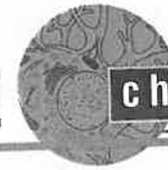

NERVOUS TISSUE

chapter 9

d you know?

Depression is characterized by a mixture of psychological and physical symptoms, nd is marked by changes in nervous system function. epression is associated with imbalances in some of the chemicals that transmit messages between nerve cells. These chemicals are called neurotransmitters. Sometimes not enough of a neurotransmitter is roduced. Other times the nerve cells do not respond to the neurotransmitter as they should. One of the neurotransmitters that plays an important role in depression is serotonin. Psychologists do not yet know whether the feelings of depression cause or are caused by neurotransmitter changes.

Focus on Wellness, page 236

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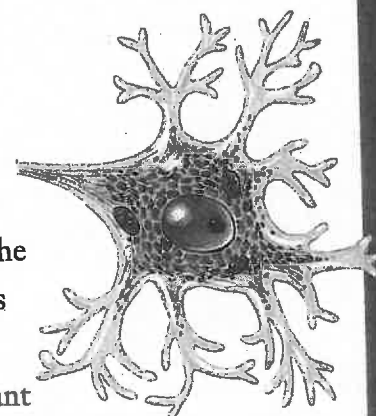


Together, all nervous tissues in the body comprise the ***nervous system***. Among the 11 body systems, the nervous system and the endocrine system play the most important roles in maintaining homeostasis. The nervous system, the subject of this and the next three chapters, can respond rapidly to help adjust body processes using nerve impulses. The endocrine system typically operates more slowly and exerts its influence on homeostasis by releasing hormones that the blood delivers to cells throughout the body. Besides helping maintain homeostasis, the nervous system is responsible for our perceptions, behaviors, and memories. It also initiates all voluntary movements. The branch of medical science that deals with the normal functioning and disorders of the nervous system is called ***neurology*** (noo-ROL-ō-jē; *neuro-* = nerve or nervous system; *-logy* = study of).

looking back to move ahead . . .

- Ion Channels (page 48)
- Sodium-potassium Pump (page 50)
- Nervous Tissue (page 90)
- Sensory Nerve Endings and Sensory Receptors in the Skin (page 100)
- Release of Acetylcholine at the Neuromuscular Junction (page 179)

OVERVIEW OF THE NERVOUS SYSTEM

OBJECTIVES • **List the structures and basic functions of the nervous system.**

• **Describe the organization of the nervous system.**

Structures of the Nervous System

The nervous system is an intricate, highly organized network of billions of neurons and even more neuroglia. The structures that make up the nervous system include the brain, cranial nerves and their branches, the spinal cord, spinal nerves and their branches, ganglia, enteric plexuses, and sensory receptors (Figure 9.1).

The skull encloses the ***brain***, which contains about 100 billion neurons. Twelve pairs (right and left) of ***cranial nerves***, numbered I through XII, emerge from the base of the brain. A ***nerve*** is a bundle of hundreds to thousands of axons plus associated connective tissue and blood vessels that lie outside the brain and spinal cord. Each nerve follows a defined path and serves a specific region of the body. For example, cranial nerve I carries signals for the sense of smell from the nose to the brain.

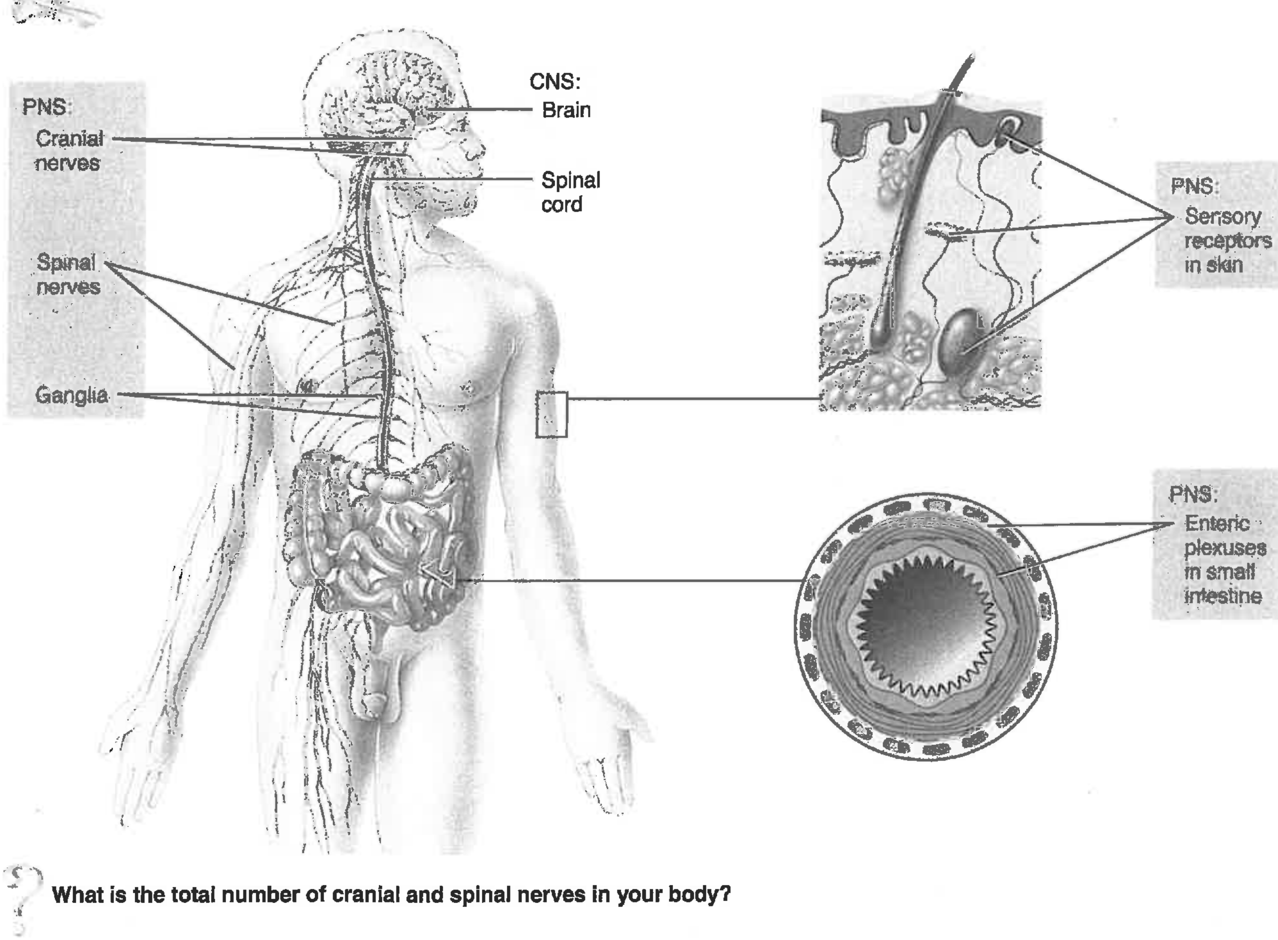
The ***spinal cord*** connects to the brain and is encircled by the bones of the vertebral column. It contains about 100 million neurons. Thirty-one pairs of ***spinal nerves*** emerge from the spinal cord, each serving a specific region on the right or left side of the body. ***Ganglia*** (GANG-lē-a = swelling or knot) are small masses of nervous tissue that are located outside the brain and spinal cord. Ganglia contain cell bodies of neurons and are closely associated with cranial and spinal nerves. In the walls of organs of the gastrointestinal tract are extensive networks of neurons, called ***enteric plexuses***, that help regulate the digestive system (Figure 9.1). ***Sensory receptors*** are either the dendrites of sensory neurons (such as sensory receptors in the skin) or separate, specialized cells that monitor changes in the internal or external environment (such as photoreceptors in the retina of the eye).

