Fundamentals of the Nervous System and Nervous Tissue

11

1. List the basic functions of the nervous system.

Organization of the Nervous System (pp. 388–389)

2. Explain the structural and functional divisions of the nervous system.

Histology of Nervous Tissue (pp. 389–397)

3. List the types of neuroglia and cite their functions.
4. Define neuron, describe its important structural components, and relate each to a functional role.
5. Differentiate between a nerve and a tract, and between a nucleus and a ganglion.
6. Explain the importance of the myelin sheath and describe how it is formed in the central and peripheral nervous systems.
7. Classify neurons structurally and functionally.

Neurophysiology (pp. 397–421)

8. Define resting membrane potential and describe its electrochemical basis.
9. Compare and contrast graded and action potentials.
10. Explain how action potentials are generated and propagated along neurons.
11. Define absolute and relative refractory periods.
12. Define saltatory conduction and contrast it to conduction along unmyelinated fibers.
13. Define synapse. Distinguish between electrical and chemical synapses structurally and in their mechanisms of information transmission.
14. Distinguish between excitatory and inhibitory postsynaptic potentials.
15. Describe how synaptic events are integrated and modified.
16. Define neurotransmitter and name several classes of neurotransmitters.

Basic Concepts of Neural Integration (pp. 421–423)

17. Describe common patterns of neuronal organization and processing.
18. Distinguish between serial and parallel processing.

Developmental Aspects of Neurons (pp. 423–426)

19. Describe the role of astrocytes and nerve cell adhesion molecules in neuronal differentiation.

You are driving down the freeway, and a horn blares to your right. You immediately swerve to your left. Charlie leaves a note on the kitchen table: "See you later. Have the stuff ready at 6." You know the "stuff" is chili with taco chips. You are dozing but you awaken instantly as your infant son makes a soft cry. What do these three events have in common? They are all everyday examples of the functioning of your nervous system, which has your body cells humming with activity nearly all the time.

The **nervous system** is the master controlling and communicating system of the body. Every thought, action, and emotion reflects its activity. Its cells communicate by electrical signals, which are rapid and specific, and usually cause almost immediate responses.

The nervous system has three overlapping functions (Figure 11.1): (1) It uses its millions of sensory receptors to monitor changes occurring both inside and outside the body. The gathered information is called **sensory input.** (2) It processes and interprets sensory input and decides what should be done at each moment—a process called **integration.** (3) It causes a *response,* called **motor output,** by activating *effector organs.* For example, when you are driving and see a red light ahead (sensory input), your nervous system integrates this information (red light means "stop"), and your foot goes for the brake (motor output).

This chapter begins with a brief overview of the organization of the nervous system. It then focuses on the functional anatomy of nervous tissue, especially that of nerve cells, or *neurons,* which are the key to neural communication.

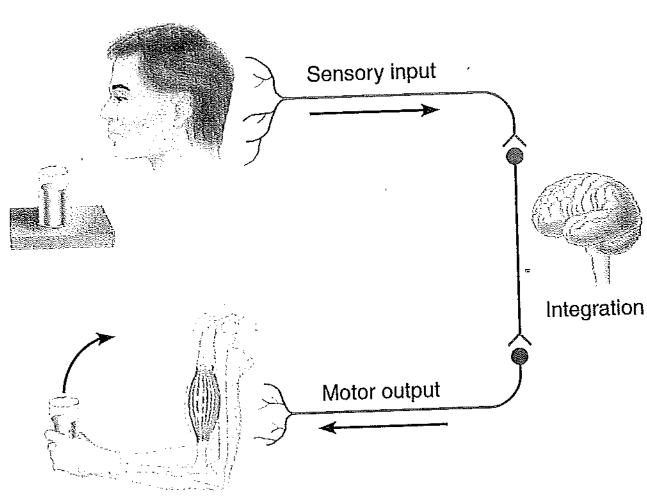


FIGURE 11.1 **The nervous system's functions.**

Organization of the Nervous System

We have only one highly integrated nervous system. However, for convenience, it can be divided into two principal parts (Figure 11.2). The **central nervous system (CNS)** consists of the *brain* and *spinal cord,* which occupy the dorsal body cavity. The CNS is the integrating and command center of the nervous system. It interprets sensory input and dictates motor responses based on past experience, reflexes, and current conditions. The **peripheral nervous system (PNS),** the part of the nervous system *outside* the CNS, consists mainly of the nerves (bundles of axons) that extend from the brain and spinal cord. *Spinal nerves* carry impulses to and from the spinal cord; *cranial nerves* carry impulses to and from the brain. These peripheral nerves serve as the communication lines that link all parts of the body to the CNS.

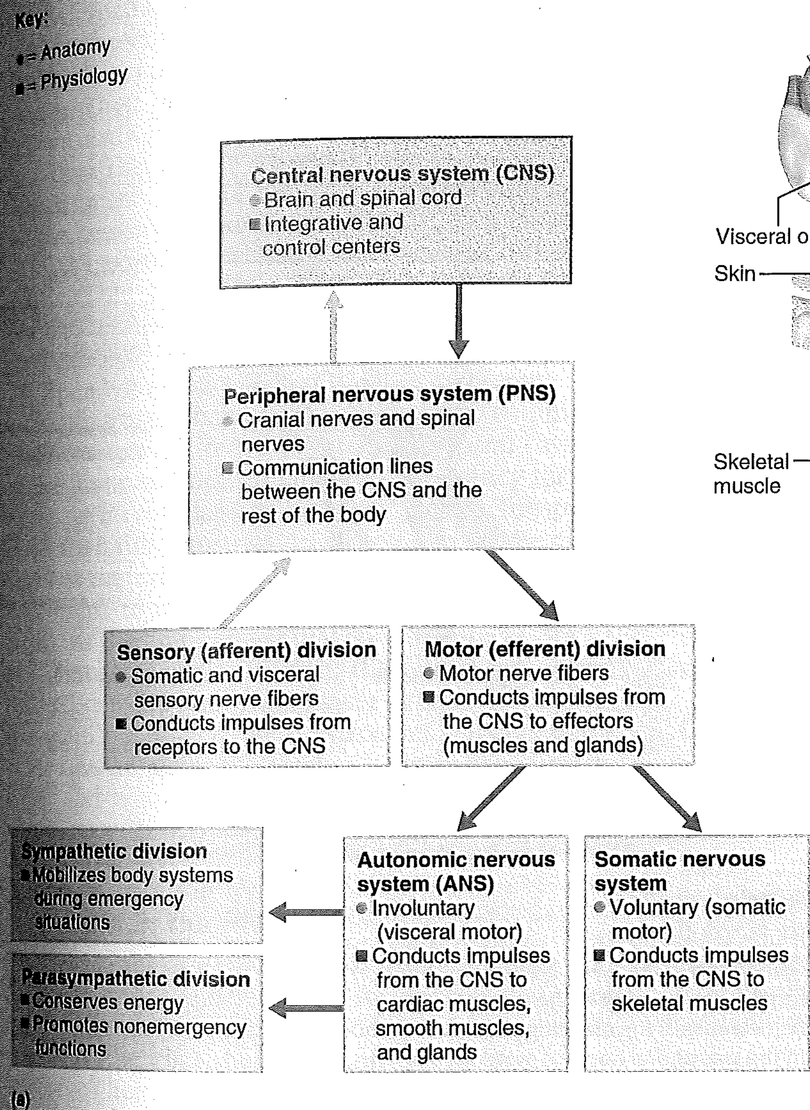
The PNS has two functional subdivisions (see Figure 11.2). The **sensory,** or **afferent, division** (af′er-ent; "carrying toward") consists of nerve fibers that convey impulses *to* the central nervous system from sensory receptors located throughout the body. Sensory fibers conveying impulses from the skin, skeletal muscles, and joints are called *somatic afferent fibers* (*soma* = body), and those transmitting impulses from the visceral organs (organs within the ventral body cavity) are called *visceral afferent fibers.* The sensory division keeps the CNS constantly informed of events going on both inside and outside the body.

