from the blood stops. A companion hormone, glucagon, is released from the pancreas when blood glucose levels fall below the set point. It stimulates the liver to break down glycogen and release glucose into the blood. As the blood glucose level rises, the amount of glucagon falls. Thus these two negative-feedback mechanisms result in a fluctuation around the set point, thus maintaining a relatively constant concentration of glucose.

The alternative to negative feedback is *positive-feedback regulation*. In **positive-feedback regulation,** a stimulus causes a response that leads to an even stronger stimulus (figure 26.1b). Obviously, this does not result in homeostasis. There are a few situations in which positive feedback is useful. For example, positive feedback occurs during childbirth. The release of the hormone oxytocin causes contractions of the uterus. Each time the uterus contracts, signals are sent to the brain, where more oxytocin is produced, causing the uterine muscles to contract again. This repeated stimulation continues until the baby is born. Blood clotting is another example of positive feedback. Chemicals released at the site of injury cause platelets to collect at the site and disintegrate, releasing substances that attract additional platelets. In both of these cases there is a limit to how long the positive feedback continues. Uterine contractions stop shortly after the baby is born and clots stop forming once the hole has been plugged.

26.1 CONCEPT REVIEW

1. Describe how insulin, the liver, and the level of glucose in the blood demonstrate negative feedback.
2. Explain why positive feedback is not involved in maintaining homeostasis.

26.2 Nervous System Function

The nervous, endocrine, and immune systems are the three major systems of the body that play key roles by integrating stimuli and generating the appropriate responses necessary to maintain homeostasis.

The nervous system is well suited to managing the rapid adjustments that must take place within the body. As we discuss the structure and function of the nervous system it is useful to have a basic understanding of how it is organized. The nervous system is organized in a fashion similar to a computer. Information from various input devices (sense organs) is delivered to the central processing unit (brain) by way of wires (sensory nerves). The information is interpreted in the central processing unit. Eventually, messages can be sent by way of cables (motor nerves) to drive external machinery (muscles and glands). The following sections describe the major structural and functional characteristics of the nervous system.

The Structure of the Nervous System

The **nervous system** consists of a network of cells, with fibrous extensions, that carry information along specific pathways from one part of the body to another. A **neuron,** or **nerve cell,** is the basic unit of the nervous system. A neuron consists of a central body, called the **soma** or *nerve cell body,* which contains the nucleus. It has several long extensions called nerve fibers. There are two kinds of nerve fibers: **axons,** which carry information away from the cell body, and **dendrites,** which carry information toward the cell body (figure 26.2). Most neurons have one axon and several dendrites.

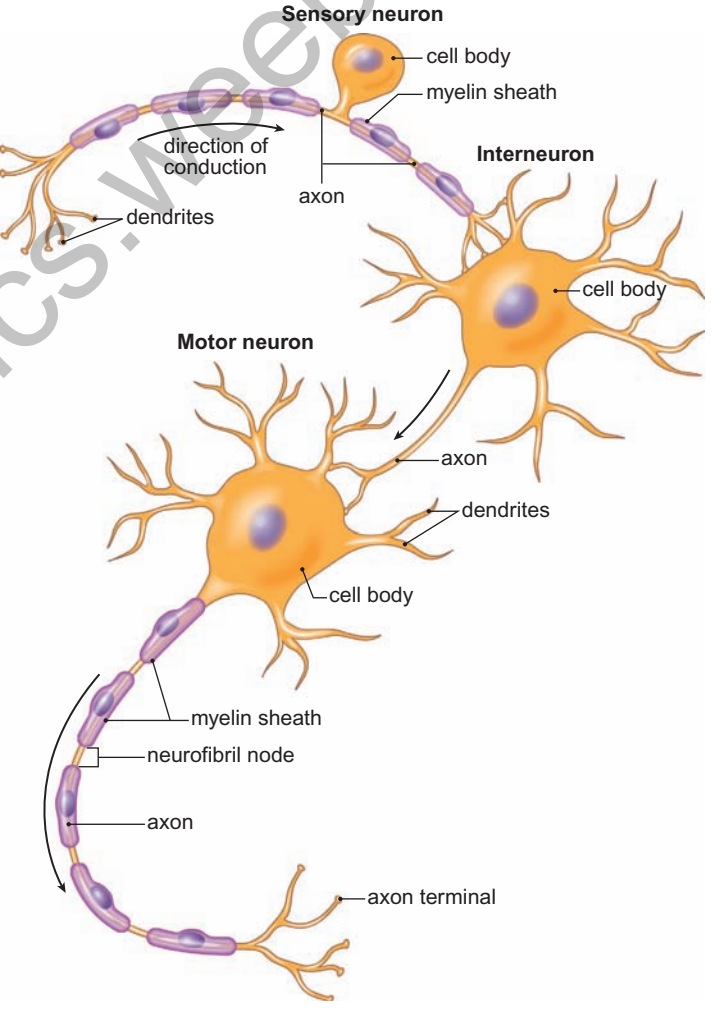


FIGURE 26.2 Structure of Neurons
Neurons consist of a nerve cell body, which contains the nucleus, and several fibrous extensions. The fibers that carry impulses to the nerve cell body are dendrites. The fiber that carries the impulse away from the cell body is the axon. Sensory neurons have a long dendrite that carries information from the sense organ to the cell body. Motor neurons have a long axon that carries information from the cell body to a muscle or gland. Most neurons other than sensory neurons have many dendrites but only one axon.

Neurons are arranged into two major systems. The **central nervous system,** which consists of the brain and spinal cord, is surrounded by the skull and the vertebrae of the spinal column. The **spinal cord** is a collection of nerve cells and nerve fibers surrounded by the vertebrae that conveys information to and from the brain. The central nervous system receives input from sense organs, interprets information, and generates responses. The **peripheral nervous system** is located outside the skull and spinal column; it consists of bundles of long axons and dendrites called **nerves.** In the peripheral nervous system, cranial nerves connect to the brain, whereas spinal nerves connect to the spinal cord. There are two sets of neurons in the peripheral nervous system: the sensory neurons and the motor neurons. **Sensory neurons** have long dendrites that carry input from sense organs to the central nervous system. **Motor neurons** carry messages from the central nervous system to muscles and glands. Motor neurons have one long axon that runs from the spinal cord to a muscle or gland. Some motor nerves constituting the *somatic nervous system,* control the skeletal (voluntary) muscles. Other motor nerves, collectively called the *autonomic nervous system,* control the smooth (involuntary) muscles, the heart, and glands. Figure 26.3 summarizes the different structural and functional portions of the nervous system.

The Nature of the Nerve Impulse

Because most neurons have long, fibrous extensions, information can be passed along the nerve cell from one end to the other. The **nerve impulse** is the message that travels along a neuron. A nerve impulse is not like an electric current; instead, it involves a specific sequence of chemical events at the cell membrane.

Because all cell membranes are differentially permeable, it is difficult for some ions to pass through the membrane, and the combination of ions inside the membrane is different from that outside it. Cell membranes also contain proteins that actively transport specific ions from one side of the membrane to the other. Active transport involves the cell's use of adenosine triphosphate (ATP) to move materials from one side of the cell membrane to the other. Because ATP is required, cells lose this ability when they die. One of the ions that is actively transported from cells is the sodium ion (Na^+). At the same time sodium ions are being transported out of cells, potassium ions (K^+) are being transported into the normal resting (not stimulated) cells. However, there are more sodium ions transported out than potassium ions transported in.

Because a normal resting cell has more positively charged Na^+ ions on the outside of the cell than on the inside, a small but measurable voltage exists across the membrane of the cell. (**Voltage** is a measure of the electrical charge difference that exists between two points or objects.) The voltage difference between the inside and the outside of a cell membrane is about 70 millivolts (0.07 volt). The two sides of the cell membrane are, therefore, polarized in the same sense that a battery is polarized, with a positive (+) and a negative (−) pole.

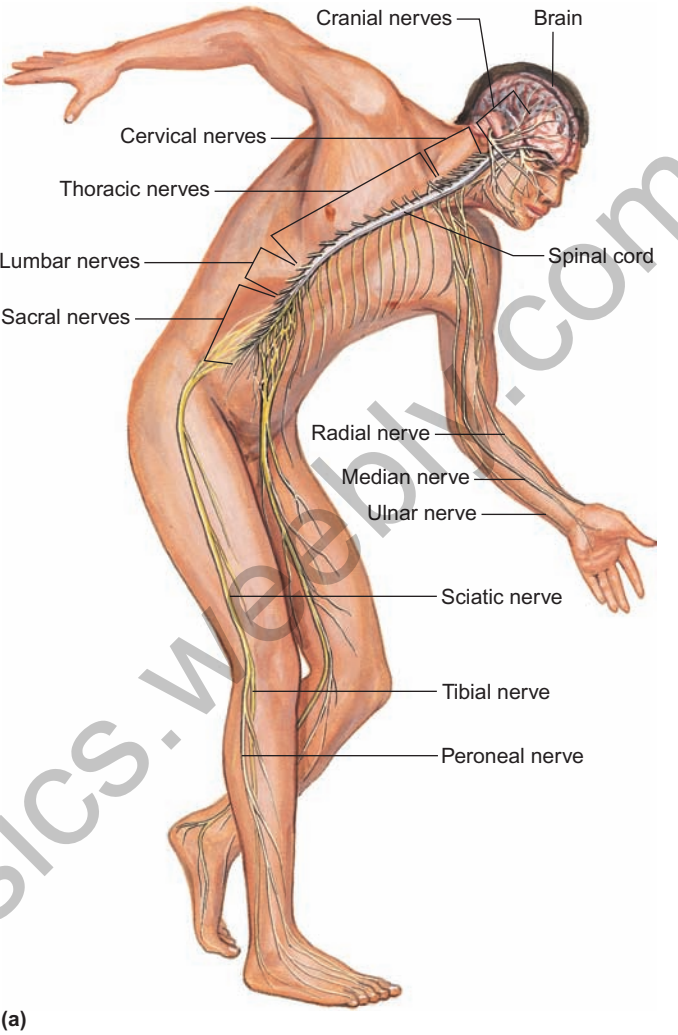


FIGURE 26.3 Organization of the Nervous System
(a) A generalized view of the central nervous system and some of the nerves of the peripheral nervous system. *(b)* The chart shows how the various functional portions of the nervous system are related to one another.

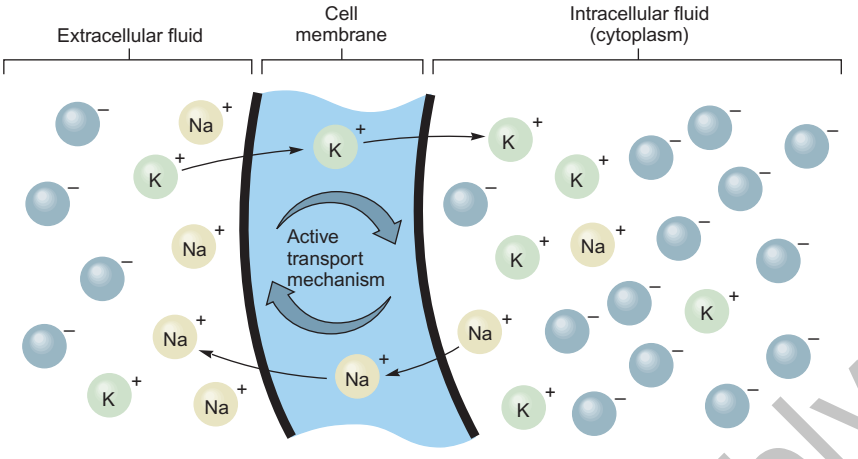


FIGURE 26.4 The Polarization of Cell Membranes
All cells, including neurons have an active transport mechanism that pumps Na^+ out of cells and simultaneously pumps K^+ into them. The end result is that there are more Na^+ ions outside the cell and more K^+ ions inside the cell. In addition, negative ions, such as Cl^-, are more numerous inside the cell. Consequently, the outside of the cell is positive (+) compared with the inside, which is negative (−).

A resting neuron has its positive pole on the outside of the cell membrane and its negative pole on the inside of the membrane (figure 26.4).

When a cell is stimulated at a specific point on the cell membrane, the cell membrane changes its permeability and lets sodium ions (Na^+) pass through it from the outside to the inside. The membrane is thus **depolarized;** it loses its difference in charge as sodium ions diffuse into the cell from the outside. Sodium ions diffuse into the cell because, initially, they are in greater concentration outside the cell than inside. When the membrane becomes more permeable, they are able to diffuse into the cell, toward the area of lower concentration. The depolarization of one point on the cell membrane causes the adjacent portion of the cell membrane to change its permeability as well, and it also depolarizes. Thus, a wave of depolarization passes along the length of the neuron from one end to the other (figure 26.5). The depolarization and passage of an impulse along any portion of the neuron is a momentary event. As soon as a section of the membrane has been depolarized, potassium ions diffuse out of the cell. This reestablishes the original polarized state, and the membrane is said to be *repolarized*. Subsequently, the continuous active transport of sodium ions out of the cell and potassium ions into the cell restores the original concentration of ions on both sides of the cell membrane. This is similar to a "wave" passing around a stadium. The "wave" is initiated by specific individuals as they stand up and "wave" (depolarization). People adjacent participate as they are affected by the initiators while at the same time the originators are sitting down (repolarization). As long as the next people in line participate, the "wave" continues. There is an "impulse" that moves around the stadium but the individuals remain in place.

When the nerve impulse reaches the end of the axon, it stimulates the release of a molecule that stimulates depolarization of the next neuron in the chain.

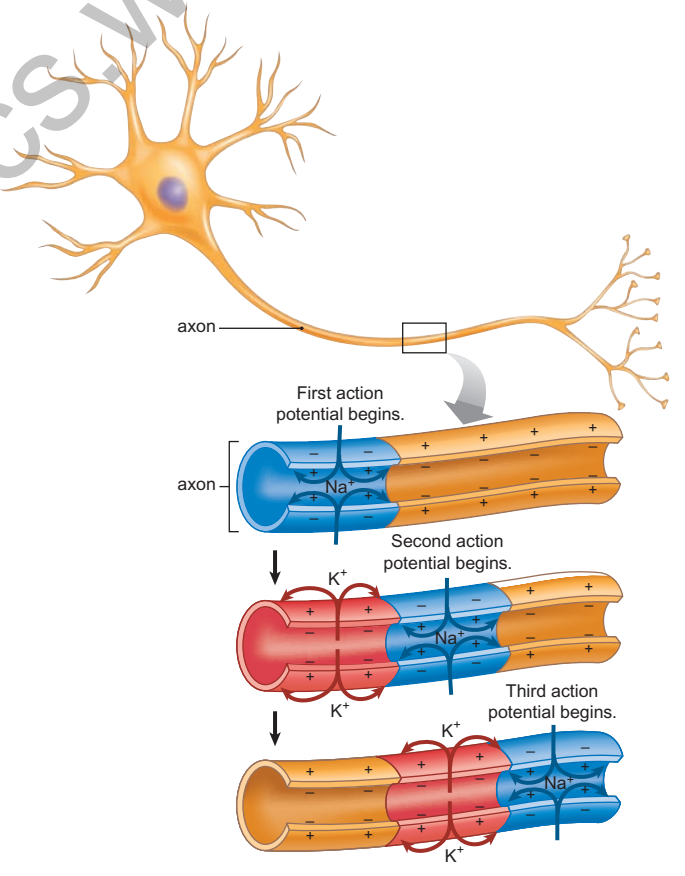


FIGURE 26.5 A Nerve Impulse
When a neuron is stimulated, a small portion of the cell membrane depolarizes as Na^+ flows into the cell through the membrane. This encourages the depolarization of an adjacent portion of the membrane, and it depolarizes a short time later. In this way, a wave of depolarization passes down the length of the neuron. Shortly after a portion of the membrane is depolarized, the ionic balance is reestablished. It is repolarized and ready to be stimulated again.

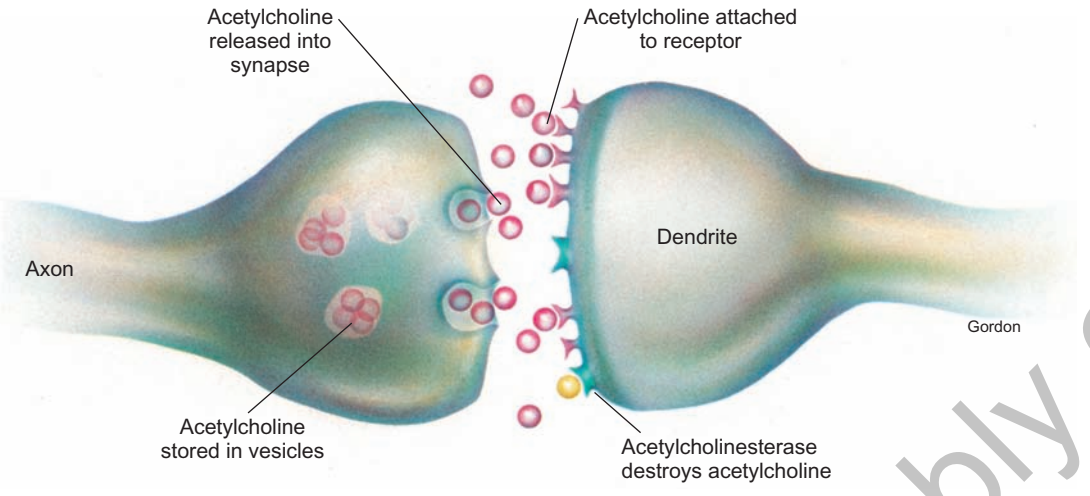


FIGURE 26.6 Activities at the Synapse
When a nerve impulse reaches the end of an axon, it releases a neurotransmitter into the synapse. In this illustration, the neurotransmitter is acetylcholine. When acetylcholine is released into the synapse, acetylcholine molecules diffuse across the synapse and bind to receptors on the dendrite, initiating an impulse in the next neuron. Acetylcholinesterase is an enzyme that destroys acetylcholine, preventing continuous stimulation of the dendrite.

Activities at the Synapse

The **synapse** is the space between the fibers of adjacent neurons in a chain. Many chemical events occur in the synapse that are important in the function of the nervous system. When a neuron is stimulated, an impulse passes along its length from one end to the other. When the impulse reaches a synapse, a molecule called a **neurotransmitter** is released into the synapse from the axon. It diffuses across the synapse and binds to specific receptor sites on the dendrite of the next neuron. When enough neurotransmitter molecules have been bound to the second neuron, an impulse is initiated in it as well. Several kinds of neurotransmitters are produced by specific neurons. These include dopamine, epinephrine, acetylcholine, and several other molecules. The first neurotransmitter to be identified was *acetylcholine*. **Acetylcholine** molecules are neurotransmitters manufactured in the soma; they migrate down the axon, where they are stored until needed.

As long as a neurotransmitter is attached to its receptor, it continues to stimulate the neuron. Thus, if acetylcholine continues to occupy receptors, the neuron continues to be stimulated again and again. **Acetylcholinesterase,** an enzyme, destroys acetylcholine and prevents this from happening. (The breakdown products of the acetylcholine can be used to remanufacture new acetylcholine molecules.) The destruction of acetylcholine allows the second neuron in the chain to return to normal (figure 26.6). Thus, it will be ready to accept another burst of acetylcholine from the first neuron a short time later. Neurons must also constantly manufacture new acetylcholine molecules, or they will exhaust their supply and be unable to conduct an impulse across a synapse.

Certain drugs, such as curare and strychnine, interfere with the activities at the synapse. Curare blocks the synapse and causes paralysis, whereas strychnine causes neurons to be stimulated continually. Many insecticides are nerve poisons and, therefore, are quite hazardous.

