factor in nearly 50 percent of fatal car crashes involving young people. Alcohol can contribute to harmful drug interactions. For example, when alcohol is combined with another depressant, the cumulative effects can slow the respiratory systems to the point of death. Alcohol consumed during pregnancy can lead to *fetal alcohol syndrome,* as shown in Figure 49-16.

FIGURE 49-16

This child shows some of the physical abnormalities associated with fetal alcohol syndrome. Children born with fetal alcohol syndrome often have physical, mental, behavioral, and learning disabilities.

FIGURE 49-17

Nicotine is a stimulant found in the leaves of the tobacco plant.

Tobacco

Tobacco products are legal for people age 18 and older. **Nicotine** is the major drug found in tobacco, shown in Figure 49-17. Nicotine is a highly addictive stimulant. When a person chews tobacco or inhales its smoke, nicotine is absorbed into the bloodstream through the mouth and lungs. It is then quickly transported throughout the body and, in pregnant women, to the fetus.

Nicotine mimics the action of a neurotransmitter called *acetylcholine* (AS-i-TIL-KOH-leen). Acetylcholine plays a role in many of the body's everyday activities. Nicotine increases blood pressure and heart rate. Nicotine decreases the oxygen supply to body tissues and the blood supply to the hands and feet. Nicotine is also a poison—60 mg of nicotine is a lethal dose for an adult.

Nicotine is not the only harmful substance found in tobacco. Burning tobacco produces *tars,* complex mixtures of chemicals and smoke particles. Tars coat and paralyze the cilia that line air passages and normally sweep particles and debris from those passageways. Tars irritate the nose, throat, trachea, and bronchial tubes, causing sore throat and coughing. Tars disrupt lung cells, reducing breathing capacity and increasing the risk of respiratory infections.

The long-term use of tobacco products has several effects. In the United States, smoking-related illnesses cause more than 400,000 deaths each year. About 25 percent of all heart attacks are associated with the use of tobacco. Smoking causes lung cancer, one of the most common forms of cancer. Many smokers contract *chronic bronchitis* (brahn-KIET-is), an inflammation of the bronchi and bronchioles, or **emphysema** (EM-fuh-SEE-muh), a degenerative lung disease in which alveoli lose their elasticity and eventually rupture.

People who chew tobacco and use snuff have higher rates of lip, gum, and mouth cancer than people who don't use smokeless tobacco. Pregnant women who smoke are twice as likely as nonsmoking mothers to suffer miscarriages. Their babies tend to have lower birth weights than babies of nonsmokers and are twice as likely to die in the first few months of life.

SECTION 4 REVIEW

1. What is the relationship between addiction and tolerance?
2. Describe the physiological mechanism of cocaine addiction.
3. What are six types of psychoactive drugs?
4. How does a stimulant differ from a depressant?
5. What are some of the effects of alcohol use?
6. What is blood alcohol concentration (BAC)?
7. How do tobacco products affect the body?

CRITICAL THINKING

8. **Recognizing Relationships** What do all psychoactive drugs have in common?
9. **Analyzing Models** Examine the model for cocaine addiction shown in Figure 49-15. How does this model illustrate the phenomenon of tolerance?
10. **Applying Concepts** Why are long-term drug abusers, who have built up a large degree of tolerance, endangered by their effective dose?

CHAPTER HIGHLIGHTS

SECTION 1 Neurons and Nerve Impulses

- Neurons are specialized cells that rapidly transmit information as electrical signals throughout the body.
- In a neuron at rest, the inside of the cell has a negative charge relative to the outside.
- During an action potential, the polarity of the membrane is reversed briefly as Na^+ ions diffuse into the neuron through voltage-gated channels.
- When an action potential reaches the presynaptic membrane, neurotransmitters are released into the synapse.

Vocabulary

nervous system (p. 1005)
neuron (p. 1005)
dendrite (p. 1005)
axon (p. 1005)
action potential (p. 1005)
axon terminal (p. 1005)
myelin sheath (p. 1005)
synapse (p. 1005)
neurotransmitter (p. 1005)
membrane potential (p. 1006)
resting potential (p. 1007)
refractory period (p. 1008)

SECTION 2 Structure of the Nervous System

- The nervous system has two divisions—the central nervous system (CNS) and peripheral nervous system (PNS).
- The CNS is made up of the brain and spinal cord. The PNS is made of neurons with cell bodies that are not part of the brain and spinal cord.
- The sensory division of the PNS contains sensory neurons and interneurons that connect to the CNS. The motor division allows the body to react to sensory information.
- The somatic nervous system controls skeletal muscles and is under voluntary control. The autonomic nervous system controls internal body conditions.

Vocabulary

central nervous system (p. 1010)
peripheral nervous system (p. 1010)
cerebrum (p. 1011)
cerebral cortex (p. 1011)
brain stem (p. 1012)
thalamus (p. 1012)
hypothalamus (p. 1012)
medulla oblongata (p. 1012)
cerebellum (p. 1013)
nerve (p. 1013)
sensory receptor (p. 1013)
motor neuron (p. 1013)
interneuron (p. 1013)
somatic nervous system (p. 1014)
reflex (p. 1014)
autonomic nervous system (p. 1015)

SECTION 3 Sensory Systems

- The ear converts sound into electrical signals that are interpreted by the brain.
- Photoreceptors in the eyes convert light into electrical signals that are interpreted by the brain.
- Stimulation of neurons in taste buds is interpreted as taste. Olfactory receptors in the nasal passages transmit signals to the brain, where they are interpreted as odor.

Vocabulary

sense organ (p. 1016)
auditory canal (p. 1017)
tympanic membrane (p. 1017)
Eustachian tube (p. 1017)
cochlea (p. 1017)
semicircular canal (p. 1018)
retina (p. 1018)
cornea (p. 1018)
pupil (p. 1018)
iris (p. 1018)
lens (p. 1018)
rod (p. 1018)
cone (p. 1018)
taste bud (p. 1019)
papilla (p. 1019)
olfactory receptor (p. 1019)

SECTION 4 Drugs and the Nervous System

- Psychoactive drugs affect the CNS. Dependence is a physical or psychological need for a drug. Tolerance is a characteristic of addiction in which larger and larger amounts of the drug are needed.
- Drug addiction involves physiological changes in neurons.
- Alcohol is an addictive depressant that widely affects the CNS. Nicotine is an addictive stimulant found in tobacco products.

Vocabulary

drug (p. 1021)
psychoactive drug (p. 1021)
dependence (p. 1021)
addiction (p. 1021)
tolerance (p. 1021)
withdrawal (p. 1021)
stimulant (p. 1022)
depressant (p. 1023)
blood alcohol concentration (p. 1023)
nicotine (p. 1024)
emphysema (p. 1024)

CHAPTER REVIEW

USING VOCABULARY

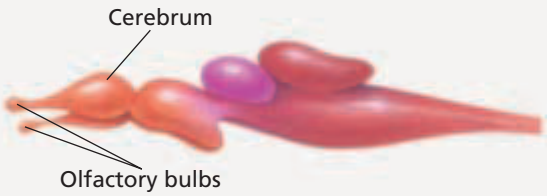
1. For each pair of terms, explain the relationship between the terms.
   a. *stimulant* and *depressant*
   b. *motor neuron* and *sensory receptor*
   c. *brain stem* and *diencephalon*
   d. *resting potential* and *action potential*
2. Use each of the following terms in a separate sentence: *neuron, dendrite, myelin sheath,* and *synapse*.
3. Use each of the following terms in a separate sentence: *thalamus, hypothalamus, pons,* and *medulla oblongata*.
4. **Word Roots and Origins** The word *pons* is derived from the Latin *pons,* which means "bridge." Using this information, explain how *pons* is an appropriate term for the part of the brain it describes.

UNDERSTANDING KEY CONCEPTS

5. **Discuss** the structure of a neuron.
6. **Describe** the chemical conditions within a neuron during resting potential and during action potential.
7. **Explain** how action potentials are transmitted from a neuron to another cell.
8. **Describe** the roles of the two main organs of the central nervous system.
9. **Define** the roles of four portions of the brain.
10. **Summarize** the roles of the sensory and motor divisions of the peripheral nervous system.
11. **Relate** the relationship between motor neurons, interneurons, and sensory receptors.
12. **Describe** the role of chemoreceptors in taste and smell.
13. **List** five different types of sensory receptors in the human body.
14. **Identify** the parts of the ear responsible for hearing and for balance.
15. **Compare** how rods and cones respond to light.
16. **Describe** how the eye receives light stimulus and sends a signal to the brain.
17. **State** the type of receptors that function in taste and smell.
18. **Explain** the role of skin in sensing touch, temperature, and pain.
19. **Relate** addiction and tolerance.
20. **Describe** the process of cocaine addiction.
21. **Identify** six types of psychoactive drugs.
22. **Identify** the effects of alcohol and tobacco on the body.
23. **CONCEPT MAPPING** Use the following terms to create a concept map that describes the effect of drugs on the nervous system: *psychoactive drugs, depressants, alcohol, stimulants, impaired judgment, confusion, increased heart rate, increased blood pressure, addiction,* and *nicotine*.

CRITICAL THINKING

24. **Analyzing Data** Epilepsy affects one out of every 200 Americans. Brain neurons normally produce small bursts of action potentials in varying patterns. During an epileptic seizure, large numbers of brain neurons send rapid bursts of action potentials simultaneously. The body of an individual having a seizure may grow rigid and jerk or convulse. From what you know about the brain's control of muscles and posture, how might you explain these symptoms?
25. **Making Predictions** Predict what could happen to the nervous system if a person has an imbalance of electrolytes, the ion-containing fluids of the body.
26. **Inferring Relationships** People who suffer from vertigo feel dizzy and disoriented in certain situations. What is the relationship between vertigo and the semicircular canals?
27. **Interpreting Graphics** The diagram below shows the brain of a fish. How does the cerebrum of a fish differ from the cerebrum of a human? The fish's brain has large olfactory bulbs. What does this indicate about the relative importance of the sense of smell to the fish?

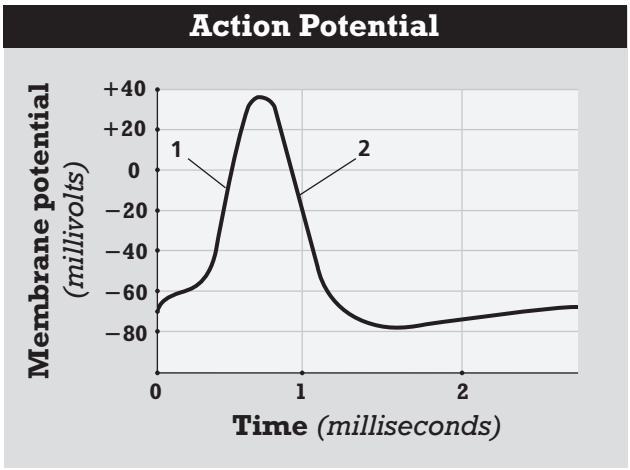


Standardized Test Preparation

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

1. Which of the following is true about the cerebral cortex?
   - **A.** It is located deep in the brain.
   - **B.** It is the folded outer covering of the brain.
   - **C.** It is part of the peripheral nervous system.
   - **D.** It is the lobed, highly folded structure located at the back of the brain.
2. When a neuron is at resting potential, which of the following is true?
   - **F.** Both sides of the cell are equally charged.
   - **G.** The inside of the cell is less positive.
   - **H.** The polarity across the membrane reverses.
   - **J.** The outside of the cell is less positive.
3. Which of the following stimuli affects mechanoreceptors?
   - **A.** heat
   - **B.** light
   - **C.** pressure
   - **D.** chemicals

INTERPRETING GRAPHICS: The graph below shows the change in voltage during an action potential. Use the graph to answer the questions that follow.

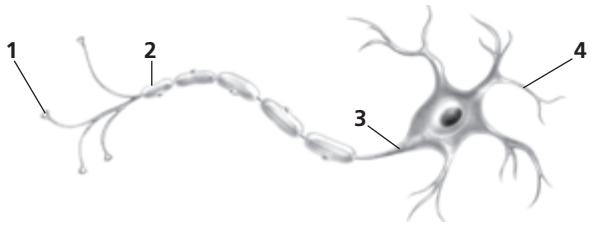


4. How long does the action potential last?
   - **F.** 1 ms
   - **G.** 1.5 ms
   - **H.** 3 ms
   - **J.** 30 ms
5. Which point on the graph represents when the voltage-gated sodium channels are open?
   - **A.** 1
   - **B.** 2
   - **C.** 1 and 2
   - **D.** There is not enough information to determine the answer.

DIRECTIONS: Complete the following analogy.

6. stimulant : nicotine :: depressant :
   - **F.** alcohol
   - **G.** cigarettes
   - **H.** neurotransmitters
   - **J.** tetrahydrocannabinol (THC)

INTERPRETING GRAPHCS: The diagram below shows a neuron. Use the diagram to answer the questions that follow.



7. Which number indicates the structure from which the neuron receives information from other neurons?
   - **A.** 1
   - **B.** 2
   - **C.** 3
   - **D.** 4
8. Which number indicates the structure that increases the speed of action potentials?
   - **F.** 1
   - **G.** 2
   - **H.** 3
   - **J.** 4

SHORT RESPONSE

The effect of a drug on the body varies with the size of the dose and an individual's tolerance to the drug.

Explain the difference between the effective dose and the lethal dose of a drug.

EXTENDED RESPONSE

Both alcohol and tobacco can have a negative effect on human health.

Part A Susan is addicted to alcohol. Predict what might happen if she quit drinking.

Part B Mark smokes a pack of cigarettes a day. Describe some of the health risks Mark faces if he continues to smoke for a long period of time.

Test TIP Choose an answer to a question based both on what you already know and on any information presented in the question.

Dissecting a Sheep's Eye

OBJECTIVES

- Describe the main external and internal structures of a sheep's eye.
- Name the various structures associated with sight.

PROCESS SKILLS

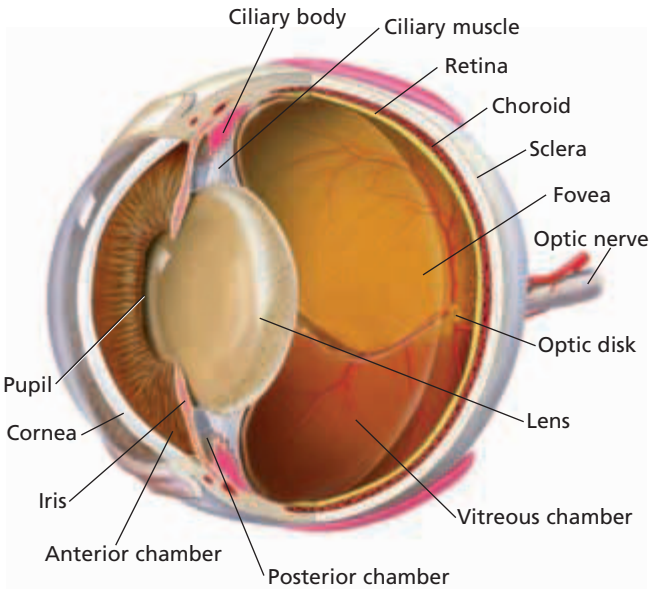
- observing
- identifying
- comparing and contrasting

MATERIALS

- safety goggles
- disposable gloves
- lab apron
- preserved sheep's eye
- dissection tray
- scalpel
- tweezers
- fine scissors
- blunt probe

Background

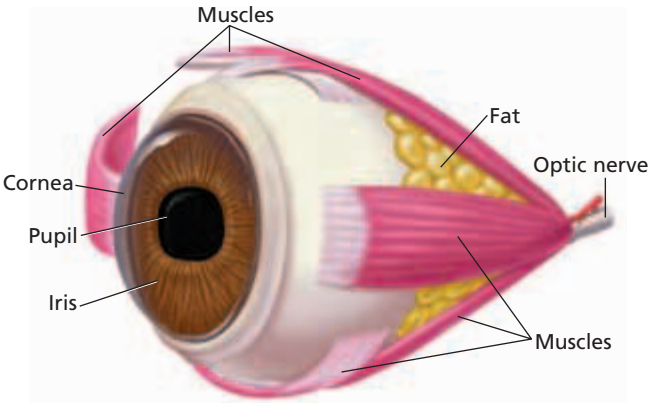
1. The sheep's eye is very similar to the human eye, as shown in the diagram below. The wall of the eyeball is made up of three layers. The outer layer, the sclera, is a tough tissue that forms the white of the eye. At the front of the eye, the sclera becomes thin and transparent to form the cornea.



2. The middle layer, the choroid, is dark and rich with blood vessels. At the front of the eye behind the cornea, the choroid is modified into the iris and the ciliary body. The pigment in the iris determines eye color. The opening in the center of the iris is the pupil. What is the function of the pupil?
3. The inner layer, the retina, is sensitive to light. What are the photoreceptors in the retina called?
4. Directly behind the iris is the elastic, transparent lens. The suspensory ligament attaches the ciliary muscle, the main part of the ciliary body, to the lens. This ring of muscle changes the shape of the lens to focus on near and far objects.
5. The lens and its suspensory ligament divide the eye into two chambers. The large vitreous chamber extends from the retina to the lens and ligaments. It is filled with a gelatinous mass, the vitreous humor. The vitreous humor helps to maintain the shape of the eye and hold the retina in place. The second chamber, which extends from the iris to the cornea, is subdivided into two parts, the anterior and posterior chambers. The anterior chamber extends from the cornea to the iris; the posterior chamber from the iris to the suspensory ligament. Both chambers contain aqueous humor, a watery substance that bathes the front part of the eye.
6. Ganglion cells form synapses with bipolar cells, which, in turn, synapse with rods and cones. In the retina, the axons of ganglion cells bundle together at the optic nerve. The region of the retina where its nerve fibers and blood vessels enter the optic nerve is the small optic disk, which contains no rods or cones. Why is the optic disk also called the blind spot?
7. A very short distance away is a yellowish spot, the fovea. It is the site of sharpest vision because it has a high concentration of photoreceptors.

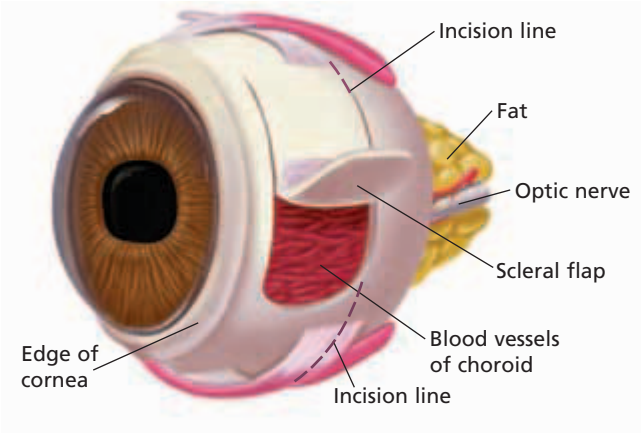
Procedure

1. Put on safety goggles, gloves, and a lab apron.
2. **CAUTION Use extreme care when handling all sharp and pointed instruments, such as scalpels.**



Locate the six main muscles on the outside of the eye, as shown in the diagram above. These muscles move the eye. Use a scalpel to carefully cut the muscles near the eye. This will expose the sclera.

3. Observe the fatty tissue that cushions the eye in its socket, especially around the optic nerve. This fatty tissue helps to prevent shock. With a tweezer and scalpel, remove the fatty tissue. This will expose the optic nerve more fully.
4. Using a scalpel, carefully cut the sclera about 1 cm behind the cornea. Using fine scissors, extend the cut to make a flap that you can lift, as shown in the diagram below.



5. With forceps, carefully remove the sclera in this area and observe the dark choroid layer immediately below the sclera.
6. Next, use a scalpel to make an incision through the eye. Following along the incision you made in step 4, cut almost completely around the eye. You have separated the eye into an anterior and a posterior portion.
7. In the posterior section, observe the whitish retina. It is probably shriveled and may have fallen into the vitreous chamber.
8. In the anterior section, use a blunt probe to expose the lens. In a preserved eye, the lens is no longer clear.
9. In the anterior section, also locate the ciliary muscle and as many other structures as possible.
10. When you have finished your dissection, remove the specimen from the dissecting tray. Dispose of your materials according to the directions from your teacher.
11. Clean up your work area, and wash your hands before leaving the lab.

Analysis and Conclusions

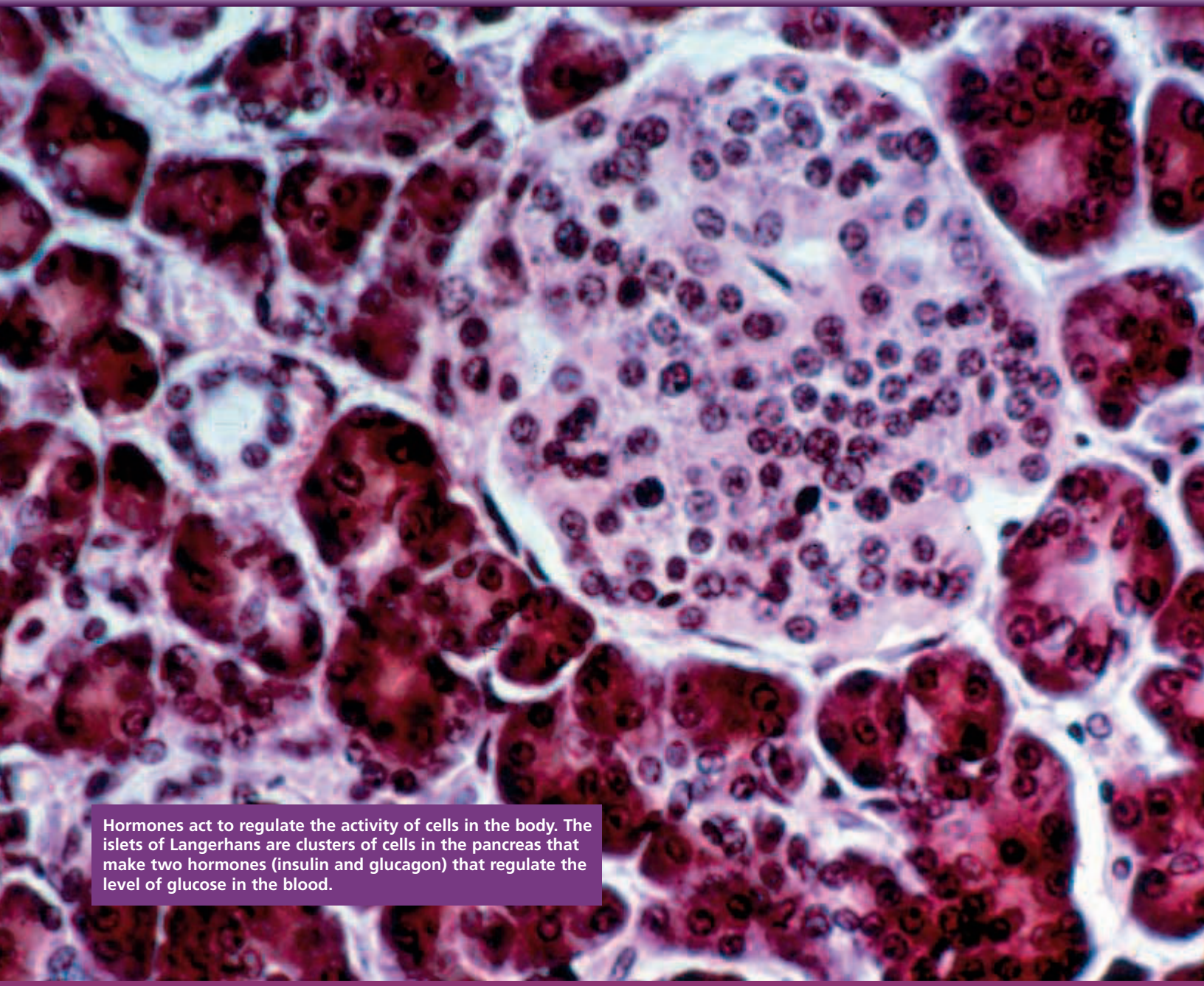
1. How is the lens different from the other structures of the eye?
2. How does the nature of the sclera and choroid change as they reach the front part of the eye?
3. How does the vitreous chamber differ from the anterior and posterior chambers?
4. What would be the result of the cornea becoming cloudy during an animal's lifetime?
5. Sometimes, the retina of the eye becomes detached. Why is it important that the retina be reattached, if possible?

Further Inquiry

You see light if the vision center of your cerebrum is stimulated electrically. Scientists are trying to find out which brain cells are involved in forming images in our brains. How might scientists someday use this knowledge to help blind people see?

CHAPTER 50

ENDOCRINE SYSTEM



Hormones act to regulate the activity of cells in the body. The islets of Langerhans are clusters of cells in the pancreas that make two hormones (insulin and glucagon) that regulate the level of glucose in the blood.

SECTION 1

HORMONES

Chemical messengers are substances that carry messages and instructions to cells. Hormones (HOHR-MOHNZ) and neurotransmitters are both chemical messengers that coordinate the body's activities. Hormones, however, are part of the endocrine system, while neurotransmitters are part of the nervous system. Hormones are often slower acting and have longer effects than neurotransmitters.

OBJECTIVES

- **State** the major functions of hormones.
- **Differentiate** between endocrine and exocrine glands.
- **Compare** the structure of amino acid–based hormones with the structure of steroid hormones.
- **Compare** how amino acid–based hormones act on their target cells with how steroid or thyroid hormones act on their target cells.
- **Relate** how neuropeptides and prostaglandins act like hormones.

VOCABULARY

hormone
endocrine gland
endocrine system
exocrine gland
amino acid–based hormone
steroid hormone
target cell
receptor
second messenger
neuropeptide
prostaglandin

FUNCTION AND SECRETION

Hormones influence almost every cell and organ in our bodies. **Hormones** are substances secreted by cells that act to regulate the activity of other cells in the body. Hormones have many functions. For example, hormones regulate growth, development, behavior, and reproduction. They also maintain homeostasis, regulate metabolism and water and mineral balance, and respond to external stimuli.

Hormones are made and secreted by endocrine (EN-doh-KRIN) glands. **Endocrine glands** are ductless organs that secrete hormones either into the bloodstream or the fluid around cells (extracellular fluid). Specialized cells in the brain, stomach, small intestine, liver, heart, and other organs also make and release hormones. The endocrine glands and specialized cells that secrete hormones are collectively called the **endocrine system.**

Some endocrine glands, such as the pancreas, are also exocrine (EKS-oh-KRIN) glands. **Exocrine glands** secrete substances through ducts (tubelike structures). These substances can include water, enzymes, and mucus. The ducts transport the substances to specific locations inside and outside the body. Sweat glands, mucous glands, salivary glands, and other digestive glands are examples of exocrine glands.

TYPES OF HORMONES

Hormones can be grouped into two types based on their structure: amino acid–based hormones and steroid (STIR-OYD) hormones. **Amino acid–based hormones** are hormones made of amino acids. An amino acid–based hormone can be either a single modified amino acid or a protein made of 3 to 200 amino acids. Most amino acid–based hormones are water soluble. **Steroid hormones** are lipid hormones that the body makes from cholesterol. Steroid hormones are fat soluble.

Word Roots and Origins

hormone

from the Greek *hormon,* meaning "to excite"

Quick Lab

Observing Solubilities

Materials 100 mL beakers (4), water, gelatin, cooking oil, vitamin E capsule, dissecting pin, spoon

Procedure

1. Put 75 mL of water into a beaker. Place 2.5 g of gelatin (protein) into the beaker. Stir. Does the gelatin dissolve? Record your observations.
2. Put 75 mL of oil into a beaker. Repeat the procedure in step 1 using oil instead of water.
3. Repeat steps 1 and 2 using the contents of a vitamin capsule (fat) instead of gelatin.

Analysis Which substance is fat soluble? Which substance is water soluble? Relate the solubilities of hormones to whether they enter their target cells or work outside them.

HORMONE ACTION

The body produces many different hormones, but each hormone affects only its target cells. **Target cells** are specific cells to which a hormone travels to produce a specific effect. Target cells have **receptors**—proteins that bind specific signal molecules that cause the cell to respond. Each receptor binds to a specific hormone. When a hormone binds to a receptor, the binding triggers events that lead to changes within the cell. Receptors can be found on the cell membrane, in the cytoplasm, or in the nucleus of a cell.

Amino Acid–Based Hormones

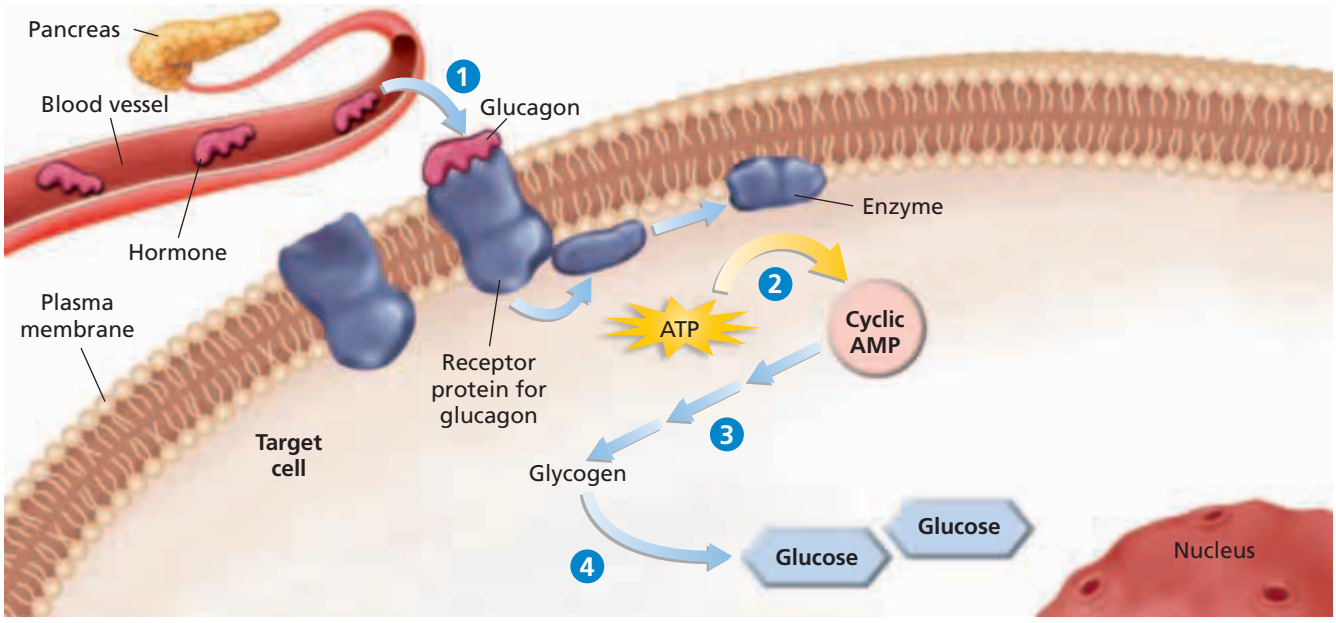
Most amino acid–based hormones bind to receptor proteins on the cell membrane. Thus, the hormone acts as a "first messenger." As the example in Figure 50-1 shows, the resulting hormone-receptor complex activates an enzyme that converts ATP to cyclic AMP (cAMP). Cyclic AMP, in turn, activates additional enzymes and proteins inside the cell. Thus, the hormone acts as a "first messenger" and cAMP acts as a "second messenger." A **second messenger** is a molecule that initiates changes inside a cell in response to the binding of a specific substance to a receptor on the outside of a cell. In addition to cAMP, cells have other second messengers.

Steroid and Thyroid Hormones

Because steroid and thyroid hormones are fat soluble, they diffuse through the cell membranes of their target cells and bind to receptors in the cytoplasm or nucleus. The hormone-receptor complexes cause the cells to activate existing enzymes or to initiate synthesis of new enzymes or proteins. Figure 50-2 shows how a hormone-receptor complex binds to DNA, activates transcription of mRNA, and stimulates production of new proteins. The proteins cause changes in the target cell.

FIGURE 50-1

1 Amino acid–based hormones, such as glucagon, bind to receptor proteins on the cell membrane. 2 The binding activates an enzyme, which converts ATP to cyclic AMP. 3 Cyclic AMP starts a cascade of enzyme activations. 4 Eventually, glycogen is broken down to individual glucose molecules.



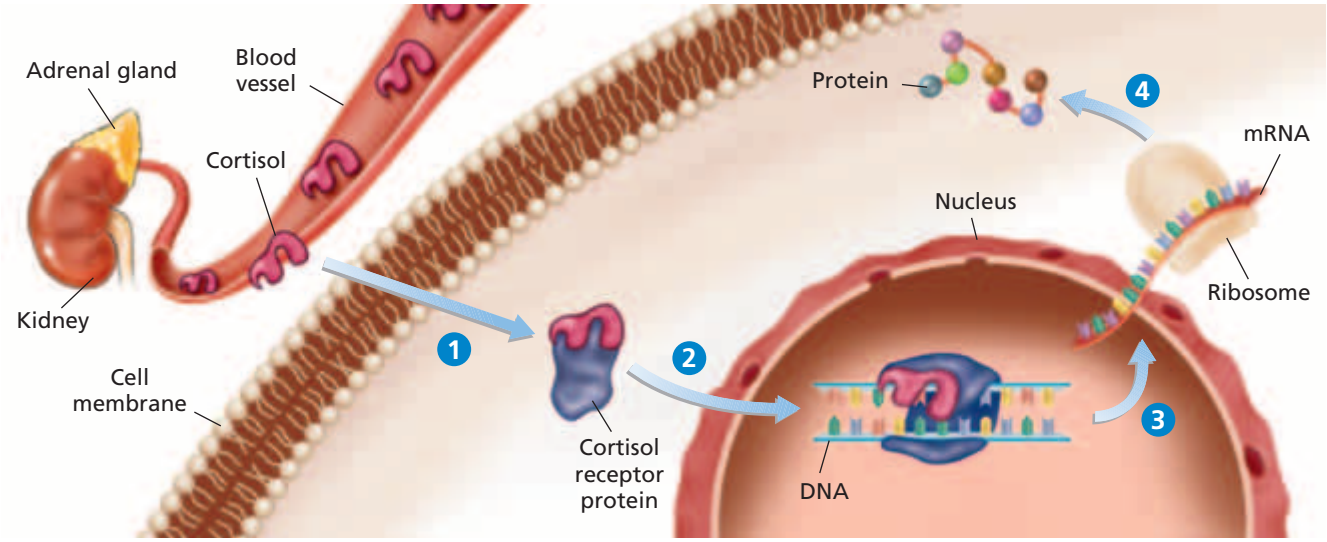


FIGURE 50-2

1 Steroid hormones, such as cortisol, diffuse through the cell membrane and attach to receptors in the cytoplasm of the cell. 2 The hormone-receptor complex enters the nucleus and binds to DNA. 3 Genes are activated. 4 Proteins are made that become active in cells.

OTHER TYPES OF HORMONES

Many other chemical messengers are now classified as hormones. These substances include neuropeptides and prostaglandins (PRAHS-tuh-GLAN-dinz).

Neuropeptides are hormones secreted by the nervous system. Unlike neurotransmitters, neuropeptides tend to affect many cells near the nerve cells that release them. One group of neuropeptides, called *endorphins* (en-DAWR finz), regulate emotions, influence pain, and affect reproduction. Another group of neuropeptides, *enkephalins* (en-KEF-uh-linz), inhibit pain messages traveling toward the brain.

Prostaglandins are modified fatty acids that are secreted by most cells. Prostaglandins accumulate in areas where tissues are disturbed or injured. Some prostaglandins reduce blood pressure; others raise blood pressure. Some prostaglandins cause smooth muscle to relax; others cause smooth muscle to contract. Some prostaglandins cause fever. Aspirin and acetaminophen reduce fever and decrease pain by inhibiting prostaglandin synthesis.

SECTION 1 REVIEW

1. Name four functions of hormones.
2. How do endocrine glands differ from exocrine glands?
3. Explain how most amino acid–based hormones affect their target cells.
4. Explain how steroid and thyroid hormones affect their target cells.
5. Why are neuropeptides and prostaglandins now classified as hormones?

CRITICAL THINKING

6. **Applying Information** Why can steroid and thyroid hormones, but not amino acid–based hormones, move across cell membranes?
7. **Organizing Information** Which types of hormones, amino acid–based, steroid, or thyroid, activate transcription and translation of a gene?
8. **Recognizing Relationships** Why are both hormones and neurotransmitters considered chemical messengers?

SECTION 2

OBJECTIVES

- **Identify** the relationship between the hypothalamus and the pituitary gland in the release of hormones.
- **List** the functions of the major endocrine glands and hormones.
- **Explain** the role of feedback mechanisms in maintaining homeostasis.
- **Compare** how negative feedback and positive feedback mechanisms are used to regulate hormone levels.
- **Summarize** how antagonistic hormones work as pairs to maintain homeostasis.

VOCABULARY

hypothalamus
pituitary gland
thyroid gland
adrenal gland
epinephrine
norepinephrine
cortisol
gonad
puberty
luteinizing hormone
follicle-stimulating hormone
estrogen
progesterone
androgen
testosterone
insulin
diabetes mellitus
melatonin
negative feedback
positive feedback

ENDOCRINE GLANDS

The endocrine glands regulate many vital processes. This section discusses the major hormones that endocrine glands make and the effects of these hormones.

HYPOTHALAMUS AND PITUITARY GLAND

As shown in Figure 50-3, endocrine glands are located throughout the body. Two organs, the hypothalamus (HIE-poh-THAL-uh-muhs) and the pituitary (pi-TOO-uh-TER-ee) gland, control the initial release of many hormones.

The **hypothalamus** is the area of the brain that coordinates many activities of the nervous and endocrine systems. It receives information from other brain regions and then responds to these signals as well as to blood concentrations of circulating hormones. The hypothalamus responds by issuing instructions in the form of hormones to the pituitary gland. As shown in Figure 50-4, the **pituitary gland** is suspended from the hypothalamus by a short stalk. The hypothalamus produces hormones that are stored in the pituitary gland or that regulate the pituitary gland's activity.

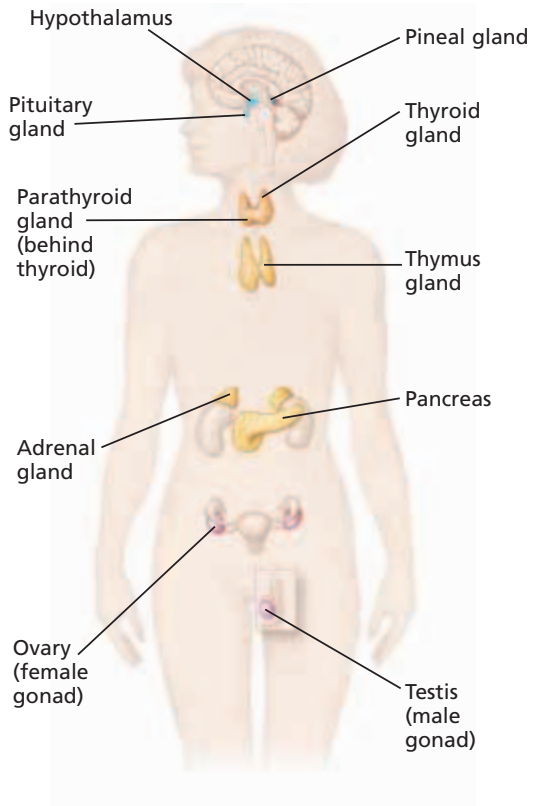


FIGURE 50-3
Endocrine glands are located throughout the body. All of these glands contain cells that secrete hormones. In addition to the organs shown, many other organs secrete hormones.

Two hormones—oxytocin (AHKS-ee-TOH-sin) and antidiuretic (AN-TIE-DIE-yoo-RET-ik) hormone (ADH)—are made by nerve cells in the hypothalamus. These nerve cells that secrete hormones are called *neurosecretory cells*. The axons of the neurosecretory cells in the hypothalamus extend into the posterior lobe of the pituitary, as shown in Figure 50-4b. Oxytocin and ADH are transported through these axons into the posterior pituitary, where they are stored for eventual release into the bloodstream.

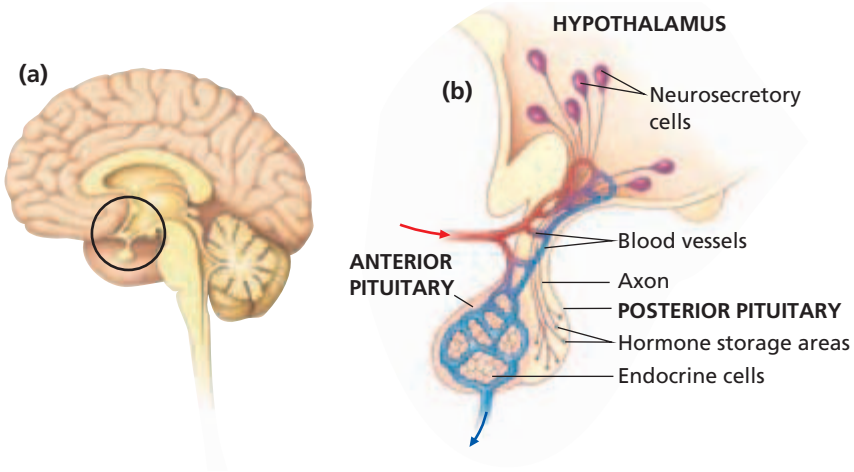


FIGURE 50-4

Neurosecretory cells in the hypothalamus produce hormones that affect the pituitary gland. The area of the brain where the hypothalamus and pituitary gland are found is circled in (a). The hypothalamus regulates the posterior pituitary through axons and the anterior pituitary through blood vessels, as shown in (b). (Blood vessels in the posterior pituitary have been omitted in order to show axon projections.)

As shown in Figure 50-4b, a special system of blood vessels connects the hypothalamus with the anterior pituitary. Nerve cells in the hypothalamus secrete releasing and release-inhibiting hormones that travel to the anterior pituitary through the blood vessels. *Releasing hormones* stimulate the anterior pituitary to make and secrete hormones. *Release-inhibiting hormones* inhibit production and secretion of anterior-pituitary hormones.