The **motor,** or **efferent, division** (ef′er-ent; "carrying away") of the PNS transmits impulses *from* the CNS to effector organs, which are the muscles and glands. These impulses activate muscles to contract and glands to secrete; that is, they *effect* (bring about) a motor response.

The motor division also has two main parts:

1. The **somatic nervous system** is composed of somatic motor nerve fibers (axons) that conduct impulses from the CNS to skeletal muscles. It is often referred to as the **voluntary nervous system** because it allows us to consciously control our skeletal muscles.

2. The **autonomic nervous system (ANS)** consists of visceral motor nerve fibers that regulate the activity of smooth muscles, cardiac muscles, and glands. *Autonomic* means "a law unto itself," and because we generally cannot control such activities as the pumping of our heart or the movement of food through our digestive tract, the ANS is also referred to as the **involuntary nervous system.** As indicated in Figure 11.2 and described in Chapter 14, the ANS has two functional subdivisions, the **sympathetic**



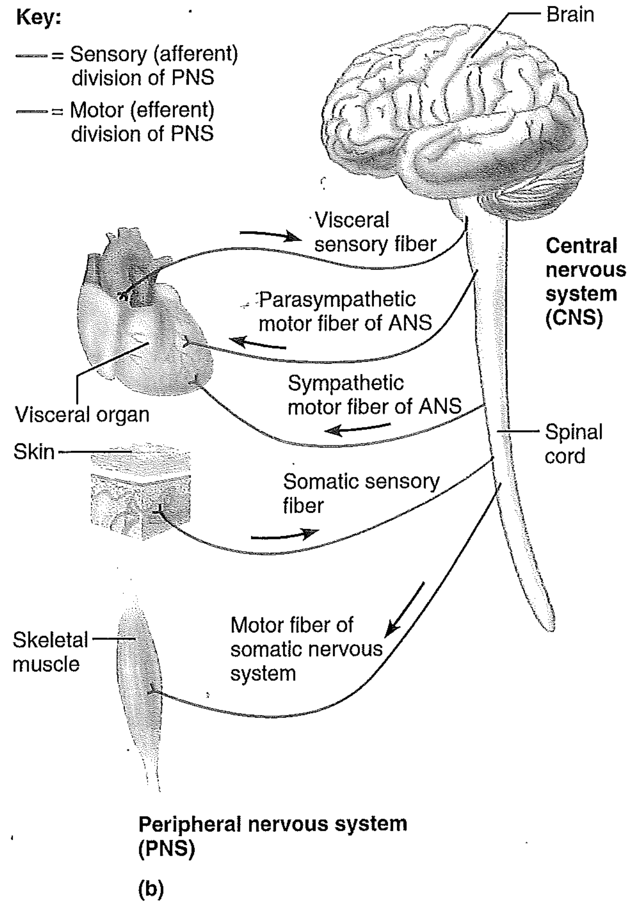


FIGURE 11.2 **Levels of organization in the nervous system.** **(a)** Organizational chart. **(b)** *Visceral organs* (primarily located in the ventral body cavity) are served by visceral sensory fibers and by motor fibers of the autonomic nervous system. The *somata* (limbs and body wall) are served by motor fibers of the somatic nervous system and by somatic sensory fibers. Arrows indicate the direction of nerve impulses.

and the **parasympathetic,** which typically work in opposition to each other—what one subdivision stimulates, the other inhibits.

Histology of Nervous Tissue

The nervous system consists mostly of nervous tissue, which is highly cellular. For example, less than 20% of the CNS is extracellular space, which means that the cells are densely packed and tightly intertwined. Although it is very complex, nervous tissue is made up of just two principal types of cells: (1) *supporting cells,* smaller cells that surround and wrap the more delicate neurons, and (2) *neurons,* the excitable nerve cells that transmit electrical signals.

