Module 9

Biological Psychology and Neurotransmission

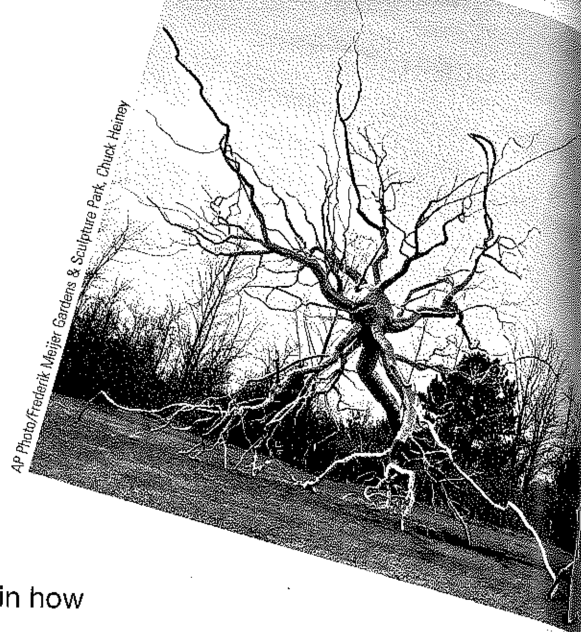
Module Learning Objectives

9-1 Explain why psychologists are concerned with human biology.

9-2 Describe the parts of a neuron, and explain how its impulses are generated.

9-3 Describe how nerve cells communicate with other nerve cells.

9-4 Describe how neurotransmitters influence behavior, and explain how drugs and other chemicals affect neurotransmission.



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Biology, Behavior, and Mind

9-1 Why are psychologists concerned with human biology?

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 would, indeed, be 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.

ScienceCartoonsPlus.com.

"Then it's agreed—you can't have a mind without a brain, but you can have a brain without a mind."

Our understanding of how the brain gives birth to the mind has come a long way. The ancient Greek 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 since overtaken philosophy on this issue. It's your brain, not your heart, that falls in love.

In the early 1800s, German physician Franz Gall proposed that *phrenology,* studying bumps on the skull, could reveal a person's mental abilities and character traits (**FIGURE 9.1**). At one point, Britain had 29 phrenological societies, and phrenologists traveled North America giving skull readings (Hunt, 1993).

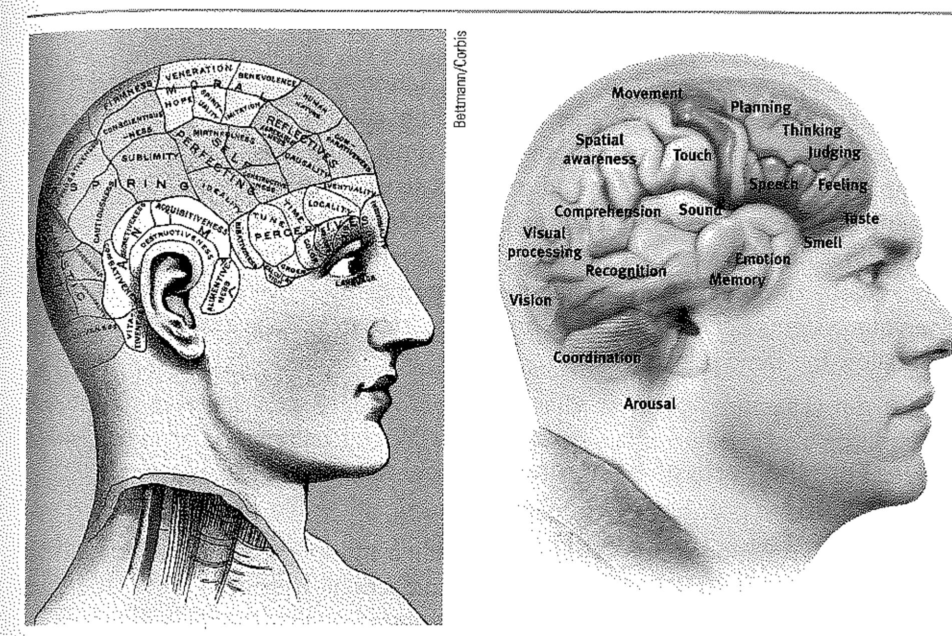

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Figure 9.1
A wrongheaded theory Despite initial acceptance of Franz Gall's speculations, bumps on the skull tell us nothing about the brain's underlying functions. Nevertheless, some of his assumptions have held true. Though they are not the functions Gall proposed, different parts of the brain do control different aspects of behavior, as suggested here (from *The Human Brain Book*) and as you will see throughout this unit.

