2: Neuroscience and Behavior

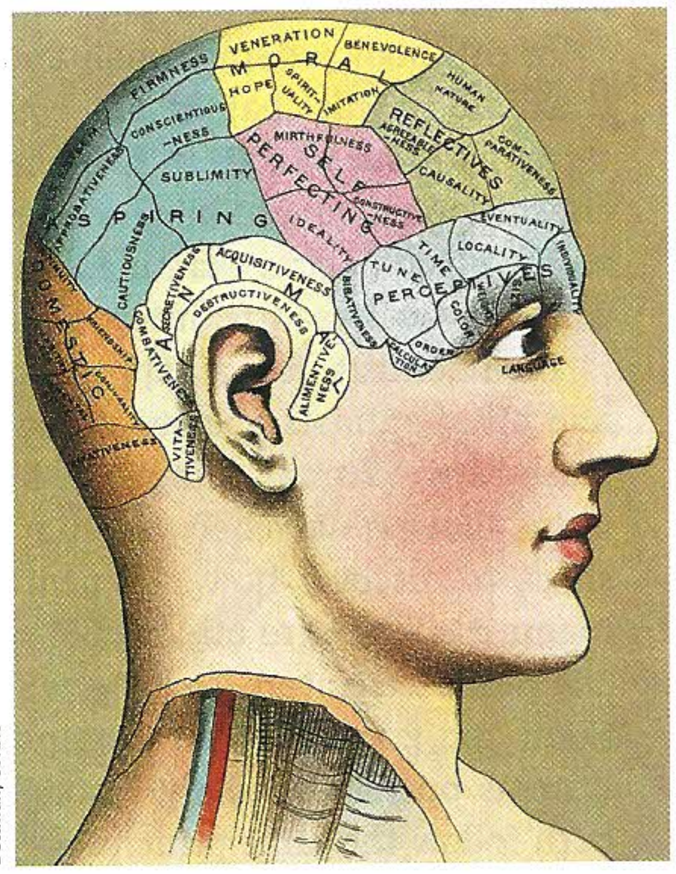
OBJECTIVE 1 | Explain why psychologists are concerned with human biology, and describe the ill-fated phrenology theory.

No principle is more central to today's psychology, or to this book, than this: *Everything psychological is simultaneously biological.* Your every idea, every mood, every urge is a biological happening. You love, laugh, and cry with your body. Without your body—your genes, your brain, your appearance—you are, indeed, nobody. Although we find it convenient to talk separately of biological and psychological influences on behavior, we need to remember: To think, feel, or act without a body would be like running without legs.

Today's science is riveted on our body's most amazing parts—the brain, its component neural systems, and their genetic instructions. The brain's ultimate challenge? To understand itself. How does our brain organize and communicate with itself? How do our heredity and our experience together wire our brain? How does the brain process the information we need to shoot a basketball? To delight in a guitarist's notes? To remember our first kiss?

Our understanding of how the brain gives birth to the mind has come a long way. The ancient philosopher Plato correctly located the mind in the spherical head—his idea of the perfect form. His student, Aristotle, believed the mind was in the heart, which pumps warmth and vitality to the body. The heart remains our symbol for love, but science has long overtaken philosophy on this issue. It's your brain, not your heart, that falls in love.

We have come far since the early 1800s, when the German physician Franz Gall invented *phrenology,* a popular but ill-fated theory that claimed bumps on the skull could reveal our mental abilities and our character traits (**FIGURE 2.1**). At one point, Britain had 29 phrenological societies, and phrenologists traveled North America giving skull readings (Hunt, 1993). Humorist Mark Twain put one famous phrenologist to the test when he came, using a pseudonym, for a skull-reading. "He found a cavity



Bettman/Corbis

FIGURE 2.1
A wrongheaded theory
Despite initial acceptance of Franz Gall's speculations, bumps on the skull tell us nothing about the brain's underlying functions. Nevertheless, some of Gall's assumptions have held true. Different parts of the brain do control different aspects of behavior, as you will see throughout this chapter.

biological psychology a branch of psychology concerned with the links between biology and behavior. (Some biological psychologists call themselves *behavioral neuroscientists, neuropsychologists, behavior geneticists, physiological psychologists,* or *biopsychologists.*)

"If I were a college student today, I don't think I could resist going into neuroscience."

Novelist Tom Wolfe, 2004

[and] startled me by saying that that cavity represented the total absence of the sense of humor!" Three months later, Twain sat for a second reading, this time identifying himself. Now "the cavity was gone, and in its place was . . . the loftiest bump of humor he had ever encountered in his life-long experience!" (Lopez, 2002). Phrenology did, however, correctly focus attention on the idea that various brain regions have particular functions.

Within little more than the last century, we have also realized that the body is composed of cells; that among these are nerve cells that conduct electricity and "talk" to one another by sending chemical messages across a tiny gap that separates them; that specific brain systems serve specific functions (though not the functions Gall supposed); and that from the information processed in these different brain systems, we construct our experience of sights and sounds, meanings and memories, pain and passion. You and I are privileged to live in a time when discoveries about the interplay of our biology and our behavior and mental processes are occurring at an exhilarating pace.

Throughout this book you will find examples of this interplay. By studying the links between biological activity and psychological events, **biological psychologists** are gaining a better understanding of sleep and dreams, depression and schizophrenia, hunger and sex, stress and disease. We therefore begin our study of psychology with a look at its biological roots.

Neural Communication

OBJECTIVE 2 | Explain how viewing each person as a biopsychosocial system helps us understand human behavior, and discuss why researchers study other animals in search of clues to human neural processes.

The body's information system is built from billions of interconnected cells called *neurons.* To fathom our thoughts and actions, memories and moods, we must first understand how neurons work and communicate.

We are each a system composed of subsystems that are in turn composed of even smaller subsystems. Tiny cells organize to form such body organs as the stomach, heart, and brain. These organs in turn form larger systems for digestion, circulation, and information processing. And those systems are part of an even larger system—the individual, who in turn is a part of a family, culture, and community. We are *biopsychosocial* systems. To understand our behavior, we need to study how these biological, psychological, and social-cultural systems work and interact.