Neuroglia

Neurons associate closely with much smaller cells called **neuroglia** (nu-rog′le-ah; "nerve glue") or simply **glial cells** (gle′al). There are six types of neuroglia—four in the CNS and two in the PNS (Figure 11.3). Each type has a unique function, but in general, these cells provide a supportive scaffolding for neurons. Some segregate and insulate neurons so that electrical activities of adjacent neurons don't

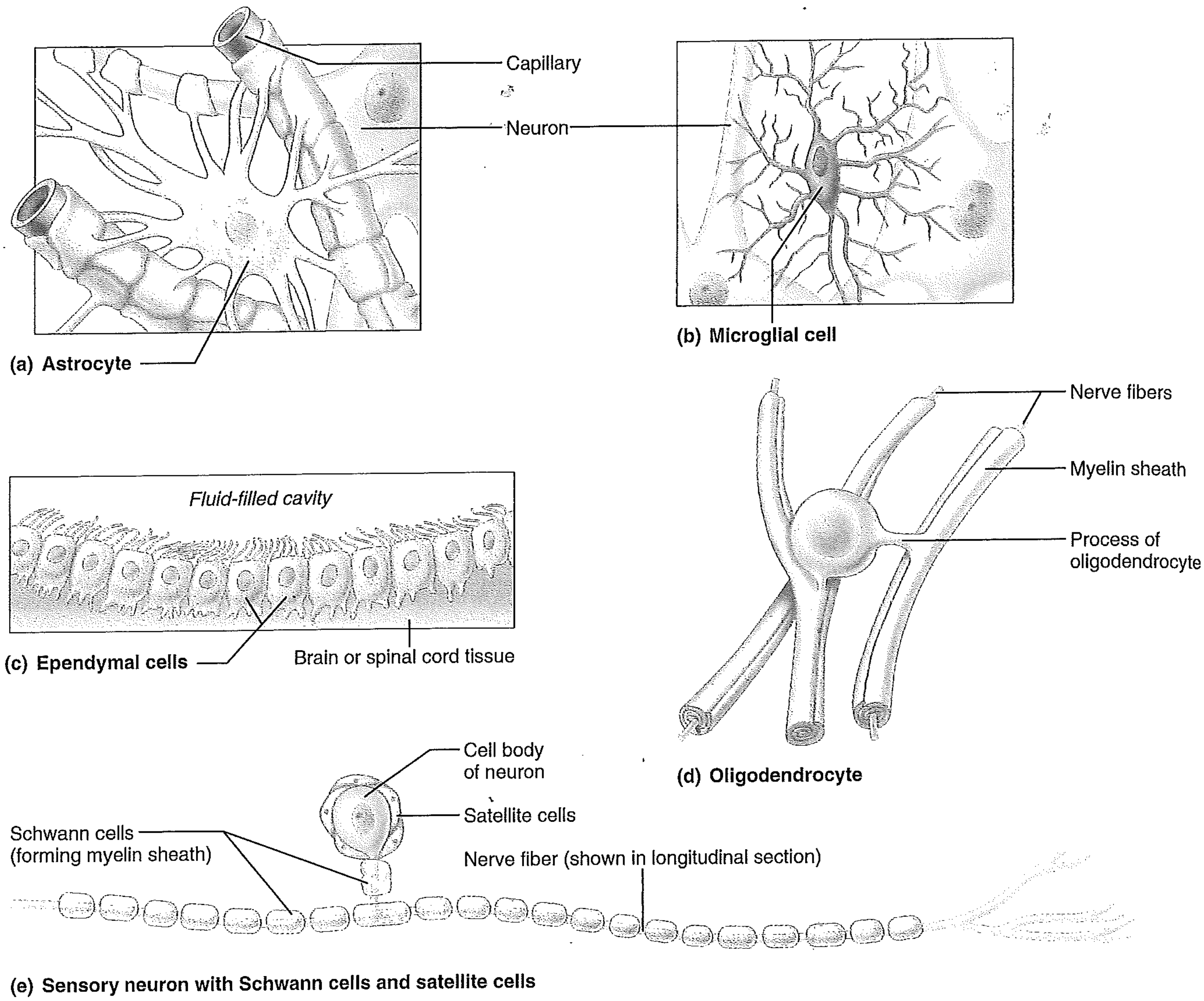


FIGURE 11.3 **Neuroglia. (a–d)** Types of neuroglia found in the CNS. Notice in (d) that it is the processes of the oligodendrocytes that form the myelin sheaths around CNS nerve fibers. **(e)** The relationships of Schwann cells (myelinating cells) and satellite cells to a sensory neuron (nerve cell) in the peripheral nervous system.

interfere with each other. Others produce chemicals that guide young neurons to the proper connections, and promote neuron health and growth.

Neuroglia in the CNS

Neuroglia in the CNS include *astrocytes, microglia, ependymal cells,* and *oligodendrocytes.* Like neurons, most glial cells have branching processes (extensions) and a central cell body (Figure 11.3a–d). Neuroglia can be distinguished, however, by their much smaller size and by their darker-staining nuclei. They outnumber neurons in the CNS by about 10 to 1, and make up about half the mass of the brain.

Shaped like delicate branching sea anemones, **astrocytes** (as′tro-sītz; "star cells") are the most abundant and most versatile glial cells. Their numerous radiating processes cling to neurons and their synaptic endings, and cover nearby capillaries, supporting and bracing the neurons and anchoring them to their nutrient supply lines, the blood capillaries (Figure 11.3a). Astrocytes have a role in making exchanges between capillaries and neurons (they take up glucose from the bloodstream and deliver it to neurons in the form of lactic acid), in guiding the migration of young neurons, in synapse formation, and in helping to determine capillary permeability. They also control the chemical environment around neurons, where their most important job is "mopping up" leaked potassium ions and recapturing (and recycling) released neurotransmitters. Furthermore, astrocytes (connected together by gap junctions) have been shown to signal one another (and perhaps neurons) via slow-paced intracellular calcium pulses. According to recent research, these calcium pulses elicit surges of Ca^{2+} in adjacent neurons and influence the neurons' electrical signaling.

Microglia (mi-kro'gle-ah) are small ovoid cells with relatively long "thorny" processes (Figure 11.3b). Their processes touch nearby neurons, monitoring their health, and when they sense that certain neurons are injured or in other trouble, the microglia migrate toward them. Where invading microorganisms or dead neurons are present, the microglia transform into a special type of macrophage that phagocytizes the microorganisms or neuronal debris. This protective role of the microglia is important because cells of the immune system are denied access to the CNS.

Ependymal cells (ĕ-pen'dĭ-mul; "wrapping garment") range in shape from squamous to columnar, and many are ciliated. They line the central cavities of the brain and the spinal cord, where they form a fairly permeable barrier between the cerebrospinal fluid that fills those cavities and the tissue fluid bathing the cells of the CNS. The beating of their cilia helps to circulate the cerebrospinal fluid that cushions the brain and spinal cord (Figure 11.3c).

Though they also branch, the **oligodendrocytes** (ol"ĭ-go-den'dro-sīts) have fewer processes (*oligo* = few; *dendr* = branch) than astrocytes. Oligodendrocytes line up along the thicker neuron fibers in the CNS and wrap their processes tightly around the fibers, producing insulating coverings called *myelin sheaths* (Figure 11.3d).

