It was a bright sunny day, without a cloud in the sky, when Malcolm's horse rose to clear the stone wall. As the rear hoofs caught on the wall, horse and rider went down with a tremendous thud. Other riders quickly dismounted and ran over to where Malcolm lay on the ground. He did not move, but his eyes were open and he was breathing; therefore, they knew he was alive. Xrays taken later showed a broken cervical vertebra and injury to the spinal cord.

The spinal cord is a ropelike bundle of long tracts that shuttle messages between the brain and the rest of the body. Together the brain and spinal cord compose the **central nervous system (CNS),** which interprets sensory input before coordinating a motor response. The **peripheral nervous system (PNS)** consists of nerves, which carry sensory information to the CNS and also motor commands from the CNS to the muscles and glands (Fig. 17.1).

When Malcolm hurt his spinal cord, the CNS lost its avenue of communication with the portion of his body located below the site of damage. He receives no sensation from most of his body nor can he command his arms and legs to move. But cranial nerves from his eyes and ears still allow him to see and hear and his brain still enables him to have emotions, remember, and reason. Also his internal organs still function, a sign that his injury was not as severe as it could have been. In this chapter we will examine the structure of the nervous system and how it carries out its numerous functions.

17.1 Neurons and How They Work

Nervous tissue contains two types of cells: neuroglial cells and neurons. **Neuroglial cells** support and service **neurons,** the cells that actually transmit nerve impulses (see Fig. 11.6).

Neuron Structure

Despite their varied appearance, all neurons have just three parts: dendrites, cell body, and an axon. It becomes apparent from studying the motor neuron in Figure 17.2 that **dendrites** are processes that send signals toward the cell body. The **cell body** is the part of a neuron that contains the nucleus and other organelles. An **axon** conducts nerve impulses along its entire length. Axons are sometimes referred to as long fibers.

There are three classes of neurons: sensory neurons, motor neurons, and interneurons, whose functions are best described in relation to the CNS (Fig. 17.2). A **sensory neuron** takes information from a sensory receptor to the CNS, and a **motor neuron** takes information away from the CNS to an effector (muscle fiber or gland). An **interneuron** conveys information between neurons in the CNS. An interneuron can receive input from sensory neurons and also from other interneurons in the CNS. Thereafter, they sum up all these signals before sending commands out to the muscles and glands by way of motor neurons.

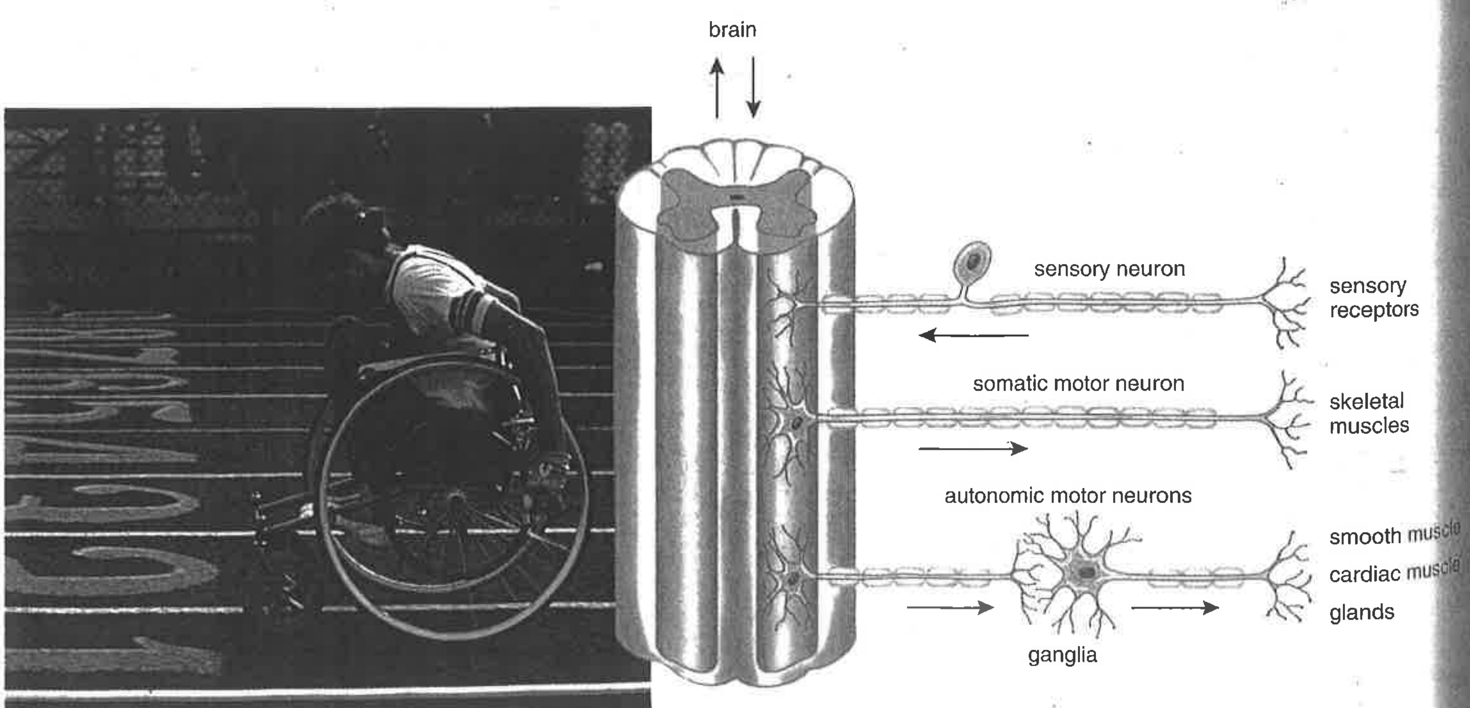


Figure 17.1 Organization of nervous system.
a. In paraplegics, messages no longer flow between the legs and the central nervous system (the spinal cord and brain). **b.** The sensory neurons of the peripheral nervous system take nerve impulses from sensory receptors to the central nervous system (CNS), and motor neurons (both somatic to skeletal muscles and autonomic to internal organs) take nerve impulses from the CNS to the organs listed.

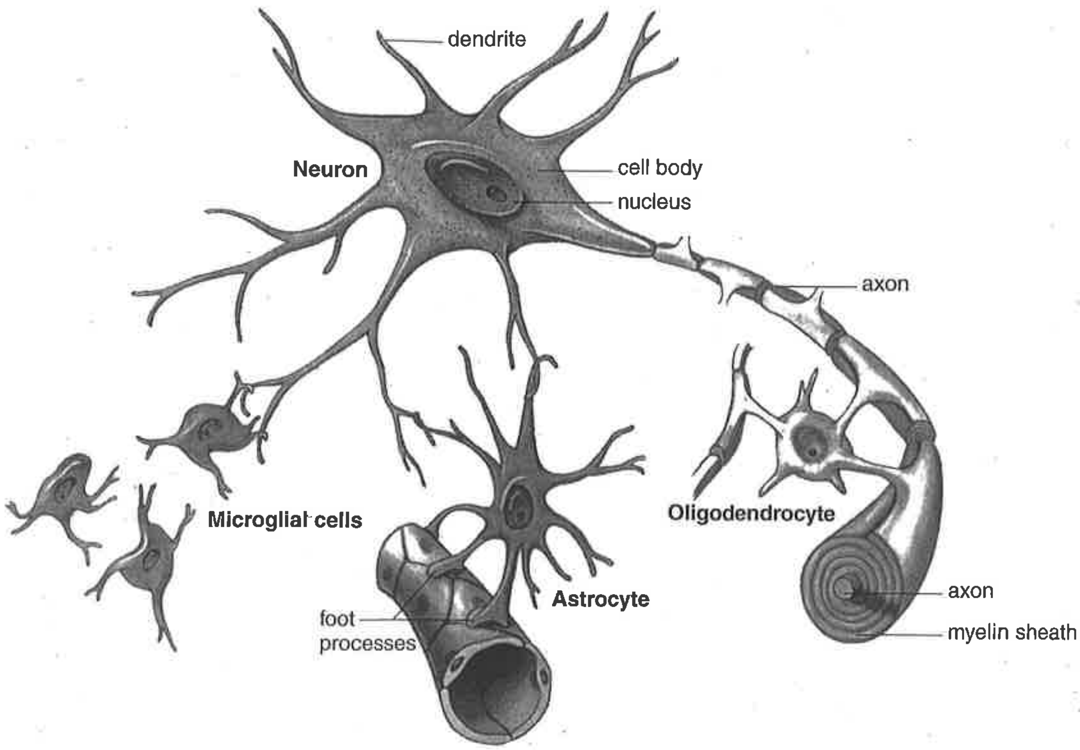


Figure 11.6 Neuron and neuroglial cells.
Neurons conduct nerve impulses. Neuroglial cells, which support and service neurons, have various functions: microglial cells are phagocytes that clean up debris. Astrocytes lie between neurons and a capillary; therefore, substances entering neurons from the blood must first pass through astrocytes. Oligodendrocytes form the myelin sheaths around fibers in the brain and spinal cord.

Nervous Tissue

Nervous tissue, which contains nerve cells called neurons, is present in the brain and spinal cord. A **neuron** is a specialized cell that has three parts: dendrites, cell body, and an axon (Fig. 11.6). A dendrite is a process that conducts signals toward the cell body. The cell body contains the major concentration of the cytoplasm and the nucleus of the neuron. An axon is a process that typically conducts nerve impulses away from the cell body. Axons can be quite long, and outside the brain and the spinal cord, long fibers, bound by connective tissue, form **nerves.**

The nervous system has just three functions: sensory input, integration of data, and motor output. Nerves conduct impulses from sensory receptors to the spinal cord and the brain where integration occurs. The phenomenon called sensation occurs only in the brain, however. Nerves also conduct nerve impulses away from the spinal cord and brain to the muscles and glands, causing them to contract and secrete, respectively. In this way, a coordinated response to the stimulus is achieved.

In addition to neurons, nervous tissue contains neuroglial cells.

Neuroglial Cells

There are several different types of neuroglial cells in the bra (Fig. 11.6), and much research is currently being conducted determine how much "glial" cells contribute to the functio ing of the brain. **Neuroglial cells** outnumber neurons nine one and take up more than half the volume of the brain, b until recently, they were thought to merely support and no ish neurons. Three types of neuroglial cells are oligodendr cytes, microglial cells, and astrocytes. Oligodendrocytes for myelin; and microglial cells, in addition to supporting neuro phagocytize bacterial and cellular debris. Astrocytes provi nutrients to neurons and produce a hormone known as gli derived growth factor, which someday might be used as a cu for Parkinson's disease and other diseases caused by neur degeneration. Neuroglial cells don't have a long process, b even so, researchers are now beginning to gather evidence th they do communicate among themselves and with neurons.

Nerve cells, called neurons, have fibers (processes) called axons and dendrites. Axons are found in nerves. Neuroglial cells support and service neurons.