Because of the way the synapse works, impulses can go in only one direction: Only axons secrete acetylcholine, and only dendrites have receptors. This explains why there are sensory and motor neurons to carry messages to and from the central nervous system.

The Organization of the Central Nervous System

The brain consists of several regions, each with a specific function. Certain parts of the brain are involved in controlling fundamental functions, such as breathing and heart rate. Others are involved in generating emotions, others decode sensory input, and others coordinate motor activity. The human brain also has considerable capacity to store information and create new responses to stimuli.

The functions of the brain can be roughly divided into three major levels: automatic activities, basic decision making and emotions, and thinking and reasoning. If we begin with the spinal cord and work our way forward, we will proceed from the more fundamental, automatic activities of the brain to its more complex, thinking portions. The **medulla oblongata** is at the base of the brain, where the spinal cord enters the skull. It controls fundamental activities, such as blood pressure, breathing, and heart rate. Most of the fibers of the spinal cord cross from one side of the body to the other in the medulla oblongata. This is why the left side of the brain affects the right side of the body.

The **cerebellum** is the large bulge at the base of the brain that is connected to the medulla oblongata. The primary function of the cerebellum is the coordination of muscle activity. It receives information from sense organs, such as the portions of the ear involved in balance, the eyes, and pressure sensors

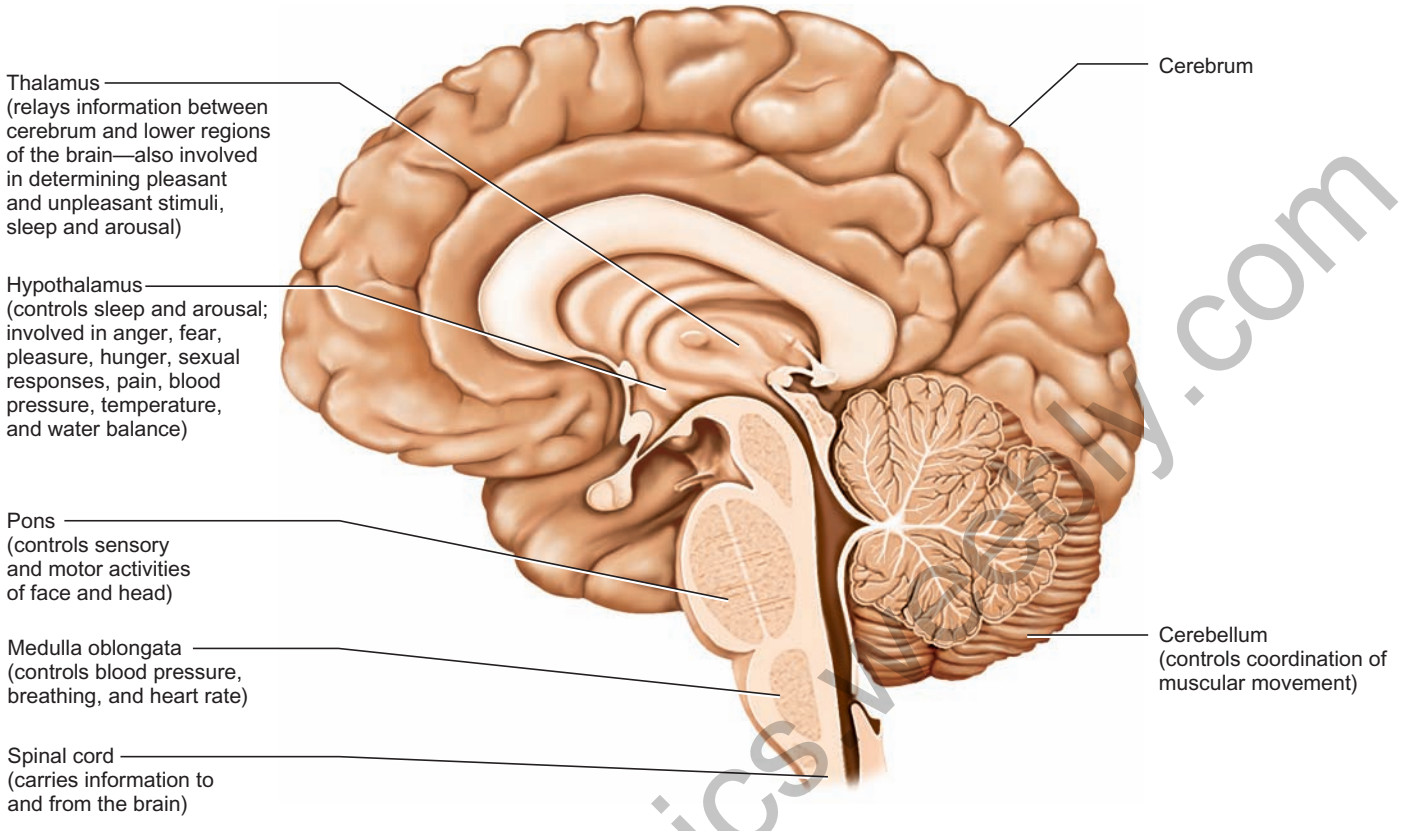


FIGURE 26.7 Functions of the More Primitive Brain Regions
The brain is organized into several levels of function. The more primitive regions of the brain connected to the spinal cord monitor and manage many essential functions automatically.

in muscles and tendons. The cerebellum uses this information to make adjustments in the strength and sequence of muscle contractions, so that the body moves in a coordinated fashion.

The **pons** is the region of the brain that is connected to the anterior end of the medulla oblongata. It also connects to the cerebellum and to higher levels of the brain. It is involved in controlling many sensory and motor functions of the sense organs of the head and face. The pons is also connected to a portion of the brain known as the *midbrain* that is connected to regions of the brain that control many automatic activities, but also are involved in some level of decision making. The primary regions are the *thalamus* and the *hypothalamus*.

The **thalamus** is the region of the brain that relays information between the cerebrum and lower portions of the brain. It also provides a level of awareness in that it determines pleasant and unpleasant stimuli and is involved in sleep and arousal. The **hypothalamus** is the region of the brain involved in regulating sleep cycles; it is important in emotions such as anger, fear, pleasure, and the sensations that accompany hunger, sexual response, and pain. Several other, more automatic functions are regulated in this region, such as body temperature, blood pressure, and water balance. The hypothalamus also is connected to the pituitary gland and influences the manufacture and release of its hormones. Figure 26.7 shows the relationship of the various, more primitive parts of the brain.

The **cerebrum** is the thinking part of the brain. It receives, interprets, and integrates information from sense organs and generates responses that involve the actions of muscles and glands. It is also the largest portion of the brain in humans. The two hemispheres of the cerebrum cover all other portions of the brain except the cerebellum. The surface of the cerebrum has been extensively mapped as to the locations of many functions. Abilities such as memory, language, the control of movement, the interpretation of sensory input, and thought are associated with specific areas of the cerebrum. Figure 26.8 illustrates the cerebrum and the locations of specific functions.

The function of the brain is not determined by structure alone. Many parts of the brain have specialized neurons, which produce specific neurotransmitter molecules used only to stimulate particular neurons that have the proper receptor sites. As scientists learn more about the functioning of the brain, they are finding more kinds of specialized neurotransmitter molecules, allowing for the treatment of many types of mental and emotional diseases. Manipulating these neurotransmitter molecules can help correct inappropriate functioning of the brain. However, the brain is still not completely understood. Scientists are at an early stage in their search to comprehend this organ, which sets us apart from other animals (How Science Works 26.1).

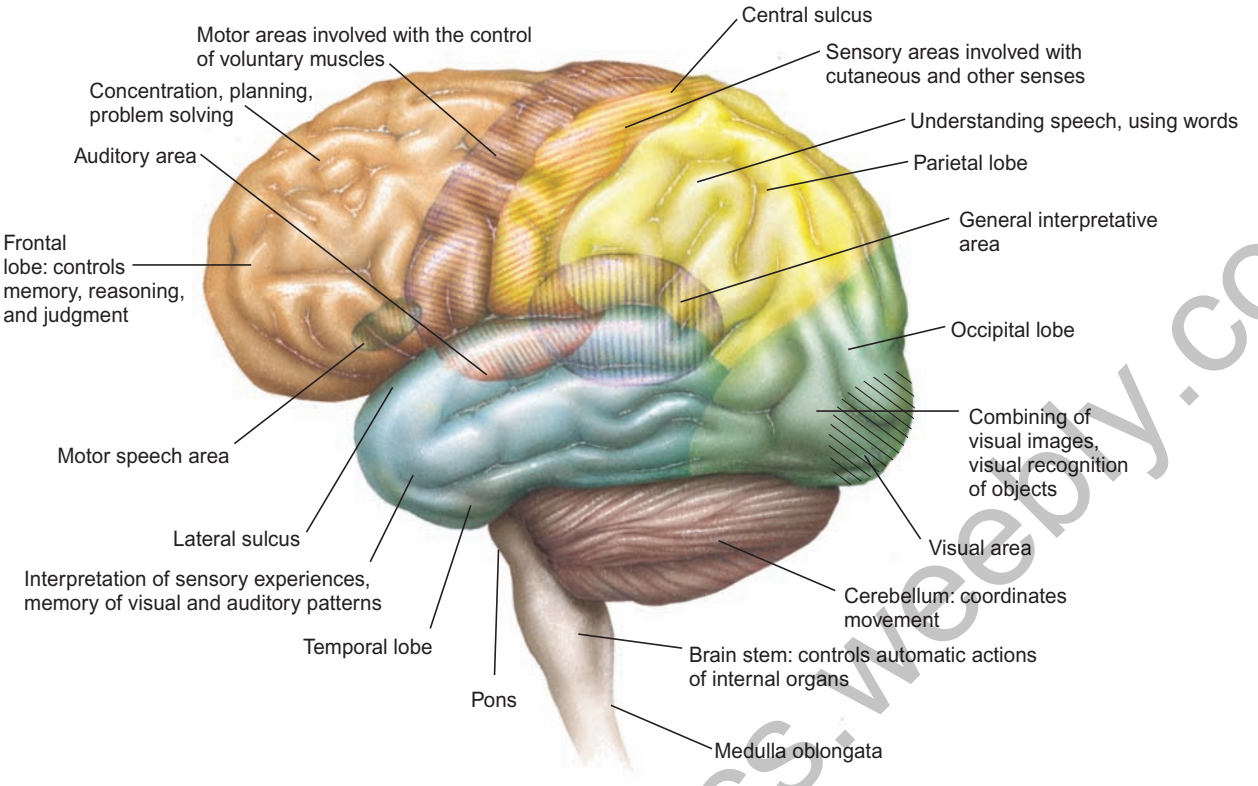
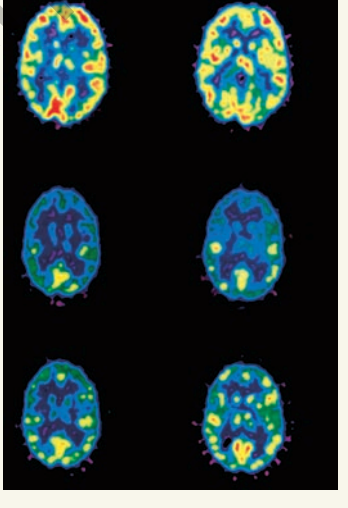


FIGURE 26.8 Specialized Areas of the Cerebrum
Each portion of the cerebrum has particular functions.

HOW SCIENCE WORKS 26.1

How Do We Know What the Brain Does?

Scientists know a great deal about the function of the brain, although there is still much more to learn. Certain functions have been identified as residing in specific portions of the brain, as a result of many kinds of studies over the past century. For example, persons who have had specific portions of their brains altered by damage from accidents or strokes have been studied. Their changes in behavior or the way they perceive things can be directly correlated with the portion of the brain that was damaged. During surgeries that require the brain to be exposed, a local anesthetic can be given and the patient can be conscious while the surgery is taking place. (The brain perceives pain from pain receptors throughout the body; however, because the brain does not have many pain receptors within it, touching or manipulating the brain does not cause pain to be perceived.) Specific portions of the brain can be stimulated and the patient can be asked to describe his or her sensations and the patient's motor functions can be observed.



Many kinds of experiments have also been done with animals, in which specific portions of the brain have been destroyed and the animals' changes in behavior noted. Electrodes have been inserted into the brains of animals to stimulate certain portions of the brain.

Modern brain-imaging techniques are used to observe changes in the electrical activity of specific portions of the brain without electrodes or other invasive procedures. This allows researchers to present stimuli to human subjects and determine which parts of the brain alter their activity. In addition to localizing the part of the brain that responds, it is also possible to determine what parts of a complex stimulus are most important in changing brain activity. For example, these techniques have revealed that languages learned by adults are processed in different places in the brain than the languages they learned as children and that the brain has a built-in mechanism for recognizing unexpected words or musical notes.

Although much is known about the brain, there is still much to learn. Current experiments are seeking ways to regenerate neurons that have been damaged. A better understanding of the chemical events that take place in the brain would enable us to cure many kinds of debilitating mental illnesses.

26.2 CONCEPT REVIEW

3. Describe how the changing permeability of the cell membrane and the movement of sodium ions cause a nerve impulse.
4. What is the role of acetylcholine in a synapse? What is the role of acetylcholinesterase?
5. List the differences between the central and peripheral nervous systems and between the motor and sensory nervous systems.

26.3 The Endocrine System

In the 1890s, many physicians began to describe the workings of chemicals in the body, suggesting that they were "internal secretions." Ernest Starling named these chemical messengers *hormones*. A **hormone** is a specific molecule that is released by one organ and transported to another organ, where it triggers a change in the other organ's activity. The **endocrine system** consists of a number of glands that communicate with one another and with other tissues through chemicals distributed throughout the organism. **Glands** are organs that manufacture molecules that either are secreted into surrounding tissue, where they are picked up by the circulatory system, or are secreted through ducts into the cavity of an organ or to the body surface. **Endocrine glands** have no ducts; they secrete their products—hormones—into the circulatory system (figure 26.9). Other glands, such as the digestive glands and sweat glands, empty their contents through ducts. These kinds of glands are called **exocrine glands.**

Endocrine System Function

As with the nervous system, it is helpful to have a general idea about how the endocrine system works as it is discussed.

The endocrine system functions the way a radio broadcast system does. Radio stations send their signals in all directions, but only the radio receivers that are tuned to the correct frequency can receive the signals. Messenger molecules (hormones) are distributed throughout the body by the circulatory system, but only the cells that have the proper receptor sites can receive and respond to them. The cells that are able to respond to a hormone are called *target cells;* they respond in one of three ways: (1) Some cells release products that have been previously manufactured; (2) some cells synthesize molecules or begin metabolic activities; and (3) some cells divide and grow. As a result of these different kinds of responses, some endocrine responses are relatively rapid, whereas others are very slow. For example, the release of the hormones **epinephrine** and **norepinephrine** (formerly called adrenalin and noradrenalin) from the adrenal medulla, located near the kidney, causes a rapid change in an organism's behavior. The heart rate increases, blood pressure rises, blood is shunted to the muscles, and the breathing rate increases. You have certainly experienced this reaction many times in your lifetime, such as when you nearly had an automobile accident or slipped and nearly fell.

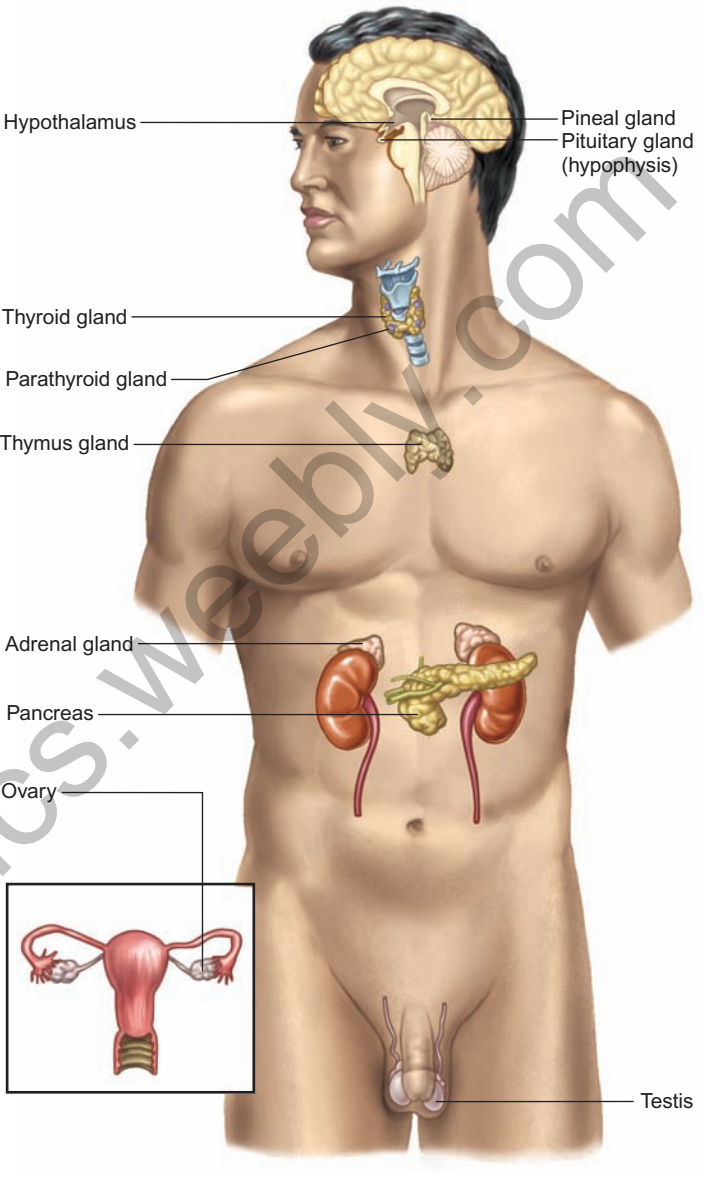


FIGURE 26.9 Endocrine Glands
The endocrine glands, located in various places in the body, secrete hormones.

Antidiuretic hormone (ADH) acts more slowly. It is released from the posterior pituitary gland at the base of the brain; it regulates the rate at which the body loses water through the kidneys. It does this by encouraging the reabsorption of water from the collecting ducts of the kidneys (see chapter 24). The effects of ADH can be noticed in a matter of minutes to hours.

Insulin is another hormone whose effects occur within minutes. It is produced by the pancreas, located near the stomach. Insulin stimulates cells—particularly muscle, liver,

and fat cells—to take up glucose from the blood. After a high-carbohydrate meal, the glucose level in the blood begins to rise, stimulating the pancreas to release insulin. The increased insulin causes glucose levels to fall as the sugar is taken up by the cells. People with diabetes have insufficient or improperly acting insulin or lack the receptors to respond to the insulin; therefore, they have difficulty regulating glucose levels in their blood.

The responses that result from the growth of cells may take weeks or years to occur. For example, **growth-stimulating hormone (GSH)** is produced by the anterior pituitary gland over a period of years and results in typical human growth. After sexual maturity, the amount of this hormone generally drops to very low levels, and body growth stops. Sexual development is also largely the result of the growth of specific tissues and organs. The male sex hormone **testosterone,** produced by the testes, causes the growth of male sex organs and a change to the adult body form. The female counterpart, **estrogen,** results in the development of female sex organs and body form. In all of these cases, it is the release of hormones over long periods, continually stimulating the growth of sensitive tissues, that results in a normal developmental pattern. The absence or inhibition of any of these hormones early in life changes the normal growth process.