Neuroglia in the PNS

The two kinds of PNS neuroglia—*satellite cells* and *Schwann cells*—differ mainly in location. **Satellite cells** surround neuron cell bodies within ganglia (Figure 11.3e), but their function is still largely unknown. Their name comes from a fancied resemblance to the moons (satellites) around a planet.

Schwann cells (also called *neurolemmocytes*) surround and form myelin sheaths around the larger nerve fibers in the peripheral nervous system (Figures 11.3e and 11.4b). Hence, they are functionally similar to oligodendrocytes. (The formation of myelin sheaths is described later in this chapter.) Schwann cells are vital to regeneration of peripheral nerve fibers.

Neurons

The billions of **neurons,** also called **nerve cells,** are the structural units of the nervous system. They are highly specialized cells that conduct messages in the form of nerve impulses from one part of the body to another. Besides their ability to conduct nerve impulses, neurons have some other special characteristics:

1. They have *extreme longevity.* Given good nutrition, neurons can function optimally for a lifetime (over 100 years).

2. They are largely *amitotic.* As neurons assume their roles as communicating links of the nervous system, they lose their ability to divide. We pay a high price for this neuron feature because they cannot replace themselves if destroyed. There *are* exceptions to this rule. For example, olfactory epithelium and some hippocampal regions contain stem cells that can produce new neurons throughout life. (The hippocampus is a brain region involved in memory.)

3. They have an exceptionally *high metabolic rate* and require continuous and abundant supplies of oxygen and glucose. Neurons cannot survive for more than a few minutes without oxygen.

Neurons are typically large, complex cells. Although they vary in structure, they all have a *cell body* from which one or more slender *processes* project (Figure 11.4). The plasma membrane of neurons is the site of electrical signaling, and it plays a crucial role in cell-to-cell interactions that occur during development.

Cell Body

The **neuron cell body** consists of a transparent, spherical nucleus with a conspicuous nucleolus surrounded by cytoplasm. Also called the **perikaryon** (*peri* = around, *kary* = nucleus) or **soma,** the cell body ranges in diameter from 5 to 140 μm. The cell body is the major *biosynthetic center* of a neuron. Except for centrioles, it contains the usual organelles. (Centrioles play an important role in forming the mitotic spindle. Their apparent absence reflects the amitotic nature of most neurons.)

The neuron cell body's protein- and membrane-making machinery, consisting of clustered free ribosomes and rough endoplasmic reticulum (ER), is probably the most active and best developed in the body. This rough ER, referred to as **Nissl bodies** (nis'l) or **chromatophilic substance** (chromatophilic = "color loving"), stains darkly with basic dyes. The Golgi apparatus is also well developed and forms an arc or a complete circle around the nucleus. Mitochondria are scattered among the other organelles. Microtubules and **neurofibrils,** bundles of intermediate filaments *(neurofilaments)*, which are important in maintaining cell shape and integrity, are seen throughout the cell body. The cell body of some neurons also contains pigment inclusions. For example, some contain a black melanin, a red iron-containing pigment, or a golden-brown pigment

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Neurons with the longest axons tend to have large cell bodies, while those with short axons usually have small cell bodies. Can you think of an explanation for this relationship?