Functions of the Nervous System

The nervous system carries out a complex array of tasks, such as sensing various smells, producing speech, remembering past events, providing signals that control body movements,

Figure 9.1 Major structures of the nervous system.

The nervous system includes the brain, cranial nerves, spinal cord, spinal nerves, ganglia, enteric plexuses, and sensory receptors.



What is the total number of cranial and spinal nerves in your body?

and regulating the operation of internal organs. These diverse activities can be grouped into three basic functions: sensory, integrative, and motor.

- ***Sensory function.*** The sensory receptors *detect* many different types of stimuli, both within your body, such as an increase in blood temperature, and outside your body, such as a touch on your arm. ***Sensory*** or ***afferent neurons*** (AF-er-ent NOOR-onz; *af-* = toward; *-ferrent* = carried) carry this sensory information into the brain and spinal cord through cranial and spinal nerves.
- ***Integrative function.*** The nervous system *integrates* (processes) sensory information by analyzing and storing some of it and by making decisions for appropriate responses. An important integrative function is ***perception***, the conscious awareness of sensory stimuli. Perception occurs in the brain. Many of the neurons that participate in integration are ***interneurons***, whose axons extend for only a short distance and contact nearby neurons in the brain or spinal cord. Interneurons comprise the vast majority of neurons in the body.
- ***Motor function.*** Once a sensory stimulus is perceived, the nervous system may elicit an appropriate motor response such as muscle contraction or gland secretion. The neurons that serve this function are ***motor*** or ***efferent neurons*** (EF-er-ent; *ef-* = away from). Motor neurons carry information from the brain toward the spinal cord or out of the brain and spinal cord to ***effectors*** (muscles and glands) through cranial and spinal nerves. Stimulation of the effectors by motor neurons causes muscles to contract and glands to secrete.