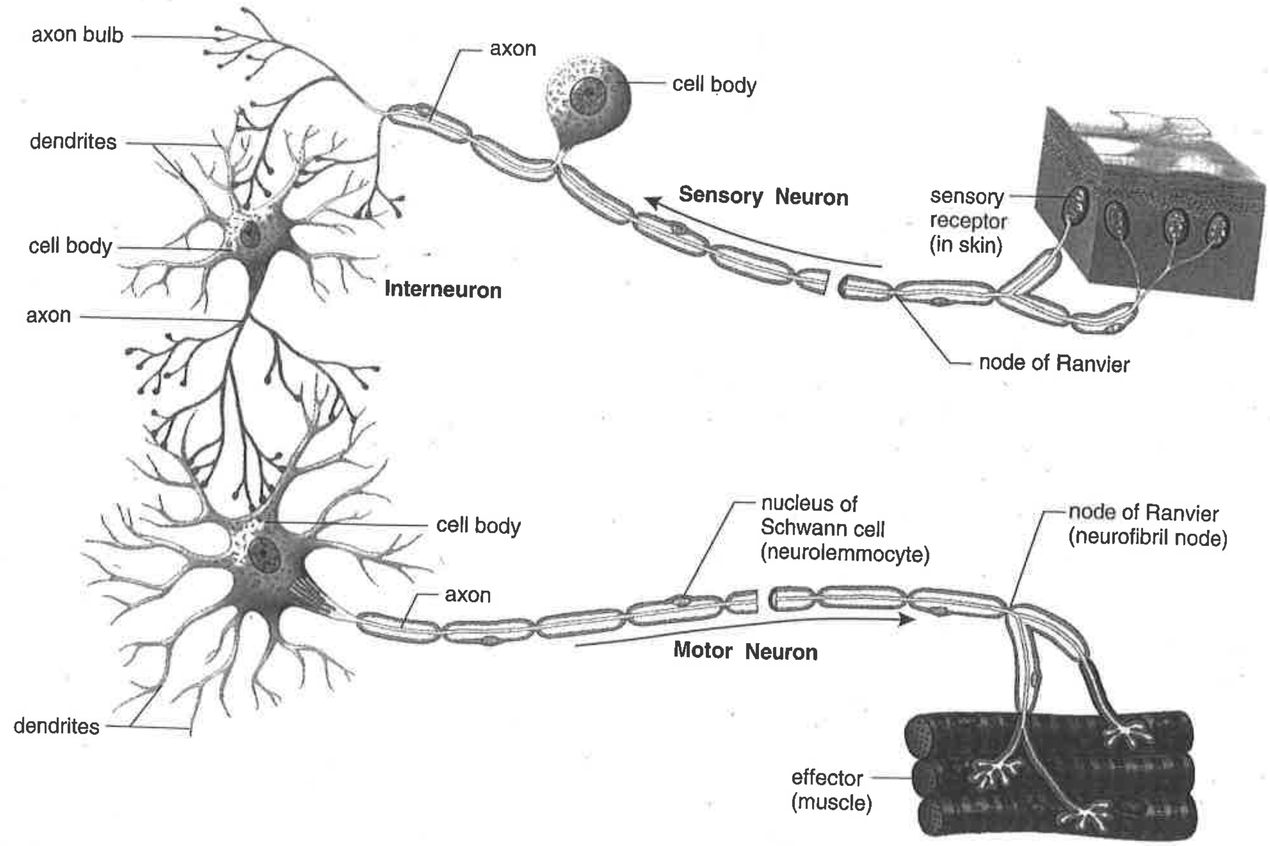


Figure 17.2 Types of neurons.
A sensory neuron, an interneuron, and a motor neuron are drawn here to show their arrangement in the body. (The breaks indicate that the fibers are much longer than shown.) How does this arrangement correlate with the function of each neuron?

Myelin Sheath

Long axons are covered by a protective **myelin sheath** formed by neuroglial cells called **Schwann cells** (neurolemmocytes). The myelin sheath develops when Schwann cells wrap themselves around an axon many times and in this way lay down several layers of plasma membrane. Schwann cell plasma membrane contains myelin, a lipid substance that is an excellent insulator. A myelin sheath, which is interrupted by gaps called **nodes of Ranvier,** gives nerve fibers their white, glistening appearance (Fig. 17.3).

Multiple sclerosis (MS) is a disease of the myelin sheath. Lesions develop and become hardened scars that interfere with normal conduction of nerve impulses, and the result is various neuromuscular symptoms. On the other hand, the myelin sheath plays an important role in nerve regeneration. If an axon is accidentally severed, the distal part of the axon degenerates but the myelin sheath remains and serves as a passageway for new fiber growth.

All neurons have three parts: dendrites, cell body, and axon. Sensory neurons take information to the CNS, and interneurons sum up sensory input before motor neurons take commands away from the CNS.

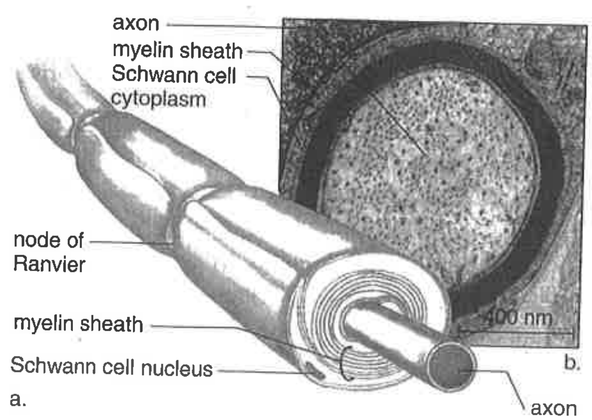
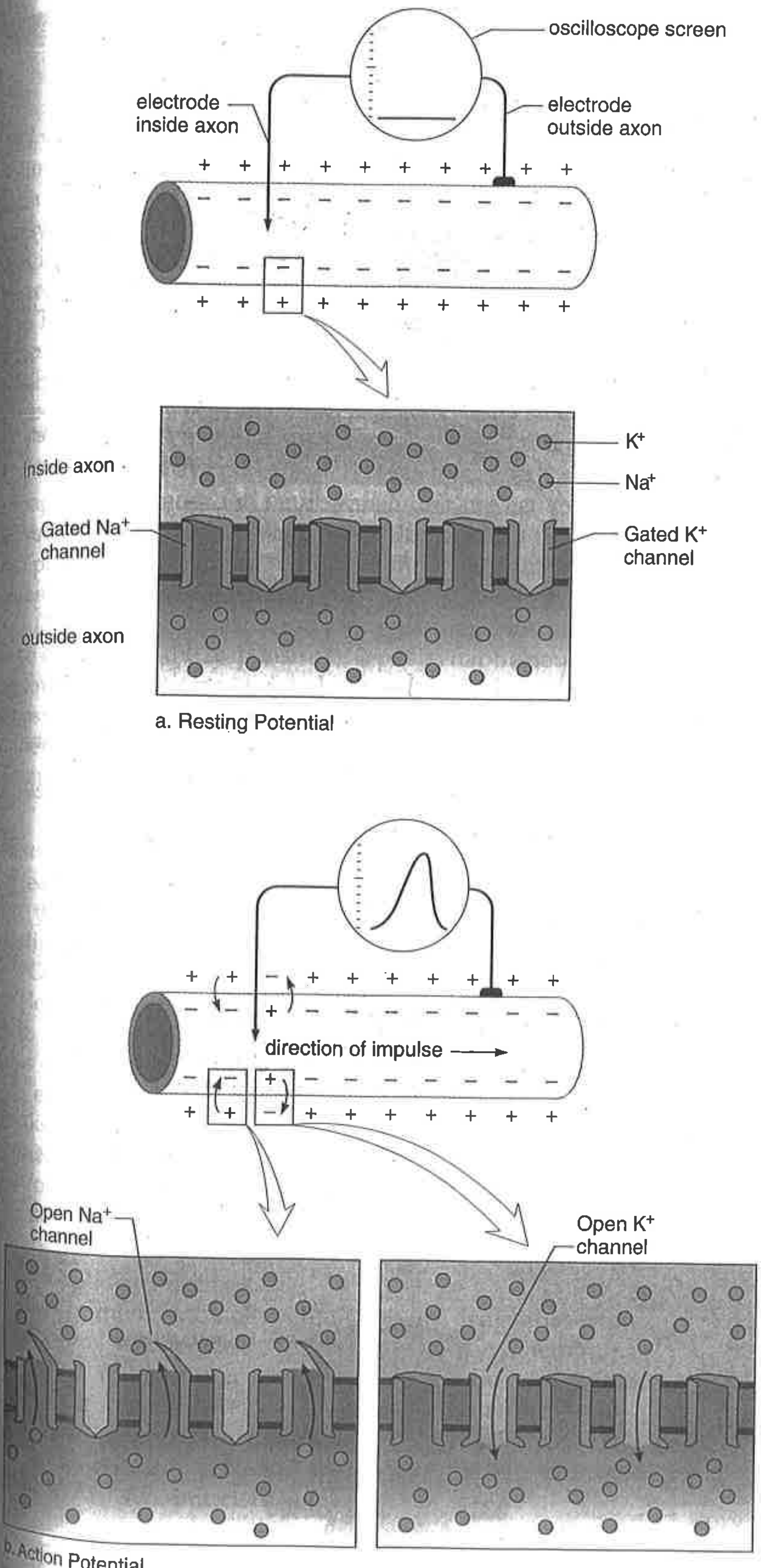


Figure 17.3 Myelin sheath.
a. A myelin sheath forms when Schwann cells wrap themselves around a nerve fiber. **b.** Electron micrograph of a cross section of an axon surrounded by a myelin sheath.