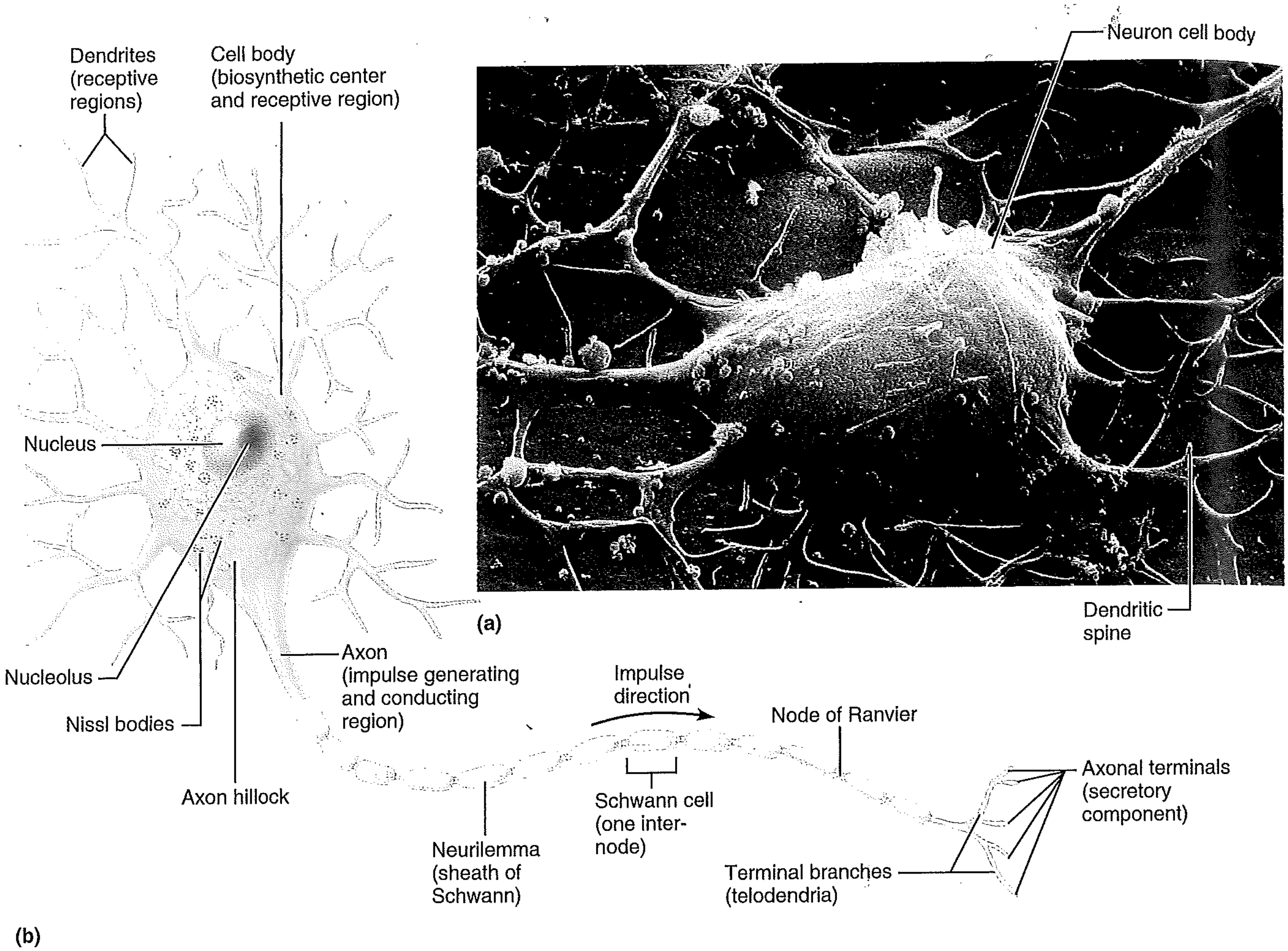


FIGURE 11.4 **Structure of a motor neuron. (a)** Scanning electron micrograph showing the cell body and dendrites with obvious dendritic spines (6000×). **(b)** Diagrammatic view.

called *lipofuscin* (lip″o-fu′sin). Lipofuscin, a harmless by-product of lysosomal activity, is sometimes called the "aging pigment" because it accumulates in neurons of elderly individuals.

The cell body is the focal point for the outgrowth of neuron processes during embryonic development. In most neurons, the plasma membrane of the cell body also acts as *part of the receptive surface* (Table 11.1, pp. 396–397) that receives information from other neurons.

Most neuron cell bodies are located in the CNS, where they are protected by the bones of the skull and vertebral column. Clusters of cell bodies in the CNS are called **nuclei,** whereas those that lie along the nerves in the PNS are called **ganglia** (gang′gle-ah; *ganglion* = knot on a string, swelling).

Processes

Armlike **processes** extend from the cell body of all neurons. The brain and spinal cord (CNS) contain both neuron cell bodies and their processes. The PNS, for the most part, consists chiefly of neuron processes. Bundles of neuron processes are called **tracts** in the CNS and **nerves** in the PNS.

The two types of neuron processes, *dendrites* and *axons* (ak′sonz), differ from each other in the structure and function of their plasma membranes. The convention is to describe these processes using

The longer the axon, the larger the cell body needed to service it. ■

a motor neuron as an example of a typical neuron. We shall follow this practice, but keep in mind that many sensory neurons and some tiny CNS neurons differ from the "typical" pattern we present here.

Dendrites **Dendrites** of motor neurons are short, tapering, diffusely branching extensions. Typically, motor neurons have hundreds of lacy dendrites clustering close to the cell body. Virtually all organelles present in the cell body also occur in dendrites. Dendrites are the main **receptive** or **input regions** (see Table 11.1). They provide an enormous surface area for receiving signals from other neurons. In many brain areas, the finer dendrites are highly specialized for information collection. They bristle with thorny appendages having bulbous or spiky ends called *dendritic spines* (Figure 11.4a), which represent points of close contact (synapses) with other neurons. Dendrites convey incoming messages *toward* the cell body. These electrical signals are *not* nerve impulses (action potentials) but are short-distance signals called *graded potentials,* as described shortly.

The Axon Each neuron has a single **axon** (*axo* = axis, axle). The initial region of the axon arises from a cone-shaped area of the cell body called the **axon hillock** ("little hill") and then narrows to form a slender process that is uniform in diameter for the rest of its length (Figure 11.4). In some neurons, the axon is very short or absent; in others it is long and accounts for nearly the entire length of the neuron. For example, axons of the motor neurons controlling the skeletal muscles of your great toe extend from the lumbar region of your spine to your foot, a distance of a meter or more (3–4 feet), making them the longest cells in the body. Any long axon is called a **nerve fiber.**

Each neuron has only one axon, but axons may have occasional branches along their length. These rare branches, called **axon collaterals,** extend from the axon at more or less right angles. Whether an axon is undivided or has collaterals, it usually branches profusely at its end (terminus): 10,000 or more **terminal branches,** or **telodendria,** per neuron is not unusual. The knoblike distal endings of the terminal branches are variously called **axonal terminals, synaptic knobs,** or **boutons** (boo-tonz; "buttons"). Take your pick!

Functionally, the axon is the **conducting component** of the neuron (Table 11.1). It *generates nerve impulses* and *transmits them,* typically away from the cell body. In motor neurons, the nerve impulse is generated at the junction of the axon hillock and axon (which is therefore called the *trigger zone*) and conducted along the axon to the axonal terminals, which are the **secretory component** of the neuron. When the impulse reaches the axonal terminals, it causes *neurotransmitters,* signaling chemicals stored in vesicles there, to be released into the extracellular space. The neurotransmitters either excite or inhibit neurons (or effector cells) with which the axon is in close contact. Because each neuron both receives signals from and sends signals to scores of other neurons, it carries on "conversations" with many different neurons at the same time.

An axon contains the same organelles found in the dendrites and cell body with two important exceptions—it lacks Nissl bodies and a Golgi apparatus, the structures involved with protein synthesis and packaging. Consequently, an axon depends (1) on its cell body to renew the necessary proteins and membrane components, and (2) on efficient transport mechanisms to distribute them. Axons quickly decay if cut or severely damaged.

Because axons are often very long, moving molecules along their length might appear to be a problem. However, through the cooperative effort of several types of cytoskeletal elements (microtubules, actin filaments, and so on), substances travel continuously along the axon both away from and toward the cell body. Movement toward the axonal terminals is *anterograde movement,* and that in the opposite direction is *retrograde movement.*

Substances moved in the anterograde direction include mitochondria, cytoskeletal elements, membrane components used to renew the axon plasma membrane, or **axolemma** (ak″so-lem′ah), and enzymes needed for synthesis of certain neurotransmitters. (Some neurotransmitters are synthesized in the cell body and then transported to the axonal terminals.)

Substances transported through the axon in the retrograde direction are mostly organelles being returned to the cell body for degradation or recycling. Retrograde transport is also an important means of intracellular communication for "advising" the cell body of conditions at the axonal terminals, and for delivering to the cell body vesicles containing signal molecules (like nerve growth factor, which activates certain nuclear genes promoting growth).

There are two or three transport mechanisms operating in axons, the fastest of which is ATP dependent, bidirectional, and uses "motor" proteins—ATPases such as kinesin, dynein, and perhaps others. These proteins propel membranous particles along the microtubules like trains along tracks.