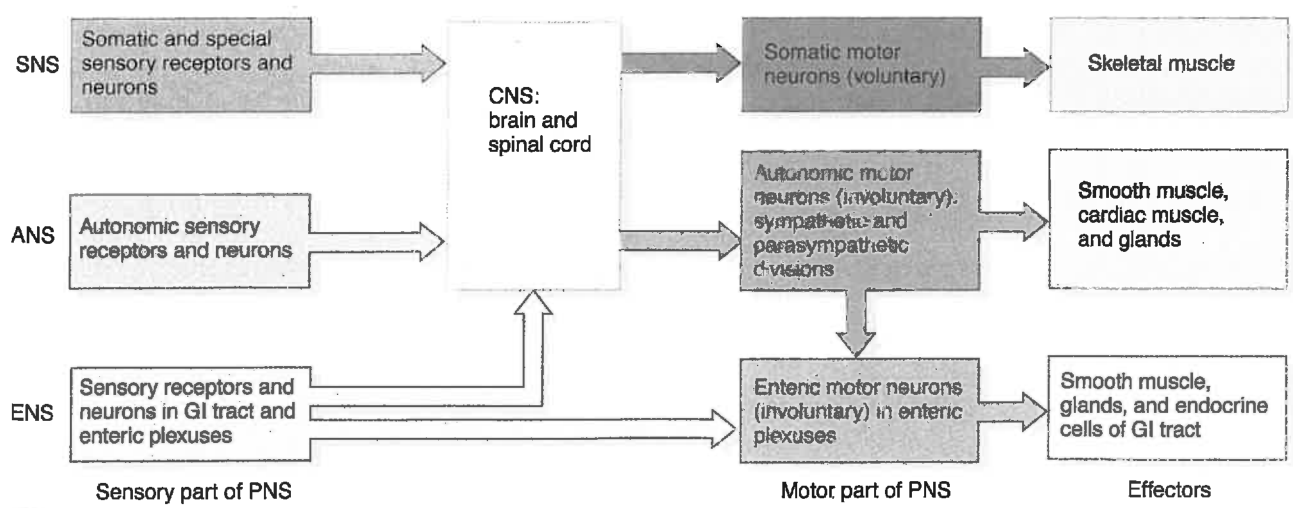
Organization of the Nervous System

The two main subdivisions of the nervous system are the ***central nervous system (CNS)***, which consists of the brain and spinal cord, and the ***peripheral*** (pe-RIF-er-al) ***nervous system (PNS)***, which includes all nervous tissue outside the CNS. The CNS integrates and correlates many different kinds of incoming sensory information. The CNS is also the source of thoughts, emotions, and memories. Most nerve impulses that stimulate muscles to contract and glands to secrete originate in the CNS. Structural components of the PNS are cranial nerves and their branches, spinal nerves and their branches, ganglia, and sensory receptors. Figure 9.2 shows the further functional subdivision of the PNS into a ***somatic nervous system (SNS)*** (*somat-* = body), an ***autonomic nervous system (ANS)*** (*auto-* = self; *-nomic* = law), and an ***enteric nervous system (ENS)*** (*enter-* = intestines). The somatic nervous system consists of (1) sensory neurons that convey information from somatic receptors in the head, body wall, and limbs and from receptors for the special senses of vision, hearing, taste, and smell to the CNS and (2) motor neurons that conduct impulses from the CNS to *skeletal muscles* only. Because these motor responses can be consciously controlled, the action of this part of the PNS is *voluntary*.

The ANS (the focus of Chapter 11) consists of (1) sensory neurons that convey information from autonomic sensory receptors, located primarily in visceral organs such as the stomach and lungs, to the CNS, and (2) motor neurons that conduct nerve impulses from the CNS to *smooth muscle*, *cardiac muscle*, and *glands*. Because its motor responses are not normally under conscious control, the action of the ANS is *invol-*

Figure 9.2 Organization of the nervous system. Subdivisions of the PNS are the somatic nervous system (SNS), the autonomic nervous system (ANS), and the enteric nervous system (ENS).

The two main subdivisions of the nervous system are (1) the central nervous system (CNS), consisting of the brain and spinal cord, and (2) the peripheral nervous system (PNS), consisting of all nervous tissue outside the CNS.



Which types of neurons carry input to the CNS and output from the CNS?

untary. The motor part of the ANS consists of two divisions, the *sympathetic division* and the *parasympathetic division*. With a few exceptions, effectors are innervated by both divisions, and usually the two divisions have opposing actions. For example, sympathetic neurons speed the heartbeat, and parasympathetic neurons slow it down. In general, the sympathetic division helps support exercise or emergency actions, so-called "fight-or-flight" responses, and the parasympathetic division takes care of "rest-and-digest" activities.

The enteric nervous system is the "brain of the gut," and its operation is involuntary. Its neurons extend most of the length of the gastrointestinal (GI) tract. Sensory neurons of the enteric nervous system monitor chemical changes within the GI tract and the stretching of its walls. Enteric motor neurons govern contraction of GI tract smooth muscle, secretions of the GI tract organs, such as acid secretion by the stomach, and activity of GI tract endocrine cells.

CHECKPOINT

1. What are the components of the CNS and PNS?
2. What kinds of problems would result from damage of sensory neurons, interneurons, and motor neurons?
3. What are the components and functions of the somatic, autonomic, and enteric nervous systems? Which subdivisions have involuntary actions?

HISTOLOGY OF NERVOUS TISSUE

OBJECTIVES • **Contrast the histological characteristics and the functions of neurons and neuroglia.**
• **Distinguish between gray matter and white matter.**

Nervous tissue consists of two types of cells: neurons and neuroglia. ***Neurons*** (nerve cells) are the basic information-processing units of the nervous system and are specialized for nerve impulse (action potential) conduction. They provide most of the unique functions of the nervous system, such as sensing, thinking, remembering, controlling muscle activity, and regulating glandular secretions. ***Neuroglia*** (noo-RŌG-lē-a; *glia* = glue) support, nourish, and protect the neurons and maintain homeostasis in the interstitial fluid that bathes neurons.

Neurons

Neurons usually have three parts: (1) a cell body, (2) dendrites, and (3) an axon (Figure 9.3). The ***cell body*** contains a nucleus surrounded by cytoplasm that includes typical organelles such as rough endoplasmic reticulum, lysosomes, mitochondria, and a Golgi complex. Most cellular molecules needed for a neuron's operation are synthesized in the cell body.

Two kinds of processes (extensions) emerge from the cell body of a neuron: multiple dendrites and a single axon. The cell body and the ***dendrites*** (= little trees) are the receiving or input parts of a neuron. Usually, dendrites are short, tapering, and highly branched, forming a tree-shaped array of processes that emerge from the cell body. The second type of process, the ***axon***, conducts nerve impulses toward another neuron, a muscle fiber, or a gland cell. An axon is a long, thin, cylindrical projection that often joins the cell body at a cone-shaped elevation called the *axon hillock* (= small hill). Nerve impulses usually arise at the axon hillock and then travel along the axon. Some axons have side branches called *axon collaterals*. The axon and axon collaterals end by dividing into many fine processes called *axon terminals*.

The site where two neurons or a neuron and an effector cell can communicate is termed a ***synapse***. The tips of most axon terminals swell into *synaptic end bulbs*. These bulb-shaped structures contain *synaptic vesicles*, tiny sacs that store chemicals called *neurotransmitters*. The neurotransmitter molecules released from synaptic vesicles are the means of communication at a synapse.

Myelination

The axons of most neurons are surrounded by a ***myelin sheath***, a many-layered covering composed of lipid and protein (Figure 9.3). Like insulation covering an electrical wire, the myelin sheath insulates the axon of a neuron and increases the speed of nerve impulse conduction. As you will learn shortly, Schwann cells in the PNS and oligodendrocytes in the CNS produce myelin sheaths by wrapping themselves around and around axons. Eventually, as many as 100 layers cover the axon, much as multiple layers of paper cover the cardboard tube in a roll of toilet paper. Gaps in the myelin sheath, called ***nodes of Ranvier*** (RON-vē-ā), appear at intervals along the axon (Figure 9.3). Axons with a myelin sheath are said to be ***myelinated***, and those without it are said to be ***unmyelinated***.