Some anterior-pituitary hormones, such as prolactin and growth hormone, are regulated through both a releasing hormone and a release-inhibiting hormone. Other hormones regulated by releasing hormones, such as follicle–stimulating hormone, thyroid-stimulating hormone, and adrenocorticotropic hormone (ACTH), in turn stimulate other endocrine glands. Table 50-1 summarizes the function of the hormones secreted by the pituitary gland.

TABLE 50-1 *Hormones Secreted by the Pituitary Gland*

Hormone	Target	Major function
Adrenocorticotropic hormone (ACTH)	adrenal cortex	stimulates secretion of cortisol and aldosterone by the adrenal cortex
Antidiuretic hormone (ADH)	kidney tubules	stimulates reabsorption of water by kidneys, reducing the concentration of solutes in the blood
Follicle-stimulating hormone (FSH)	ovaries in females; testes in males	stimulates egg production in females; stimulates sperm production in males
Growth hormone (GH)	muscle and bone	regulates development of muscles and bones
Luteinizing hormone (LH)	ovaries in females; testes in males	stimulates progesterone and estrogen production; initiates ovulation in females; stimulates testosterone production in males
Oxytocin	uterine muscles and mammary glands	initiates uterine contractions during childbirth; stimulates flow of milk from breasts during lactation
Prolactin (PRL)	mammary glands	stimulates milk production in breasts during lactation
Thyroid-stimulating hormone (TSH)	thyroid gland	regulates secretion of the thyroid hormones—thyroxine and triiodothyronine

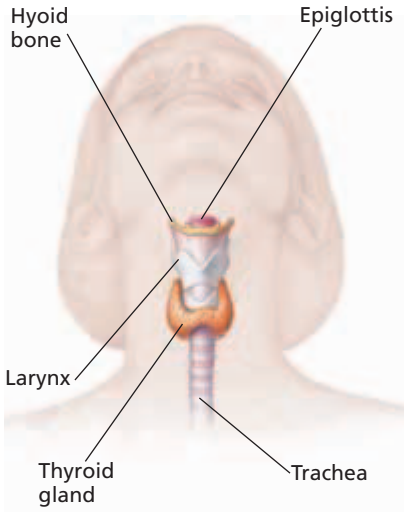


FIGURE 50-5

The thyroid gland is located under the larynx and on the trachea.

THYROID GLAND

The two lobes of the **thyroid** (THIE-ROYD) **gland** are located near the lower part of the larynx, as shown in Figure 50-5. The thyroid gland produces and secretes the hormones thyroxine (thie-RAHKS-een) and triiodothyronine (TRIE-ie-oh-DOH-THIE-roh-NEEN). Both of these hormones are derived from the same amino acid and are synthesized with iodine atoms. Thyroid-stimulating hormone (TSH) regulates the release of the thyroid hormones. Release of TSH from the anterior pituitary is regulated primarily by a releasing hormone as well as release-inhibiting hormones secreted by the hypothalamus.

The thyroid hormones help maintain normal heart rate, blood pressure, and body temperature. They stimulate enzymes that are associated with glucose oxidation and oxygen consumption, generating heat and increasing cellular metabolic rates. They also promote carbohydrate usage over fat usage for energy.

The thyroid gland is important to human development because thyroid hormones promote the development of many of the body's systems. The thyroid gland also produces calcitonin (KAL-sih-TOH-nin), a hormone that stimulates the transfer of calcium ions from blood to bone, where the calcium ions can be used to generate bone tissue. Calcitonin acts to decrease blood calcium levels.

Abnormal thyroid activity can be detrimental to the body's metabolism. Overproduction of the thyroid hormones is called hyperthyroidism (HIE-puhr-THIE-royd-iz-uhm). Symptoms of hyperthyroidism include overactivity; weight loss; and high blood pressure, heart rate, and body temperature. Hyperthyroidism can be treated with medication or by surgical removal of part of the thyroid gland.

Thyroid-hormone deficiency is known as *hypothyroidism* (HIE-poh-THIE-royd-iz-uhm). Symptoms of hypothyroidism include growth retardation, lethargy, weight gain, and low heart rate and body temperature. Hypothydroidism can also cause cretinism (KREET-uhn-IZ-uhm), a form of mental retardation, if the hypothyroidism occurs during fetal and childhood development. If hypothyroidism is caused by iodine deficiency, then goiter (GOY-tuhr), or swelling of the thyroid gland, results. Goiters resulting from iodine deficiency are now rare in the United States because iodine is added to commercially available table salt. Hypothyroidism can be treated with supplementary thyroxine.

ADRENAL GLANDS

One **adrenal gland** (uh-DREE-nuhl gland) is located above each kidney, as shown in Figure 50-6. Each adrenal gland has an inner core, the medulla, and an outer layer, the cortex. The medulla and cortex function as separate endocrine glands. Secretion of hormones in the medulla is controlled by the nervous system, whereas hormones in the anterior pituitary regulate secretion of hormones in the cortex.

Adrenal Medulla

The adrenal medulla produces two amino acid–based hormones: **epinephrine** (EP-uh-NEF-rin) and **norepinephrine** (NAWR-EP-uh-NEF-rin), also known as adrenaline (uh-DREN-uh-lin) and noradrenaline (NOR-uh-DREN-uh-lin), respectively. These hormones orchestrate the nervous system's reaction to stress and its "fight-or-flight" response to danger. When a person is stressed, the medulla secretes epinephrine and norepinephrine into the bloodstream. These hormones increase heart rate, blood pressure, blood glucose level, and blood flow to the heart and lungs. Epinephrine and norepinephrine also stimulate enlargement of the bronchial tubes and dilation of the pupils.

Adrenal Cortex

The adrenal cortex responds to adrenocorticotropic (uh-DRE-noh-KOHR-ti-koh-TROH-pik) hormone (ACTH), which is secreted by the anterior pituitary. Stress causes the hypothalamus to secrete ACTH-releasing hormone. ACTH then stimulates the adrenal cortex to produce the steroid hormone cortisol (KOHRT-uh-SAWL) and aldosterone. **Cortisol** promotes the production of glucose from proteins making usable energy available to cells. Aldosterone (al-DAHS-tuh-ROHN), helps raise blood pressure and volume by stimulating salt and water retention by the kidneys.

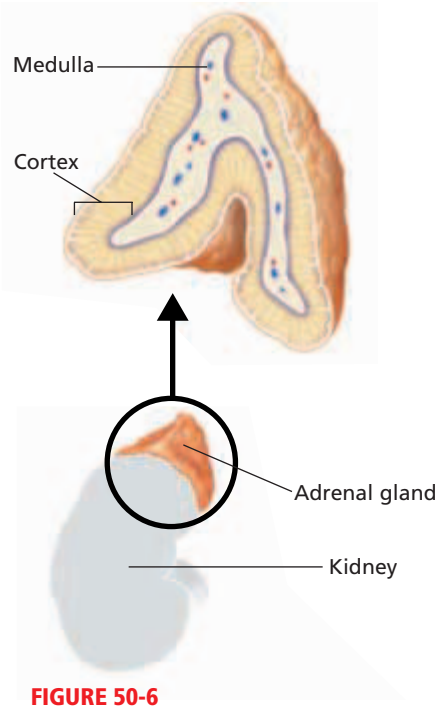


FIGURE 50-6

The adrenal glands, located above each kidney, consist of an inner medulla and an outer cortex. Epinephrine and norepinephrine are produced in the medulla. Cortisol and aldosterone are produced in the cortex.

GONADS

Gonads—the ovaries in females and the testes in males—are gamete-producing organs that also produce a group of steroid sex hormones. Sex hormones regulate body changes that begin at puberty. **Puberty** (PYOO-buhr-tee) is the adolescent stage during which the sex organs mature and secondary sex characteristics, such as facial hair, appear. During puberty in males, sperm production begins, the voice deepens, the chest broadens, and hair grows on the body and face. In females, the menstrual cycle begins, the breasts grow, and the hips widen.

When secreted by the anterior pituitary, the hormones **luteinizing** (LOO-tee-in-IZE-ing) **hormone (LH)** and **follicle-stimulating** (FOL-uh-kuhl STIM-yoo-LAYT-ing) **hormone (FSH)** stimulate secretion of sex hormones from the gonads. In females, LH and FSH stimulate secretion of **estrogen** (ES-truh-jen) and **progesterone** (proh-JES-tuh-ROHN) from the ovaries. In preparation for a possible pregnancy, these sex hormones cause the monthly release of an egg by an ovary and buildup of the uterine lining. Estrogen also regulates female secondary sex characteristics. In males, LH stimulates the testes to secrete a group of sex hormones called **androgens** (AN-druh-jenz). **Testosterone** (tes-TAHS-tuh-rohn) is an androgen that regulates male secondary sex characteristics. Along with FSH, testosterone also stimulates sperm production.

EARLY ONSET OF PUBERTY IN GIRLS

Until a few decades ago, girls began puberty at about age 11 and completed puberty by about age 13. Now, it is more common to see puberty in girls beginning at about 9 and 10 years of age and sometimes as early as 6 or 7 years of age. Researchers are investigating why puberty starts earlier in girls than it used to and what type of implications this may have for a person's health.

What is Causing the Early Onset of Puberty?

Genetics is one of several factors that influence the onset of puberty in girls. One study showed that girls with two copies of a specific version of a gene that breaks down testosterone began puberty earlier than girls with a different version of the gene.

Some researchers hypothesize that the increasing prevalence of obesity in young girls could be one factor triggering puberty. These researchers found that girls who were overweight or obese started puberty earlier than girls who were not.

Other researchers hypothesize that pollutants could be triggering the onset of early puberty. For example, there are pollutants called *hormone mimics* that behave like natural hormones. Some pollutants, called *hormone disrupters*, prevent natural hormones from functioning normally.

Most hormone disrupters interfere with the sex hormones. Such hormone disrupters prevent normal production of testosterone in males or increase the chances of sexual abnormality in females. Examples of hormone disrupters include phthalate *(THAH-late)* esters (found in plastic toys, vinyl flooring, and cosmetics), and bisphenol A and polybrominated biphenyls (used to make plastic food and drink containers).

Does Early Puberty Affect a Person's Health?

Researchers have studied the effect of early puberty on a person's health. One study investigated 1,811 sets of female twins in which one or both of the twins developed breast cancer as adults. The twin who entered puberty first was five times more likely to develop breast cancer first. The link was stronger if menstruation started earlier than average. As a result of these and other findings, many scientists and physicians are calling for more research to determine the causes of early puberty.

Many factors influence the age at which a girl begins puberty. Researchers are studying why girls today are starting puberty earlier than girls 30 years ago and what effect this may have on their health.

REVIEW

1. What are three hypotheses for the early onset of puberty?
2. **Applying Information** If humans are increasingly exposed to pollutants that act as hormone mimics or hormone disrupters, what are some possible results?
3. **Supporting Reasoned Opinions** Do you think government research agencies should fund research investigating the effects of hormone mimics and hormone disrupters on the onset of puberty? Explain.

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PANCREAS

The pancreas mostly contains exocrine cells, but specialized cells in the pancreas called the *islets of Langerhans* (LANG-uhr-HANZ) function as an endocrine gland. Shown in Figure 50-7, these endocrine cells secrete two amino acid–based hormones that regulate the level of sugar in the blood. **Insulin** (IN-suh-lin) lowers the blood sugar level by stimulating body cells, especially muscles, to store glucose or use it for energy. In contrast, glucagon (GLOO-kuh-gahn) stimulates release of glucose into the bloodstream by liver cells.

Insulin deficiency causes **diabetes mellitus** (die-uh-BEET-eez muh-LIET-uhs), a condition in which cells are unable to obtain glucose, resulting in abnormally high blood glucose concentrations. In type I diabetes the immune system attacks the insulin-producing islet cells. The cells die. Type I generally is treated with daily injections of insulin into the blood and sometimes with islet cell transplant. Type II diabetes usually occurs after age 40, and it is more common than type I. Type II is caused by insufficient insulin or less responsive target cell receptors. Although type II is hereditary, its onset correlates with obesity and an inactive lifestyle. Type II diabetes can often be controlled through exercise and diet. In diabetes, excess glucose inhibits water reabsorption by the kidneys, producing large amounts of urine. Dehydration and kidney damage can result. Lack of insulin can lead to acid-base and electrolyte imbalances. These changes may result in nausea, rapid breathing, heart irregularities, depression of the nervous system, coma, or even death.

FIGURE 50-7

A cross section of pancreatic tissue shows the islets of Langerhans (lightly colored region). These endocrine cells are surrounded by exocrine cells that produce digestive fluids. (LM 315×)

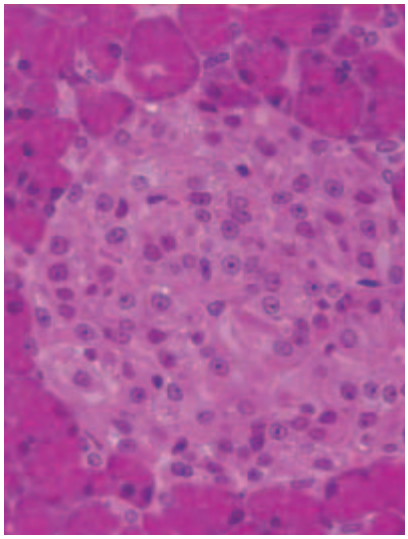


TABLE 50-2 ***Summary of Major Endocrine Glands and Their Functions***

Glands	Hormone	Function
Adrenal cortex	aldosterone cortisol	promotes salt and water retention promotes production of glucose from proteins
Adrenal medulla	epinephrine, norepinephrine	initiate body's response to stress and the "fight-or-flight" response to danger
Ovaries	estrogen progesterone	regulates female secondary sex characteristics maintains growth of uterine lining
Pancreas (islets of Langerhans)	glucagon insulin	stimulates release of glucose stimulates absorption of glucose by cells
Parathyroid glands	parathyroid hormone	increases blood calcium concentration
Pineal gland	melatonin	regulates sleep patterns
Pituitary gland	see Table 50-1	see Table 50-1
Testes	androgens (testosterone)	regulate male secondary sex characteristics; stimulate sperm production
Thymus gland	thymosin	stimulates T-cell maturation
Thyroid gland	thyroxine, triiodothyronine calcitonin	regulate metabolism and development decreases blood calcium concentration

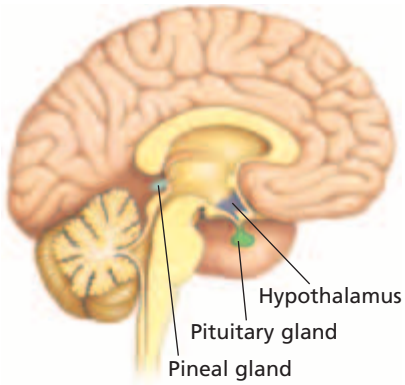


FIGURE 50-8

The pineal gland, located near the base of the brain, secretes the hormone melatonin at night.

Excessive insulin causes *hypoglycemia* (HIE-poh-glie-SEE-mee-uh), a disorder in which glucose is stored, rather than being properly delivered to body cells. This leads to a lowered blood glucose concentration and subsequent release of glucagon and epinephrine. Symptoms of hypoglycemia include lethargy, dizziness, nervousness, overactivity, and in extreme cases, unconsciousness and death.

OTHER ENDOCRINE GLANDS

There are several other glands in the endocrine system, including the thymus gland, the pineal gland, and the parathyroid glands. There are also specialized endocrine cells in the brain, stomach, small intestine, liver, and other organs. The major endocrine glands and their functions are listed in Table 50-2.

Thymus Gland

The thymus (THIE-muhs) gland, located beneath the sternum and between the lungs, plays a role in the development of the immune system. The thymus gland secretes *thymosin* (THIE-moh-sin), an amino acid–based hormone that stimulates maturation of T cells, which help defend the body from pathogens.

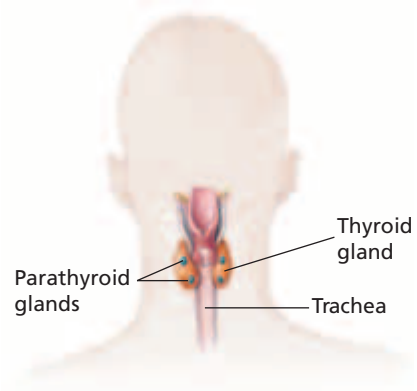
Pineal Gland

The pineal (PIEN-ee-uhl) gland is located near the base of the brain, as shown in Figure 50-8. It secretes the hormone melatonin. **Melatonin** (mel-uh-TOH-nin) concentrations increase sharply at night and decrease dramatically during the day. This cyclic release of melatonin suggests that it helps regulate sleep patterns.

Parathyroid Glands

FIGURE 50-9

As shown from this back view of the head, the four parathyroid glands are located on the posterior side of the thyroid gland. They secrete a hormone that regulates the concentration of calcium ions in the blood.

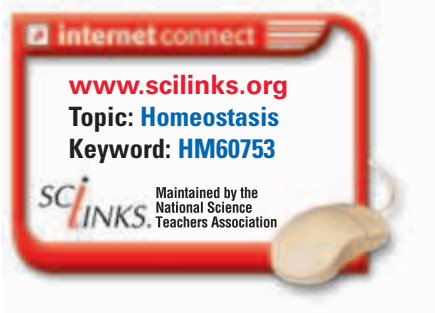


As Figure 50-9 shows, the four parathyroid glands are embedded in the back of the thyroid gland, two in each lobe. These glands secrete *parathyroid hormone,* which stimulates the transfer of calcium ions from the bones to the blood. Thus, parathyroid hormone has the opposite effect of calcitonin. A proper balance of calcium ions is necessary for cell division, muscle contraction, blood clotting, and neural signaling.

Digestive Cells

Endocrine cells within the walls of some digestive organs also secrete a variety of hormones that control digestive processes. For example, when food is eaten, endocrine cells in the stomach lining secrete *gastrin* (GAS-trin), a hormone that stimulates other stomach cells to release digestive enzymes and hydrochloric acid. Endocrine cells of the small intestine release *secretin* (si-KREE-tin), a hormone that stimulates the release of various digestive fluids from the pancreas.

FEEDBACK MECHANISMS



Homeostasis is defined as a stable internal environment. The endocrine system plays an important role in the maintenance of homeostasis because hormones regulate the activities of cells, tissues, and organs throughout the body. To maintain homeostasis, feedback mechanisms control hormone secretion. A feedback mechanism is one in which the last step in a series of events controls the first. Feedback mechanisms can be negative or positive. Most hormone systems use negative feedback.

Negative Feedback

In **negative feedback,** the final step in a series of events inhibits the initial signal in the series. An example of negative feedback in regulating the levels of thyroid hormones is shown in Figure 50-10. When the hypothalamus detects low levels of thyroid hormones, it secretes a hormone called thyrotropin releasing hormone (TRH) to the anterior pituitary. TRH stimulates the anterior pituitary to secrete thyroid-stimulating hormone (TSH) into the bloodstream. TSH stimulates the thyroid gland to secrete thyroid hormones. When the thyroid hormone levels are high, two major negative feedback loops operate, as shown by the negative signs in Figure 50-10. In one loop, the thyroid hormones act on the hypothalamus to inhibit the release of TRH. In the second loop, the thyroid hormones act on the anterior pituitary to inhibit the release of TSH. The result is that the level of thyroid hormones in the blood decreases. In turn, this decrease causes the amount of negative feedback inhibition to decline. The interplay of these mechanisms helps to keep the concentration of thyroid hormones relatively stable.

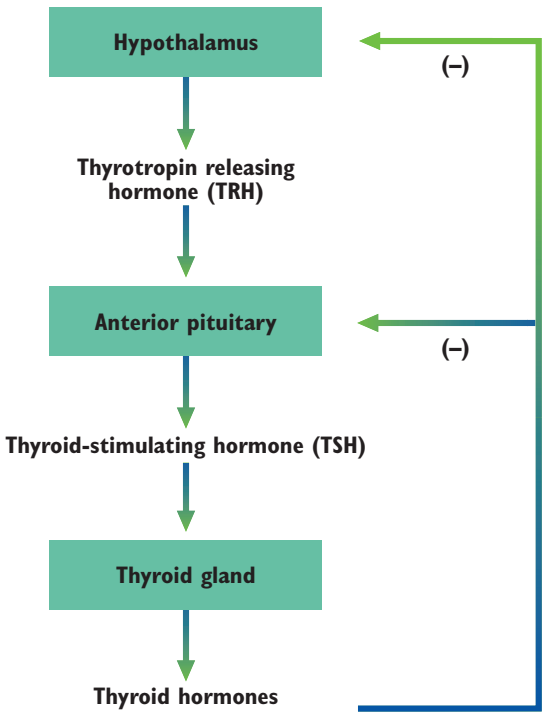


FIGURE 50-10
The thyroid hormones regulate cellular metabolic rates through several negative feedback mechanisms. Two are shown. High concentrations of thyroid hormones inhibit the hypothalamus from releasing TRH and the anterior pituitary from releasing TSH.

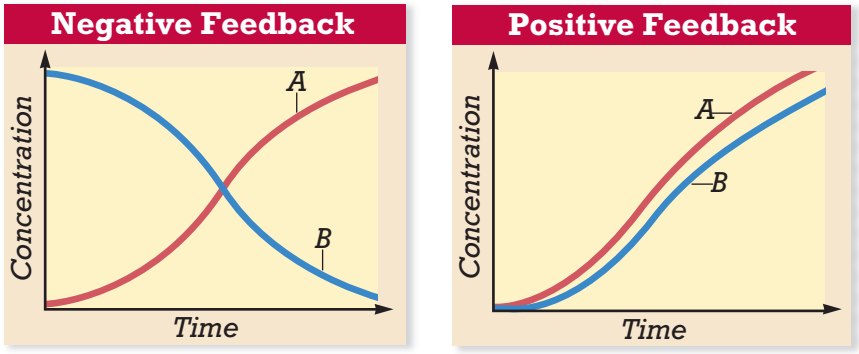


FIGURE 50-11
In negative feedback, a secondary substance (A) inhibits production of the initial stimulating substance (B). In positive feedback, a secondary substance (A) stimulates production of the initial stimulating substance (B).

Positive Feedback

When hormones are regulated by **positive feedback,** release of an initial hormone stimulates release or production of other hormones or substances, which stimulate further release of the initial hormone. For example, increased estrogen concentrations stimulate a surge in luteinizing hormone secretion prior to ovulation. Figure 50-11 illustrates the difference between negative and positive feedback systems.

Antagonistic Hormones

A number of hormones work together in pairs to regulate the levels of critical substances. These hormones are referred to as *antagonistic hormones* because their actions have opposite effects.

Glucagon and insulin are examples of antagonistic hormones. They maintain a specific level of blood glucose in the blood. When the level of glucose in the blood is high, such as after eating a meal, insulin triggers the transfer of glucose from the blood into the body cells for storage or immediate use. In contrast, when the level of glucose in the blood is low, such as between meals, glucagon promotes the release of glucose into the blood from storage sites in the liver and elsewhere. Together, insulin and glucagon ensure that the level of glucose in the blood is maintained. Calcitonin and parathyroid hormone are other examples of antagonistic hormones.

Word Roots and Origins

antagonistic

from the Greek *anti,* meaning "against" and *agonizesthai,* meaning "to contend for a prize"

SECTION 2 REVIEW

1. How do the hypothalamus and the pituitary gland interact to control the release of some of the hormones in the endocrine system?
2. List six major endocrine glands and the function of these glands.
3. How do feedback mechanisms help maintain homeostasis?
4. How do negative feedback mechanisms differ from positive feedback mechanisms?
5. Compare the effects of glucagon and insulin on blood glucose levels.

CRITICAL THINKING

6. **Relating Concepts** A classmate states that hormones from the adrenal medulla, but not from the adrenal cortex, are secreted in response to stress. Do you agree? Explain.
7. **Applying Information** Why might overactive parathyroid glands cause bone problems?
8. **Evaluating Models** Dietary iodine is needed for the body to make thyroid hormones. How would lack of dietary iodine affect the negative feedback of the thyroid hormones?

CHAPTER HIGHLIGHTS

SECTION 1 Hormones

- Hormones are chemical messengers secreted by cells that act to regulate the activity of other cells.
- Hormones have many functions, including regulation of growth; maintenance of homeostasis; and regulation of energy production, use, and storage.
- Ductless glands called endocrine glands make most of the body's hormones. Specialized cells in the brain, stomach, and other organs also make and release hormones. Exocrine glands secrete nonhormonal chemicals into specific body locations.
- Amino acid–based hormones bind to cell-membrane receptors of their target cells, activating a second messenger that then activates or deactivates enzymes in a cascade fashion.
- Steroid and thyroid hormones bind to receptors inside the cell. The hormone-receptor complex binds to DNA in the nucleus and turns genes either on or off.
- Similar to hormones, neuropeptides and prostaglandins act on nearby cells to regulate cellular activities.

Vocabulary

hormone (p. 1031)
endocrine gland (p. 1031)
endocrine system (p. 1031)
exocrine gland (p. 1031)
amino acid–based hormone (p. 1031)
steroid hormone (p. 1031)
target cell (p. 1032)
receptor (p. 1032)
second messenger (p. 1032)
neuropeptide (p. 1033)
prostaglandin (p. 1033)

SECTION 2 Endocrine Glands

- The hypothalamus and pituitary gland serve as the major control centers for the release of many hormones.
- The thyroid gland secretes thyroid hormones that regulate metabolism and development and calcitonin that helps regulate blood calcium levels.
- The adrenal glands secrete epinephrine, norepinephrine, cortisol, aldosterone, and other hormones that help regulate metabolism, the body's responses to stress and danger, and water balance.
- The gonads secrete estrogen and progesterone in females and androgens, including testosterone, in males. These hormones regulate reproductive functions.
- The islets of Langerhans of the pancreas secrete glucagon and insulin, which regulate blood glucose levels.
- Other endocrine glands include the thymus gland, the pineal gland, the parathyroid glands, and endocrine cells of the digestive system.
- Feedback mechanisms help maintain homeostasis.
- In negative feedback, the final product in a series inhibits the first step. Many hormones use negative feedback systems because they prevent excess accumulation of a hormone product.
- In positive feedback, the final product in a series stimulates the first step.
- Antagonistic hormones, such as glucagon and insulin, work together to regulate the levels of critical substances.

Vocabulary

hypothalamus (p. 1034)
pituitary gland (p. 1034)
thyroid gland (p. 1036)
adrenal gland (p. 1036)
epinephrine (p. 1037)
norepinephrine (p. 1037)
cortisol (p. 1037)
gonad (p. 1037)
puberty (p. 1037)
luteinizing hormone (p. 1037)
follicle-stimulating hormone (p. 1037)
estrogen (p. 1037)
progesterone (p. 1037)
androgen (p. 1037)
testosterone (p. 1037)
insulin (p. 1039)
diabetes mellitus (p. 1039)
melatonin (p. 1040)
negative feedback (p. 1041)
positive feedback (p. 1042)

CHAPTER REVIEW

USING VOCABULARY

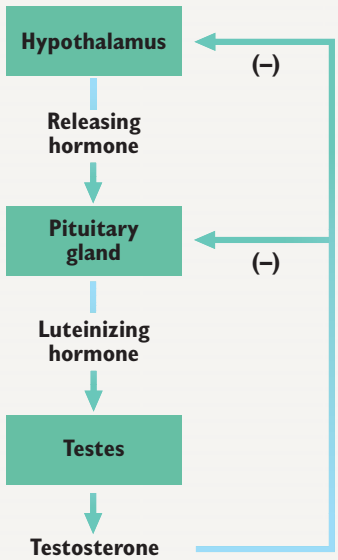
1. For each set of terms, choose the one that does not belong, and then explain why it does not belong.
   a. *insulin, prostaglandin, glucagon*
   b. *oxytocin, epinephrine, antidiuretic hormone*
   c. *aldosterone, cortisol, glucagon*
2. Explain the relationship between the following pairs of terms:
   a. *target cells* and *receptors*
   b. *pituitary gland* and *thyroid gland*
   c. *exocrine gland* and *endocrine gland*
3. Use the following terms in the same sentence: *estrogen, progesterone,* and *testosterone.*
4. **Word Roots and Origins** In Greek, the word *hormon* means "to excite." Why was the name *hormones* chosen for these molecules?

UNDERSTANDING KEY CONCEPTS

5. **Identify** four major functions of hormones.
6. **Differentiate** how endocrine glands differ from exocrine glands.
7. **Sequence** the steps that occur when most amino acid–based hormones act on their target cells.
8. **Sequence** the steps that occur when a steroid or thyroid hormone acts on its target cell.
9. **Describe** why neuropeptides and prostaglandins are hormones.
10. **Describe** two ways in which the endocrine system and the nervous system are similar.
11. **Discuss** how the hypothalamus and the pituitary gland interact to control the release of many hormones.
12. **Summarize** the major functions of the thyroid hormones.
13. **Name** the two hormones in the adrenal medulla that are released when a person experiences stress.
14. **State** the two hormones that stimulate secretion of the sex hormones from the gonads.
15. **Summarize** the nonhereditary factors that are associated with the onset of type II diabetes.
16. **Describe** how the hormone gastrin helps in the process of digestion.
17. **Summarize** the role of feedback mechanisms in maintaining homeostasis.
18. **Explain** why positive feedback is not an efficient way to control hormone levels.
19. **Explain** how negative feedback regulates the level of thyroid hormones.
20. **Describe** how insulin and glucagon work together as antagonistic hormones to control the level of glucose in the blood.
21. **CONCEPT MAPPING** Use the following terms to create a concept map that describes the endocrine system: *hypothalamus, pituitary gland, thyroid gland, hormones, adrenal glands, pancreas,* and *target cell.*

CRITICAL THINKING

22. **Making Comparisons** Why might damage to the pituitary gland be considered far more serious than damage to one of the other endocrine glands?
23. **Inferring Relationships** Describe the importance of "fit" between a receptor protein and a hormone.
24. **Analyzing Graphics** Identify and describe the type of feedback mechanism operating in the diagram shown below.



Standardized Test Preparation

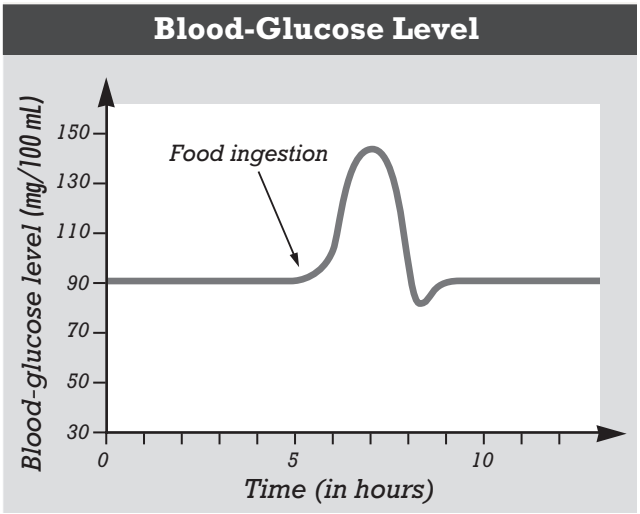
DIRECTIONS: Choose the letter of the answer choice that best answers the question.

1. What are the chemical messengers of the endocrine system called?
- **A.** neurons
- **B.** hormones
- **C.** blood cells
- **D.** carbohydrates

2. *X* and *Y* are hormones. *X* stimulates the secretion of Y, which exerts negative feedback on the cells that secrete *X*. Suppose the level of Y decreases. What should happen immediately afterwards?
- **F.** Less *X* is secreted.
- **G.** More *X* is secreted.
- **H.** Secretion of *Y* stops.
- **J.** Secretion of *X* stops.

3. Endocrine glands
- **A.** function only after puberty.
- **B.** function only before puberty.
- **C.** release products through ducts.
- **D.** release products into the bloodstream.

INTERPRETING GRAPHICS: Study the figure below to answer the following questions.



4. What happens after food is eaten?
- **F.** Blood glucose levels increase.
- **G.** Blood glucose levels decrease.
- **H.** Blood glucose levels remain the same.
- **J.** Blood glucose levels decrease and then increase.

5. Which hormones are primarily responsible for the changes in blood glucose levels about 2 hours after food is eaten?
- **A.** insulin
- **B.** estrogen and progesterone
- **C.** epinephrine and norepinephrine
- **D.** aldosterone and parathyroid hormones

DIRECTIONS: Complete the following analogy:

6. neurotransmitters : nervous system :: hormones :
- **F.** feedback system
- **G.** endocrine system
- **H.** circulatory system
- **J.** respiratory system

INTERPRETING GRAPHICS: The table below gives the relative levels of thyroid-stimulating hormone (TSH) during a 12 hour period. Use the table below to answer the question that follows.

Time (hours)	Blood level of thyroid-stimulating hormone
0	normal
4	high
8	normal
12	low

7. Thyroid-stimulating hormone (TSH) is a hormone that stimulates the release of the thyroid hormones from the thyroid gland. At what time would you expect thyroid hormone levels to be at their lowest?
- **A.** 0 hours
- **B.** 4 hours
- **C.** 8 hours
- **D.** 12 hours

SHORT RESPONSE

The pancreas is an organ that carries out many functions related to digestion.

Explain why the pancreas is considered to be both an exocrine gland and an endocrine gland.

EXTENDED RESPONSE

The endocrine system is involved in maintaining homeostasis. Many of the activities regulated by the endocrine system require maintaining a critical substance at levels that do not vary much.

Part A Explain how pairs of hormones are involved in regulating levels of critical substances.

Part B Describe a specific example of a pair of hormones that work together to maintain the level of a critical substance.

Test TIP Sometimes, only one part of a graph or table is needed to answer a question. In such cases, focus only on that information to answer the question.

Observing the Effects of Thyroxine on Frog Metamorphosis

OBJECTIVES

- Observe the effects of the hormone thyroxine on the development of tadpoles.

PROCESS SKILLS

- observing
- measuring
- comparing and contrasting
- organizing data
- inferring

MATERIALS

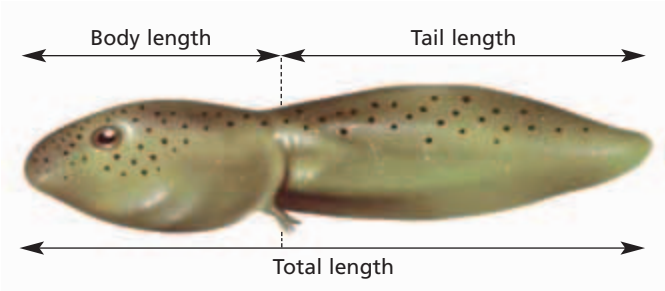
- safety goggles
- protective gloves
- lab apron
- glass-marking pencil
- six 600 mL beakers
- pond water
- 10 mL graduated cylinder
- 0.01% thyroxine solution
- strained spinach
- graph paper marked in 1 mm squares
- Petri dish
- small fish net
- 9 tadpoles with budding hind legs
- 3 pencils in different colors

Background

1. What is a hormone?
2. What is metamorphosis?
3. Describe the stages of frog development.
4. What are the effects of thyroxine in humans?
5. What effects do you predict the hormone thyroxine will have on tadpole growth and development?

PART A Setting Up the Experiment

1. In your lab report, make a data table similar to the one shown on the facing page.
2. Use a glass-marking pencil to label three beakers "A" "B" and "C". Also, write your initials on the beakers.
3. Add 500 mL of pond water to each beaker.
4.  **CAUTION Put on a lab apron and safety goggles. If you get thyroxine on your skin or clothing, rinse with water while calling to your teacher. If you get thyroxine in your eyes, immediately flush them with water at the eyewash station while calling to your teacher.**
5. Use a graduated cylinder to measure 10 mL of thyroxine solution. Add the 10 mL of solution to beaker A. Measure and add 5 mL of thyroxine solution to beaker B.
6. Add equal amounts (about 1 mL) of strained spinach to beakers A, B, and C.
7. Place a sheet of graph paper, ruled side up, under a Petri dish.
8.  **CAUTION You will be working with live animals. Handle them with care, and follow directions carefully.** Catch a tadpole with a fish net, and place the tadpole in the Petri dish. Measure the tadpole's total length, tail length, and body length in millimeters by counting the number of squares that it covers on the graph paper. Then, place the tadpole in beaker A.



9. Repeat step 8 with two more tadpoles. Average the total length, tail length, and body length of the three tadpoles that you placed in beaker A. In your data table, record the average measurements under the column labeled "Beaker A."

10. Repeat step 8 with three more tadpoles, this time placing the tadpoles in beaker B. Average the total length, tail length, and body length of the three tadpoles. Record your average measurements in your data table under "Beaker B."
11. Repeat step 8 with three more tadpoles. Place these three tadpoles in beaker C. Average the total length, tail length, and body length of the three tadpoles. Record your average measurements in your data table under "Beaker C." You should have measured a total of nine tadpoles and placed three in each beaker.
12.  Clean up your materials, and wash your hands before leaving the lab.

PART B Observing the Effects of Thyroxine on Tadpoles

13. Feed each beaker of tadpoles 1 mL of spinach every other day. Be careful not to overfeed the tadpoles. Change the water in the beakers every 4 days, adding thyroxine solution in the original amounts to beakers A and B. Label the beakers, and do not mix up the tadpoles during the water changes.
14. Measure the tadpoles once a week for 3 weeks, and average the length of the tadpoles in each beaker. Record the average lengths in your data table.
15. Calculate the average growth per week for each set of three tadpoles. For example, the average growth in total length during the second week is equal to the average total length at the end of week 2 minus the average total length at the end of week 1. Record your values in the appropriate spaces of your data table.
16. Graph your data using a different colored pencil for the tadpoles in each beaker. Label the horizontal axis "Time in weeks," and label the vertical axis "Length in centimeters." You should have three graphs. Each graph should include the changes in average total length, average tail length, and average body length for one group of tadpoles.
17.  Clean up your materials, and wash your hands before leaving the lab.

Analysis and Conclusions

1. Did this investigation include a control group? If so, describe it. If not, suggest a possible control that you could have used.
2. Why are three tadpoles used for each beaker rather than just one?
3. According to the data that you collected in this investigation, what is the effect of thyroxine on tadpole metamorphosis?
4. Which concentration of thyroxine solution caused the greatest visible change in the tadpoles?
5. How do average body length and tail length change during metamorphosis?

Further Inquiry

Iodine, typically in the form of iodide, is needed to make thyroxine. Design—but do not conduct—an experiment that shows the effect of adding iodine to water that contains tadpoles. **CAUTION: Iodine is a highly poisonous substance.**

MEASUREMENT OF TADPOLE GROWTH

	Beaker A			Beaker B			Beaker C		
	Average total length	Average tail length	Average body length	Average total length	Average tail length	Average body length	Average total length	Average tail length	Average body length
Initial									
End of week 1									
End of week 2									
End of week 3									

CHAPTER 51

REPRODUCTIVE SYSTEM

This is a photograph of an 8-week-old fetus. Notice the umbilical cord and the placenta, through which oxygen and nutrients are passed from the mother to the fetus. The umbilical cord and the placenta function as the lifeline between the fetus and its mother.

MALE REPRODUCTIVE SYSTEM

The gonads—testes and ovaries—are endocrine glands that secrete sex hormones. However, the primary function of the gonads is not to produce hormones but to produce and store gametes—sperm and eggs. Other organs in the male reproductive system prepare sperm for the possible fertilization of an egg.

SECTION 1

OBJECTIVES

- **Identify** the major structures of the male reproductive system.
- **Describe** the function of each structure of the male reproductive system.
- **Relate** the structure of a human sperm cell to its function.
- **Trace** the path that sperm follow in leaving the body.

VOCABULARY

testis
seminiferous tubule
scrotum
epididymis
vas deferens
seminal vesicle
prostate gland
bulbourethral gland
semen
penis
ejaculation

MALE REPRODUCTIVE STRUCTURES

Sexual reproduction involves the formation of a diploid zygote from two haploid gametes through fertilization. The roles of a male in sexual reproduction are to produce sperm cells and to deliver the sperm cells to the female reproductive system to fertilize an egg cell.

The male reproductive system contains two egg-shaped testes. The **testes** (TES-TEEZ) (singular, *testis*) are the gamete-producing organs of the male reproductive system. Each testis, which is about 4 cm (1.5 in.) long and 2.5 cm (1 in.) in diameter, has about 250 compartments. As shown in Figure 51-1, these compartments contain many tightly coiled tubules, called **seminiferous** (SEM-uh-NIF-uhr-uhs) **tubules.** Each seminiferous tubule is approximately 80 cm (32 in.) long. If all of the tubules in both testes were stretched out end to end, they would extend about 500 m (1,640 ft). Sperm form through meiosis in the specialized lining of this extensive network of tubules.

The testes develop within the abdominal cavity. Before a male is born, the testes leave this cavity and descend into an external sac called the **scrotum** (SKROHT-uhm). The temperature within the scrotum is about 2°C to 3°C cooler than the temperature inside the abdomen. Normal body temperature, 37°C, is too high to allow sperm to complete development. The slightly cooler temperature of the scrotum is necessary for the development of normal sperm.

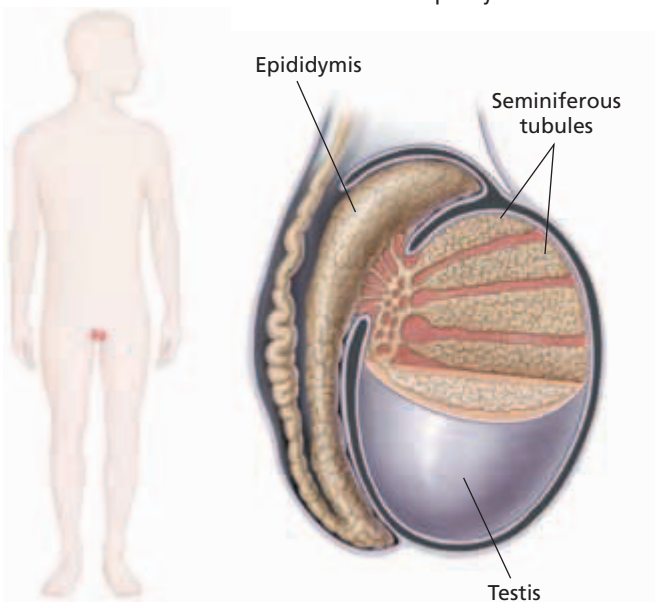


FIGURE 51-1
Sperm are formed continuously within the seminiferous tubules, which make up the bulk of each testis. Before leaving the body, sperm mature and are stored in each epididymis.