Negative-Feedback Inhibition and Hormones

Many endocrine glands and their hormones are under negative-feedback inhibition. At the beginning of the chapter, insulin and glucagon were used as examples of molecules involved in simple negative-feedback inhibition. However, glands within the endocrine system often interact with one another so that the secretions of one gland alter the actions of others. When several glands interact in negative-feedback inhibition, an increased amount of one hormone interferes with the production of a different hormone in the chain of events. The production of *thyroxine* and *triiodothyronine* by the thyroid gland is regulated by negative-feedback inhibition involving the actions of other glands. The production of these two hormones is stimulated by the increased production of a hormone from the hypothalamus called *thyroid-releasing hormone (TRH)* which stimulates the anterior pituitary to produce a hormone called *thyroid-stimulating hormone (TSH)*. The thyroid gland's control lies in the quantity of TSH produced. When the anterior pituitary produces high levels of thyroid-stimulating hormone, the thyroid is stimulated to grow and secrete more thyroxine and triiodothyronine. But when increased amounts of thyroxine and triiodothyronine are produced, these hormones have a negative effect on the pituitary and hypothalamus, so that production of thyroid-stimulating hormone and thyroid-releasing hormone are decreased, leading to reduced production of thyroxine and triiodothyronine. If the amount of the thyroid hormones falls too low, the pituitary and hypothalamus are no longer inhibited and begin to release their hormones. As a result of the interaction of these hormones, their concentrations are maintained within certain limits (figure 26.10).

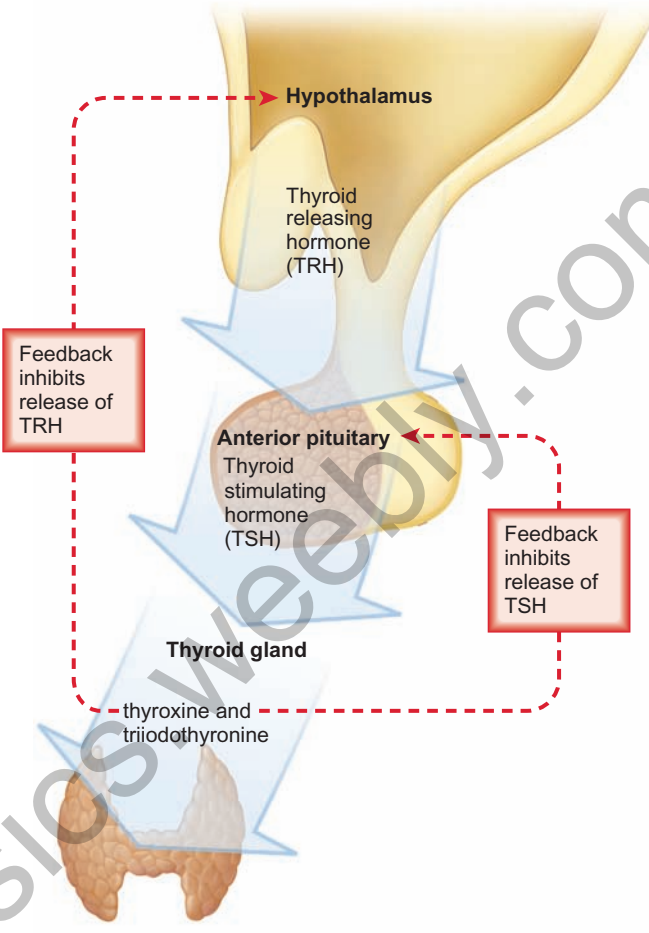


FIGURE 26.10 Negative-Feedback Inhibition of Thyroid Secretion
The hypothalamus sends the thyroid-releasing hormone (TRH) to the pituitary, which releases thyroid-stimulating hormone (TSH). Thyroid-stimulating hormone causes the thyroid to produce thyroxine and triiodothyronine. These two hormones inhibit the hypothalamus and pituitary.

26.3 CONCEPT REVIEW

6. How do exocrine and endocrine glands differ?
7. Give an example of negative-feedback control in the endocrine system.
8. List three hormones and give their functions.

26.4 The Integration of Nervous and Endocrine Function

Although we still tend to think of the nervous and endocrine systems as separate and different, it is becoming clear that they are interconnected and cooperate to bring about appropriate responses to environmental challenges. The nervous system is particularly involved in activities that are of short duration, such as sensory input and muscle contractions. The endocrine system participates in some short-duration activities, such as the actions of epinephrine, but is more typically involved in medium- to long-term activities such as regulating glucose levels or modifying growth.

When endocrine and nervous systems interact, usually the pituitary gland is involved. The pituitary gland is located at the base of the brain and is divided into two parts. The posterior pituitary, which is directly connected to the brain, develops from nervous tissue during embryology. The other part, the anterior pituitary, develops from the lining of the roof of the mouth in early fetal development. Certain pituitary hormones are produced in the brain and transported down axons to the posterior pituitary, where they are stored before being released. The anterior pituitary also receives a continuous input of messenger molecules from the brain, but these are delivered by way of blood vessels, which pick up hormones produced by the hypothalamus and deliver them to the anterior pituitary.

The pituitary gland produces a variety of hormones that are responsible for causing other endocrine glands, such as the thyroid, ovaries and testes, and adrenals, to secrete their hormones. Pituitary hormones also influence milk production, skin pigmentation, body growth, mineral regulation, and blood glucose levels (figure 26.11).

Because the pituitary is constantly receiving information from the hypothalamus, many kinds of sensory stimuli to the body can affect the functioning of the endocrine system. One example is the way in which the nervous system and endocrine system interact to influence the menstrual cycle. At least three hormones are involved in the cycle of changes that affects the ovary and the lining of the uterus (see chapter 27 for details). It is well documented that stress caused by tension or worry can interfere with the normal cycle of hormones and delay or stop menstrual cycles. In addition, young women living in groups, such as those in college dormitories, often find that their menstrual cycles become synchronized. Although the exact mechanism involved in this phenomenon is unknown, it is suspected that input from the nervous system causes this synchronization. (Odors and sympathetic feelings have been suggested as causes.)

In many animals, the changing length of the day causes hormonal changes related to reproduction. In the spring, birds respond to lengthening days and begin to produce hormones that gear up their reproductive systems for the summer breeding season. The pineal body, a portion of the brain, serves as the receiver of light stimuli and changes the amounts of hormones secreted by the pituitary, resulting in changes in the levels of reproductive hormones. These hormonal changes modify the birds' behavior. Courtship, mating, and nest-building behaviors increase in intensity. Therefore, it appears that a change in hormone level is affecting the animals' behavior; the endocrine system is influencing the nervous system (figure 26.12). It has been known for centuries that changes in the levels of sex hormones cause changes in animals' behavior. The castration (the removal of the testes) of male domesticated animals, such as cattle, horses, and pigs, is sometimes done in part to reduce their aggressive behavior and make them easier to control. The use of anabolic steroids by humans to increase muscle mass is known to cause behavioral changes and "moodiness."

As scientists learn more about the molecules produced in the brain, it is becoming clear that the brain produces many molecules that act as hormones. Some of these molecules affect adjacent parts of the brain, others affect the pituitary, and still others may have effects on more distant organs (How Science Works 26.2).

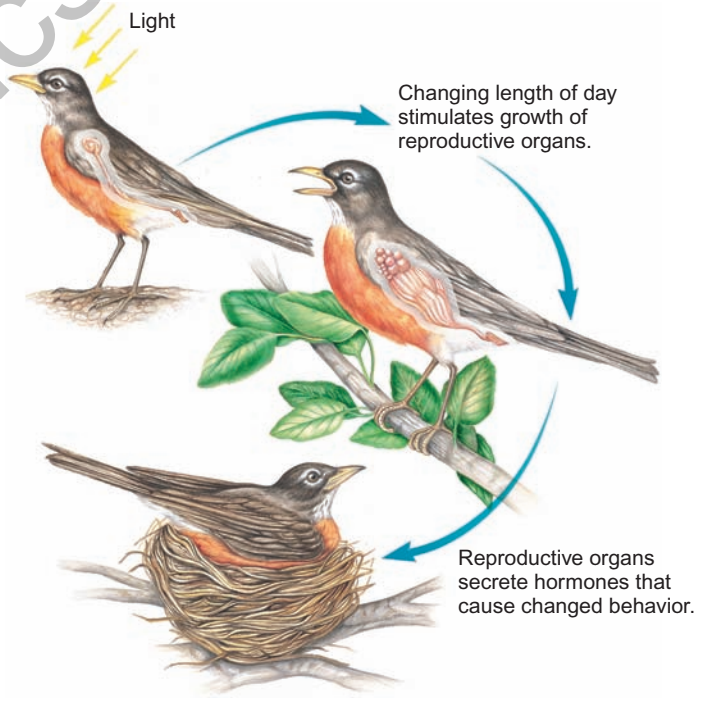


FIGURE 26.12 Interaction Between the Nervous and Endocrine Systems
In birds and many other animals, reproduction is a seasonal activity triggered by changing length of day. The brain receives information about the changing length of day, which causes the pituitary to produce hormones that stimulate sex organs. The testes or ovaries grow and secrete their hormones in increased amounts. Increased levels of testosterone or estrogen result in changed behavior, including increased aggression, mating behavior, and nest-building activity.

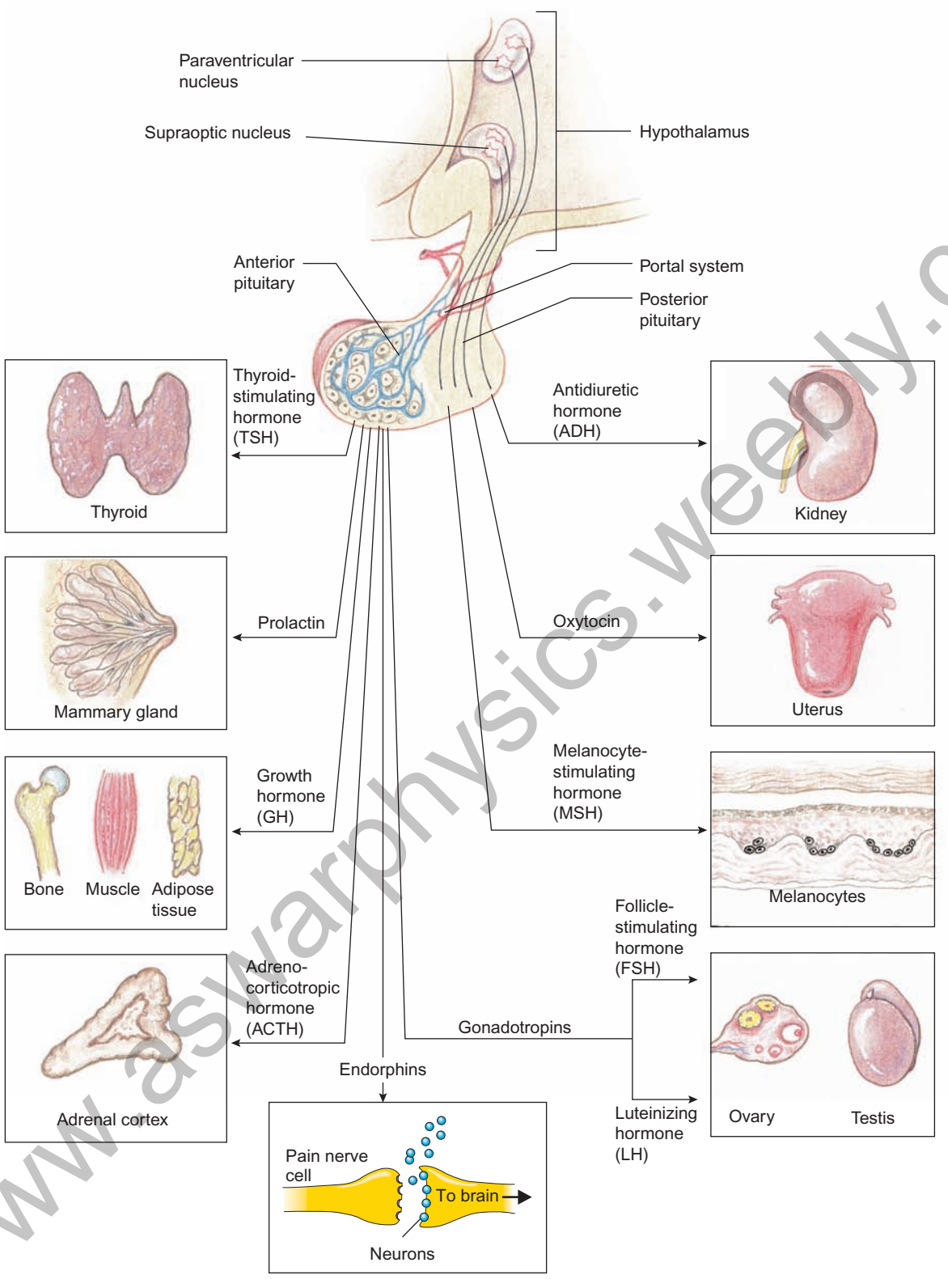
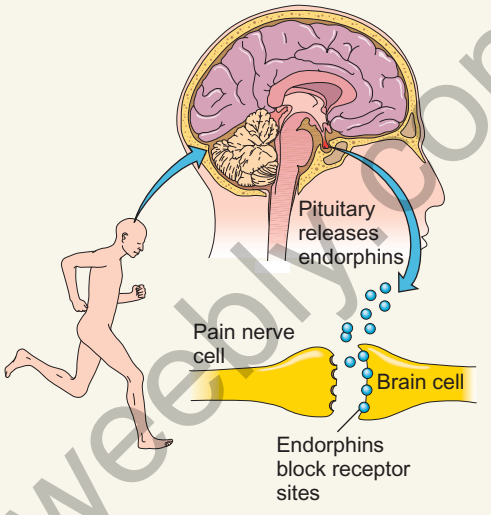


FIGURE 26.11 Hormones of the Pituitary and Their Target Organs
The anterior pituitary gland produces several hormones that regulate growth and the secretions of target tissues. The posterior pituitary produces hormones that change the behavior of the kidney and uterus but do not influence the growth of these organs.

HOW SCIENCE WORKS 26.2

Endorphins: Natural Pain Killers

The pituitary gland and the brain produce a group of small molecules that act as pain suppressors, called *endorphins*. It is thought that these molecules are released when excessive pain or stress occurs in the body. They attach to the same receptor molecules of brain cells associated with the feeling of pain. Endorphins work on the brain in the same manner as morphine and opiate drugs. Once endorphins are attached to the brain cells, the feeling of pain goes away, and a euphoric feeling takes over. Long-distance runners and other athletes talk about feeling good as a "runner's high." These responses may be due to an increase in endorphin production. It is thought that endorphins are also released by mild electric stimulation and the use of acupuncture needles.



26.4 CONCEPT REVIEW

9. Describe two ways in which the function of the nervous system differs from that of the endocrine system.
10. Give an example of the interaction between the endocrine system and the nervous system.

26.5 Sensory Input

The activities of the nervous and endocrine systems are often responses to input received from the sense organs. Sense organs of various types are located throughout the body. Many of them are located on the surface, where environmental changes can be detected easily. Hearing, sight, and touch are good examples. Other sense organs are located within the body and indicate to the organism how its various parts are changing. For example, pain and pressure are often used to monitor internal conditions. The sense organs detect changes, but the brain is responsible for **perception**—the recognition that a stimulus has been received. Sensory input is detected through many kinds of mechanisms, including chemical recognition, the detection of energy changes, and the monitoring of physical forces.

Chemical Detection

All cells have receptors on their surfaces that can bind selectively to molecules they encounter. This binding process can cause changes in the cells in several ways. In some cells, it causes depolarization. When this happens, the binding of molecules to the cell can stimulate neurons and cause messages to be sent to the central nervous system, informing it of a change in the surroundings. Many internal sense organs respond to specific molecules. For example, the brain and aorta contain cells that respond to concentrations of hydrogen ions, carbon dioxide, and oxygen in the blood. In other cases, a molecule binding to the cell surface may cause certain genes to be expressed, and the cell responds by changing the molecules it produces. This is typical of the way the endocrine system receives and delivers messages. Taste and smell are two ways of detecting chemicals in our surroundings.

Taste

Most cells have specific binding sites for specific molecules. Some, such as the taste buds on the tongue, soft palate, and throat appear to respond to classes of molecules. Traditionally, four kinds of tastes have been identified: sweet, sour, salt, and bitter. However, recently, a fifth kind of taste, *umami* (meaty), has been identified. Umami receptors respond to the amino acid glutamate, which is present in many kinds of foods and often is added to food as a flavor enhancer (monosodium glutamate—MSG).

The taste buds that give us the sour sensation respond to the presence of hydrogen ions (H^+). (Acidic foods taste sour.) The hydrogen ions stimulate the cells in two ways: They enter the cell directly or they alter the normal movement of sodium and potassium ions across the cell membrane. In either case, the cell depolarizes and stimulates a neuron. In similar fashion, sodium ions (Na^+) stimulate the taste buds that give us the sensation of a salty taste by directly entering the cell, which causes the cell to depolarize.

However, the sensations of sweetness, bitterness, and umami occur when molecules bind to specific surface

receptors on the cell. Sweetness can be stimulated by many kinds of organic molecules, including sugars and artificial sweeteners, as well as by inorganic lead compounds. When a molecule binds to a sweetness receptor, a series of molecular changes occurs within the cell that leads to the depolarization of the cell. The sweet taste of lead salts in old paints partly explains why children sometimes eat paint chips. Because the lead interferes with normal brain development, this behavior can have disastrous results.

The cells that respond to bitter sensations have a variety of receptor molecules on their surface that bind to many kinds of compounds. When a substance binds to one of the receptors, the cell depolarizes. In the case of umami, it is the glutamate molecule that binds to receptors on the receptor cells.

Each of these tastes has a significance from an evolutionary point of view. Carbohydrates are a major food source, and many carbohydrates taste sweet; therefore, this sense is useful in identifying foods that have high food value. Similarly, proteins and salts are necessary in the diet. Therefore, being able to identify these items in potential foods is extremely valuable. This is true for salt, which must often be obtained from mineral sources. On the other hand, many bitter and sour materials are harmful. Many plants produce bitter-tasting toxic materials, and acids are often the result of the bacterial decomposition (spoiling) of foods. Being able to identify bitter and sour allows organisms to avoid potentially harmful foods.

Much of what we often refer to as *taste* involves such inputs as appearance, temperature, texture, and smell. If food does look appealing, it will probably influence how it tastes to a person. Cold coffee has a different taste than hot coffee, even though they are chemically the same. Lumpy, cooked cereal and smooth cereal have different tastes. If we are unable to smell food, it doesn't taste as it should, which is why we sometimes lose our appetite when we have a stuffy nose. There still is much to learn about how taste cells detect chemicals and the role of associated senses in modifying taste.

Smell

The sense of smell is much more versatile than taste; it can detect thousands of different molecules at very low concentrations. The cells that make up the **olfactory epithelium**, the lining of the nasal cavity, which responds to smells, bind molecules to receptors on their surfaces. Recent research shows that each receptor cell binds to only one kind of odor molecule. The difference in cells is determined by the expression of genes. Each cell contains thousands of genes for detecting odors but only one of those is activated in each receptor cell and is expressed as a particular receptor molecule on the surface of the cell. The receptor cells are extremely sensitive. In some cases, a single molecule of a substance is sufficient to cause a receptor cell to send a message to the brain, where the sensation of odor is perceived. These sensory cells also fatigue rapidly. For instance, when we first walk into a room, we readily detect specific odors; however, after a few minutes, we are unable to detect them. Most perfumes and aftershaves are undetectable after 15 minutes of continuous exposure to them.