In this book we start small and build from the bottom up—from nerve cells up to the brain in this chapter, and to the environmental and cultural influences that interact with our biology in later chapters. We will also work from the top down, as we consider how our thinking and emotions influence our brain and our health. At all levels, psychologists examine how we process information—how we take in information; how we organize, interpret, and store it; and how we use it.

For scientists, it is a happy fact of nature that the information systems of humans and other animals operate similarly—so similarly, in fact, that you could not distinguish between small samples of brain tissue from a human and a monkey. This similarity allows researchers to study relatively simple animals, such as squids and sea slugs, to discover how our neural systems operate. It allows them to study other mammals' brains to understand the organization of our own. Cars differ, but all have engines, accelerators, steering wheels, and brakes. A Martian could study any one of them and grasp the operating principles. Likewise, animals differ, yet their nervous systems operate similarly. Though the human brain is more complex than a rat's, both follow the same principles.

Neurons

OBJECTIVE 3 | Describe the parts of a neuron, and explain how its impulses are generated.

Our body's neural information system is complexity built from simplicity. Its building blocks are neurons, or nerve cells. There are many different types of **neurons,** but all are variations on the same theme (**FIGURE 2.2**). Each consists of a cell body and its branching fibers. The bushy **dendrite** fibers receive information and conduct it toward the cell body. From there, **axon** fibers pass the message along to other neurons or to muscles or glands. Axons speak. Dendrites listen.

Unlike the short dendrites, axons are sometimes very long, projecting several feet through the body. Motor neurons, which control muscles, are the neural system's giant redwoods. A neuron carrying orders to a leg muscle has a cell body and axon roughly on the scale of a basketball attached to a rope 4 miles long. A layer of fatty tissue, called the **myelin sheath,** insulates the axons of some neurons and helps speed their impulses. The myelin sheath's importance is evident in multiple sclerosis, a disease in which the myelin sheath degenerates. The result is a slowing of all communication to muscles and the eventual loss of muscle control.

Depending on the type of fiber, the neural impulse travels at speeds ranging from a sluggish 2 miles per hour to a breakneck 200 or more miles per hour. But even this top speed is 3 million times slower than that of electricity through a wire. We measure brain activity in milliseconds (thousandths of a second) and computer activity in nanoseconds (billionths of a second). That helps to explain why, unlike the nearly instantaneous reactions of a high-speed computer, your reaction to a sudden event, such as a child darting in front of your car, may take a quarter-second or more. Your brain is vastly more complex than a computer, but not faster at executing simple responses.

A neuron fires an impulse when it receives signals from sense receptors stimulated by pressure, heat, or light, or when it is stimulated by chemical messages from neighboring neurons. The impulse, called the **action potential,** is a brief electrical charge that travels down the axon.

Neurons, like batteries, generate electricity from chemical events. The chemistry-to-electricity process involves the exchange of electrically charged atoms, called *ions*. The fluid interior of a resting axon has an excess of negatively charged ions, while the fluid outside the axon membrane has more positively charged ions. This

neuron a nerve cell; the basic building block of the nervous system.

dendrite the bushy, branching extensions of a neuron that receive messages and conduct impulses toward the cell body.

axon the extension of a neuron, ending in branching terminal fibers, through which messages pass to other neurons or to muscles or glands.

myelin [MY-uh-lin] **sheath** a layer of fatty tissue segmentally encasing the fibers of many neurons; enables vastly greater transmission speed of neural impulses as the impulse hops from one node to the next.

action potential a neural impulse; a brief electrical charge that travels down an axon. The action potential is generated by the movement of positively charged atoms in and out of channels in the axon's membrane.

I sing the body electric."