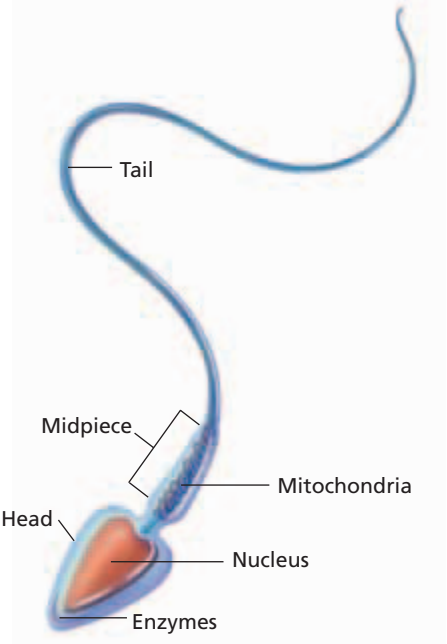


FIGURE 51-2

A mature sperm is an elongated cell with three distinct parts (a head, a midpiece, and a tail), all of which are enclosed by a cell membrane.

FORMATION OF SPERM

Males begin to produce sperm during puberty, the adolescent stage of development when changes in the body make reproduction possible. Two hormones released by the anterior pituitary regulate the functioning of the testes. Luteinizing hormone (LH) stimulates secretion of the sex hormone testosterone. Testosterone is the main androgen (male sex hormone) produced by the testes. Cells located between the seminiferous tubules secrete testosterone. Follicle-stimulating hormone (FSH), along with testosterone, stimulates sperm production in the seminiferous tubules. A male will continue to produce sperm as long as his testosterone level is high enough—usually for most of his life.

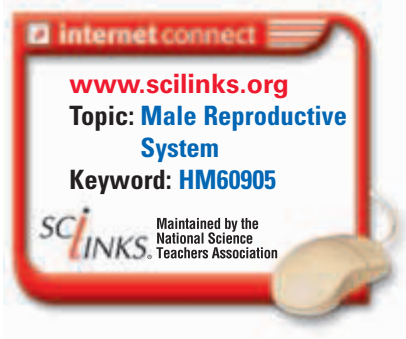
The formation of gametes in humans involves the process of meiosis. Meiosis results in a reduction of the number of chromosomes from the diploid ($2n$) number to the haploid ($1n$) number. As the cells that produce sperm within the testes undergo meiosis, their chromosome number drops from 46 to 23. Four sperm cells result from each cell that begins meiosis. These immature sperm then undergo significant changes that prepare the sperm for passage through the female reproductive system.

The structure of a mature sperm is shown in Figure 51-2. Notice that a mature sperm consists of three regions—a head, a midpiece, and a tail, or flagellum. The tip of the head region contains enzymes. During fertilization, these enzymes help the sperm penetrate the protective layers that surround an egg cell. Also located in the head region are the 23 chromosomes that will be delivered to the egg. The midpiece is packed with mitochondria. These mitochondria supply the energy that is required for sperm to reach an egg. The tail consists of a single, powerful flagellum that propels the sperm.

Path of Sperm Through the Male Body

Mature sperm move through and past several other male reproductive structures, some of which further prepare the sperm for a possible journey through the female reproductive system. The path taken by sperm as they exit the body is shown in Figure 51-3.

Sperm move from the seminiferous tubules in the testes to the **epididymis** (EP-uh-DID-i-mis), a long, coiled tubule that is closely attached to each testis. Within each epididymis, a sperm matures and gains the ability to swim as its flagellum completes development. Although most sperm remain stored in each epididymis, some leave the epididymis and pass through the **vas deferens** (vas DEF-uh-RENZ), a duct that extends from the epididymis. Smooth muscles that line each vas deferens contract to help move sperm along as they exit the body. Each vas deferens enters the abdominal cavity, where it loops around the urinary bladder and merges with the urethra. The urethra is the duct through which urine exits the urinary bladder. Thus, in a male, both urine and sperm exit the body through the urethra, but not at the same time.



In the urethra, sperm mix with fluids that are secreted by three exocrine glands—the seminal vesicles, the prostate gland, and the bulbourethral (buhl-boh-yoo-REE-thruhl) glands. Ducts that extend from these glands connect with the urethra. The glands secrete fluids that nourish and protect the sperm as they move through the female reproductive system. The **seminal vesicles,** which lie between the bladder and the rectum, produce a fluid rich in sugars that sperm use for energy. The **prostate** (PRAHS-tayt) **gland,** which is located just below the bladder, secretes an alkaline fluid that neutralizes the acids in the female reproductive system. Before sperm leave the body, the **bulbourethral glands** secrete an alkaline fluid that neutralizes traces of acidic urine in the urethra. Together, sperm and these secretions form a fluid called **semen** (SEE-muhn). To help sperm move through the female reproductive system, semen also contains prostaglandins that stimulate contractions of smooth muscles that line the female reproductive tract.

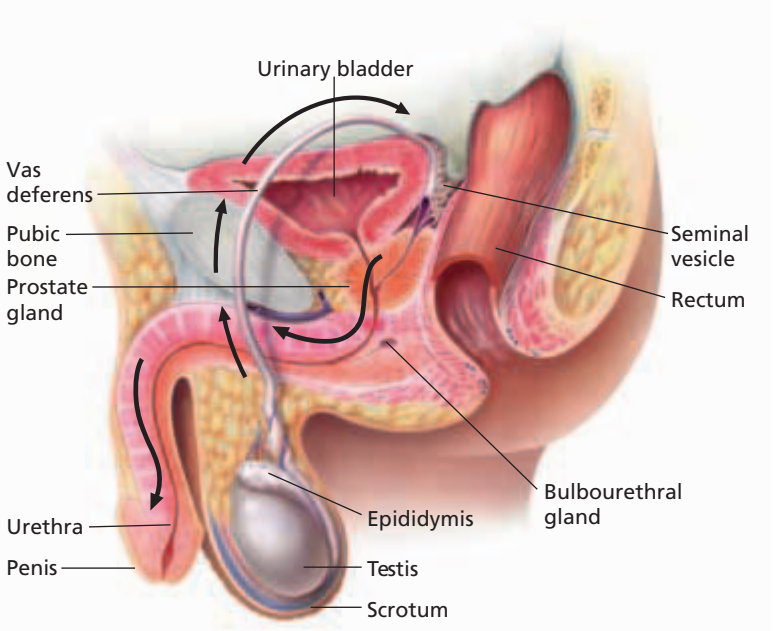


FIGURE 51-3
The male reproductive system consists of several internal and external structures. Arrows indicate the path taken by sperm as they leave the body.

Delivery of Sperm

The urethra passes through the **penis,** the organ that deposits sperm in the female reproductive system. When a male becomes sexually aroused, the spongy tissue in the penis, which is shown in Figure 51-4, fills with blood. This causes the penis to become erect, enabling it to deposit sperm. Semen is forcefully expelled from the penis by contractions of the smooth muscles that line the urethra. This process is called **ejaculation** (ee-JAK-yoo-LAY-shun). Each ejaculation expels 3 to 4 mL (0.10 to 0.14 fl oz) of semen. Sperm make up only 10 percent of this volume. Although a single ejaculation can expel 300 million to 400 million sperm, very few of these sperm reach the site of fertilization. Most sperm are killed by the acidic environment of the female reproductive tract.

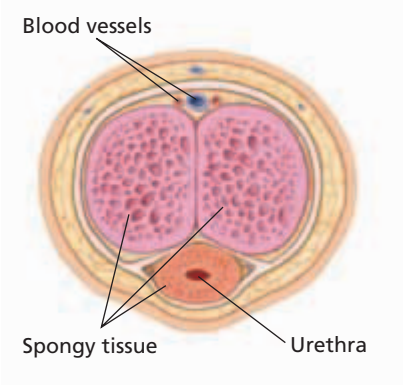


FIGURE 51-4
When the spaces in the spongy tissue of the penis fill with blood, the penis becomes erect.

SECTION 1 REVIEW

1. Explain why the testes are found in the scrotum and not inside the male body.
2. Describe a mature sperm.
3. Describe the path that sperm take in exiting the body.
4. What is the function of the vas deferens?
5. Which structures in a male produce fluids that mix with sperm to form semen?

CRITICAL THINKING

6. **Applying Information** Why are so many sperm produced by the male reproductive system?
7. **Making Comparisons** In what way are sperm different from the body's other cells?
8. **Analyzing Concepts** The wearing of tight underwear has been linked to low sperm counts in some men. Explain how such clothing could lead to low sperm counts.

SECTION 2

OBJECTIVES

- **Identify** the major structures of the female reproductive system.
- **Describe** the function of each structure of the female reproductive system.
- **Describe** how eggs are produced.
- **Summarize** the stages of the ovarian cycle.

VOCABULARY

ovary
fallopian tube
uterus
cervix
vagina
vulva
labium
ovum
ovarian cycle
menstrual cycle
follicular phase
follicle
ovulation
corpus luteum
luteal phase
menstruation
menopause

FEMALE REPRODUCTIVE SYSTEM

Like the testes, the female gonads—ovaries—are endocrine glands that produce gametes. The female reproductive system prepares the female gametes—eggs—for possible fertilization. It also contains structures that enable fertilization to occur and that house and nourish a developing baby.

FEMALE REPRODUCTIVE STRUCTURES

The female reproductive system contains two almond-shaped ovaries that are located in the lower abdomen. The **ovaries** (OH-vuh-reez) are the gamete-producing organs of the female reproductive system. Eggs mature near the surface of the ovaries, which are about 3.5 cm (1.4 in.) long and 2 cm (0.8 in.) in diameter. A mature egg is released into the abdominal cavity, where it is swept by cilia into the opening of a nearby **fallopian** (fuh-LOH-pee-uhn) **tube,** or uterine tube. Smooth muscles lining the fallopian tube contract rhythmically and move the mature egg down the tub. The fallopian tube leads to the uterus (YOOT-uhr-uhs), as shown in Figure 51-5. The **uterus** is a hollow, muscular organ about the size of a small fist. If an egg is fertilized, it will develop in the uterus.

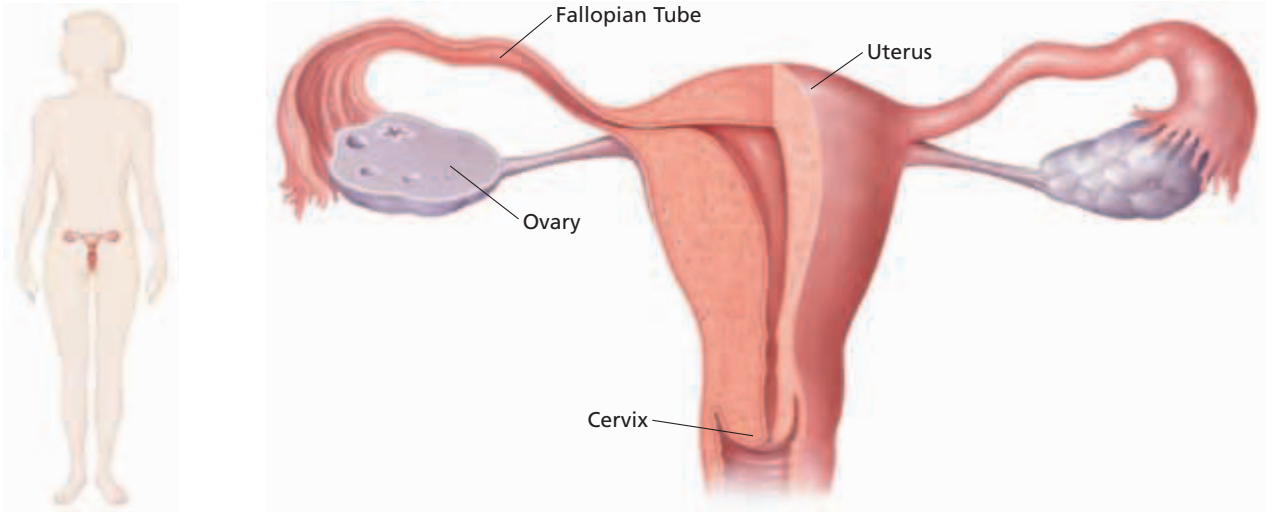


FIGURE 51-5
Ovaries are the gamete-producing organs of the female reproductive system. The uterus nurtures the fetus during pregnancy.

The lower entrance to the uterus is called the **cervix** (SUHR-VIKS). A sphincter muscle in the cervix controls the opening to the uterus. Leading from the cervix to the outside of the body is a muscular tube called the **vagina** (vuh-JIE-nuh), as shown in Figure 51-6. The vagina receives sperm from the penis; it is also the channel through which a baby passes during childbirth. The external structures of the female reproductive system are collectively called the **vulva** (VUHL-vuh). The vulva includes the **labia** (LAY-bee-uh) (singular, *labium*), folds of skin and mucous membranes that cover and protect the opening to the female reproductive system.

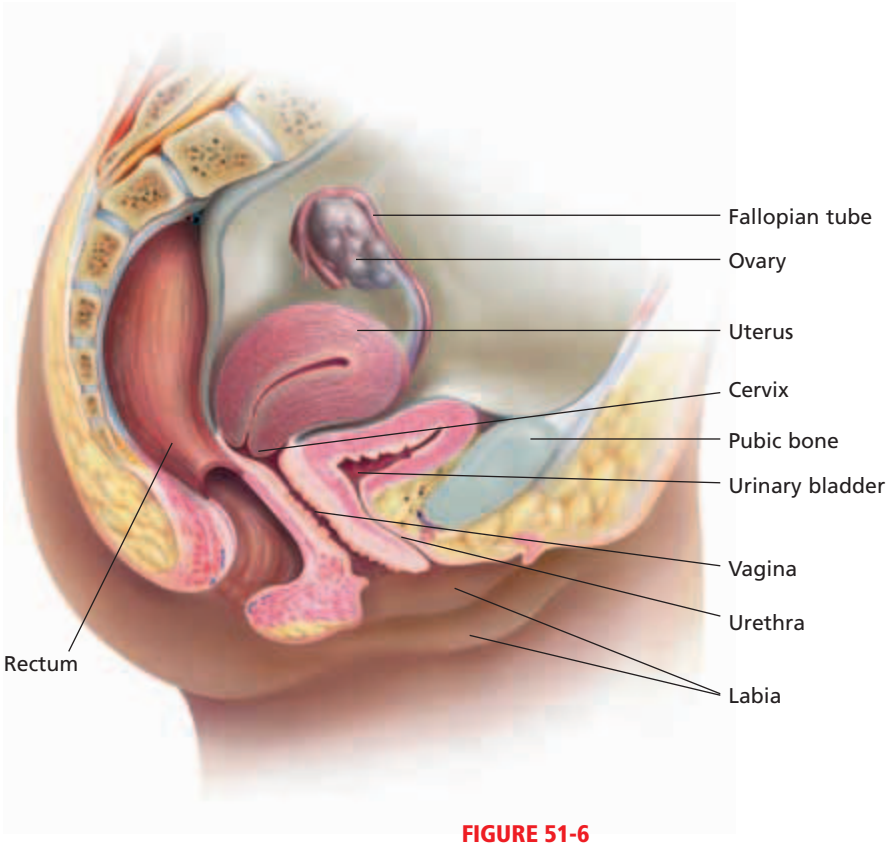


FIGURE 51-6
The female reproductive system consists of several internal and external structures that enable fertilization and development.

FORMATION OF EGGS

A female is born with more than 400,000 eggs in her ovaries. These eggs are immature and cannot be fertilized. Typically, a female will release 300 to 400 mature eggs during her lifetime, averaging one egg about every 28 days from puberty to about age 50. Thus, less than 1 percent of her eggs will mature.

Like sperm formation, egg formation occurs through meiosis. So, each mature egg cell has 23 chromosomes (the haploid number). Unlike sperm formation—in which four functional sperm result from each cell that begins meiosis—egg formation results in one functional egg from each cell that begins meiosis. All immature eggs begin meiosis but stall in prophase I until the female reaches puberty, when the sex hormones stimulate egg maturation. Then, every 28 days these hormones signal 10 to 20 immature eggs to resume meiosis. Generally, only one of these eggs completes meiosis I and is released from an ovary. Meiosis I produces two haploid cells. One cell receives most of the cytoplasm and can go on to become a mature egg. The second haploid cell, or first polar body, contains a very small amount of cytoplasm. In humans, the first polar body usually dies without dividing again. Meiosis II is not completed unless a sperm fertilizes the egg. If fertilized, the egg completes the final meiotic division by dividing into a mature egg and a second polar body. The mature egg, or **ovum** (OH vuhm), retains most of the cytoplasm, which provides nutrients for the egg through the early stages of development. The second polar body dies. An ovum, shown in Figure 51-7, is about 75,000 times larger than a sperm and is visible to the unaided eye.

FIGURE 51-7
This ovum is being approached by a single sperm. Notice the tremendous size difference between the egg and the sperm.

Word Roots and Origins

menstrual

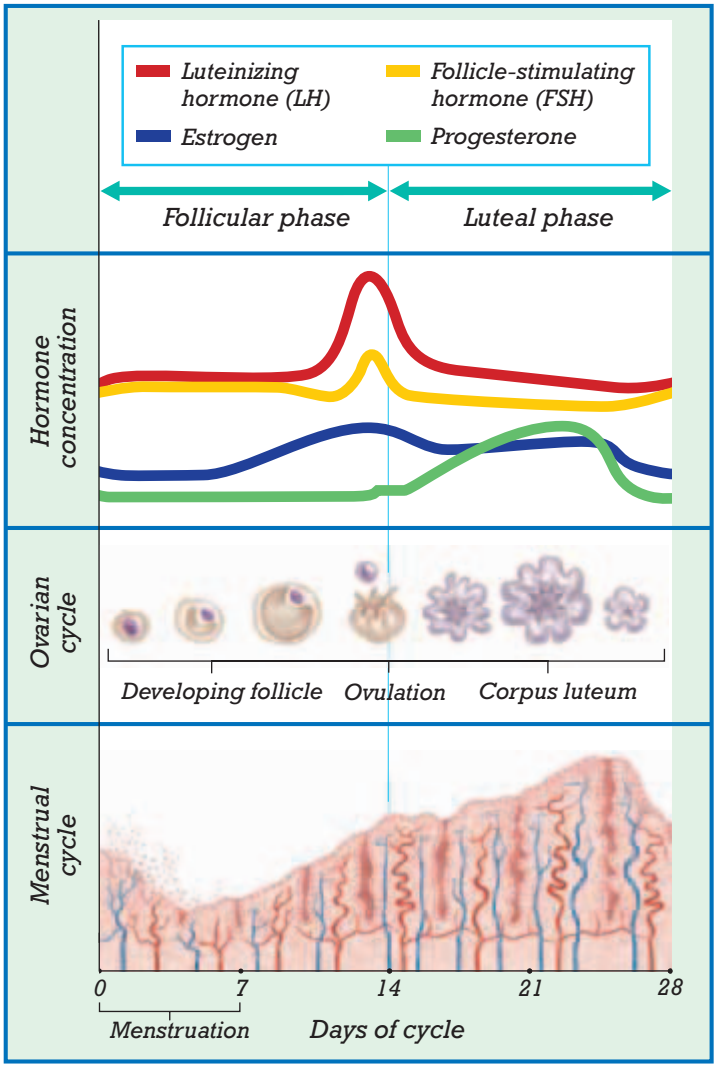
from the Latin *mensis,* meaning "month"

PREPARATION FOR PREGNANCY

Each month, the female reproductive system prepares and releases an ovum in a series of events called the **ovarian cycle.** During this time, an egg matures and enters a fallopian tube, where it is able to fuse with a sperm. If the egg does not fuse with a sperm, the egg degenerates. The ovarian cycle has three stages: the follicular phase, ovulation, and the luteal phase. These stages are regulated by hormones secreted by the endocrine system. While the ovarian cycle occurs, the **menstrual** (MEN-struhl) **cycle** prepares the uterus for a possible pregnancy. For most women, the ovarian and menstral cycles last about 28 days. Figure 51-8 summarizes the stages of the ovarian and menstrual cycles.

FIGURE 51-8

During the 28-day ovarian and menstrual cycles, an egg matures and is released by an ovary, and the uterus prepares for a possible pregnancy. The events of the menstrual cycle are regulated by hormones that are produced by the anterior pituitary and the ovaries.



Follicular Phase

An immature egg cell completes its first meiotic division during the **follicular** (fuh-LIK-yoo-luhr) **phase.** This phase begins when the hypothalamus secretes a releasing hormone that stimulates the anterior pituitary to secrete follicle-stimulating hormone (FSH). FSH stimulates cell division in a **follicle,** a layer of cells that surrounds an immature egg. Follicle cells supply nutrients to the egg. They also secrete estrogen, which stimulates mitotic divisions of cells in the lining of the uterus, causing the lining to thicken. The follicular phase lasts approximately 14 days. During this time, the estrogen level in the blood continues to rise until it reaches a peak and the egg moves to the surface of the ovary. The elevated estrogen level acts as a positive feedback mechanism by stimulating the anterior pituitary to secrete luteinizing hormone (LH), which initiates the next stage of the menstrual cycle.

Ovulation

The sharp rise in the LH level that occurs midway through the ovarian cycle causes the follicle to rupture and release its egg. The release of an egg from a ruptured follicle is called **ovulation** (AHV-yoo-LAY-shuhn). Following ovulation, an egg is swept into a fallopian tube, where it awaits fertilization as it travels through the tube toward the uterus. The egg has enough stored nutrients to survive about 24 hours.

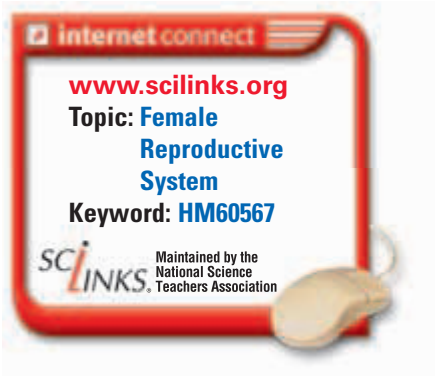
Luteal Phase

The cells of the ruptured follicle grow larger and fill the cavity of the follicle, forming a new structure called a **corpus luteum** (KAWR-puhs LOOT-ee-uhm). Thus, this stage of the ovarian cycle is called the **luteal** (LOOT-ee-uhl) **phase.** The corpus luteum begins to secrete large amounts of progesterone and estrogen. Progesterone stimulates growth of blood vessels and storage of fluids and nutrients in the lining of the uterus during the menstrual cycle. This stimulation causes the uterine lining to become thicker. In addition, increased levels of estrogen and progesterone acts as a negative feedback mechanism by causing the pituitary gland to stop secreting LH and FSH. The luteal phase lasts about 14 days. During this time, estrogen and progesterone levels in the blood rise, while the FSH and LH levels drop.

Menstruation

If an egg is fertilized, the resulting zygote attaches to the lining of the uterus, where it will develop for the next nine months. A hormone that is produced early in pregnancy stimulates the corpus luteum to continue producing estrogen and progesterone, and the thickened lining of the uterus is maintained. If the egg is not fertilized, the corpus luteum stops producing sex hormones, which marks the end of the ovarian cycle. Without estrogen and progesterone to maintain the thickened uterine lining, the lining begins to slough off. In this stage of the menstrual cycle, called **menstruation** (MEN-STRAY-shuhn), the lining of the uterus and blood from ruptured blood vessels are discharged through the vagina. Menstruation lasts the first five to seven days of the follicular phase.

Menstruation continues in most women until about age 50. At this time, a woman no longer ovulates. Most of a woman's follicles have either matured and ruptured or degenerated. Without follicles, the ovaries cannot secrete enough estrogen and progesterone to continue the menstrual cycle, and menstruation ceases. This stage is called **menopause** (MEN-uh-PAWZ).



SECTION 2 REVIEW

1. Identify the main female reproductive organs.
2. What is the function of the uterus?
3. How are eggs and sperm similar, and how are they different?
4. How do high levels of estrogen and progesterone during the luteal phase of the ovarian cycle affect the uterus?
5. What role does luteinizing hormone (LH) play in the ovarian cycle?
6. What is the corpus luteum?

CRITICAL THINKING

7. **Predicting Results** What might happen if two or more eggs were released from the ovaries at the same time?
8. **Relating Concepts** A 48-year-old woman stops having menstrual periods. She thinks she may be pregnant. What is another possible explanation?
9. **Making Comparisons** Which male and female reproductive organs are similar to one another in function?

SECTION 3

OBJECTIVES

- **Sequence** the events of fertilization, cleavage, and implantation.
- **Describe** the three stages of pregnancy.
- **Summarize** the development of an embryo during pregnancy.
- **Discuss** the effects of unnecessary drug use on development.
- **Describe** the changes in a mother's body during birth.

VOCABULARY

gestation
blastocyst
implantation
pregnancy
trimester
embryo
amniotic sac
chorionic villus
placenta
umbilical cord
human chorionic gonadotropin
fetus
labor
afterbirth

FIGURE 51-9

Several sperm surround this ovum, but only one will be able to fertilize it. (SEM 1165×)

GESTATION

A new individual is produced when a sperm fertilizes an egg, resulting in the formation of a zygote. During a nine-month period, a series of changes transforms a single cell into a complex organism made of trillions of cells—a human.

FERTILIZATION

Recall that with one ejaculation, a male releases hundreds of millions of sperm into the vagina of a female. Once sperm are released, they swim through the vagina, cervix, and uterus and, finally, up the fallopian tubes. If ovulation occurs anytime from 72 hours before to 48 hours after ejaculation, sperm may encounter an egg in one of the fallopian tubes. Fertilization occurs when a sperm and an egg fuse and form a zygote. From this point, human development takes about nine months—a period known as **gestation** (jes-TAY-shuhn).

An egg in a fallopian tube is encased in a jellylike substance and surrounded by a layer of cells from the follicle of the ovary. As shown in Figure 51-9, several sperm may attach to an egg and attempt to penetrate its outer layers. Recall that the head of a sperm contains digestive enzymes. These enzymes break down an egg's outer layers and enable the cell membrane that surrounds the head of the sperm to fuse with the egg's cell membrane. The sperm's nucleus and midpiece then enter the cytoplasm of the egg. The tail of the sperm remains outside the egg. Usually, only one sperm is successful in penetrating an egg. Electrical changes that occur in an egg's cell membrane after a sperm enters the egg help keep other sperm from penetrating the egg.

After a sperm enters an egg, the egg completes meiosis II, and the sperm's nucleus fuses with the egg's nucleus. The diploid cell that results from this fusion is called a *zygote*. Recall that each gamete contains 23 chromosomes, the haploid ($1n$) number. Thus, fusion of a sperm nucleus and an egg nucleus causes a zygote to have 46 chromosomes, thus restoring the diploid ($2n$) number.

Cleavage and Implantation

Immediately following fertilization and while still in the fallopian tube, the zygote begins a series of mitotic divisions known as *cleavage*. The resulting cells do not increase in size during these cell divisions. Cleavage produces a ball of cells called a *morula* (MAWR-yoo-luh), which is not much larger than the zygote. Cells of the morula divide and release a fluid, resulting in a blastocyst. A **blastocyst** (BLAS-toh-SIST) is a ball of cells with a large, fluid-filled cavity.

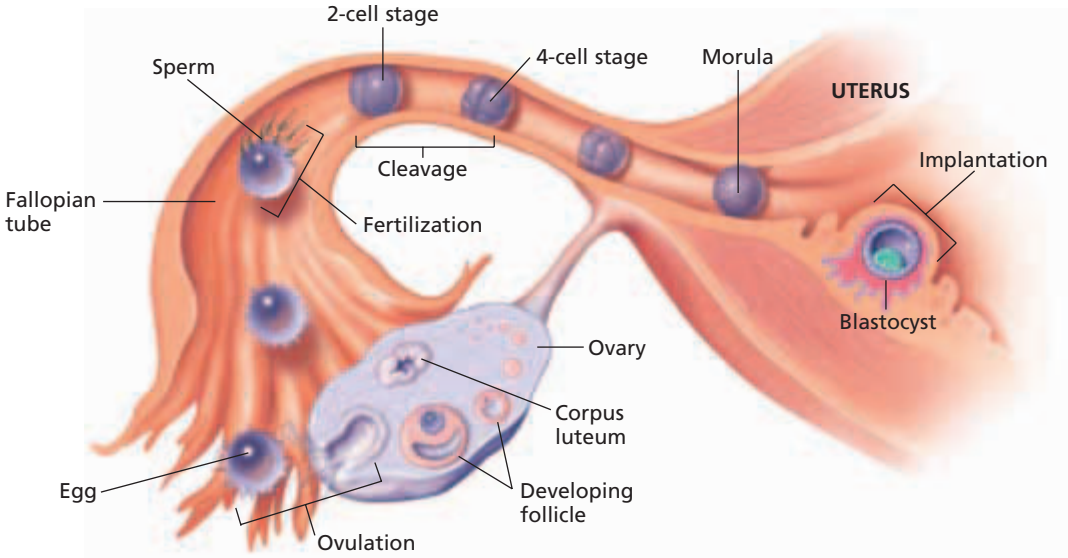


FIGURE 51-10

The earliest stages of development occur within a fallopian tube as a zygote travels toward the uterus. It takes about a week for the zygote to travel from the fallopian tube to the uterine lining.

As shown in Figure 51-10, the morula has become a blastocyst by the time it reaches the uterus. In the uterus, the blastocyst attaches to the thickened uterine lining. The blastocyst then releases an enzyme that breaks down the epithelial tissue that lines the uterus and burrows into the thickened lining. The process in which the blastocyst burrows and embeds itself into the lining of the uterus is called **implantation** (IM-plan-TAY-shuhn). Pregnancy begins at implantation, which occurs about a week after fertilization.

PREGNANCY

After implantation, the blastocyst slowly takes on the recognizable features of a human infant. This nine-month period of development is called *gestation,* or **pregnancy.** Pregnancy is divided into three equal periods, or **trimesters.** Significant changes occur during each trimester.

First Trimester

The most dramatic changes in human development take place during the first trimester. For the first eight weeks of pregnancy, the developing human is called an **embryo.** Throughout the first two to three weeks following fertilization, a developing human embryo resembles the embryos of other animals. The embryo develops from the mass of cells on the inner surface of the blastocyst. At first, all of the cells in the mass look alike. But the cells soon reorganize, first into two and then into three distinct types of cells, forming the primary germ layers: the ectoderm, mesoderm, and endoderm. Different parts of the body develop from each of the primary germ layers.

Four membranes that aid the development of the embryo also form during the first trimester. One of these membranes, called the *amnion* (AM-nee-uhn), forms the fluid-filled **amniotic** (AM-nee-AHT-ik) **sac,** which surrounds the developing embryo.

Quick Lab

Summarizing Vocabulary

Materials pencil, paper, dictionary

Procedure Write and define the following list of words: *ovary, ovum, follicle, gestation, morula, blastocyst, amnion, chorion, umbilical, uterus, corpus,* and *luteum.* Identify the roots and meanings of the roots for each word.

Analysis Do any of the meanings of the words surprise you? Explain. How does knowing the roots and meanings of the words help you remember them?

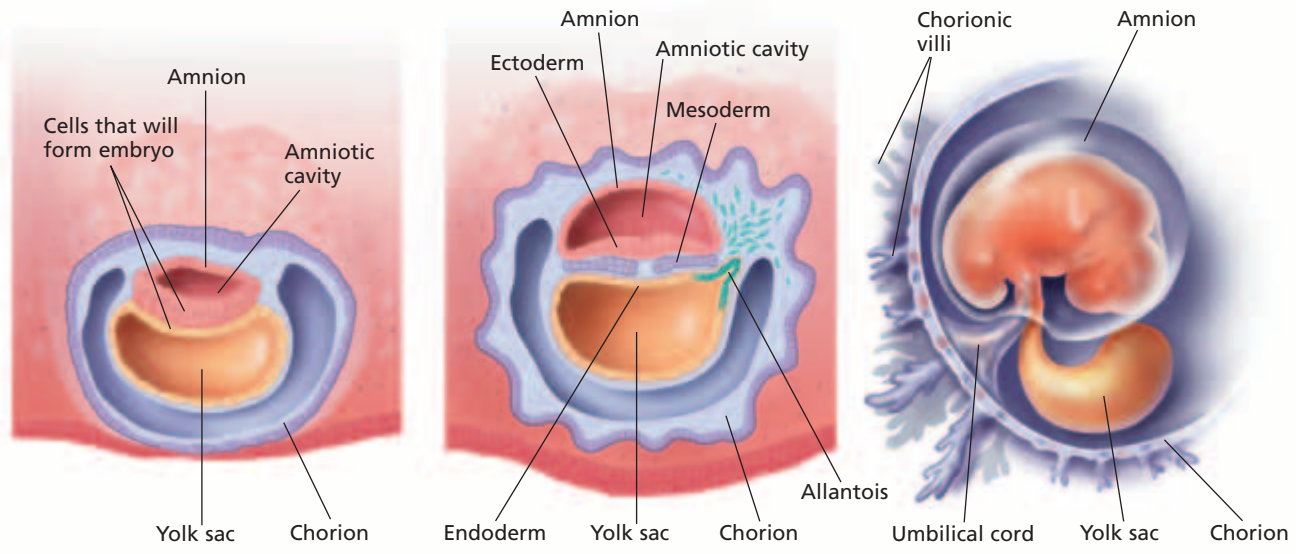


FIGURE 51-11

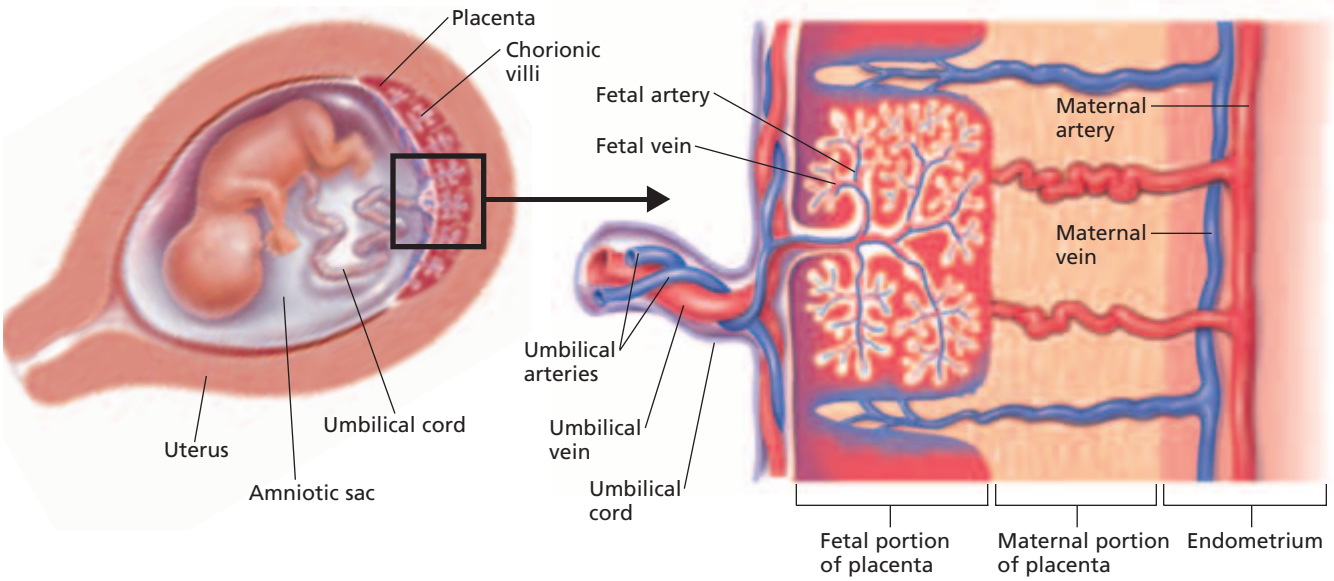
(a) An embryo develops from the mass of cells on one side of a blastocyst. (b) The primary germ layers develop by the third week of pregnancy, and the four embryonic membranes form. (c) By the end of the first month of pregnancy, all of the embryonic membranes are formed.

The fluid in the amniotic sac cushions the embryo from injury and keeps it moist. A second membrane forms the *yolk sac.* Although it does not contain yolk, the yolk sac is an important structure because it is where the first blood cells originate. A third membrane, called the *allantois* (uh-LAN-toh-is), forms near the yolk sac. The fourth membrane, the *chorion* (KAWR-ee-AHN), surrounds all of the other membranes. As shown in Figure 51-11, one side of the chorion forms small, fingerlike projections called **chorionic villi** (KAWR-ee-AHN-ik VIL-IE), which extend into the uterine lining. Blood vessels that form within the chorionic villi originate in the allantois.

Together, chorionic villi and the portion of the uterine lining that they invade form a close-knit structure called the placenta. The **placenta** is the structure through which the mother nourishes the embryo. Nutrients, gases, pathogens, drugs, and other substances can pass from the mother to the embryo through the placenta.

FIGURE 51-12

About two weeks after fertilization, the placenta begins to develop. The mother nourishes the developing embryo through the placenta for the duration of the pregnancy.



Thus, women should abstain from alcohol and avoid all unnecessary drugs throughout pregnancy. Alcohol use by women, especially during early pregnancy, is the leading cause of birth defects, such as fetal alcohol syndrome (FAS). FAS can result in severe mental, behavioral, and physical retardation.

The embryo is attached to the placenta by the **umbilical** (uhm-BIL-i-kuhl) **cord,** which contains arteries and veins that carry blood between the embryo and the placenta. As Figure 51-12 shows, blood from the mother and fetus never mixes. Materials such as nutrients and wastes are exchanged across the placenta.

A developing placenta begins to secrete a hormone called **human chorionic gonadotropin** (HCG) early in the second week after fertilization. In the early stages of pregnancy, HCG stimulates the corpus luteum to continue producing sex hormones, and thus the uterine lining and the embryo are retained. Otherwise, the corpus luteum will stop producing estrogen and progesterone, and menstruation will occur. As the placenta grows, it begins to secrete large amounts of progesterone and estrogen, which take over maintenance of the uterine lining. Production of estrogen and progesterone throughout pregnancy prevents the release of FSH and LH, and eggs are not released.

The brain, spinal cord, and the rest of the nervous system begin to form in the third week. The heart begins to beat at 21 days. By the fifth week, arms, legs, eyes, and ears have begun to develop. At six weeks, the fingers and toes form, and the brain shows signs of activity. The embryo also begins to move, although the mother cannot yet feel it. From eight weeks until birth, the developing child is called a **fetus** (FEET-uhs). The fetus is only about 5 cm (2 in.) long when the first trimester ends, but all of its organ systems have begun to form, as shown in Figure 51-13.

Word Roots and Origins

fetus

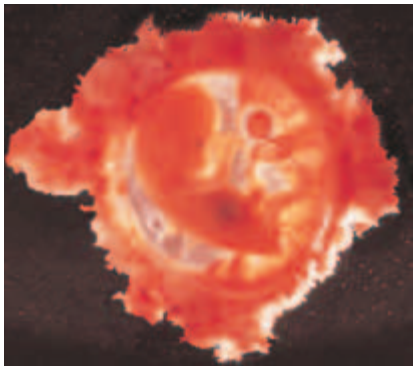
from the Latin *fetus,* meaning "offspring"

Second Trimester

During the second trimester, the mother's uterus enlarges. The fetus's heartbeat can be heard, its skeleton begins to form, and a layer of soft hair called *lanugo* grows over its skin. The fetus also begins to wake and sleep. The mother may feel the fetus move. The fetus swallows and sucks its thumb. It can make a fist, hiccup, kick its feet, and curl its toes. By the end of the second trimester, the fetus is about 34 cm (13.4 in.) long and about 900g (2 lb) in weight.

FIGURE 51-13

By 12 weeks, the fetus's arms and legs are developing, and 20 buds for future teeth appear. By week 21, eyelashes, eyebrows, and fingernails have formed, and the skin is covered with fine hair called *lanugo.* By eight months, the fetus's bones have hardened, lanugo has disappeared, and body fat is developing.



12 weeks

21 weeks

Eight months

Third Trimester

In the third trimester, the fetus grows quickly and undergoes changes that will enable it to survive outside the mother. The fetus can see light and darkness through the mother's abdominal wall, and it can react to music and loud sounds. During the last half of this trimester, the fetus develops fat deposits under its skin. These fat deposits, which make the fetus look rounded and less wrinkled, insulate the body so that it can maintain a steady body temperature.

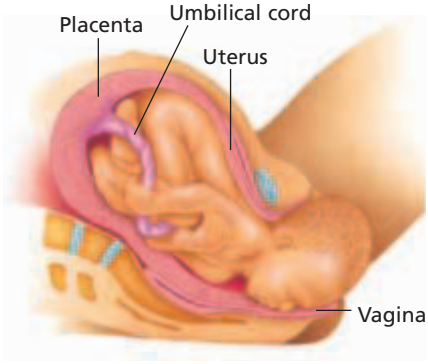
BIRTH

Birth occurs about 270 days (38 weeks) after fertilization. Prostaglandins produced by the fetal membranes and hormones produced by both the fetus and the mother initiate childbirth. High levels of estrogen, prostaglandins, and oxytocin, a pituitary hormone, cause the smooth muscles of the uterus to contract. The amniotic sac breaks, and the amniotic fluid flows out through the vagina, a process called "breaking water." Muscles in the cervix and vagina relax, enabling the cervix and vagina to enlarge and allowing the fetus to pass through them. The muscular contractions and other events that lead up to childbirth are called **labor.**

During childbirth, contractions of the uterus push a fetus through the cervix, vagina, and body, as shown in Figure 51-14. The placenta, amnion, and uterine lining, collectively called **afterbirth,** are expelled shortly after the baby is born. Following birth, the newborn baby's lungs expand for the first time as the baby begins to breathe on its own. The umbilical cord is tied and cut. Umbilical arteries and veins close off within 30 minutes after birth. This and other changes in the baby's blood vessels lead to the completion of cardiopulmonary and renal circulation, which allows the baby to function independently of the mother. The newborn baby's respiratory and excretory systems soon become fully functional.