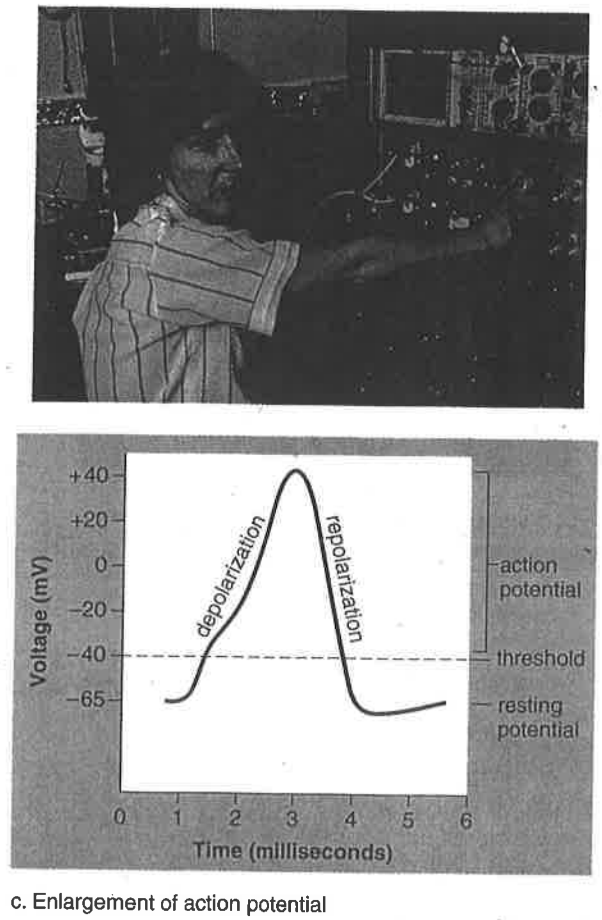
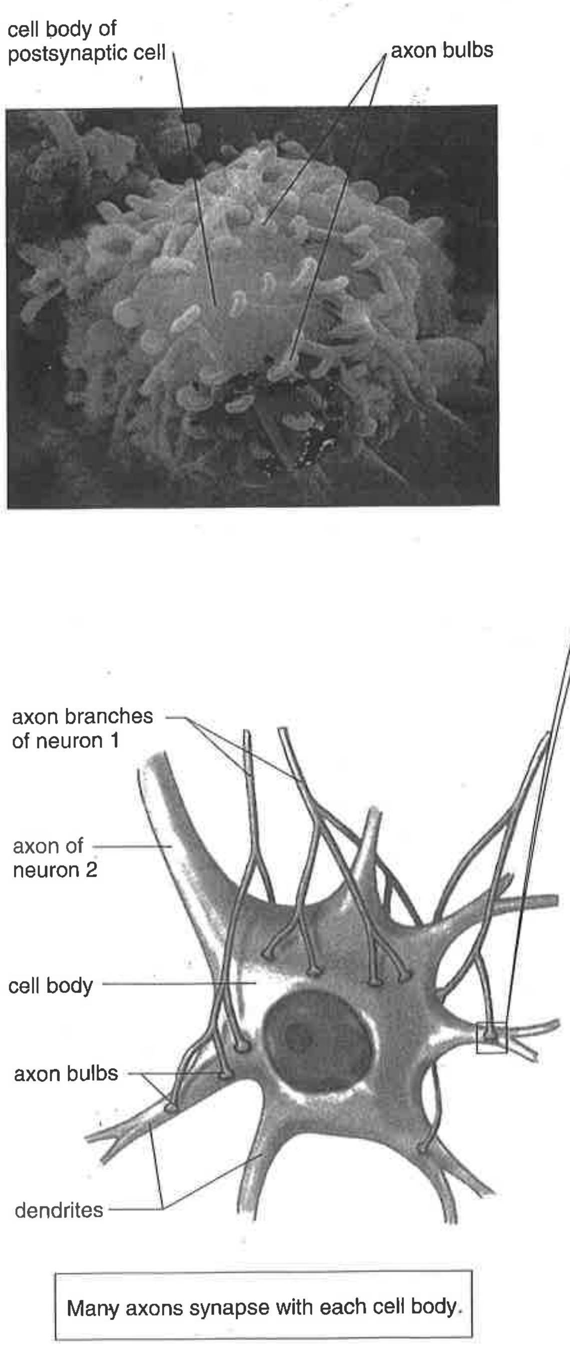


Figure 17.4 **Resting and action potential.**
a. Resting potential. An oscilloscope records a resting potential of −65 mV. There is a preponderance of Na^+ outside the axon and preponderance of K^+ inside the axon. The permeability of the membrane to K^+ compared to Na^+ causes the inside to be negative compared to the outside. **b.** Action potential. A depolarization occurs when Na^+ gates open and Na^+ moves to inside the axon, and a repolarization occurs when K^+ gates open and K^+ moves to outside the axon. **c.** Enlargement of the action potential, which is seen by an experimenter using an oscilloscope, an instrument that records voltage changes.

Visual Focus



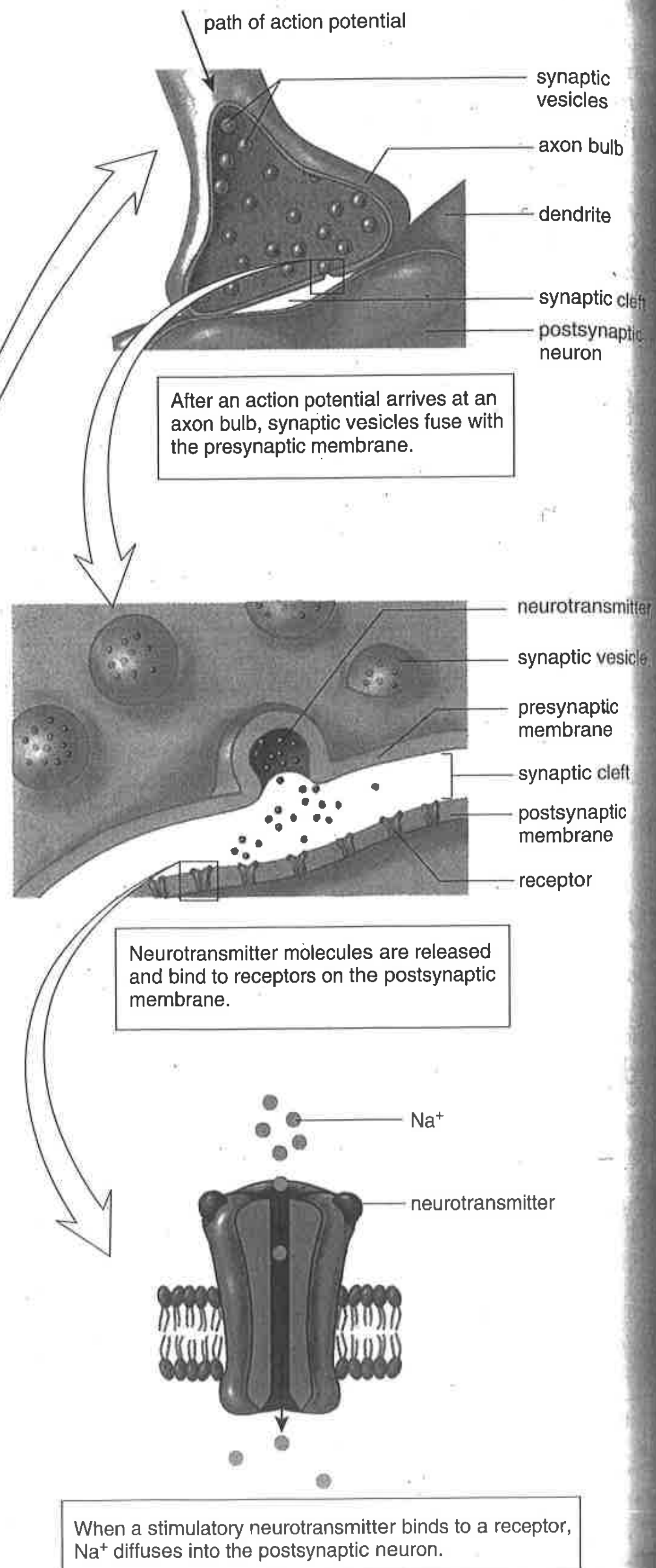


Figure 17.5 Synapse structure and function. Transmission across a synapse from one axon to another occurs when a neurotransmitter is released by the presynaptic neuron and diffuses across a synaptic cleft and binds to a receptor in the postsynaptic neuron.

Transmission Across a Synapse

Every axon branches into many fine endings, each tipped by a small swelling, called an **axon bulb** (Fig. 17.5). Each bulb lies very close to the dendrite (or the cell body) of another neuron. This region of close proximity is called a **synapse.** At a synapse, the membrane of the first neuron is called the *pre*synaptic membrane, and the membrane of the next neuron is called the *post*synaptic membrane. The small gap between is the **synaptic cleft.**

Transmission across a synapse is carried out by molecules called **neurotransmitters,** which are stored in synaptic vesicles (Fig. 17.5*b, c*). When nerve impulses traveling along an axon reach an axon bulb, gated channels for calcium ions (Ca^{2+}) open and calcium enters the bulb. This sudden rise in Ca^{2+} stimulates synaptic vesicles to merge with the presynaptic membrane, and neurotransmitter molecules are released into the synaptic cleft. They diffuse across the cleft to the postsynaptic membrane, where they bind with specific receptor proteins (Fig. 17.5*c*).

Depending on the type of neurotransmitter and/or the type of receptor, the response of the postsynaptic neuron can be toward excitation or toward inhibition. Excitatory neurotransmitters that utilize gated ion channels are fast acting. Other neurotransmitters affect the metabolism of the postsynaptic cell and therefore are slower acting.

Neurotransmitter Molecules

At least 25 different neurotransmitters have been identified, but two very well-known neurotransmitters are **acetylcholine (ACh)** and **norepinephrine (NE).**

Once a neurotransmitter has been released into a synaptic cleft and has initiated a response, it is removed from the cleft. In some synapses, the postsynaptic membrane contains enzymes that rapidly inactivate the neurotransmitter. For example, the enzyme **acetylcholinesterase (AChE)** breaks down acetylcholine. In other synapses, the presynaptic membrane rapidly reabsorbs the neurotransmitter, possibly for repackaging in synaptic vesicles or for molecular breakdown. The short existence of neurotransmitters at a synapse prevents continuous stimulation (or inhibition) of postsynaptic membranes.

It is of interest to note here that many drugs that affect the nervous system act by interfering with or potentiating the action of neurotransmitters. As described in Figure 17.18, drugs can enhance or block the release of a neurotransmitter, mimic the action of a neurotransmitter or block the receptor, or interfere with the removal of a neurotransmitter from a synaptic cleft.

Transmission across a synapse is dependent on the release of neurotransmitters, which diffuse across the synaptic cleft from one neuron to the next.

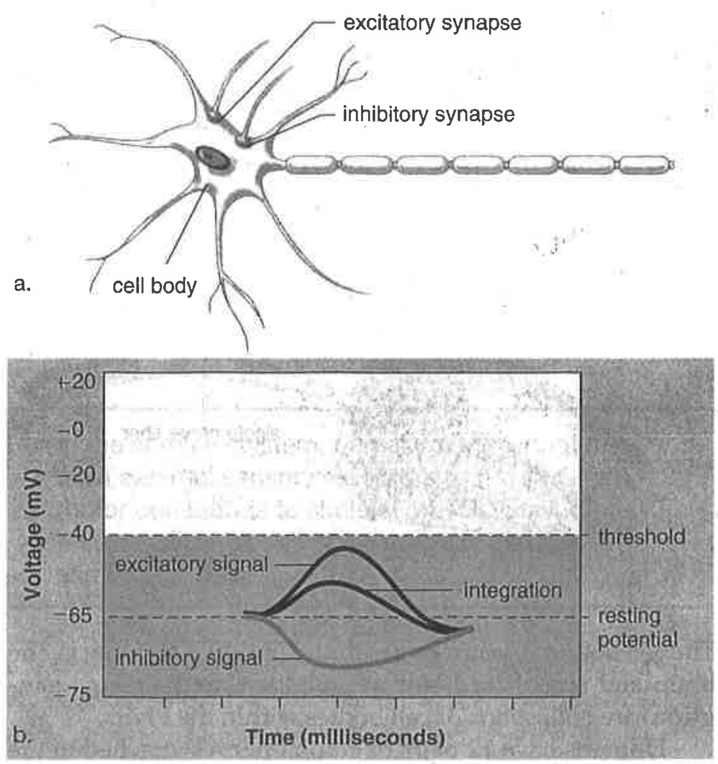


Figure 17.6 **Integration.**
a. Inhibitory signals and excitatory signals are summed up in the dendrite and cell body of the postsynaptic neuron. Only if the combined signals cause the membrane potential to rise above threshold does an action potential occur. **b.** In this example, threshold was not reached.

Synaptic Integration

A single neuron has many dendrites plus the cell body and both can have synapses with many other neurons. One thousand to ten thousand synapses per a single neuron is not uncommon. Therefore, a neuron is on the receiving end of many excitatory and inhibitory signals. An excitatory neurotransmitter produces a potential change called a signal that drives the neuron closer to an action potential, and an inhibitory neurotransmitter produces a signal that drives the neuron further from an action potential. Excitatory signals have a depolarizing effect, and inhibitory signals have a hyperpolarizing effect (Fig. 17.6).

