35–2 The Nervous System

Play any team sport—basketball, softball, soccer—and you will discover that communication is one of the keys to success. Coaches call plays, players signal to one another, and the very best teams communicate in a way that enables them to play as a single unit. Communication can make the difference between winning and losing.

The same is true for living organisms. Nearly all multicellular organisms have communication systems. Specialized cells carry messages from one cell to another so that communication among all body parts is smooth and efficient. In humans, these cells include those of the nervous system. **The nervous system controls and coordinates functions throughout the body and responds to internal and external stimuli.**

Neurons

The messages carried by the nervous system are electrical signals called impulses. The cells that transmit these impulses are called **neurons.** Neurons can be classified into three types according to the direction in which an impulse travels. Sensory neurons carry impulses from the sense organs to the spinal cord and brain. Motor neurons carry impulses from the brain and the spinal cord to muscles and glands. Interneurons connect sensory and motor neurons and carry impulses between them. Although neurons come in all shapes and sizes, they have certain features in common. **Figure 35–5** shows a typical neuron. The largest part of a typical neuron is the **cell body.** The cell body contains the nucleus and much of the cytoplasm. Most of the metabolic activity of the cell takes place in the cell body.

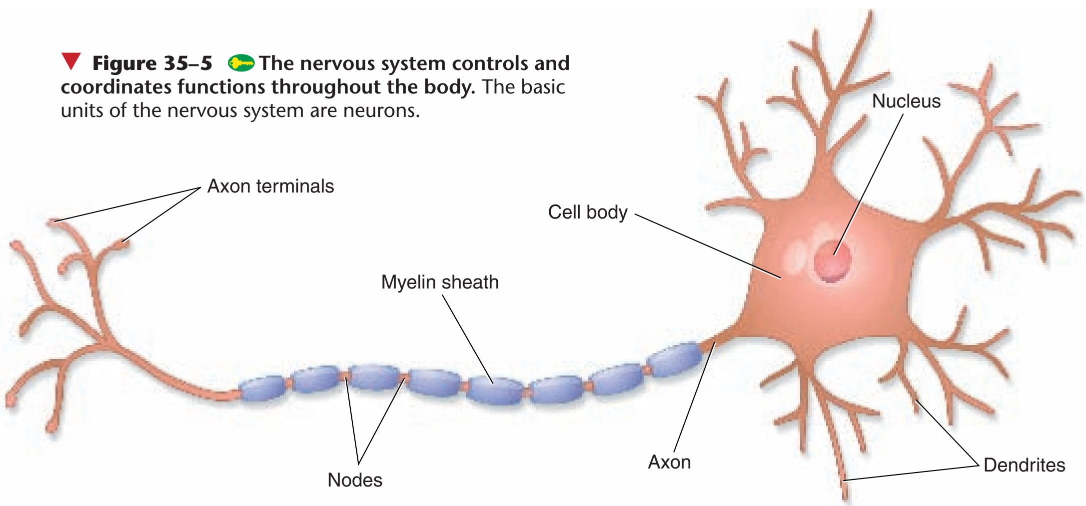
Guide for Reading

Key Concepts
- What are the functions of the nervous system?
- How is a nerve impulse transmitted?

Vocabulary
neuron
cell body
dendrite
axon
myelin sheath
resting potential
action potential
threshold
synapse
neurotransmitter

Reading Strategy: Summarizing As you read, find the main ideas for each paragraph. Write down a few key words from each main idea. Then, use the key words in your summary.

▼ **Figure 35–5** **The nervous system controls and coordinates functions throughout the body.** The basic units of the nervous system are neurons.



SECTION RESOURCES

TIME SAVER

Print:
- ***Teaching Resources,*** Lesson Plan 35–2, Adapted Section Summary 35–2, Adapted Worksheets 35–2, Section Summary 35–2, Worksheets 35–2, Section Review 35–2
- ***Reading and Study Workbook A,*** Section 35–2
- ***Adapted Reading and Study Workbook B,*** Section 35–2

Technology:
- ***iText,*** Section 35–2
- ***Animated Biological Concepts DVD,*** 48 Action Potential, 49 Synaptic Transmission
- ***Transparencies Plus,*** Section 35–2

Section 35–2

1 FOCUS

Objectives

35.2.1 ***Identify*** the functions of the nervous system.
35.2.2 ***Describe*** how a nerve impulse is transmitted.

Guide for Reading

Vocabulary Preview

Tell students that the prefix *neuro-* comes from the Greek word for nerve. Ask: **What do you think the Vocabulary terms *neuron* and *neurotransmitter* mean?** *(A neuron is a nerve cell; a neurotransmitter is a chemical that transmits messages from a neuron to another cell.)*

Reading Strategy

As students read, they should look for Vocabulary words and Key Concepts in the captions and the text. Suggest that students include the Vocabulary words and Key Concepts in their summary.