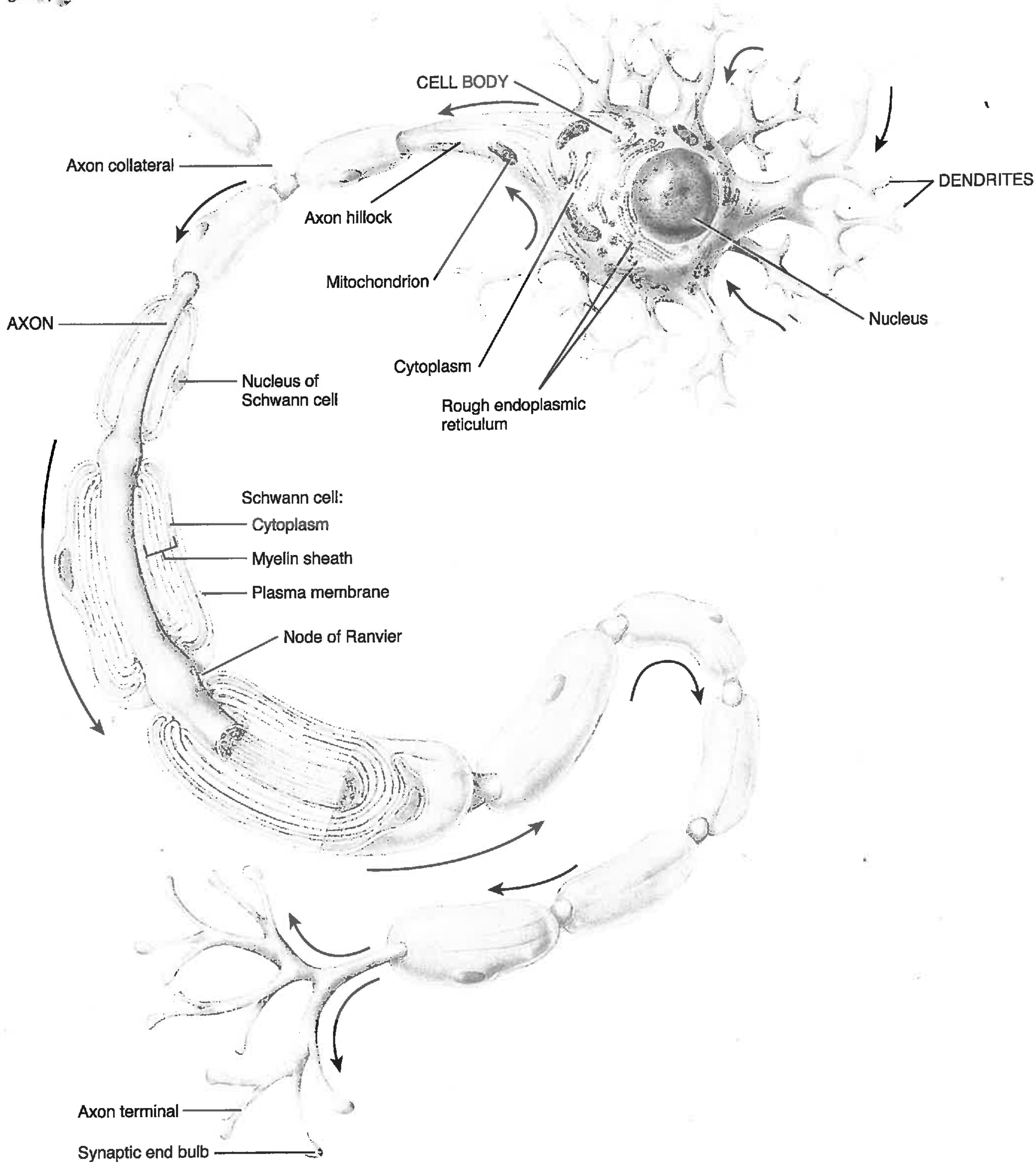
The amount of myelin increases from birth to maturity, and its presence greatly increases the speed of nerve impulse conduction. By the time a baby starts to talk, most myelin sheaths are partially formed, but myelination continues into the teenage years. An infant's responses to stimuli are neither as rapid nor as coordinated as those of an older child or an adult, in part because myelination is still in progress during infancy. Certain diseases, such as multiple sclerosis (see page 237) and Tay-Sachs disease (see page 56), destroy myelin sheaths.

Gray and White Matter

In a freshly dissected section of the brain or spinal cord, some regions look white and glistening, and others appear

Figure 9.3 Structure of a typical multipolar neuron. Arrows indicate the direction of information flow: dendrites → cell body → axon → axon terminals → synaptic end bulbs.

The basic parts of a neuron are several dendrites, a cell body, and a single axon.



What roles do the axon and axon terminals play in the communication of one neuron with another?

gray. The ***white matter*** of nervous tissue consists primarily of myelinated axons of many neurons. The whitish color of myelin gives white matter its name. The ***gray matter*** of nervous tissue contains neuronal cell bodies, dendrites, unmyelinated axons, axon terminals, and neuroglia. It looks grayish, rather than white, because the cellular organelles impart a gray color and there is little or no myelin in these areas. Blood vessels are present in both white and gray matter.

In the spinal cord, the outer white matter surrounds an inner core of gray matter shaped like a butterfly or the letter H (see Figure 10.1 on page 243). In the brain, a thin shell of gray matter (cortex) covers the surface of the largest parts of the brain, the cerebrum and cerebellum (see Figures 10.10 and 10.11 on pages 254 and 256, respectively). When used to describe nervous tissue, a ***nucleus*** is a cluster of neuronal cell bodies within the CNS. (Recall that the term *ganglion* refers to a similar arrangement within the PNS). Many nuclei of gray matter lie deep within the brain. Much of the CNS white matter consists of ***tracts***, which are bundles of axons in the CNS that extend for some distance up or down the spinal cord or connect parts of the brain with each other and with the spinal cord. (Recall that the term *nerve* refers to a bundle of axons in the PNS).