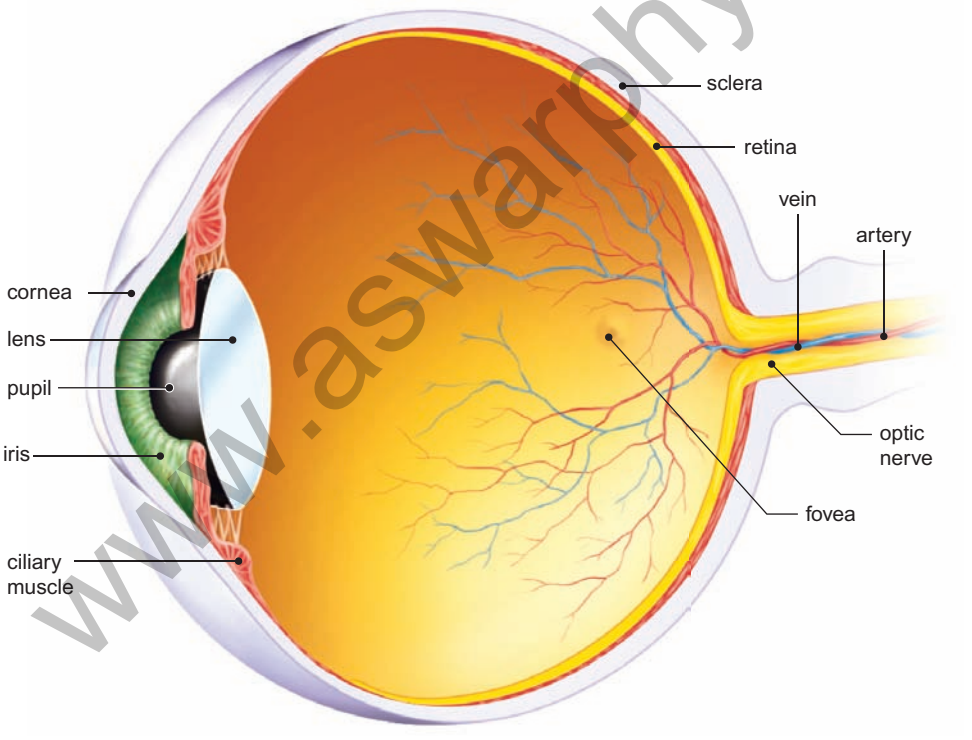


FIGURE 26.13 Structure of the Eye
Light enters the eye through the an opening in the iris known as the pupil. The cornea and lens focus light on the retina where the light is detected.

Vision

The eyes primarily respond to changes in the flow of light energy. The curved surfaces of the cornea and the lens focus light on a light-sensitive layer of the back of the eye, known as the **retina** (figure 26.13). Muscles attached to the lens allow it to change shape so that we can focus on both near and far objects.

There are two kinds of receptors in the retina of the eye (figure 26.14). The cells called **rods** respond to a broad range of wavelengths of light and are responsible for black-and-white vision. Because rods are very sensitive to light, they are useful in dim light. Rods are located over most of the retinal surface, except for the area of most acute vision, known as the **fovea centralis.** The other kind of receptor cells, called **cones**, are not as sensitive to light, but they can

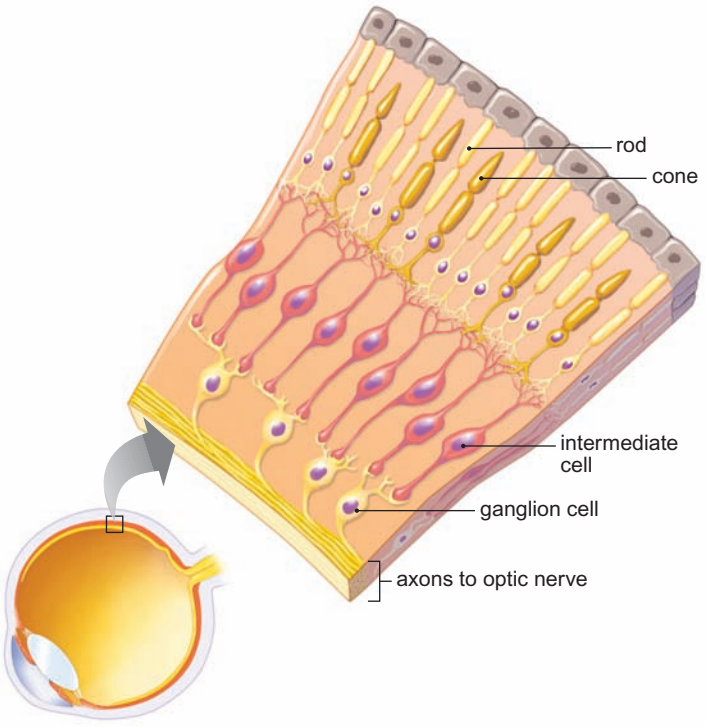


FIGURE 26.14 Structure of the Retina
The retina contains two kinds of receptor cells—rods and cones. When light strikes the rods and cones, they depolarize and stimulate nerve cells that send impulses to the brain.

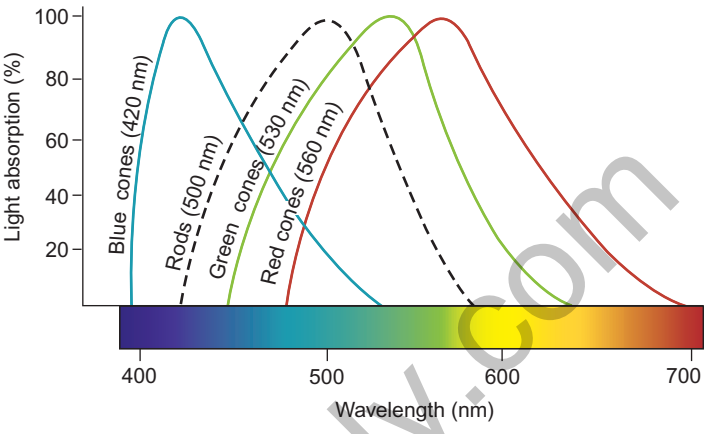


FIGURE 26.15 Light Reception by Cones
There are three different kinds of cones. Each responds differently to red, green, and blue wavelengths of light. Stimulation of combinations of these three kinds of cones gives us the ability to detect many different shades of color.

detect different wavelengths of light. They are found throughout the retina but are concentrated in the fovea centralis. This combination of receptors gives us the ability to detect color when light levels are high, but we rely on black-and-white vision at night. There are three varieties of cones: One type responds best to red light, one type responds best to green light, and the third type responds best to blue light. The stimulation of various combinations of these three kinds of cones allows us to detect different shades of color (figure 26.15).

Rods and the three kinds of cones each contain a pigment that decomposes when struck by light of the proper wavelength and sufficient strength. **Rhodopsin** is the pigment found in rods. This change in the structure of rhodopsin causes the rod to depolarize. Cone cells have a similar mechanism of action, and each of the three kinds of cones has a different pigment. Because rods and cones synapse with neurons, they stimulate a neuron when depolarized and cause a message to be sent to the brain. Thus, the pattern of color and light intensity recorded on the retina is detected by rods and cones and converted into a series of nerve impulses, which the brain receives and interprets.

Hearing and Balance

Sound is produced by the vibration of molecules. The ears respond to changes in sound waves. Consequently, the ears detect changes in the quantity of energy and the quality of sound waves. Sound has several characteristics. Loudness, or volume, is a measure of the intensity of sound energy that arrives at the ear. Very loud sounds literally vibrate the body and can cause hearing loss if they are too intense. Pitch is a quality of sound that is determined by the frequency of the sound vibrations. High-pitched sounds have short wavelengths; low-pitched sounds have long wavelengths.

The sound that arrives at the ear is first funneled by the external ear to the **tympanum,** also known as the *eardrum*. The cone shape of the external ear focuses sound on the tympanum and causes it to vibrate at the same frequency as the sound waves reaching it. Attached to the tympanum are three tiny bones: the **malleus** (hammer), **incus** (anvil), and **stapes** (stirrup). The malleus is attached to the tympanum, the incus is attached to the malleus and stapes, and the stapes is attached to a small, membrane-covered opening called the **oval window,** in a snail-shaped, fluid-filled structure known as the **cochlea.** The vibration of the tympanum causes the tiny bones (malleus, incus, and stapes) to vibrate; in turn, they cause a corresponding vibration in the membrane of the oval window.

The cochlea detects sound. When the oval window vibrates, the fluid in the cochlea begins to move, causing the **basilar membrane** to vibrate. Cells on this membrane depolarize when they are stimulated by its vibrations. Because they synapse with neurons, messages can be sent to the brain (figure 26.16).

Most sounds consist of a mixture of pitches. High-pitched, short-wavelength sounds cause the basilar membrane to vibrate at the base of the cochlea near the oval window. Low-pitched, long-wavelength sounds vibrate the basilar membrane far from the oval window. Loud sounds cause the basilar membrane to vibrate more vigorously than do faint sounds. Thus, the brain can perceive the loudness of various sounds as well as their pitch.

Associated with the cochlea are two fluid-filled chambers and a set of fluid-filled tubes, called the *semicircular canals*. The **semicircular canals** are not involved in hearing but are

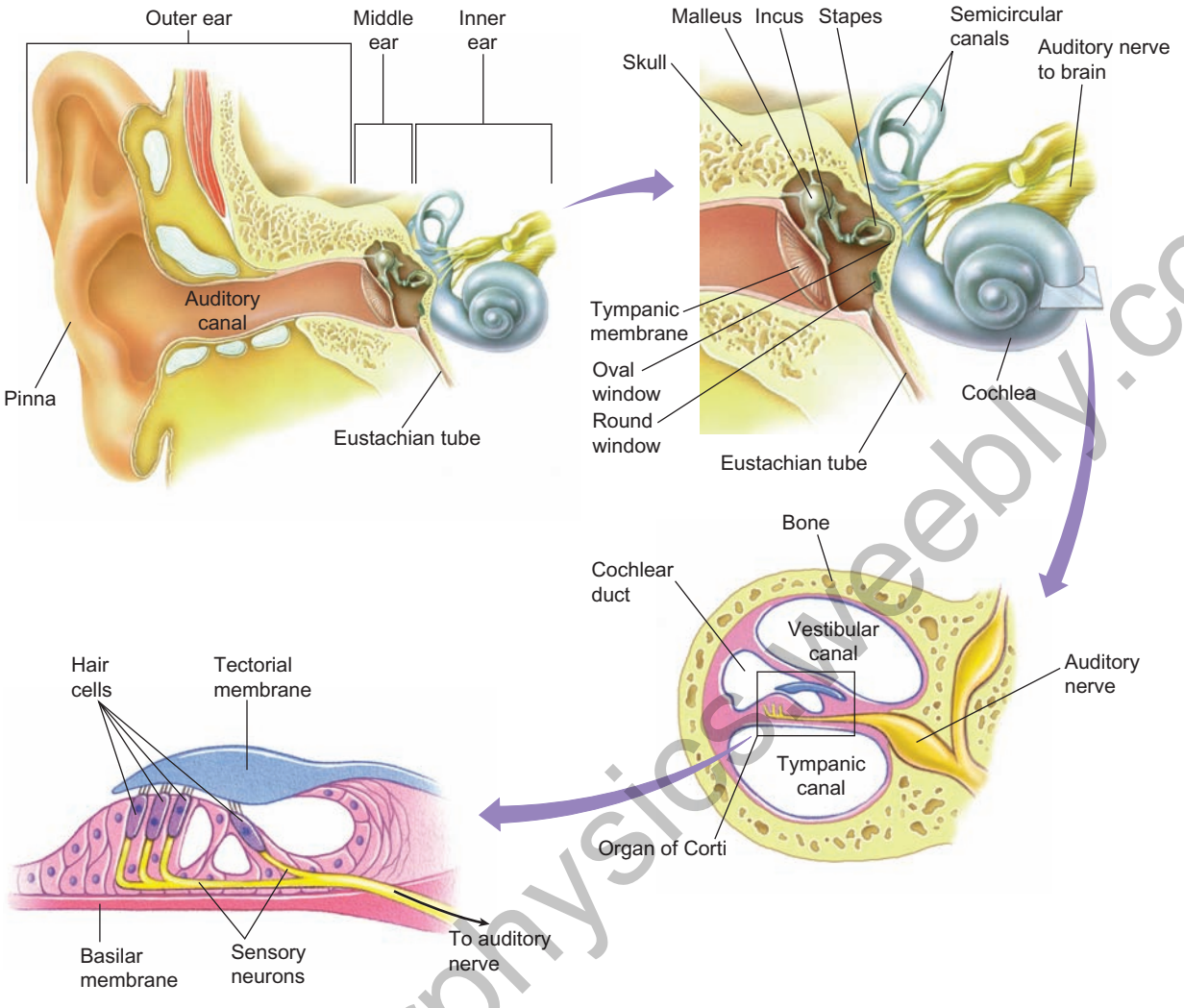


FIGURE 26.16 The Anatomy of the Ear
The ear consists of an external cone, which directs sound waves to the tympanum. Vibrations of the tympanum move the ear bones and vibrate the oval window of the cochlea, where the sound is detected. The semicircular canals monitor changes in the position of the head, helping us maintain balance.

involved in maintaining balance and posture. In the walls of these canals and chambers are cells similar to those found on the basilar membrane. These cells are stimulated by movements of the head and by the position of the head with respect to the force of gravity. The head's constantly changing position gives sensory input that is important in maintaining balance.

Touch

What we normally call the sense of *touch* consists of a variety of kinds of input, which are responded to by three kinds of receptors: Some receptors respond to pressure, others to temperature, and others, which we call *pain receptors,* to cell damage (figure 26.17). When these receptors are appropriately stimulated, they send a message to the brain. Because receptors are stimulated in particular parts of the body, the brain can localize the sensation. However, not all parts of the body are equally supplied with these receptors. The finger tips, lips, and external genitals have the highest density of these nerve endings, whereas the back, legs, and arms have far fewer receptors.

Some internal receptors, such as pain and pressure receptors, are important in allowing us to monitor our internal activities. Many pains generated by the internal organs are often perceived as if they were somewhere else. For example, the pain associated with a heart attack is often perceived to be in the left arm or jaw. Pressure receptors in joints and muscles provide information about the degree of stress being placed on a portion of the body. This is also important information to send back to the brain so that adjustments can be made in movements to maintain posture. If you have ever had your foot "go to sleep" because the nerve stopped functioning, you have experienced what it is like to lose this constant input of nerve messages from the pressure sensors that assist in guiding

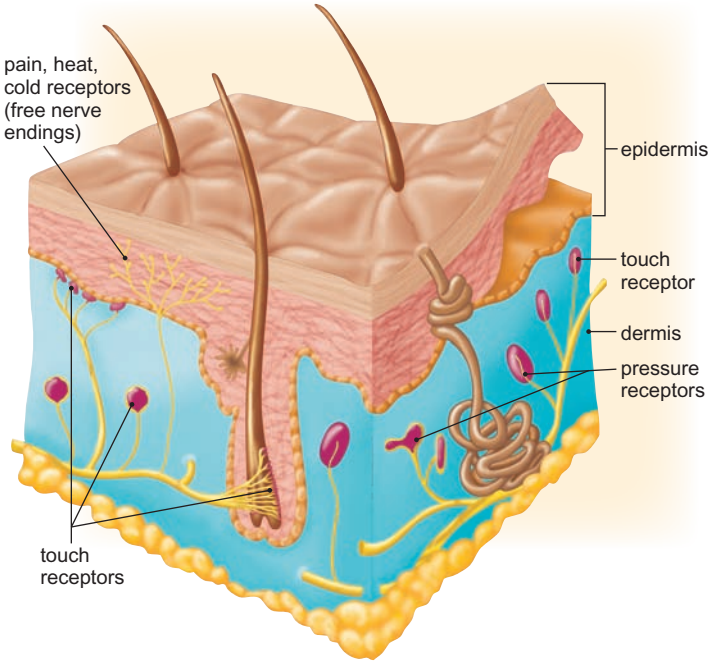


FIGURE 26.17 The Sense of Touch
The sense of touch is really a mixture of sensory cells located in the skin, muscles, joints, and certain internal organs. They send impulses to the brain, which interprets the input and generates responses to the stimuli.

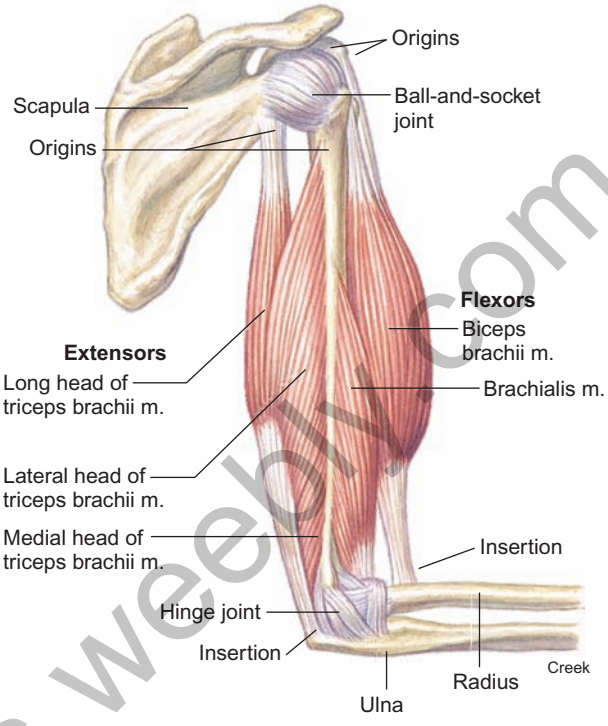


FIGURE 26.18 Antagonistic Muscles
Because muscles cannot actively lengthen, sets of muscles oppose one another. The contraction and shortening of one muscle causes the stretching of its relaxed antagonistic partner.

the movements you make. Your movements become uncoordinated until the nerve function returns to normal.

26.5 CONCEPT REVIEW

11. What is detected by the nasal epithelium, the cochlea of the ear, and the retina of the eye?
12. Name the five kinds of taste that humans are able to detect. What other factors are involved in taste?
13. List three kinds of receptors associated with touch.

26.6 Output Coordination

The nervous system and endocrine system cause changes in several ways. Both systems can stimulate muscles to contract and glands to secrete. The endocrine system is also able to change the metabolism of cells and regulate the growth of tissues. The nervous system acts on two kinds of organs: muscles and glands. The actions of muscles and glands are simple and direct: Muscles contract and glands secrete.

Muscular Contraction

The ability to move is one of the fundamental characteristics of animals. Through the coordinated contraction of many muscles, the intricate, precise movements of a dancer, basketball player, or writer are accomplished. Muscles can do work only when they pull while contracting. When muscles relax, they do not lengthen unless there is some force available to stretch a muscle after it has stopped contracting and relaxes. Therefore, the muscles that control the movements of the skeleton are present in antagonistic sets—for every muscle's action there is another muscle with the opposite action. For example, the biceps muscle causes the arm to flex (bend) as the muscle shortens. The contraction of its antagonist, the triceps muscle, causes the arm to extend (straighten) and simultaneously stretches the relaxed biceps muscle (figure 26.18).

What we recognize is that a muscle is composed of many muscle cells, which in turn are made up of threadlike fibers, myofibrils, composed of two kinds of myofilaments arranged in a regular pattern. Thin myofilaments composed of the proteins **actin, tropomyosin,** and **troponin** alternate with thick myofilaments composed primarily of the protein **myosin** (figure 26.19). The mechanism by which muscle contracts involves the movement of protein filaments past one another as adenosine triphosphate (ATP) is used.

Myosin molecules are shaped like a golf club. The head of the club-shaped molecule sticks out from the thick myofilament and can combine with the actin of the thin myofilament. However, the troponin and tropomyosin proteins associated with the actin (i.e., a troponin-tropomyosin-actin complex), cover actin in such a way that myosin cannot bind with it. When actin is uncovered, myosin can bind to it, and muscle contraction occurs when ATP is used.