Neurons integrate these incoming signals. **Integration** is the summing up of excitatory and inhibitory signals. If a neuron receives many excitatory signals (either from different synapses or at a rapid rate from one synapse), the chances are the axon will transmit a nerve impulse. On the other hand, if a neuron receives both inhibitory and excitatory signals, the summing up of these signals may prohibit the axon from firing.

Integration is the summing up of inhibitory and excitatory signals received by a postsynaptic neuron.

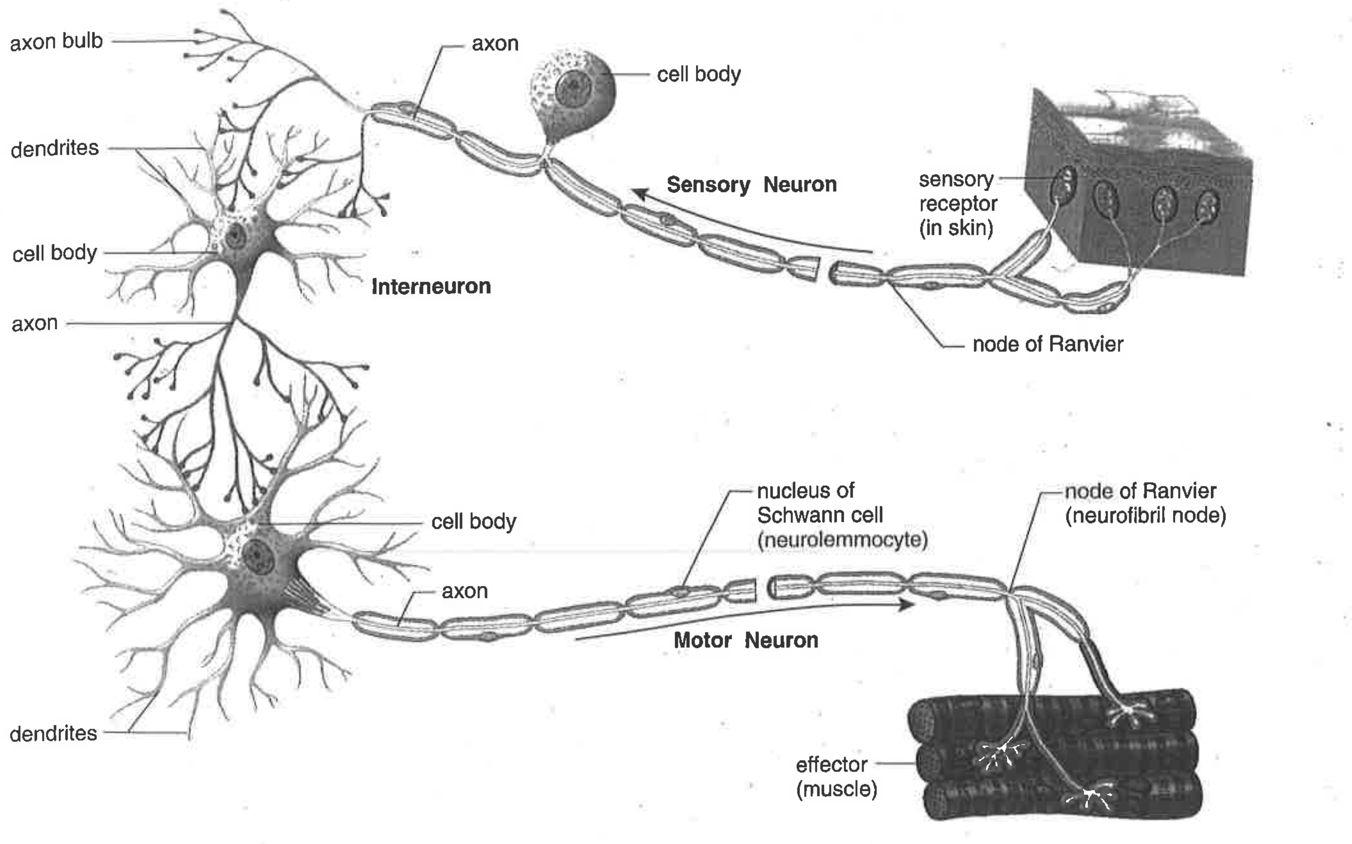


Figure 17.2 Types of neurons.
A sensory neuron, an interneuron, and a motor neuron are drawn here to show their arrangement in the body. (The breaks indicate that the fibers are much longer than shown.) How does this arrangement correlate with the function of each neuron?

Myelin Sheath

Long axons are covered by a protective **myelin sheath** formed by neuroglial cells called **Schwann cells** (neurolemmocytes). The myelin sheath develops when Schwann cells wrap themselves around an axon many times and in this way lay down several layers of plasma membrane. Schwann cell plasma membrane contains myelin, a lipid substance that is an excellent insulator. A myelin sheath, which is interrupted by gaps called **nodes of Ranvier,** gives nerve fibers their white, glistening appearance (Fig. 17.3).

Multiple sclerosis (MS) is a disease of the myelin sheath. Lesions develop and become hardened scars that interfere with normal conduction of nerve impulses, and the result is various neuromuscular symptoms. On the other hand, the myelin sheath plays an important role in nerve regeneration. If an axon is accidentally severed, the distal part of the axon degenerates but the myelin sheath remains and serves as a passageway for new fiber growth.

All neurons have three parts: dendrites, cell body, and axon. Sensory neurons take information to the CNS, and interneurons sum up sensory input before motor neurons take commands away from the CNS.

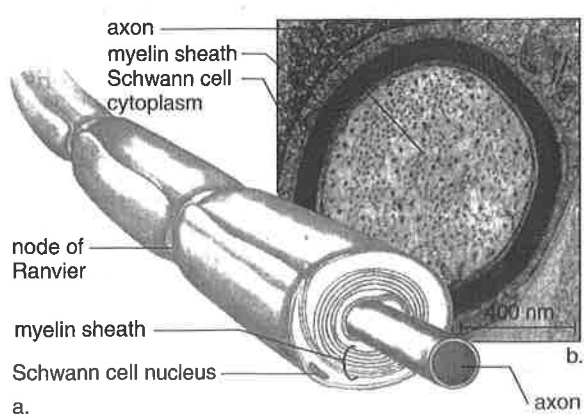
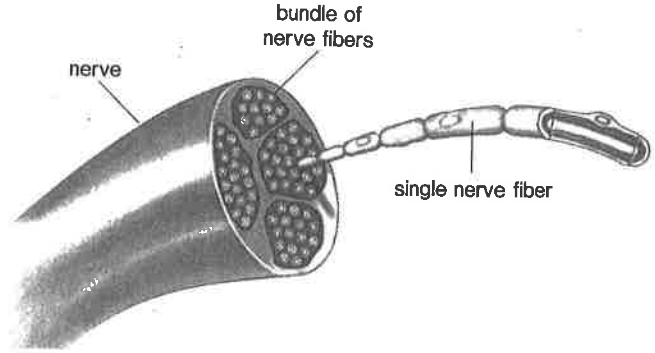


Figure 17.3 Myelin sheath.
a. A myelin sheath forms when Schwann cells wrap themselves around a nerve fiber. **b.** Electron micrograph of a cross section of an axon surrounded by a myelin sheath.

17.2 Peripheral Nervous System

The *peripheral nervous system (PNS)* lies outside the central nervous system and contains **nerves** which are bundles of axons. Axons that occur in nerves are also called nerve fibers.



The cell bodies of neurons are found in the CNS—that is, the brain and spinal cord—or in ganglia. Ganglia (sing., **ganglion**) are collections of cell bodies within the PNS.

Humans have 12 pairs of **cranial nerves** attached to the brain (Fig. 17.7*a*). Some of these are sensory nerves; that is, they contain only sensory nerve fibers. Some are mo nerves that contain only motor fibers, and others are mix nerves that contain both sensory and motor fibers. Cran nerves are largely concerned with the head, neck, and fac regions of the body. However, the vagus nerve has branch not only to the pharynx and larynx, but also to most of t internal organs.

Humans have 31 pairs of **spinal nerves** (Fig. 17.7*b*). Th paired spinal nerves emerge from the spinal cord by tw short branches, or roots. The *dorsal root* contains the axons sensory neurons, which are conducting impulses to th spinal cord from sensory receptors. The cell body of a se sory neuron is in the **dorsal-root ganglion.** The *ventral ro* contains the axons of motor neurons, which are conductin impulses away from the cord to effectors. These two roo join to form a spinal nerve. All spinal nerves are mixe nerves that contain many sensory and motor fibers. Eac spinal nerve serves the particular region of the body i which it is located.

In the PNS, cranial nerves take impulses to and/or from the brain, and spinal nerves take impulses to and from the spinal cord.