HOMEOSTATIC IMBALANCE

Certain viruses and bacterial toxins that damage neural tissues use retrograde axonal transport to reach the cell body. This transport mechanism has

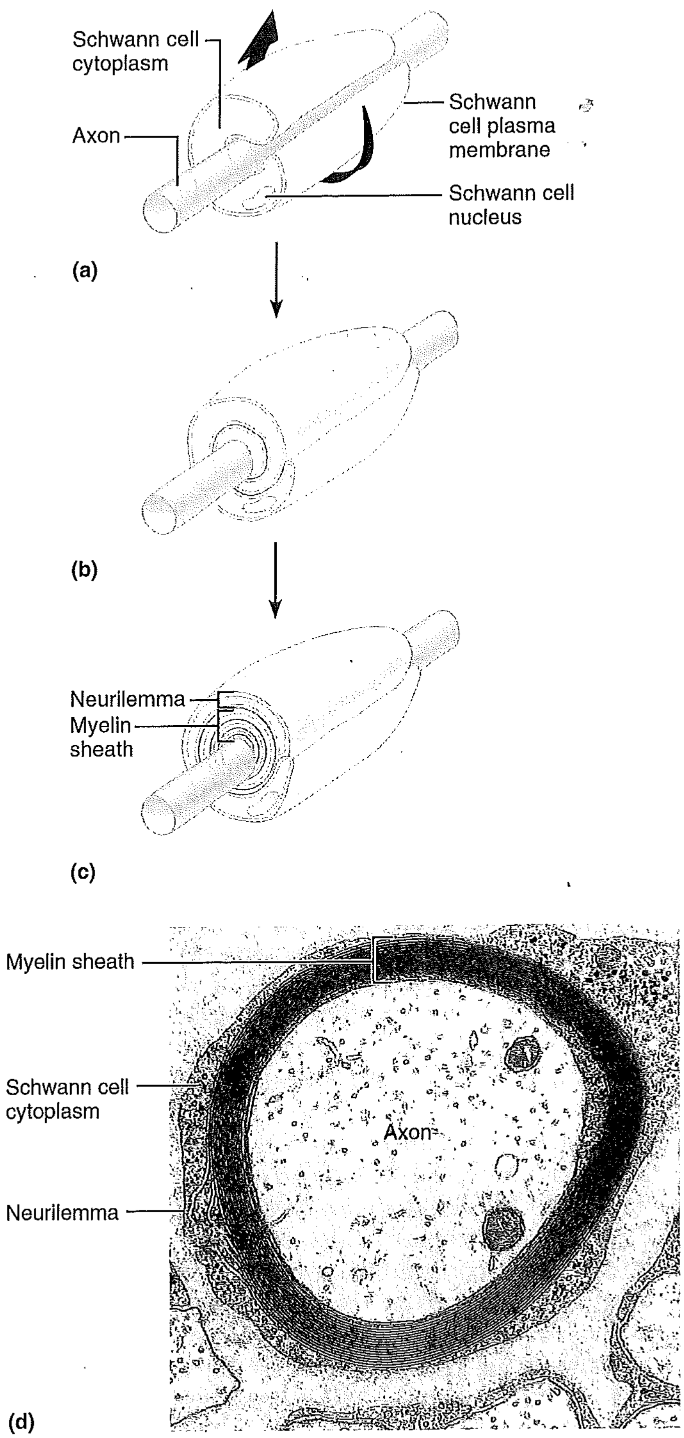


FIGURE 11.5 **Relationship of Schwann cells to axons in the PNS.** **(a–c)** Myelination of a nerve fiber (axon). As illustrated, a Schwann cell envelops an axon in a trough. It then begins to rotate around the axon, enveloping the axon loosely in successive layers of its plasma membrane. Eventually, the Schwann cell cytoplasm is forced from between the membranes and comes to lie peripherally just beneath the exposed portion of the Schwann cell plasma membrane. The tight membrane wrappings surrounding the axon form the myelin sheath; the area of Schwann cell cytoplasm and its exposed membrane is referred to as the neurilemma. **(d)** Electron micrograph of a myelinated axon, cross-sectional view (20,000×).

been demonstrated for polio, rabies, and herpes simplex viruses and for tetanus toxin. Its use as a tool to treat genetic diseases by introducing viruses containing "corrected" genes is under investigation.

Myelin Sheath and Neurilemma Many nerve fibers, particularly those that are long or large in diameter, are covered with a whitish, fatty (protein-lipoid), segmented **myelin sheath** (mi'ĕ-lin). Myelin protects and electrically insulates fibers from one another, and it increases the speed of transmission of nerve impulses. **Myelinated fibers** (axons bearing a myelin sheath) conduct nerve impulses rapidly, whereas **unmyelinated fibers** conduct impulses quite slowly. Note that myelin sheaths are associated only with axons. Dendrites are *always* unmyelinated.

Myelin sheaths in the PNS are formed by Schwann cells, which indent to receive an axon and then wrap themselves around it in a jelly roll fashion (Figure 11.5). Initially the wrapping is loose, but the Schwann cell cytoplasm is gradually squeezed from between the membrane layers. When the wrapping process is complete, many concentric layers of Schwann cell plasma membrane enclose the axon, much like gauze wrapped around an injured finger. This tight coil of wrapped membranes *is* the myelin sheath, and its thickness depends on the number of spirals. Plasma membranes of myelinating cells contain much less protein than the plasma membranes of most body cells. Channel and carrier proteins are notably absent, a characteristic that makes myelin sheaths exceptionally good electrical insulators. Another unique characteristic of these membranes is the presence of specific protein molecules that interlock to form a sort of molecular Velcro between adjacent myelin membranes.

The nucleus and most of the cytoplasm of the Schwann cell end up as a bulge just external to the myelin sheath. This portion of the Schwann cell, which includes the exposed part of its plasma membrane, is called the **neurilemma** ("neuron husk"). Adjacent Schwann cells along an axon do not touch one another, so there are gaps in the sheath. These gaps, called **nodes of Ranvier** (ran'vēr) or **neurofibril nodes,** occur at regular intervals (about 1 mm apart) along the myelinated axon. It is at these nodes that axon collaterals can emerge from the axon.