FIGURE 51-14

During childbirth, the fetus passes through the greatly enlarged cervix and vagina.



SECTION 3 REVIEW

1. How is a zygote formed?
2. What is the process of implantation?
3. How is a fetus nourished during development?
4. Summarize the changes in a mother's body during pregnancy.
5. How can alcohol affect a fetus?
6. What changes occur in a fetus during the third trimester of pregnancy?
7. Summarize the changes in a mother's body that take place during birth.

CRITICAL THINKING

8. **Recognizing Relationships** Why is it important for a pregnant woman to eat healthfully and to avoid unhealthy substances?
9. **Applying Information** When blood type A is mixed with blood type B, agglutination, or the formation of clots, occurs. Consider a mother with blood type A carrying a fetus with blood type B. Will agglutination be a problem? Explain.
10. **Predicting Results** Why must a blastocyst be implanted in the uterus and not elsewhere?

CHAPTER HIGHLIGHTS

SECTION 1 Male Reproductive System

- The male reproductive structures include two testes, two epididymides, two vasa deferenta, the urethra, and the penis.
- The testes are contained in the scrotum, where the cooler temperature allows normal sperm development.
- Sperm form in the seminiferous tubules of the testes. Meiosis reduces the number of chromosomes in sperm to 23.
- A mature sperm consists of a head, which contains the nucleus and chromosomes; a midpiece, which contains mitochondria; and a tail, which consists of a flagellum.
- Sperm take the following path to exit the body: seminiferous tubules of the testes → epididymis → vas deferens → urethra.
- Fluids that are secreted by various exocrine glands are mixed with sperm to produce semen.

Vocabulary

testis (p. 1049)
seminiferous tubule (p. 1049)
scrotum (p. 1049)
epididymis (p. 1050)
vas deferens (p. 1050)
seminal vesicle (p. 1051)
prostate gland (p. 1051)
bulbourethral gland (p. 1051)
semen (p. 1051)
penis (p. 1051)
ejaculation (p. 1051)

SECTION 2 Female Reproductive System

- The female reproductive structures include two ovaries, two fallopian tubes, the uterus, the cervix, the vagina, two labia, and the vulva.
- Eggs form in ovaries. Meiosis reduces the chromosome number in eggs to 23. Eggs are about 75,000 times larger than sperm are.
- Starting at puberty, the ovarian and menstrual cycles occur approximately every 28 days.
- The ovarian cycle consists of three phases: follicular phase, ovulation, and luteal phase.
- In the follicular phase, FSH causes a follicle to grow. Estrogen produced by the follicle causes an egg to mature and the uterine lining to build up.
- Ovulation occurs midway through the ovarian cycle, when LH causes the follicle to rupture and release its egg.
- In the luteal phase, the follicle becomes a corpus luteum. The corpus luteum secretes progesterone, which stimulates further buildup of the uterine lining.
- Menstruation occurs at the end of the menstrual cycle, when a corpus luteum stops secreting hormones.

Vocabulary

ovary (p. 1052)
fallopian tube (p. 1052)
uterus (p. 1052)
cervix (p. 1053)
vagina (p. 1053)
vulva (p. 1053)
labium (p. 1053)
ovum (p. 1053)
ovarian cycle (p. 1054)
menstrual cycle (p. 1054)
follicular phase (p. 1054)
follicle (p. 1054)
ovulation (p. 1054)
corpus luteum (p. 1055)
luteal phase (p. 1055)
menstruation (p. 1055)
menopause (p. 1055)

SECTION 3 Gestation

- Fertilization occurs in a fallopian tube. Pregnancy begins when a blastocyst implants itself in the lining of the uterus.
- The three primary germ layers—the ectoderm, mesoderm, and endoderm—form early in embryonic development. Four membranes—the amnion, yolk sac, allantois, and chorion—also form early in embryonic development.
- Nutrients, gases, and other substances pass through the placenta by diffusion from the mother to the fetus.
- For the first eight weeks of pregnancy, the developing human is a called an *embryo.* From the eighth week until birth, a developing human is known as a *fetus.*
- Unnecessary drug use can negatively affect an embryo or fetus.
- During childbirth, contractions of the uterus initiated by prostaglandins and oxytocin push the baby from the mother's body through the vagina.

Vocabulary

gestation (p. 1056)
blastocyst (p. 1056)
implantation (p. 1057)
pregnancy (p. 1057)
trimester (p. 1057)
embryo (p. 1057)
amniotic sac (p. 1057)
chorionic villus (p. 1058)
placenta (p. 1058)
umbilical cord (p. 1059)
human chorionic gonadotropin (p. 1059)
fetus (p. 1059)
labor (p. 1060)
afterbirth (p. 1060)

CHAPTER REVIEW

USING VOCABULARY

1. Name the male and female gamete-producing organs.
2. Explain the differences between sperm and semen.
3. Explain the relationships between the following terms: *menstrual cycle, menstruation,* and *menopause*.
4. **Word Roots and Origins** The word *blastocyst* is derived from the Greek *blastos,* which means "bud," and *kustis,* which means "liquid-filled sac." Using this information, explain why the term *blastocyst* is a good name for the biological structure that the term describes.

UNDERSTANDING KEY CONCEPTS

5. **Name** the sac of skin that houses the testes.
6. **Identify** the organ that deposits sperm in the female reproductive system.
7. **Explain** how semen is formed.
8. **Describe** the structure of a mature human sperm cell.
9. **Sequence** the path that sperm follow in leaving the body.
10. **Identify** four major parts of the female reproductive system.
11. **Identify** the function of the uterus.
12. **State** where eggs are produced.
13. **Compare** the formation of sperm to the formation of eggs.
14. **Describe** the function of the labia.
15. **Predict** in which period of the ovarian cycle that fertilization is most likely to occur.
16. **Identify** the part of the menstrual cycle that does not occur if implantation takes place.
17. **Explain** how a sperm penetrates an egg during fertilization.
18. **Describe** the processes of cleavage and implantation.
19. **Discuss** how the developing fetus receives nourishment.
20. **List** the differences between an embryo and a fetus.
21. **Summarize** the effects of drug use on development.
22. **Outline** fetal development during the second trimester.
23. **State** the changes the cervix undergoes during childbirth.
24. **CONCEPT MAPPING** Use the following terms to create a concept map that shows the ovarian and menstrual cycles: *corpus luteum, estrogen, follicle, hormones, follicular phase, menstrual cycle, luteal phase, ovarian cycle, ovulation, ovum, progesterone,* and *uterus*.

CRITICAL THINKING

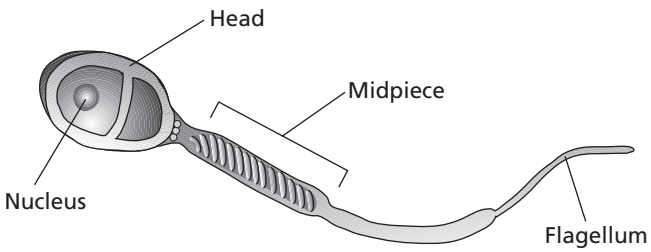
25. **Predicting Results** What do you think might happen if more than one sperm were able to penetrate the cell membrane of an egg?
26. **Evaluating Differences** A human female produces, on average, only one mature egg every 28 days. In contrast, a female salmon lays 50 million eggs at each spawning. Hypothesize why there is such a great difference in egg production between the two species.
27. **Recognizing Relationships** Women who consume tobacco, alcoholic beverages, or other drugs or harmful substances during pregnancy are at high risk of giving birth to infants who are addicted to drugs, have severe birth defects, or tend to develop learning disabilities. Explain.
28. **Interpreting Graphics** What is the fetus doing in the photograph below? Suggest an adaptive advantage for this activity.

Standardized Test Preparation

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

1. Which of the following is the correct pathway for sperm as it exits the body?
   - **A.** the testes to the penis to the epididymis
   - **B.** the urethra to the vas deferens to the testes
   - **C.** the epididymis to the vas deferens to the urethra
   - **D.** the testes to the vas deferens to the epididymis
2. Which of the following is true about follicle-stimulating hormone?
   - **F.** It is secreted by the follicle.
   - **G.** It is secreted by the pituitary gland.
   - **H.** It promotes contractions of the uterus.
   - **J.** It stimulates the development of the placenta.
3. Which of the following help form the placenta and umbilical cord?
   - **A.** the amnion and chorion
   - **B.** the amnion and yolk sac
   - **C.** the chorion and yolk sac
   - **D.** the chorion and allantois
4. By the end of the first trimester, which of the following has occurred in the fetus?
   - **F.** The fetus has a full head of hair.
   - **G.** The fetus uses its lungs to breathe.
   - **H.** The brain of the fetus is fully developed.
   - **J.** All of the organs of the fetus have begun to form.

INTERPRETING GRAPHICS: Study the image of the sperm cell below to answer the questions that follow.

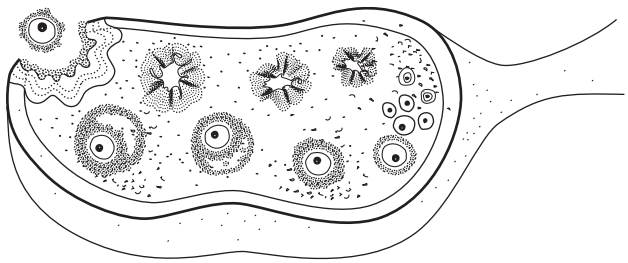


5. Where are the enzymes that help the sperm penetrate the ovum found?
   - **A.** in the head
   - **B.** in the nucleus
   - **C.** in the midpiece
   - **D.** in the flagellum
6. Where are the mitochondria that supply the energy that sperm need for movement found?
   - **F.** in the head
   - **G.** in the nucleus
   - **H.** in the midpiece
   - **J.** in the flagellum

DIRECTIONS: Complete the following analogy.

7. testis : ovary :: vas deferens :
   - **A.** sperm
   - **B.** urethra
   - **C.** fallopian tube
   - **D.** prostate gland

INTERPRETING GRAPHICS: The image below shows an ovary. Use the image to answer the question that follows.



8. What event is illustrated by this figure?
   - **F.** ovulation
   - **G.** ejaculation
   - **H.** fertilization
   - **J.** menstruation

SHORT RESPONSE

Sperm are able to survive for around 48 hours in a female even though they have very little cytoplasm to provide nutrients. Explain why you think sperm can survive with few nutrients.

EXTENDED RESPONSE

During the 1950s, a number of women were prescribed thalidomide, a drug to relieve morning sickness. These women gave birth to babies with serious limb defects. Scientists later discovered that thalidomide caused limb defects in fetuses.

Part A Do you think it is safe for a woman to take thalidomide during her first and second trimesters of pregnancy? Explain your answer.

Part B Do you think it is safe for a woman to take thalidomide during the third trimester of her pregnancy? Explain your answer.

Test TIP If at first you are unsure of the correct answer to a question, start by crossing out answers you know are wrong. Reducing the number of answer choices in this way may help you choose the correct answer.

Observing Embryonic Development

OBJECTIVES

- Identify the stages of early animal development.
- Describe the changes that occur during early development.
- Compare the stages of human embryonic development with those of echinoderm embryonic development.

PROCESS SKILLS

- observing
- comparing and contrasting
- making drawings
- drawing conclusions

MATERIALS

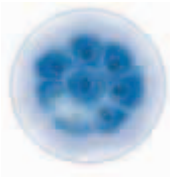
- prepared slides of sea-star development, including
  - unfertilized egg
  - zygote
  - 2-cell stage
  - 4-cell stage
  - 8-cell stage
  - 16-cell stage
  - 32-cell stage
  - 64-cell stage
  - blastula
  - early gastrula
  - middle gastrula
  - late gastrula
  - young sea-star larva
- compound light microscope
- paper and pencil

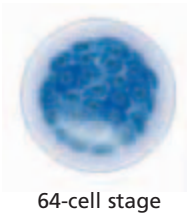
Background

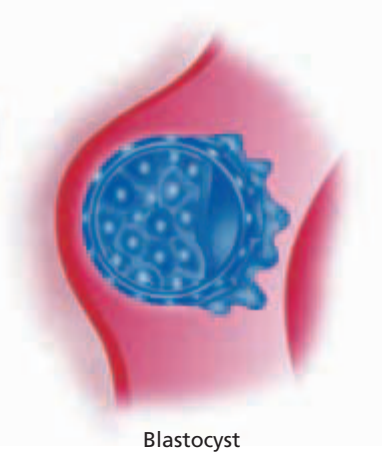
1. Most members of the animal kingdom (including sea stars and humans) begin life as a single cell—the fertilized egg, or zygote.
2. The early stages of development are quite similar in different species. Cleavage follows fertilization. During cleavage, the zygote divides many times without growing. The new cells migrate and form a hollow ball of cells called a *blastula.* The cells then begin to organize into the three primary germ layers: endoderm, mesoderm, and ectoderm. During this process, the developing organism is called a *gastrula.*
3. The early stages of mammalian development are difficult to study because mammalian eggs are tiny and are not produced in great numbers. In addition, mammalian embryos develop within the mother's body. In the laboratory, it is difficult to replicate the internal conditions of the mother's body. Because the early stages of echinoderm development are similar to those of human development, and because echinoderm development is easier to study in the laboratory than human development, you will observe the early developmental stages of an echinoderm—the sea star—in this investigation.


2-cell stage


4-cell stage


8-cell stage


64-cell stage


Blastocyst

4. As development continues, the cells continue to specialize as they become part of specific tissues and complex structures. Ectoderm forms the epidermis and nerve tissue. Mesoderm forms muscle, connective tissue, and vascular organs. Endoderm forms the lining of the digestive, urinary, and respiratory tracts.
5. Similarities and differences in early stages of development reflect evolutionary relationships between species.

Procedure

1. Obtain a set of prepared slides that show sea-star eggs at different stages of development. Choose slides labeled unfertilized egg, zygote, 2-cell stage, 4-cell stage, 8-cell stage, 16-cell stage, 32-cell stage, 64-cell stage, blastula, early gastrula, middle gastrula, late gastrula, and young sea-star larva. (Note: *Blastula* is the general term for the embryonic stage that results from cleavage. In mammals, a blastocyst is a modified form of the blastula.)
2. Examine each slide using a compound light microscope. Using the microscope's low-power objective first, focus on one good example of the developmental stage listed on the slide's label. Then switch to the high-power objective, and focus on the image with the fine adjustment.
3. In your lab report, draw a diagram of each developmental stage that you examine (in chronological order). Label each diagram with the name of the stage it represents and the magnification used. Record your observations as soon as they are made. Do not redraw your diagrams. Draw only what you see; lab drawings do not need to be artistic or elaborate. They should be well organized and include specific details.
4. Compare your diagrams with the diagrams of human embryonic stages shown on previous page.
5.  Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. Compare the size of the sea-star zygote with that of the blastula. At what stage does the embryo become larger than the zygote?
2. At what stage do all of the cells in the embryo not look exactly like each other?
3. How do cell shape and size change during successive stages of development?
4. Do the cell nuclei stay the same size, get larger, or get smaller as the stages progress?
5. Compare the number of chromosomes in a fertilized sea-star egg with the number of chromosomes in one cell of each of the following phases: 2-cell stage, blastula, gastrula, and adult stage.
6. From your observations of changes in cellular organization, why do you think the blastocoel (the space in the center of the hollow sphere of cells of a blastula) is important during embryonic development?
7. Label the endoderm and ectoderm in your drawing of the late gastrula stage. What do these two tissue types eventually develop into?
8. How are the symmetries of a sea-star embryo and a sea-star larva different from the symmetry of an adult sea star? Would you expect to see a similar change in human development?
9. What must happen to the sea-star gastrula before it becomes a mature sea star?
10. How do your drawings of sea-star embryonic development compare with those of human embryonic development? Based on your observations, in what ways do you think sea-star embryos could be used to study early human development?
11. Describe one way that the cleavage of echinoderms and mammals is alike.
12. Describe two ways in which cleavage in echinoderms differs from cleavage in mammals.
13. Why are sea-star eggs a good choice for the study of embryonic development in humans?

Further Inquiry

Using the procedure that you followed in this investigation, compare embryonic development in other organisms with embryonic development in sea stars. Which types of organisms would you expect to develop similarly to sea stars? Which types of organisms would you expect to develop differently from sea stars?

SAFE LABORATORY PRACTICES

It is your responsibility to protect yourself and other students by conducting yourself in a safe manner while in the laboratory. You will avoid accidents in the laboratory by following directions, handling materials carefully, and taking your work seriously. Read the following general safety guidelines before attempting to work in the laboratory. Make sure that you understand all safety guidelines before entering the laboratory. If necessary, ask your teacher for clarification of laboratory rules and procedures.

General Guidelines for Laboratory Safety

Do not perform experiments not specifically assigned by your teacher. Do not attempt any laboratory procedure without your teacher's direction, and do not work in the laboratory by yourself.

Familiarize yourself with the experiment and all safety precautions before entering the lab. Be aware of the potential hazards of the required materials and procedures. Ask your teacher to explain any confusing parts of an experiment before you begin.

Before beginning work, tie back long hair, roll up loose sleeves, and put on any required personal protective equipment as directed by your teacher. Avoid or confine loose clothing that could knock things over, catch on fire, or absorb chemical solutions. Nylon and polyester fabrics burn and melt more readily than cotton fabrics do. Do not wear open-toed shoes, sandals, or canvas shoes in the lab.

Always wear a lab apron and safety goggles in the lab. Wear this equipment at all times, even if you are not working on an experiment at the time. Laboratories contain chemicals that can damage your clothing, skin, and eyes. If your safety goggles cloud up or are uncomfortable, ask your teacher for help. Lengthening the strap slightly, washing the goggles with soap and warm water, or using an anti-fog spray may help alleviate the problems.

Do not wear contact lenses in the lab. Even if you are wearing safety goggles, chemicals could get between contact lenses and your eyes and cause irreparable eye damage. If your doctor requires that you wear contact lenses instead of glasses, then you should wear eye-cup safety goggles—similar to goggles that are worn for underwater swimming—in the lab. Ask your doctor or your teacher how to use eye-cup safety goggles to protect your eyes.

Know the location of all safety and emergency equipment used in the laboratory before you begin a lab. Ask your teacher where the nearest eyewash stations, safety blankets, safety shower, fire extinguisher, first-aid kit, and chemical spill kit are located.

Immediately report any accident, incident, or hazard—no matter how trivial—to your teacher. Any incident involving bleeding, burns, fainting, chemical exposure, or ingestion should also be reported immediately to the school nurse or to a physician.

In case of fire, alert the teacher and leave the laboratory. Follow standard school fire safety procedures.

Do not fool around in the lab. Take your lab work seriously, and behave appropriately in the lab. Be aware of your classmates' safety as well as your own at all times.

Do not have or consume food, chew gum, or drink in the laboratory. Do not store food in the laboratory. Keep your hands away from your face. Do not apply cosmetics in the laboratory. Some hair-care products and nail polish are highly flammable.

Keep your work area neat and uncluttered. Have only books and other materials that are needed to conduct the experiment in the laboratory.

Clean your work area at the conclusion of each lab period as your teacher directs. Dispose of broken glass, chemicals, and other laboratory waste products in separate, special containers. Dispose of waste materials as directed by your teacher.

Wash your hands with soap and water after each lab period. Also wash your hands before each lab period to avoid contamination.

Key to Safety Symbols and Their Precautions

Before you begin working in the laboratory, familiarize yourself with the following safety symbols that are used in this textbook and the guidelines that you should follow when you see these symbols.

EYE SAFETY

- **Wear approved safety goggles as directed.** Goggles should always be worn in the laboratory, especially when you are working with a chemical, a chemical solution, a heat source, or a mechanical device.
- **In case of eye contact, do the following:** Go to an eyewash station immediately, and flush your eyes (including under the eyelids) with running water for at least 15 minutes. Hold your eyelids open with your thumb and fingers, and roll your eyeball around. While doing this, have another student notify your teacher.
- **Do not wear contact lenses in the laboratory.** Chemicals can be drawn up under the contact lens and into the eye. If you must wear contacts, tell your teacher. You must also wear approved eye-cup safety goggles to protect your eyes.
- **Do not look directly at the sun through any optical device or lens system or reflect direct sunlight to illuminate a microscope.** Such actions concentrate light rays to an intensity that can severely burn your retina and that may cause blindness.

HAND SAFETY

- **Do not cut objects while holding them in your hand.** Dissect specimens in a dissecting tray.
- **Wear protective gloves when working with an open flame, chemicals, solutions, or wild or unknown plants.**

SAFETY WITH GASES

- **Do not inhale any gas or vapor unless directed to do so by your teacher.** Do not breathe pure gases. If your teacher directs you to note the odor of a gas, do so by waving the fumes toward you with your hand.
- **Handle materials prone to emit vapors or gases in a well-ventilated area.** This work should be done in an approved chemical fume hood.

SHARP-OBJECT SAFETY

- **Use extreme care when handling all sharp and pointed instruments, such as scalpels, scissors, sharp probes, and knives.**
- **Do not use double-edged razor blades in the laboratory.**
- **Do not cut objects while holding them in your hand.** Cut objects on a suitable work surface. Always cut in a direction away from your body.

CLOTHING PROTECTION

- **Wear an apron or laboratory coat at all times in the laboratory to prevent chemicals or solutions from contacting skin or clothes.**

ANIMAL CARE AND SAFETY

- **Do not touch or approach wild animals.** When working in the field, be aware of poisonous or dangerous animals in the area.
- **Always obtain your teacher's permission before bringing any animal (including pets) into the school building.**
- **Handle animals only as your teacher directs.** Mishandling or abusing any animal will not be tolerated.

SAFE LABORATORY PRACTICES *continued*

GLASSWARE SAFETY

- **Inspect glassware before use; do not use chipped or cracked glassware.** Use heat-resistant glassware for heating materials or storing hot liquids.
- **Do not attempt to insert glass tubing into a rubber stopper without specific instruction from your teacher.**
- **Immediately notify your teacher if a piece of glassware breaks. Do not attempt to clean up broken glass unless directed to do so by your teacher.**

HEATING SAFETY

- **Be aware of any source of flames, sparks, or heat (open flames, electric heating coils, hot plates, etc.) before working with flammable liquids or gases.**
- **When heating chemicals or reagents in a test tube, do not point the test test toward anyone.**
- **Avoid using open flames.** If possible, work only with hot plates that have an on/off switch and an indicator light. Do not leave hot plates unattended. Do not use alcohol lamps. Turn off hot plates and open flames when they are not in use.
- **Know the location of laboratory fire extinguishers and fire-safety blankets.**
- **Use tongs or other appropriate, insulated holders when heating objects.** Heated objects often do not appear to be hot. Thus, do not pick up an object with your hand if the object could be warm.
- **Keep flammable substances away from heat, flames, and other ignition sources.**

HYGIENIC CARE

- **Keep your hands away from your face and mouth while working in the laboratory.**
- **Wash your hands thoroughly before leaving the laboratory.**
- **Remove contaminated clothing immediately.** If you spill caustic substances on your skin or clothing, use the safety shower or a faucet to rinse. Remove affected clothing while under the shower, and call to your teacher. (It may be temporarily embarrassing to remove clothing in front of your classmates, but failing to rinse a chemical off your skin could cause permanent damage.)
- **Launder contaminated clothing separately.**
- **Use the proper technique demonstrated by your teacher when handling bacteria or similar microorganisms.** Do not open Petri dishes to observe or count bacterial colonies.

PROPER WASTE DISPOSAL

- **Clean and decontaminate all work surfaces and personal protective equipment after each lab period as directed by your teacher.**
- **Dispose of all sharp objects (such as broken glass) and other contaminated materials (biological or chemical) in special containers as directed by your teacher.**

ELECTRICAL SAFETY

- **Do not use equipment with frayed electrical cords or loose plugs.**
- **Fasten electrical cords to work surfaces with tape.** This will prevent tripping and will ensure that equipment cannot fall off the table.
- **Do not use electrical equipment near water or with wet hands or clothing.**
- **Hold the rubber cord when you plug in or unplug equipment. Do not touch the metal prongs of the plug, and do not unplug equipment by pulling on the cord.**

PLANT SAFETY

- **Do not ingest any plant part used in the laboratory (especially commercially sold seeds).** Do not touch any sap or plant juice directly. Always wear gloves.
- **Wear disposable polyethylene gloves when handling any wild plant.**
- **Wash hands thoroughly after handling any plant or plant part (particularly seeds).** Avoid touching your face and eyes.
- **Do not inhale or expose yourself to the smoke of any burning plant.** Smoke contains irritants that can cause inflammation in the throat and lungs.
- **Do not pick wildflowers or other wild plants unless your teacher instructs you otherwise.**

CHEMICAL SAFETY

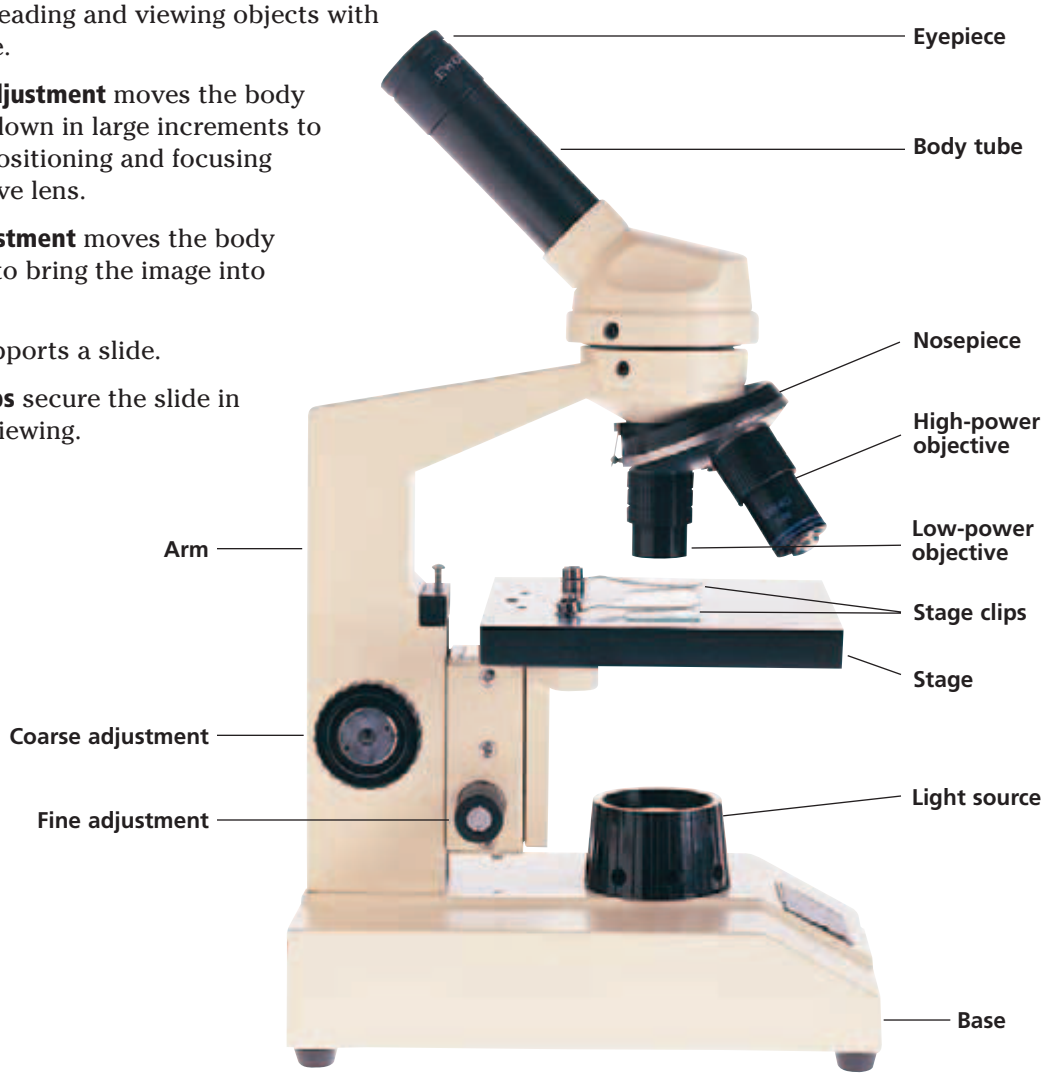
- **Always wear appropriate protective equipment.** Always wear eye goggles, gloves, and a lab apron or lab coat when working with any chemicals or chemical solutions.
- **Do not taste, touch, or smell any substance or bring it close to your eyes, unless specifically instructed to do so by your teacher.** If your teacher directs you to note the odor of a substance, do so by waving the fumes toward you with your hand. Do not pipette any substance by mouth; use a suction bulb as directed by your teacher.
- **Always handle chemicals and solutions with care.** Check the labels on bottles, and observe safety procedures. Do not return unused chemicals or solutions to their original containers. Return unused reagent bottles or containers to your teacher.
- **Do not mix any chemicals unless specifically instructed to do so by your teacher.** Two harmless chemicals can be poisonous if combined.
- **Do not pour water into a strong acid or strong base.** The mixture can produce heat and splatter.
- **Report any spill immediately to your teacher.** Do not clean up spills yourself unless your teacher instructs you otherwise.

USING A COMPOUND LIGHT MICROSCOPE

Microscopes are tools that extend human vision by making enlarged images of objects. Scientists use microscopes to see very small objects, such as microorganisms, cells and even cell parts. Microscopes help scientists reveal details that might otherwise be difficult, or even impossible to see.

Parts of the Compound Light Microscope

- The **eyepiece** magnifies the image, usually 10×.
- The **low-power objective** further magnifies the image, up to 4×.
- The **high-power objectives** further magnify the image, from 10× to 43×.
- The **nosepiece** holds the objectives and can be turned to change from one objective to another.
- The **body tube** maintains the correct distance between the eyepiece and the objectives. This distance is usually about 25 cm (10 in.), the normal distance for reading and viewing objects with the naked eye.
- The **coarse adjustment** moves the body tube up and down in large increments to allow gross positioning and focusing of the objective lens.
- The **fine adjustment** moves the body tube slightly to bring the image into sharp focus.
- The **stage** supports a slide.
- The **stage clips** secure the slide in position for viewing.
- The **diaphragm** (not labeled), located under the stage, controls the amount of light that is allowed to pass through the object being viewed.
- The **light source** provides light for viewing the image. It can be either a light reflected with a mirror or an incandescent light from a small lamp. NEVER use reflected direct sunlight as a light source.
- The **arm** supports the body tube.
- The **base** supports the microscope.



Proper Handling and Use of the Compound Light Microscope

1. Carry the microscope to your lab table by using both hands, one supporting the base and the other holding the arm of the microscope. Hold the microscope close to your body.
2. Place the microscope on the lab table at least 5 cm (2 in.) from the edge of the table.
3. Check to see what type of light source the microscope has. If the microscope has a lamp, plug it in and make sure that the cord is out of the way. If the microscope has a mirror, adjust it to reflect light through the hole in the stage.

   CAUTION If your microscope has a mirror, do not use direct sunlight as a light source. Using direct sunlight can damage your eyes.

   CAUTION If your microscope has a lamp, be careful not to touch the bulb of the lamp. The bulb can get very hot.
4. Adjust the revolving nosepiece so that the low-power objective is in line with the body tube.
5. Place a prepared slide over the hole in the stage, and secure the slide with the stage clips.
6. Look through the eyepiece, and move the diaphragm to adjust the amount of light that passes through the specimen.
7. Now look at the stage at eye level, and slowly turn the coarse adjustment to raise the stage until the objective almost touches the slide. Do not allow the objective to touch the slide.
8. While looking through the eyepiece, turn the coarse adjustment to lower the stage until the image is in focus. Never focus objectives downward. Use the fine adjustment to attain a sharply focused image. Keep both eyes open while viewing a slide.
9. Make sure that the image is exactly in the center of your field of vision. Then, switch to the high-power objective. Focus the image with the fine adjustment. Never use the coarse adjustment at high power.
10. When you are finished using the microscope, remove the slide. Clean the eyepiece and objectives with lens paper, and return the microscope to its storage area.

Procedure for Making a Wet Mount

1. Use lens paper to clean a glass slide and coverslip.
2. Place the specimen that you wish to observe in the center of the slide.
3. Using a medicine dropper, place one drop of water on the specimen.
4. Position the coverslip so that it is at the edge of the drop of water and at a 45° angle to the slide. Make sure that the water runs along the edge of the coverslip.
5. Lower the coverslip slowly to avoid trapping air bubbles.
6. If a stain or solution will be added to a wet mount, place a drop of the staining solution on the microscope slide along one side of the coverslip. Place a small piece of paper towel on the opposite side of the coverslip.
7. As the water evaporates from the slide, add another drop of water by placing the tip of the medicine dropper next to the edge of the coverslip, just as you would if you were adding stains or solutions to a wet mount. If you have added too much water, remove the excess by using the corner of a paper towel as a blotter. Do not lift the coverslip to add or remove water.

USING SI UNITS FOR MEASUREMENT

Scientists throughout the world use the Système International d'Unités, or International System of Units. It is usually referred to simply as SI. You will often use SI units to express the measurements that you will make in the laboratory. Most measurements in this book are expressed in SI units.

SI is a decimal system; that is, all relationships between SI units are based on powers of 10. Most units have a prefix that indicates the relationship of that unit to a base unit. For example, the SI base unit for length is the meter. A meter equals 100 centimeters (cm), or 1,000 millimeters (mm). A meter also equals 0.001 kilometers (km). Table 1 summarizes the prefixes and abbreviations that are commonly used to represent SI units.

TABLE 1 *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

SI Units

BASE UNITS

Seven fundamental quantities are represented by base units in SI. These base units include familiar quantities, such as length, mass, and time. These base quantities, their units, and their symbols are given in Table 2.

TABLE 2 *SI Base Units*

Base quantity	Unit	Symbol
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

DERIVED UNITS

The base units in Table 2 cannot be used to express measurements such as the surface area of a wildlife preserve or the speed of a running cheetah. Therefore, other important quantities, such as area, volume, and velocity, are expressed in derived units. Derived units are mathematical combinations of one or more base units.

TABLE 3 *SI-Derived Units Often Used in Biology*

Derived quantity	Unit	Symbol
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
Velocity	meter per second	m/s
Celsius temperature	degree Celsius	°C

Table 3 lists some derived units that you may encounter in your study of biology. Like base units, derived units can be expressed by using prefixes. In the lab, you will often express volume measurements in cubic centimeters (cm^3). Graduated cylinders are calibrated in milliliters or cubic centimeters. A square meter equals 10,000 square centimeters (cm^2). Large area measurements are often expressed in hectares (ha). A hectare equals 10,000 square meters (m^2).

UNITS ACCEPTED FOR USE WITH SI

Certain units of measure that are not SI units are still acceptable for use with SI units. They are the minute, hour, and day (units of time); the liter (a unit of volume); and the metric ton (a unit of mass). These units are listed in Table 4.

TABLE 4 *Examples of Units Accepted for Use with SI*

Unit	Symbol	Value in SI units
Minute	min	1 min = 60 s
Hour	h	1 h = 3,600 s 1 h = 60 min
Day	d	1 d = 24 h
Liter	L	1 L = 0.001 mg^3
Metric ton	t	1 t = 1,000 kg

Equivalent Measurements and Conversions

Conversion between SI units requires a conversion factor. For example, to convert from meters to centimeters, you need to know the relationship between meters and centimeters.

$$1 \text{ cm} = 0.01 \text{ m} \quad \text{or} \quad 1 \text{ m} = 100 \text{ cm}$$

If you needed to convert a lab measurement of 15.5 centimeters to meters, you could do either of the following:

$$15.5 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}} = 0.155 \text{ m}$$

or

$$15.5 \text{ cm} \times \frac{0.01 \text{ m}}{1 \text{ cm}} = 0.155 \text{ m}$$

The following are some measurement equivalents for length, area, mass, and volume.

LENGTH

1 kilometer (km) = 1,000 m
1 meter (m) = base unit of length
1 centimeter (cm) = 0.01 m
1 millimeter (mm) = 0.001 m
1 micrometer (μm) = 0.000001 m

AREA

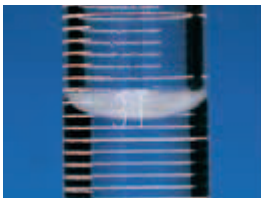
1 square kilometer (km^2) = 100 ha
1 hectare (ha) = 10,000 m^2
1 square meter (m^2) = 10,000 cm^2
1 square centimeter (cm^2) = 100 mm^2

MASS

1 kilogram (kg) = base unit of mass
1 kg = 1,000 grams (g)
1 gram (g) = 0.001 kg
1 milligram (mg) = 0.001 g
1 microgram (μg) = 0.000001 g

LIQUID VOLUME

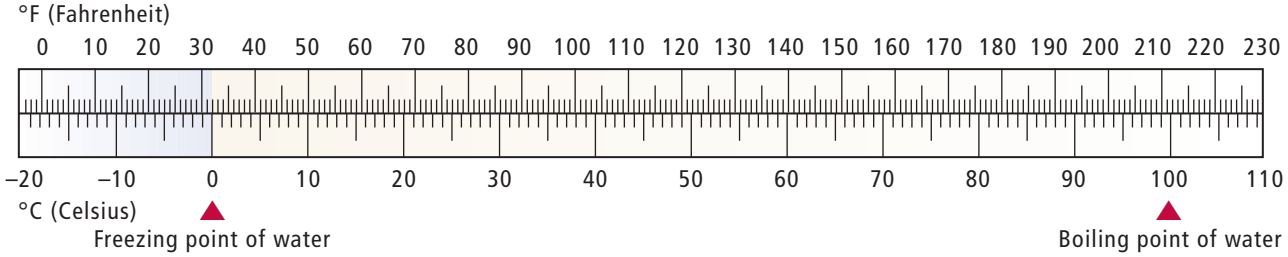
1 kiloliter (kL) = 1,000 L
1 liter (L) = base unit of liquid volume
1 milliliter (mL) = 0.001 L
1 mL = 1 cm^3



NOTE: When measuring liquid volume in a graduated cylinder, read the measurement at the bottom of the meniscus, or curve.

TEMPERATURE

In this textbook, the Celsius scale is used to express temperature measurements. In degrees Celsius, 0° is the freezing point of water, and 100° is the boiling point of water. You can use the scale shown below to convert between the Celsius scale and the Fahrenheit scale.



ANALYZING WORD PARTS

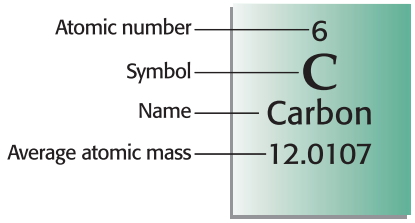
Part of learning biology involves learning many new words. By breaking down some of the words, you can more easily understand their meaning. The table below provides a simple definition and example of some common prefixes, suffixes, and word roots. Refer to this table as you explore each chapter in this textbook.

WORD PREFIXES, SUFFIXES, AND WORD ROOTS

Prefix, suffix, or word root	Definition	Example
a-	not, without	asymmetrical: not symmetrical
ab-	away, apart	abduct: move away from the middle
-able	able	viable: able to live
ad-	to, toward	adduct: move toward the middle
amphi-	both	amphibian: type of vertebrate that lives both on land and in water
ante-	before	anterior: front of an organism
anti-	against	antibiotic: substance, such as penicillin, capable of killing bacteria
arche-	ancient	Archaeopteryx: a fossilized bird
arthro-	joint	arthropod: jointed-limbed organism belonging to the phylum Arthropoda
auto-	self, same	autotrophic: able to make its own food
bi-	two	bivalve: mollusk with two shells
bio-	life	biology: the study of life
blast-	embryo	blastula: hollow ball stage in the development of an embryo
carcin-	cancer	carcinogenic: cancer-causing
cereb-	brain	cerebrum: part of the vertebrate brain
chloro-	green	chlorophyll: green pigment in plants needed for photosynthesis
chondro-	cartilage	Chondrichthyes: cartilaginous fish
chromo-	color	chromatin: plant pigment that absorbs different-colored wavelengths
-cide	kill	insecticide: a substance that kills insects
circ-	around	circulatory: system for moving fluids through the body
co-, con-	with, together	conjoined twins: identical twins physically joined by a shared portion of anatomy at birth
-cycle	circle	pericycle: layer of plant cells
cyt-	cell	cytology: the study of cells
de-	remove	dehydration: removal of water
derm-	skin	dermatology: study of the skin
di-	two	diploid: full set (which is two sets) of chromosomes
dia-	through	dialysis: separating molecules by passing them through a membrane
ecol-	dwelling, house	ecology: the study of living things and their environments
ecto-	outer, outside	ectoderm: outer germ layer of developing embryo
-ectomy	removal	appendectomy: removal of the appendix
endo-	inner, inside	endoplasm: cytoplasm within the cell membrane
epi-	upon, over	epiphyte: plant growing upon another plant
ex-, exo-	outside of	exobiology: the search for life elsewhere in the universe
gastro-	stomach	gastropod: type of mollusk
-gen	type	genotype: genes in an organism
-gram	write or record	climatogram: depicting the annual precipitation and temperature for an area
hemi-	half	hemisphere: half of a sphere
hetero-	different	heterozygous: different alleles inherited from parents
hist-	tissue	histology: the study of tissues

Prefix, suffix, or word root	Definition	Example
homeo-	the same	homeostasis: maintaining a constant condition
hydro-	water	hydroponics: growing plants in water instead of soil
hyper-	above, over	hypertension: blood pressure higher than normal
hypo-	below, under	hypothalamus: part of the brain located below the thalamus
-ic	of or pertaining to	hypodermic: pertaining to under the skin
inter-	between, among	interbreed: breed within a family or strain
intra-	within	intracellular: inside a cell
iso-	equal	isogenic: having an identical set of genes
-ist	someone who practices or deals with something	biologist: someone who studies life
-logy	study of	biology: the study of life
macro-	large	macromolecule: large molecule, such as DNA or a protein
mal-	bad	malnourishment: poor nutrition
mega-	large	megaspore: larger of two types of spores produced by some ferns and flowering plants
meso-	in the middle	mesoglea: jellylike material found between outer and inner layers of coelenterates
meta-	change	metamorphosis: change in form
micro-	small	microscopic: too small to be seen with unaided eye
mono-	one, single	monoploid: one set of alleles
morph-	form	morphology: study of the form of organisms
neo-	new	neonatal: newborn
nephr-	kidney	nephron: functional unit of the kidneys
neur-	nerve or sinew	neurotransmitter: chemical released by a neuron
oo-	egg	oogenesis: gamete formation in female diploid organisms
-oma	swelling	carcinoma: cancerous tumor
org-	living	organism: living thing
orth-	straight	orthodontics: the practice of straightening teeth
pachy-	thick	pachyderm: thick-skinned animal, such as an elephant
para-	near, on	parasite: organism that lives on and gets nutrients from another organism
path-	disease	pathogen: disease-causing agent
peri-	around	pericardium: membrane around the heart
photo-	light	phototropism: bending of plants toward light
phyto-	plants	phytoplankton: plankton that consists of plants
-pod	foot	pseudopod: false foot that projects from the main part of an amoeboid cell
poly-	many	polypeptide: sequence of many amino acids joined together to form a protein
pre-	before	prediction: a forecast of events before they take place
-scope	instrument used to see something	microscope: instrument used to see very small objects
semi-	partially	semipermeable: allowing some particles to move through
-some	body	chromosome: structure found in eukaryotic cells that contains DNA
sub-	under	substrate: molecule on which an enzyme acts
super-, supra-	above	superficial: on or near the surface of a tissue or organ
syn-	with	synapse: junction of a neuron with another cell
-tomy	to cut	appendectomy: operation in which the appendix is removed
trans-	across	transformation: the transfer of genetic material from one organism to another
ur-	referring to urine	urology: study of the urinary tract
visc-	organ	viscera: internal organs of the body

Key:



Metals
- Alkali metals
- Alkaline-earth metals
- Transition metals
- Other metals

Nonmetals
- Halogens
- Noble gases
- Other nonmetals

- Hydrogen
- Semiconductors (also known as *metalloids*)

- Essential to plants
- Found in the atmosphere
- Found in humans

Hydrogen is a component of all organic molecules and water. As an ion, hydrogen influences the pH of cellular and body fluids.