Using a false name, humorist Mark Twain put one famous phrenologist to the test. "He found a cavity [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). Although its initial popularity faded, phrenology succeeded in focusing attention on the *localization of function*—the idea that various brain regions have particular functions.

You and I are living in a time Gall could only dream about. By studying the links between biological activity and psychological events, **biological psychologists** are announcing discoveries about the interplay of our biology and our behavior and mind at an exhilarating pace. Within little more than the past century, researchers seeking to understand the biology of the mind have discovered that

- the body is composed of cells.
- among these are nerve cells that conduct electricity and "talk" to one another by sending chemical messages across a tiny gap that separates them.
- specific brain systems serve specific functions (though not the functions Gall supposed).
- we integrate information processed in these different brain systems to construct our experience of sights and sounds, meanings and memories, pain and passion.
- our adaptive brain is wired by our experience.

We have also realized that we are each a system composed of subsystems that are in turn composed of even smaller subsystems. Tiny cells organize to form body organs. These organs 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. Thus, we are *biopsychosocial* systems. To understand our behavior, we need to study how these biological, psychological, and social systems work and interact.

In this unit we start small and build from the bottom up—from nerve cells up to the brain, and then to the environmental influences that interact with our biology. We will also work from the top down, as we consider how our thinking and emotions influence our brain and our health.

AP® Exam Tip

There is a ton of vocabulary in this unit. However, learning vocabulary is really not so hard: The secret is to work on it every day. Try flash cards. Work with a study buddy. Impress your non-psych friends with your new vocabulary. Just don't leave it until the night before the test. If you rehearse the vocabulary throughout the unit, you will do better on the unit test. The big bonus is that you will also retain far more information for the AP® exam.

"If I were a college student today, I don't think I could resist going into neuroscience."
-Novelist Tom Wolfe, 2004

biological psychology the scientific study of the links between biological (genetic, neural, hormonal) and psychological processes. (Some biological psychologists call themselves *behavioral neuroscientists, neuropsychologists, behavior geneticists, physiological psychologists,* or *biopsychologists.*)

Neural Communication

For scientists, it is a happy fact of nature that the information systems of humans and other animals operate similarly—so similarly 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. An alien 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.

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

dendrites a neuron's bushy, branching extensions that receive messages and conduct impulses toward the cell body.

axon the neuron extension that passes messages through its branches to other neurons or to muscles or glands.

myelin [MY-uh-lin] **sheath** a fatty tissue layer segmentally encasing the axons of some neurons; enables vastly greater transmission speed as neural impulses hop from one sausage-like node to the next.

action potential a neural impulse; a brief electrical charge that travels down an axon.

"I sing the body electric." -Walt Whitman, "Children of Adam" (1855)

Neurons

9-2 What are the parts of a neuron, and how are neural impulses generated?

Our body's neural information system is complexity built from simplicity. Its building blocks are **neurons,** or nerve cells. To fathom our thoughts and actions, memories and moods, we must first understand how neurons work and communicate.

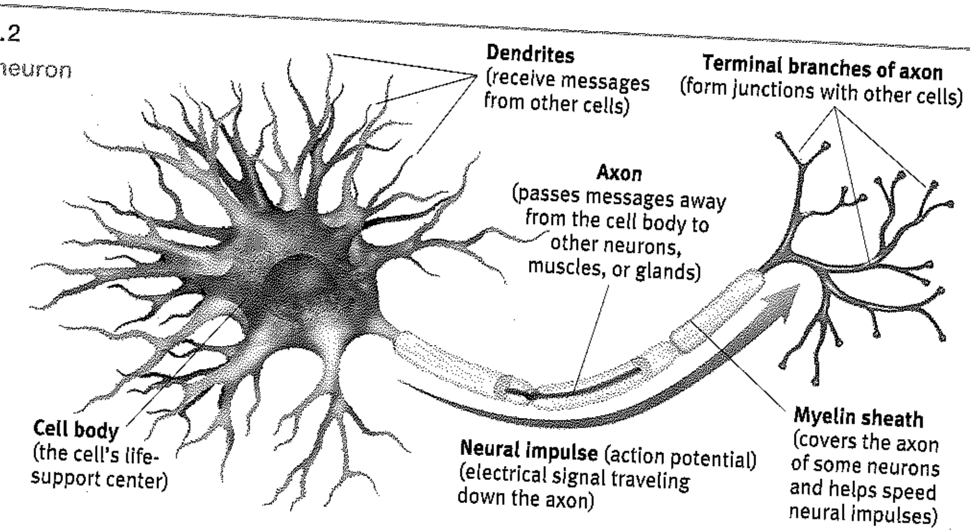
Neurons differ, but all are variations on the same theme (**FIGURE 9.2**). Each consists of a *cell body* and its branching fibers. The bushy **dendrite** fibers receive information and conduct it toward the cell body. From there, the cell's lengthy **axon** fiber passes the message through its terminal branches to other neurons or to muscles or glands. Dendrites listen. Axons speak.