Walt Whitman, "Children of Adam," 1855

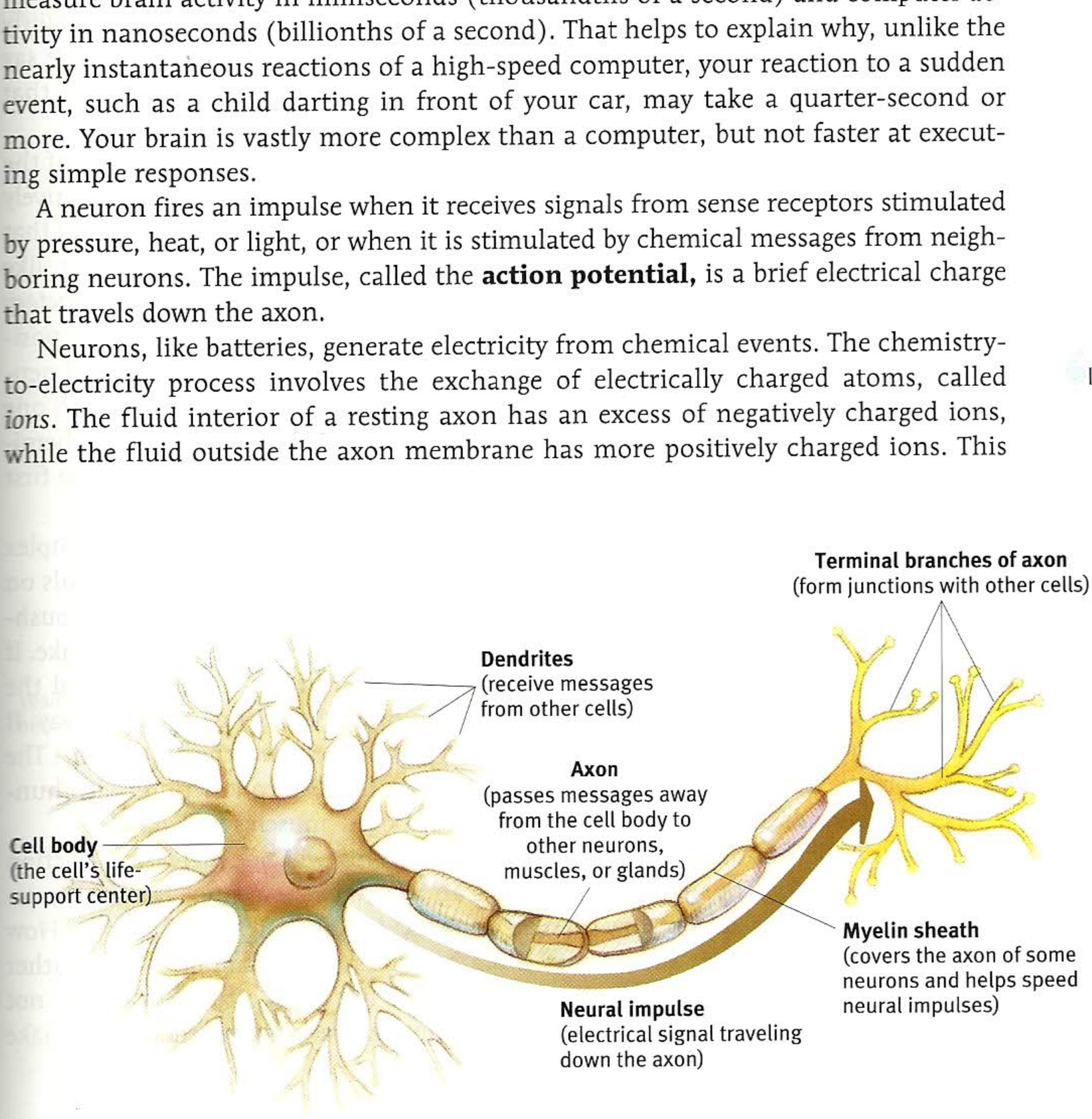


FIGURE 2.2
A motor neuron

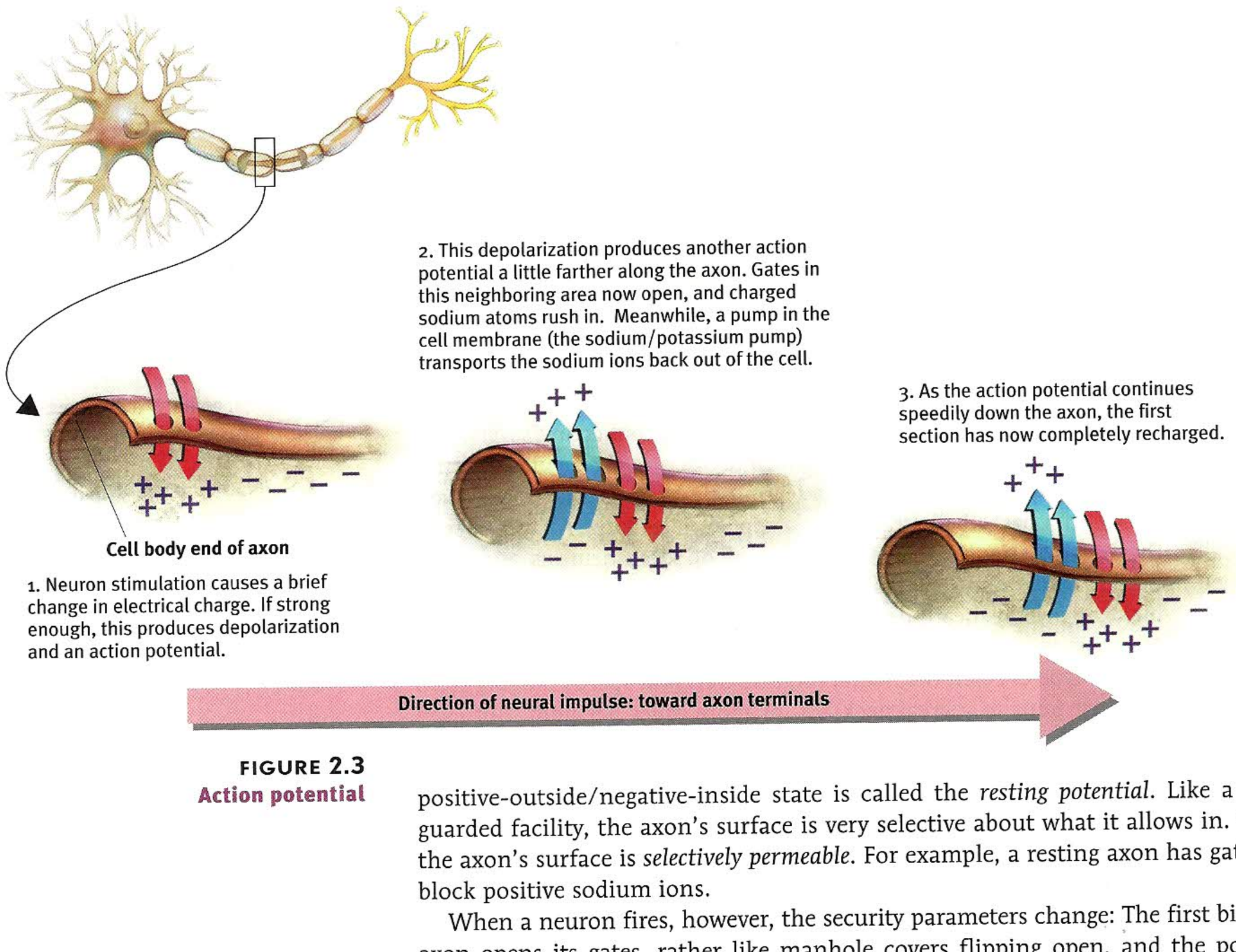


FIGURE 2.3
Action potential

positive-outside/negative-inside state is called the *resting potential*. Like a tightly guarded facility, the axon's surface is very selective about what it allows in. We say the axon's surface is *selectively permeable*. For example, a resting axon has gates that block positive sodium ions.

When a neuron fires, however, the security parameters change: The first bit of the axon opens its gates, rather like manhole covers flipping open, and the positively charged sodium ions flood through the membrane (**FIGURE 2.3**). This *depolarizes* that part of the axon, causing the axon's next channel to open, and then the next, like dominoes falling, each one tripping the next. During a resting pause (the *refractory period,* rather like a camera flash pausing to recharge), the neuron pumps the positively charged sodium ions back outside. Then it can fire again. (In myelinated neurons, as in Figure 2.2, page 55, the action potential speeds up by hopping from one myelin "sausage" to the next.) The mind boggles when imagining this electrochemical process repeating up to 100 or even 1000 times a second. But this is just the first of many astonishments.

"What one neuron tells another neuron is simply how much it is excited."