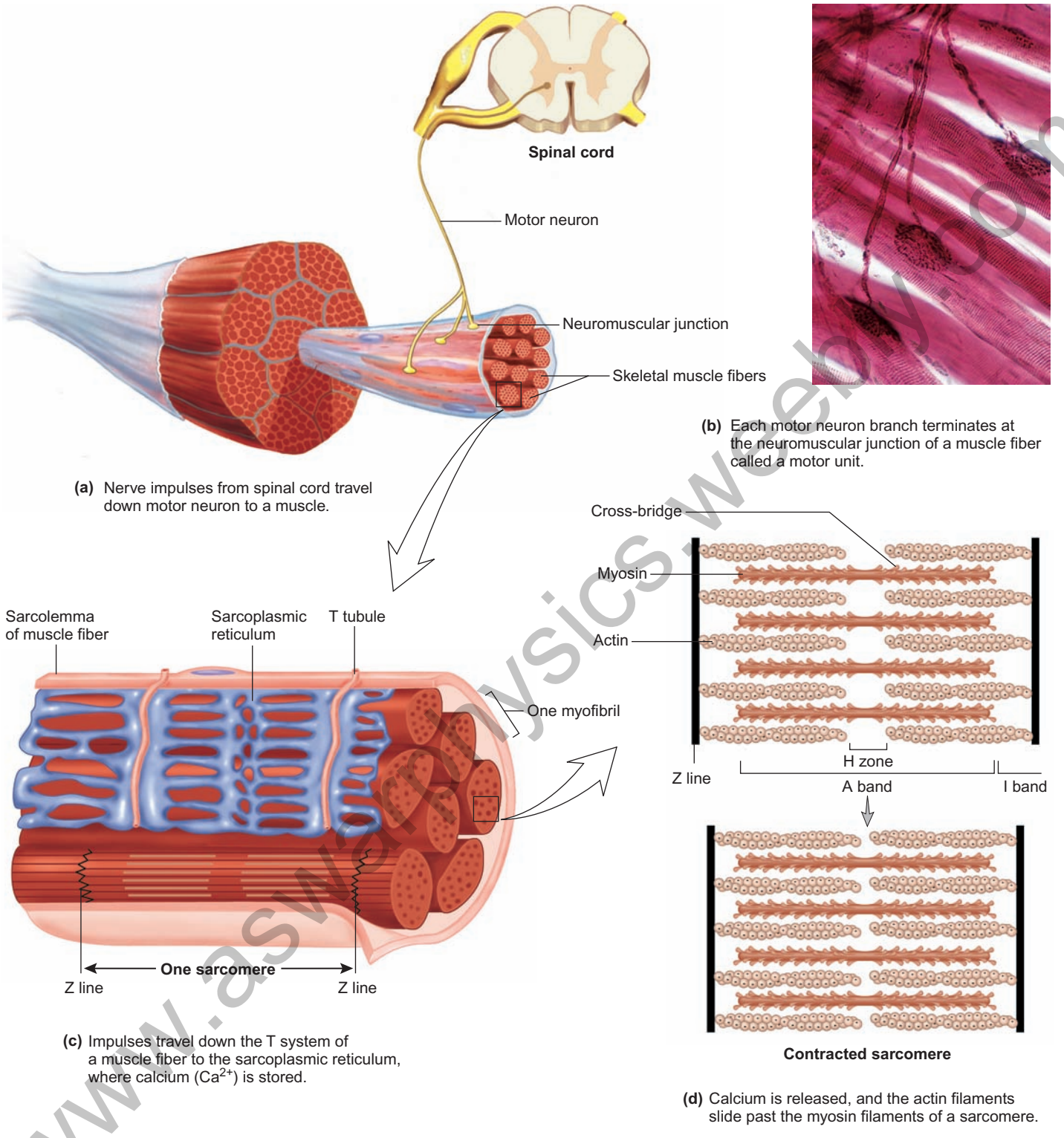


FIGURE 26.19 The Microanatomy of a Muscle

(a–c) Muscles are made of cells that contain bundles known as myofibrils. The myofibrils are composed of two kinds of myofilaments: thick myofilaments composed of myosin, and thin myofilaments containing actin, troponin, and tropomyosin. *(d)* The actin- and myosin-containing myofilaments are arranged in a regular fashion into units called sarcomeres. Each sarcomere consists of two sets of actin-containing myofilaments inserted into either end of bundles of myosin-containing myofilaments. The actin-containing myofilaments slide past the myosin-containing myofilaments, shortening the sarcomere.

The process of muscle-cell contraction involves several steps. The arrival of a nerve impulse at a muscle cell causes the muscle cell to depolarize. When muscle cells depolarize, calcium ions (Ca^{2+}) contained within membranes are released among the actin and myosin myofilaments. The calcium ions (Ca^{2+}) combine with the troponin molecules, causing the troponin-tropomyosin complex to expose actin, so that it can bind with myosin. While the actin and myosin molecules are attached, the head of the myosin molecule can flex as ATP is used and the actin molecule is pulled past the myosin molecule. Thus, a tiny section of the muscle cell shortens (figure 26.20).

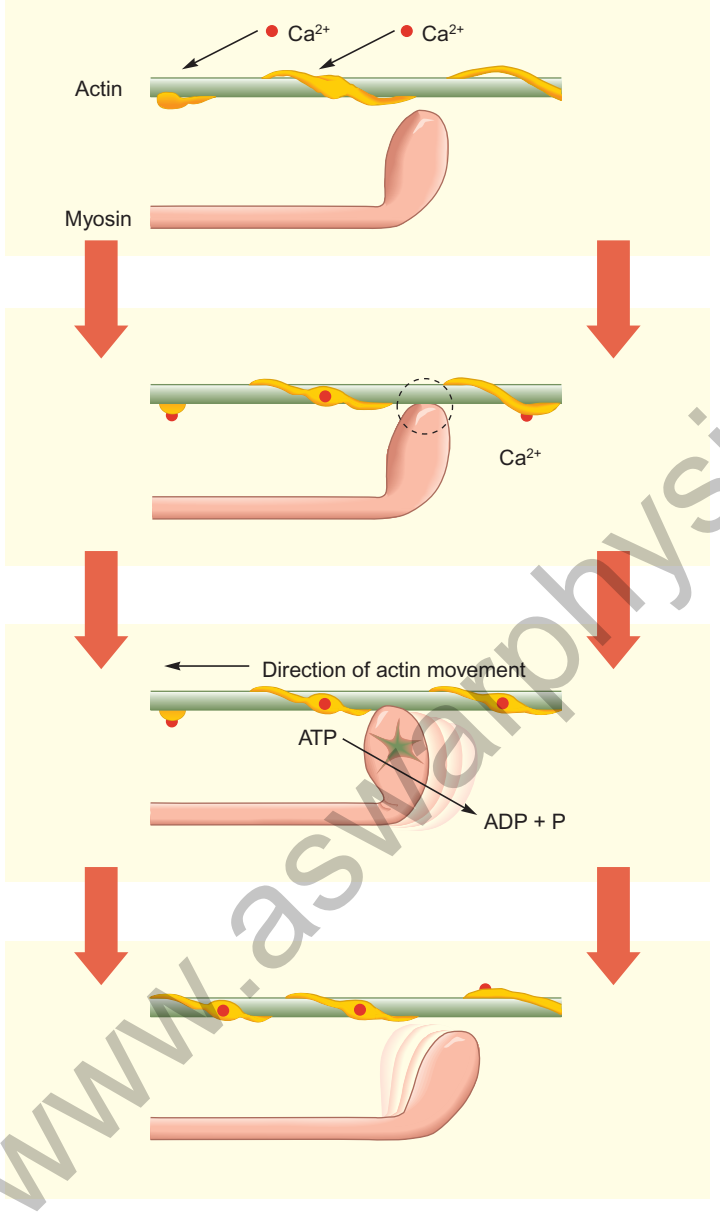


FIGURE 26.20 Interaction Between Actin and Myosin
When calcium ions (Ca^{2+}) enter the region of the muscle cell containing actin and myosin, they allow the actin and myosin to bind to each other. ATP is broken down to ADP and P with the release of energy. This energy allows the club-shaped head of the myosin to flex and move the actin along, causing the two molecules to slide past each other.

When one muscle contracts, thousands of such interactions take place within a tiny portion of a muscle cell, and many cells within a muscle contract at the same time.

The Types of Muscle

There are three major types of muscle: skeletal, smooth, and cardiac. These differ from one another in several ways.

Skeletal muscle is voluntary muscle; it is under the control of the nervous system. The brain or spinal cord sends a message to skeletal muscles, and they contract to move the legs, fingers, and other parts of the body. This does not mean that we must make a conscious decision every time we want to move a muscle. Many of the movements we make are learned initially but become automatic as a result of practice. For example, walking, swimming, and riding a bicycle required a great amount of practice originally but become automatic for many people. They are, however, still considered voluntary actions.

Skeletal muscles are constantly bombarded with nerve impulses, which result in repeated contractions of differing strength. Many neurons end in each muscle, and each one stimulates a specific set of muscle cells, called a *motor unit* (figure 26.21). A **motor unit** is a single neuron and all the muscle fibers to which it connects. Because each muscle consists of many motor units, it is possible to have a wide variety of intensities of contraction within one muscle organ. This allows a single set of muscles to have a wide variety of functions. For example, the same muscles of the arms and shoulders that are used to play a piano can be used in other combinations to grip and throw a baseball.

If the nerves going to a muscle are destroyed, the muscle becomes paralyzed and begins to shrink. The regular nervous stimulation of skeletal muscle is necessary for it to maintain its size and strength. Any kind of prolonged inactivity leads to the degeneration of muscles, known as *atrophy*. Muscle maintenance is one of the primary functions of physical therapy and a benefit of regular exercise.

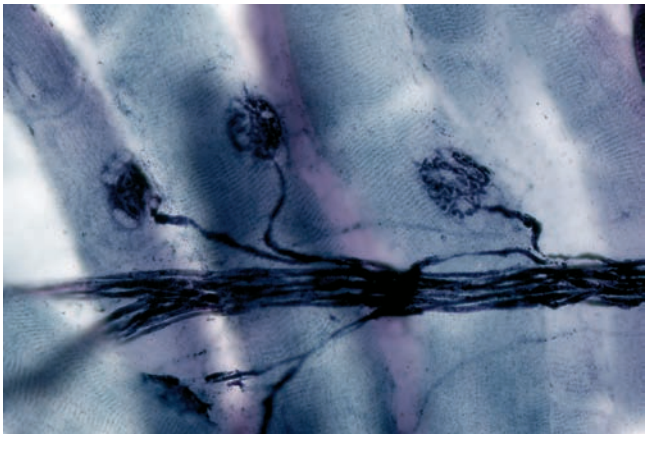


FIGURE 26.21 Motor Unit
This photo shows a motor unit—the muscle fibers stimulated by the endings of one axon.

Skeletal muscles can contract quickly, but they cannot remain contracted for long periods. Even when we contract a muscle for a minute or so, the muscle is constantly shifting the individual motor units within it that are in a state of contraction. A single skeletal muscle *cell* cannot stay in a contracted state but by shifting the individual muscle *cells* that are contracted, the muscle *organ* can remain contracted for a short time.

Smooth muscles make up the walls of muscular internal organs, such as the gut, blood vessels, and reproductive organs. They contract as a response to being stretched. Because much of the digestive system is being stretched constantly, the responsive contractions contribute to the normal rhythmic movements associated with the digestive system. These are involuntary muscles; they can contract on their own without receiving direct messages from the nervous system. This can be demonstrated by removing portions of the gut or uterus from experimental animals. When these muscular organs are kept moist with special solutions, they go through cycles of contraction without any possible stimulation from neurons. However, they do receive nervous stimulation, which can modify the rate and strength of their contraction. This kind of muscle also has the ability to stay contracted for long periods without becoming fatigued. Many kinds of smooth muscle, such as the muscle of the uterus, also respond to the presence of hormones. Specifically, the hormone **oxytocin,** which is released from the posterior pituitary, causes strong contractions of the uterus during labor and childbirth. Similarly, several hormones produced by the duodenum influence certain muscles of the digestive system to either contract or relax.

Cardiac muscle makes up the heart. It can contract rapidly, like skeletal muscle, but does not require nervous stimulation to do so. Nervous stimulation can, however, cause the heart to speed or slow its rate of contraction. Hormones, such as epinephrine and norepinephrine, also influence the heart by increasing its rate and strength of contraction. Cardiac muscle also has the characteristic of being *unable* to stay contracted; it will contract quickly but must have a short period of relaxation before it is able to contract a second time. This makes sense in light of its continuous, rhythmic, pumping function. Table 26.1 summarizes the differences among skeletal, smooth, and cardiac muscles.

The Activities of Glands

Recall that there are two types of glands: endocrine glands, such as the pituitary, thyroid, ovary, and testis; and exocrine glands, such as the salivary glands, intestinal mucous glands, and sweat glands. Some of these glands, such as salivary glands and sweat glands, are under nervous control. When stimulated by the nervous system, they secrete their contents.

Russian physiologist Ivan Petrovich Pavlov showed that salivary glands are under the control of the nervous system, when he trained dogs to salivate in response to hearing a bell. You may recall from chapter 18 that, initially, the animals were presented with food at the same time the bell was rung. Eventually, they would salivate when the bell was rung even if food was not present. This demonstrated that saliva release is under the control of the central nervous system.

Many other exocrine glands are under hormonal control. Many of the digestive enzymes of the stomach and intestine are secreted in response to local hormones produced in the gut. These are circulated through the blood to the digestive glands, which respond by secreting the appropriate digestive enzymes and other molecules.

Growth Responses

The hormones produced by the endocrine system can have a variety of effects. Hormones can stimulate smooth muscle to contract and can influence the contraction of cardiac muscle. In addition, the hormones released by one gland can cause another gland to secrete its own hormone. However, the endocrine system has one major effect that is not equaled by the nervous system: Hormones regulate growth. Several examples of the many kinds of long-term growth changes that are caused by the endocrine system were given earlier in the chapter. Growth-stimulating hormone (GSH) is produced over a period of years to bring about the increase in size of most of the structures of the body. A low level of this hormone results in a person with small body size. The amount of growth-stimulating hormone (GSH) present varies from time to time; it is present in fairly high amounts throughout childhood and results in steady growth. It also appears to be present at higher levels at certain times, resulting in growth spurts. Finally, as adulthood is reached, the level of this hormone falls, and growth stops.

Similarly, testosterone produced during adolescence influences the growth of bone and muscle to provide men with larger, more muscular bodies than those of women. In addition, there is growth of the penis, of the larynx, and of hair on the face and body. The primary female hormone, estrogen, causes the growth of reproductive organs and the

TABLE 26.1 Characteristics of the Three Kinds of Muscle

Kind of Muscle	Stimulus	Length of Contraction	Rapidity of Response
Skeletal	Nervous system	Short; tires quickly	Most rapid
Smooth	Self-stimulated; also responds to nervous and endocrine systems	Long; doesn't tire quickly	Slow
Cardiac	Self-stimulated; also responds to nervous and endocrine systems	Short; cannot stay contracted	Rapid

development of breast tissue. It is also involved, along with other hormones, in the cyclic growth and sloughing of the wall of the uterus.

26.6 CONCEPT REVIEW

14. How do skeletal, cardiac, and smooth muscles differ in (1) speed of contraction, (2) ability to stay contracted, and (3) cause of contraction?
15. What is the role of each of the following in muscle contraction: actin, myosin, ATP, troponin, and tropomyosin?
16. Why must muscles be in antagonistic pairs?
17. What determines the timing and rate of growth of tissues?

26.7 The Body's Defense Mechanisms—Immunity

Immunity is the body's ability to maintain homeostasis by resisting or defending against potentially harmful agents, including microbes, toxins, and abnormal cells, such as cancer cells. The body's **immune system** comprises specialized cells and messenger molecules, that work together to defend against infection and disease. Immune responses can be divided into two general categories: innate immune mechanisms and adaptive immune mechanisms. *Innate immune mechanisms* (also known as *nonspecific immune mechanisms*) are generic and protect the body against many kinds of agents. They are present and function from birth. *Adaptive immune mechanisms* (also known as *specific immune mechanisms*) are able to identify specific pathogens based on their exact chemical makeup. They are not present at birth and require exposure to a harmful agent to be activated. Once activated, adaptive immune mechanisms use specific combinations of chemicals and cells to destroy a specific enemy. Adaptive immune mechanisms also involve cellular memory, which allows the body to mount a rapid response to an enemy it has encountered previously.

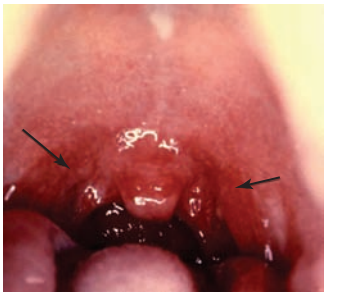
Innate Immunity

The body has three kinds of innate defenses—physical barriers, protective chemicals, and certain kinds of defensive cells. All three may work together to safeguard the body.

Physical barriers are extremely important in protecting the body. For example, the skin and mucous membranes are barriers that prevent most bacteria, viruses, parasitic worms, and large toxic molecules from getting through and causing harm. The cells of the upper respiratory system are ciliated and covered with mucus. Should bacteria or dust particles be caught in the fluid, the cilia's upward beating moves them toward the mouth and nose, where they can be eliminated by sneezing, coughing, or swallowing. If the threatening agent is swallowed, stomach acid (about pH 2) also acts as an innate defense. A mixture of materials with a low pH forms a protective barrier in the vagina.

Protective chemicals are produced by several kinds of cells and are involved in various ways in destroying pathogens. The enzyme *lysozyme,* found in sweat, tears, mucus, saliva, breast milk, and gastric secretions, destroys the cell walls of bacteria. *Complement* is a group of proteins primarily manufactured in the liver that circulate in the blood and help other systems defend against threats of cellular pathogens, such as bacteria, fungi, and protozoa. Complement proteins can help form holes in pathogens, allowing their content to leak out. *Interferons* are proteins that attach to the surface of cells and cause the cells to interfere with the ability of viruses to replicate. If a cell becomes infected with a virus, it produces interferons, which help control the virus in the cell but also act as messengers. These are sent to nearby cells, preparing them to produce their own interferons and initiate reactions that will inhibit viral replication should the virus arrive.

Many kinds of cells are involved in innate immunity. Various kinds of white blood cells recognize pathogens and communicate to other cells that there is a problem. Other white blood cells respond by producing and releasing a variety of chemicals. These chemicals can recruit other defensive cells to the site of injury or infection, kill pathogens directly, cause dilation of blood vessels, or perform other defensive functions. Certain white blood cells actively attack pathogens and kill them. Others engulf pathogens and the body cells that have been killed by infection. This pattern of interaction at the site of an infection is commonly called *inflammation.* **Inflammation** is a pattern of events that leads to increased temperature, redness, swelling, and pain in the affected area. Because of the pain and swelling associated with inflammation, most people don't think of it as a good thing. However, it is an important part of the innate immune response.



Inflamed tonsils

Inflammation also occurs when tissue cells are damaged even though there may not be pathogens present. If you hit your thumb with a hammer or are stung by a bee, inflammation occurs because damaged tissue cells release chemicals that initiate inflammation. The events that occur during inflammation are summarized in table 26.2.

Under certain circumstances, the inflammatory process can get out of hand. If inflammation continues unchecked, the process can result in tissue damage. Under such circumstances, anti-inflammatory medications, such as nonsteroidal anti-inflammatory drugs (NSAIDs), can be used to interfere with the inflammatory process. Aspirin, ibuprofen, ketoprofen, and naproxen are all over-the-counter NSAIDs.