2 INSTRUCT

Demonstration

Help students appreciate how quickly the cells of the nervous system communicate. Have a volunteer repeat a movement, such as nodding the head, at irregular intervals. Have another volunteer respond to the first movement with a different movement, such as raising a finger. Challenge the class to measure the time it takes for the second volunteer's nervous system to sense, interpret, and respond to the movement made by the first volunteer. *(Students probably will find that the response time is too short to measure.)* L1 L2

Neurons

Use Visuals

Figure 35–5 Point out the nucleus in the cell body. Name each of the other parts of the neuron, and have students locate them in the figure. Urge students to refer to the figure as they read about the parts of a neuron and how they are involved in the transmission of nerve impulses. L1 L2

35–2 (continued)

Go Online NSTA SciLinks

Download a worksheet on the nervous system for students to complete, and find additional teacher support from NSTA SciLinks.

Build Science Skills

Using Models Give interested students a chance to make a three-dimensional model of a neuron. Provide them with materials such as string, beads, dry pasta, and modeling clay. Remind students to provide a key for the parts of their model. Allow them to display their models in the classroom. L2

The Nerve Impulse

Use Visuals

Figure 35–6 Have students look at the distribution of potassium and sodium ions. Then, have them answer the question in the caption. Ask: **Why do you think the drawing has many sodium ions and one potassium ion outside the cell but one sodium ion and many potassium ions inside the cell?** *(To indicate that potassium ions diffuse across the cell membrane into the cell more easily than do sodium ions)* This difference in the ability of the positive ions to diffuse creates the difference in electrical charge across the cell membrane. L2

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For: Links on the nervous system
Visit: www.SciLinks.org
Web Code: cbn-0352

Spreading out from the cell body are short, branched extensions called **dendrites.** Dendrites carry impulses from the environment or from other neurons toward the cell body. The long fiber that carries impulses away from the cell body is called the **axon.** The axon ends in a series of small swellings called axon terminals, located some distance from the cell body. Neurons may have dozens of dendrites but usually have only one axon. In most animals, axons and dendrites are clustered into bundles of fibers called nerves. Some nerves contain only a few neurons, but many others have hundreds or even thousands of neurons.

In some neurons, the axon is surrounded by an insulating membrane known as the **myelin** (MY-uh-lin) **sheath.** The myelin sheath that surrounds a single long axon leaves many gaps, called nodes, where the axon membrane is exposed. As an impulse moves along the axon, it jumps from one node to the next, which increases the speed at which the impulse can travel.

The Nerve Impulse

A nerve impulse is similar to the flow of electrical current through a metal wire. The best way to understand a nerve impulse is to first look at a neuron at rest.

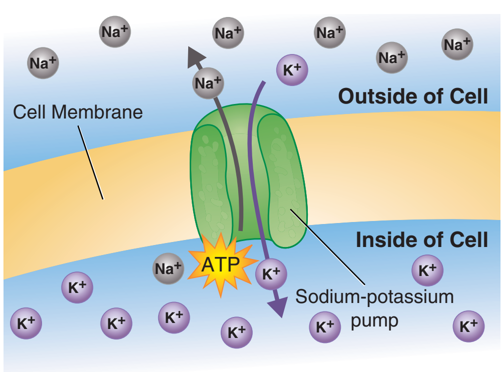
The Resting Neuron When a neuron is resting (not transmitting an impulse), the outside of the cell has a net positive charge, and the inside of the cell has a net negative charge. The cell membrane is said to be electrically charged because there is a difference in electrical charge between its outer and inner surfaces. Where does this difference come from? Some of the differences come from the selective permeability of the membrane. Most of the differences, however, are the result of active transport of ions across the cell membrane.

The nerve cell membrane pumps sodium (Na^+) ions out of the cell and potassium (K^+) ions into the cell by means of active transport. The active transport mechanism that performs this pumping action is called the sodium-potassium pump, shown in **Figure 35–6.** As a result of active transport, the inside of the cell contains more K^+ ions and fewer Na^+ ions than the outside.

The neuron cell membrane allows more K^+ ions to leak across it than Na^+ ions. As a result, K^+ ions leak out of the cell to produce a negative charge on the inside of the membrane. Because of this, there is a positive charge on the outside of the membrane and a negative charge on the inside. The electrical charge across the cell membrane of a neuron in its resting state is known as the **resting potential** of the neuron. The neuron, of course, is not actually "resting," because it must produce a constant supply of ATP to fuel active transport.