Francis Crick, *The Astonishing Hypothesis*, 1994

The neuron is a miniature decision-making device that performs some complex calculations. From hundreds, even thousands of other neurons, it receives signals on its dendrites and cell body. Most of these signals are *excitatory,* somewhat like pushing a neuron's accelerator. Other signals are *inhibitory,* more like pushing its brake. If excitatory signals minus inhibitory signals exceed a minimum intensity, called the **threshold,** the combined signals trigger an action potential. (Think of it this way: If the excitatory party animals outvote the inhibitory party poopers, the party's on.) The action potential transmits down the axon, which branches into junctions with hundreds or thousands of other neurons and with the body's muscles and glands.

threshold the level of stimulation required to trigger a neural impulse.

Increasing the stimulus above the threshold, however, will not increase the action potential's intensity. The neuron's reaction is an *all-or-none response:* Like guns, neurons either fire or they don't. How then do we detect the intensity of a stimulus? How do we distinguish a gentle touch from a big hug? A strong stimulus—a slap rather than a tap—can trigger more neurons to fire, and to fire more often. But it does not affect the action potential's strength or speed. Squeezing a trigger harder won't make a bullet go faster.

How Neurons Communicate

OBJECTIVE 4 | Describe how nerve cells communicate.

Neurons interweave so intricately that even with a microscope it is hard to see where one neuron ends and another begins. Scientists once believed that the branching axon of one cell fused with the dendrites of another in an uninterrupted fabric. Then a Spanish anatomist, Santiago Ramon y Cajal (1852–1934), described gaps between individual nerve cells and concluded that the individual neurons must function as independent agents within the nervous system. At the same time, the British physiologist Sir Charles Sherrington (1857–1952) noticed that neural impulses were taking an unexpectedly long time to travel a neural pathway. Sherrington inferred there must be a brief interruption in the transmission.

We now know that the axon terminal of one neuron is in fact separated from the receiving neuron by a gap less than a millionth of an inch wide. Sherrington called this junction the **synapse,** and the gap is called the *synaptic gap* or *cleft*. To Cajal, these near-unions of neurons—"protoplasmic kisses," he called them—were another of nature's marvels. "Like elegant ladies air-kissing so as not to muss their makeup, dendrites and axons don't quite touch," notes Diane Ackerman (2004). How do the neurons execute this protoplasmic kiss? How does information cross the tiny synaptic gap? The answer is one of the important scientific discoveries of our age.

When the action potential reaches the knoblike terminals at an axon's end, it triggers the release of chemical messengers, called **neurotransmitters** (**FIGURE 2.4**).

synapse [SIN-aps] the junction between the axon tip of the sending neuron and the dendrite or cell body of the receiving neuron. The tiny gap at this junction is called the *synaptic gap* or *cleft*.

neurotransmitters chemical messengers that traverse the synaptic gaps between neurons. When released by the sending neuron, neurotransmitters travel across the synapse and bind to receptor sites on the receiving neuron, thereby influencing whether that neuron will generate a neural impulse.

"All information processing in the brain involves neurons 'talking to' each other at synapses."

Neuroscientist Solomon H. Snyder (1984)

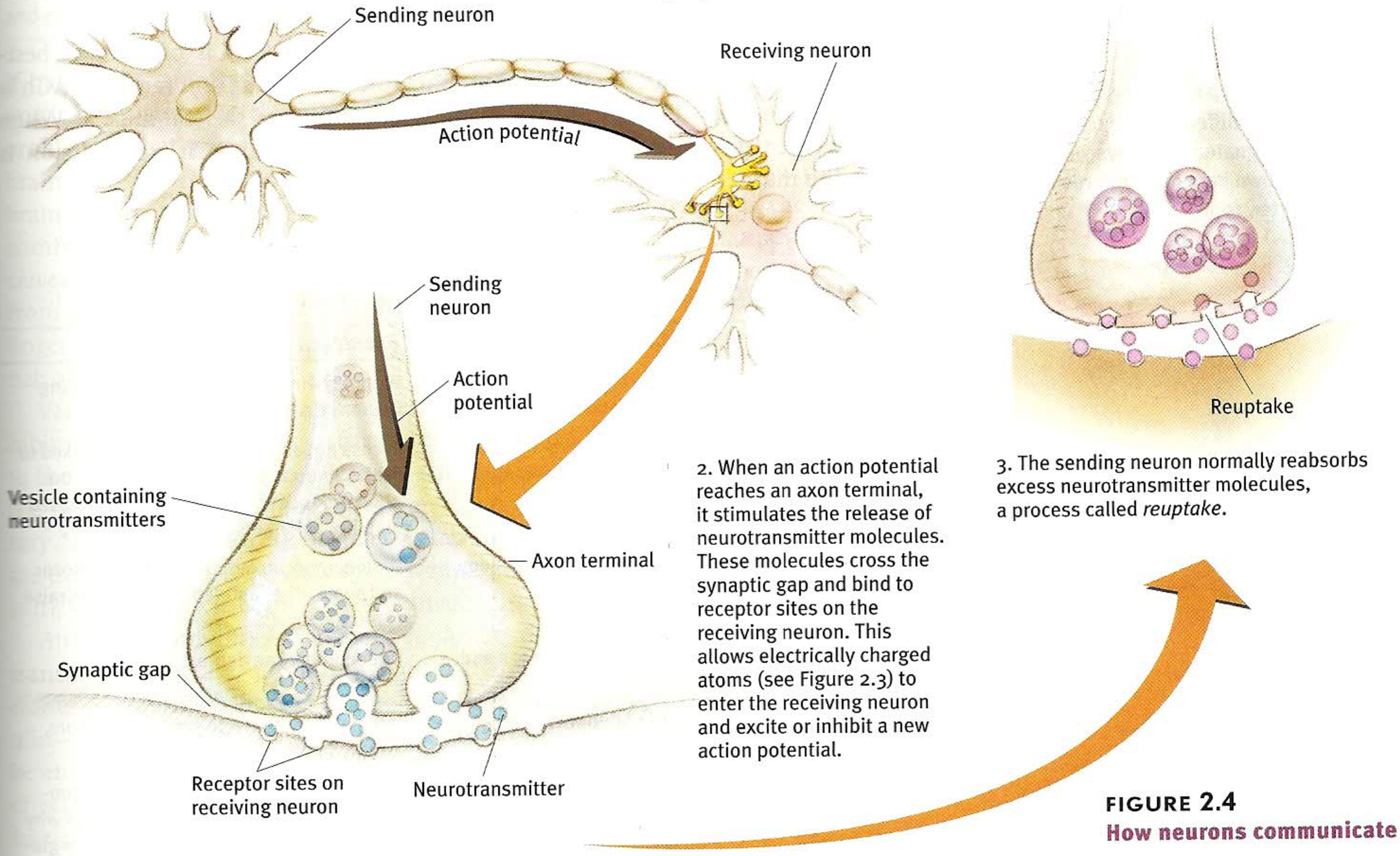


FIGURE 2.4
How neurons communicate

acetylcholine [ah-seat-el-KO-leen] **(ACh)** a neurotransmitter that enables learning and memory and also triggers muscle contraction.