Unlike the short dendrites, axons may be very long, projecting several feet through the body. A neuron carrying orders to a leg muscle, for example, has a cell body and axon roughly on the scale of a basketball attached to a rope 4 miles long. Much as home electrical wire is insulated, some axons are encased in a **myelin sheath,** a layer of fatty tissue that insulates them and speeds their impulses. As myelin is laid down up to about age 25, neural efficiency, judgment, and self-control grow (Fields, 2008). If the myelin sheath degenerates, *multiple sclerosis* results: Communication to muscles slows, with eventual loss of muscle control.

Neurons transmit messages when stimulated by signals from our senses or when triggered by chemical signals from neighboring neurons. In response, a neuron fires an impulse, called the **action potential**—a brief electrical charge that travels down its axon.

Depending on the type of fiber, a neural impulse travels at speeds ranging from a sluggish 2 miles per hour to a breakneck 180 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

Figure 9.2
A motor neuron



milliseconds (thousandths of a second) and computer activity in nanoseconds (billionths of a second). Thus, unlike the nearly instantaneous reactions of a high-speed computer, your reaction to a sudden event, such as a book slipping off your desk during class, may take a quarter-second or more. Your brain is vastly more complex than a computer, but slower at executing simple responses. And if you are an elephant—whose round-trip message travel time from a yank on the tail to the brain and back to the tail is 100 times longer than for a tiny shrew—reflexes are slower yet (More et al., 2010).

Like batteries, neurons generate electricity from chemical events. In the neuron's chemistry-to-electricity process, *ions* (electrically charged atoms) are exchanged. The fluid outside an axon's membrane has mostly positively charged ions; a resting axon's fluid interior has mostly negatively charged ions. This 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 through its gates. We say the axon's surface is *selectively permeable.*

When a neuron fires, however, the security parameters change: The first section of the axon opens its gates, rather like sewer covers flipping open, and positively charged sodium ions flood through the cell membrane (**FIGURE 9.3**). This *depolarizes* that axon section, causing another axon channel to open, and then another, like a line of falling dominos, each tripping the next.