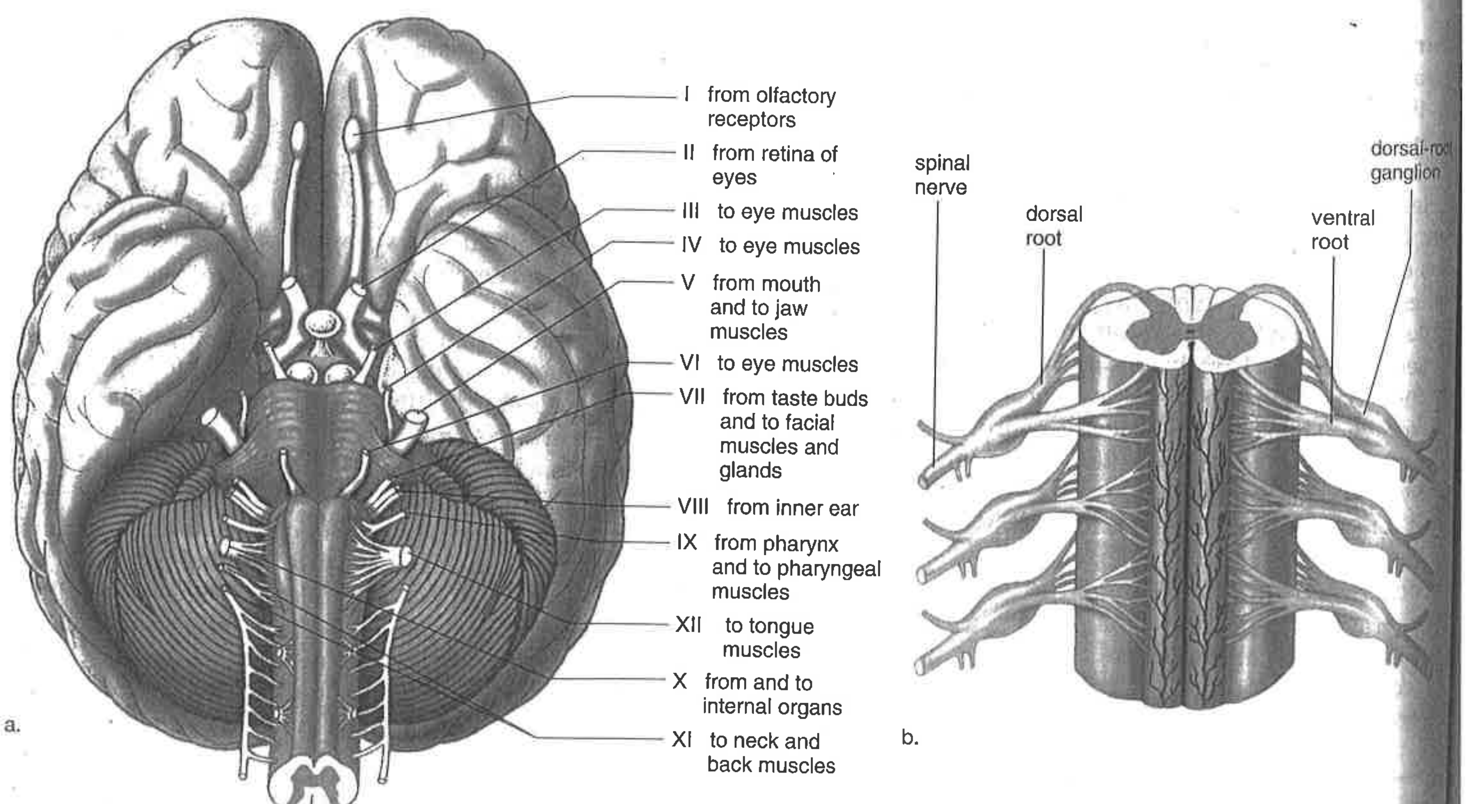


Figure 17.7 Cranial and spinal nerves.
a. Ventral surface of the brain showing the attachment of the 12 pairs of cranial nerves. **b.** Cross section of the spinal cord, showing a few spinal nerves. The human body has 31 pairs of spinal nerves and each spinal nerve has a dorsal root and a ventral root attached to the spinal cord.

Visual Focus

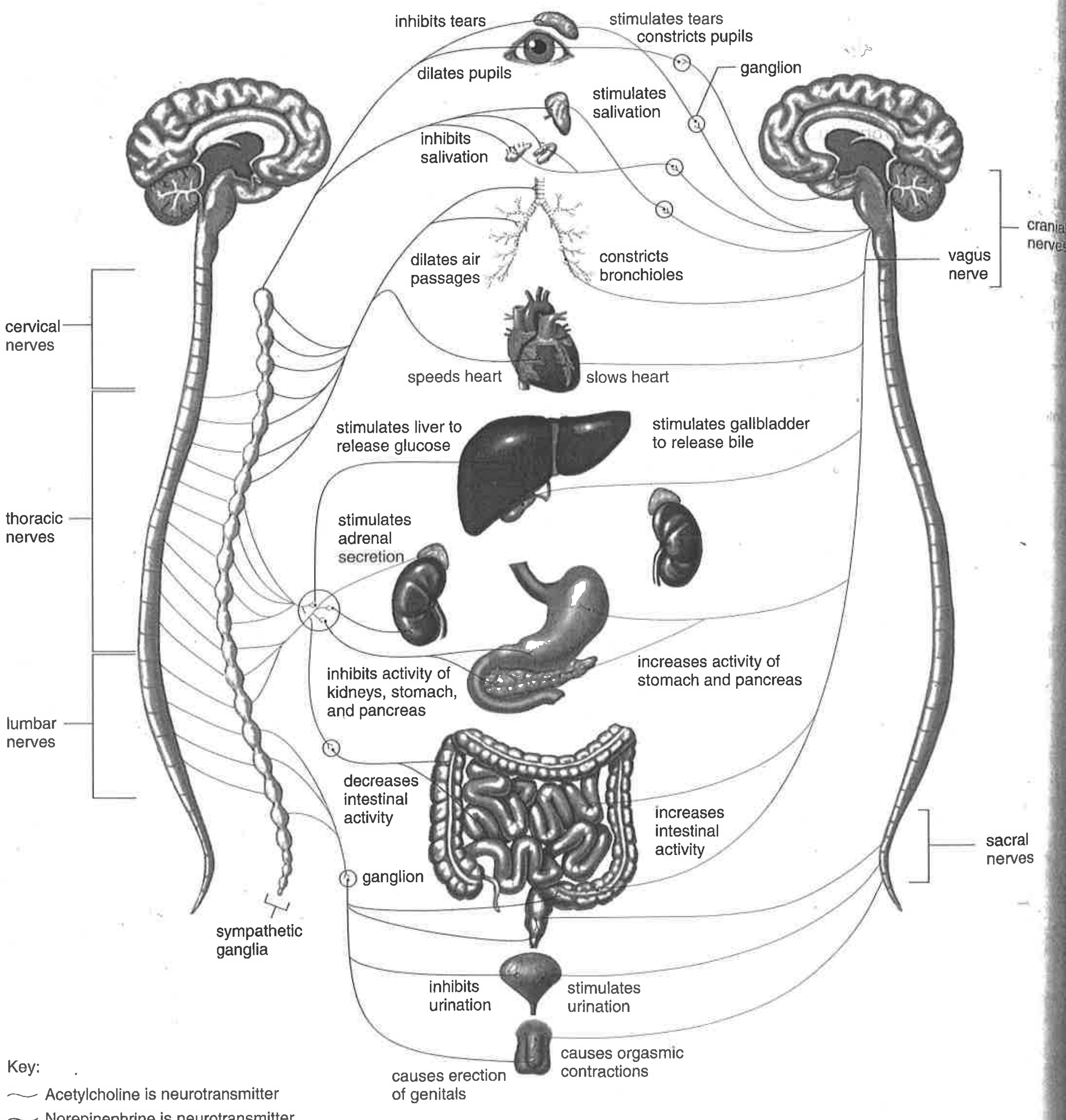


Figure 17.9 Autonomic system structure and function.
Sympathetic preganglionic fibers arise from the thoracic and lumbar portions of the spinal cord; parasympathetic preganglionic fibers arise from the brain and the sacral portion of the spinal cord. Each system innervates the same organs but has contrary effects as described.

17.9

Somatic System

The **somatic system** includes the nerves that take sensory information from external sensory receptors to the CNS and motor commands away from the CNS to skeletal muscles. Voluntary control of skeletal muscles always originates in the brain. Involuntary responses to stimuli, called **reflexes,** can involve either the brain or just the spinal cord. Flying objects cause eyes to blink and sharp tacks cause hands to jerk away even without us having to think about it.

The Reflex Arc

Figure 17.8 illustrates the path of a reflex that involves only the spinal cord. If your hand touches a sharp tack, sensory receptors in the skin generate nerve impulses that move along sensory axons toward the spinal cord. Sensory neurons which enter the cord dorsally pass signals on to many interneurons. Some of these interneurons synapse with motor neurons. The short dendrites and the cell bodies of motor neurons are in the spinal cord but their axons leave the cord ventrally. Nerve impulses travel along motor axons to an effector, which brings about a response to the stimulus. In this case a muscle contracts so that you withdraw your hand from the tack. Various other reactions are possible—you will most likely look at the tack, wince, and cry out in pain. This whole series of responses is explained by the fact some of the interneurons involved carry nerve impulses to the brain. The brain makes you aware of the stimulus and directs these other reactions to it.

In the somatic system, nerves take information from external sensory receptors to the CNS and motor commands to skeletal muscles. Involuntary reflexes allow us to respond rapidly to external stimuli.

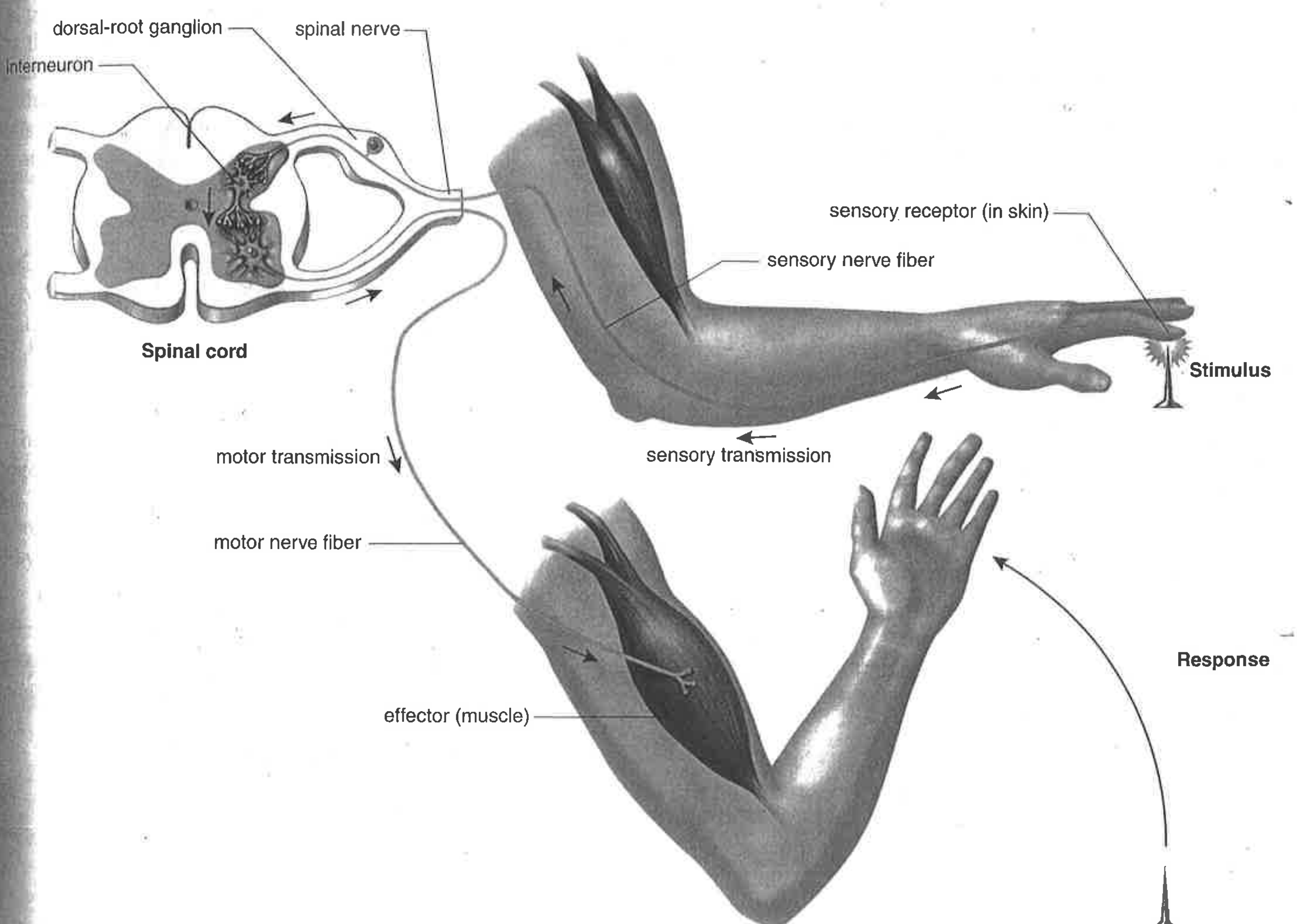


Figure 17.8 A reflex arc showing the path of a spinal reflex.
A stimulus (e.g., sharp tack) causes sensory receptors in the skin to generate nerve impulses that travel in sensory nerve fibers to the spinal cord. Interneurons integrate data from sensory neurons and then relay signals to motor neurons. Motor nerve fibers convey nerve impulses from the spinal cord to a skeletal muscle which contracts. Movement of the hand away from the tack is the response to the stimulus.