Within 1/10,000th of a second, the neurotransmitter molecules cross the synaptic gap and bind to receptor sites on the receiving neuron—as precisely as a key fits a lock. For an instant, the neurotransmitter unlocks tiny channels at the receiving site. This allows ions to enter the receiving neuron, thereby either exciting or inhibiting its readiness to fire. Excess neurotransmitters are reabsorbed by the sending neuron in a process called *reuptake*.

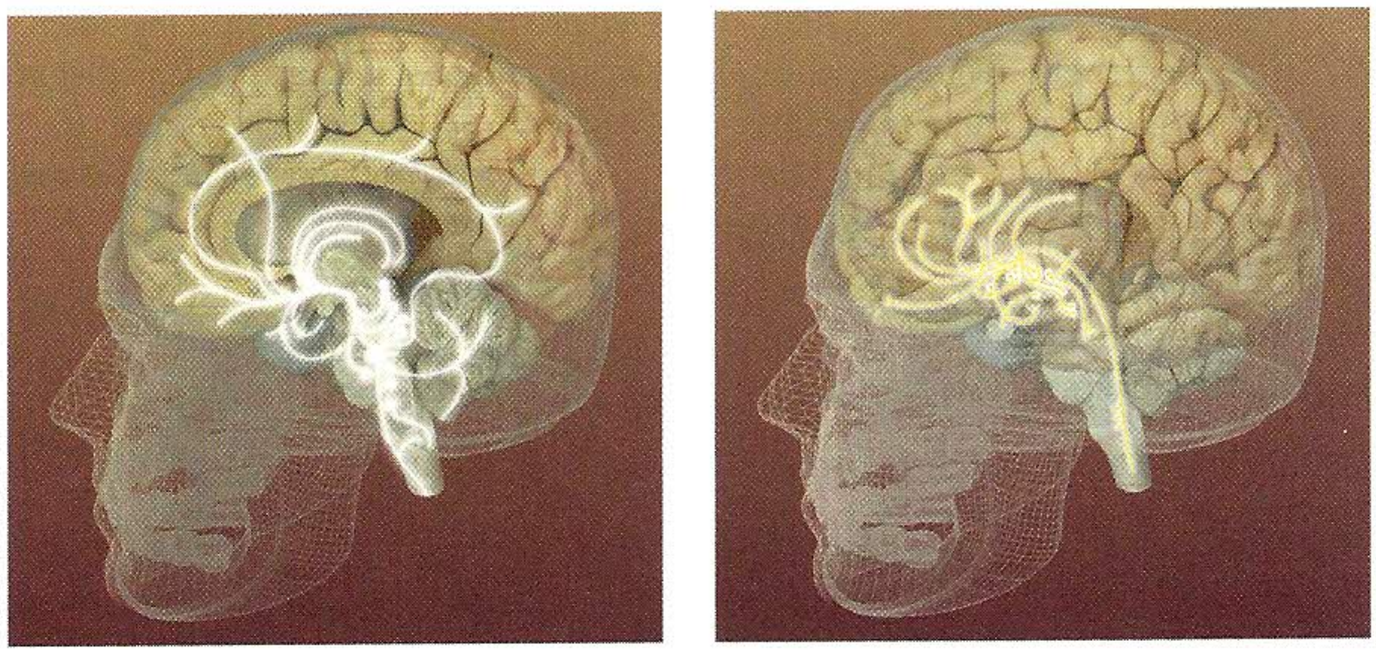
How Neurotransmitters Influence Us

OBJECTIVE 5 | Explain how neurotransmitters affect behavior, and outline the effects of acetylcholine and the endorphins.

> "When it comes to the brain, if you want to see the action, follow the neurotransmitters."
>
> Neuroscientist Floyd Bloom (1993)

As researchers discovered dozens of different neurotransmitters, they also encountered new questions: Are certain neurotransmitters found only in specific places? How do they affect our moods, memories, and mental abilities? Can we boost or diminish these effects through drugs or diet?

In later chapters we will examine neurotransmitter influences on depression and euphoria, hunger and thinking, addictions and therapy. For now, let's glimpse how neurotransmitters influence our motions and our emotions. We now know that a particular neural pathway in the brain may use only one or two neurotransmitters (**FIGURE 2.5**), and that particular neurotransmitters may have particular effects on behavior and emotions. (**TABLE 2.1** offers examples.)



Both photos from *Mapping the Mind*, Rita Carter, © 1989 University of California Press

Serotonin pathways | Dopamine pathways

FIGURE 2.5
Neurotransmitter pathways
Each of the brain's differing chemical messengers has designated pathways where it operates, as shown here for serotonin and dopamine (Carter, 1998).

Acetylcholine (ACh) is one of the best-understood neurotransmitters. In addition to its role in learning and memory, ACh is the messenger at every junction between a motor neuron and skeletal muscle. When ACh is released to our muscle cells, the muscle contracts. If ACh transmission is blocked, the muscles cannot contract.

Stanley Chou/Getty Images

TABLE 2.1
SOME NEUROTRANSMITTERS AND THEIR FUNCTIONS

Neurotransmitter	Function	Examples of Malfunctions
Acetylcholine (ACh)	Enables muscle action, learning, and memory.	With Alzheimer's disease, ACh-producing neurons deteriorate.
Dopamine	Influences movement, learning, attention, and emotion.	Excess dopamine receptor activity linked to schizophrenia. Starved of dopamine, the brain produces the tremors and decreased mobility of Parkinson's disease.
Serotonin	Affects mood, hunger, sleep, and arousal.	Undersupply linked to depression; Prozac and some other antidepressant drugs raise serotonin levels.
Norepinephrine	Helps control alertness and arousal.	Undersupply can depress mood.
GABA (gamma-aminobutyric acid)	A major inhibitory neurotransmitter.	Undersupply linked to seizures, tremors, and insomnia.
Glutamate	A major excitatory neurotransmitter; involved in memory.	Oversupply can overstimulate brain, producing migraines or seizures (which is why some people avoid MSG, monosodium glutamate, in food).