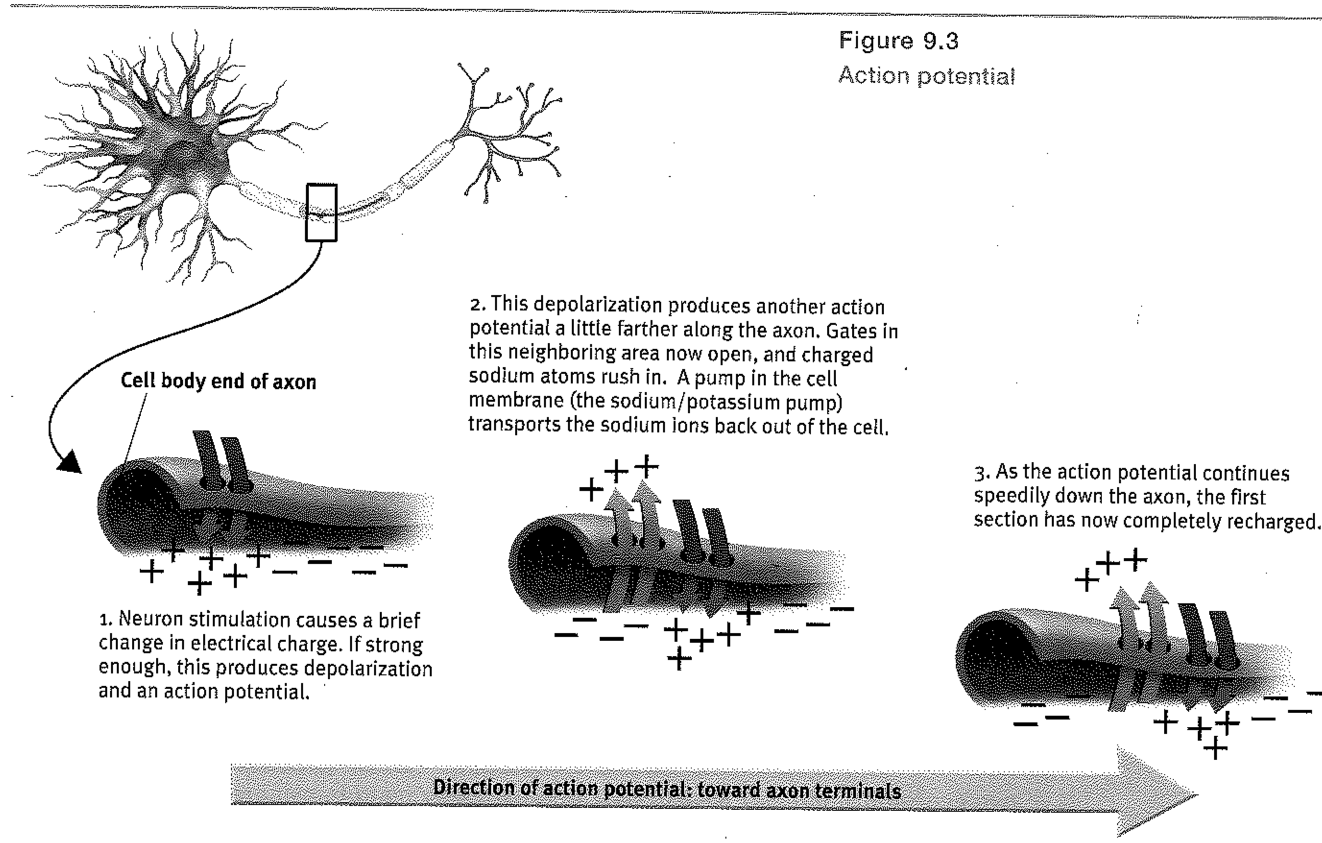
During a resting pause called the **refractory period,** rather like a web page pausing to refresh, the neuron pumps the positively charged sodium ions back outside. Then it can fire again. (In myelinated neurons, as in Figure 9.2, the action potential speeds up by hopping from the end of one myelin "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.

refractory period a period of inactivity after a neuron has fired.

"What one neuron tells another neuron is simply how much it is excited." -Francis Crick, *The Astonishing Hypothesis,* 1994

Each neuron is itself a miniature decision-making device performing complex calculations as it receives signals from hundreds, even thousands, of other neurons. Most signals are *excitatory,* somewhat like pushing a neuron's accelerator. Some are *inhibitory,* more like

Figure 9.3
Action potential



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

all-or-none response a neuron's reaction of either firing (with a full-strength response) or not firing.

pushing its brake. If excitatory signals exceed inhibitory signals by a minimum intensity, or **threshold,** the combined signals trigger an action potential. (Think of it as a class vote: If the excitatory people with their hands up outvote the inhibitory people with their hands down, then the vote passes.) The action potential then travels down the axon, which branches into junctions with hundreds or thousands of other neurons or with the body's muscles and glands.

Increasing the level of stimulation above the threshold will not increase the neural impulse'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 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.

AP® Exam Tip

Note the important shift here. So far, you have been learning about how just one neuron operates. The action potential is the mechanism for communication *within* a single neuron. Now you are moving on to a discussion of two neurons and how communication occurs *between* them. Very different, but equally important.

"All information processing in the brain involves neurons 'talking to' each other at synapses."
-NEUROSCIENTIST SOLOMON H. SNYDER (1984)

How Neurons Communicate

9-3 How do nerve cells communicate with other nerve cells?

Neurons interweave so intricately that even with a microscope you would have trouble seeing where one neuron ends and another begins. Scientists once believed that the axon of one cell fused with the dendrites of another in an uninterrupted fabric. Then British physiologist Sir Charles Sherrington (1857–1952) noticed that neural impulses were taking an unexpectedly long time to travel a neural pathway. Inferring that there must be a brief interruption in the transmission, Sherrington called the meeting point between neurons a **synapse.**

We now know that the axon terminal of one neuron is in fact separated from the receiving neuron by a *synaptic gap* (or *synaptic cleft*) less than 1 millionth of an inch wide. Spanish anatomist Santiago Ramón y Cajal (1852–1934) marveled at these near-unions of neurons, calling them "protoplasmic kisses." "Like elegant ladies air-kissing so as not to muss their makeup, dendrites and axons don't quite touch," notes poet Diane Ackerman (2004, p. 37). How do the neurons execute this protoplasmic kiss, sending information across the tiny synaptic gap? The answer is one of the important scientific discoveries of our age.