Magnesium activates plant and animal enzymes and is a component of chlorophyll.

Manganese activates plant and animal enzymes.

Cobalt is a component of the vitamin B_{12}, which is needed for maturation of red blood cells.

Sodium is important in nerve function and muscle contraction and helps maintain water balance.

Molybdenum plays a role in nitrogen fixation and is a component of some enzymes.

Iron is a component of hemoglobin and certain enzymes.

Potassium is critical for plant protein synthesis and is important in animal nerve function.

Calcium is part of the structure of bones and teeth, is involved in blood clotting, triggers muscle contraction, and is needed to maintain plant cell walls and membranes.

Period	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9
1	1 H Hydrogen 1.007 94								
2	3 Li Lithium 6.941	4 Be Beryllium 9.012 182							
3	11 Na Sodium 22.989 770	12 Mg Magnesium 24.3050							
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955 910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938 049	26 Fe Iron 55.845	27 Co Cobalt 58.933 200
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.905 85	40 Zr Zirconium 91.224	41 Nb Niobium 92.906 38	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.905 50
6	55 Cs Cesium 132.905 43	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217
7	87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)

* The systematic names and symbols for elements greater than 110 will be used until the approval of trivial names by IUPAC.

			58 Ce Cerium 140.116	59 Pr Praseodymium 140.907 65	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36
			90 Th Thorium 232.0381	91 Pa Protactinium 231.035 88	92 U Uranium 238.028 91	93 Np Neptunium (237)	94 Pu Plutonium (244)

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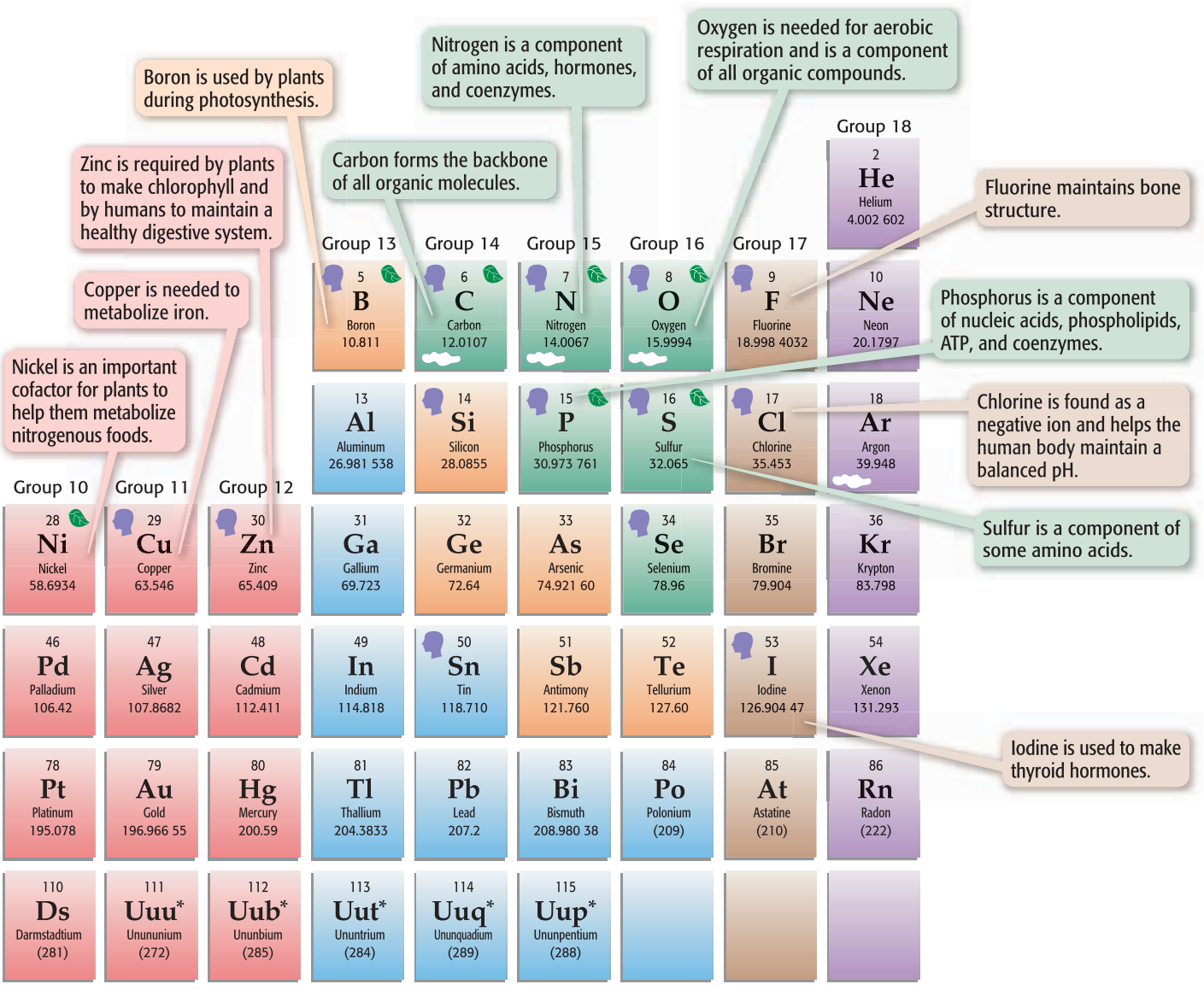
Topic: Periodic Table
Go To: go.hrw.com
Keyword: HOLT PERIODIC

Visit the HRW Web site for updates on the periodic table.



A team at Lawrence Berkeley National Laboratories reported the discovery of elements 116 and 118 in June 1999. The same team retracted the discovery in July 2001. The discovery of elements 113, 114, and 115 has been reported but not confirmed.

63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925 34	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930 32	68 Er Erbium 167.259	69 Tm Thulium 168.934 21	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

The atomic masses listed in this table reflect the precision of current measurements. (Values listed in parentheses are the mass numbers of those radioactive elements' most stable or most common isotopes.)

The classification system used in this book is based on both the commonly recognized six-kingdom system and the newer, three-domain system. A **kingdom** is a group of related phyla, whereas a **domain** is a larger-scale grouping that can encompass kingdoms. In the three-domain system, all living organisms are classified into one of three domains based on cellular similarities. Two of the three domains consist of prokaryotes, and one domain consists of eukaryotes. The table below compares the two systems of classification.

The domain **Bacteria** aligns with the kingdom Eubacteria. The domain **Archaea** aligns with the kingdom Archaebacteria. Both archaea and bacteria are prokaryotic microbes, although the two groups differ significantly.

The third domain, **Eukarya,** consists of all of the eukaryotic organisms. The four kingdoms that align with the domain Eukarya are Animalia (animals), Plantae (plants), Fungi (fungi), and Protista (protists).

The information on the following pages is conveniently organized into commonly recognized subgroups. However, not all of the existing subgroups are presented here, and all classifications are sometimes debated and revised by the scientific community. For example, biologists have proposed several new kingdoms to replace Protista, because the subgroups of Protista are no longer thought to be strongly related. Also, scientists are still uncertain about the number of species in each group.

PROKARYOTES		EUKARYOTES			
Domain Bacteria	Domain Archaea	Domain Eukarya			
Kingdom Eubacteria	Kingdom Archaebacteria	Kingdom Protista	Kingdom Fungi	Kingdom Plantae	Kingdom Animalia

DOMAIN BACTERIA

All bacteria are prokaryotic and lack membrane-bound organelles. Most are unicellular and reproduce by fission. Most species are heterotrophic, but some are photosynthetic or chemosynthetic. More than 4,000 living, described species of bacteria exist.

Proteobacteria

Alpha Proteobacteria many species, such as *Rhizobium* sp., are parasitic or mutualistic bacteria that live within eukaryotic hosts

Beta Proteobacteria diverse modes of nutrition; some species, such as *Nitrosomonas* sp., are important in the nitrogen cycle

Gamma Proteobacteria some species are photosynthetic; some species derive energy by reducing ammonia and hydrogen sulfide; some species, such as *Escherichia coli,* are enteric

Delta Proteobacteria some species, such as *Bdellovibrio* sp., are predators of other bacteria

Epsilon Proteobacteria many species, such as *Helicobacter pylori,* are pathogenic

Gram-Positive Bacteria

Most, but not all, members of this diverse group are Gram-positive. One subgroup, the actinomycetes, is the source of many antibiotics. Many species, including actinomycetes, can cause disease.

Spirochetes

These long, spiral cells have flagellated ends. Some cause serious diseases such as syphilis.

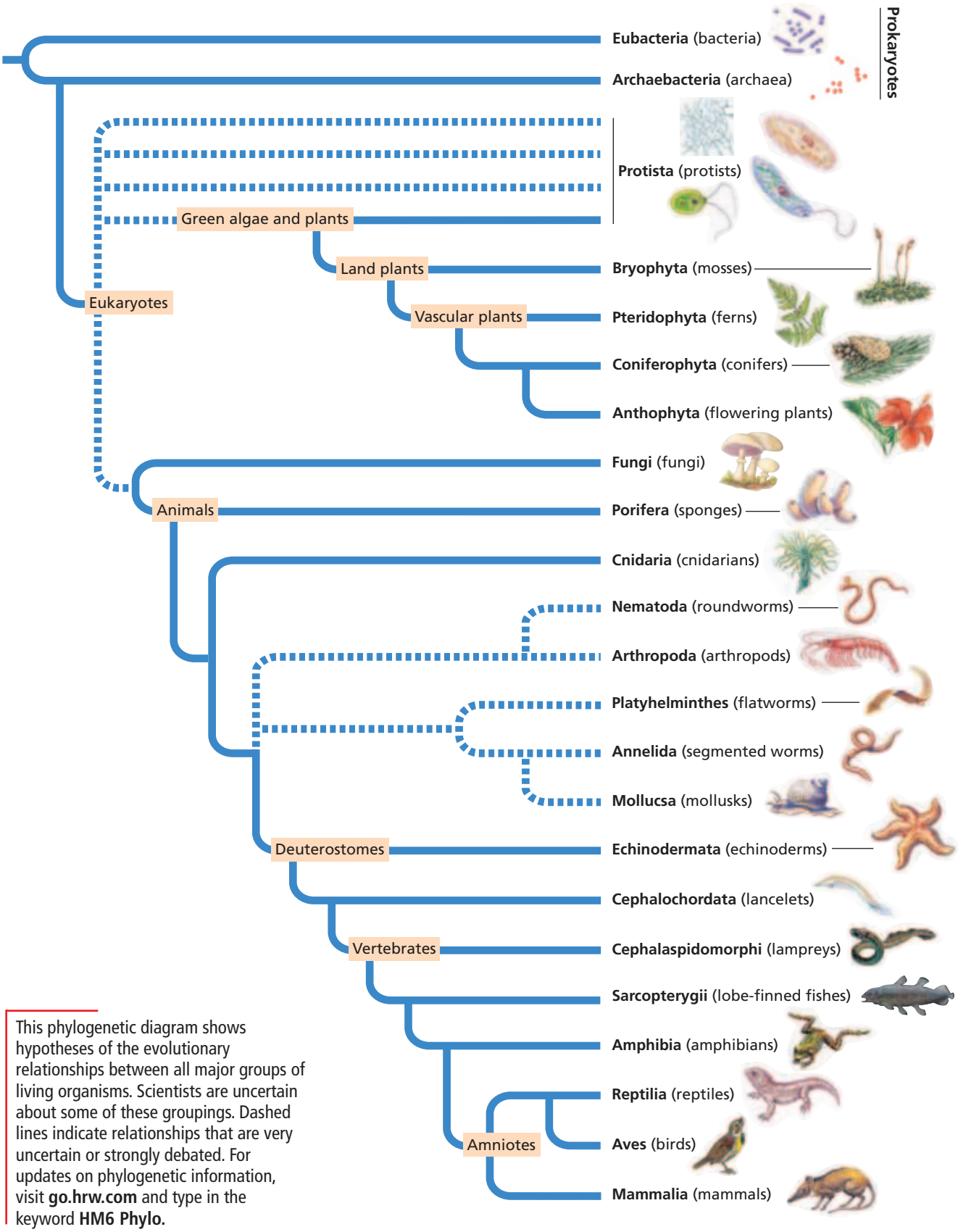
Chlamydia

This group includes obligate internal parasities. Some cause diseases.

Cyanobacteria

This group includes photosynthetic bacteria which are common on land and in water. The chloroplasts of some protists probably evolved from cyanobacteria.

Lyngbya sp.,
a cyanobacterium



This phylogenetic diagram shows hypotheses of the evolutionary relationships between all major groups of living organisms. Scientists are uncertain about some of these groupings. Dashed lines indicate relationships that are very uncertain or strongly debated. For updates on phylogenetic information, visit **go.hrw.com** and type in the keyword **HM6 Phylo.**

DOMAIN ARCHAEA

Kingdom Archaebacteria

This kingdom is made up of prokaryotes called *archaea.* Many archaea live in extreme environments. They differ from eubacteria in cell wall and cell membrane structure. Genetic similarities between archaea and eukaryotes suggest that archaea are more closely related to eukaryotes than to bacteria. Fewer than 100 living, described species exist.

Extreme Halophiles

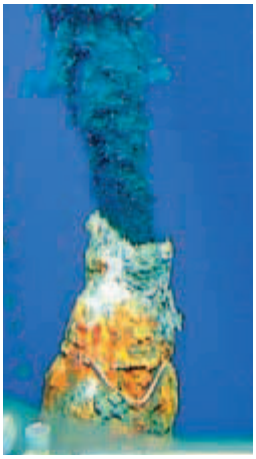
Extreme halophiles inhabit environments of very high salinity, such as the Dead Sea and Great Salt Lake (salinity 15 to 20 percent). Many are aerobic.

Methanogens

Methanogens are anaerobic methane producers that inhabit soil, swamps, and the digestive tracts of animals—particularly the tracts of grazing mammals such as cattle. Most use CO_2 as a carbon source. Methanogens produce nearly 2 trillion kilograms (2 billion tons) of methane gas annually.

Thermoacidophiles

Thermoacidophiles inhabit hot, acidic areas, tolerate extreme heat, and require sulfur. Most are anaerobic.



This undersea hydrothermal vent is home to thermoacidophiles.

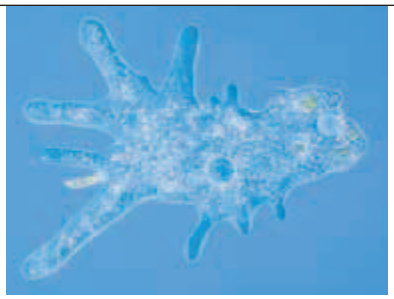
DOMAIN EUKARYA

Kingdom Protista

Kingdom Protista is a diverse group of eukaryotes that are not plants, fungi, or animals. Traditionally, species have been classified in Protista whenever their characteristics do not clearly match with those of one of the other eukaryotic kingdoms.

Because protists are not defined clearly, are so diverse, and are so poorly understood, the classification of protists is problematic. Many scientists have proposed groupings and names that differ from those listed here. In fact, three or more new kingdoms have been proposed to replace Protista. However, scientists have not yet clearly favored any particular new system.

Protists can be unicellular or multicellular. Most have chromosomes, mitochondria, and internal compartments. Some have chloroplasts and conduct photosynthesis, and some have cell walls. They may reproduce sexually, asexually, or both. They occur in many environments, including water, soil, and inside of other organisms. More than 40,000 living, described species exist.



Amoeba proteus, an amoeba

Animal-like Protists (includes Protozoa and Sarcomastigophora)

Sarcodina or Rhizopoda amoebas; unicellular, heterotrophic, and amorphous; move by using cytoplasmic extensions, or *pseudopodia*

Radiozoa or Actinipoda radiolarians; unicellular, heterotrophic, and marine; have pored shells through which cytoplasmic threads project

Ciliophora ciliates; unicellular, heterotrophic, and complex; have rows of cilia and two types of nuclei

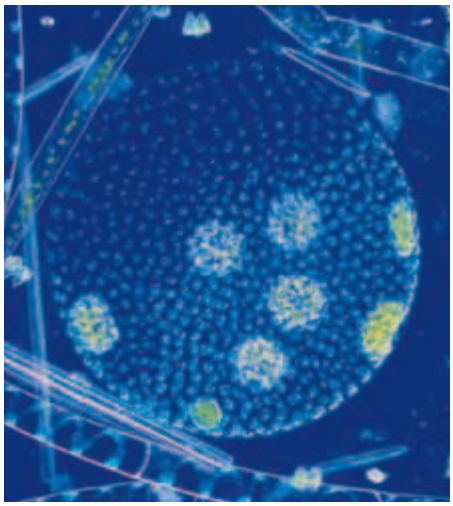
Mastigophora or Kinetoplastida mastigophorans; have at least one flagellum; most are unicellular and heterotrophic; some cause disease

Apicomplexa or Sporozoa unicellular, heterotrophic, and spore-forming; have complex life cycles; adults are nonmotile parasites; undergo asexual and sexual reproduction

Kingdom Protista, *continued*

Plantlike Protists

Chlorophyta green algae; unicellular, colonial, multicellular, and photosynthetic; contain chlorophylls *a* and *b;* their chloroplasts are similar to those of plants; scientists think that plants descended from green algae



Volvox sp., a green alga

Euglenophyta euglenoids; unicellular, photosynthetic, and heterotrophic; reproduce asexually; most species live in fresh water; chloroplasts resemble the chloroplasts of green algae and may have evolved from the same symbiotic bacteria from which green algae chloroplasts evolved; some are considered to be animal-like and are classified in Euglenozoa

Bacillariophyta diatoms; unicellular and photosynthetic; secrete a unique shell that is made of opaline silica and that resembles a lidded box; have chloroplasts that resemble the chloroplasts of brown algae; contain chlorophylls *a* and *c* and fucoxanthin

Phaeophyta brown algae; multicellular and photosynthetic; contain chlorophylls *a* and *c* and fucoxanthin (the source of their brownish color)

Dinoflagellata unicellular; heterotrophic and autotrophic species; most species are marine and are enclosed by two cellulose plates; most species contain carotenoids and chlorophylls *a* and *c.;* sometimes grouped in Alveolata with the animal-like protist groups Apicomplexa and Ciliata

Corallina sp., a red alga

Rhodophyta red algae; multicellular and photosynthetic; most are marine and contain chlorophyll *a* and phycobilins; chloroplasts probably evolved from symbiotic cyanobacteria

Funguslike Protists

Myxomycota plasmodial slime molds; heterotrophic; individuals stream as part of a multinucleate mass of cytoplasm; can produce spores that give rise to new individuals; sometimes grouped with other slime molds in Mycetozoa within Protozoa

Oomycota or Pseudofungi water molds, white rusts, and downy mildews; unicellular heterotrophs; parasites or decomposers; cell walls consist of cellulose; sometimes grouped in Stramenopila with Bacillariophyta, Chrysophyta, and Phaeophyta

Dictyostelida cellular slime molds; heterotrophic cells that take on different forms depending on food availability; cells are usually amoeba-shaped but may aggregate into a moving mass called a *slug;* a slug may produce spores

Dictyostelium sp., a cellular slime mold

DOMAIN EUKARYA, *continued*

Kingdom Fungi

Fungi are heterotrophic by absorption and eukaryotic. Most are multicellular and are composed of filaments called *hyphae.* Although all fungi that are yeasts are unicellular, some are dimorphic, or have both hyphal and unicellular stages. Hyphae are multinucleate, have divisions called *septae* between cells, and have chitinous cell walls. Most fungi reproduce sexually and asexually. Some lack a sexual stage or are difficult to classify and are labeled *Fungi Imperfecti,* or *Deuteromycetes.* About 70,000 living, described species of fungi exist.

Phylum Zygomycota

Zygomycetes, such as bread molds, usually lack septae. Some are terrestrial. Some are parasitic. Fusion of hyphae leads to formation of a zygote, which divides by meiosis when it germinates.

Phylum Ascomycota

Ascomycetes—such as brewer's and baker's yeasts, molds, morels, and truffles—include terrestrial, marine, and freshwater species. Septae are usually perforated. Fusion of the hyphae forms a dense, interwoven mass that contains characteristic microscopic reproductive structures called *asci* (singular, *ascus*). Many fungi formerly classified as Deuteromycetes are now classified as Ascomycota.

Phylum Basidiomycota

Basidiomycetes reproduce sexually. Hyphae usually have incomplete septae. Fusion of the hyphae forms a *mushroom,* a densely interwoven structure that contains characteristic microscopic reproductive structures called *basidia* (singular, *basidium*). Basidiomycota includes mushrooms, toadstools, shelf fungi, rusts, and smuts.

Morchella sp., a mushroom

Kingdom Plantae

Plants are multicellular eukaryotes whose cell walls contain cellulose. Most are autotrophic and terrestrial and contain tissues and organs. Plants contain chlorophylls *a* and *b* in plastids and have a life cycle in which sexual and asexual reproduction alternate. About 280,000 living, described species exist.

Phylum Bryophyta

Bryophytes, or mosses, are nonvascular plants whose gametophytes are larger than their sporophytes. The sporophytes grow on the gametophytes. Bryophytes have simple conducting tissue and lack roots, stems, and leaves.

Marchantia sp., a liverwort

Phylum Hepatophyta

Hepatophytes, or liverworts, are nonvascular plants whose gametophytes are larger than their sporophytes. The sporophytes grow on the gametophytes and lack stomata, roots, stems, and leaves.

Phylum Anthocerophyta

Anthocerophytes, or hornworts, are nonvascular plants whose gametophytes are larger than their sporophytes. The sporophytes grow on the gametophytes, have stomata, and lack roots, stems, and leaves.

Dicksonia antartica, a fern

Ginko biloba, a ginkophyte

Phylum Pteridophyta

Pteridophytes, or ferns, are seedless vascular plants whose sporophytes are larger than their small, flat, independent gametophytes. The sporophytes have roots and stems. The lower surfaces of the leaves produce spores.

Phylum Lycophyta

Lycophytes, such as club mosses, are seedless vascular plants whose sporophytes are larger than their small, flat, independent gametophytes. The sporophytes resemble the gametophytes of mosses; they produce spores in cones and have roots, stems, and leaves.

Phylum Sphenophyta

Sphenophytes, such as horsetails, are seedless vascular plants whose sporophytes are larger than their small, flat, independent gametophytes. The sporophytes produce spores in cones and have roots, leaves, and jointed stems.

Phylum Psilotophyta

Psilophytes, such as whisk ferns, are seedless vascular plants whose sporophytes are larger than their small, flat, independent gametophytes. The sporophytes lack leaves, have roots and stems, and produce spores in sporangia at stem tips.

Phylum Coniferophyta

Conifers are gymnosperms such as pines, spruces, firs, larches, and yews. Most have sporophytes that are evergreen trees or shrubs that have needlelike or scalelike leaves. Microscopic gametophytes develop from spores produced within cones on the sporophytes.

Phylum Cycadophyta

Cycads are gymnosperms and seed-bearing vascular plants. The sporophytes are evergreen trees and shrubs that have palmlike leaves. Microscopic gametophytes develop from spores produced in cones on separate sporophytes.

Phylum Ginkgophyta

Ginkgophyta contains one species: a gymnosperm called *Ginkgo biloba.* The sporophyte is a deciduous tree that has fan-shaped leaves and fleshy seeds. Microscopic gametophytes develop from spores produced on separate sporophytes.

Phylum Gnetophyta

Gnetophytes are gymnosperms and seed-bearing vascular plants whose sporophytes are shrubs or vines that have some angiosperm features. Microscopic gametophytes develop from spores produced in cones on the sporophytes.

Phylum Anthophyta

Anthophytes are angiosperms, or flowering plants, and are seed-bearing vascular plants whose sporophytes are flowering trees, shrubs, herbs, or vines. Microscopic gametophytes develop from spores produced in flower reproductive structures.

Class Monocotyledones monocots; embryos have one cotyledon; flower parts in multiples of three; leaf veins parallel; includes grasses, sedges, lilies, irises, palms, and orchids

Class Dicotyledones dicots; embryos have two cotyledons; flower parts in multiples of two, four, or five; includes most flowering plants, such as daisies, legumes, hardwood trees, shrubs, and vines

Helianthus annuus, a dicot

DOMAIN EUKARYA, *continued*

Kingdom Animalia

Animals are multicellular, eukaryotic, and heterotrophic organisms. Most obtain nutrition by ingestion and have specialized tissues. Many have complex organs and organ systems. None have cell walls or chloroplasts. Most undergo sexual reproduction. They are aquatic or terrestrial. More than 1 million living, described species exist.

Phylum Porifera

Poriferans, or sponges, are asymmetrical and lack tissues and organs. Their body wall consists of two layers of interdependent cells. Poriferans undergo sexual and asexual reproduction. Most are marine.

Phylum Cnidaria

Cnidarians are radially symmetrical and are marine or freshwater. Most are gelatinous and have distinct tissues and a baglike body of two cell layers.

Cribrinopsis fernadli, a sea anemone

Class Hydrozoa hydras
Class Cubozoa box jellies
Class Scyphozoa jellyfish
Class Anthozoa sea anemones and corals

Phylum Ctenophora

Ctenophores, or comb jellies, are radially symmetrical, marine, transparent, and gelatinous.

Phylum Platyhelminthes

Flatworms are bilaterally symmetrical.

Class Turbellaria planarians
Classes Trematoda and Monogenea flukes
Class Cestoda tapeworms

Phylum Nematoda

Nematodes, or roundworms, are parasitic, unsegmented, long, and slender pseudocoelomates.

Phylum Rotifera

Rotifers are free-living, aquatic pseudocoelomates.

Phylum Mollusca

Mollusks are soft-bodied protostomes whose three-part body consists of a foot, a visceral mass, and a mantle. They are terrestrial, freshwater, or marine.

Class Polyplacophora chitons
Class Gastropoda gastropods
Class Bivalvia bivalves
Class Cephalopoda cephalopods

Phylum Annelida

Annelids are serially segmented, bilaterally symmetrical protostomes.

Class Polychaeta bristle worms
Class Oligochaeta earthworms
Class Hirudinea leeches

Phylum Arthropoda

Arthropods are bilaterally symmetrical, segmented protostomes that are aerial, terrestrial, or aquatic and have paired, jointed appendages and a chitinous exoskeleton.

Subphylum Chelicerata includes arachnids
Subphylum Crustacea crustaceans
Subphylum Myriapoda centipedes and millipedes
Subphylum Hexapoda insects and parainsecta

Phylum Echinodermata

Echinoderms are marine deuterostomes. Adults have radial symmetry and a five-part body plan. Most have a water-vascular system and tube feet.

Class Crinoidea sea lilies and feather stars
Class Ophiuroidea brittle stars and basket stars
Class Echinoidea sea urchins and sand dollars
Class Holothuroidea sea cucumbers
Class Asteroidea sea stars

Phylum Chordata

Chordates are bilaterally symmetrical, aquatic or terrestrial deuterostomes that have a notochord, a dorsal nerve cord, pharyngeal slits, and a tail.

Ambystoma cingulatum, a vertebrate

Subphylum Urochordata tunicates
Subphylum Cephalochordata lancelets
Subphylum Vertebrata vertebrates

The Geologic Time Scale

Era	Period	Epoch	Beginning of interval (mya*)	Characteristics from geologic and fossil evidence
Cenozoic 	Quaternary	Holocene	0.0115	The last glacial period ends; complex human societies develop.
		Pleistocene	1.8	Woolly mammoths, rhinos, and humans appear.
	Tertiary	Pliocene	5.3	Large carnivores (bears, lions, wolves) appear.
		Miocene	23.0	Grazing herds are abundant; raccoons and wolves appear.
		Oligocene	33.9	Deer, pigs, horses, camels, cats, and dogs appear.
		Eocene	55.8	Horses, flying squirrels, bats, and whales appear.
		Paleocene	65.5	Age of mammals begins; first primates appear.
Mesozoic 	Cretaceous		146	Flowering plants and modern birds appear; mass extinctions mark the end of the Mesozoic Era.
	Jurassic		200	Dinosaurs are the dominant life-form; primitive birds and flying reptiles appear.
	Triassic		251	Dinosaurs appear; ammonites are common; cycads and conifers are abundant; and mammals appear.
Paleozoic 	Permian		299	Pangaea comes together; mass extinctions mark the end of the Paleozoic Era.
	Carboniferous	Pennsylvanian Period	318	Giant cockroaches and dragonflies are common; coal deposits form; and reptiles appear.
		Mississippian Period	359	Amphibians flourish; brachiopods are common in oceans; and forests and swamps cover most land.
	Devonian		416	Age of fishes begins; amphibians appear; and giant horsetails, ferns, and cone-bearing plants develop.
	Silurian		444	Eurypterids, land plants, and animals appear.
	Ordovician		488	Echinoderms appear; brachiopods increase; trilobites decline; graptolites flourish; atmosphere reaches modern O_2-rich state.
	Cambrian		542	Shelled marine invertebrates appear; trilobites and brachiopods are common. First vertebrates appear.
Precambrian time			4,600	The Earth forms; continental shields appear; fossils are rare; and stromatolites are the most common organism.

*millions of years ago

Glossary

Sound symbol	Key word(s)	Phonetic respelling
a	map	MAP
ay	face day	FAYS DAY
ah	father cot	FAH-thuhr KAHT
aw	caught law	KAWT LAW
ee	eat ski	EET SKEE
e	wet rare	WET RER
oy	boy foil	BOY FOYL
ow	out now	OWT NOW
oo	shoot suit	SHOOT SOOT
u	book put	BUK PUT
uh	sun cut	SUHN KUHT
i	lip	LIP
ie	tide sigh	TIED SIE
oh	over coat	OH-vuhr KOHT
yoo	yule globule	YOOL GLAH-byool
yu	cure	KYUR
uhr	paper fern	PAY-puhr FUHRN
k	card kite	KAHRD KIET
s	cell sit	SEL SIT
y	yes	YES
j	job	JAHB
g	got	GAHT
zh	pleasure	PLE-zhuhr

Each page number provided indicates where the word is defined and not necessarily where it is first used. Remember to refer to the index for more page numbers if further investigation is needed.

A

abdomen in arthropods, the posterior tagma; in vertebrates, the region that comprises the posterior part of the coelom and the viscera; the internal organs other than the heart, lungs, thymus (728)

abdominal cavity the hollow part of the body that is below the diaphragm and above the pelvis; contains the organs of digestion, excretion, and reproduction (910)

abiotic factor an environmental factor that is not associated with the activities of living organisms (363)

abscisic acid a hormone in plants that helps regulate the growth of buds and the germination of seeds (abbreviation, ABA) (635)

abscission the separation of leaves or other plant structures by the formation of a layer of cells that develops on the base of the plant structure when the structure is ready to fall (634)

absolute age the numeric age of an object or event, often stated in years before the present, as established by an absolute-dating process, such as radiometric dating (303)

accessory pigment a pigment that absorbs light energy and transfers it to chlorophyll in photosynthesis (511)

acclimation an organism's change in response to a change in the organism's environment (364)

acetyl-CoA acetyl coenzyme A, a compound that is synthesized by cells and that plays a major role in metabolism (138)

acid any compound that increases the number of hydronium ions when dissolved in water; acids turn blue litmus paper red and react with bases and some metals to form salts (43)

acid precipitation precipitation, such as rain, sleet, or snow, that contains a high concentration of acids, often because of the pollution of the atmosphere (441)

acoelomate an animal that lacks a coelom, or body cavity (665)

actin a protein that makes up the thin filaments of muscle fibers and that functions in the contraction and relaxation of muscle (919)

action potential a sudden change in the polarity of the membrane of a neuron, gland cell, or muscle fiber that facilitates the transmission of electrical impulses (1005)

activation in genetics, the initiation of transcription of a particular gene (219)

activation energy the minimum amount of energy required to start a chemical reaction (36)

active site the site on an enzyme that attaches to a substrate (57)

active transport the movement of chemical substances, usually across the cell membrane, against a concentration gradient; requires cells to use energy (103)

adaptation the process of becoming adapted to an environment; an anatomical, physiological, or behavioral trait that improves an organism's ability to survive and reproduce (12, 300)

adaptive radiation an evolutionary pattern in which many species evolve from a single ancestral species (309)

addiction the condition in which a person can no longer control his or her drug use (1021)

adhesion the attractive force between two bodies of different substances that are in contact with each other (41)

adrenal gland one of the two endocrine glands located above each kidney (1036)

adventitious root a root that occurs in an unusual position, such as on stems or leaves (588)

aerobic respiration the process in which pyruvic acid is broken down and NADH is used to make a large amount of ATP; the part of respiration that is carried out in the presence of oxygen (131)

aflatoxin a toxic fungal poison that causes liver cancer; found as contaminants in peanuts and corn; produced by a species of the genus *Aspergillus* (535)

afterbirth the remains of the placenta and the membranes, which are expelled from the mother's body following birth (1060)

agar a gel-like polysaccharide compound used for culturing microbes; extracted from certain red algae (518)

age structure the classification of members of a population into groups according to age or the distribution of members of a population in terms of age groups (384)

Agent Orange a mixture of plant hormones that has been used to cause plants to lose their leaves; has been used in military campaigns to defoliate large areas of forest (633)

aggressive behavior threatening behavior or physical conflict between animals (893)

agricultural revolution the change from a hunting and gathering society to an agricultural society that began about 10,000 years ago (390)

agriculture the raising of crops and livestock for food or for other products that are useful to humans (545)

AIDS acquired immune deficiency syndrome, a disease caused by HIV; an infection that results in an ineffective immune system (970)

albumen the white of an egg, composed primarily of the protein albumin (823)

alcoholic fermentation the anaerobic process by which yeasts and other microorganisms break down sugars to form carbon dioxide and ethanol (135)

algae autotrophic eukaryotic organisms that convert the sun's energy into food through photosynthesis but that do not have roots, stems, or leaves (singular, *alga*) (510)
algal bloom a vast increase in the concentration of algae and cyanobacteria in a body of eutrophic water which causes harmful changes in the water; some species of algae produce toxins that kill other sea life (517)
alginate a polysaccharide derivative of alginic acid that is found in brown algae and that has many industrial uses including thickening agent in foods and a dental impression agent (518)
allantois a membranous sac that acts as an organ of respiration and nutrition for the embryo; in humans, its blood vessels become the blood vessels of the umbilical cord (823)
allele one of the alternative forms of a gene that governs a characteristic, such as hair color (178)
allele frequency the proportion of gene copies in a population that are a given allele, expressed as a percentage (318)
allergy a physical response to an antigen, which can be a common substance that produces little or no response in the general population (968)
alternation of generations the alternation of sexual reproduction and asexual reproduction in certain plants and animals (565)
altricial describes organisms that are not very developed when born and that require care or nursing (849)
altruistic behavior self-sacrificing behavior that benefits another individual (754)
alveolus any of the tiny air cells of the lungs where oxygen and carbon dioxide are exchanged (plural, *alveoli*) (826, 947)
amino acid an organic molecule that contains a carboxyl and an amino group and that makes up proteins; a protein monomer (56, 664)
amino acid–based hormone a hormone that is made up of simple amino acids, peptides, or proteins (1031)
ammonia a colorless gas that has an alkaline reaction in water; forms in nature as an end product of animal metabolism (formula, NH_3) (993)
ammonification the formation of ammonia compounds in the soil by the action of bacteria on decaying matter (374)
amniocentesis a procedure used in fetal diagnosis in which amniotic fluid is removed from the uterus of the pregnant woman (245)
amnion in mammals, birds, and reptiles, the membrane that contains a developing embryo and its surrounding fluid (823)
amniotic egg a type of egg that is produced by reptiles, birds, and egg-laying mammals and that contains a large amount of yolk; usually surrounded by a leathery or hard shell within which the embryo and its embryonic membranes develop (823)
amniotic sac the sac formed by the amnion (1057)
amoebocyte within the body wall of a sponge, a specialized cell that crawls about and delivers nutrients from the choanocytes to the rest of the body cells (674)
amoeboid movement a characteristic movement of protozoa that occurs because of the formation of pseudopodia (506)
amplexus the copulatory embrace of amphibians (810)
ampulla on the upper end of a tube foot of an echinoderm, a bulblike sac that forces water into the tube foot and causes the tube foot to expand (766)
anaerobic describes a process that does not require oxygen (131)
anal pore in protozoa, an opening from which wastes are eliminated (508)
analogous structure an anatomical structure in one species that is similar in function and appearance, but not in evolutionary origin, to another anatomical structure in another species (305)
anaphase a phase of mitosis and meiosis in which the chromosomes separate (157)
androgen a hormone that is secreted by the testes and that controls secondary male characteristics (1037)
angiosperm a flowering plant that produces seeds within a fruit (565)
animal a multicellular, heterotrophic organism that lacks cell walls and that is usually characterized by movement and sexual reproduction; a member of Kingdom Animalia (651)
Animalia in a traditional taxonomic system, a kingdom made up of complex, multicellular organisms that lack cell walls, are usually able to move around, and possess specialized sense organs that help them quickly respond to their environment (350)
annual ring in secondary xylem (wood), the growth ring formed in one season (595)
antenna a feeler that is on the head of an invertebrate, such as a crustacean or an insect, and that senses touch, taste, or smell (728)
antennule in crustaceans, a second pair of antennae, usually smaller than the first (728)
anterior the front part of a body or structure (655)
anther in flowering plants, the tip of a stamen, which contains the pollen sacs where grains form (613)
antheridium a reproductive structure that produces male sex cells in flowerless and seedless plants (532, 609)
anthropoid primate one of a subgroup of primates that includes monkeys, apes, and humans (876)
antibiotic a substance that inhibits the growth of or kills microorganisms (465)
antibiotic resistance the ability of a population of bacteria to survive the lethal effects of an antibiotic (473)
antibody a protein that reacts to a specific antigen or that inactivates or destroys toxins (941, 964)
anticodon a region of tRNA that consists of three bases complementary to the codon of mRNA (208)
antigen a substance that stimulates an immune response (943, 962)
aorta the main artery in the body; it carries blood from the left ventricle to systemic circulation (935)
aortic arch a muscular blood vessel that links the blood vessels from the dorsal and ventral parts of an animal's body (715)
aphotic zone the deeper parts of the ocean, where there is so little light that plants cannot carry out photosynthesis (423)
apical dominance the inhibition of lateral bud growth on the stem of a plant by auxin produced in the terminal bud (633)
apical meristem the growing region at the tips of stems and roots in plants (586)
apical organ in ctenophores, a sensory structure that enables the animal to sense its orientation in water; in annelids, a ciliated plate located at the back of the larva (682)
aposematic coloration in animals, bright coloration that warns predators that a potential prey animal is poisonous (896)
appendage a structure that extends from the main body, such as a limb, tentacle, fin, or wing (723)
appendicular skeleton the bones of the arms and legs, along with scapula, clavicle, and pelvis (911)
aqueous solution a solution in which water is the solvent (42)
arachnid an arthropod that has eight legs and no wings or antennae; a spider, scorpion, mite, or tick (731)
archaea prokaryotes, most of which are known to live in extreme environments; differentiated from other prokaryotes by genetic differences and differences in the make up of their cell walls (singular, *archaeon*) (289, 347)
Archaea in a modern taxonomic system, a domain made up of prokaryotes that can live in extreme environments and that are differentiated from other prokaryotes by various important chemical differences; this domain aligns with the traditional kingdom Archaebacteria (347)
Archaebacteria in a traditional taxonomic system, a kingdom made up of prokaryotes that can live in extreme environments; differentiated from other prokaryotes by various important chemical differences; biologists more recently prefer to classify these organisms as Domain Archaea (348)
archegonium a female reproductive structure of small, nonvascular plants that produces a single egg and in which fertilization and development take place (609)