An exciting discovery about neurotransmitters occurred when Candace Pert and Solomon Snyder (1973) attached a radioactive tracer to morphine, showing them where it was taken up in an animal's brain. Their discovery: The morphine, an opiate drug that elevates mood and eases pain, bound to receptors in areas linked with mood and pain sensations.

It was hard to imagine why the brain would contain these "opiate receptors" unless it had its own naturally occurring opiates. Why would the brain have a chemical lock, unless it also had a corresponding key? Researchers soon confirmed that the brain does indeed contain several types of neurotransmitter molecules similar to morphine. Named **endorphins** (short for *end*ogenous [produced within] m*orphine*), these natural opiates are released in response to pain and vigorous exercise. They may therefore help explain good feelings such as the "runner's high," the painkilling effects of acupuncture, and the indifference to pain in some severely injured people, such as David Livingstone reported in his 1857 *Missionary Travels:*

> I heard a shout. Starting, and looking half round, I saw the lion just in the act of springing upon me. I was upon a little height, he caught my shoulder as he sprang, and we both came to the ground below together. Growling horribly close to my ear, he shook me as a terrier does a rat. The shock produced a stupor similar to that which seems to be felt by a mouse after the first shake of the cat. It caused a sort of dreaminess in which there was no sense of pain nor feeling of terror, though [I was] quite conscious of all that was happening. . . . This peculiar state is probably produced in all animals killed by the carnivora; and if so, is a merciful provision by our benevolent Creator for lessening the pain of death.

endorphins [en-DOR-fins] "morphine within"—natural, opiatelike neurotransmitters linked to pain control and to pleasure.

Physician Lewis Thomas, on the endorphins: "There it is, a biologically universal act of mercy. I cannot explain it, except to say that I would have put it in had I been around at the very beginning, sitting as a member of a planning committee."

The Youngest Science, 1983

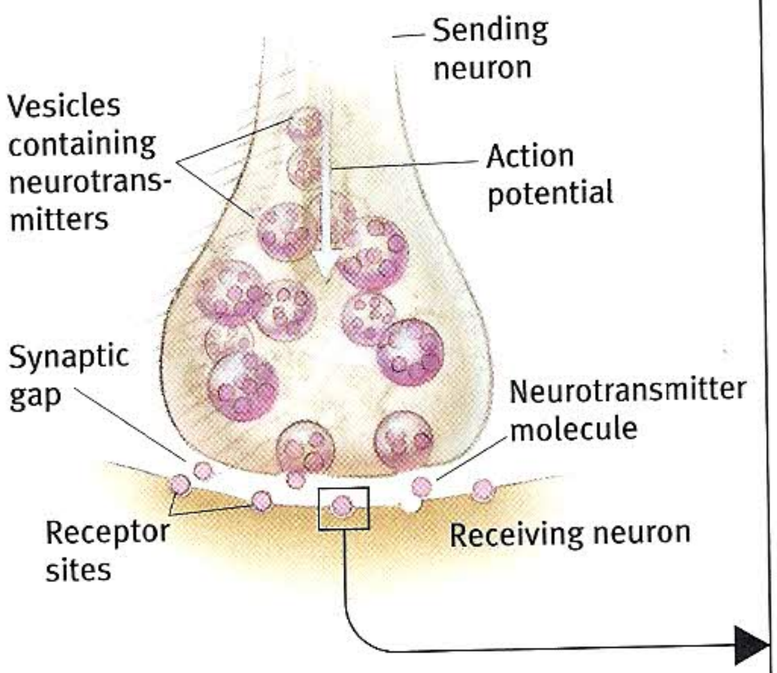
How Drugs and Other Chemicals Alter Neurotransmission

OBJECTIVE 6 | Explain how drugs and other chemicals affect neurotransmission, and describe the contrasting effects of agonists and antagonists.

If indeed the endorphins lessen pain and boost mood, why not flood the brain with artificial opiates, thereby intensifying the brain's own "feel-good" chemistry? One problem is that when flooded with opiate drugs such as heroin and morphine, the brain may stop producing its own natural opiates. When the drug is withdrawn, the brain may then be deprived of any form of opiate. For a drug addict, the result is discomfort that persists until the brain resumes production of its natural opiates or receives more artificial opiates. As we will see in later chapters, mood-altering drugs, from alcohol to nicotine to heroin, share a common effect: They trigger unpleasant, lingering aftereffects. For suppressing the body's own neurotransmitter production, nature charges a price.

Various drugs affect communication at the synapse, often by either exciting or inhibiting neurons' firing. *Agonists* excite. An agonist molecule may be similar enough to the neurotransmitter to mimic its effects (**FIGURE 2.6b** on page 60) or it may block the neurotransmitter's reuptake. Some opiate drugs, for example, produce a temporary "high" by amplifying normal sensations of arousal or pleasure. Not so pleasant are the effects of black widow spider venom, which floods synapses with ACh. The result? Violent muscle contractions, convulsions, and possible death.

Antagonists inhibit. An antagonist can be a drug molecule that inhibits a neurotransmitter's release. Botulin, a poison that can form in improperly canned food, causes paralysis by blocking ACh release from the sending neuron. (Injections of botulin—Botox—smooth wrinkles by paralyzing the underlying facial muscles.) Or it may be enough like the natural neurotransmitter to occupy its receptor site and block its effect, as in **FIGURE 2.6c,** but not similar enough to stimulate the receptor (rather like foreign coins that fit into, but won't operate, a soda or candy machine). Curare, a poison that certain South American Indians apply to the tips of their hunting darts,