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 *synaptic cleft.*

neurotransmitters chemical messengers that cross 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.

reuptake a neurotransmitter's reabsorption by the sending neuron.

When an action potential reaches the knob-like terminals at an axon's end, it triggers the release of chemical messengers, called **neurotransmitters** (**FIGURE 9.4**). 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, and ions flow in, exciting or inhibiting the receiving neuron's readiness to fire. Then, in a process called **reuptake,** the sending neuron reabsorbs the excess neurotransmitters.

How Neurotransmitters Influence Us

9-4 How do neurotransmitters influence behavior, and how do drugs and other chemicals affect neurotransmission?

In their quest to understand neural communication, researchers have discovered dozens of different neurotransmitters and almost as many 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?

Later modules explore neurotransmitter influences on hunger and thinking, depression and euphoria, addictions and therapy. For now, let's glimpse how neurotransmitters influence our motions and our emotions. A particular brain pathway may use only one or two neurotransmitters (**FIGURE 9.5**), and particular neurotransmitters may affect specific

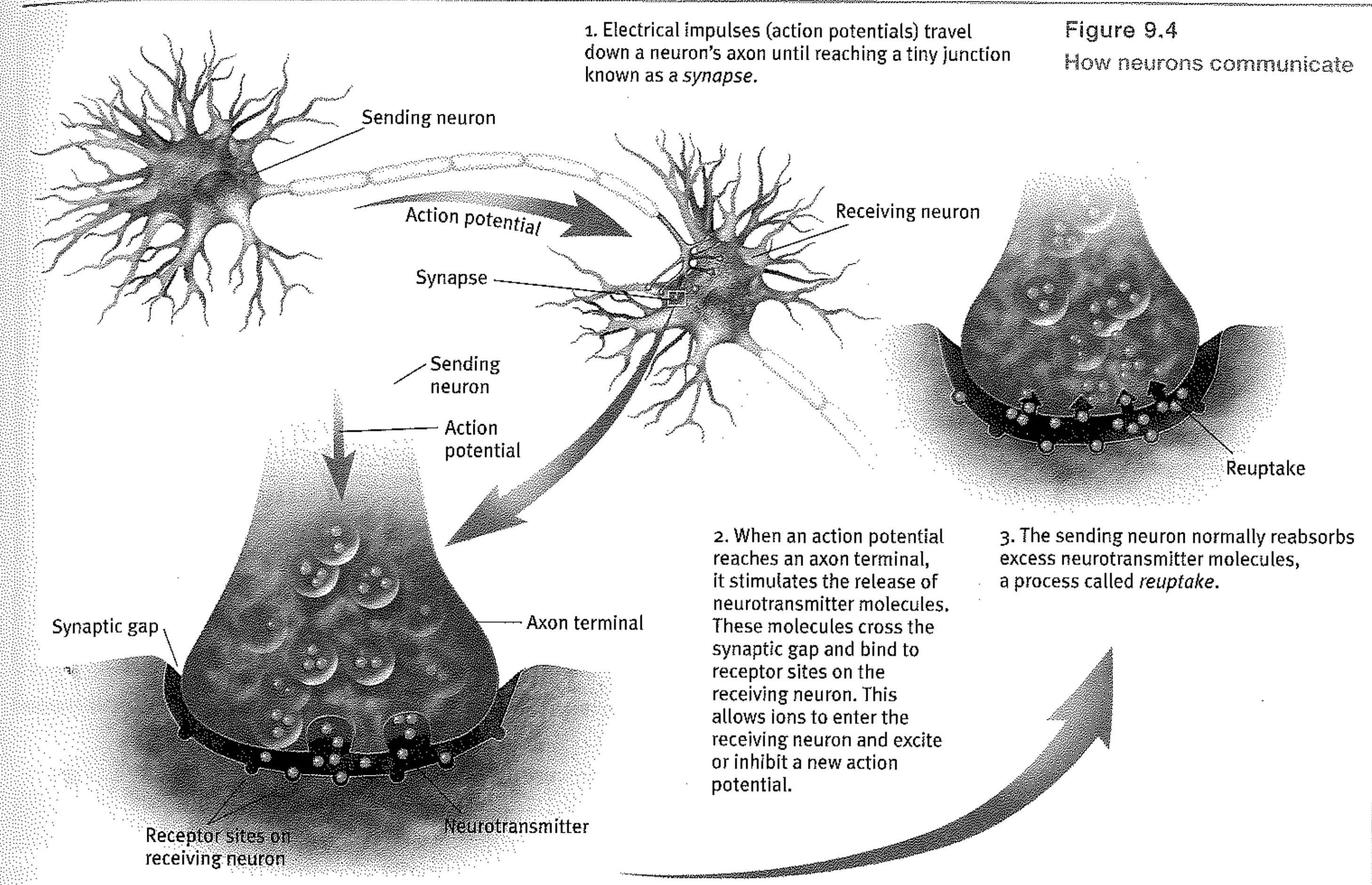
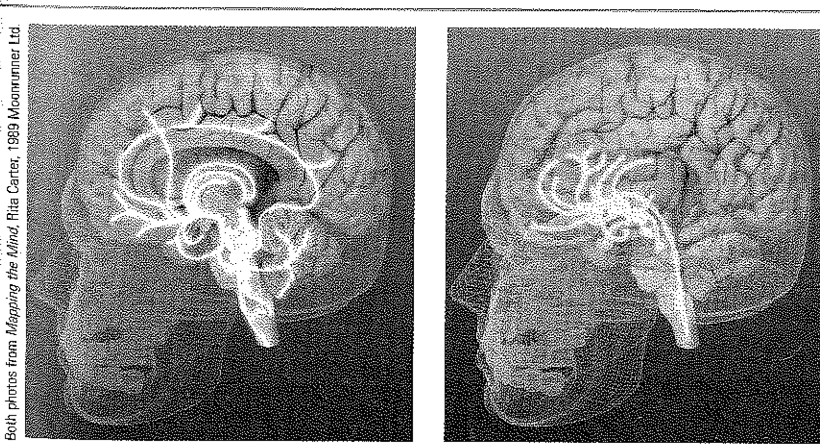