TABLE 26.2 Inflammation

What You Observe	What's Really Happening
The event that triggers inflammation	Damage to tissue by molecules, microbes, or other materials; for example, a scratch, infecting bacteria releasing toxins, a splinter.
General events of inflammation	Inflammatory chemicals released by injured cells and immune system cells serve as signals calling neutrophils from nearby capillaries. White blood cells (lymphocytes, monocytes, macrophages) go through the blood vessel walls and move to the damaged area, where they attack the enemy and clean up damaged cells by phagocytosis. The pH of tissue fluid decreases, helping control pathogens.
Increased temperature	Inflammatory chemicals such as histamine cause dilation (an increase in the diameter) of capillaries which causes increased flow of warm blood to the area.
Swelling	As capillaries dilate, they also become more porous, allowing fluid and white blood cells to move from the vessel into the tissue.
Redness	Inflammatory chemicals cause increased blood flow in the area.
Pain	Inflammatory chemicals and the pressure caused by swelling affect nerve endings.

Adaptive Immunity

Adaptive immune mechanisms are targeted at specific pathogens. Although a person is born with an immune system with the ability to develop adaptive immunity, these defenses must be "turned on" in order to work. To be "turned on," the body must be exposed to an *antigen* associated with the pathogen. An **antigen** is a large organic molecule, usually a protein, that is recognized by cells of the immune system, which stimulate them to begin a series of events that result in the destruction of that specific antigen-bearing agent. Antigens can be individual molecules, such as botulism toxin. They can also be parts of cells, such as molecules found on the surface or inside bacteria, viruses, or eukaryotic cells. Furthermore, with adaptive immunity, the immune system cells remember the antigen and can react quickly to the pathogen if the body encounters the pathogen again. This mechanism is often called *acquired immunity* because it begins to work only after certain cells of the immune system have come into contact with a specific antigen. The cells that respond to antigens are primarily T-lymphocytes and B-lymphocytes. The way each of these cells responds is very different, so adaptive immune mechanisms are subdivided into *B-cell* or *antibody-mediated immunity* and *T-cell* or *cell-mediated immunity*. However, a great deal of interaction between these two cell types must occur to defend a person against a specific enemy.

B-Cells and Antibody-Mediated Immunity

B-lymphocytes (B-cells) are produced and mature in the bone marrow. They are hard to find in the blood but are found in large numbers in the lymph nodes and spleen. When a B-cell contacts an antigen, chemical messengers are sent from the cell surface to its nucleus and genes are activated. In these B-cells, certain portions of the DNA are cut and spliced to produce a new nucleotide sequence. This new gene causes the synthesis of a specific protein able to combine with that antigen. These protein molecules are called immunoglobulins or *antibodies*. An **antibody** is a protein made by the B-cells in response to an antigen (figure 26.22). There are five classes of antibodies, differing in their structures and functions (table 26.3).

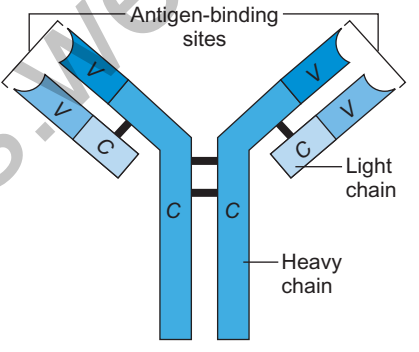


FIGURE 26.22 Structure of an Immunoglobulin Gamma (IgG) Antibody
An IgG antibody contains two heavy (long) polypeptide chains and two light (short) chains arranged so that there are two "variable regions" at the top of the Y-shaped molecule. This is where the antigen combines with the antibody (V = variable region, C = constant region).

When B-cells become specialized for the production of a specific antibody, they remain specialized for the rest of their lives. These specialized B-cells undergo mitosis, and their descendents become either plasma cells, which produce antibodies, or memory B-cells. Plasma cells produce large quantities of antibodies, which enter the circulatory system. When an antibody molecule contacts the antigen, they combine. Figure 26.23 summarizes these events. If the antigen is an isolated toxin molecule or a virus, it is prevented from causing harm or *neutralized*. If the antigen is part of a pathogen, the antigen-antibody combination along with other molecules such as complement, causes holes to be formed in the cell, killing the pathogen. The antigen-antibody combination can also act as an attractant for phagocytes, such as macrophages

TABLE 26.3 Classes of Antibodies

Class	Location	Function
Immunoglobulin gamma (IgG) (also called gamma globulin)	Blood and tissue fluids	1. Most abundant immunoglobulin in the blood 2. Binds with free antigens or those on cell surfaces 3. Activates complement proteins to destroy pathogens 4. Encourages phagocytosis of pathogens 5. The only class that passes to the fetus through the placenta, which gives passive immunity to fetus
Immunoglobulin mu (IgM)	Blood	1. The first immunoglobulin produced after B-cell encounters antigen 2. Activates complement 3. Causes pathogen cells to clump, encouraging phagocytosis
Immunoglobulin alpha (IgA)	Blood, mucus, saliva, tears, breast milk	1. Produced in huge quantities on mucous membranes of the digestive, urogenital, and respiratory systems 2. Prevents pathogens from attaching to the surface of cells
Immunoglobulin delta (IgD)	Blood	1. Found on surface of B-cells 2. Probably involved in development and activation of B-cells
Immunoglobulin epsilon (IgE)	Blood—attached to basophils	1. Protects against parasitic worm infections 2. Binds to allergens and causes release of histamine from basophils; therefore, responsible for many allergic reactions, such as asthma and hay fever

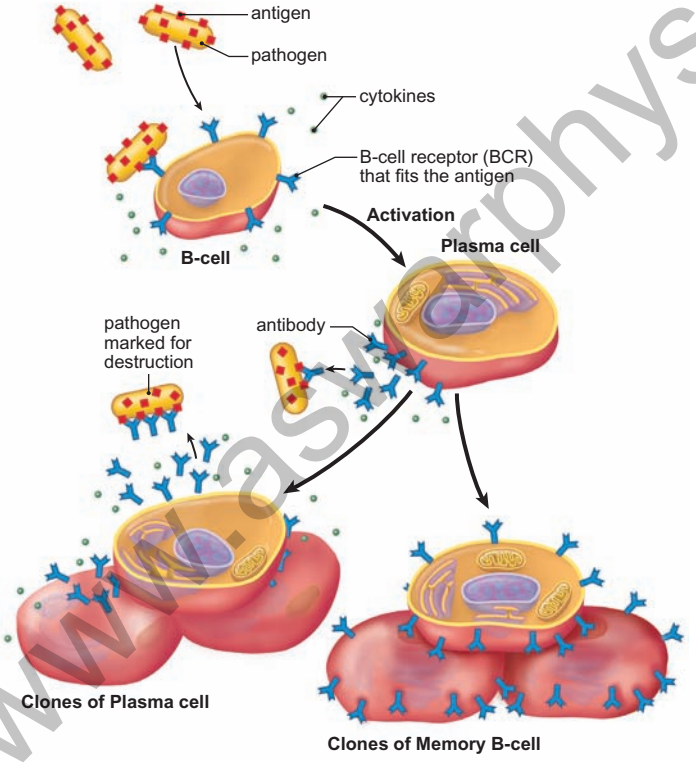
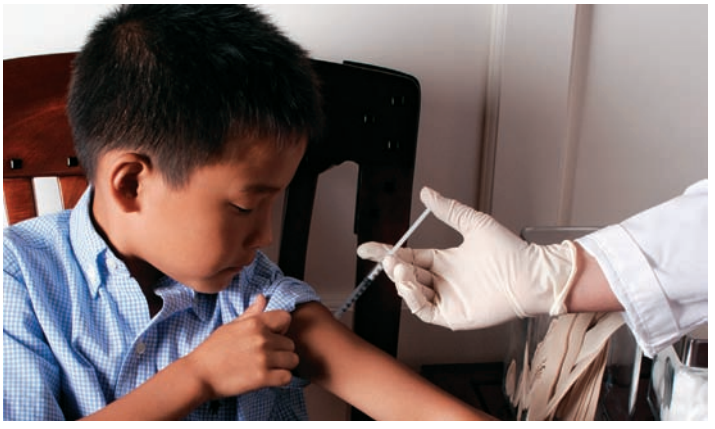


FIGURE 26.23 B-cells and Production of Antibodies
When a B-cell first encounters an antigen, it is triggered to express genes that produce antibodies against the antigen. The activated B-cell divides and produces large numbers of plasma cells that produce the antibodies and memory cells that can be activated later when the person is again exposed to the same pathogen.

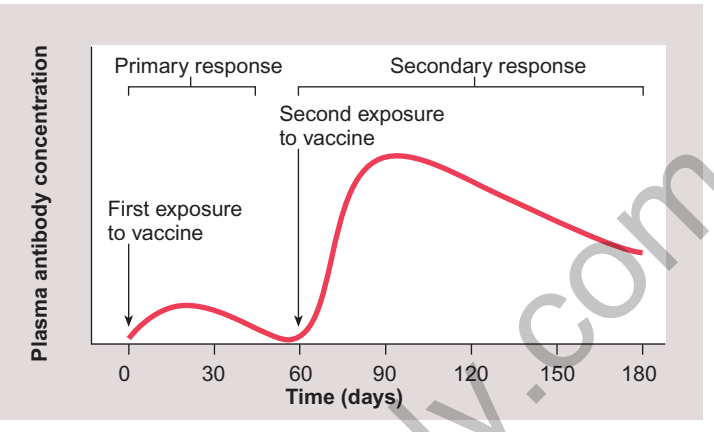
and neutrophils, causing them to engulf and destroy the pathogen.

Once the trouble is brought under control, the number of plasma cells slowly drops and so does the antibody level. This leaves the memory B-cells to serve as a backup team, should that antigen appear in the future. Memory B-cells know how to make the correct antibody to defend against that specific antigen, but they don't make much of it. The antibodies they produce are on their surface. If the same antigens appear again, they attach to the antibodies causing the memory B-cells to undergo mitosis, changing into a large population of antibody-secreting plasma cells. A second exposure to an antigen results in a more rapid increase in the level of antibodies because the memory cells already have the ability to produce the antibody needed. The amount of antibody increases rapidly and again protects the body from harm.

Immunization is the technique used to induce the immune system to develop an acquired immunity to a specific disease by the use of a *vaccine*. **Vaccines** are antigens made so they can start an active immunity without causing disease. A vaccine can be a solution that contains whole, live pathogens in a form so changed that they are not harmful. It can also contain dead organisms or just the antigenic portion of the pathogen; some vaccines are synthetic. When the vaccine is first given, B-cells become activated, just as they do when they encounter an actual disease organism. This is called the primary immune response (figure 26.24). The next time the person is exposed to the vaccine, there is a sharp increase in the amount of antibody produced. This is called the secondary immune response. As time passes, the amount of antibody



(a)



(b)

FIGURE 26.24 **Active Immunity Due to Immunization**

(a) Vaccines immunize children against various childhood diseases. *(b)* The primary immune response, after the first exposure to a vaccine, is minimal, but the secondary immune response, which may occur after the second exposure, shows a dramatic rise in the amount of antibody present in the plasma.

will begin to fall. It will remain high only if the person is repeatedly exposed to the same antigen, either by accident or as the result of a booster shot. For example, if a person lives or works in an area where tetanus toxin can regularly stimulate a secondary immune response (e.g., through a puncture wound), a constant high level of immunity to tetanus toxin is naturally maintained. Each time the memory B-cells come in contact with tetanus toxin, the amount of antibody is "boosted" to its maximum protective level. If natural exposure does not occur, the amount of antibody falls slowly, sometimes reaching a low, unprotective level. There are no quick ways to determine how "naturally" protected someone is. If a physician suspects that a patient might develop a case of tetanus, a booster injection of tetanus vaccine is given to stimulate antibody production artificially to ensure a high level of protection.

As a disease travels through a population, surviving individuals have developed an immunity that makes them resistant to reinfection. It also keeps them from becoming the source of infection to others. Thus, the population as a whole develops what is known as *herd immunity*. This concept is based on the relative proportions of immune and susceptible individuals in the population (herd). In other words, if enough people become immune as the result of contracting the illness or immunization, there is less chance that the susceptible people will get the illness. You see herd immunity develop during the "flu season." At first, there is an increase in the number of cases, they reach a peak, and finally the number of cases decreases as more people become immune. If enough people in the population (herd) were to be vaccinated before the virus arrived, the immunized people would protect those who, for whatever reason, did not or could not get the vaccine. Public health officials try to immunize large portions of the susceptible population in an attempt to maintain a high level of herd immunity. The proportion of immune to susceptible persons must be constantly monitored because new susceptible individuals continuously enter a population through migration and birth and because pathogens change so that they do not necessarily display the same antigens.

T-Cells and Cell-Mediated Immunity

Cells that will become T-lymphocytes (T-cells) are initially produced in the bone marrow but travel to the thymus gland where they differentiate into T-cells. After they are differentiated they leave the thymus and are found in the blood, lymph, and lymph tissue. Like B-cells, T-cells must be brought into battle through an activation process. To activate T-cells, the antigen must be "presented" to them by other cells, called antigen-presenting cells (APCs) which are often macrophages that have phagocytosed the pathogen. Phagocytosis was covered in chapter 4. Inside an APC, the pathogen is broken down, and each antigenic molecule is attached to a molecule already present in the APC. This new combination is inserted into the APC's cell membrane so that each molecule sticks out on the APC's surface like a microscopic hair. The APC activates the T-cells by presenting the antigen to T-cells when they attach to one another at receptor sites on the surface of the T-cells (figure 26.25). Several kind of T-cells with specific functions have been identified.

T-helper cells produce chemicals called *cytokines*. When disease organisms invade the body or other cellular abnormalities occur, cytokines stimulate the actions of B-cells to produce antibodies; stimulate cytotoxic T-cells to kill infected body cells; and recruit macrophages and phagocytes to consume damaged cells.

T-regulator cells produce cytokines that are responsible for shutting down the immune response of both B- and T-cells following a period when they were activated to fight an infection. They are also important in preventing immune system cells from attacking normal body cells.

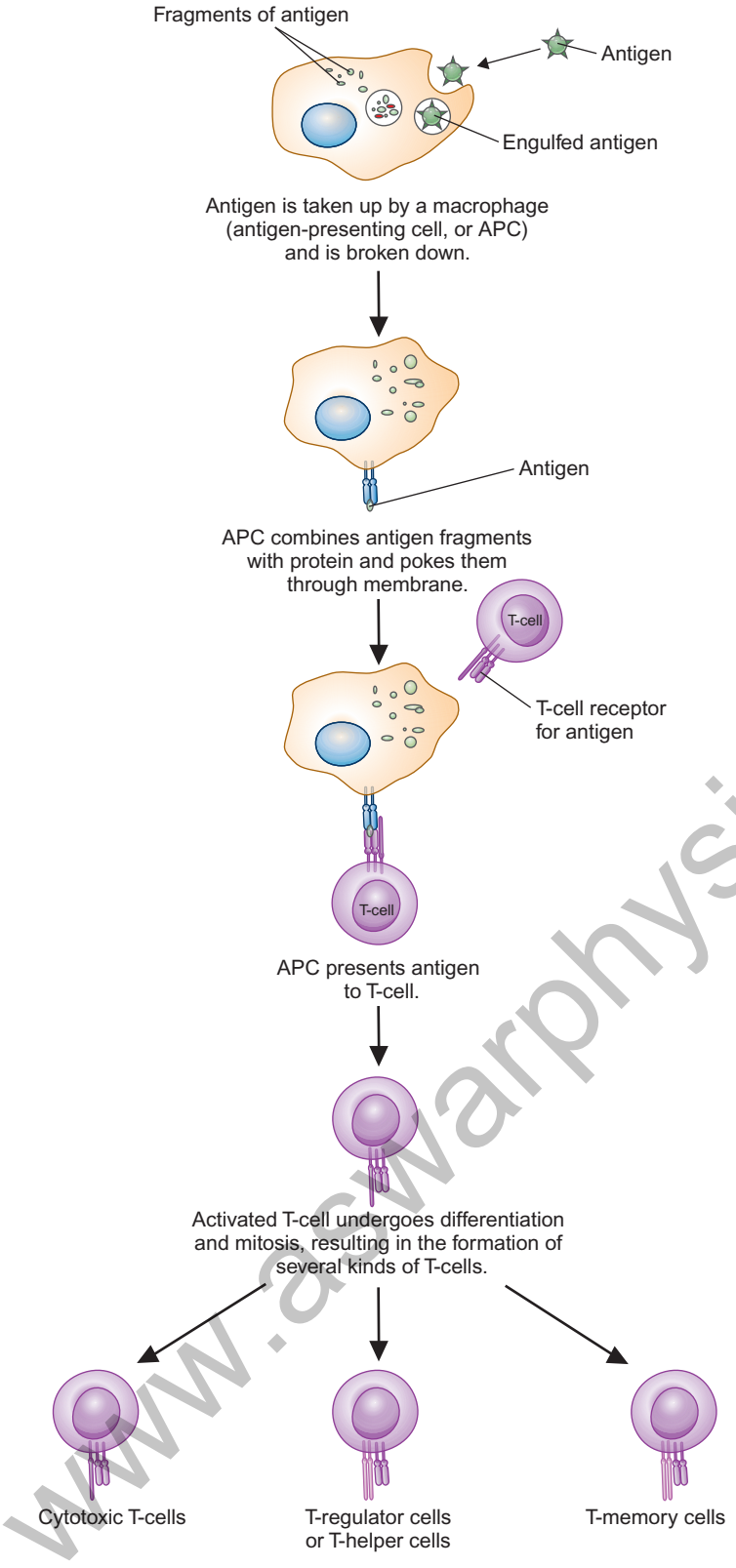


FIGURE 26.25 Specialized T-Cells
T-cells become specialized as T-regulator cells, T-helper cells, cytotoxic T-cells, or T-memory cells by interaction with an antigen-presenting cell (APC). APCs are macrophages that have engulfed an antigen and present it to undifferentiated T-cells. Once differentiated, each kind of T-cell has a special job to perform in defending the body against harm.

Cytotoxic T-cells are specialized for killing body cells that cause disease. After identifying the enemy cells, cytotoxic T-cells move toward their target cells, press up against their surface, and make holes in them. Cytotoxic T-cells target cancer cells, cells infected with viruses or intracellular bacteria or protozoa, and foreign cells, such as cells from an organ transplant.

T-memory cells are generated in much the same fashion as B-memory cells, and they play a similar role. They remember the specific antigen of their enemy and can multiply when exposed to the same antigen at a later time (Outlooks 26.1).

Immune System Diseases

As with other body systems, the immune system can malfunction, resulting in diseases. The most common are allergic reactions, autoimmune diseases, and immunodeficiency diseases. An **allergy** is an abnormal immune reaction to an antigen. Possibly the most familiar are allergies to foods, pollens, and drugs. Such allergies are also known as *type I hypersensitivities*. All allergies involve the interaction of an antigen with a B-cell antibody. An antigen that causes an allergy and comes from outside the body, such as dust, pollen, tobacco, fungi, eggs, and penicillin, is called an *allergen*.

Type I hypersensitivities are associated with immunoglobulin E (IgE). B-cells capable of producing IgE are first exposed to the allergen through the skin, respiratory tract, or intestinal tract and become activated. Unlike most other immunoglobulins, IgE can bind to the surface of mast cells and basophils (figure 26.26). When a person comes in contact with the allergen a second time, the allergen (antigen) attaches to the antibody, which is already attached to mast cells and basophils. This causes the release of large amounts of histamine, leukotrienes, and prostaglandins that cause a variety of symptoms. Symptoms vary greatly in people and include skin rashes, hives, itching throat, asthma, eczema, migraine headaches, and bedwetting.