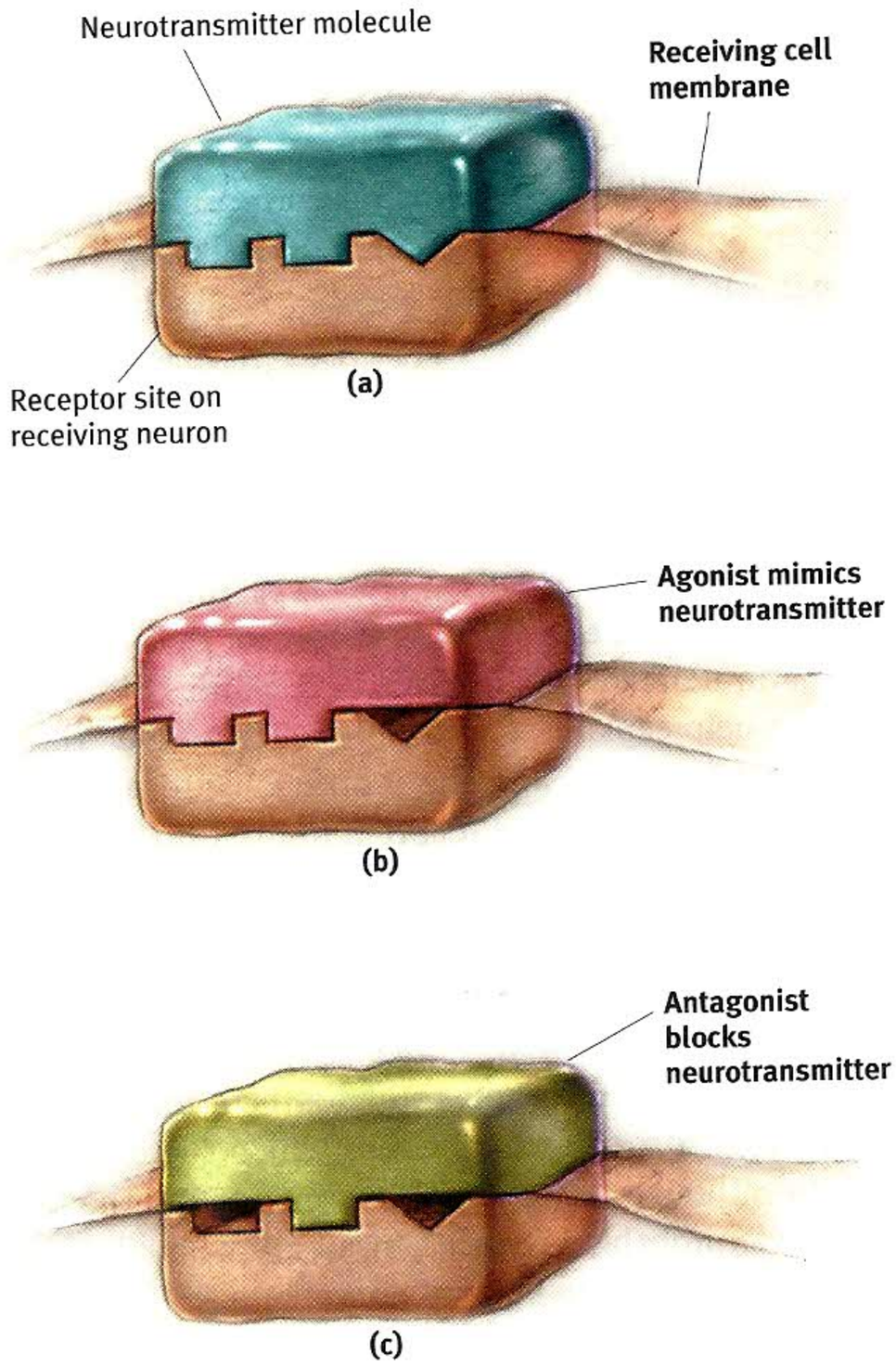
Neurotransmitters carry a message from a sending neuron across a synapse to receptor sites on a receiving neuron.

FIGURE 2.6
Agonists and antagonists

This neurotransmitter molecule fits the receptor site on the receiving neuron, much as a key fits a lock.

This agonist molecule excites. It is similar enough in structure to the neurotransmitter molecule to mimic its effects on the receiving neuron. Morphine, for instance, mimics the action of endorphins.

This antagonist molecule inhibits. It has a structure similar enough to the neurotransmitter to occupy its receptor site and block its action, but not similar enough to stimulate the receptor. Curare poisoning paralyzes its victims by blocking ACh receptors involved in muscle movement.



occupies and blocks ACh receptor sites, leaving the neurotransmitter unable to affect the muscles. Struck by one of these darts, an animal becomes paralyzed.

Neurotransmitter research is leading to new therapeutic drugs to alleviate depression, schizophrenia, and other disorders. But designing a drug can be harder than it sounds. A *blood-brain barrier* enables the brain to fence out unwanted chemicals circulating in the blood. Scientists know, for example, that the tremors of Parkinson's disease result from the death of nerve cells that produce dopamine. Giving the patient dopamine doesn't help, because dopamine cannot cross the blood-brain barrier. But some chemicals can slither through this barrier. One, L-dopa, a raw material the brain can convert to dopamine, enables many patients to regain better muscular control.

>> Learning Outcomes

Neural Communication

Objective 1 | Explain why psychologists are concerned with human biology, and describe the ill-fated phrenology theory.

For convenience, we may talk separately about biological or psychological influences on behavior, but in reality, everything psychological is simultaneously biological. Franz Gall did not subject his beliefs about phrenology to scientific tests, but this early theory did help scientists to begin thinking about links among our biology, behavior, and mental processes.

Objective 2 | Explain how viewing each person as a biopsychosocial system helps us understand human behavior, and discuss why researchers study other animals in search of clues to human neural processes.

Viewing each person as a biopsychosocial system lets us study behavior from multiple levels of analysis. At the biological level, neurons and other cells compose organs, which form larger systems (digestion, circulation, information processing). At the social-cultural level, people live in specific times and places and are subject to specific environmental and

social-cultural influences. At the psychological level, people's thoughts and emotions interact with their biology and personal history to produce that unique individual. Scientists gain much from their study of neural processes in other mammals and in relatively simple animals because humans and other animals have similar neural systems.

OBJECTIVE 3 | Describe the parts of a neuron, and explain how its impulses are generated.

The body's circuitry, the nervous system, consists of billions of individual cells called neurons. Neurons send signals through their *axon,* which is sometimes encased in a myelin sheath. Neurons receive signals from other cells through their branching *dendrites* and their *cell body*. If the combined signals are strong enough, the neuron fires, transmitting an electrical impulse (the action potential) down its axon, by means of a chemistry-to-electricity process in which ions are exchanged. The neuron's reaction is an all-or-none response.