Figure 9.4 How neurons communicate

behaviors and emotions (**TABLE 9.1** on the next page). But neurotransmitter systems don't operate in isolation; they interact, and their effects vary with the receptors they stimulate. *Acetylcholine (ACh),* which is one of the best-understood neurotransmitters, plays a role in learning and memory. In addition, it is the messenger at every junction between motor neurons (which carry information from the brain and spinal cord to the body's tissues) and skeletal muscles. When ACh is released to our muscle cell receptors, the muscle contracts. If ACh transmission is blocked, as happens during some kinds of anesthesia, the muscles cannot contract and we are paralyzed.

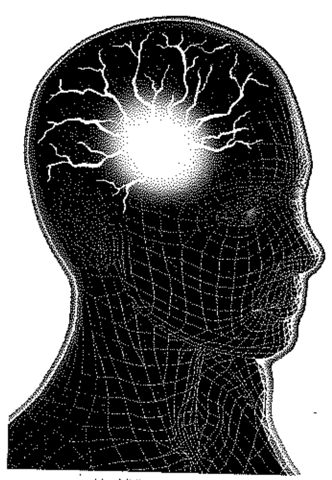
"When it comes to the brain, if you want to see the action, follow the neurotransmitters."
-NEUROSCIENTIST FLOYD BLOOM (1993)



Serotonin pathways — Dopamine pathways

Both photos from *Mapping the Mind,* Rita Carter, 1999 Moonrunner Ltd.

Figure 9.5 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).



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AP® Exam Tip

As the text indicates, there are dozens of different neurotransmitters. Though there's no way to predict exactly which ones you'll see on the AP® exam, it's quite possible that the ones in Table 9.1 are ones you'll be asked about.

Table 9.1 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.	Oversupply linked to schizophrenia. Undersupply linked to tremors and decreased mobility in Parkinson's disease.
Serotonin	Affects mood, hunger, sleep, and arousal.	Undersupply linked to depression. Some 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 the brain, producing migraines or seizures (which is why some people avoid MSG, monosodium glutamate, in food).

Researchers made an exciting discovery about neurotransmitters when they attached a radioactive tracer to morphine, showing where it was taken up in an animal's brain (Pert & Snyder, 1973). The morphine, an opiate drug that elevates mood and eases pain, bound to receptors in areas linked with mood and pain sensations. But why would the brain have these "opiate receptors"? Why would it have a chemical lock, unless it also had a natural key to open it?