Human neurons have very limited powers of **regeneration**, the capability to replicate or repair themselves. In the PNS, axons and dendrites may undergo repair if the cell body is intact and if the Schwann cells are functional. The Schwann cells on either side of an injured site multiply by mitosis, grow toward each other, and may form a **regeneration tube** across the injured area. The tube guides axonal regrowth from the proximal area across the injured area into the distal area previously occupied by the original axon. Regrowth is slow, in part, because many needed materials must be transported from their sites of synthesis in the cell body several inches or feet down the axon to the growth region. New axons cannot grow if the gap becomes filled with scar tissue. In the CNS, even when the cell body remains intact, a cut axon is usually not repaired. The presence of CNS myelin is one factor that actively inhibits regeneration of neurons.

Neuroglia

Neuroglia constitute about half the volume of the CNS. Their name derives from the idea of early histologists that they were the "glue" that held nervous tissue together. We now know that neuroglia are not merely passive bystanders but rather active participants in the operation of nervous tissue. Generally, neuroglia are smaller than neurons, and they are 5 to 50 times more numerous. In contrast to neurons, glia do not generate or conduct nerve impulses, and they can multiply and divide in the mature nervous system. In cases of injury or disease, neuroglia multiply to fill in the spaces formerly occupied by neurons. Brain tumors derived from glia, called ***gliomas***, often are highly malignant and grow rapidly. Of the six types of neuroglia, four—astrocytes, oligodendrocytes, microglia, and ependymal cells—are found only in the CNS. The remaining two types—Schwann cells and satellite cells—are present in the PNS. Table 9.1 shows the appearance of neuroglia and lists their funcions.

■ **CHECKPOINT**

4. What are the functions of the dendrites, cell body, axon, and synaptic end bulbs of a neuron?
5. Which cells produce myelin in nervous tissue, and what is the function of a myelin sheath?
6. What are the functions of neuroglia?

ACTION POTENTIALS

OBJECTIVE • Describe how a nerve impulse is generated and conducted.

Neurons communicate with one another by means of nerve action potentials, also called nerve impulses. Recall from Chapter 8 that a muscle fiber contracts in response to a muscle action potential. The generation of action potentials in both muscle fibers and neurons depends on two basic features of the plasma membrane: the existence of a resting membrane potential and the presence of specific types of ion channels. Many body cells exhibit a ***membrane potential***, a difference in the amount of electrical charge on the inside of the plasma membrane as compared to the outside. The membrane potential is like voltage stored in a battery. A cell that has a membrane potential is said to be ***polarized***. When muscle fibers and neurons are "at rest" (not conducting action potentials), the voltage across the plasma membrane is termed the ***resting membrane potential***.

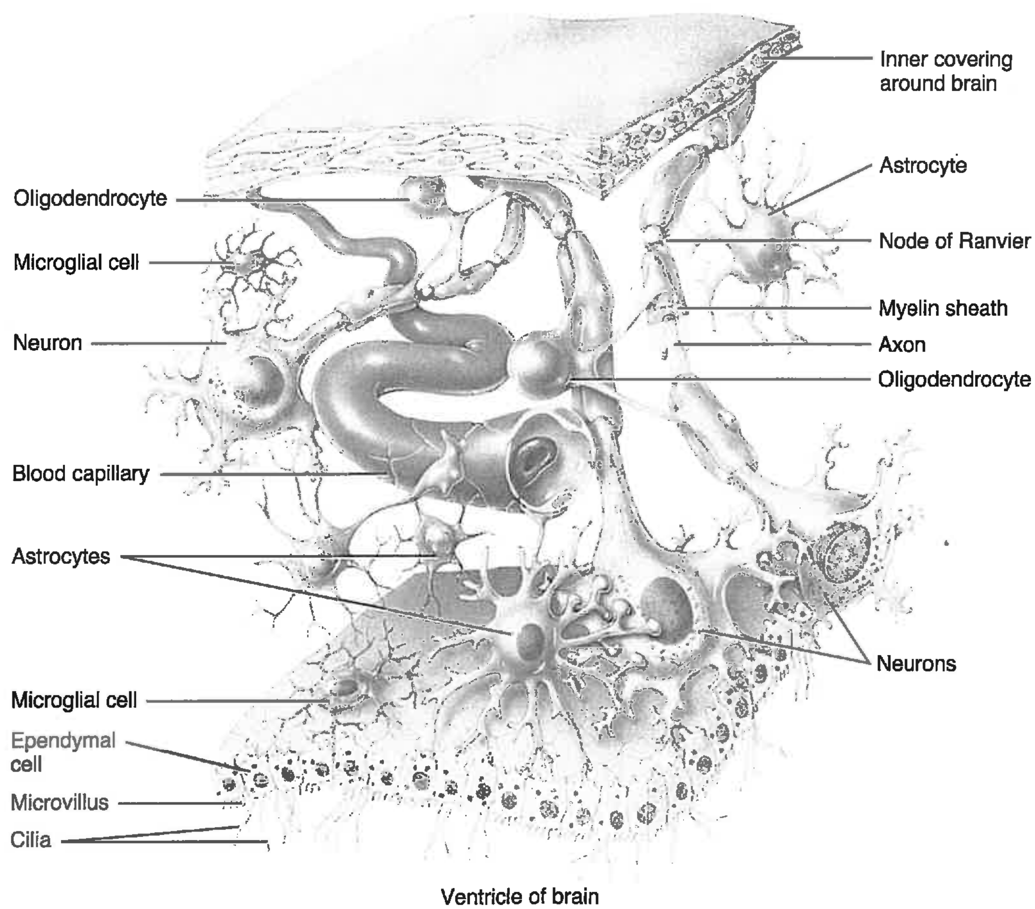
If you connect the positive and negative terminals of a battery with a piece of metal (look in the battery compartment of your portable radio), an *electrical current* carried by electrons flows from the battery, allowing you to listen to your favorite music. In living tissues, the flow of *ions* (rather than electrons) constitutes electrical currents. The main sites where ions can flow across the membrane are through the pores of various types of ion channels.