Sometimes Schwann cells surround peripheral nerve fibers but the coiling process does not occur. In such instances, a single Schwann cell can partially enclose 15 or more axons, each of which occupies a separate recess in the Schwann cell surface. Nerve fibers associated with Schwann cells in this manner are said to be *unmyelinated* and are typically thin fibers.

Both myelinated and unmyelinated axons are also found in the central nervous system. However, it is oligodendrocytes that form CNS myelin sheaths (Figure 11.3d). In contrast to Schwann cells, each of which forms only one segment (internode) of a myelin sheath, oligodendrocytes have multiple flat processes that can coil around as many as 60 axons at the same time. Nodes of Ranvier are present, but are more widely spaced than in the PNS. CNS myelin sheaths lack a neurilemma because cell extensions are doing the coiling and the squeezed-out cytoplasm is forced not peripherally but back toward the centrally located nucleus. As in the PNS, the smallest diameter axons are unmyelinated. These unmyelinated axons are covered by the long extensions of adjacent glial cells.

Regions of the brain and spinal cord containing dense collections of myelinated fibers are referred to as **white matter** and are primarily fiber tracts. **Gray matter** contains mostly nerve cell bodies and unmyelinated fibers.

Classification of Neurons

Neurons are classified both structurally and functionally. We describe both classifications here but use the functional classification in most discussions.

Structural Classification Neurons are grouped structurally according to the number of processes extending from their cell body. Three major neuron groups make up this classification: multipolar (*polar* = end, pole), bipolar, and unipolar neurons (Table 11.1).

Multipolar neurons have three or more processes. They are the most common neuron type in humans (more than 99% of neurons belong to this class) and the major neuron type in the CNS.

Bipolar neurons have two processes—an axon and a dendrite—that extend from opposite sides of the cell body. These rare neurons are found only in some of the special sense organs, where they act as receptor cells. Examples include some neurons in the retina of the eye and in the olfactory mucosa.

Unipolar neurons have a single short process that emerges from the cell body and divides T-like into proximal and distal branches. The more distal process, which is often associated with a sensory receptor, is the **peripheral process,** whereas that entering the CNS is the **central process** (Table 11.1). Unipolar neurons are more accurately called **pseudounipolar neurons** (*pseudo* = false) because they originate as bipolar neurons. Then, during early embryonic development, the two processes converge and partially fuse to form the short single process that issues from the cell body. Unipolar neurons are found chiefly in ganglia in the PNS, where they function as sensory neurons.

The fact that the fused peripheral and central processes of unipolar neurons are continuous and function as a single fiber might make you wonder whether they are axons or dendrites. The central process is definitely an axon because it conducts impulses away from the cell body (one definition of axon). However, the peripheral process is perplexing. Facts that favor classifying it as an axon are: (1) It generates and conducts an impulse (functional definition of axon); (2) when large, it is heavily myelinated; and (3) it has a uniform diameter and is indistinguishable microscopically from an axon. However, the older definition of a dendrite as a process that transmits impulses *toward* the cell body interferes with that conclusion. So which is it? In this book, we have chosen to emphasize the newer definition of an axon as generating and transmitting an impulse. Hence, *for unipolar neurons,* we will refer to the combined length of the peripheral and central process as an axon. In place of "dendrites," unipolar neurons have *receptive endings* (sensory terminals) at the end of the peripheral process.

Functional Classification This scheme groups neurons according to the direction in which the nerve impulse travels relative to the central nervous system. Based on this criterion, there are sensory neurons, motor neurons, and interneurons (Table 11.1).

Sensory, or **afferent, neurons** transmit impulses from sensory receptors in the skin or internal organs *toward* or *into* the central nervous system. Except for the bipolar neurons found in some special sense organs, virtually all sensory neurons are unipolar, and their cell bodies are located in sensory ganglia *outside* the CNS. Only the most distal parts of these unipolar neurons act as impulse receptor sites and the peripheral processes are often very long. For example, fibers carrying sensory impulses from the skin of your great toe travel for more than a meter before they reach their cell bodies in a ganglion close to the spinal cord.

Although the receptive endings of some sensory neurons are naked, in which case those terminals themselves function as sensory receptors, many bear receptors that include other cell types. The various types of general sensory receptor end organs, such as those of the skin, are described in Chapter 13. The special sensory receptors (of the ear, eye, etc.) are the topic of Chapter 15.

Motor, or **efferent, neurons** carry impulses *away from* the CNS to the effector organs (muscles and glands) of the body periphery. Motor neurons are multipolar, and except for some neurons of the autonomic nervous system, their cell bodies are located in the CNS.

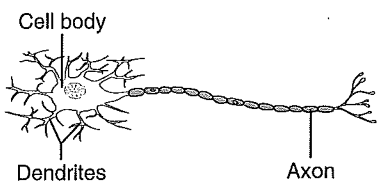
Interneurons, or **association neurons,** lie between motor and sensory neurons in neural

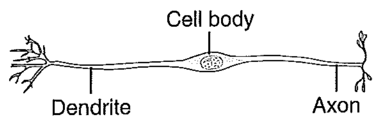
TABLE 11.1 **Comparison of Structural Classes of Neurons**

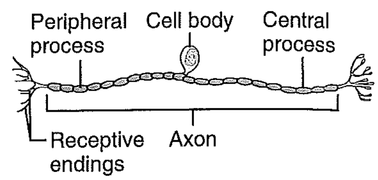
Neuron Type		
Multipolar	*Bipolar*	*Unipolar (Pseudounipolar)*

Structural Class: Neuron Type According to the Number of Processes Extending from the Cell Body

Multipolar	Bipolar	Unipolar (Pseudounipolar)
Many processes extend from the cell body; all dendrites except for a single axon.	Two processes extend from the cell body: one is a fused dendrite, the other is an axon.	One process extends from the cell body and forms central and peripheral processes, which together comprise an axon.

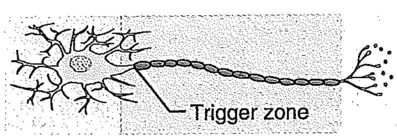


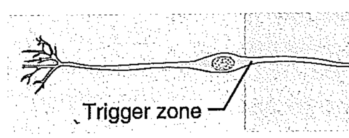


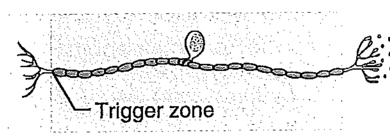


Relationship of Anatomy to the Three Functional Regions

Multipolar	Bipolar	Unipolar (Pseudounipolar)
= Receptive region (receives stimulus). Plasma membrane exhibits chemically gated ion channels.	= Conducting region (generates/ transmits action potential). Plasma membrane exhibits voltage-gated Na^+ and K^+ channels.	= Secretory region (axonal terminals release neurotransmitters). Plasma membrane exhibits voltage-gated Ca^+ channels.