17.3 Central Nervous System

The *central nervous system (CNS)* consists of the spinal cord and the brain where sensory information is received and motor control is initiated. Both the spinal cord and the brain are protected by bone; the brain is enclosed by the skull and the spinal cord is surrounded by vertebrae. Also, both the spinal cord and brain are wrapped in protective membranes known as **meninges** (sing., meninx). Meningitis is an infection of these coverings. The spaces between the meninges are filled with **cerebrospinal fluid,** which cushions and protects the CNS. A small amount of this fluid sometimes is withdrawn from around the cord for laboratory testing when a spinal tap (i.e., lumbar puncture) is performed.

Cerebrospinal fluid is also contained within the ventricles of the brain and in the central canal of the spinal cord. The brain's **ventricles** are interconnecting cavities that produce and serve as a reservoir for cerebrospinal fluid. Normally, any excess cerebrospinal fluid drains away into the circulatory system. However, blockages can occur. In an infant, the brain can enlarge due to cerebrospinal fluid accumulation, and this condition is called "water on the brain." If cerebrospinal fluid collects in an adult, the brain cannot enlarge and instead, the brain is pushed against the skull, possibly causing injury.

The CNS, which lies in the midline of the body and consists of the brain and the spinal cord, receives sensory information and initiates voluntary motor control.

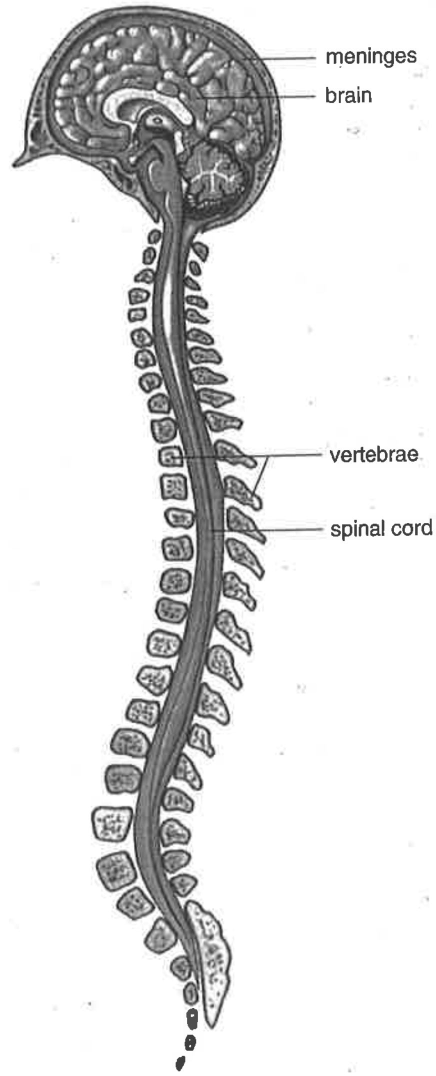


Figure 17.10 **Central nervous system.**
The central nervous system consists of the brain and spinal cord. The brain is protected by the skull and the spinal cord is protected by the vertebrae.

The Spinal Cord

The **spinal cord** extends from the base of the brain through a large opening in the skull called the foramen magnum and into the vertebral canal formed by the vertebrae (Fig. 17.10).

Structure of the Spinal Cord

Figure 17.11*a* shows how the individual vertebrae join to form the vertebral canal which protects the spinal cord. The spinal nerves which project from the cord pass through openings between the vertebrae of the vertebral canal.

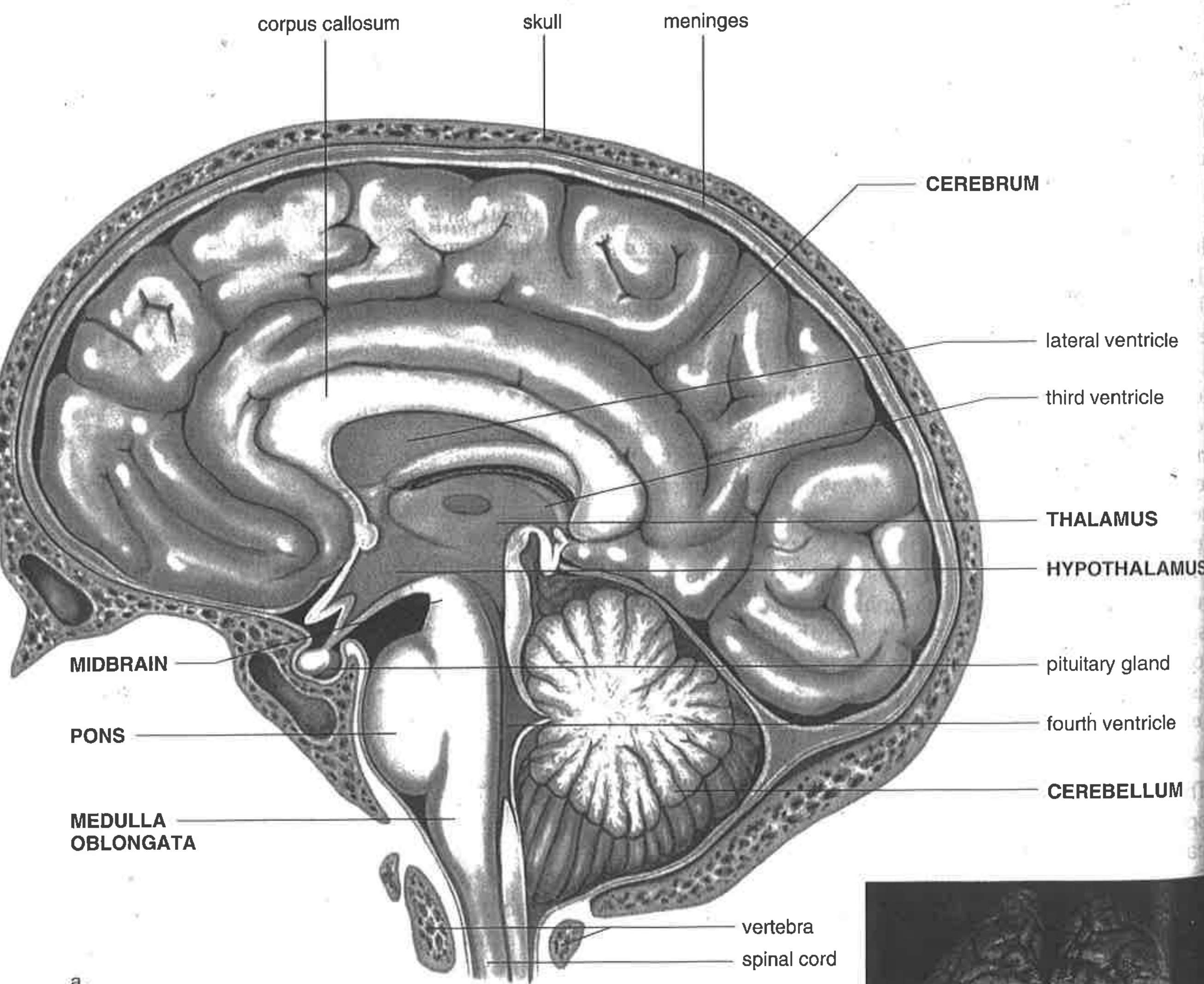
A cross section of the spinal cord shows that the spinal cord has a central canal, gray matter, and white matter (Fig. 17.11*b, c*). The central canal contains cerebrospinal fluid, as do the meninges that protect the spinal cord. The **gray matter** is centrally located and shaped like the letter H. It is gray because it contains cell bodies and short, nonmyelinated fibers. Portions of sensory neurons and motor neurons are found here, as are interneurons that communicate with these two types of neurons. The dorsal root of a spinal nerve contains sensory nerve fibers entering the gray matter, and the ventral root of a spinal nerve contains motor nerve fibers exiting the gray matter. The dorsal and ventral roots join before the spinal nerve leaves the vertebral canal. Spinal nerves are a part of the PNS.

The **white matter** of the spinal cord occurs in areas around the gray matter. The white matter is white because it contains myelinated axons of interneurons that run together in bundles called **tracts.** Ascending tracts taking information to the brain are primarily located dorsally, and descending tracts taking information from the brain are primarily

The Brain

The human **brain** has been called the last great frontier of biology. The goal of modern neuroscience is to understand the structure and function of the brain's various parts so well that it will be possible to prevent or correct the more than 1,000 mental disorders that rob human beings of a normal life. This section gives only a glimpse of what is known about the brain and the modern avenues of research.

We will discuss the parts of the brain with reference to the brain stem, the diencephalon, and the cerebrum. The brain has four **ventricles** called, in turn, the fourth ventricle, the third ventricle, and the two lateral ventricles. It may be helpful to you to associate the brain stem with the fourth ventricle, the diencephalon with the third ventricle, and the cerebrum with the two lateral ventricles (Fig. 17.12*a*).



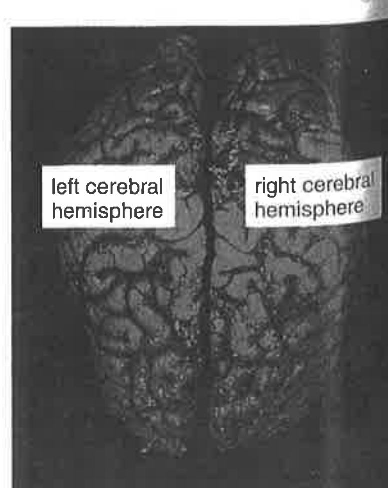


Figure 17.12 **The human brain.**
a. The cerebrum is the largest part of the brain in humans.
b. The cerebrum has a left and right cerebral hemisphere which are connected by the corpus callosum.

located ventrally. Because the tracts cross just after they enter and exit the brain, the left side of the brain controls the right side of the body, and the right side of the brain controls the left side of the body.

The spinal cord extends from the base of the brain into the vertebral canal formed by the vertebrae. A cross section shows that the spinal cord has a central canal, gray matter, and white matter.

Functions of the Spinal Cord

The spinal cord is the center for thousands of reflex arcs. Figure 17.8 indicates the path of a spinal reflex from sensory receptors to muscle effectors. Each interneuron in the spinal cord has synapses with many other neurons, and therefore they carry out integration of incoming information before sending signals to other interneurons and motor neurons (see Fig. 17.6).

The spinal cord provides a means of communication between the brain and the peripheral nerves that leave the cord. When someone touches your hand, sensory information passes from sensory receptors through sensory nerve fibers to the spinal cord and up ascending tracts to the brain. When we voluntarily move our limbs, motor impulses originating in the brain pass down descending tracts to the spinal cord and out to our muscles by way of motor nerve fibers. Therefore, if the spinal cord is severed, we suffer a loss of sensation and a loss of voluntary control—that is, we suffer a paralysis. If the spinal cord is completely cut across in the thoracic region, paralysis of the lower body and legs occurs. This condition is known as paraplegia. If the injury is in the neck region, the four limbs are usually affected. This condition is called quadriplegia.