Ion Channels

When they are open, ion channels allow specific ions to diffuse across the plasma membrane from where the ions are more concentrated to where they are less concentrated. Similarly, positively charged ions will move toward a negatively

Table 9.1 Neuroglia in the CNS and PNS

Type of Neuroglial Cell	Functions	Type of Neuroglial Cell	Functions
Central Nervous System			
Astrocytes (AS-trō-sītz; *astro-* = star; *-cyte* = cell)	Support neurons; protect neurons from harmful substances; help maintain proper chemical environment for generation of nerve impulses; assist with growth and migration of neurons during brain development; play a role in learning and memory; help form the blood–brain barrier.	**Oligodendrocytes** (OL-i-gō-den′-drō- sītz; *oligo-* = few; *dendro-* = tree)	Produce and maintain myelin sheath around several adjacent axons of CNS neurons.
Microglia (mī-KROG-lē-a; *micro-* = small)	Protect CNS cells from disease by engulfing invading microbes; migrate to areas of injured nerve tissue where they clear away debris of dead cells.	**Ependymal cells** (ep-EN-di-mal; *epen-* = above; *dym-* = garment)	Line ventricles of the brain (cavities filled with cerebrospinal fluid) and central canal of the spinal cord; form cerebrospinal fluid and assist in its circulation.
Peripheral Nervous System			
Schwann cells	Produce and maintain myelin sheath around a single axon of a PNS neuron; participate in regeneration of PNS axons.	**Satellite cells** (SAT-i-līt)	Support neurons in PNS ganglia and regulate exchange of materials between neurons and interstitial fluid.



charged area, and negatively charged ions will move toward a positively charged area. As ions diffuse across a plasma membrane to equalize differences in charge or concentration, the result is a flow of current that can change the membrane potential.

Two different types of ion channels are leakage channels and gated channels. ***Leakage channels*** allow a small but steady stream of ions to leak across the membrane. Because plasma membranes typically have many more potassium ion (K^+) leakage channels than sodium ion (Na^+) leakage channels, the membrane's permeability to K^+ is much higher than its permeability to Na^+. ***Gated channels***, in contrast, open and close on command (see Figure 3.5 on page 48). ***Voltage-gated channels***—channels that open in response to a change in membrane potential—are used to generate and conduct action potentials.

Resting Membrane Potential

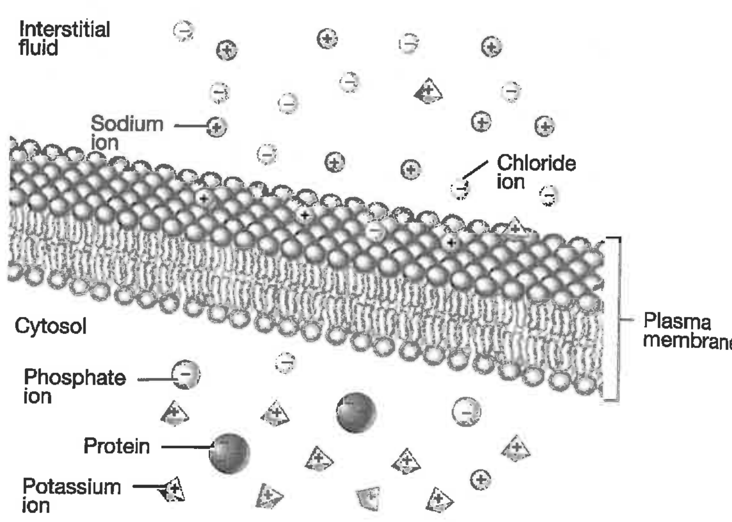
In a resting neuron, the outside surface of the plasma membrane has a positive charge and the inside surface has a negative charge. The separation of positive and negative electrical charges is a form of potential energy, which can be measured in volts. For example, two 1.5-volt batteries can power a portable radio. Voltages produced by cells typically are much smaller and are measured in millivolts (1 millivolt = 1 mV = 1/1000 volt). In neurons, the resting membrane potential is about −70 mV. The minus sign indicates that the inside of the membrane is negative relative to the outside.

The resting membrane potential arises from the unequal distributions of various ions in cytosol and interstitial fluid (Figure 9.4). Interstitial fluid is rich in sodium ions (Na^+) and chloride ions (Cl^-). Inside cells, the main positively charged ions in the cytosol are potassium ions (K^+), and the two dominant negatively charged ions are phosphates attached to organic molecules, such as the three phosphates in ATP (adenosine triphosphate), and amino acids in proteins. Because the concentration of K^+ is higher in cytosol and because plasma membranes have many K^+ leakage channels, potassium ions diffuse down their concentration gradient—out of cells into the interstitial fluid. As more and more positive potassium ions exit, the inside of the membrane becomes increasingly negative, and the outside of the membrane becomes increasingly positive. Another factor contributes to the negativity inside: Most negatively charged ions inside the cell are not free to leave. They cannot follow the K^+ out of the cell because they are attached either to large proteins or to other large molecules.

Membrane permeability to Na^+ is very low because there are only a few sodium leakage channels. Nevertheless, sodium ions do slowly diffuse inward, down their concentration gradient. Left unchecked, such inward leakage of Na^+ would eventually destroy the resting membrane potential. The small inward Na^+ leak and outward K^+ leak are offset by

Figure 9.4 The distribution of ions that produces the resting membrane potential.

The resting membrane potential is due to a small buildup of negatively charged ions, mainly organic phosphates (PO_4^{3-}) and proteins, in the cytosol just inside the membrane and an equal buildup of positively charged ions, mainly sodium ions (Na^+), in the interstitial fluid just outside the membrane.



What is a typical value for the resting membrane potential of a neuron?

the sodium-potassium pumps (see Figure 3.9 on page 51). These pumps help maintain the resting membrane potential by pumping out Na^+ as fast as it leaks in. At the same time, the sodium-potassium pumps bring in K^+.