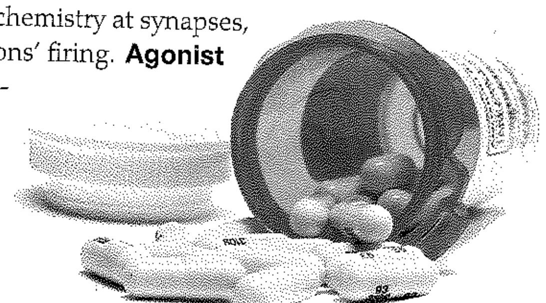
Researchers soon confirmed that the brain does indeed produce its own naturally occurring opiates. Our body releases several types of neurotransmitter molecules similar to morphine in response to pain and vigorous exercise. These **endorphins** (short for *endogenous* [produced within] *morphine*) help explain good feelings such as the "runner's high," the painkilling effects of acupuncture, and the indifference to pain in some severely injured people. But once again, new knowledge led to new questions.

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

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, causing intense discomfort. For suppressing the body's own neurotransmitter production, nature charges a price.

Drugs and other chemicals affect brain chemistry at synapses, often by either exciting or inhibiting neurons' firing. **Agonist** molecules may be similar enough to a neurotransmitter to bind to its receptor and mimic its effects. Some opiate drugs are agonists and produce a temporary "high" by amplifying normal sensations of arousal or pleasure.



Stephen VanHorn/Shutterstock

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

agonist a molecule that, by binding to a receptor site, stimulates a response.

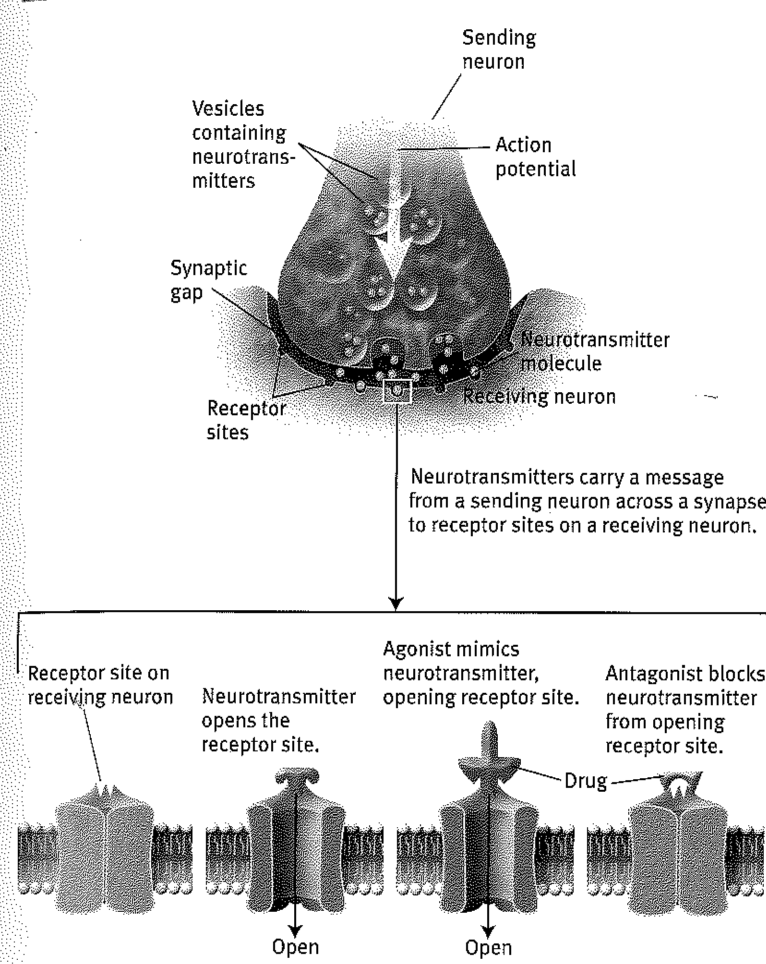


Figure 9.6
Agonists and antagonists
Curare poisoning paralyzes its victims by blocking ACh receptors involved in muscle movements. Morphine mimics endorphin actions. Which is an agonist, and which is an antagonist? (Art adapted from Higgins & George, 2007.)

ANSWER: Morphine is an agonist; curare is an antagonist.

Antagonists also bind to receptors but their effect is instead to block a neurotransmitter's functioning. Botulin, a poison that can form in improperly canned food, causes paralysis by blocking ACh release. (Small injections of botulin—Botox—smooth wrinkles by paralyzing the underlying facial muscles.) These antagonists are enough like the natural neurotransmitter to occupy its receptor site and block its effect, as in **FIGURE 9.6**, but are not similar enough to stimulate the receptor (rather like foreign coins that fit into, but won't operate, a candy machine). Curare, a poison some South American Indians have applied to hunting-dart tips, occupies and blocks ACh receptor sites on muscles, producing paralysis in animals struck by the darts.

antagonist a molecule that, by binding to a receptor site, inhibits or blocks a response.