The spinal cord is a center for reflex action. The spinal cord also serves as a means of communication between the brain and much of the body. Because tracts to and from the brain cross over, the left side of the brain controls the right side of the body and vice versa.

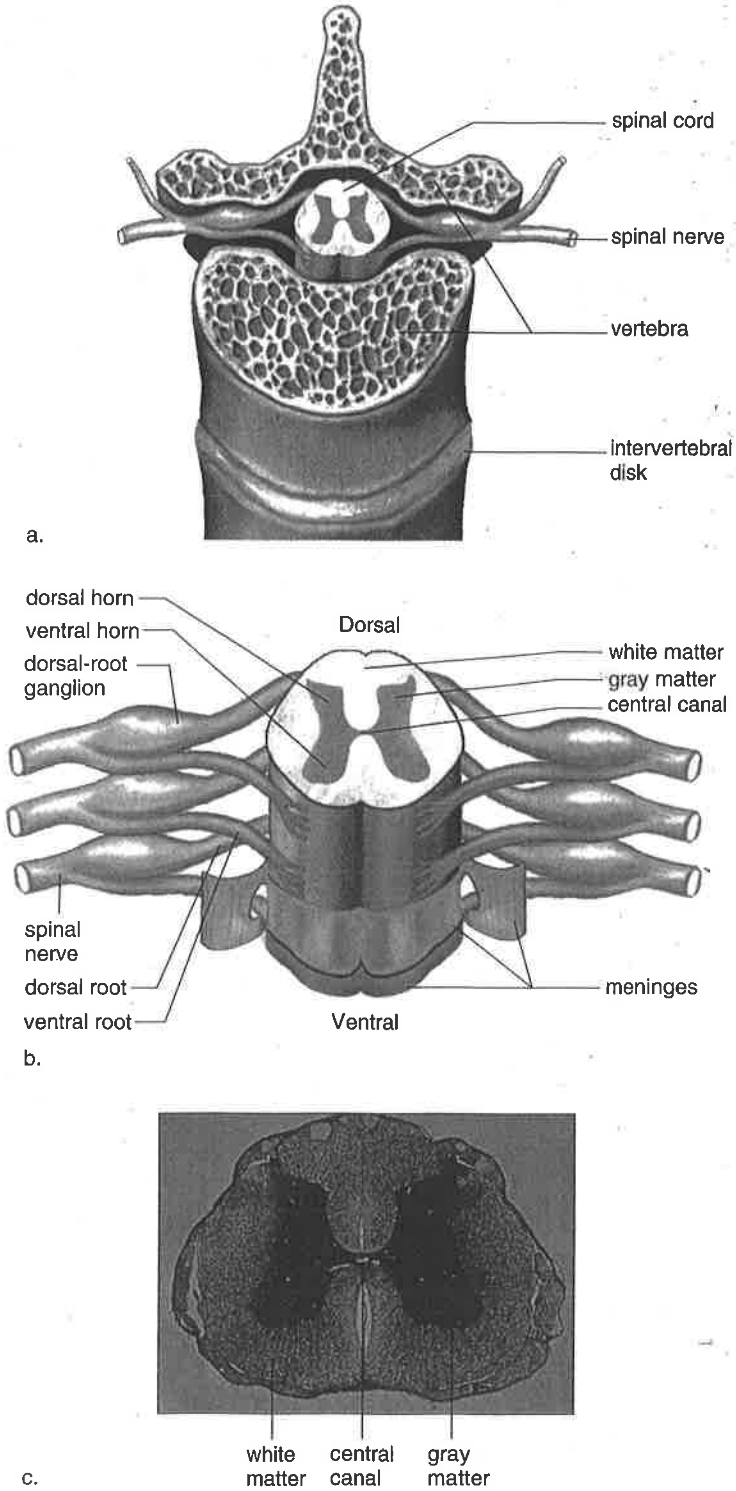


Figure 17.11 **Spinal cord.**
a. The spinal cord passes through the vertebral canal formed by the vertebrae. **b.** The spinal cord has a central canal filled with cerebrospinal fluid, H-shaped gray matter, and white matter. The white matter contains tracts that take nerve impulses to and from the brain. **c.** Photomicrograph.

17.4 The Cerebral Hemispheres

A deep groove called the longitudinal fissure divides the left from the right cerebral hemisphere; shallow grooves called sulci (sing., sulcus) divide each hemisphere into lobes (Fig. 17.14). The frontal lobe is toward the front of a cerebral hemisphere and the parietal lobe is toward the back of a cerebral hemisphere. The occipital lobe is dorsal to (behind) the parietal lobe and the temporal lobe lies below the frontal and parietal lobes.

The Cerebral Cortex

The **cerebral cortex** is a thin but highly convoluted outer layer of gray matter that covers the cerebral hemispheres. The cerebral cortex contains over one billion cell bodies and is the region of the brain that accounts for sensation, voluntary movement, and all the thought processes we associate with consciousness.

The cerebral cortex contains motor areas and sensory areas and also association areas. The **primary motor area** is in the frontal lobe just ventral to (before) the central sulcus. Voluntary commands begin in the primary motor area and each part of the body is controlled by a certain section. Our versatile hand takes up an especially large area of the primary motor area. Ventral to the primary motor area is a *premotor area.* The premotor area organizes motor functions for skilled motor activities before the primary motor area sends signals to the cerebellum which integrates them. The unique ability of humans to speak is partially dependent upon *Broca's area,* a motor speech area located in the left frontal lobe. Signals originating here pass to the premotor area before reaching the primary motor area.

The **primary somatosensory area** is just dorsal to the central sulcus in the parietal lobe. Sensory information from the skin and skeletal muscles arrives here, where each part of the body is sequentially represented. A primary visual area in the occipital lobe receives information from our eyes, and a primary auditory area in the temporal lobe receives information from our ears. A primary taste area in the parietal lobe accounts for taste sensations.

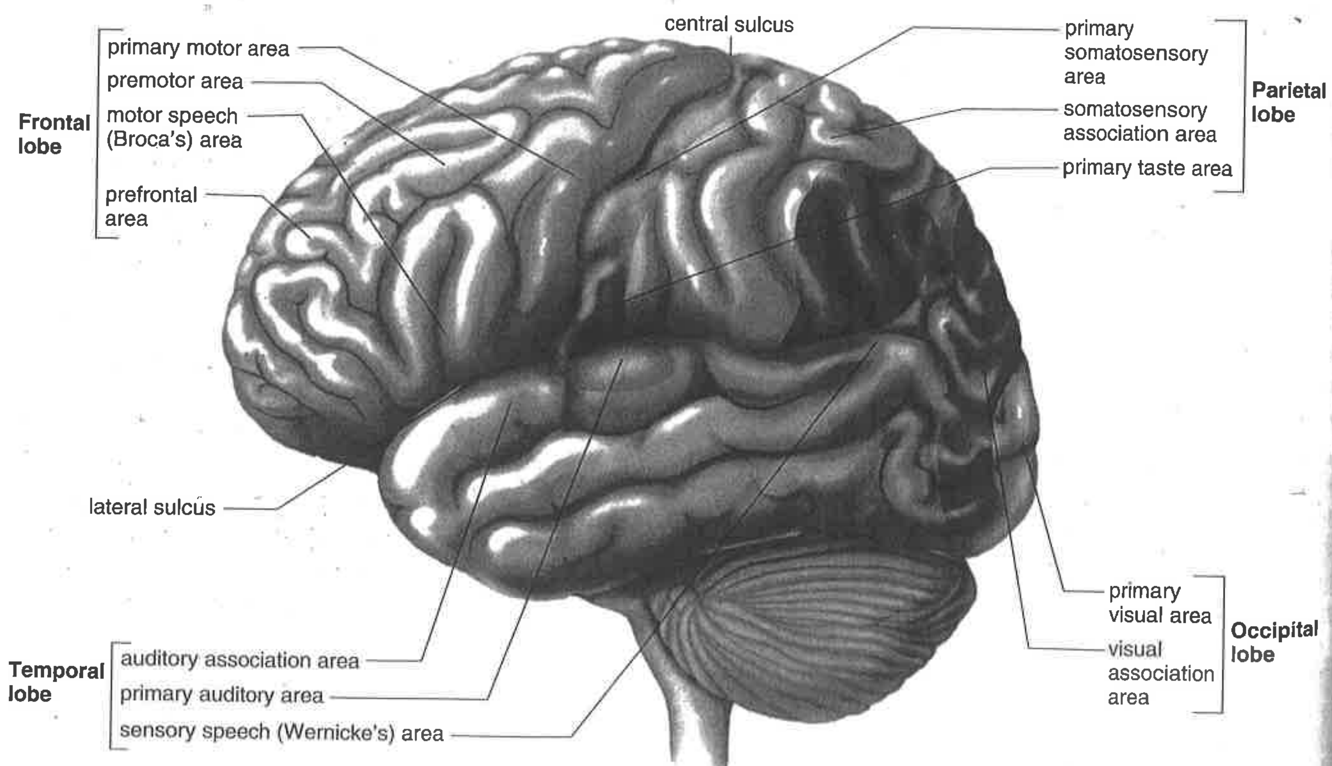


Figure 17.14 The cerebral cortex.
The cortex of the cerebrum is divided into four lobes: frontal, parietal, temporal, and occipital. The frontal lobe has motor areas and an association area called the prefrontal area. The other lobes have sensory areas and also association areas.

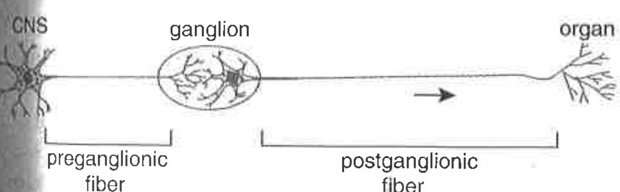
Autonomic System

The **autonomic system** of the PNS regulates the activity of cardiac and smooth muscle and glands. The system is divided into the sympathetic and parasympathetic divisions (Fig. 17.9 and Table 17.1). Both of these divisions (1) function automatically and usually in an involuntary manner; (2) innervate all internal organs; and (3) utilize two neurons and one ganglion for each impulse. The first neuron has a cell body within the CNS and a *preganglionic fiber.* The second neuron has a cell body within the ganglion and a *postganglionic fiber.*

Reflex actions, such as those that regulate the blood pressure and breathing rate, are especially important to the maintenance of homeostasis. These reflexes begin when the sensory neurons in contact with internal organs send information to the CNS. They are completed by motor neurons within the autonomic system.

Sympathetic Division

Most preganglionic fibers of the **sympathetic division** arise from the middle, or *thoracic-lumbar,* portion of the spinal cord and almost immediately terminate in ganglia that lie near the cord. Therefore, in this division, the preganglionic fiber is short, but the postganglionic fiber that makes contact with an organ is long.

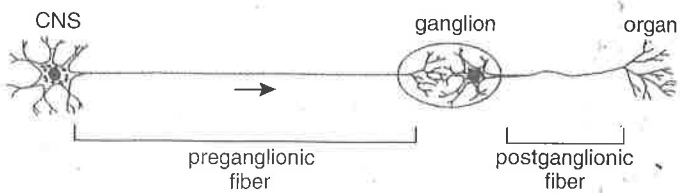


The sympathetic division is especially important during emergency situations and is associated with **"fight or flight."** If you need to fend off a foe or flee from danger, active muscles require a ready supply of glucose and oxygen. The sympathetic division accelerates the heartbeat and dilates the bronchi. On the other hand, the sympathetic division inhibits the digestive tract—digestion is not an immediate necessity if you are under attack. The neurotransmitter released by the postganglionic axon is primarily norepinephrine (NE). The structure of NE is like that of epinephrine (adrenaline), an adrenal medulla hormone that usually increases heart rate and contractility.