Generation of Action Potentials

An ***action potential (AP)*** or ***impulse*** is a sequence of rapidly occurring events that decrease and reverse the membrane potential and then eventually restore it to the resting state. The ability of muscle fibers and neurons to convert stimuli into action potentials is called ***electrical excitability***. A ***stimulus*** is anything in the cell's environment that can change the resting membrane potential. If a stimulus causes the membrane to depolarize to a critical level, called ***threshold*** (typically, about −55 mV), then an action potential arises (Figure 9.5). An action potential has two main phases: a depolarizing phase and a repolarizing phase. During the ***depolarizing phase***, the negative membrane potential becomes less negative, reaches zero, and then becomes positive. Then, during the ***repolarizing phase***, the membrane polarization is restored to its resting state of −70 mV (Figure 9.5). In neurons, the depolarizing and repolarizing phases of an action potential typically last about one millisecond (1/1000 sec).

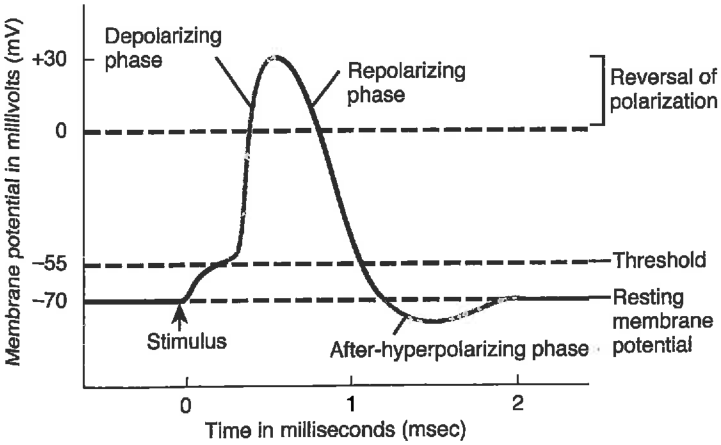
During an action potential, depolarization to threshold briefly opens two types of voltage-gated ion channels. In neurons, these channels are present mainly in the plasma membrane of the axon and axon terminals. First, a threshold depolarization opens voltage-gated Na^+ channels. As these channels open, about 20,000 sodium ions rush into the cell, causing the depolarizing phase. The inflow of Na^+ causes the membrane potential to pass 0 mV and finally reach +30 mV (Figure 9.5). Second, the threshold depolarization also opens voltage-gated K^+ channels. The voltage-gated K^+ channels open more slowly, so their opening occurs at about the same time the voltage-gated Na^+ channels are automatically closing. As the K^+ channels open, potassium ions flow out of the cell, producing the repolarizing phase.

While the voltage-gated K^+ channels are open, outflow of K^+ may be large enough to cause an ***after-hyperpolarizing phase*** of the action potential (Figure 9.5). During hyperpolarization, the membrane potential becomes even *more negative* than the resting level. Finally, as K^+ channels close, the membrane potential returns to the resting level of −70 mV.

Action potentials arise according to the ***all-or-none principle***. As long as a stimulus is strong enough to cause depolarization to threshold, the voltage-gated Na^+ and K^+ channels open, and an action potential occurs. A much stronger stimulus cannot cause a larger action potential because the size of an action potential is always the same. A weak stimulus that fails to cause a threshold-level depolarization does not elicit an action potential. For a brief time after an action potential begins, a muscle fiber or neuron cannot generate another action potential. This time is called the *refractory period*.

Figure 9.5 Action potential (AP). When a stimulus depolarizes the membrane to threshold, an action potential is generated.

An action potential consists of depolarizing and repolarizing phases.



Which channels are open during depolarization? During repolarization?

Conduction of Nerve Impulses

To communicate information from one part of the body to another, nerve impulses must travel from where they arise, usually at the axon hillock, along the axon to the axon terminals (Figure 9.6). This type of impulse movement, which operates by positive feedback, is called ***conduction*** or ***propagation***. Depolarization to threshold at the axon hillock opens voltage-gated Na^+ channels. The resulting inflow of sodium ions depolarizes the adjacent membrane to threshold, which opens even more voltage-gated Na^+ channels, a positive feedback effect. Thus, a nerve impulse self-conducts along the axon plasma membrane. This situation is similar to pushing on the first domino in a long row: When the push on the first domino is strong enough, that domino falls against the second domino, and eventually the entire row topples.