OBJECTIVE 4 | Describe how nerve cells communicate.

When action potentials reach the end of an axon (the axon terminals), they stimulate the release of neurotransmitters. These chemical messengers carry a message from the sending neuron across a synapse to receptor sites on a receiving neuron. The sending neuron, in a process called *reuptake,* then normally absorbs the excess neurotransmitter molecules in the synaptic gap. The receiving neuron, if the signals from that neuron and others are strong enough, generates its own action potential and relays the message to other cells.

OBJECTIVE 5 | Explain how neurotransmitters affect behavior, and outline the effects of acetylcholine and the endorphins.

Each neurotransmitter travels a designated path in the brain and has a particular effect on behavior and emotions. Acetylcholine, one of the best-understood neurotransmitters, affects muscle action, learning, and memory. The endorphins are natural opiates released in response to pain and exercise.

OBJECTIVE 6 | Explain how drugs and other chemicals affect neurotransmission, and describe the contrasting effects of agonists and antagonists.

Drugs and other chemicals affect communication at the synapse. Agonists, such as some of the opiates, excite by mimicking particular neurotransmitters or by blocking their reuptake. Antagonists, such as curare, inhibit a particular neurotransmitter's release or block its effect.

ASK YOURSELF: Can you recall a time when the endorphin response may have protected you from feeling extreme pain?

The Nervous System

OBJECTIVE 7 | Describe the nervous system's two major divisions, and identify the three types of neurons that transmit information through the system.

To live is to take in information from the world and the body's tissues, to make decisions, and to send back information and orders to the body's tissues. Neurons are the elementary components of our **nervous system,** our body's speedy electrochemical information network (**FIGURE 2.7**). The brain and spinal cord form the **central nervous system (CNS).** The **peripheral nervous system (PNS)** links the central nervous system with the body's sense receptors, muscles, and glands.

- **nervous system** the body's speedy, electrochemical communication network, consisting of all the nerve cells of the peripheral and central nervous systems.
- **central nervous system (CNS)** the brain and spinal cord.
- **peripheral nervous system (PNS)** the sensory and motor neurons that connect the central nervous system (CNS) to the rest of the body.

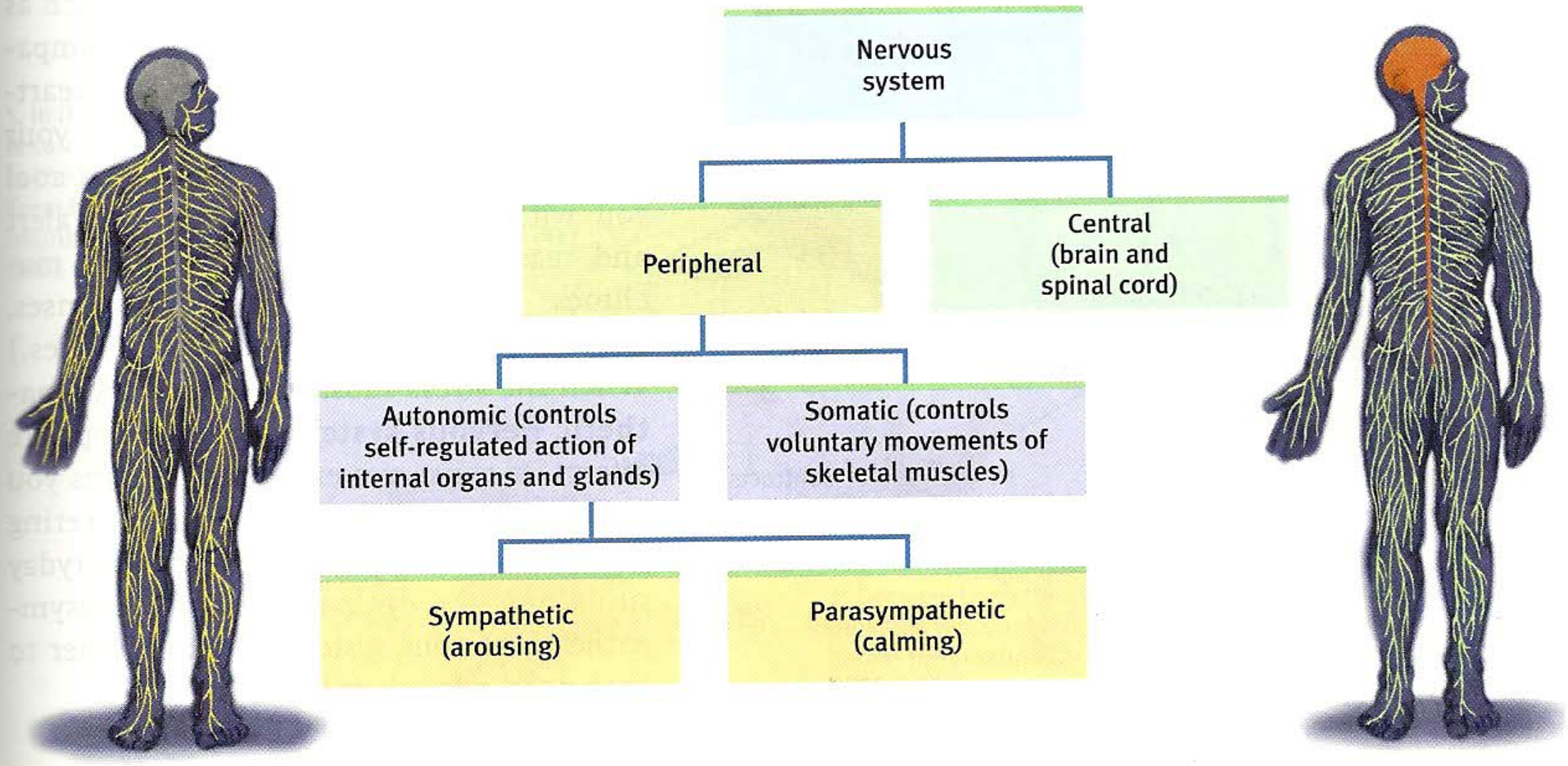


FIGURE 2.7
The functional divisions of the human nervous system