Glossary

archenteron the primitive gastric cavity of an embryo (664)
artery a blood vessel that carries blood away from the heart to the body's organs (936)
arthropod a member of the phylum Arthropoda, which includes invertebrate animals such as insects, crustaceans, and arachnids; characterized by having segmented bodies and paired appendages (723)
artificial selection the selective breeding of organisms (by humans) for specific desirable characteristics (310)
ascocarp the reproductive portion of an ascomycete (532)
ascogonium the female sexual organ or cell in ascomycetes (532)
ascospore a spore produced in an ascus by ascomycetes (532)
ascus the spore sac where ascomycetes produce ascospores (532)
asexual reproduction reproduction that does not involve the union of gametes and in which a single parent produces offspring that are genetically identical to the parent (155)
aspirin the common name of acetylsalicylic acid, a pain reliever (548)
assortative mating sexual reproduction in which males and females do not breed randomly (323)
asteroid-impact hypothesis an explanation for the mass extinction of most of the dinosaurs; holds that a giant asteroid struck Earth and caused catastophic climate change about 66 million years ago (821)
asthma a lung disorder characterized by labored breathing due to narrowing of the bronchioles; associated with shortness of breath, wheezing, and coughing; and caused by a reaction to certain irritants (968)
atherosclerosis a disease characterized by the buildup of fatty materials on the interior walls of the arteries (938)
atom the smallest unit of an element that maintains the chemical properties of that element (32)
atomic number the number of protons in the nucleus of an atom; the atomic number is the same for all atoms of an element (32)
ATP (adenosine triphosphate) an organic molecule that acts as the main energy source for cell processes; composed of a nitrogenous base, a sugar, and three phosphate groups (54)
atriopore an opening from the atrial cavity to the exterior in certain fish (770)
atrium a chamber that receives blood that is returning to the heart (933)
auditory canal the tube through which air enters the ear (1017)
australopithecine one of a subfamily of early hominids that lived between 4.2 million and 1 million years ago; includes the genus *Australopithecus* and possibly the genus *Paranthropus* (877)
autoimmune disease a disease in which the immune system attacks the organism's own cells (969)
autonomic nervous system the part of the nervous system that controls involuntary actions (1015)
autosome any chromosome that is not a sex chromosome (152, 236)
autotomy the ability of an organism to drop a body part and, usually, to regenerate a new one (832)
autotroph an organism that produces its own nutrients from inorganic substances or from the environment instead of consuming other organisms (113, 469)
AV node (atrioventricular node) a mass of specialized cardiac muscle that is located between the right atrium and right ventricle and that generates electrical impulses that cause the ventricles of the heart to contract (935)
axial skeleton the bones of the skull, ribs, vertebral column, and sternum (911)
axon an elongated extension of a neuron that carries impulses away from the cell body (1005)
axon terminal the end of an axon (1005)

B

B cell a white blood cell that matures in bones and makes antibodies (962)
bacillus a rod-shaped bacterium (463)
Bacteria in a modern taxonomic system, a domain made up of prokaryotes that usually have a cell wall and that usually reproduce by cell division; this domain aligns with the traditional kingdom Eubacteria (347)
bacteriophage a virus that infects bacteria (195, 486)
baleen the thin plates of keratin that hang from the mouth of some whales; used to filter out water but to retain solids when whales feed (865)
bark a tissue of dead cells that forms on the exterior of woody plants for protection (595)
base any compound that increases the number of hydroxide ions when dissolved in water; bases turn red litmus paper blue and react with acids to form salts (44)
base pairing rules the rules stating that cytosine pairs with guanine and adenine pairs with thymine in DNA, and that adenine pairs with uracil in RNA (198)
base unit one of the fundamental units of measurement that describes length, mass, time, and other quantities and from which other units are derived (23)
basidiocarp the part of a basidiomycete that produces spores (531)
basidiospore an asexual spore formed by a basidium (531)
basidium a structure that produces asexual spores in basidiomycetes (531)
behavior an action that an individual carries out in response to a stimulus or to the environment (887)
bell curve on a graph of the frequency of some variable, a curve that first rises and then falls and thus forms a symmetric bell-shaped curve (317)
benthic zone the bottom region of oceans and bodies of fresh water (424)
biennial a plant that has a two-year life cycle (642)
bilateral symmetry a condition in which two equal halves of a body mirror each other (655)
binary fission a form of asexual reproduction in single-celled organisms by which one cell divides into two cells of the same size (154, 504)
binomial nomenclature a system for giving each organism a two-word scientific name that consists of the genus name followed by the species name (339)
biodiversity the variety of organisms considered at all levels, from populations to ecosystems (337, 438)
biodiversity hotspot region of the biosphere that has been identified by conservationists as having high species diversity and as being highly threatened by human impacts (449)
bioethics the study of ethical issues related to DNA technology (270)
biogenesis the scientific principle that living organisms come only from other living organisms (279)
biogeochemical cycle the circulation of substances through living organisms from or to the environment (371)
biogeography the study of the geographical distribution of living organisms and fossils on Earth (305)
bioindicator a species that is especially sensitive to ecological change and thus can serve as an indicator of environmental conditions (447)
bioinformatics a technology that combines biological science, computer science, and information technology to enable the discovery of new biological insights and unifying principles (263)
biological magnification the accumulation of increasingly large amounts of toxic substances within each successive link of the food chain (442)
biological molecule chemical compound that provides physical structure and brings about movement, energy use, and other cellular functions (7)
biological species concept the concept that a species is a population of organisms that can interbreed but cannot breed with other populations (327)
biology the study of life (5)
bioluminescence the production of light by means of a chemical reaction in an organism (513, 682)
biomass any organic material that has been produced in an ecosystem (366)
biome a large region characterized by a specific type of climate and certain types of plant and animal communities (417)

bioremediation the biological treatment of hazardous waste by natural or genetically engineered microorganisms (476)
biosphere the part of Earth where life exists; includes all of the living organisms on Earth (361, 437)
biotic factor an environmental factor that is associated with or results from the activities of living organisms (363)
bipedalism in hominids, the condition of being adapted to walk primarily upright on two legs (876)
bipinnaria the larva of starfish (767)
birth rate the number of births that occur in a period of time in a given area (383)
bivalve an aquatic mollusk that has a shell divided into two halves connected by a hinge, such as a clam, oyster, or mussel (708)
blade the broad, flat portion of a typical leaf (600)
blastocyst the modified blastula stage of mammalian embryos (1056)
blastopore an opening that develops in the blastula (664)
blastula the stage of an embryo before gastrulation (664)
blood alcohol concentration a measurement of the amount of alcohol in a person's blood (abbreviation, BAC) (1023)
blood pressure the force that blood exerts on the walls of the arteries (936)
blood type a classification of blood that depends on the type of antigen present on the surface of the red blood cell (943)
bolting the premature production of flowers and seeds, especially during the first year of a biennial plant (642)
bone marrow soft tissue inside bones where red and white blood cells are produced (913)
book lung in spiders and scorpions, an organ for respiration that has parallel folds that resemble the pages of a book (732)
Bowman's capsule the cup-shaped structure of the nephron of a kidney that encloses the glomerulus and in which filtration takes place (994)
brainstem the stemlike portion of the brain that connects the cerebral hemispheres with the spinal cord and that maintains the necessary functions of the body, such as breathing and circulation (1012)
bronchiole a small air passage that branches from the bronchi within the lungs (947)
bronchus one of the two tubes that connect the lungs with the trachea (947)
brood patch on the abdomen of birds, a thickened, featherless patch of skin that is used for incubating eggs (848)
bryophyte a plant that has no vascular tissue and absorbs nutrients and water from the soil through rootlike hairs; examples include mosses and liverworts (567)
bud a shoot or flower that has immature leaves folded in the growing tip (593)
bud scale a modified leaf that forms a protective covering for a bud until it opens (593)
budding asexual reproduction in which a part of the parent organism pinches off and forms a new organism (528)
buffer a solution made from a weak acid and its conjugate base that neutralizes small amounts of acids or bases added to it (44)
bulbourethral gland one of the two glands in the male reproductive system that add fluid to the semen during ejaculation (1051)

C

C_4 pathway a carbon-fixing process in which carbon dioxide is bound to a compound to form a four-carbon intermediate (122)
Calvin cycle a biochemical pathway of photosynthesis in which carbon dioxide is converted into glucose using ATP (120)
CAM pathway a water-conserving, carbon-fixing process; CAM plants take in carbon at night and fix it into various organic compounds and release it during the day (122)
cancer a tumor in which the cells begin dividing at an uncontrolled rate and become invasive (225)
canine a sharp tooth located on either side of both jaws (865)
canopy the layers of treetops that shade the forest floor (419)
capillarity the attraction between molecules that results in the rise of a liquid in small tubes (41)
capillary a tiny blood vessel that allows an exchange between blood and cells in tissue (936)
capsid a protein sheath that surrounds the nucleic acid core in a virus (484)
capsule in mosses, the part that contains spores; in bacteria, a protective layer of polysaccharides around the cell wall (468)
carapace a shieldlike plate that covers the cephalothorax of some crustaceans and reptiles (728, 830)
carbohydrate any organic compound that is made of carbon, hydrogen, and oxygen and that provides nutrients to the cells of living things (55)
carbon cycle the movement of carbon from the nonliving environment into living things and back (372)
carbon fixation the synthesis of organic compounds from carbon dioxide, such as in photosynthesis (120)
carcinogen a cancer-causing substance (226)
carcinoma a malignant tumor that grows in the skin or in the tissues that line organs (228)
cardiac muscle the type of involuntary muscle found in the heart (907)
cardiac sphincter a circular muscle located between the esophagus and the stomach (988)
cardiovascular system a collection of organs that transport blood throughout the body; the organs in this system include the heart, the arteries, and the veins (933)
carnivore an organism that eats animals (367)
carotenoid a class of pigments that are present in the thylakoid membrane of plants and that aid in photosynthesis (115)
carpel the structure where the ovule is in flowering plants (613)
carrageenan a sticky polysaccharide that coats the cell walls of certain species of red algae and that is used in the food industry to control the texture of many food products (518)
carrier in genetics, an individual who has one copy of a recessive autosomal allele that causes disease in the homozygous condition (242)
carrier protein a protein that transports substances across a cell membrane (101)
carrying capacity the largest population that an environment can support at any given time (387)
cartilage a flexible and strong connective tissue (784)
catalyst a substance that changes the rate of a chemical reaction without being consumed or changed significantly (36)
cecum in some herbivorous animals, a sac usually found at the beginning of the large intestine that acts as a fermentation chamber for plant materials (866)
cell in biology, the smallest unit that can perform all life processes; cells are covered by a membrane and contain DNA and cytoplasm (7, 69)
cell differentiation the process by which a cell becomes specialized for a specific structure or function (223)
cell division the formation of two cells from one existing cell (8)
cell plate the precursor of a new plant cell wall that forms during cell division and divides a cell into two (7, 158)
cell theory the theory that states that all living things are made up of one or more cells, that cells are the basic units of organisms, that each cell in a multicellular organism has a specific job, and that cells come only from existing cells (70)
cell wall a rigid structure that surrounds the cell membrane and provides support to the cell (88)
cell-mediated immune response an immune response that functions to defend cells against invasion by foreign cells and that depends on the action of T cells (963)
cellular respiration the process by which cells obtain energy from carbohydrates; atmospheric oxygen combines with glucose to form water and carbon dioxide (131)
cellular slime mold a type of protist that lives as an individual haploid amoeboid cell that gathers with other such cells in a

dense structure called a pseudoplasmodium when nutrients become scarce (514)

central nervous system the brain and the spinal cord; its main function is to control the flow of information in the body (1010)

central vacuole in some protists and in most plant cells, a large, fluid-filled organelle that stores water, enzymes, metabolic wastes, and other materials (88)

centriole an organelle that is composed of two short microtubules at right angles to each other and that has an active role in mitosis (85)

centromere the region of the chromosome that holds the two sister chromatids together during mitosis (152)

cephalization the concentration of nerve tissue and sensory organs at the anterior end of an organism (655)

cephalopod a marine mollusk that has tentacles extending from the head; an octopus, squid, cuttle-fish, or nautilus (710)

cephalothorax in arachnids and some crustaceans, the body part made up of the head and the thorax (728)

cereal any grass that produces grains that can be used for food, such as rice, wheat, corn, oats, or barley (546)

cerebellum a posterior portion of the brain that coordinates muscle movement and controls subconscious activities and some balance functions (1013)

cerebral cortex the gray, outer portion of the cerebrum that controls the higher mental functions, general movement, organ function, perception, and behavioral reactions (1011)

cerebral ganglion one of a pair of nerve-cell clusters that serve as a primitive brain at the anterior end of some invertebrates, such as annelids (691)

cerebrum the upper part of the brain that receives sensation and controls movement (1011)

cervix the neck of the uterus (1053)

chaparral a type of vegetation that includes broad-leafed evergreen shrubs and that is located in areas with hot, dry summers and mild, wet winters (421)

chelicera in some arthropods, either of a pair of pincerlike appendages used to attack prey (724)

cheliped in arthropods, one of the pair of appendages that have claws (728)

chemical bond the attractive force that holds atoms or ions together (33)

chemical reaction the process by which one or more substances change to produce one or more different substances (36)

chemiosmosis in chloroplasts and mitochondria, a process in which the movement of protons down their concentration gradient across a membrane is coupled to the synthesis of ATP (118)

chemoreception the ability to detect chemicals in the environment (783)

chemosynthesis the production of carbohydrates through the use of energy from inorganic molecules instead of light (289, 366)

chemotaxis in prokaryotes and protists, the movement toward or away from a chemical stimulus, such as the movement toward food or away from a toxin (517)

chemotroph an organism that gets its energy from chemicals taken from the environment (469)

chemotropism the tendency of an organism or a part of an organism to grow toward or away from a chemical stimulus (638)

chitin a carbohydrate that forms part of the exoskeleton of arthropods and other organisms, such as insects, crustaceans, fungi, and some algae (527, 715, 723)

chlorofluorocarbon a type of hydrocarbon in which some or all of the hydrogen atoms are replaced by chlorine and fluorine; used in coolants for refrigerators and air conditioners and in cleaning solvents (abbreviation, CFC) (440)

chlorophyll a green pigment that is present in most plant cells, that gives plants their characteristic green color, and that reacts with sunlight, carbon dioxide, and water to form carbohydrates (89, 115)

chloroplast an organelle found in plant and algae cells where photosynthesis occurs (89, 114)

choanocyte any of the flagellate cells that line the cavities of a sponge (673)

chordate an animal that at some stage in its life cycle has a dorsal nerve, a notochord, and pharyngeal pouches; examples include mammals, birds, reptiles, amphibians, fish, and some marine lower forms (654)

chorion the outer membrane that surrounds an embryo (823)

chorionic villi fingerlike projections of the chorion that extend into the uterine lining (singular, *chorionic villus*) (1058)

chorionic villi sampling a procedure in which the chorionic villi to are analyzed to diagnose fetal genotypes (246)

chromatid one of the two strands of a chromosome that become visible during meiosis or mitosis (152)

chromatin the material that makes up both mitotic and interphase chromosomes; a complex of proteins and DNA strands that are loosely coiled such that translation and transcription can occur (152)

chromosome in a eukaryotic cell, one of the structures in the nucleus that are made up of DNA and protein; in a prokaryotic cell, the main ring of DNA (79, 151)

chromosome map a diagram of gene positions on a chromosome (238)

chronic bronchitis a long-term inflammation of the bronchi (1024)

chyme the mixture formed in the stomach from digested food particles and gastric fluid (988)

cilium a hairlike structure arranged in tightly packed rows that projects from the surface of some cells (plural, *cilia*) (85, 507)

circadian rhythm a biological daily cycle (898)

cirrus in arthropods, one of several long, curved, hair-shaped appendages (plural, *cirri*) (727)

citric acid a six-carbon compound formed in the Krebs cycle (138)

clade a taxonomic grouping that includes only a single ancestor and all of its descendants (343)

cladistics a phylogenetic classification system that uses shared derived characters and ancestry as the sole criterion for grouping taxa (342)

cladogram a diagram that is based on patterns of shared, derived traits and that shows the evolutionary relationships between groups of organisms (343)

class in a traditional taxonomic system, the category contained within a phylum or division and containing orders (339)

classical conditioning a type of learning in which an animal learns to produce a specific response to a predictive stimulus in anticipation of receiving external reinforcement (890)

cleavage in biological development, a series of cell divisions that occur immediately after an egg is fertilized (664)

climax community a community that, after a process of ecological sucession, has reached a generally stable state (410)

clitellum in leeches and earthworms, a thick depression of the body wall that functions in reproduction (715)

cloaca in all vertebrates except mammals and reptiles, a chamber in the intestine that receives materials from the digestive, reproductive, and excretory systems (698)

clone an organism that is produced by asexual reproduction and that is genetically identical to its parent; to make a genetic duplicate (258, 623)

cloning by nuclear transfer the introduction of the nucleus of a somatic (body) cell into an egg cell that has been stripped of its genetic material for the purpose of cloning a whole organism (268)

closed circulatory system a circulatory system in which the heart circulates blood through a network of vessels that form a closed loop; the blood does not leave the blood vessels, and materials diffuse across the walls of the vessels (658)

cnidocyte a stinging cell of a cnidarian (677)

coacervate a mass of droplets of colloidal susbstances, such as lipids, amino acids, and sugars, that are held together by electrostatic attraction (286)

coccus a sphere-shaped bacterium (463)

cochlea a coiled tube that is found in the inner ear and that is essential to hearing (1017)

codominance a condition in which both alleles for a gene are fully expressed (184, 244)
codon in DNA, a three-nucleotide sequence that encodes an amino acid or signifies a start signal or a stop signal (207)
coelom a body cavity that is completely lined by mesoderm and that contains the internal organs of an animal (665)
coenocytic describes filaments that do not have cell walls (528)
coevolution the evolution of two or more species that is due to mutual influence, often in a way that makes the relationship more mutually beneficial (310)
cohesion the force that holds molecules of a single material together (41)
cohesion-tension theory an explanation for the movement of water up the stem xylem of tall plants; states that water is pulled up the xylem vessels by the cohesive force between the water molecules and the adhesion of the water molecules to the rigid vessel walls (597)
collenchyma a group of elongated, thick-walled plant cells that support the growth of leaves and stems (583)
colloblast a cell that is found on the tentacles of a ctenophore and that secretes a sticky substance (682)
colon a section of the large intestine (991)
colonial organism a collection of genetically identical cells that are permanently associated but in which little or no integration of cell activities occurs (76)
columella the axis of the cochlea in the ear bones of some animals (809)
commensalism a relationship between two organisms in which one organism benefits and the other is unaffected (403)
communication a transfer of a signal or message from one animal to another that results in some type of response (896)
community a group of various species that live in the same habitat and interact with each other (362)
compact bone the layer of bone that is just beneath the periosteum and that gives that bone its strength and rigidity (913)
companion cell a specialized parenchyma cell that assists in transport and that gives rise to sieve tubes in angiosperms (585)
complement system a system of proteins that circulate in the bloodstream and that combine with antibodies to protect against antigens (960)
complementary base pair the nucleotide bases in one strand of DNA or RNA that are paired with those of another strand; adenine pairs with thymine or uracil, and guanine pairs with cytosine (198)
complete dominance a relationship in which one allele is completely dominant over another (184)
complete metamorphosis an animal life cycle in which the individual undergoes two major stages of development (larva, pupa) between the egg stage and the adult stage (748)
complex character a character such as skin color that is influenced strongly by both genes and the environment (243)
compound a substance made up of atoms of two or more different elements joined by chemical bonds (33)
compound eye an eye composed of many light detectors separated by pigment cells (723)
compound leaf a type of leaf in which the blade is divided into leaflets (600)
compound light microscope a microscope that uses light to illuminate a specimen that is then magnified by two lenses (21)
concentration the amount of a particular substance in a given quantity of a mixture, solution, or ore (42)
concentration gradient a difference in the concentration of a substance across a distance (97)
condensation reaction a chemical reaction in which two or more molecules combine to produce water or another simple molecule (53)
cone in plants, a seed-bearing structure; in animals, a photoreceptor within the retina that can distinguish colors and is very sensitive to bright light (572, 1018)
conidiophore a type of hypha that bears asexual spores called conidia (528)
conidium an asexual spore produced in certain fungi (528)
coniferous tree a tree belonging to a group of tree species that bear their seeds in cones and tend to be evergreen (419)
conjugation in algae and fungi, an exchange of genetic material that occurs between two temporarily joined cells; in prokaryotes, the process by which two organisms bind together and one cell transfers DNA to the other cell through a structure called a sex pilus (471, 504)
connective tissue a tissue that has a lot of intracellular substance and that connects and supports other tissues (908)
conservation biology a branch of biology that is the study of the management of natural resources and the preservation of biodiversity (446)
constrictor a snake that kills its prey by crushing and suffocating it (833)
consumer an organism that eats other organisms or organic matter instead of producing its own nutrients or obtaining nutrients from inorganic sources (367)
contractile vacuole in protists, an organelle that accumulates water and then releases it periodically to maintain osmotic pressure (99, 508)
control group in an experiment, a group that serves as a standard of comparison with another group to which the control group is identical except for one factor (15)
convergent evolution the process by which unrelated species become more similar as they adapt to the same kind of environment (309)
coral reef a limestone ridge found in tropical climates and composed of coral fragments that are deposited around organic remains (681)
cork the outer layer of bark of any woody plant (586)
cork cambium a layer of tissue under the cork layer where cork cells are produced (586)
cornea a transparent membrane that forms the front portion of the eyeball (1018)
corpus luteum the structure that forms from the ruptured follicle in the ovary after ovulation; it releases hormones (1055)
cortex in plants, the primary tissue located in the epidermis; in animals, the outermost portion of an organ (589, 993)
cortisol a hormone that regulates certain phases of carbohydrate, protein, and water metabolism; affects muscle tone; increases gastric secretion; and alters tissue response to injury (1037)
cotyledon the embryonic leaf of a seed (576)
countercurrent flow in fish gills, an arrangement whereby water flows away from the head and blood flows toward the head (791)
courtship an animal behavior that functions to attract mates (895)
covalent bond a bond formed when atoms share one or more pairs of electrons (33)
cranial cavity the area of the skull within which the brain rests (910)
cranium the skeleton of the head, especially the portion of the skull where the brain is enclosed (779)
crista one of the many foldings of the inner membrane of mitochondria (80)
critical night length a minimum amount of darkness required per solar day by some plant species in order to flower (640)
crop in the digestive systems of birds and some invertebrates, a sac or pouch that temporarily stores food (714, 846)
crop milk a nutritious milklike fluid secreted by the crop of pigeons and doves to feed their young (853)
crossing-over the exchange of genetic material between homologous chromosomes during meiosis; can result in genetic recombination (162)
cross-pollination a reproductive process in which pollen from one plant is transferred to the stigma of another plant (174)
cryptosporidiosis a diarrheal disease caused by the protist *Cryptosporidium parvum,* which is spread by contact with fecally contaminated water (520)
cutaneous respiration in animals, respiration through the skin (806)
cuticle a waxy or fatty and watertight layer on the external wall of epidermal cells (563, 584, 695)
cutting a root, stem, or leaf that is cut from a living plant and that can produce a new plant (624)

cyanobacteria a group of bacteria that can carry out photosynthesis (singular, *cyanobacterium*); formerly called blue-green algae (289)
cyst a cavity or cell that contains embryos or bacteria in a resting stage (694)
cytokinesis the division of the cytoplasma of a cell; cytokinesis follows the division of the cell's nucleus by mitosis or meiosis (155)
cytokinin a plant hormone that affects cell division, plant metabolism, and the synthesis of RNA and proteins (635)
cytolysis the bursting of a cell (100)
cytoplasm the region of the cell within the membrane that includes the fluid, the cytoskeleton, and all of the organelles except the nucleus (74)
cytoskeleton the cytoplasmic network of protein filaments and tubes that plays an essential role in cell movement, shape, and division (84)
cytosol the soluble portion of the cytoplasm, which includes molecules and small particles, such as ribosomes, but not the organelles covered with membranes (74)
cytotoxic T cell a type of T cell that recognizes and destroys infected cells and cancer cells (963)

D

2,4-D a synthetic plant hormone that is used as a weedkiller (633)
death rate the number of deaths occurring in a period of time (383)
decapod a crustacean that has five pairs of legs; examples include shrimp, crabs, and lobsters (728)
deciduous tree a tree that sheds and regrows its leaves in response to seasonal changes (419)
decomposer an organism that feeds by breaking down organic matter from dead organisms; examples include bacteria and fungi (367)
dehydration a condition resulting from excessive water loss (984)
deletion the loss of a part of DNA from a chromosome (239)
demographic transition the general pattern of demographic change from high birth and death rates to low birth and death rates, as observed in the history of more-developed countries (392)
dendrite a cytoplasmic extension of a neuron that receives stimuli (1005)
denitrification the liberation of nitrogen from nitrogen-containing compounds by bacteria in the soil (374)
density-dependent factor a variable affected by the number of organisms present in a given area (388)
density-independent factor a variable that affects a population regardless of the population density, such as climate (388)
deoxyribose a five-carbon sugar that is a component of DNA nucleotides (197)
dependence the state in which a person relies on a drug physically or emotionally in order to function (1021)
dependent variable in an experiment, the factor that changes as a result of manipulation of one or more other factors; also called a *responding variable* (15)
depressant a drug that reduces functional activity and produces muscular relaxation (1023)
derived character a feature that evolved only within a particular taxonomic group (342)
dermis the layer of skin below the epidermis (925)
desert a region that has little or no vegetation, long periods without rain, and extreme temperatures; usually found in warm climates (422)
detritivore a consumer that feeds on dead organisms or on the parts or wastes of other organsims (367)
deuterostome an organism whose embryonic blastopore develops into an anus, whereas its mouth develops from a second opening at the opposite end of the archenteron; usually characterized by an embryo that undergoes indeterminate, radial cleavage (665)
developed country a modern, industrialized country in which people are generally better educated and healthier and live longer than people in developing countries do (391)
developing country a country in which the society is less modern and less industrialized and in which inhabitants are generally poorer than they are in developed countries (391)
development the gene-directed process by which an organism matures (8)
diabetes mellitus a serious disorder in which cells are unable to obtain glucose from the blood; caused by a deficiency of insulin or lack of response to insulin (1039)
diaphragm a dome-shaped muscle that is attached to the lower ribs and that functions as the main muscle in respiration (865, 910, 949)
diatom a unicellular alga that has a double shell that contains silica (512)
diatomaceous earth a soft, fine, porous deposit that is composed mainly of the skeletons of diatoms (518)
dicot a dicotyledonous plant; an angiosperm that has two cotyledons, net venation, and flower parts in groups of four or five (576)
differentiation the structural and functional specialization of cells during an organism's development (652)
diffusion the movement of particles from regions of higher density to regions of lower density (97)
digestion the breaking down of food into chemical substances that can be used to obtain energy (985)
digestive gland any gland that secretes a substance to help transform food into substances that the body can use (729)
dihybrid cross a cross between individuals that have different alleles for the same gene (185)
dimorphism the ability of some organisms, such as fungi, to exist in two forms, depending in general on the temperature and availability of nutrients (528)
dinosaur one of a varied group of mostly-extinct reptiles that lived from about 235 million years ago to about 66 million years ago (819)
diploid a cell that contains two haploid sets of chromosomes (153)
directional selection a type of natural selection in which the most extreme form of a trait is favored and becomes more common (325)
disaccharide a sugar formed from two monosaccharides (56)
dispersion in ecology, the pattern of distribution of organisms in a population (382)
disruptive selection a type of natural selection in which two extreme forms of a trait are selected (324)
disturbance in ecology, an event that changes a community by removing or destroying organisms or altering resource availability (407)
divergent evolution the process by which two or more related but reproductively isolated populations become more and more dissimilar (309)
division in a traditional taxonomic system for plants, the category contained within a kingdom and containing classes (339)
DNA (deoxyribonucleic acid) the material that contains the information that determines inherited characteristics (60)
DNA fingerprint the pattern of bands that results when an individual's DNA sample is radiolabeled and exposed to X rays after being fragmented, replicated, and separated (257)
DNA polymerase an enzyme that catalyzes the formation of the DNA molecule (200)
DNA replication the process of making a copy of DNA (200)
DNA vaccine a vaccine that is made from the DNA of a pathogen and that does not have disease-causing capabilities (269)
domain in a modern taxonomic system, the broadest category; the category that contains kingdoms (11, 339)
dominance hierarchy in competitive animal groups, a ranking of individuals from most dominant to most subordinate (894)
dominant describes the allele that is fully expressed when carried by only one of a pair of homologous chromosomes (177)
dormancy a state in which seeds, spores, bulbs, and other reproductive organs stop growth and development and reduce their metabolism, especially respiration (365, 621)
dorsal lying on or near the back (655)

dorsal nerve chord a neural tube dorsal to the notochord (654)
double fertilization the process by which one of the two sperm nuclei fuses with the egg nucleus to produce a diploid zygote and the other fuses with the polar nuclei to produce a triploid endosperm (617)
drone a male bee that develops from an unfertilized egg and functions only to fertilize eggs from the queen (752)
drug any substance that causes a change in an organism's physical or psychological state (1021)
duodenum the first section of the small intestine (807)

E

echinoderm a radially symmetrical marine invertebrate that has an endoskeleton, such as a starfish, a sea urchin, or a sea cucumber (761)
echolocation the process of using reflected sound waves to find objects; used by animals such as bats (866)
ecological model a model that represents or describes the relationships between the components of an ecological system (360)
ecological succession a gradual process of change and replacement in a community (408)
ecology the study of the interactions between organisms and the other living and nonliving components of their environment (11, 359)
ecosystem a community of organisms and their abiotic environment (11, 362)
ecotourism a form of tourism that supports the conservation and sustainable development of ecologically unique areas (450)
ectoderm the outermost of the three germ layers of an embryo that develops into the epidermis and epidermal tissues, the nervous system, external sense organs, and the mucous membranes lining the mouth and anus (664)
ectotherm an organism that needs sources of heat outside of itself (828)
ejaculation the expulsion of seminal fluids from the urethra of the penis during sexual intercourse (1051)
elapid a venomous snake that has two small, fixed fangs in the front of the mouth (833)
electron a subatomic particle that has a negative charge (32)
electron transport chain a series of molecules, found in the inner membranes of mitochondria and chloroplasts, through which electrons pass in a process that causes protons to build up on one side of the membrane (117)
element a substance that cannot be separated or broken down into simpler substances by chemical means; all atoms of an element have the same atomic number (31)
elephantiasis a disease in humans that is caused by filarial worms and that is characterized by fluid accumulation that results in thickened skin around swollen extremities (697)
embryo an organism in an early stage of development of plants and animals; in humans, a developing individual is referred to as an embryo from the second through the eighth week of pregnancy (1057)
embryo sac in plants, the female gametophyte that develops from a megaspore; contains the ovum that fuses with a sperm nucleus during fertilization to form an embryo and seven other cells, including the polar bodies that fuse with another sperm nucleus to form endosperm (614)
emerging disease a disease that is caused by new or reappearing infectious agents that typically exist in animal populations (491)
emigration the movement of an individual or group out of an area (321, 385)
emphysema a degenerative lung disease that is characterized by the breakdown of alveoli, which reduces the area available for gas exchange (1024)
endocrine gland a ductless gland that secretes hormones into the blood or extracellular fluid (1031)
endocrine system a collection of glands and groups of cells that secrete hormones that regulate growth, development, and homeostasis; includes the pituitary, thyroid, parathyroid, and adrenal glands, the hypothalamus, the pineal body, and the gonads (1031)
endocytosis the process by which a cell membrane surrounds a particle and encloses the particle in a vesicle to bring the particle into the cell (105)
endoderm the innermost germ layer of the animal embryo; develops into the epithelium of the pharynx, respiratory tract, digestive tract, bladder, and urethra (664)
endodermis the single layer of cells that surrounds the vascular tissue in the roots and in some stems of plants; the innermost layer of cortex in seed plants (589)
endoplasmic reticulum a system of membranes that is found in a cell's cytoplasm and that assists in the production, processing, and transport of proteins and in the production of lipids (81)
endoskeleton an internal skeleton made of bone and cartilage (660)
endospore a thick-walled protective spore that forms inside a bacterial cell and resists harsh conditions (469)
endosymbiosis a mutually beneficial relationship in which one organism lives within another; a theory that eukaryotic cells originated through endosymbiotic relationships between ancient prokaryotic cells (290)
endotherm an animal that can generate body heat through metabolism and can maintain a constant body temperature despite temperature changes in the animal's environment (828)
endothermy in animals, the characteristic of maintaining a high, constant body temperature through regulation of metabolism and heat loss (861)
endotoxin a toxin that occurs in the outer membrane of Gram negative bacteria and that is released when the bacterial cell breaks apart (472)
energy the capacity to do work (35)
enhancer a DNA sequence that recognizes certain transcription factors that can stimulate transcription of nearby genes (222)
enterocoely in deuterostomes, the method of coelom formation in which the embryonic mesoderm develops from pouches within the archenteron (666)
entomology the study of insects and other terrestrial arthropods (742)
envelope a membranelike layer that covers the capsids of some viruses (484)
enzyme a type of protein or RNA molecule that speeds up metabolic reactions in plant and animals without being permanently changed or destroyed (36, 57)
epicotyl the portion of the stem of a plant embryo that is between the cotyledons and the first true leaves (620)
epidermis the outer surface layer of cells of a plant or animal (584, 676, 924)
epididymis the long, coiled tube that is on the surface of a testis and in which sperm mature (1050)
epiglottis a structure that hangs at the entrance of the larynx and prevents food from entering the larynx and the trachea while swallowing (947, 986)
epinephrine a hormone that is released by the adrenal medulla and that rapidly stimulates the metabolism in emergencies, decreases insulin secretion, and stimulates pulse and blood pressure; also called *adrenaline* (1037)
epiphyseal plate the point at which bones elongate during growth; it is found at joint ends of long bones, is composed of cartilage, and becomes an epiphyseal line in mature bone (914)
epiphyte a plant that uses another plant for support, but not for nourishment (419)
epithelial tissue a tissue that is composed of a sheet of cells and that covers a body surface or lines a body cavity (908)
equilibrium in biology, a state that exists when the concentration of a substance is the same throughout a space (97)
erythrocyte a red blood cell (940)
estrogen a hormone that regulates the sexual development and reproductive function of females (1037)
estuary an area where fresh water from rivers mixes with salt water from the ocean; the part of a river where the tides meet the river current (425)
ethephon a chemical used as a growth regulator for fruit (634)
ethologist a person who specializes in the scientific study of animal behavior (887)

ethylene a gaseous plant hormone that plays a role in the ripening of fruits (634)
Eubacteria in a traditional taxonomic system, a kingdom that contains all prokaryotes except Kingdom Archaebacteria (Domain Archaea); biologists more recently prefer to classify these organisms as Domain Bacteria (348)
euchromatin a region of DNA that is uncoiled and undergoing active transcription into RNA (220)
euglenoid a flagellated unicellular algae (513)
Eukarya in a modern taxonomic system, a domain made up of all eukaryotes; aligns with the traditional kingdoms Protista, Fungi, Plantae, and Animalia (348)
eukaryote an organism made up of cells that have a nucleus enclosed by a membrane, multiple chromosomes, and a mitotic cycle; eukaryotes include animals, plants, and fungi but not bacteria or archaea (75)
Eustachian tube a channel that connects the middle ear to the mouth cavity (1017)
eutrophic lake a lake that contains a large amount of decaying organic matter and lacks oxygen as a result (427)
evolution a heritable change in the characteristics within a population from one generation to the next; the development of new types of organisms from preexisting types of organisms over time (12, 297)
excretion the process of eliminating metabolic wastes (993)
excurrent siphon a tube through which water exits the mantle cavity of a bivalve (709)
exocrine gland a gland that discharges its secretions through a duct (925, 1031)
exocytosis the process by which a substance is released from the cell through a vesicle that transports the substance to the cell surface and then fuses with the membrane to let the substance out (106)
exon in a structural gene, one of the segments that are ultimately transcribed and translated when the gene is expressed (220)
exoskeleton a hard, external, supporting structure that develops from the ectoderm (658)
exotoxin a potent, extracellular toxin secreted by some gram positive bacteria (472)
experiment a procedure that is carried out under controlled conditions to discover, demonstrate, or test a fact, theory, or general truth (13)
experimental group in an experiment, a group that is identical to a control group except for one factor and that is compared with the control group (15)
expiration the process in which air is forced out of the lungs (950)
exponential model a model of population growth in which a constant and unlimited growth rate results in geometric increases in population size (386)
extensor a muscle that extends a joint (921)
external fertilization the union of gametes outside the bodies of the parents, as in many fishes and amphibians (784)
external respiration the exchange of gases between the atmosphere and the lungs (946)
extinction the death of every member of a species (442)
eyepiece the part of a compound light microscope that magnifies an image, usually 10 times, also called an *ocular lens* (21)
eyespot an organ that is covered by pigment in some invertebrates and protozoa and that detects changes in the quantity and quality of light (691)

F

F_1 generation the first generation of offspring obtained from an experimental cross of two organisms (175)
F_2 generation the second generation of offspring, obtained from an experimental cross of two organisms; the offspring of the F_1 generation (175)
facilitated diffusion the transport of substances through a cell membrane along a concentration gradient with the aid of carrier proteins (101)
facultative anaerobe an organism that can live with or without oxygen (470)
FAD flavin adenine dinucleotide, a compound that acts as a hydrogen acceptor in dehydrogenation reactions (139)
fall color change in the color of deciduous tree leaves in the fall in response to changes in average temperature and day length (642)
fallopian tube a tube through which eggs move from the ovary to the uterus (1052)
family in a traditional taxonomic system, the category contained within an order and containing genera (339)
fatty acid an organic acid that is contained in lipids, such as fats or oils (59)
feather in birds, a modified scale that provides lift for flight and conserves body heat (844)
fermentation the breakdown of carbohydrates by enzymes, bacteria, yeasts, or mold in the absence of oxygen (133)
fertilization the union of a male and female gamete to form a zygote (663)
fertilizer a compound that improves the quality of the soil to produce plants (548)
fetus a developing human during the period from the eight week after fertilization until birth (1059)
fibrin a protein that forms a network of fibers during blood clotting (942)
fibrous root system a system of adventitious roots of approximately equal diameter that arise from the base of the stem of a plant (587)
fiddlehead the tightly coiled new leaves of a fern (572)
filament in flowers, the part of a stamen that supports the anther (613)
filarial worm one of a group of nematodes that cause diseases such as elephantiasis in humans and heartworm disease in dogs and cats (697)
filter feeding in an aquatic animal, a method of feeding in which the animal traps organic material that is floating in the surrounding water (674)
filtration the process of separating dissolved substances, such as impurities in the blood by passing them through a porous material; occurs between the glomerulus and the Bowman's capsule in the nephrons of a kidney (995)
fitness in evolutionary theory, a measure of an individual's hereditary contribution to the next generation (301)
fixed action pattern behavior an innate behavior that is characteristic of certain species (888)
fixed joint a joint at which no movement occurs; examples include the joints between the bones of the skull (915)
flagellum a long, hairlike structure that grows out of a cell and enables the cell to move (plural, *flagella*) (85, 508)
flame cell in a flatworm, a cell that has flagella or cilia that move waste products through the body (690)
flexor a muscle that bends a joint (921)
fluke a parasitic flatworm of the class Trematoda or Monogenea (691)
follicle a small, narrow cavity or sac in an organ or tissue, such as the ones on the skin that contain hair roots or the ones in the ovaries that contain the developing eggs (844, 1054)
follicle-stimulating hormone a gonadotropin that stimulates sperm production in the male and the growth and maturation of the ovarian follicles in the female (abbreviation, FSH) (1037)
follicular phase the stage in which an immature egg completes its first meiotic division (1054)
food chain the pathway of energy transfer through various stages as a result of the feeding patterns of a series of organisms (368)
food web a diagram that shows the feeding relationships among organisms in an ecosystem (368)
fossil the trace or remains of an organism that lived long ago, most commonly preserved in sedimentary rock (302)
fracture an injury in which the tissue of a bone is broken (913)
fragmentation in fungi, a reproductive process in which septate hypha dry and shatter and individual cells that act as spores are released (528)
frameshift mutation a mutation, such as the insertion or deletion of a nucleotide in a coding sequence, that results in the misreading of the code during translation because of a change in the reading frame (240)
freshwater wetland an area of land that is covered in fresh water for at least part of each year (428)

frond the leaf of a fern or palm (572)
fruit a mature plant ovary; the plant organ in which the seeds are enclosed (547)
fruiting body a part of a plant, fungus, or protist that produces seeds or spores (514)
functional group the portion of a molecule that is active in a chemical reaction and that determines the properties of many organic compounds (52)
Fungi in a traditional taxonomic system, a kingdom made up of nongreen, eukaryotic organisms that get food by breaking down organic matter and absorbing the nutrients, reproduce by means of spores, and have no means of movement (349)
furcula in birds, the fused pair of collarbones; commonly called the wishbone (842)