The most severe allergic reaction is anaphylactic shock. Within minutes after exposure to the allergen, this shock reaction progresses from (1) extensive skin reddening and itching to (2) smooth muscle spasms to (3) capillary breakage in the skin, eyes, and internal organs to (4) a burning sensation in the rectum, the mouth, and possibly the vagina to (5) severe headache to (6) hot flashes to (7) a quick drop in blood pressure to (8) a constriction of bronchial smooth muscle, resulting in respiratory failure, to (9) death. To counteract anaphylactic shock, people with severe allergic reactions are advised to carry and use an EpiPen as soon as they are exposed to the allergen. The medication in this single-use hypodermic syringe is epinephrine (adrenalin), which quickly counteracts the symptoms. However, after using the pen, the person should seek medical attention immediately, because the EpiPen may not totally control the reaction.

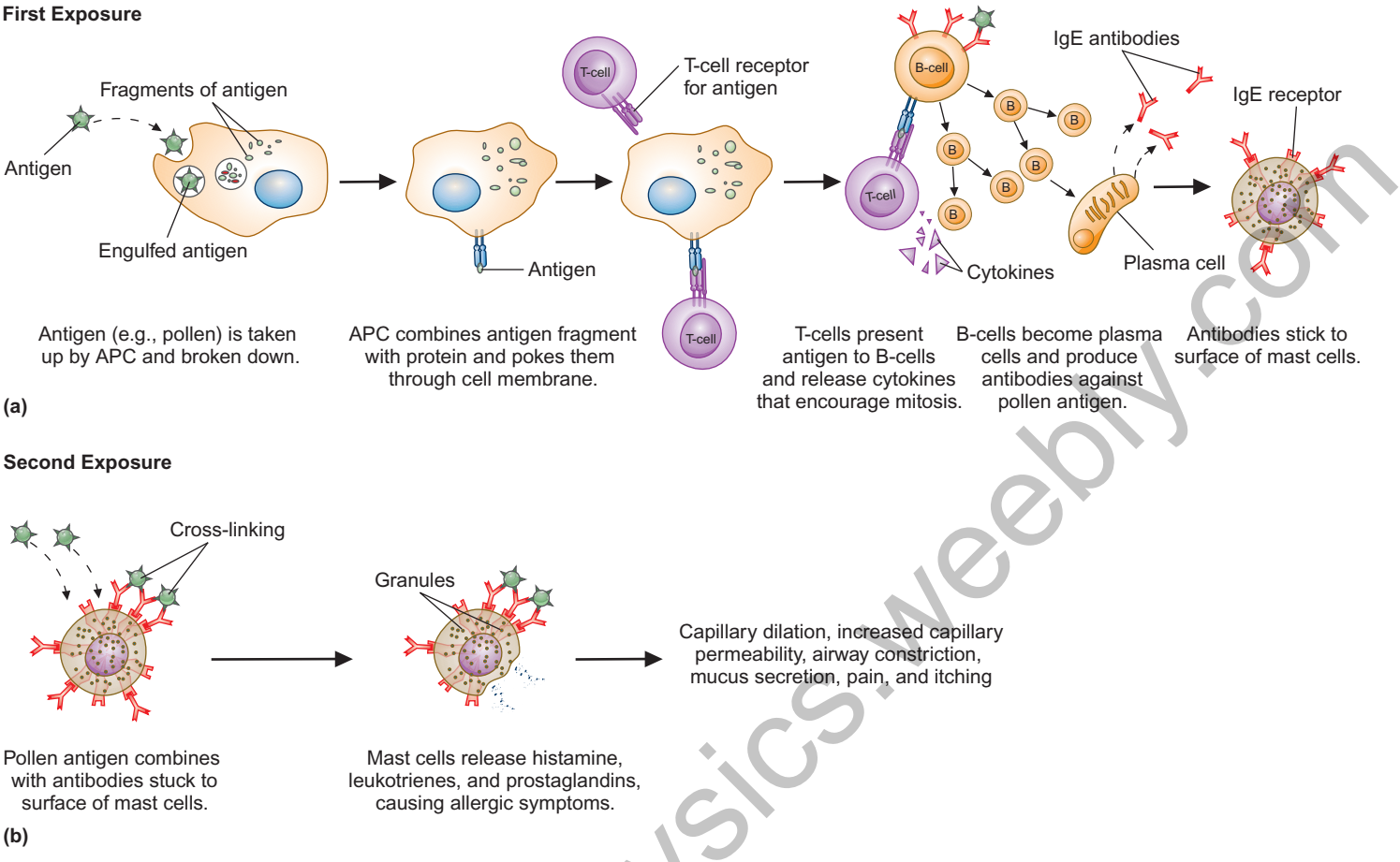


FIGURE 26.26 How an IgE Allergy Works
(a) When a person is first exposed to an allergen, such as pollen, the allergen is taken up by an antigen-presenting cell (APC), which initiates a complex series of events that lead to the release of IgE antibodies, which stick to the surface of mast cells and basophils. A few days later, when pollen is encountered again, *(b)* the increased population of antibody-coated mast cells combines with the allergen, causing them to release the chemicals responsible for the symptoms.

Autoimmune diseases are disorders that result from the immune system's turning against the normal chemicals and cells of the body. In other words, the immune response makes a mistake, sees healthy cells as harmful, and attacks them. Some examples of autoimmune diseases are rheumatoid arthritis, type 1 (insulin-dependent) diabetes, systemic lupus, Crohn's disease, and psoriasis. In rheumatoid arthritis, B-cells produce antibodies that mistakenly identify proteins in the cartilage and bone as dangerous and destroy them. In type 1 diabetes, the insulin-producing cells of the pancreas are destroyed by T-cells.

Immunodeficiency diseases are disorders that result from the immune system's not producing one or more component cells or chemicals. In this situation, the system cannot provide the protection needed to maintain health. People with such disorders are more susceptible to infections and cancers. People born with the genetic disorder severe combined immunodeficiency disease (SCIDS), or "boy-in-the-bubble" disease, lack the ability to synthesize the enzyme adenosine deaminase (ADA), which is crucial to the formation of T-cells.

Acquired immunodeficiency syndrome (AIDS) is also an immunodeficiency disease but is not genetic. AIDS is the result of a virus infection caused by the human immunodeficiency virus (HIV). HIV infects T- and B-cells and eventually destroys them. When the immune system's population of T-cells has been reduced significantly, it can no longer defend the body against microbial infections. It also loses its ability to recognize and destroy tumor cells.

26.7 CONCEPT REVIEW

18. What are the differences between innate and adaptive immunity?
19. How do B-cell and T-cell systems work to defend against disease?

OUTLOOKS 26.1

The Immune System and Transplants

People who have damaged tissues or organs often die even though the other parts of their body are functioning normally. Therefore, transplantation of healthy tissues or organs from one person to another could save lives. Because our immune system is designed to attack organisms or cells that display foreign antigens on their surface, successful transplants must avoid being attacked by the recipient's immune system.

There are genes on chromosome 6 in humans that produce proteins that are displayed on the surface of all cells. The proteins are called human leukocyte antigen (HLA) proteins. (The genes are also called major histocompatibility complex [MHC] genes and are found in nearly all vertebrates.) There are on the order of 200 different alleles for these genes. Each person has a specific set of these genes and the proteins they produce and, since there are so many possible combinations of these alleles, each person displays a unique combination of these antigens on their cell surfaces. For the transplant of most tissues or organs to be successful, the antigens of the donor tissue must resemble those of the recipient as closely as possible.

Determining whether the tissues of a donor and recipient are closely matched is a three-step process. First, the blood types (A, B, AB, O) of the donor and the recipient must be compatible (see chapter 10 for a discussion of blood type). Second, a set of HLA proteins are matched. Six of these proteins are considered when making a match. The greatest success is achieved when all six antigens are the same for both the donor and the recipient. Finally, a cross-match is made to make sure that the recipient has not been exposed previously to an antigenic substance in the donor tissue that would trigger a reaction against the donor tissue. The most common causes of exposure to other human antigens are pregnancy (exposure to some of a fetus's antigens), blood transfusions, and previous transplants.

A few kinds of tissues do not have blood vessels (cornea of the eye, tendons, cartilage). Because the recipient's blood and the B- and T-lymphocytes in the blood do not flow through these tissues, the recipient does not become sensitized to the foreign

material. Therefore, transplanting these structures usually does not cause the recipient's immune system to reject the transplant.

Blood transfusions are also a special case of tissue transplantation that does not require matching of the HLA antigens. This is because the red blood cells do not express the HLA genes and platelets express these genes very weakly. Although lymphocytes do express the HLA genes, the rejection reaction is usually not a problem because blood transfusions are a temporary replacement. Instead of the three-step process, the blood type (A, B, AB, and O) and a second blood type called the Rh factor, of the donor and recipient are matched and a sample of the donor's red blood cells is mixed with a sample of the recipient's plasma to determine if there are any antigens on the donor's red blood cells that will cause a problem.

All other organ and tissue transplants require all three steps to assure that there is a reasonable chance that the donated tissue will be accepted by the recipient's immune system. Even when the match is as close as possible, most transplant recipients must use drugs that suppress the immune system for their lifetime.

Summary

A nerve impulse is caused by sodium ions entering the cell as a result of a change in the permeability of the cell membrane. Thus, a wave of depolarization passes down the length of a neuron to the synapse. The axon of a neuron secretes a neurotransmitter, such as acetylcholine, into the synapse, where these molecules bind to the dendrite of the next cell in the chain, resulting in an impulse in it as well. The acetylcholinesterase present in the synapse destroys acetylcholine, so that it does not repeatedly stimulate the dendrite. The brain is composed of several functional units. The lower portions of the brain control automatic activities, the middle portion of the brain controls the basic categorizing of sensory input, and the higher levels of the brain are involved in thinking and self-awareness.

Several kinds of sensory inputs are possible. Many kinds of chemicals can bind to cell surfaces and be recognized. This is how the senses of taste and smell function. Light energy can be detected because light causes certain molecules in the retina of the eye to decompose and stimulate neurons. Sound can be detected because fluid in the cochlea of the ear is caused to vibrate, and special cells detect this movement and stimulate neurons. The sense of touch consists of a variety of receptors that respond to pressure, cell damage, and temperature.

Muscles shorten because of the ability of actin and myosin to bind to one another. A portion of the myosin molecule

is caused to bend when ATP is used, resulting in the sliding of actin and myosin molecules past each other. Skeletal muscle responds to nervous stimulation to cause movements of the skeleton. Smooth muscle and cardiac muscle have internally generated contractions, which can be modified by nervous stimulation or hormones.

There are two types of glands: exocrine glands, which secrete through ducts into the cavity of an organ or to the surface of the skin; and endocrine glands, which release their secretions into the circulatory system. Digestive glands and sweat glands are examples of exocrine glands. Endocrine glands, such as the ovaries, testes, and pituitary gland, change the activities of cells and often cause responses resulting in growth over a period of time. The endocrine system and the nervous system are interrelated. Actions of the endocrine system can change how the nervous system functions, and the reverse is also true.

The immune system defends the body against potentially harmful agents, including microbes, toxins, and abnormal cells. Innate immune mechanisms protect the body against many kinds of harmful agents. Adaptive immune mechanisms can tell the difference between one kind of threat and another based on their exact chemical makeup. After recognizing the enemy, the body selects a specific combination of chemicals and cells to send into the battle to destroy only that enemy. Cells important to the system include B-lymphocytes, T-lymphocytes, and macrophages. Abnormally functioning immune systems can result in allergies, immunodeficiency, and autoimmune diseases.

Key Terms

*Use the interactive flash cards on the **Concepts in Biology**, 14/e website to help you learn the meaning of these terms.*

acetylcholine 588
acetylcholinesterase 588
actin 599
allergy 607
antibody 604
antidiuretic hormone (ADH) 591
antigen 604
autoimmune diseases 608
axons 585
basilar membrane 597
central nervous system 586
cerebellum 588
cerebrum 589
cochlea 597
cones 596
dendrites 585
depolarized 587
endocrine glands 591
endocrine system 591
epinephrine 591
estrogen 592
exocrine glands 591
fovea centralis 596
glands 591
growth-stimulating hormone (GSH) 592
homeostasis 584
hormone 591
hypothalamus 589
immune system 603
immunity 603
immunization 605
immunodeficiency diseases 608
incus 597
inflammation 603
malleus 597
medulla oblongata 588
motor neurons 586
motor unit 601
myosin 599
negative-feedback inhibition 584
nerve cell 585
nerve impulse 556
nerves 586
nervous system 585
neuron (nerve cell) 585
neurotransmitter 588
norepinephrine 591
olfactory epithelium 596
oval window 597
oxytocin 602
perception 595
peripheral nervous system 586
pons 589
positive-feedback regulation 585
retina 596
rhodopsin 597
rods 596
semicircular canals 597
sensory neurons 586
soma 585
spinal cord 586
stapes 597
synapse 588
testosterone 592
thalamus 589
tropomyosin 599
troponin 599
tympanum 597
vaccines 605
voltage 586

Basic Review

1. The _____ is the space between the fibers of adjacent neurons in a chain.
2. In the _____, the somatic nervous system controls the skeletal (voluntary) muscles and the autonomic nervous system controls smooth (involuntary) muscles, the heart, and glands.
   a. peripheral nervous system
   b. central nervous system
   c. immune system
   d. medulla oblongata
3. The cells that a specific hormone affects are called
   a. target cells.
   b. neurons.
   c. motor units.
   d. T-lymphocytes.
4. _____ glands have no ducts and secrete their products into the circulatory system.
   a. Exocrine
   b. Endocrine
   c. Salivary
   d. Sweat

5. The mechanism by which an increase in a stimulus causes a reduction in a response is called
   a. positive-feedback regulation.
   b. immune.
   c. negative-feedback control.
   d. absolute.
6. Molecules that are neurotransmitters manufactured in the soma and migrate down the axon, where they are stored until needed, are called
   a. somas.
   b. acetylcholine.
   c. cytokines.
   d. estrogen.
7. Which of the following is a resulting symptom of inflammatory chemicals that cause increased blood flow and dilation of capillaries?
   a. swelling
   b. estrogens
   c. atherosclerosis
   d. nausea
8. Which cells of the immune system produce memory cells?
   a. both B- and T-lymphocytes
   b. B-lymphocytes only
   c. T-lymphocytes only
   d. macrophages
9. Histamine, leukotrienes, and prostaglandins are compounds produced and released by which cells during an allergic reaction?
   a. WBCs
   b. RBCs
   c. basophils
   d. macrophages
10. In muscle, thin myofilaments composed of the proteins actin, tropomyosin, and troponin alternate with thick myofilaments composed primarily of the protein _____.
11. A nerve impulse involves
   a. a change in the permeability of the cell membrane.
   b. the flow of sodium ions into the nerve cell.
   c. depolarization of the nerve cell membrane.
   d. All of the above are correct.
12. The chemicals produced by endocrine glands that cause changes in other tissues are called _____.
13. The cells in the retina of the eye that are able to detect different colors are called _____.
14. The chemical sense of taste
   a. has only about five kinds of chemical receptors.
   b. is only found on the tip of the tongue.
   c. fatigues very rapidly.
   d. is learned.
15. Hearing involves
   a. the movement of tiny hairs in the cochlea.
   b. the movement of fluid in the cochlea.
   c. nerve impulses from the cochlea to the brain.
   d. All of the above are correct.

Answers
1. synapse 2. a 3. a 4. b 5. c 6. b 7. a 8. a 9. c 10. myosin 11. d 12. hormones 13. cones 14. a 15. d

Thinking Critically

Can We Improve Our Sense of Smell?
Humans are considered to have a poor sense of smell. However, when parents are presented with baby clothing, they are able to identify the clothing with which their own infant had been in contact with a high degree of accuracy. Specially trained individuals, such as wine and perfume testers, are able to identify large numbers of different kinds of molecules that the average person cannot identify. Birds rely primarily on sound and sight for information about their environment; they have a poor sense of smell. Most mammals are known to have a very well-developed sense of smell. Is it possible that we have evolved into sound-and-sight-dependent organisms, like birds, and have lost the keen sense of smell of our ancestors? Or is it that we just don't use our sense of smell to its full potential? Devise an experiment that would help shed light on this question.

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CHAPTER 27

Human Reproduction, Sex, and Sexuality

CHAPTER OUTLINE

Are Sperm Counts Falling?

Environmental factors could be involved.

In recent years there have been several studies that suggest that sperm counts have been falling. One British study suggests that sperm counts have fallen by 29% in 12 years. Another study found that men with higher levels of certain pesticides in their blood had lower sperm counts. There are many critics of the various studies, who question the way the data were collected or the conclusions reached. For example, some data were collected at fertility clinics where men might be expected to have low sperm counts. Other studies had very small sample sizes or had other problems with the way the study was designed and carried out.

Regardless of the quality of the data, people with particular views have used these studies to support their concerns about environmental chemicals—pesticides, chemicals in plastics—the use of birth control pills, consumption of high amounts of beef, and a variety of other environmental factors. Some have even suggested that tight pants or the heat from laptop computers could raise the temperature of the testes and reduce sperm counts.

- **Could environmental factors affect sperm production?**
- **Is fertility falling?**
- **Should a well-designed, worldwide study of sperm counts be done?**

Background Check

Concepts you should already know to get the most out of this chapter:

- The nature of meiosis and gamete production (chapter 9)
- The fundamentals of genetics (chapter 10)
- The basic structure and function of the endocrine system (chapter 26)

27.1 Sexuality from Various Points of View

Probably nothing interests people more than sex and sexuality. **Sex** is the nature of the biological differences between males and females. By **sexuality,** we mean all the factors that contribute to one's female or male nature. A person's sexuality includes the structure and function of the sex organs, sexual behavior, and the ways in which culture influences sexual behavior. Males and females have different behavior patterns for a variety of reasons. Some behavioral differences are learned (e.g., patterns of dress, the use of facial makeup), whereas others appear to be less dependent on culture (e.g., degree of aggressiveness, the frequency of sexual thoughts).

There are several ways of looking at human sexuality. The behavioral sciences tend to focus on the behaviors associated with being male and female and what is considered appropriate or inappropriate sexual behavior. Psychologists consider sexual behavior to be a strong drive, appetite, or urge. They describe the sex drive as a basic impulse to satisfy a biological, social, or psychological need. Other social scientists, such as sociologists and cultural anthropologists, are interested in sexual behavior as it occurs in various cultures. When a variety of cultures are examined, it becomes very difficult to classify various kinds of sexual behavior as normal or abnormal. What is considered abnormal in one culture may be normal in another. For example, public nudity is considered abnormal in many cultures, but not in others (figure 27.1).

Biologists have studied the sexual behavior of nonhuman animals for centuries. They have long considered the function of sexuality in light of its value to the population or species. Sexual reproduction results in new combinations of genes, which are important in the process of natural selection. Many biologists are attempting to look at human sexual behavior from an evolutionary perspective and speculate on why certain sexual behaviors are common. The behaviors of courtship, mating, the raising of the young, and the division of labor between the sexes are complex in all social animals, including humans, as demonstrated in the elaborate social behaviors surrounding picking a mate and forming a family. It is difficult to draw the line between the biological development of sexuality and the social customs related to the sexual aspects of human life. However, the biological mechanism that determines whether an individual will develop into a female or a male has been well documented.

FIGURE 27.1 Culture and Sexuality
In the culture of Papua New Guinea, tradition patterns of dress typically involve partial nudity. This would be unacceptable in many Muslim cultures, which regards exposure of skin as immodest. In both cultures there are differences in the dress of men and women.

27.1 CONCEPT REVIEW

1. Define the term *sexuality.*
2. How do psychologists, biologists, and anthropologists differ in how they view sexuality?