The sympathetic division brings about those responses we associate with "fight or flight."

Parasympathetic Division

The **parasympathetic division** includes a few cranial nerves (e.g., the vagus nerve) and also fibers that arise from the sacral (bottom) portion of the spinal cord. Therefore, this division often is referred to as the craniosacral portion of the autonomic system. In the parasympathetic division, the preganglionic fiber is long, and the postganglionic fiber is short because the ganglia lie near or within the organ.



The parasympathetic division, sometimes called the "housekeeper division," promotes all the internal responses we associate with a relaxed state; for example, it causes the pupil of the eye to contract, promotes digestion of food, and retards the heartbeat. The neurotransmitter utilized by the parasympathetic division is acetylcholine (ACh).

The parasympathetic division brings about the responses we associate with a relaxed state.

Table 17.1 Comparison of Somatic Motor and Autonomic Motor Pathways

Items	Somatic Motor Pathway	Autonomic Motor Pathways	
		Sympathetic	Parasympathetic
Type of control	Voluntary/involuntary	Involuntary	Involuntary
Number of neurons per message	One	Two (preganglionic shorter than postganglionic)	Two (preganglionic longer than postganglionic)
Location of motor fiber	Most cranial nerves and all spinal nerves	Thoracolumbar spinal nerves	Cranial (e.g., vagus) and sacral spinal nerves
Neurotransmitter	Acetylcholine	Norepinephrine	Acetylcholine
Effectors	Skeletal muscles	Smooth and cardiac muscle, glands	Smooth and cardiac muscle, glands

Endocrine Glands

Endocrine glands can be contrasted with exocrine glands. The latter have ducts and secrete their products into these ducts for transport into body cavities. For example, the salivary glands send saliva into the mouth by way of the salivary ducts. **Endocrine glands** are ductless; they secrete their hormones directly into the bloodstream for distribution throughout the body.

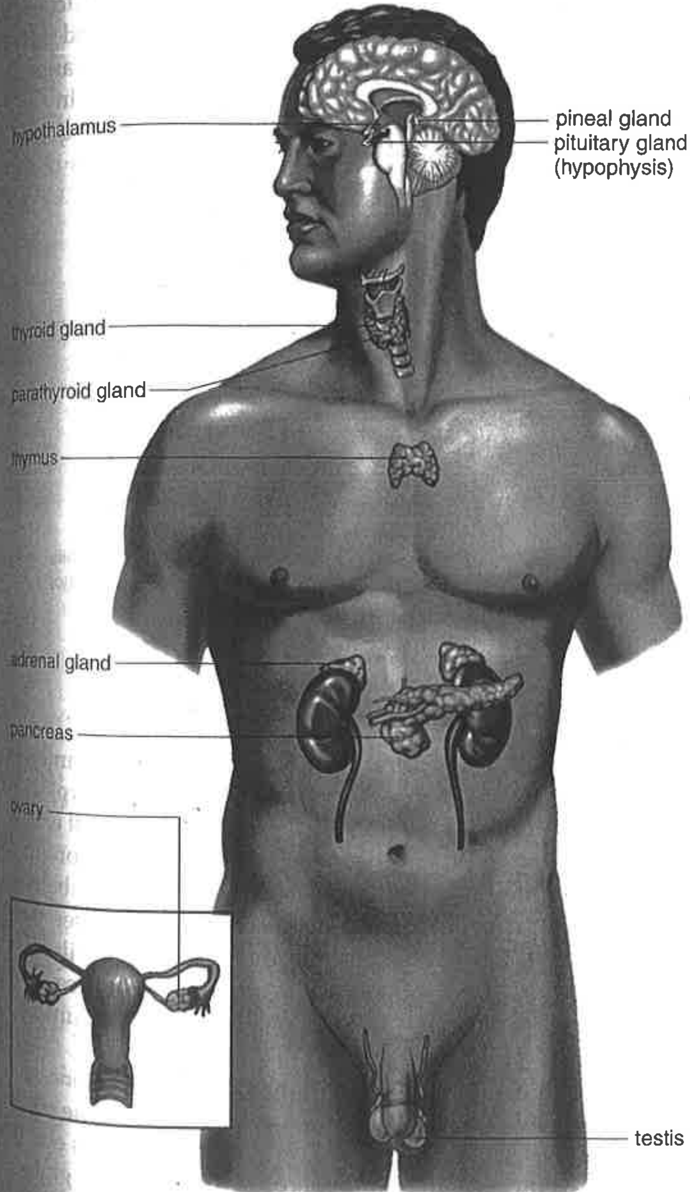


Figure 20.3 The endocrine system.
Anatomical location of major endocrine glands in the body.

Table 20.1 lists the hormones released by the principal endocrine glands, which are depicted in Figure 20.3. The hypothalamus, a part of the brain, is in close proximity to the pituitary. The hypothalamus controls the pituitary gland and this, too, exemplifies the close association between the nervous and endocrine systems. The pineal gland is also located in the brain. The thyroid and parathyroids are located in the neck, and the thymus lies just beneath the sternum, in the thoracic cavity. The adrenal glands and pancreas are located in the abdominal cavity. The gonads include the ovaries, located in the pelvic cavity, and the testes, located outside this cavity in the scrotum.

Like the nervous system, the endocrine system is especially involved in homeostasis, that is, the dynamic equilibrium of the internal environment. The internal environment is the blood and tissue fluid that surrounds the body's cells. Notice that several hormones directly affect the osmolarity of the blood. Others control the calcium and glucose levels. Several hormones are involved in the maturation and function of the reproductive organs. In fact, many people are most familiar with the effect of hormones on sexual functions.

There are two mechanisms that control the effect of endocrine glands. Quite often a negative feedback mechanism controls the secretion of hormones. An endocrine gland can be sensitive to either the condition it is regulating or to the blood level of the hormone it is producing. For example, when the blood glucose level rises, the pancreas produces insulin, which causes the cells to take up glucose and the liver to store glucose. The stimulus for the production of insulin has thereby been dampened, and therefore the pancreas stops producing insulin. On the other hand, when the blood level of thyroid hormones rises, the anterior pituitary stops producing thyroid-stimulating hormones. We will discuss these examples in more detail later.

The presence of contrary hormonal actions is a way the effect of a hormone is controlled. The action of insulin, for example, is offset by the production of glucagon by the pancreas. Notice there are other examples of contrary hormonal actions in Table 20.1. The thyroid lowers the blood calcium level, but the parathyroids raise the blood calcium level. We will also have the opportunity to point out other instances in which hormones work opposite to one another and thereby bring about the regulation of a substance in the blood.

The secretion of a hormone is often controlled by negative feedback, and the effect of a hormone is often opposed by a contrary hormone. The end result is homeostasis and the normal functioning of body parts.

Visual Focus

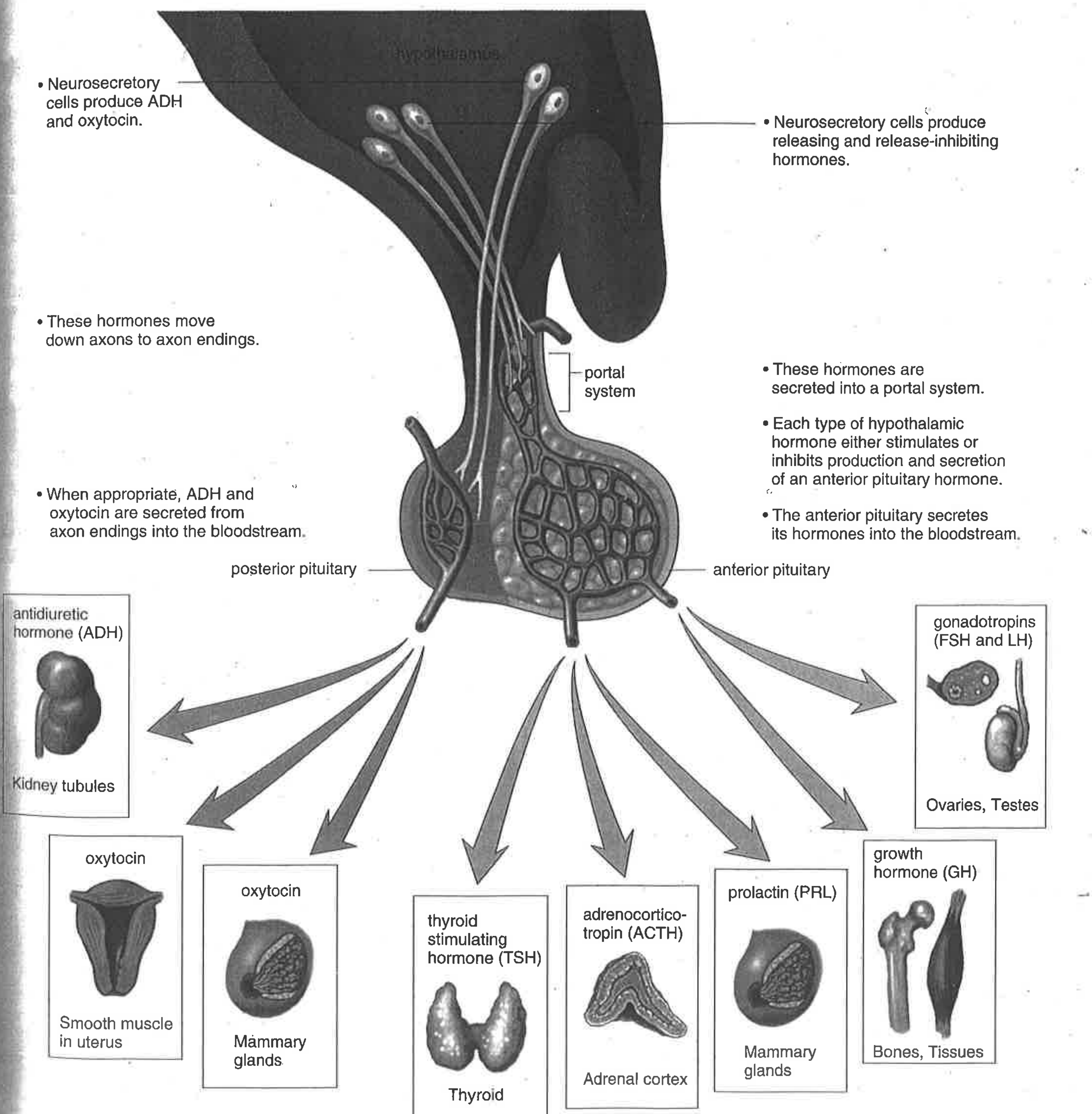


Figure 20.4 Hypothalamus and the pituitary.
The hypothalamus produces two hormones, ADH and oxytocin, which are stored and secreted by the posterior pituitary. The hypothalamus controls the secretions of the anterior pituitary, and the anterior pituitary controls the secretions of the thyroid, adrenal cortex, and gonads, which are also endocrine glands.