G

gallbladder a sac-shaped organ that stores bile produced by the liver (988)
gametangium a cell or an organ that produces gametes (510, 530)
gamete a haploid reproductive cell that unites with another haploid reproductive cell to form a zygote (155)
gametocyte a cell that is not differentiated and that develops into a gamete (519)
gametophyte in alternation of generations, the phase in which gametes are formed; a haploid individual that produces gametes (565)
ganglion a cluster of nerve cells (plural, *ganglia*) (706)
gasohol a mixture of gasoline and alcohol that is used as a fuel (551)
gastric fluid a liquid secreted by gastric glands in the stomach (988)
gastrodermis in cnidarians, the layer of cells surrounding the digestive tract (676)
gastrointestinal tract the digestive tract from the mouth to the anus, including the stomach and intestines (985)
gastropod a mollusk that has a well-developed head and a flattened foot, such as a snail, slug, or conch (707)
gastrovascular cavity a cavity that serves both digestive and circulatory purposes in some cnidarians (676)
gastrula the embryo in the stage of development after the blastula; contains the embryonic germ layers (664)
gastrulation the transformation of the blastula into the gastrula or the formation of the embryonic germ layers (664)
gel electrophoresis a technique used to separate nucleic acids or proteins according to size and charge in an agarose or acrylamide gel (257)
gemmule an asexual reproductive structure produced by some freshwater sponges (675)
gene a short segment of DNA that contains the instructions for a single trait (9)
gene expression the activation, or "turning on" of a gene that results in transcription and the production of mRNA (217)
gene flow the movement of genes into or out of a population due to interbreeding (321)
gene pool all of the genes of the reproductively active members of a population (9, 318)
gene therapy a technique that places a gene into a cell to correct a hereditary disease or to improve the genome (248, 267)
generative cell in a pollen grain, the cell that divides mitotically and forms two sperm cells (615)
genetic code the rule that describes how a sequence of nucleotides, read in groups of three consecutive nucleotides (triplets) that correspond to specific amino acids, specifies the amino acid sequence of a protein (207)
genetic counseling the process of testing and informing potential parents about their genetic makeup and the likelihood that they will have offspring with genetic defects or hereditary diseases (247)
genetic disorder an inherited disease or disorder that is caused by a mutation in a gene or by a chromosomal defect (242)
genetic diversity the amount of variation in the genetic material within all members of a popualtion (438)
genetic drift the random change in allele frequency in a population (322)
genetic engineering a technology in which the genome of a living cell is modified for medical or industrial use (258)
genetic recombination the regrouping of genes in an offspring that results in a genetic makeup that is different from that of the parents (162)
genetics the science of heredity and of the mechanisms by which traits are passed from parents to offspring (173)
genome the complete genetic material contained in an individual (210, 217)
genotype the entire genetic makeup of an organism; also the combination of genes for one or more specific traits (180)
genotypic ratio the ratio of the genotypes that appear in offspring (183)
genus in a traditional taxonomic system, the category contained within a family and containing species (plural, *genera*) (339)
geographic isolation the physical separation of populations due to geographic barriers that prevent interbreeding (327)
germ layer one of the layers of tissue that develop in the embryos of all animals except sponges (655)
germ-cell mutation mutation that occurs in an organism's gametes (239)
germinate to begin to grow from an embryo into a mature form (572)
gestation in mammals, the process of carrying young from fertilization to birth (1056)
giardiasis a diarrheal illness caused by the parasitic protozoan *Giardia lamblia* and characterized by intestinal cramping and diarrhea (1056)
gibberellin a plant hormone that stimulates growth of stems and leaves (633)
gill in aquatic animals, a respiratory structure that consists of many blood vessels surrounded by a membrane that allows for gas exchange (658)
gill arch one of the jointed and cartilaginous or bony structures behind the jaws in fish and larval amphibians (781)
gizzard an enlargement of the digestive tract of some invertebrates, such as annelids and insects, that grinds food; a muscular region in the digestive tract of birds that grinds and softens food (714, 846)
glomerulus a cluster of capillaries that is enclosed in a Bowman's capsule in a nephron of the kidney, where blood is filtered (994)
glycocalyx a bacterial capsule that is made of a fuzzy coat of sticky sugars (468)
glycolysis the anaerobic breakdown of glucose to pyruvic acid, which makes a small amount of energy available to cells in the form of ATP (132)
Golgi complex cell organelle that helps make and package materials to be transported out of the cell (82)
gonad an organ that produces gametes (1037)
gradualism a model of evolution in which gradual change over a long period of time leads to biological diversity (330)
grafting a technique in which a portion of one plant is attached to the root or shoot of another plant and grows there (624)
Gram-negative bacterium a bacterium that, in the Gram stain process, is stained reddish-pink and that has a small amount of peptidoglycan in its cell wall (463)
Gram-positive bacterium a bacterium that, in the Gram stain process, is stained purple and that has a large amount of peptidoglycan in its cell wall (463)
granum a stack of thylakoids in a chloroplast (plural, *grana*) (114)
gravitropism the growth of a plant in a particular direction in response to gravity (638)
great ape an ape whose face has little hair and whose hands have nails and complex fingerprints, such as an orangutan, gorilla, or chimpanzee (876)
green gland an excretory organ of some crustaceans that is located at the base of the antennae (730)
greenhouse effect the warming of the surface and lower atmosphere of Earth that occurs when carbon dioxide, water vapor, and other gases in the air absorb and reradiate infrared radiation (436)
gross primary productivity the rate at which organic matter is assimilated by plants and other producers during a period of time over a certain area (366)
groundwater the water that is beneath the Earth's surface (371)
growth rate an expression of the increase in the size of an organism or population over a given period of time (385)

growth retardant a chemical that prevents growth, especially the growth of vegetation (635)
guard cell one of a pair of specialized cells that border a stoma and regulate gas exchange (602)
gullet in protozoa, an opening into which the mouth pore opens (508)
gymnosperm a woody, vascular seed plant whose seeds are not enclosed by an ovary or fruit (565)

H

habitat the place where an organism usually lives (363)
habituation a type of learning in which an animal learns to ignore a frequent, harmless stimulus (889)
half-life the time required for half of a sample of a radioactive isotope to break down by radioactive decay to form a daughter isotope (283)
halophile an organism that can grow in, or favors environments that have very high salt concentrations (462)
haploid describes a cell, nucleus, or organism that has only one set of unpaired chromosomes (153)
Hardy-Weinberg principle the principle that states that the frequency of alleles in a population does not change over generations unless outside forces act on the population (320)
Haversian canal a channel containing blood vessels in compact bone tissue (913)
hay fever a pollen allergy that results in sneezing, a runny nose, and watering eyes (556)
helicase an enzyme that separates DNA strands (200)
helper T cell a white blood cell necessary for B cells to develop normal levels of antibodies (963)
hemocoel the blood-filled space or body cavity of some invertebrates (707)
hemoglobin the oxygen-carrying protein in red blood cells (940)
hemolymph the fluid that circulates through the body of an animal that has an open circulatory system (707)
herbivore an organism that eats only plants (367)
heredity the passing of genetic traits from parent to offspring (173)
hermaphrodite an organism that has both male and female reproductive organs (659, 675)
heterospory the production of two or more kinds of asexual spores (611)
heterotroph an organism that obtains organic food molecules by eating other organisms or their byproducts and that cannot synthesize organic compounds from inorganic materials (113, 469)
heterozygous describes an individual that has two different alleles for a trait (181)
hibernation a period of inactivity and lowered body temperature that some animals undergo in winter as a protection against cold weather and lack of food (898)
hilum on a plant seed, a scar that marks where the seed was attached to the ovary wall (620)
histamine a chemical that stimulates the autonomous nervous system, secretion of gastric juices, and dilation of capillaries (959)
histone a type of protein molecule found in the chromosomes of eukaryotic cells but not prokaryotic cells (151)
HIV human immunodeficiency virus, the virus that causes AIDS (970)
homeobox a DNA sequence within a homeotic gene that regulates development in animals (224)
homeostasis the steady-state physiological condition of the body (8)
homeotic gene a gene that controls the development of a specific adult structure (223)
hominid a member of the family Hominidae of the order Primates; characterized by bipedalism, relatively long lower limbs, and lack of a tail; examples include humans and their ancestors (877)
homologous chromosomes chromosomes that have the same sequence of genes, that have the same structure, and that pair during meiosis (152)
homologous structures anatomical structures in one species that, compared to other anatomical structures in another species, originated from a single anatomical structure in a common ancestor of the two species (305)
homospory the production of only one kind of spore (610)
homozygous describes an individual that has identical alleles for a trait on both homologous chromosomes (181)
hookworm a parasitic roundworm found in the intestines of mammals (696)
hormone a substance that is secreted by cells and that that acts to regulate the activity of other cells in the body (1031, 631)
hornwort a member of the phylum Anthocerophyta, a unique group of bryophytes that grow close to the ground in moist, shady areas and that are characterized by long, thin, photosynthetic sporophytes (569)
human a member of the genus *Homo* of the family Hominidae; includes modern humans and closely related extinct species (879)
human chorionic gonadotropin a hormone that is secreted by the placenta and that stimulates ovulation and secretion of progesterone or testosterone (abbreviation, HCG) (1059)
Human Genome Project a worldwide scientific research effort to map and sequence the human genome (261)
humoral immunity a type of immune response that is produced by the action of antibodies within body fluids (964)
hunter-gatherer lifestyle a way of life in which people obtain their food by hunting and gathering wild animals and plants (390)
Huntington's disease a rare hereditary disease of the brain characterized by involuntary movements of the limbs or face, decreasing mental abilities, and eventual death (245)
hydrogen bond the intermolecular force occurring when a hydrogen atom that is bonded to a highly electronegative atom of one molecule is attracted to two unshared electrons of another molecule (40)
hydrolysis a chemical reaction between water and another substance to form two or more new substances; a reaction between water and a salt to create an acid or a base (53)
hydronium ion an ion consisting of a proton combined with a molecule of water; H_3O^+ (43)
hydroxide ion the OH^- ion (43)
hypertension a condition of high blood pressure (936)
hypertonic describes a solution whose solute concentration is higher than the solute concentration inside a cell (98)
hypha a nonreproductive filament of a fungus (527)
hypocotyl the portion of the stem of a plant embryo that is between the cotyledons and the embryonic root (620)
hypothalamus the region of the brain that coordinates the activities of the nervous and endocrine systems and that controls many body activities related to homeostasis (1012, 1034)
hypothesis in science, an idea or explanation that is based on observations and that can be tested (13)
hypotonic describes a solution whose solute concentration is lower than the solute concentration inside a cell (98)

I

ileum the middle portion of the small intestine where many nutrients are absorbed (807)
immigration the movement of an individual or group into an area (321, 385)
immune response the reaction of the body against an antigen (962)
immune system the cells and tissues that recognize and attack foreign substances in the body (961)
immunity the ability to resist an infectious disease (966)
implantation the process by which the newly fertilized egg in the blastocyst stage embeds itself in the lining of the uterus (1057)
imprinting learning that occurs early and quickly in a young animal's life and that cannot be changed once learned (891)
inbreeding the crossing or mating of plants or animals with close relatives (389)

incisor any of the four cutting teeth located between the canines in the upper and lower jaws (865)
incomplete dominance a condition in which a trait in an individual is intermediate between the phenotype of the individual's two parents because the dominant allele is unable to express itself fully (184, 244)
incomplete metamorphosis an animal life cycle in which the individual undergoes gradual development through several nymph stages after the egg stage and before the adult stage (748)
incurrent siphon a tube through which water enters the body of a bivalve (709)
independent assortment the random distribution of the pairs of genes on different chromosomes to the gametes (162)
independent variable in an experiment, the factor that is deliberately manipulated, also called the *manipulated variable* (15)
inducer a substance that combines with and inactivates a repressor which allows the transcription of a gene (219)
infectious disease a disease that is caused by pathogenic bacteria, viruses, fungi, or protists (957)
inflammatory response a protective response of tissues affected by disease or injury, characterized by redness, swelling, and pain (959)
ingestion the process of taking in food (652)
innate behavior an inherited behavior that does not depend on the environment or experience (752, 888)
insertion in anatomy, the point at which a muscle is attached to a moving bone (921)
insertion mutation a mutation in which one or more nucleotides are added to a gene (240)
inspiration the process of taking air from the outside of the body into the lungs (949)
insulin a hormone that is produced by a group of specialized cells in the pancreas and that lowers blood glucose levels (1039)
integument the outer, protective covering of a body, a body part, an ovule, or a sporangium (612, 660)
interdependence the dependence of every organism on its connections with other living and nonliving parts of its environment (359)
interferon a protein that is produced by cells infected by a virus and that can protect uninfected cells from reproduction of the virus (960)
intermediate host a host that gives food and shelter to immature stages of a parasite (693)
internal fertilization fertilization of an egg by sperm that occurs inside the body of a female (786)
internal respiration the exchange of gases between the blood and the cells of the body (946)
interneuron a neuron located between the afferent neuron and the final neuron in a neural chain (1013)
internode the part of a plant stem between two consecutive nodes (593)
interphase a period between two mitotic or meiotic divisions during which the cell grows, copies its DNA, and synthesizes proteins (155)
interspecific competition a relationship between two species in which both species compete for limited resources such that both species are negatively affected by the relationship (401)
intertidal zone an area along ocean shorelines that lies between low and high water lines (423)
intron a segment of a structural gene that is transcribed but not translated (220)
inversion a reversal in the order of the genes, or of a chromosome segment, within a chromosome (239)
invertebrate an animal that does not have a backbone (651)
involuntary muscle a muscle whose movement cannot be controlled voluntarily, such as the cardiac muscle (918)
ion an atom, radical, or molecule that has gained or lost one or more electrons and has a negative or positive charge (34)
ion channel a complex of protein molecules in a cell membrane that form a pore through which ions can pass (102)
ionic bond the attractive force between oppositely charged ions, which form when electrons are transferred from one atom to another (34)
iris the colored, circular part of the eye (1018)
isopod a crustacean that has seven pairs of identical legs and no carapace; examples include sowbugs and pill bugs (727)
isotonic describes a solution whose solute concentration is equal to the solute concentration inside a cell (99)
isotope an atom that has the same number of protons (or the same atomic number) as other atoms of the same element do but that has a different number of neutrons (and thus a different atomic mass) (32, 282)

J

Jacobson's organ an olfactory sac that opens into the mouth and is highly developed in reptiles (827)
joint a place where two or more bones meet (915)

K

karyotype a micrograph of the array of chromosomes visible in a cell during metaphase; a graphical display that shows an individual's chromosomes arranged in homologous pairs and in order of diminishing size (153)
keratin a hard protein that forms hair, bird feathers, nails, and horns (824, 924)
keystone species a species that is critical to the functioning of the ecosystem in which it lives because it affects the survival and abundance of many other species in its community (443)
kidney one of the organs that filter water and wastes from the blood, excrete products as urine, and regulate the concentration of certain substances in the blood (661)
kilocalorie a unit of energy equal to 1,000 calories (135)
kin selection a mechanism for increasing the frequency of one's genes in a population by helping increase the reproductive success of relatives (754, 879)
kingdom in a traditional taxonomic system, the highest taxonomic category, which contains a group of similar phyla (11, 339)
Koch's postulates a four-stage procedure that Robert Koch formulated for identifying a specific pathogen as the cause of a specific disease (957)
Krebs cycle a series of biochemical reactions that convert pyruvic acid into carbon dioxide and water; it is the major pathway of oxidation in animal, bacterial, and plant cells, and it releases energy (138)

L

labium in some animals, one of a pair of lips around the mouth; also, in some female animals, one of two pairs of folds of skin and mucous membranes that cover and protect the openings of the vulva; in insects, a mouthpart that functions as a lower lip (plural, *labia*) (746, 1053)
labor the process by which the fetus and the placenta come out of the uterus (1060)
labrum in arthropods, a mouthpart that functions as an upper lip (746)
***lac* operon** a gene system whose operator gene and three structural genes control lactose metabolism in *E. coli* (218)
lactic acid fermentation the chemical breakdown of carbohydrates that produces lactic acid as the main end product (134)
larva an independent and immature form of an organism that is morphologically different from the adult form (659)
larynx the area of the throat that contains the vocal cords and produces vocal sounds (947)
lateral line a faint line visible on both sides of a fish's body that runs the length of the body and marks the location of sense organs that detect vibrations in water (783)
lateral meristem dividing tissue that runs parallel to the long axis of a stem or a root (586)

law of independent assortment the law that states that genes separate independently of one another in meiosis (178)
law of segregation Mende's law that states that the pairs of homologous chromosomes separate in meiosis so that only one chromosome from each pair is present in each gamete (177)
layering the process of causing roots to form on stems or branches of a plant that are covered with soil (624)
leaflet one segment of a compound leaf (600)
learning the development of behaviors through experience or practice (889)
legume any plant of the family Leguminosae (Fabaceae), such as a bean, pea, or lentil; the name for the type of fruit produced by members of this family (547)
lens a convex transparent structure in the eye that focuses light on the retina (1018)
lethal mutation a gene or chromosomal mutation that influences the development of an organism in such a way that the organism cannot survive (239)
leukemia a progressive, malignant disease of the blood-forming organs (228)
leukocyte a white blood cell (941)
lichen a mass of cells formed by a fungus in symbiosis with a photosynthetic partner (usually a cyanobacterium or green algae); lichen typically grow on nutrient-poor surfaces, such as rocks and tree bark (533)
life expectancy the average length of time that an individual is expected to live (383)
ligament a type of connective tissue that holds together the bones in a joint (915)
light reactions the initial reactions in photosynthesis, which are triggered by the absorption of light by photosystems I and II and include the passage of electrons along the electron transport chains, the production of NADPH and oxygen gas, and the synthesis of ATP through chemiosmosis (114)
limiting factor an environmental factor that prevents an organism or population from reaching its full potential of distribution or activity (386)
linked gene one of a pair of genes that tend to be inherited together (238)
lipid a large, nonpolar organic molecule, including fats and steroids; lipids store energy and make up cell membranes (59)
liverwort a member of the phylum Hepatophyta, a unique group of bryophytes that grow close to the ground in moist, shady areas and that are characterized by unique structures on the gametophytes (568)
lobe-finned fish a kind of fish that has fleshy fins that are supported by a series of bones; living species include lungfishes and the coelocanth (787)
logistic model a model of population growth that assumes that finite resource levels limit population growth (387)
loop of Henle in the kidney, the long, U-shaped part of a nephron that reabsorbs water and salts from the urine collected by the glomerulus (997)
lung the central organ of the respiratory system in which oxygen from the air is exchanged with carbon dioxide from the blood (660, 946)
luteal phase the menstrual stage in which the corpus luteum develops (1055)
luteinizing hormone a hormone that stimulates ovulation and progesterone secretion by the corpus luteum in the female and testosterone secretion in the male (abbreviation, LH) (1037)
lymph the fluid that is collected by the lymphatic vessels and nodes (939)
lymphatic system a collection of organs whose primary function is to collect extracellular fluid and return it to the blood; the organs in this system include the lymph nodes and the lymphatic vessels (933)
lymphocyte a type of white blood cell that exists in two primary forms, T cells and B cells (961)
lymphoma a tumor in the lymphoid tissues (228)
lysis the disintegration of a cell by disruption of the plasma membrane (486)
lysogenic cycle a method of viral replication in which a viral genome is replicated as a provirus without destroying the host cell (487)
lysosome a cell organelle that contains digestive enzymes and that buds from the Golgi apparatus (82)
lytic cycle a method of viral replication that results in the destruction of a host cell and the release of many new virus particles (486)

M

macromolecule a very large organic molecule, usually a polymer, composed of hundreds or thousands of atoms (53)
macronucleus in many protozoans, the larger of two types of cell nuclei and the one that contains multiple copies of DNA (508)
macronutrient an element required in relatively large amounts (590)
macrophage an immune system cell that engulfs pathogens and other materials (960)
madreporite the porous structure through which water enters and exits the water-vascular system of echinoderms (766)
magnification the increase of an object's apparent size by using lenses or mirrors (22)
malaria an infectious tropical disease caused by a protozoan and transmitted to humans by a mosquito; it produces high fevers, chills, sweating, and anemia (519)
Malpighian tubule an excretory tube that opens into the back part of the intestine of most insects and certain arthropods (732)
mammary gland a gland that is located in the chest of a female mammal and that secretes milk (861)
mandible in some arthropods, a jawlike mouthpart used to pierce and suck food; in vertebrates, the lower part of the jaw (724)
mantle in biology, a layer of tissue that covers the body of many invertebrates (706)
mantle cavity the space between the mantle and body mass in mollusks and brachiopods (706)
map unit in chromosome mapping, an increment of 1 percent in the frequency of crossing-over (238)
marsupial a mammal that lacks a true placenta and gives birth to relatively undeveloped young, and then carries and nourishes the young in a pouch (863)
mass a measure of the amount of matter in an object; a fundamental property of an object that is not affected by the forces that act on the object, such as the gravitational force (31)
mass number the sum of the numbers of protons and neutrons in the nucleus of an atom (32, 283)
mastax the muscular pharynx in rotifers (698)
matrix an extracellular substance that gives connective tissue its strength and flexibility; can be solid, semisolid, or liquid (908)
matter anything that has mass and takes up space (31)
medulla the innermost portion of an organ, such as the kidney (993)
medulla oblongata in fish, the posterior brain lobes that regulate the internal organs; in humans, the lower portion of the brain stem, which regulates circulation, respiration, and certain special senses (1012)
medusa a free-swimming, jellyfish-like, and often umbrella-shaped sexual stage in the life cycle of a cnidarian; also a jellyfish or a hydra (676)
megaspore the larger of the two types of spores produced by heterosporous plants; develops into a female gametophyte (611)
meiosis a process in cell division during which the number of chromosomes decreases to half the original number by two divisions of the nucleus, which results in the production of sex cells (gametes or spores) (155)
melanin a pigment that helps determine skin color (924)
melatonin a hormone that is produced by the pineal gland during the night and that helps regulate certain biorhythms, such as sleep patterns (1040)
membrane potential the difference in electric potential between the two sides of a cell membrane (1006)

memory cell an immune system B cell or T cell that does not respond the first time that it meets with an antigen or an invading cell but that recognizes and attacks the antigen or invading cell during subsequent infections (965)
menopause the termination of the menstrual cycle; occurs between the ages of 45 and 55 (1055)
menstrual cycle the female reproductive cycle, characterized by a monthly change of the lining of the uterus and the discharge of blood (1054)
menstruation the discharge of blood and discarded tissue from the uterus during the menstrual cycle (1055)
meristem a region of undifferentiated plant cells that are capable of dividing and developing into specialized plant tissues (586)
merozoite the infective stage of the plasmodial life cycle, infects red blood cells of the host organism (519)
mesentery a membrane that attaches the small intestine to the abdominal wall (807)
mesoderm in an embryo, the middle layer of cells that gives rise to muscles, blood, and various systems (664)
mesoglea in cnidarians, the jellylike material located between the ectoderm and the endoderm (676)
mesophyll in leaves, the tissue between epidermal layers, where photosynthesis occurs (600)
metabolism the sum of all chemical processes that occur in an organism (8, 36)
metamorphosis a phase in the life cycle of many animals during which a rapid change from the immature organism to the adult takes place; an example is the change from larva to adult in insects (748)
metaphase one of the stages of mitosis and meiosis, during which all of the chromosomes move to the cell's equator (157)
metastasis the spread of cancer cells beyond the original site of growth (226)
methanogen a microorganism that produces methane gas (462)
metric system a decimal-based standard system of measurement that is used by scientists; similar to the *Systeme Internationale* (abbreviation, *SI*) (23)
microevolution a change in the collective genetic material of a population (317)
microfilament a fiber found inside eukaryotic cells that is composed mainly of the protein actin and that has a role in cell structure and movement (84)
micronucleus the smaller, reproductive nucleus found in some protozoans (508)
micronutrient a chemical needed in very small amounts for plant growth, such as manganese, iron, and zinc (590)
micropyle the small opening in the wall of an ovule through which a pollen tube enters the ovule (612)
microsphere a microscopic spherical structure composed of many protein molecules that are organized as a membrane (286)
microspore the smaller of the two types of spores produced by most plants that develops into the male gametophyte (611)
microtubule one of the small, tubular fibers composed of the protein tubulin that are found in the cytoplasm of eukaryotic cells, that compose the cytoskeleton, and that play a role in cell structure and movement (84)
migration in general, any movement of individuals or populations from one location to another; specifically, a periodic group movement that is characteristic of a given population or species (365, 898)
mimicry a defense in which one organism resembles another that is dangerous or poisonous (896)
mineral a class of nutrients that are inorganic compounds and that are necessary for certain body processes, such as enzyme activity and bone formation (982)
mitochondrial matrix the fluid that is inside the inner membrane of a mitochondrion (137)
mitochondrion in eukaryotic cells, the cell organelle that is surrounded by two membranes and that is the site of cellular respiration, which produces ATP (plural, *mitochondria*) (80)
mitosis in eukaryotic cells, a process of cell division that forms two new nuclei, each of which has the same number of chromosomes (155)
molar a large tooth that is located in the back of the mouth and that is used to grind and crush food (865)
mold in biology, a fungus that grows in the form of a tangled mass of filaments (527)
molecular genetics the study of the structure of nucleic acids and the function and regulation of genes (178)
molecule a group of atoms that are held together by chemical forces; a molecule is the smallest unit of matter that can exist by itself and retain all of a substance's chemical properties (33)
molting the shedding of an exoskeleton, skin, feathers, or hair to be replaced by new parts (724)
monocot a monocotyledonous plant; a plant that produces seeds that have only one cotyledon (576)
monohybrid cross a cross between individuals that involves one pair of contrasting traits (182)
monomer a simple molecule that can combine with other like or unlike molecules to make a polymer (53)
monosaccharide a simple sugar that is the basic subunit, or monomer, of a carbohydrate (55)
monotreme a mammal that lays eggs (863)
morphology the study of the structure and form of an organism (326)
motor neuron a nerve cell that conducts nerve impulses from the central nervous system to the muscles and glands (1013)
mouth pore in protozoa, an opening into which the oral groove opens (508)
movable joint a joint at which a wide range of motion occurs; examples include ball-and-socket, hinge, pivot, saddle, and gliding joints (915)
mRNA (messenger RNA) a single-stranded RNA molecule that encodes the information to make a protein (205)
mucous gland a gland in the skin of an amphibian that produces lubricants to keep the skin moist (804)
mucous membrane the layer of epithelial tissue that covers internal surfaces of the body and that secretes mucus (958)
multicellular describes a tissue, organ, or organism that is made of many cells (7)
multiple alleles more than two alleles (versions of the gene) for a genetic trait (244)
multiple fission a form of cell division that produces more than two cells (504)
muscle fatigue the physiological inability of a muscle to contract (922)
muscle fiber a multinucleate muscle cell, especially of skeletal or cardiac muscle tissue (917)
muscle tissue the tissue made of cells that can contract and relax to produce movement (907)
mutation a change in the nucleotide-base sequence of a gene or DNA molecule (202)
mutualism a relationship between two species in which both species benefit (403)
mycelium the mass of fungal filaments, or hyphae, that forms the body of a fungus (527)
mycology the study of fungi (527)
mycorrhiza a symbiotic association between fungi and plant roots (533)
myelin sheath a layer of fatty material that surrounds certain nerve fibers and that acts as an electrical insulator (1005)
myofibril a bundle of threadlike structures found within a striated muscle cell and mostly made up of actin and myosin (919)
myosin the most abundant protein in muscle tissue and the main constituent of the thick filaments of muscle fibers (919)

N

NAD^+ (nicotinamide adenine dinucleotide) an organic molecule that serves as an electron carrier by being oxidized to NAD^+ and reduced to NADH (133)
NADH the reduced form of NAD^+; an electron-carrying molecule that functions in cellular respiration (131)
naphthalene acetic acid a synthetic plant hormone that is used to promote root formation on stems and leaf cuttings (abbreviation, NAA) (632)
nastic movement a type of plant response that is independent of the direction of a stimulus (638)
natural killer cell a type of white blood cell that is present in individuals who

have not been immunized and that kills a variety of cells (960)

natural selection the process by which individuals that are better adapted to their environment survive and reproduce more successfully than less well adapted individuals do; a theory to explain the mechanism of evolution (12, 300)

nauplius the free-swimming larva of most crustaceans (726)

nectar a sugar-containing fluid secreted by flowers to attract birds or insects for pollination (616)

negative feedback a mechanism of homeostasis whereby a step in a series of events inhibits the initial signal in the series (1041)

nematocyst in cnidarians, a stinging cell that is used to inject a toxin into prey (677)

nephridium a tubule through which some invertebrates eliminate wastes (715)

nephron the functional unit of the kidney (994)

neritic zone a shallow marine environment that is near the shore or over the continental shelf and that is rich in minerals and nutrients produced by biotic activity (423)

nerve a collection of nerve fibers through which impulses travel between the central nervous system and other parts of the body (1013)

nerve net in cnidarians, a network of nerve cells that lacks a central control; impulses pass in any or all directions to produce a generalized response (677)

nervous system the structures that control the actions and reactions of the body in response to stimuli from the environment; a body system formed by billions of specialized nerve cells (1005)

nervous tissue the tissue of the nervous system, which consists of neurons, their supporting cells, and connective tissue (907)

net primary productivity the rate at which biomass accumulates in an ecosystem (366)

net venation a nonparallel, branching network of veins that is typical of the leaves of dicots (576, 600)

neuron a nerve cell that is specialized to receive and conduct electrical impulses (907, 1005)

neuropeptide a hormone secreted by the nervous system (1033)

neurotransmitter a chemical substance that transmits nerve impulses across a synapse (1005)

neutron a subatomic particle that has no charge and that is located in the nucleus of an atom (32)

neutrophil a large leukocyte that contains a lobed nucleus and many cytoplasmic granules (960)

niche the unique position occupied by a species, both in terms of its physical use of its habitat and its function within an ecological community (365)

nicotine a toxic, addictive alkaloid that is derived from tobacco and that is one of the major contributors to the harmful effects of smoking (1024)

nictitating membrane a third eyelid found under the lower eyelid of many vertebrates, including birds, reptiles, and amphibians (809)

nitrification the process by which nitrites and nitrates are produced by bacteria in the soil (374)

nitrogen cycle the process in which nitrogen circulates among the air, soil, water, plants, and animals in an ecosystem (373)

nitrogen fixation the process by which gaseous nitrogen is converted into nitrates, compounds that organisms can use to make amino acids and other nitrogen-containing organic molecules (373)

nitrogen-fixing bacterium a bacterium that converts atmospheric nitrogen into ammonia (373)

nitrogenous base an organic base that contains nitrogen, such as a purine or pyrimidine; a subunit of a nucleotide in DNA and RNA (197)

node in biology, a joint between two adjacent sections in the stem of a plant where buds form and leaves or branches start to grow; usually marked by a knot or swelling (593)

nondisjunction the failure of homologous chromosomes to separate during meiosis I or the failure of sister chromatids to separate during mitosis or meiosis II (239)

nonvascular plant the three groups of plants (liverworts, hornworts, and mosses) that lack specialized conducting tissues and true roots, stems, and leaves (564)

norepinephrine a chemical that is both a neurotransmitter produced by the sympathetic nerve endings in the autonomic nervous system and a hormone secreted by the adrenal medulla to stimulate the functions of the circulatory and respiratory systems especially (1037)

nosepiece the part of a compound light microscope that holds the objective lenses in place above the specimen (22)

notochord in the embryos of all chordates and in many adult chordates, a firm, flexible rod of tissue that is located in the dorsal part of the body (654)

nuclear envelope the double membrane that surrounds the nucleus of a eukaryotic cell (79)

nucleic acid an organic compound, either RNA or DNA, whose molecules are made up of one or two chains of nucleotides and carry genetic information (60)

nucleolus the part of the eukaryotic nucleus where ribosomal RNA is synthesized (79)

nucleotide in a nucleic-acid chain, a subunit that consists of a sugar, a phosphate, and a nitrogenous base (60, 197)

nucleus in physical science, an atom's central region, which is made up of protons and neutrons (32)

nucleus in a eukaryotic cell, a membrane-bound organelle that contains the cell's DNA and that has a role in processes such as growth, metabolism, and reproduction (74)

nut a dry fruit that has one seed and a hard shell; cultivated as a food crop (547)

nutrient a substance or compound that provides nourishment (or food) or raw materials needed for life processes (979)

nyctinastic movement a nastic movement that occurs in a plant in response to cycles of dark and light (639)

nymph an immature stage of some insects that is similar in function and structure to the adult (748)

O

objective lens the part of a compound light microscope that is located directly above the specimen and that magnifies the image of the specimen (21)

obligate anaerobe an organism that needs the absence of oxygen in order to live (470)

observation the process of obtaining information by using the senses; the information obtained by using the senses (13)

oceanic zone the regions of the open sea that lie beyond and between the continental shelves (424)

ocular lens the part of a compound light microscope that magnifies an image, usually 10 times, also called the *eyepiece* (21)

oil gland an exocrine gland that secretes an oily substance called sebum; also known as a *sebaceous gland* (925)

olfactory receptor a cell found in the nasal passages that is stimulated by certain substances, produces nerve impulses, and gives rise to the sense of smell (1019)

oligotrophic lake a lake that lacks organic nutrients and, as a result, contains high levels of dissolved oxygen in its lower layer (427)

omnivore an organism that eats a variety of other organisms, including animals and plants (367)

oncogene a gene that induces cancer, or uncontrolled cell proliferation (225, 491)

oogenesis the production, growth, and maturation of an egg, or ovum (164)

open circulatory system a type of circulatory system in which the circulatory fluid is not contained entirely within vessels; a heart pumps fluid through vessels that empty into spaces called sinuses (658)

operant conditioning a type of learning in which specific animal behaviors are deterred or reinforced by external actions upon the animal; usually refers to a controlled experimental situation (889)

operator a short sequence of viral or bacterial DNA to which a repressor binds to prevent transcription (mRNA synthesis) of the adjacent gene in an operon (218)
operculum in fish, a hard plate that is attached to each side of the head, that covers gills, and that is open at the rear (788)
operon a unit of gene regulation and transcription in bacterial DNA that consists of a promoter, an operator, and one or more structural genes (218)
opportunistic infection an infection caused by a microorganism that normally does not cause disease but that becomes pathogenic if the patient's immune system is weakened (971)
opposable thumb in primates, a thumb that can touch and move in opposition to the other fingers of the hand (876)
optic tectum the largest part of the midbrain of a fish; receives and processes information from the fish's visual, auditory, and lateral-line systems (792)
optimality hypothesis a prediction of the ratio of the energy expended to the energy gained as an animal searches for food; holds that animals tend to behave in a way that maximizes food intake while minimizing efforts to find food and avoiding danger (893)
oral groove a depressed region around the mouth of some ciliate protozoans, such as paramecia (508)
orbital a region in an atom where there is a high probability of finding electrons (32)
order in a traditional taxonomic system, the category contained within a class and containing families (339)
organ a collection of tissues that carry out a specialized function of the body (7, 76, 909)
organelle one of the small bodies that are found in the cytoplasm of a cell and that are specialized to perform a specific function (7, 75)
organic compound a covalently bonded compound that contains carbon, excluding carbonates and oxides (51)
organism an independent individual that possesses all characteristics of life (7)
organization the high degree of order within an organism's internal and external parts and in its interactions with the living world (6)
origin in anatomy, the point at which a muscle attaches to a stationary bone (921)
ornithologist a person who specializes in the scientific study of birds (849)
osculum an opening in a sponge's body through which water exits (673)
osmosis the diffusion of water or another solvent from a more dilute solution (of a solute) to a more concentrated solution (of the solute) through a membrane that is permeable to the solvent (98)
ossicle one of the small, calcium carbonate plates that make up the endoskeleton of an echinoderm (762)
ossification the process by which cartilage is converted into bone (914)
osteoarthritis a degenerative joint disease in which the cartilage covering the surface of the bones becomes thinner and rougher (916)
osteocyte a bone cell (913)
ostium one of the small openings in a sponge's body through which water enters (673)
ovarian cycle a series of hormone-induced changes in which the ovaries prepare and release a mature ovum each month (1054)
ovary in the female reproductive system of animals, an organ that produces eggs; in flowering plants, the lower part of a pistil that produces eggs in ovules (575, 613, 1052)
oviduct the tube that leads from an ovary to the uterus (848)
oviparity in egg-laying amniotes, a reproductive method in which the female's reproductive tract encloses each egg in a tough, protective shell (829)
oviparous describes organisms that produce eggs that develop and hatch outside the body of the mother (863)
ovipositor in many female insects, a structure that is at the end of the abdomen and that is used to lay eggs (748)
ovoviviparity in amniotes, a reproductive method wherein shelled eggs are produced, develop, and sometimes hatch inside the body of the mother (829)
ovoviviparous describes organisms that produce eggs that develop and hatch inside the body of the mother (829)
ovulation the release of an ovum from a follicle of the ovary (1054)
ovule a structure in the ovary of a seed plant that contains an embryo sac and that develops into a seed after fertilization; in gymnosperms the ovule is found in the carpel and is structurally simple and naked (612)
ovum a mature egg cell (1053)
oxaloacetic acid a four-carbon compound of Krebs cycle that combines with acetyl CoA to form citric acid (138)
oxidation reaction a chemical reaction in which a reactant loses one or more electrons such that the reactant becomes more positive in charge (37)
oxygen debt the extra amount of oxygen that must be taken in by the body to replenish the muscles' oxygen reserves and to allow for the breakdown of lactic acid within the muscles, especially after strenuous activity (922)
ozone a gas molecule that is made up of three oxygen atoms (289)
ozone layer the layer of the atmosphere at an altitude of 15 to 40 km in which ozone absorbs ultraviolet solar radiation (436)