27.2 The Sexuality Spectrum

Although we tend to think of our species as being clearly divided into two genders, male and female, sexuality really is a spectrum that includes anatomical and behavioral components. Both anatomy and behavior are the result of a complex interplay between genetic and developmental processes that are influenced by environmental factors.

Anatomy

Hermaphrodites are organisms that have both ovaries and testes in the same body. This condition is extremely rare in humans. However, incidences of partial development of the genitalia (sex organs) of both sexes in one individual may be more frequent than most people realize. About 1% of births show some level of ambiguity related to sexual anatomy. These people are referred to as *intersexual* because their sexual anatomy is not clearly male or female. Sometimes, this abnormal development occurs because the hormone levels are out of balance at critical times in the development of the embryo. This hormonal imbalance also may be related to an abnormal number of sex-determining chromosomes, or it may be the result of abnormal functioning of the endocrine glands.

When children with abnormal combinations of sex organs are born, they are usually assessed by a physician in consultation with the parents to determine which sexual structures should be retained or surgically reconstructed. The physician might also decide that hormone therapy might be a more successful treatment. These decisions are not made easily because they involve children who have not fully developed their sexual nature. An increasingly vocal group advocates that children who are diagnosed with this condition not be surgically "corrected" as infants, recommending that, if the parents can cope with the unusual genitalia, they allow the child to grow older without having the surgery. They believe that people should choose for themselves once they are more mature. However, few long-term studies have examined whether delaying reconstructive surgery presents fewer social and psychological adjustment issues than performing reconstructive surgery in children.

Behavior

A person's gender is his or her sexual identity based on anatomy. However, a person also has a psychological gender. More and more frequently, we are becoming aware of individuals whose physical gender does not match their psychological gender. These individuals are often referred to as *transgender* persons. A male with normal male sex organs may "feel" like a female. The same situation may occur with structurally female individuals. Because some of these individuals might dress as a member of the opposite sex, they are sometimes called *cross-dressers* or *transvestites*. Some of these individuals may dress as the other sex in private but dress and behave in public appropriate to their anatomical sex. Others completely change their public and private behaviors to reflect their inner desire to function as the other sex. A male may dress as a female, work in a traditionally female occupation, and make social contacts as a female. Tremendous psychological and emotional pressures develop from this condition. Frequently, many of these individuals choose to undergo gender reassignment surgery—a sex-change operation. Their goal is to interact with society without being detected as having been a different gender at one time. This surgery and the follow-up hormonal treatment can cost tens of thousands of dollars and take several years.

Homosexuality is a condition in which a person desires romantic and sexual relationships with members of their own sex. However, it is a complex behavioral pattern with many degrees of expression. Some individuals are exclusively homosexual, while others can be considered bisexual because they form sexual relationships with either males or females. Some are transgender individuals while others clearly accept their biological sex but prefer relationships with others of the same sex. However, it is becoming clear that sexual orientation in most cases is not a simple choice or a learned behavior. There appear to be differences in brain function and genetic makeup that are important. For example, certain studies suggest that genetic regions on chromosomes 7, 8, and 10 may influence homosexuality. Some regions on chromosome 7 and 8 have been linked with male sexual orientation, regardless of whether the male receives the chromosomes from his mother or father. The regions on chromosome 10 appear to be linked with male sexual orientation only if they were inherited from the mother.

Sexuality ranges from strongly heterosexual to strongly homosexual. Human sexual orientation is a complex trait, and evidence suggests that there is no one gene that determines where a person falls on the sexuality spectrum. It is most likely a combination of various genes acting together and interacting with environmental factors (figure 27.2).

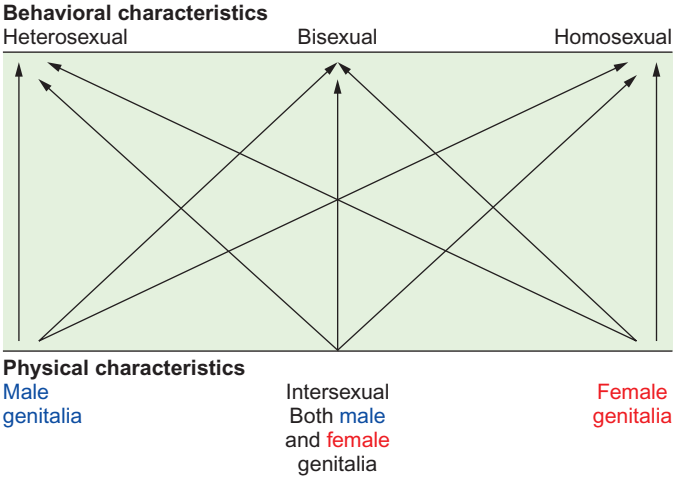


FIGURE 27.2 The Sexuality Spectrum
A person's sexuality involves both anatomical and psychological components. This figure shows how behavioral and physical sexual characteristics interrelate. At the ends of the behavioral spectrum, individuals can be strongly heterosexual or strongly homosexual, or (in the center) they might be bisexual, attracted to both sexes. On the anatomical spectrum they may be clearly anatomically male or female or be intersexual.

27.2 CONCEPT REVIEW

3. What does the term *intersexual* mean? How does it differ from the term *transgender*?
4. How is homosexuality different from transgender behavior?

27.3 Components of Human Sexual Behavior

The primary *biological* goal of sexual intercourse (coitus, mating) is the union of sperm and egg to form offspring. However, in humans and some other animals, sexual intercourse between willing partners usually is enjoyable and is an important part of the social and psychological aspects of life. Sexuality is a complex interaction that involves distinct components.

Sexual attraction involves many factors, but sight and smell are probably the most important. How one person appears to another is usually what catches the other's attention. If we find a person pleasing in appearance, we say he or she is "attractive"; that is, we want to be closer. Like many other organisms, humans release chemicals that act as attractants. These chemicals are called *pheromones*. The existence of pheromones in humans has been well-documented even though we usually are not aware of their actions. The cosmetic and fashion industries are founded on these fundamentals of sexual attraction (figure 27.3). After the initial attraction, the couple will usually talk. The conversation will better acquaint the two, present the idea that there is an attraction, and may suggest that they are interested in sexual intercourse. This period is often called courtship and may be brief or develop into a long-term relationship depending on how the two respond to one another. However, ultimately, sexual intercourse occurs or the relationship ends.

Foreplay is the term used to describe sexual stimulation that precedes sexual intercourse. Hugging, kissing, and fondling (petting) arouse sexual excitement and desire. This leads to changes in the levels of certain hormone production and an increase blood flow in both male and female genitals. In males, tissues in the penis become engorged with blood, causing the penis to stiffen or become erect. In females, the clitoris becomes erect and the labia become swollen. In addition, lubricating fluids are released from male and female reproductive tracts. Throughout arousal, the heart rate increases, breathing quickens, and blood pressure increases.

Sexual intercourse involves inserting the erect penis into the vagina. Once the penis is inside the vagina, pelvic movements result in stimulation of both the male and female and usually results in ejaculation by the male. **Ejaculation** is the release of semen, which contains sperm and other fluids, from the penis. It occurs with a pulsating of smooth muscle in the tubes that lead from the testes to the penis. This release is generally accompanied by a sensation called orgasm. **Orgasm** is the pleasurable climax of sexual activity. In addition to the muscles of sex organs (vagina, uterus, and male sex organs), muscles throughout the body begin to spasm. Following orgasm, blood, which had accumulated and caused erection of the penis or clitoris and swelling of labia, leaves and these organs return to normal. This period is typically associated with a period of complete relaxation.

Two other forms of sexual intercourse practiced are anal (penis in anus) and oral (penis in mouth or oral stimulation of vagina or clitoris). These two variations may also be part of the arousal phase of a sexual encounter.

Long-term relationships usually involve a conscious decision by the two partners to live together and make joint decisions about many aspects of their lives. However, an important part of maintaining such relationships is paying attention to the sexual aspects of the relationship. Maintaining an active, enjoyable sex life in a long-term relationship requires the same amount of effort that was extended at the beginning of the relationship. Things that can interfere include work (time away, lack of free time, tiredness), family problems (kids, relatives), physical exhaustion (work, sports), affairs, emotions (depression, anger, jealousy), and a person's overall health (overweight, strength, pain, long-term illness). The use of alcohol, street drugs, or certain prescription medications can lead to a reduction of sex drive and may include erectile dysfunction (ED). Since sight plays an initial and important role in sexual attraction and self-image, changes in a person's anatomy can also dampen sexual activity; for example, changes such as a mastectomy due to cancer or disfigurement due to an accident. In addition, acquiring a sexually transmitted disease can place limits on sexual activity in socially responsible individuals.

FIGURE 27.3 Sexual Attraction
Both males and females find appearance to be of primary importance in mate selection.

27.3 CONCEPT REVIEW

5. What is the primary biological function of sexuality?
6. Describe changes in the body that are associated with foreplay and orgasm.

27.4 Sex Determination and Embryonic Sexual Development

In humans and some other organisms, the sex of an offspring is determined by the chromosomes they inherit from their parents.

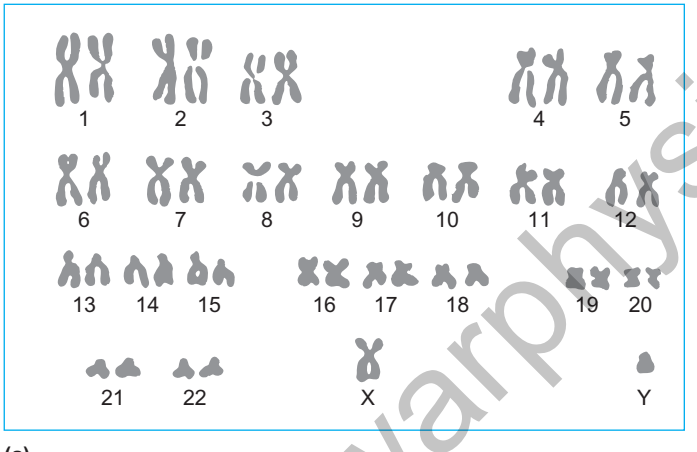
Chromosomal Determination of Sex

Recall from chapter 10 that two of the 46 chromosomes are involved in determining sex and are called **sex-determining chromosomes.** The other 44 chromosomes are known as *autosomes*. There are two kinds of sex-determining chromosomes: the **X chromosome** and the **Y chromosome** that do not carry equivalent amounts of information, nor do they have equal functions (figure 27.4).

X chromosomes carry genetic information about the production of a variety of proteins, in addition to their function in determining sex. For example, the X chromosome carries information on blood clotting, color vision, and other characteristics. The Y chromosome, with about 80 genes, however, appears to be primarily concerned with determining male sexual differentiation.

When a human **sperm,** a haploid sex cell produced by sexually mature males, is produced, it carries 22 autosomes and a sex-determining chromosome. Unlike eggs, which always carry an X chromosome, half the sperm cells carry an X chromosome and the other half carry a Y chromosome. If an X-carrying sperm cell fertilizes an X-containing egg cell, the resultant embryo will develop into a female. If a Y-carrying sperm cell fertilizes the egg, a male embryo will develop. It is the presence or absence of the **s**ex-determining **r**egion **Y** (SRY) gene located on the short arm of the Y chromosome that determines the sex of the developing individual. The SRY gene produces a chemical, called testes determining factor (TDF), which acts as a master switch that triggers the events that converts the embryo into a male. Without this gene, the embryo would become female.

The early embryo resulting from fertilization and cell division is not recognizable as either male or female. Sexual



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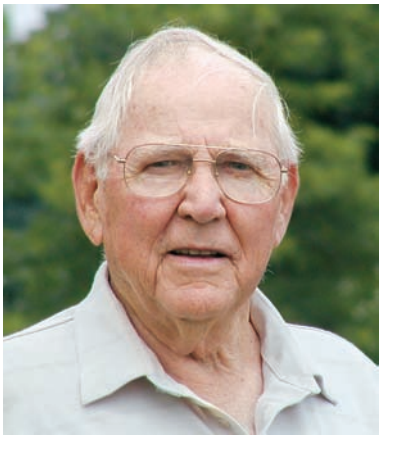

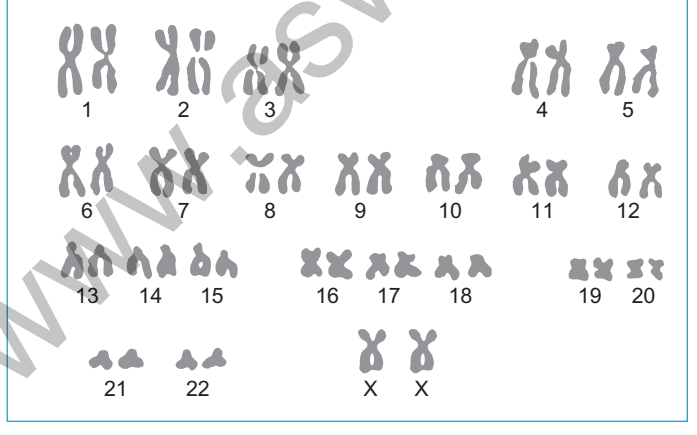

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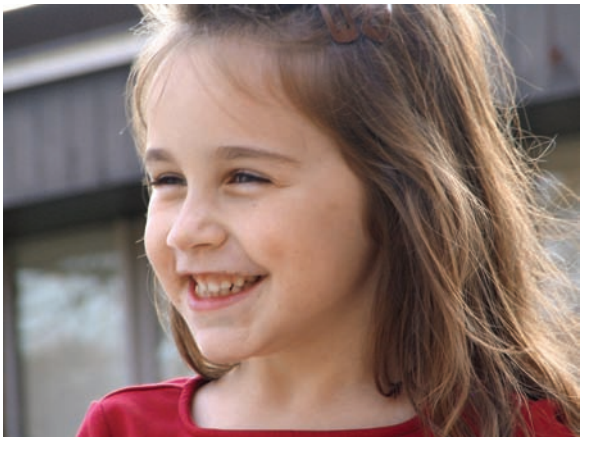


FIGURE 27.4 Human Male and Female Chromosomes
The chromosomes have been arranged into homologous pairs: *(a)* a male karyotype, with an X and a Y chromosome, and *(b)* a female karyotype, with two X chromosomes.

development begins when certain cells become specialized, forming the embryonic *gonads* known as the female ovaries and the male testes. This specialization of embryonic cells is called differentiation. If the SRY gene is present and functioning, the embryonic gonads begin to differentiate into testes 5 to 7 weeks after conception (fertilization).

Chromosomal Abnormalities and Sexual Development

Evidence that the Y chromosome and its SRY gene control male development comes from many kinds of studies, including research on individuals who have an abnormal number of chromosomes. An abnormal meiotic division that results in sex cells with too many or too few chromosomes is a form of *nondisjunction* (see chapter 9). If nondisjunction affects the X and Y chromosomes, a gamete might be produced that has only 22 chromosomes and lacks a sex-determining chromosome. On the other hand, it might have 24, with 2 sex-determining chromosomes. If a cell with too few or too many sex chromosomes is fertilized, sexual development is usually affected. If a normal egg cell is fertilized by a sperm cell with no sex chromosome, the offspring will have only 1 X chromosome. These people, always women, are designated as XO. They develop a collection of characteristics known as *Turner's syndrome* (figure 27.5).

About 1 in 2,000 girls born has Turner's syndrome. A female with this condition is short for her age and fails to mature sexually, resulting in sterility. In addition, she may have a thickened neck (termed *webbing*), hearing impairment, and some abnormalities in her cardiovascular system. When the condition is diagnosed, some of the physical conditions can be modified with treatment. Treatment involves the use of growth-stimulating hormone to increase her growth rate and female sex hormones to stimulate sexual development, although sterility is not corrected.

An individual who has XXY chromosomes is basically male (figure 27.6). This genetic condition is termed *Klinefelter's syndrome*. It is one of the most common examples of abnormal chromosome number in humans. This condition is present in about 1 in 500 to 1,000 men. Most of these men lead healthy, normal lives and it is impossible to tell them apart from normal males. However, those with Klinefelter's syndrome may be sterile and show breast enlargement, incomplete masculine body form, lack of facial hair, and some minor learning problems. These traits vary greatly in degree, and many men are diagnosed only after they undergo testing to determine why they are infertile. Treatments include breast-reduction surgery and testosterone therapy.

Fetal Sexual Development

The development of embryonic gonads begins very early during fetal growth. First, a group of cells begins to differentiate into primitive gonads at about week 5 (figure 27.7). By week 5 to 7, if a Y chromosome is present, the gene product (testes determining factor) from the chromosome begins the differentiation

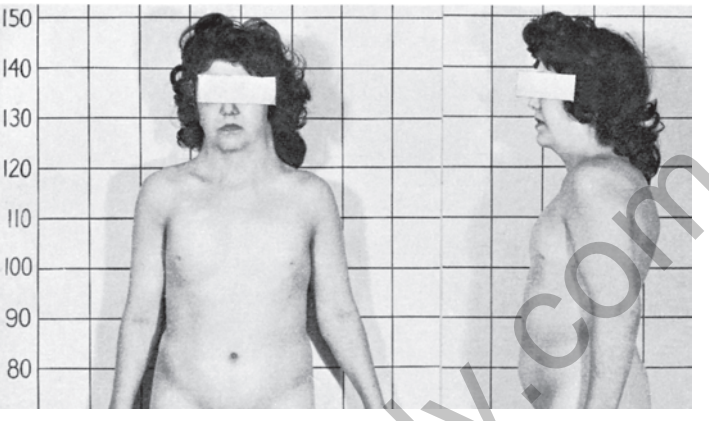
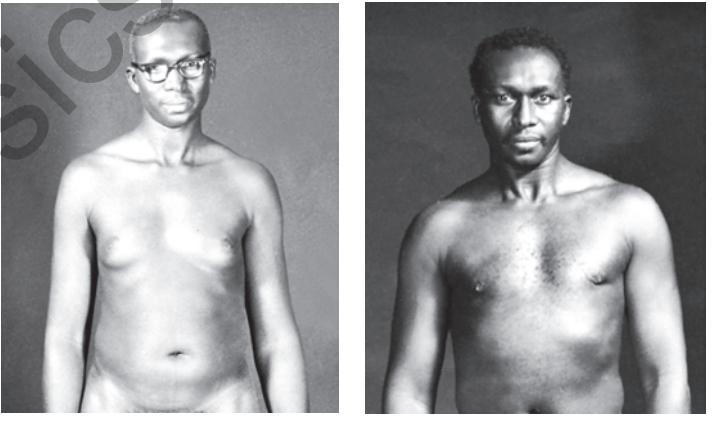


FIGURE 27.5 Turner's Syndrome
Individuals with Turner's syndrome have 45 chromosomes. They have only 1 of the sex chromosomes, and it is an X chromosome. Individuals with this condition are female, have delayed growth, and fail to develop sexually. This woman is less than 150 cm (5 ft) tall and lacks typical secondary sexual development for her age. She also has the "webbed neck" that is common among individuals with Turner's syndrome.



(a) Before hormone therapy (b) After hormone therapy

FIGURE 27.6 Klinefelter's Syndrome
Individuals with two X chromosomes and a Y chromosome are male, are sterile, and often show some degree of breast development and female body form. They are typically tall. The two photos show an individual with Klinefelter's syndrome before and after receiving testosterone hormone therapy.

of these embryonic gonads into testes. They will develop into ovaries beginning about week 12 if 2 X chromosomes are present (and the Y chromosome is absent).

As soon as the gonad has differentiated into an embryonic testis at about week 8, it begins to produce testosterone. The presence of testosterone results in the differentiation of male sexual anatomy, and the absence of testosterone results in the differentiation into female sexual anatomy in the developing embryo (Outlooks 27.1).