AP® Exam Tip

Be very clear on this. Neurotransmitters are produced inside the body. They can excite and inhibit neural communication. Drugs and other chemicals come from outside the body. They can have an agonistic effect or an antagonistic effect on neurotransmission.

Before You Move On

▶ **ASK YOURSELF**

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

▶ **TEST YOURSELF**

How do neurons communicate with one another?

Answers to the Test Yourself questions can be found in Appendix E at the end of the book.

Module 9 Review

9-1 Why are psychologists concerned with human biology?

- Psychologists working from a *biological* perspective study the links between biology and behavior.
- We are biopsychosocial systems, in which biological, psychological, and social-cultural factors interact to influence behavior.

9-2 What are the parts of a neuron, and how are neural impulses generated?

- *Neurons* are the elementary components of the nervous system, the body's speedy electrochemical information system.
- A neuron receives signals through its branching *dendrites*, and sends signals through its *axons*.
- Some axons are encased in a *myelin sheath*, which enables faster transmission.
- If the combined received signals exceed a minimum *threshold*, the neuron fires, transmitting an electrical impulse (the *action potential*) down its axon by means of a chemistry-to-electricity process. The neuron's reaction is an *all-or-none process*.

9-3 How do nerve cells communicate with other nerve cells?

- 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 reabsorbs the excess neurotransmitter molecules in the synaptic gap.
- If incoming signals are strong enough, the receiving neuron generates its own action potential and relays the message to other cells.

9-4 How do neurotransmitters influence behavior, and how do drugs and other chemicals affect neurotransmission?

- Neurotransmitters travel designated pathways in the brain and may influence specific behaviors and emotions.
- Acetylcholine (ACh) affects muscle action, learning, and memory.
- *Endorphins* are natural opiates released in response to pain and exercise.
- Drugs and other chemicals affect brain chemistry at synapses.
- *Agonists* excite by mimicking particular neurotransmitters or by blocking their reuptake.
- *Antagonists* inhibit a particular neurotransmitter's release or block its effect.

Multiple-Choice Questions

1. Multiple sclerosis is a result of degeneration in the

a. dendrite.
b. axon.
c. myelin sheath.
d. terminal button.
e. neuron.

2. Junita does not feel like getting out of bed, has lost her appetite, and feels tired for most of the day. Which of the following neurotransmitters likely is in short supply for Junita?

a. Dopamine
b. Serotonin
c. Norephinephrine
d. Acetylcholine
e. Glutamate

3. Which neurotransmitter inhibits CNS activity in order to calm a person down during stressful situations?

a. GABA
b. Norepinephrine
c. Acetylcholine
d. Dopamine
e. Serotonin

4. Phrenology has been discredited, but which of the following ideas has its origins in phrenology?

a. Brain lateralization
b. Brain cavities contributing to sense of humor
c. Bumps in the left hemisphere leading to emotional responses
d. Brain function localization
e. Belief that the mind pumps warmth and vitality into the body

5. When there is a negative charge inside an axon and a positive charge outside it, the neuron is

a. in the process of reuptake.
b. not in the refractory period.
c. said to have a resting potential.
d. said to have an action potential.
e. depolarizing.

6. Morphine elevates mood and eases pain, and is most similar to which of the following?

a. Dopamine
b. Serotonin
c. Endorphins
d. Acetylcholine
e. GABA

7. Neurotransmitters cross the ________ to carry information to the next neuron.

a. synaptic gap
b. axon
c. myelin sheath
d. dendrites
e. cell body

8. What neurotransmitters are most likely in undersupply in someone who is depressed?

a. Dopamine and GABA
b. ACh and norepinephrine
c. Dopamine and norepinephrine
d. Serotonin and norepinephrine
e. Serotonin and glutamate

Practice FRQs

1. While hiking, Ken stumbled and fell down a 10-foot drop-off. Upon landing, he sprained his ankle badly. Ken was surprised that he felt very little pain for the first half hour. Explain how the following helped Ken feel little pain in the moments after the injury.

- Endorphins
- The synapse

Answer

1 point: Endorphins are natural, opiate-like neurotransmitters linked to controlling pain.

1 point: The synapse is the space between neurons where neurotransmitters like the endorphins carry information that influences how Ken feels.

2. Explain the role each of the following plays in sending a message through a neuron.

- Dendrites
- Axon
- Myelin sheath

(3 points)