P

P generation parental generation, the first two individuals that mate in a genetic cross (175)
palisade mesophyll in plants, the layer of vertically elongated cells that contains chloroplasts, that is located beneath the upper epidermis of leaves, and that participates in photosynthesis (600)
papilla one of the bumps of tissue on the tongue, between which taste buds are embedded (plural, *papillae*)(1019)
parallel venation a parallel arrangement of veins; typical of the leaves of monocots (576, 600)
parapodium in polychaete annelid worms, one of the two flap-shaped appendages that are used for locomotion or gas exchange (713)
parasitism a relationship between two species in which one species, the parasite, benefits from the other species, the host, which is harmed (403)
parenchyma in higher plants, the fundamental tissue that is composed of thin-walled living cells that function in photosynthesis and storage (583)
parthenogenesis a type of reproduction in which unfertilized eggs develop into adults (698)
passive transport the movement of substances across a cell membrane without the use of energy by the cell (97)
pathogen a virus, microorganism, or other organism that causes disease; an infectious agent (957)
pathology the scientific study of disease (472)
PCR (polymerase chain reaction) a molecular biology technique that is used to make many copies of selected segments of DNA (256)
pedicellaria on the surface of some echinoderms, very small pincers that are used for protection against ectoparasites (765)
pedigree a diagram that shows the occurrence of a genetic trait in several generations of a family (241)
pedipalp one of the second pair of appendages that are beside the mouth of an arachnid and that are used for chewing and handling prey (731)
peer review the process in which experts in a given field examine the results and conclusions of a scientist's study before that study is accepted for publication (19)
pelagic zone the upper, central, or open region of a body of water (424)
pellicle a protective envelope of nonliving material that covers many protozoans (508)
pelvic cavity the hollow part of the body that is below the abdominal cavity and that contains the organs of the reproductive and excretory systems (910)
penis the male organ that transfers sperm to the female reproductive tract during sexual intercourse and that carries urine out of the body (1051)

peptide bond the chemical bond that forms between the carboxyl group of one amino acid and the amino group of another amino acid (57)
peptidoglycan a protein-carbohydrate compound that makes the cell walls of bacteria rigid (462)
pericycle in plants, the outer portion of the central cylinder of vascular tissue (590)
periosteum a white, double-layered membrane that covers the entire surface of bone except for the joint surfaces, it is richly supplied with nerve fibers and blood vessles (912)
peripheral nervous system all of the parts of the nervous system except for the brain and the spinal cord (the central nervous system); includes the cranial nerves and nerves of the neck, chest, lower back, and pelvis (1010)
peristalsis the series of rhythmic muscular contractions that move food through the digestive tract (987)
permafrost in arctic regions, the permanently frozen layer of soil or subsoil (418)
pesticide a poison used to destroy pests, such as insects, rodents, or weeds; examples include insecticides, rodenticides, and herbicides (548)
petal one of the usually brightly colored, leaf-shaped parts that make up one of the rings of a flower (613)
petiole the stalk that attaches a leaf to the stem of a plant (600)
pH scale a range of values that are used to express the acidity or alkalinity (basicity) of a system; each whole number on the scale indicates a tenfold change in acidity; a pH of 7 is neutral, a pH of less than 7 is acidic, and a pH of greater than 7 is basic (44)
phagocyte a cell that ingests and destroys (digests) foreign matter or microorganisms (105, 941, 959)
phagocytosis the process by which a cell engulfs large particles or whole cells, either as a defense mechanism or as a means to obtain food (105)
pharyngeal pouch one of the lateral sacs that branch from the pharynx of chordate embryos and that may open to the outside as gill slits in adult fishes and invertebrate chordates (654)
pharynx in flatworms, the muscular tube that leads from the mouth to the gastrovascular cavity; in animals with a digestive tract, the passage from the mouth to the larynx and esophagus (690, 947)
phenotype an organism's appearance or other detectable characteristic that results from the organism's genotype and the environment (180)
phenotype frequency the ratio of individuals with a particular phenotype to the total number of individuals in a population (319)
phenotypic ratio the ratio of phenotypes produced by a cross (183)
pheromone a substance that is released by the body and that causes another individual of the same species to react in a predictable way (751, 896)
phloem in vascular plants, the tissue that carries organic and inorgnaic nutrients in any direction, depending on the plant's needs (564)
phospholipid a lipid that contains phosphorus and that is a structural component in cell membranes (59)
phospholipid bilayer a double layer of phospholipids that makes up plasma and organelle membranes (77)
phosphorus cycle the cyclic movement of phosphorus in different chemical forms from the environment to organisms and then back to the environment (374)
photic zone the area of an aquatic system that receives enough light for photosynthesis to occur (423)
photoperiodism the response of plants to seasonal changes in the relative length of nights and days (640)
photosynthesis the process by which plants, algae, and some bacteria use sunlight, carbon dioxide, and water to produce carbohydrates and oxygen (113)
photosystem in the thylakoid membranes of chloroplasts, a cluster of chlorophyll and other pigment molecules that harvest light energy for the light reactions of photosynthesis (116)
phototroph an organism that gets its energy from sunlight (469)
phototropism a plant growth movement that occurs in response to the direction of a source of light (636)
phylogenetic diagram a branching diagram that models the relationships by ancestry between different species or other taxonomic groups (341)
phylogenetics the analysis of evolutionary, or ancestral, relationships between taxa (341)
phylogeny the evolutionary history of a species or taxonomic group; the relationships by ancestry among species or taxonomic groups (307)
phylum in a traditional taxonomic system for organisms other than plants, the category contained within a kingdom and containing classes (339)
phytochrome a protein pigment that regulates flowering in plants in response to light absorption and seed germination (641)
phytoplankton the microscopic, photosynthetic organisms that float near the surface of marine or fresh water and that are the basic source of food in many aquatic ecosystems; examples include algae and cyanobacteria (510)
pigment a substance that gives another substance or a mixture its color (115)
pilus a short, thick hair-like protein structure that allows a bacterium to attach to other bacteria and surfaces (plural, *pili*) (468)
pinniped an aquatic, fin-footed, carnivorous animal, such as a sea lion, walrus, or seal (872)
pinocytosis a method of active transport across the cell membrane in which the cell takes in extracellular fluids (105)
pinworm a nematode worm parasite that lives in the intestine of humans and animals; females lay their eggs around the anus, which causes itching (697)
pioneer species a species that colonizes an uninhabited area and that starts an ecological cycle in which many other species become established (408)
pistil the female reproductive part of a flower that produces seeds and consists of an ovary, style, and stigma, made of one or more fused carpels (614)
pit in plants, the thin, porous areas of a thracheid cell wall (585)
pith the tissue that is located in the center of the stem of most vascular plants and that is used for storage (594)
pituitary gland an endocrine gland that is located at the base of the brain, stores and releases hormones produced by the hypothalamus, and secretes hormones under the control of the hypothalamus (1034)
placenta the structure that attaches a developing fetus to the uterus and that enables the exchange of nutrients, wastes, and gases between the mother and the fetus (829, 863, 1058)
placental mammal a mammal that nourishes its unborn offspring through a placenta inside its uterus (863)
placoid scale one of the hard scales that resemble vertebrate teeth and cover skin of sharks and rays (784)
plankton the mass of mostly microscopic organisms that float or drift freely in the waters of aquatic (freshwater and marine) environments (424)
plant hormone organic chemical messengers that affect a plant's ability to respond to its environment (631)
Plantae in a traditional taxonomic system, a kingdom made up of eukaryotic, multicellular organisms that have cell walls made mostly of cellulose, that have pigments that absorb light, and that supply energy and oxygen to themselves and to other life-forms through photosynthesis (350)
planula the free-swimming, ciliated larva of a cnidarian (680)
plasma in biology, the liquid component of blood (940)
plasma cell a type of white blood cell that produces antibodies (964)
plasma membrane or cell membrane, the cell's outer boundary (74)
plasmid a circular DNA molecule that is usually found in bacteria and that can replicate independent of the main chromosome (259, 468)
plasmodial slime mold a type of protist that has ameboid cells, flagellated cells,

and a plasmodial feeding stage in its life cycle (514)

plasmolysis the contraction or shrinking of the cell membrane of a plant cell in a hypertonic solution in response to the loss of water by osmosis (100)

plastid an organelle of plant cells that contains specific substances and performs specific functions for the cell; examples include chloroplasts and chromoplasts (89)

plastron the bottom, or ventral, portion of a turtle's shell (830)

platelet a fragment of a cell that is needed to form blood clots (942)

plumule the developing shoot above the cotyledons in plant embryos; consists of the epicotyl and young leaves (620)

point mutation a mutation in which only one nucleotide or nitrogenous base in a gene is changed (240)

polar describes a molecule with opposite charges on opposite ends (39)

polar body a short-lived product of the formation of gametes by meiosis (164)

polar nucleus one of the two haploid nuclei in the embryo sac of a seed plant that fuse with a male gamete to form the triploid cell that develops into the endosperm (plural, *polar nuclei*) (613)

pollen grain the structure that contains the male gametophyte of seed plants (612)

pollen tube a tubular structure that grows from a pollen grain, enters the embryo sac, and allows the male reproductive cells to move to the ovule (612)

pollination the transfer of pollen from the male reproductive structures (the anthers) to the tip of a female reproductive structure (the pistil) of a flower in angiosperms or to the ovule in gymnosperms (174, 612)

polygenic describes a characteristic that is influenced by many genes (242)

polymer a large molecule that is formed by more than five monomers, or small units (53)

polyp a form of a cnidarian that has a cylindrical, hollow body and that is usually attached to a rock or to another object (676)

polypeptide a long chain of several amino acids (57)

polysaccharide one of the carbohydrates made up of long chains of simple sugars; polysaccharides include starch, cellulose, and glycogen (56)

population a group of organisms of the same species that live in a specific geographical area and interbreed (362, 381)

population density the number of individuals of the same species that live in a given unit of area (382)

population genetics the study of the frequency and interaction of alleles and genes in populations (317)

positive feedback the release of an initial hormone that stimulates release or production of other hormones or substances, which stimulate further release of the initial hormone (1042)

posterior in animals with bilateral symmetry, refers to the end of the body that is opposite the head; rear (655)

preadaptation an adaptation in an ancestral group that evolves through natural selection to allow new functions in a descendant group (799)

precocial describes a species of birds or mammals whose young are born at an advanced stage of development, with open eyes and the ability to walk and run almost immediately (849)

predation a relationship between two species in which one species, the predator, feeds on the other species, the prey (399)

prediction a statement made in advance that expresses the results that will be obtained from testing a hypothesis if the hypothesis is supported; the expected outcome if a hypothesis is accurate (13)

preen gland in birds, a special gland that secretes oil that a bird spreads over its feathers to clean and waterproof them (844)

pregnancy the period of time between implantation and birth (1057)

prehensile appendage an appendage that can grasp objects, as in a primate's hand, foots, or tail (875)

premolar one of the eight teeth that are located between the molars and the canines (865)

pre-mRNA precursor mRNA; the first strand of mRNA produced by gene transcription that contains both introns and exons (221)

pressure-flow hypothesis an explanation for the movement of carbohydrates in the phloem of plants; holds that carbohydrates are actively transported into sieve tubes (596)

primary electron acceptor in chloroplasts, an acceptor of electrons lost from chlorophyll a; found in the thylakoid membrane (117)

primary host the host from which an adult parasite gets its nourishment and in which reproduction occurs (692)

primary succession succession that begins in an area that previously did not support life (408)

primer a short, single-stranded fragment of DNA or RNA that is required for the initiation of DNA replication (256)

prion an infectious particle that consists only of a protein and that does not contain DNA or RNA (494)

probability the likelihood that a possible future event will occur in any given instance of the event; the mathematical ratio of the number of times one outcome of any event is likely to occur to the number of possible outcomes of the event (181)

probe a strand of RNA or single-stranded DNA that has been labeled with a radioactive element or fluorescent dye and that is used to bind with and identify a specific gene in genetic engineering (259)

producer an organism that can make organic molecules from inorganic molecules; a photosynthetic or chemosynthetic autotroph that serves as the basic food source in an ecosystem (366)

product a substance that forms in a chemical reaction (36)

progesterone a steroid hormone that is secreted by the corpus luteum of the ovary, that stimulates changes in the uterus to prepare for the implantation of a fertilized egg, and that is produced by the placenta during pregnancy (1037)

proglottid one of the many body sections of a tapeworm; contains reproductive organs (693)

prokaryote a single-celled organism that has no nucleus and has no membrane-bound organelles; examples include bacteria and archaea (75, 461)

promoter a nucleotide sequence on a DNA molecule to which an RNA polymerase molecule binds, which initiates the transcription of a specific gene (206)

propagation the production of new individuals (618)

prophage the viral genome (DNA) of a bacteriophage that has entered a bacterial cell, has become attached to the bacterial chromosome, and is replicated with the host bacterium's DNA (487)

prophase the first stage of mitosis and meiosis in cell division; characterized by the condensation of the chromosomes and the dissolution of the nuclear envelope (156)

prostaglandin a type of hormone that is synthesized in the body tissues and that usually acts locally; prostaglandins have a variety of effects, such as the dilatation of blood vessels, the contraction and relaxation of smooth muscle, and the regulation of the kidney function (1033)

prostate gland a gland in males that contributes to the seminal fluid (1051)

protease inhibitor a type of drug that blocks the synthesis of new viral capsid and that is used to treat diseases such as AIDS (491)

protein an organic compound that is made of one or more chains of amino acids and that is a principal component of all cells (56)

protein synthesis the formation of proteins by using information contained in DNA and carried by mRNA (204, 207)

proteome an organism's complete set of proteins (262)

proteomics the study of all of an organism's proteins, including its identity, structure, interaction, and abundance (264)

protist an organism that is classified a a member of the kingdom Protista; generally, a single-celled or simple multicellular eukaryote that cannot be readily

classified as either plant, animal, or fungus (501)

Protista in a traditional taxonomic system, a kingdom made up of mostly one-celled eukaryotic organisms that are not readily classified as either plants, animals, or fungi (349)

proton a subatomic particle that has a positive charge and that is located in the nucleus of an atom; the number of protons of the nucleus is the atomic number, which determines the identity of an element (32)

proto-oncogene a gene that regulates normal cell division but that can become a cancer-causing oncogene as a result of mutation or recombination (225, 491)

protostome an organism whose embryonic blastopore develops into the mouth, whose coelom arises by schizocoely, and whose embryo has determinate cleavage (665)

proventriculus the first of the two chambers in the stomach of a bird (846)

provirus viral DNA that has attached to a host cell's chromosome and that is replicated with the chromosome's DNA (485)

pseudocoelom the type of body cavity, derived from the blastocoel and referred to as a "false body cavity," that forms between the mesoderm and the endoderm in rotifers and roundworms (665)

pseudopodium a retractable, temporary cytoplasmic extension that functions in food ingestion and movement in certain amoeboid cells (506)

psychoactive drug a drug or medicine that affects and changes the functioning of the central nervous system (1021)

puberty the stage of human life in which menstruation begins in females, sperm production begins in males, and secondary sex characteristics begin to appear (1037)

pulmonary circulation the flow of blood from the right ventricle of the heart to the lungs and back to the left atrium of the heart through the network of pulmonary arteries, capillaries, and veins (805, 937)

pulmonary respiration in animals, respiration through the lungs (806)

pulse the rhythmic pressure of the blood against the walls of a vessel, particularly an artery (935)

punctuated equilibrium a model of evolution in which short periods of drastic change in species, including mass extinctions and rapid speciation, are separated by long periods of little or no change (330)

Punnett square a graphic used to predict the results of a genetic cross (182)

pupa the immobile, nonfeeding stage between the larva and the adult of insects that have complete metamorphosis; as a pupa, the organism is usually enclosed in a cocoon or chrysalis and undergoes important anatomical changes (749)

pupil the opening that is located in the center of the iris of the eye and that controls the amount of light that enters the eye (1018)

purine a nitrogenous base that has a double-ring structure; one of the two general categories of nitrogenous bases found in DNA and RNA; either adenine or guanine (198)

pygostyle in birds, the fused terminal vertebrae of the spine; supports the tail feathers (845)

pyloric sphincter the circular muscle that controls the flow of chyme from the stomach to the small intestine (988)

pyrimidine a nitrogenous base that has a single-ring structure; one of the two general categories of nitrogenous bases found in DNA and RNA; thymine, cytosine, or uracil (198)

pyruvic acid the three-carbon compound that is produced during glycolysis and needed for both the aerobic and anaerobic pathways of cellular respiration that follow glycolysis (131)

Q

queen bee the mature, fertile female that lays eggs in a colony of bees (752)

queen factor a pheromone that is produced by a queen bee and that prevents other female larvae from developing into queens (753)

R

radial symmetry a body plan in which the parts of an animal's body are organized in a circle around a central axis (655)

radicle in plants, the embryonic, or primary, root (620)

radioactive decay the disintegration of an unstable atomic nucleus into one or more different nuclides, accompanied by the emission of radiation, the nuclear capture or ejection of electrons, or fission (283)

radioactive isotope an isotope that has an unstable nucleus and that emits radiation (283)

radiometric dating a method of determining the absolute age of an object by comparing the relative percentages of a radioactive (parent) isotope and a stable (daughter) isotope (282)

radula a rasping, tonguelike organ that is covered with chitinous teeth and that is used for feeding by many mollusks (706)

ray-finned fish a kind of fish whose fins are supported by long, segmented, and flexible bony elements called rays (788)

reabsorption the process in the kidneys by which materials return to the blood from the nephrons (996)

reactant a substance or molecule that participates in a chemical reaction (36)

reasoning a type of problem solving that requires the ability to solve a problem that has not been encountered previously (890)

receptacle the enlarged tip of a flower stalk to which the flower is attached (613)

receptor a specialized sensory nerve that responds to specific types of stimuli (1032)

recessive describes a trait or an allele that is expressed only when two recessive alleles for the same characteristic are inherited (177)

recombinant DNA DNA molecules that are artificially created by combining DNA from different sources (258)

red blood cell a disc-shaped cell that has no nucleus, that contains hemoglobin, and that transports oxygen in the circulatory system (940)

red tide a population explosion of certain marine dinoflagellates that causes the water to turn a red or red-brown color and to contain poisonous alkaloids produced by the dinoflagellates (513)

redox reaction a reaction in which electrons are transferred between atoms; also known as an oxidation-reduction reaction (37)

reduction reaction a chemical change in which electrons are gained, either by the removal of oxygen, the addition of hydrogen, or the addition of electrons (37)

reflex an involuntary and almost immediate movement in response to a stimulus (1014)

refractory period a short period of time after the stimulation of a nerve during which the nerve cannot be stimulated (1008)

regeneration the regrowth of missing tissues or organs (675)

regulator gene a genetic unit that regulates or suppresses the activity of one or more structural genes (219)

relative age the age of an object in relation to the ages of other objects (302)

renal tubule the long, tubular portion of a nephron that produces and that takes urine to the renal pelvis of a kidney (995)

replication fork a Y-shaped point that results when the two strands of a DNA double helix separate so that the DNA molecule can be replicated (200)

repressor protein a regulatory protein that binds to an operator and blocks transcription of the genes of an operon (219)

reproduction the process of producing offspring (9)

reproductive isolation the inability of members of a population to successfully interbreed with members of another population of the same or a related species (328)

resolution in microscopes, the ability to form images with fine detail (22)

respiratory system a collection of organs whose primary function is to take in oxygen and expel carbon dioxide; the organs of this system include the lungs,

the throat, and the passageways that lead to the lungs (946)

resting potential the electric potential across the cell membrane of a nerve cell or muscle cell when the cell is not active (1007)

restoration biology the science of rehabilitating, replacing, or acquiring the equivalent of any natural resources that have been injured, destroyed, or lost (446)

restriction enzyme an enzyme that destroys foreign DNA molecules by cutting them at specific sites (257)

retina the light-sensitive inner layer of the eye, which receives images formed by the lens and transmits them through the optic nerve to the brain (1018)

retrovirus a virus that contains single-stranded RNA and produces a reverse transcriptase, which converts RNA to DNA (486)

reverse transcriptase an enzyme that catalyzes the formation of DNA from an RNA template (486)

Rh factor one of several blood-group antigens carried on the surface of red blood cells (944)

rheumatoid arthritis a chronic immune-system disorder that causes stiff and painful joints (916)

rhizoid a rootlike structure in nonvascular plants, such as mosses or liverworts, that holds the plants in place and aids in absorption (530)

rhizome a horizontal, underground stem that provides a mechanism for asexual reproduction (572)

ribose a five-carbon sugar present in RNA (205)

ribosome a cell organelle composed of RNA and protein; the site of protein synthesis (79)

ribozyme a type of RNA that can act as an enzyme (288)

RNA (ribonucleic acid) a natural polymer that is present in all living cells and that plays a role in protein synthesis (60, 204)

RNA polymerase an enzyme that starts (catalyzes) the formation of RNA by using a strand of a DNA molecule as a template (206)

rod one of the two types of light-detecting cells in the eye; rods can detect dim light and play a major role in noncolor and night vision (1018)

root cap the protective layer of cells that covers the tip of a root (588)

root crop a plant root or underground stem that is rich in carbohydrates and can serve as the major part of a diet (547)

root hair an extension of the epidermis of a root that increases the root's surface area for absorption (588)

rotifer a member of the phylum Rotifera, which consists of small, aquatic invertebrates whose ring of cilia around the mouth makes the animal look like a spinning wheel (698)

roundworm a member of the phylum Nematoda, which consists of animals that have smooth skin and a long, cylindrical, and unsegmented body that tapers at both ends (695)

royal jelly a high-protein substance secreted by worker bees and fed to a queen bee and female larvae that develop into queen bees (752)

rRNA (ribosomal RNA) an organelle that contains most of the RNA in the cell and that is responsible for ribosome function (205)

rumen the first of the four compartments in the stomach of a ruminant mammal (866)

S

saliva the watery fluid that is secreted by the salivary glands of the mouth, that softens and moistens food, and that begins digestion (986)

sarcoma a malignant tumor that grows in bone or muscle tissue (228)

sarcomere the basic unit of contraction in skeletal and cardiac muscle (919)

saturated solution a solution that cannot dissolve any more solute under the given conditions (42)

savanna a plain full of grasses and scattered trees and shrubs; found in tropical and subtropical habitats and mainly in regions with a dry climate, such as East Africa (421)

scanning electron microscope a microscope that produces an enlarged, three-dimensional image of an object by using a beam of electrons rather than light (abbreviation, *SEM*) (22)

schistosomiasis a disease that is caused by a parasitic blood fluke of the genus *Schistosoma* and that affects the skin, intestines, liver, vascular system, or other organs (693)

schizocoely the method of coelom formation in protosomes in which the embryonic mesoderm splits into two layers (666)

scientific methods the series of steps followed to solve problems, including collecting data, formulating a hypothesis, testing the hypothesis, and stating conclusions (13)

sclerenchyma a type of plant tissue composed of cells that have thickened secondary cell walls that function in plant support (584)

scolex the head of a tapeworm, which has hooks and suckers to adhere to the host tissues (693)

scrotum the sac that contains the testes in most male mammals (1049)

sebum the oily secretion of the sebaceous glands (925)

second messenger a molecule that is generated when a specific substance attaches to a receptor on the outside of a cell membrane, which produces a change in cellular function (1032)

secondary succession the process by which one community replaces another community that has been partially or totally destroyed (408)

secretion the process by which the glands of the body release their substances; a substance produced by a gland; the process by which substances pass from the blood into the kidneys (996)

seed a plant embryo that is enclosed in a protective coat (563)

seed coat the protective, outer covering of a seed (620)

seed plant a plant that produces seeds (565)

seedling a young plant grown from a seed (572)

segmentation the division of the body of an organism into a series of similar parts (657)

self-pollination the transfer of pollen grains from an anther to the stigma of the same flower or to the stigma of another flower on the same plant (174)

semen the fluid that contains sperm and various secretions produced by the male reproductive organs (1051)

semicircular canal the fluid-filled canal in the inner ear that helps maintain balance and coordinate movements (1018)

semi-conservative replication in each new DNA double helix, one strand is from the original molecule, and one strand is new (200)

semimovable joint a joint at which limited movement occurs; examples include the joints between the bones of the vertebral column (915)

seminal receptacle a saclike organ of female or hermaphroditic invertebrates that stores sperm (715)

seminal vesicle one of two glandular structures in male vertebrates that hold and secrete seminal fluid (1051)

seminiferous tubule one of the many tubules in the testis where sperm are produced (1049)

sense organ an organ that receives stimuli and gives rise to the senses such as sight, smell, hearing, and pain (1016)

sensitive period in an animal's development, the specific phase during which imprinting occurs (891)

sensory receptor a specialized structure that contains the ends of sensory neurons and that responds to specific types of stimuli (1013)

sepal in a flower, one of the outermost rings of modified leaves that protect the flower bud (613)

septum a dividing wall, or partition, such as the wall between adjacent cells in a fungal hypha, the internal wall between adjacent segments of an annelid, and the thick wall between the right and left chambers of the heart (plural, *septa*) (527, 825, 933)

sessile describes an organism that remains attached to a surface for its entire life and does not move (673)

seta one of the external bristles or spines that project from the body of an animal (plural, *setae*) (713)
sex chromosome one of the pair of chromosomes that determine the sex of an individual (152, 236)
sex-influenced trait an autosomal trait that is influenced by the presence of male or female sex hormones (245)
sex-linked trait a trait that is determined by a gene found on one of the sex chromosomes, such as the X chromosome or the Y chromosome in humans (237)
sexual reproduction reproduction in which gametes from two parents unite (164)
sexual selection an evolutionary mechanism by which traits that increase the ability of individuals to attract or acquire mates appear with increasing frequency in a population; selection in which a mate is chosen on the basis of a particular trait or traits (323, 894)
shared character a feature that is shared by all members of a particular group of organisms (342)
shell the cell wall of a diatom (512)
sieve plate a region that connects two sieve cells and that has one or more sieve areas, which consist of clusters of pores through which the cytoplasm of the cells is connected and through which materials are transported (585)
sieve tube in the phloem of a flowering plant, a conducting tube that is made up of a series of sieve-tube members stacked end to end (585)
sieve-tube member one of the component cells of a sieve tube, which is found mainly in flowering plants (585)
simple leaf a leaf that has an undivided blade (600)
single nucleotide polymorphism a unique area of DNA where individuals differ by a single nucleotide; important in mapping the genome (abbreviation, SNP) (262)
sink any place where a plant stores or uses organic nutrients, such as sugar or starches (596)
sinoatrial node a mass of cardiac muscle cells that lies at the junction of the superior vena cava with the right atrium and that initiates and regulates contraction of the heart (abbrevation, *SA node*) (935)
skeletal muscle a voluntary muscle that is attached to the bones and that moves parts of the body (907)
skeleton the bones of a human or animal body that form the framework of the body, support the muscles and organs, and protect the inner organs (911)
smog urban air pollution composed of a mixture of smoke and fog produced from industrial pollutants and burning fuels (440)
smooth muscle the elongated muscle that is not under voluntary control and that is found in the digestive tract, blood vessels, glands, and hair follicles, but not in the heart (907)
social behavior the interaction between animals of the same species that are not related or are only distant relatives (897)
social insect an insect that lives in a large community, such as an ant or a bee (752)
sodium-potassium pump a carrier protein that uses ATP to actively transport sodium ions out of a cell and potassium ions into the cell (103)
solar tracking the movement of leaves or flowers in response to the sun's movement across the sky (637)
solute in a solution, the substance that dissolves in the solvent (42)
solution a homogeneous mixture throughout which two or more substances are uniformly dispersed (42)
solvent in a solution, the substance in which the solute dissolves (42)
somatic nervous system the portion of the neural structure that provides nerve connections to the skin, skeleton, and muscles of the body, but not to the viscera, blood vessels, and glands (1014)
somatic-cell mutation a mutation that occurs in a body cell (239)
sorus a cluster of spores or sporangia (611)
source a part of a plant that makes sugars and other organic compounds and from which these compounds are transported to other parts of the plant (596)
spawning a method of reproduction in fish, amphibians, mollusks, and crustaceans in which eggs or sperm are deposited into water (792)
specialization the evolutionary adaptation of a cell, organ, organism, or population for a particular function or environment (651)
speciation the formation of new species as a result of evolution (326)
species a group of organisms that are closely related and can mate to produce fertile offspring; also the level of classification below genus and above subspecies (339)
species diversity an index that combines the number and relative abundance of different species in a community (438)
species evenness a measure of the relative adundance of each species in an ecological community (405)
species richness the number of different species in an area or community (405)
species-area effect a pattern in which the number of species in an area increases as the area increases (406)
spermatid an immature sperm cell that has almost completed its development (164)
spermatogenesis the process by which male gametes form (164)
spicule a needle of silica or calcium carbonate in the skeleton of some sponges (673)
spinal cavity the hollow part of the body that contains the spinal cord (910)
spindle fiber one of the microtubules that extend across a dividing eukaryotic cell; assists in the movement of chromosomes (156)
spinneret an organ that spiders and certain insect larvae use to produce silky threads for webs and cocoons (732)
spiracle an external opening in an insect or arthropod, used in respiration (732)
spirillum a spiral-shaped bacterium (463)
spleen the largest lymphatic organ in the body; serves as a blood reservoir, disintegrates old red blood cells, and produces lymphocytes and plasmids (962)
sponge an aquatic invertebrate of the phylum Porifera that attaches to stones or plants and that has a porous structure and a tough, elastic skeleton (673)
spongin a fibrous protein that contains sulfur and composes the fibers of the skeleton of some sponges (673)
spongy bone less-dense bone tissue that has many open spaces (913)
spongy mesophyll inside a leaf, the tissue that is made up of loosely arranged parenchyma cells that contain chloroplasts and are surrounded by air spaces that promote the diffusion of oxygen, carbon dioxide, and water throughout the leaf (600)
spontaneous generation an early and now disproved theory that living organisms come to life spontaneously from nonliving material (279)
sporangiophore a plant or fungal structure that bears a sporangium or spores (528)
sporangium a specialized sac, case, capsule, or other structure that produces spores (528)
spore a reproductive cell or multicellular structure that is resistant to environmental conditions and that can develop into an adult without fusion with another cell (563)
sporophyte in plants and algae that have alternation of generations, the diploid individual or generation that produces haploid spores (565)
sporozoite a sporozoan that has been released from the oocyst and is ready to penetrate a new host cell (519)
stability the tendency of a community to maintain a relatively constant structure (407)
stabilizing selection a type of natural selection in which the average form of a trait is favored and becomes more common (324)
stage a platform of a compound light microscope that supports the slide holding the specimen (21)
stamen the male reproductive structure of a flower that produces pollen and consists of an anther at the tip of a filament (613)
staphylococcus a coccus that grows with others in grapelike clusters; examples include cocci of the species *Staphlococcus aureus* (463)
sternum in birds, the large, keel-shaped pectoral bone to which flight muscles attach; commonly called the breastbone (845)

steroid a type of lipid that consists of four carbon rings to which various functional groups are attached and that usually has a physiological action (60)
steroid hormone a type of hormone that is derived from the steroid cholesterol; various steroid hormones are secreted by the adrenal cortex, testis, ovary, and placenta (1031)
stigma the expanded apex of a pistil, supported by the style; the part of the pistil that receives the pollen (613)
stimulant a drug that increases the activity of the body or the activity of some part of the body (1022)
stolon in plants, a creeping stem that can develop roots and shoots at its nodes or at its tip to form new individuals; the creeping hypha of some fungi that gives rise to new individuals (530)
stoma one of many openings in a leaf or a stem of a plant that enable gas exchange to occur (plural, *stomata*) (121)
strata layers of rock (singular, *stratum*) (298)
streptococcus a coccus that grows with others in chains; examples include cocci of the disease-causing species *Streptococcus mutans* (463)
strobilus a conelike structure of sporangia-bearing leaves (571)
stroma in plants, the solution that surrounds the thylakoids in a chloroplast (114)
structural gene a gene that codes for a product, such as an enzyme, protein, or RNA, rather than serving as a regulator (218)
style in plants, the slender, upper part of the pistil (613)
subspecies a taxonomic classification below species that groups organisms that live in different geographical areas, differ morphologically from other populations of the species, but can interbreed with other populations of the species (339)
substitution a mutation in which a nucleotide or a codon in DNA is replaced with a different nucleotide (240)
substrate a part, substance, or element that lies beneath and supports another part, substance, or element; the reactant in reactions catalyzed by enzymes (57)
superposition a principle that states that younger rocks lie above older rocks if the layers have not been disturbed (302)
surface area–to-volume ratio the relationship of a cell's outer surface area to its volume (73)
survivorship curve a graph of the mortality data of a population; indicates the probability that individuals will survive to any given age (384)
sustainability the condition in which human needs are met in such a way that a human population can survive indefinitely (444)
sweat gland an exocrine gland that secretes sweat; these glands are distributed over the skin surface of most of the body (925)
swim bladder in bony fishes, a gas-filled sac that is used to control buoyancy (787)
swimmeret in some crustaceans, an abdominal appendage modified to allow movement, respiration, or the carrying of eggs (728)
symbiosis a relationship in which two different organisms live in close association with each other (403)
symmetry a body arrangement in which parts that lie on opposite sides of a central line are identical (654)
synapse the junction at which the end of the axon of a neuron meets the end of a dendrite or the cell body of another neuron or meets another cell (1005)
synapsid a lineage of amniotes that gave rise to mammals; characterized by skulls that have a single opening in a bone behind the eye socket (862)
synapsis the pairing of homologous chromosomes during meiosis (161)
synovial fluid the transparent fluid that lubricates joints (915)
syrinx the sound-producing organ of birds (853)
systematics the classification of living organisms in terms of their natural relationships; it includes describing, naming, and classifying the organisms (341)
systemic circulation the movement of blood from the heart to all parts of the body and back to the heart (805, 937)

T

T cell a cell that derives from the thymus and that participates in many immune reactions mediated by cells (962)
tadpole the aquatic, fishlike larva of a frog or toad (802)
tagma in arthropods, a structure that is composed of several fused body segments and that is typically specialized for a specific function (plural, *tagmata*) (724)
taiga a region of evergreen, coniferous forest below the arctic and subarctic tundra regions (420)
taproot a root that develops from the radicle of a plant embryo, grows vertically downward, and forms branches called lateral roots (587)
target cell a specific cell to which a hormone is directed to produce a specific effect (1032)
taste bud one of many oval concentrations of sensory nerve endings on the tongue, palate, and pharynx (1019)
taxon any particular group within a taxonomic system (338)
taxonomy the science of describing, naming, and classifying organisms (338)
tegument the external skin of an organism; on the external surface of a parasitic invertebrate, a layer that counters the defenses of the host's body (692)
telomere a repeated DNA sequence that is found at the end of chromosomes and that shortens with each cell division (268, 303)
telophase the final stage of mitosis or meiosis, during which a nuclear membrane forms around each set of new chromosomes (157)
telson the unpaired, terminal abdominal segment of crustaceans (729)
temperate deciduous forest a region of forest that has pronounced seasons, moderate temperatures, and moderate precipitation; characterized by trees that shed their leaves in the fall (420)
temperate grassland a region that has cold winters and rainfall that is intermediate between that of a forest and a desert; characterized by extensive grasses and few trees (421)
temperate virus a virus whose replication includes the lysogenic cycle (487)
tendon a tough connective tissue that attaches a muscle to a bone or to another body part (921)
tendril an organ of climbing plants that grows in spiral form and wraps around another body to help support the plant (599)
tension-cohesion theory the theory that water moves up the stem of a plant because of the strong attraction between water molecules (462)
tentacle a flexible appendage with which an animal feeds itself, grasps objects, or feels its environment (676)
termination signal a specific sequence of nucleotides that marks the end of a gene (206)
territory an area that is occupied by one animal or a group of animals that do not allow other members of the species to enter (894)
test in some protists and invertebrates, a protective covering that the organism secretes or builds around itself (507, 763)
test cross the crossing of an individual of unknown genotype with a homozygous recessive individual to determine the unknown genotype (183)
testes the primary male reproductive organs, which produce sperm cells and testosterone (singular, *testis*) (1049)
testosterone a hormone that regulates male secondary sex characteristics and the production of sperm cells (1037)
tetrad the four chromatids in a pair of homologous chromosomes that come together as a result of synapsis during meiosis (161)
thalamus the part of the brain that directs incoming sensory and motor signals to the proper region (1012)
thallus the body type of an algae, fungus, or plant that is not differentiated into roots, stems, or leaves (510)
theory an explanation for some phenomenon that is based on observation, experimentation, and reasoning; that is supported by a large quantity of evidence; and that does not conflict with

any existing experimental results or observations (17)

therapsid a lineage of synapsids that were abundant during the late Permian period and gave rise to mammals; characterized by limbs positioned directly beneath the body; some may have been endothermic (862)

thermoacidophile an organism that grows well in a warm, acidic environment (462)

thermoregulation the processes by which the body regulates its internal temperature (828)

thigmonastic movement a nastic movement that occurs in a plant in response to touch (638)

thigmotropism a response of an organism or part of an organism to touch, such as the coiling of a vine around an object (637)

thoracic cavity the part of the human body cavity that is between the neck and the abdomen and that contains the heart and the lungs (910)

thorax in higher vertebrates, the part of the body between the neck and the abdomen; in other animals, the body region behind the head; in anthropods, the mid-body region (728)

thylakoid a membrane system found within chloroplasts that contains the components for photosynthesis (89, 114)

thymus the gland that produces T lymphocytes (961)

thyroid gland an endocrine gland that is located at the base of the neck and that produces secretions important in regulating many aspects of metabolism and mineral balance (1036)

tissue a collection of specialized cells and cell products that perform a specific function (7, 76)

tissue culture the technique for growing living cells in an artificial medium (624)

tolerance the condition of drug addiction in which greater amounts of a drug are needed to achieve the desired effect (1021)

tolerance curve a graph of the perfomance of an organism versus the value of an environmental vairable (363)

trachea in insects, myriapods, and spiders, one of a network of air tubes; in vertebrates, the tube that connects the larynx to the lungs (732, 947)

tracheid a thick-walled, cylindrical cell with tapered ends that is found in xylem and that provides support and conducts water and nutrients (585)

trait a genetically determined variant of a characteristic (173)

transcription the process of forming a nucleic acid by using another molecule as a template; particularly the process of synthesizing RNA by using one strand of a DNA molecule as a template (204)

transcription factor a regulatory protein that binds to DNA and stimulates the transcription of certain genes (222)

transduction the transfer of a bacterial gene from one bacterium to another through a bacteriophage (471)

transformation the transfer of genetic material in the form of DNA fragments from one cell to another or from one organism to another (194, 471)

translation the portion of protein synthesis that takes place at ribosomes and that uses the codons in mRNA molecules to specify the sequence of amino acids in polypeptide chains (204)

translocation the movement of a segment of DNA from one chromosome to another, which results in a change in the position of the segment; also the movement of soluble nutrients from one part of a plant to another (239, 596)

transmission electron microscope a microscope that transmits a beam of electrons through a very thin slice of specimen and that can magnify up to 200,000 times (abbreviation, *TEM*) (22)

transpiration the process by which plants release water vapor into the air through stomata; also the release of water vapor into the air by other organisms (372, 597)

trichinosis a disease that is caused by a parasitic roundworm of the genus *Trichinella* that results from eating the larvae in undercooked meat and that is characterized by diarrhea, fever, abdominal and muscle pain, and affliction of the lungs, nervous system, and heart (697)

trichomoniasis a common sexually transmitted infection that is caused by the mastigophoran *Trichomonas vaginalis*; symptoms include discolored discharge, genital itching, and an urge to urinate (520)

triglyceride a lipid made of three fatty acid molecules and one glycerol molecule (175)

trilobite a member of the class Trilobita; an extinct type of arthropods that is characterized by many body segments each of which had one pair of appendages (724)

trimester one of the three equal periods of about 12 weeks into which the human gestation period is divided (1057)

tRNA (transfer RNA) an RNA molecule that transfers amino acids to the growing end of a polypeptide chain during translation (205)

trochophore a free-swimming, ciliated larva of many worms and some mollusks (705)

trophic level an organism's relative position in a sequence of energy transfers in a food chain or food pyramid, examples include producers and primary, secondary, and tertiary consumers (368)

tropical forest a region of forest or jungle that located near the equator and that is characterized by large amounts of rain and little variation in temperature (419)

tropism the movement of all or part of an organism in response to an external stimulus, such as light or heat; movement is either toward or away from the stimulus (636)

true-breeding describes organisms or genotypes that are homozygous for a specific trait and thus always produce offspring that have the same phenotype for that trait (175)

tube cell the cell of a pollen grain that gives rise to the pollen tube (615)

tube foot one of many small, flexible, fluid-filled tubes that project from the body of an echinoderm and that are used in locomotion, feeding, gas exchange, and excretion (762)

tumor a growth that arises from normal tissue but that grows abnormally in rate and structure and lacks a function (225)

tumor suppressor gene a gene that suppresses tumor formation but that, when mutated, causes a loss in cell function, which results in tumor formation (225)

tundra a treeless plain that is located in the Arctic or Antarctic and that is characterized by very low winter temperatures; short, cool summers; and vegetation that consists of grasses, lichens, and perennial herbs (418)

turgor pressure the pressure that is exerted on the inside of cell walls and that is caused by the movement of water into the cell (100)

two-dimensional gel electrophoresis a laboratory method that separates proteins according to their isoelectric points and molecular weights (264)

tympanic membrane the eardrum (809, 1017)

tympanum a sound-sensing membrane on the abdomen of an insect (747)

typhlosole in some animals, an infolding of the intestinal wall that increases the surface area available for digestion (714)

u

ulcer a lesion of the surface of the skin or a mucous membrane; sometimes occurs in the digestive system (988)

umbilical cord the structure that connects an embryo and then the fetus to the placenta and through which blood vessels pass (1059)

ungulate a hoofed mammal (872)

unicellular describes an organism that consists of a single cell (7)

urban ecology the study of ecology in areas that are densely populated by humans (452)

urea the principal nitrogenous product of the metabolism of proteins that forms in the liver from amino acids and from compounds of ammonia and that is found in urine and other body fluids (993)

ureter one of the two narrow tubes that carry urine from the kidneys to the urinary bladder (997)

urethra the tube that carries urine from the urinary bladder to the outside of the body (997)

urinary bladder a hollow, muscular organ that stores urine (997)
urine the liquid excreted by the kidneys, stored in the bladder, and passed through the urethra to the outside of the body (994)
uropod a flattened posterior appendage in some crustaceans (729)
uterus in female mammals, the hollow, muscular organ in which a fertilized egg is embedded and in which the embryo and fetus develop (1052)

V

vaccination the administration of treated microorganisms or material from a pathogen into humans or animals to induce an immune response (966)
vagina the female reproductive organ that connects the outside of the body to the uterus and that receives sperm during reproduction (1053)
valve a fold of membranes that controls the flow of a fluid (934)
variable a factor that changes in an experiment in order to test a hypothesis (937)
vas deferens a duct through which sperm move from the epididymis to the ejaculatory duct at the base of the penis (plural, *vasa deferentia*) (848, 1050)
vascular cambium in a plant, the lateral meristem that produces secondary xylem and phloem (586)
vascular plant a plant that has has true roots, stems, and leaves and a vascular system composed of xylem and phloem which are specialized tissues that conduct materials from one part of the plant to another (564)
vascular tissue the specialized conducting tissue that is found in higher plants and that is made up mostly of xylem and phloem (564)
vector in biology, any agent, such as a plasmid or a virus, that can incorporate foreign DNA and transfer that DNA from one organism to another; an intermediate host that transfers a pathogen or a parasite to another organism (258, 489)
vegetable a plant part that is used as food but that is not classified botanically as a fruit (547)
vegetative propagation the growth of plants by some means of asexual reproduction (623)
vegetative reproduction a type of asexual reproduction in which new plants grow from nonreproductive plant parts (623)
vein in plants, a bundle of vascular tissue that transports fluids and nutrients; in animals, a vessel that carries blood to the heart (576, 600, 937)
venation the arrangement of veins in a leaf (600)
vent in some animals, the body opening to which the cloaca is connected and through which wastes exit (807)
ventral the lower or abdominal part of an organism (655)
ventricle one of the two large muscular chambers that pump blood out of the heart (933)
vernalization in plants, the exposure of seeds or seedlings to a period of cold (642)
vertebra one of the 33 bones in the spinal column (backbone) (660, 779)
vertebrate an animal that has a backbone; includes mammals, birds, reptiles, amphibians, and fish (651)
vesicle a small cavity or sac that contains materials in a eukaryotic cell; forms when part of the cell membrane surrounds the materials to be taken into the cell or transported within the cell (105)
vessel in plants, a tubelike structure in the xylem that is composed of connected cells that conduct water and mineral nutrients; in animals, a tube or duct that carries blood or another bodily fluid (585)
vessel element in plants, one of the cellular components of a xylem vessel (585)
vestigial structure a structure in an organism that is reduced in size and function and that may have been complete and functional in the organism's ancestors (306)
villus one of the many tiny projections from the cells in the lining of the small intestine; increases the surface area of the lining for absorption (plural, *villi*) (990)
viper a venomous snake that has two large, mobile fangs at the front of the mouth (833)
viroid an infectious agent that is made up of a short, circular, single strand of RNA that does not have a capsid; the smallest known particle that is able to replicate (494)
virulent describes a microorganism that causes disease and that is highly infectious; strictly, refers only to viruses that reproduce by the lytic cycle (193, 486)
virus a nonliving, infectious particle composed of a nucleic acid and a protein coat; it can invade and destroy a cell (483)
visceral mass the central section of a mollusk's body that contains the mollusk's organs (706)
vitamin an organic compound that participates in biochemical reactions and that builds various molecules in the body; some vitamins are called coenzymes and activate specific enzymes (982)
viviparity in amniotes, a reproductive method in which eggs that lack shells are produced and develop inside the body of the mother, who then gives birth to the offspring (829)
viviparous an organism whose offspring develop within the mother's body and are born alive (863)
voluntary muscle a muscle whose movement can be consciously controlled (917)
vulva the external part of the female reproductive organs (1053)

W

water cycle the continuous movement of water between the atmosphere, the land, and the oceans (371)
water mold a funguslike protist that is composed of branching filaments of cells (514)
water vascular system a system of canals filled with a watery fluid that circulates throughout the body of an echinoderm (762)
wax a type of structural lipid consisting of a long fatty-acid chain that is joined to a long alcohol chain (60)
weed undesirable plants that often crowd out crop plants or native plant species (556)
white blood cell a type of cell in the blood that destroys bacteria, viruses, and toxic proteins and helps the body develop immunities (941)
withdrawal uncomfortable physical and psychological symptoms produced when a physically dependent drug user stops using drugs (1021)
wood secondary xylem produced in gymnosperm and dicot stems (594)
worker bee a bee that does not reproduce but that works for the community by collecting food and maintaining the hive (752)

X

xylem the type of tissue in vascular plants that provides support and conducts water and nutrients from the roots (564)

Y

yeast a very small, unicellular fungus that ferments carbohydrates into alcohol and carbon dioxide; used to ferment beer and to leven bread and used as a source of vitamins and proteins (527)
yolk sac the membrane that is attached to a vertebrate embryo and that encloses the yolk and thus stores energy reserves for the developing embryo (823)

Z

Z line the line formed by the attachment of actin filaments between two sarcomeres of a muscle fiber in striated muscle cells (919)
zoonosis a disease that can pass from animals to humans; an example is Lyme disease, which can be passed from deer to humans through infected ticks (474)
zygosporangium in members of the phylum Zygomycota, a sexual structure that is formed by the fusion of two gametangia and that contains one or more zygotes that resulted from the fusion of gametes produced by the gametangia (531)
zygote the cell that results from the fusion of gametes; a fertilized egg (652)

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