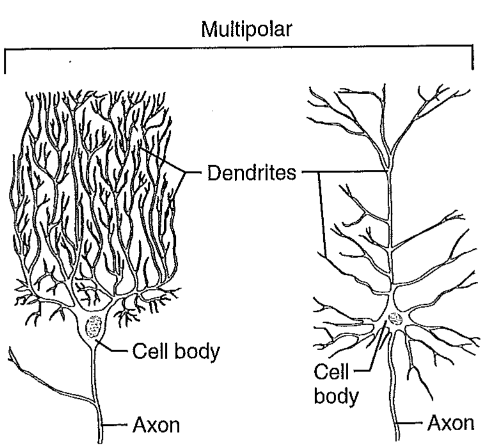


(Many bipolar neurons do not generate action potentials and, in those that do, the location of the trigger zone is not universal.)

Relative Abundance and Location in Human Body

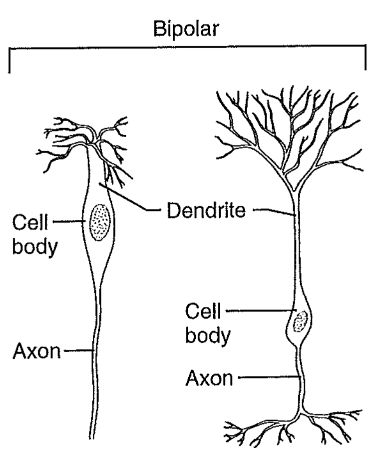
Multipolar	Bipolar	Unipolar (Pseudounipolar)
Most abundant in body. Major neuron type in the CNS.	Rare. Are found in some special sensory organs (olfactory mucosa, eye).	Found mainly in the PNS. Common only in dorsal root ganglia of the spinal cord and sensory ganglia of cranial nerves.

Structural Variations



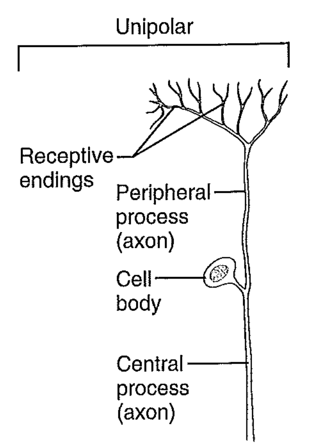
Purkinje cell of cerebellum

Pyramidal cell



Olfactory cell

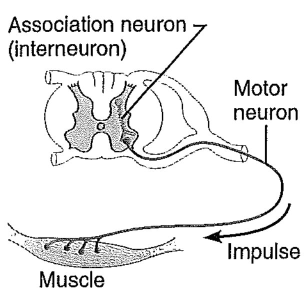
Retinal cell

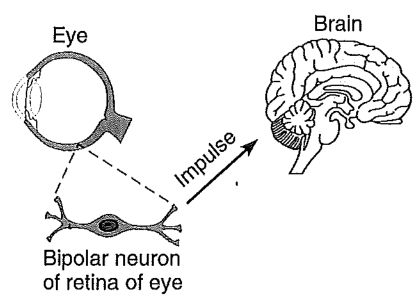


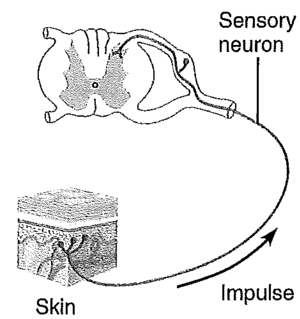
Dorsal root ganglion cell

TABLE 11.1 *(continued)*

Neuron Type		
Multipolar	*Bipolar*	*Unipolar (Pseudounipolar)*
Functional Class: Neuron Type According to Direction of Impulse Conduction		
1. Some multipolar neurons are **motor neurons** that conduct impulses along the efferent pathways from the CNS to an effector (muscle/gland). 2. Some multipolar neurons are higher level sensory neurons that convey sensory input from the first-order sensory neurons to higher CNS levels. 3. Most multipolar neurons are **interneurons (association neurons)** that conduct impulses within the CNS; may be one of a chain of CNS neurons, or single neuron connecting sensory and motor neurons.	Essentially all bipolar neurons are **sensory neurons** that are located in some special sense organs. For example, bipolar cells of the retina are involved with the transmission of visual inputs from the eye to the brain (via an intermediate chain of neurons).	Most unipolar neurons are **sensory neurons** that conduct impulses along afferent pathways to the CNS for interpretation. (These sensory neurons are primary or first-order sensory neurons.)







pathways and shuttle signals through CNS pathways where integration occurs. Most interneurons are confined within the CNS. They make up over 99% of the neurons of the body, including most of those in the CNS. Almost all interneurons are multipolar, but there is considerable diversity in both size and fiber-branching patterns. The Purkinje and pyramidal cells illustrated as structural variations in Table 11.1 are just two examples of their variety.

Neurophysiology

Neurons are highly *irritable* (responsive to stimuli). When a neuron is adequately stimulated, an electrical impulse is generated and conducted along the length of its axon. This response, called the *action potential (nerve impulse),* is always the same, regardless of the source or type of stimulus, and it underlies virtually all functional activities of the nervous system.

In this section, we will consider how neurons become excited or inhibited and how they communicate with other cells. First, however, we need to explore some basic principles of electricity and revisit the resting membrane potential.

Basic Principles of Electricity

The human body is electrically neutral; it has the same number of positive and negative charges. However, there are areas where one type of charge predominates, making such regions positively or negatively charged. Because opposite charges attract each other, energy must be used (work must be done) to separate them. On the other hand, the coming together of opposite charges liberates energy that can be used to do work. Thus, situations in which there are separated electrical charges of opposite sign have potential energy.

Some Definitions: Voltage, Resistance, Current

The measure of potential energy generated by separated charge is called **voltage** and is measured in either *volts* or *millivolts* (1 mV = 0.001 V). Voltage is always measured between two points and is called