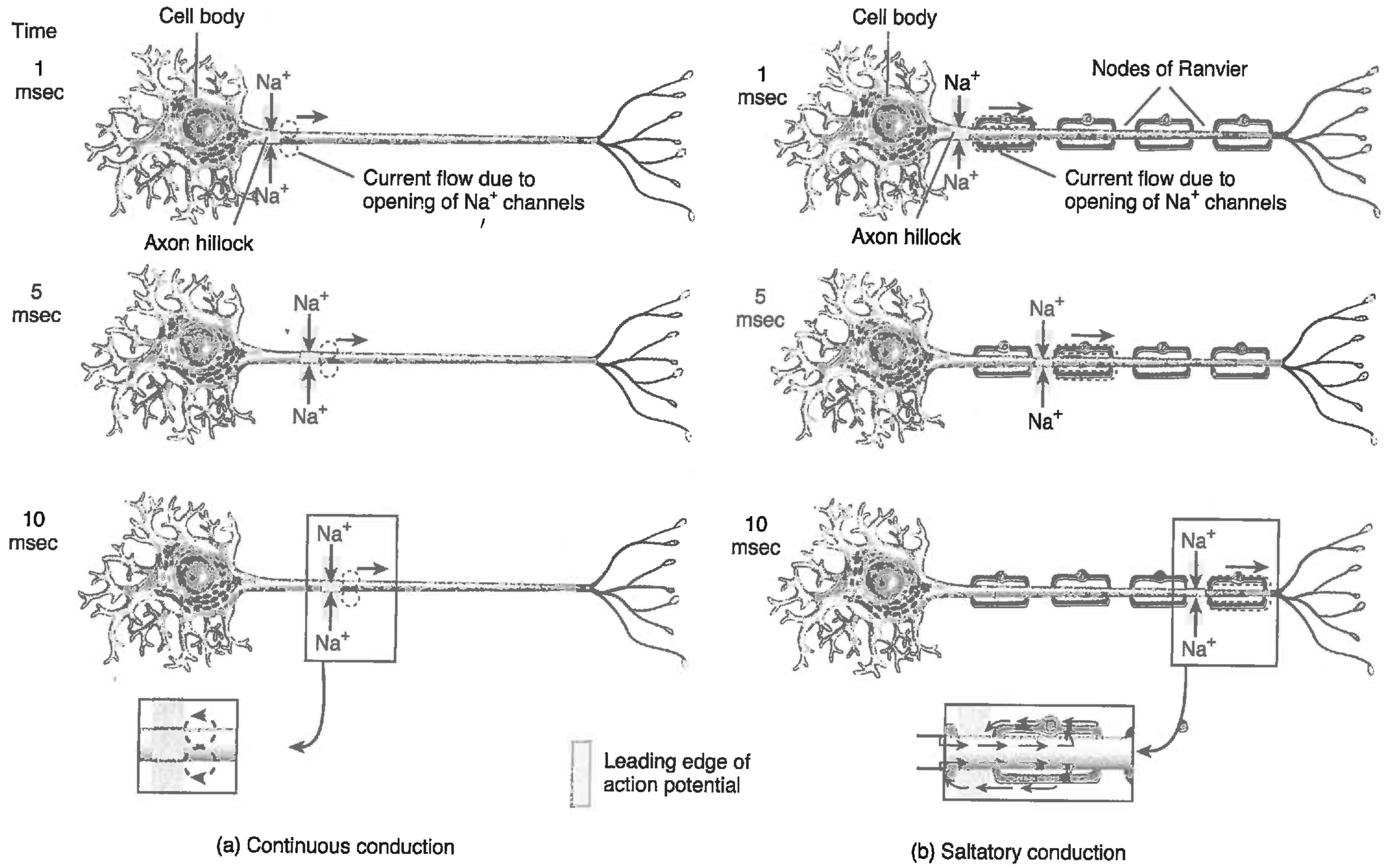
The type of action potential conduction that occurs in unmyelinated axons (and in muscle fibers) is called ***continuous conduction***. In this case, each adjacent segment of the plasma membrane depolarizes to threshold and generates an action potential that depolarizes the next patch of the membrane (Figure 9.6a). Note that the impulse has traveled only a relatively short distance after 10 milliseconds (10 msec).

In myelinated axons, conduction is somewhat different. The voltage-gated Na^+ and K^+ channels are located primarily at the nodes of Ranvier, the gaps in the myelin sheath. When a nerve impulse conducts along a myelinated axon, current carried by Na^+ and K^+ flows through the interstitial fluid surrounding the myelin sheath and through the cytosol from one node to the next (Figure 9.6b). The nerve impulse at the first node generates ionic currents that open voltage-gated Na^+ channels at the second node and trigger a nerve impulse there. Then the nerve impulse from the second node generates an ionic current that opens voltage-gated Na^+ channels at the third node, and so on. Each node depolarizes and then repolarizes. Note the impulse has traveled much farther along the myelinated axon in Figure 9.6b in the same interval. Because current flows across the membrane only at the nodes, the impulse appears to leap from node to node as each nodal area depolarizes to threshold. This type of impulse conduction is called ***saltatory conduction*** (SAL-ta-tō-rē; *saltat-* = leaping).

The diameter of the axon and the presence or absence of a myelin sheath are the most important factors that determine the speed of nerve impulse conduction. Axons with large diameters conduct impulses faster than those with small diameters. Also, myelinated axons conduct impulses faster than do unmyelinated axons. Axons with the largest diameters are all myelinated and therefore capable of saltatory conduction. The smallest diameter axons are unmyelinated, so their conduction is continuous. Axons conduct impulses at higher speeds when warmed and at lower speeds when cooled. Pain resulting from tissue injury such as that caused by a minor burn can be reduced by the application of ice because cooling slows conduction of nerve impulses along the axons of pain-sensitive neurons.

Figure 9.6 Conduction of a nerve impulse after it arises at the axon hillock. Dotted lines indicate ionic current flow. (a) In continuous conduction along an unmyelinated axon, ionic currents flow across each adjacent portion of the plasma membrane. (b) In saltatory conduction along a myelinated axon, the nerve impulse at the first node generates ionic currents in the cytosol and interstitial fluid that open voltage-gated Na^+ channels at the second node, and so on at each subsequent node.

Unmyelinated axons exhibit continuous conduction, and myelinated axons exhibit saltatory conduction.



What factors influence the speed of nerve impulse conduction?

Local anesthetics are drugs that block pain. Examples include procaine (Novocaine®) and Lidocaine, which may be used to produce anesthesia in the skin during suturing of a gash, in the mouth during dental work, or in the lower body during childbirth. These drugs act by blocking the opening of voltage-gated Na^+ channels. Nerve impulses cannot conduct past the obstructed region, so pain signals do not reach the CNS.

CHECKPOINT

7. What are the meanings of the terms resting membrane potential, depolarization, repolarization, nerve impulse, and refractory period?
8. How is saltatory conduction different from continuous conduction?

SYNAPTIC TRANSMISSION

OBJECTIVE • **Explain the events of synaptic transmission and the types of neurotransmitters used.**

Now that you know how action potentials arise and conduct along the axon of an individual neuron, we will explore how neurons communicate with one another. At synapses, neurons communicate with other neurons or with effectors by a series of events known as ***synaptic transmission***. In Chapter 8 we examined the events occurring at the neuromuscular junction, the synapse between a somatic motor neuron and a skeletal muscle fiber (see Figure 8.5 on page 178). Synapses between neurons operate in a similar way. The neuron sending the signal is called the ***presynaptic neuron*** (*pre-* = before), and the neuron receiving the message is called the ***postsynaptic neuron*** (*post-* = after).