CHECKPOINT *What is resting potential?*

▼ **Figure 35–6** The sodium-potassium pump in the neuron cell membrane uses the energy of ATP to pump Na^+ out of the cell and, at the same time, to pump K^+ in. This ongoing process maintains resting potential. **Applying Concepts** *Is this process an example of diffusion or active transport?*



UNIVERSAL ACCESS

Less Proficient Readers
Provide students with a familiar way to visualize the concept of electrical potential in nerve impulses. Point out that a spring represents another type of energy potential: kinetic potential. Demonstrate by depressing and then releasing the spring. Ask: **What happens when the spring is released?** *(A burst of energy moves the spring back to its resting state.)* Explain how this is similar to a nerve impulse. L1 L2

English Language Learners
Have students compile a section glossary that includes all the highlighted, boldface terms and any technical terms used in the text or captions. Suggest that students write definitions in both English and their native language. Students also may find it helpful to illustrate their glossaries. Encourage active use of the terms by asking volunteers to share their glossaries with the rest of the class. L1 L2

The Moving Impulse A neuron remains in its resting state until it receives a stimulus large enough to start a nerve impulse. The impulse causes a movement of ions across the cell membrane. **An impulse begins when a neuron is stimulated by another neuron or by the environment.** Once it begins, the impulse travels rapidly down the axon away from the cell body and toward the axon terminals. As **Figure 35–7** shows, an impulse is a sudden reversal of the membrane potential. What causes the reversal?

The cell membrane of a neuron contains thousands of protein channels that may allow ions to pass through, depending on the state of "gates" within the channels. Generally, the gates within these channels are closed. At the leading edge of an impulse, however, gates within the sodium channels open, allowing positively charged Na^+ ions to flow inside the cell membrane. The inside of the membrane temporarily becomes more positive than the outside, reversing the resting potential. This reversal of charges, from negative to positive, is called a nerve impulse, or an **action potential.**

As the impulse passes, gates within the potassium channels open, allowing K^+ ions to flow out. This restores the resting potential so that the neuron is once again negatively charged on the inside of the cell membrane and positively charged on the outside.

A nerve impulse is self-propagating; that is, an impulse at any point on the membrane causes an impulse at the next point along the membrane. You could compare the flow of an impulse to the fall of a row of dominoes. As each domino falls, it causes the next domino to fall.

Threshold The strength of an impulse is always the same—either there is an impulse in response to a stimulus or there is not. In other words, a stimulus must be of adequate strength to cause a neuron to transmit an impulse. The minimum level of a stimulus that is required to activate a neuron is called the **threshold.** Any stimulus that is stronger than the threshold will produce an impulse. Any stimulus that is weaker than the threshold will produce no impulse. Thus, a nerve impulse follows the all-or-none principle: Either the stimulus will produce an impulse, or it will not produce an impulse.

The all-or-none principle can be illustrated by using a row of dominoes. If you were to gently press the first domino in a row, it might not move at all. A slightly harder push might make the domino teeter back and forth but not fall. A slightly stronger push would cause the first domino to fall into the second. You have reached the threshold at which the row of dominoes would fall.

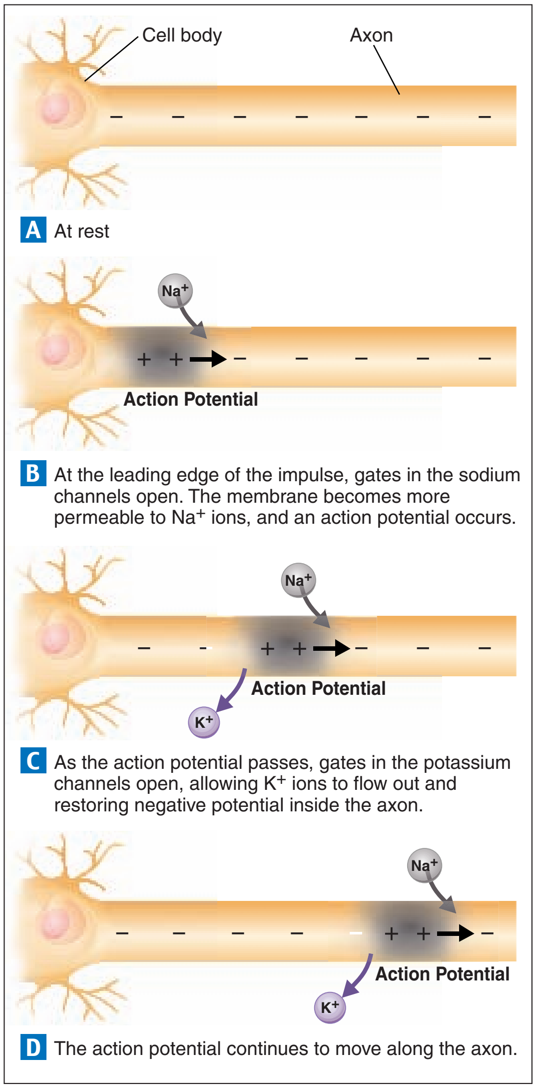


Figure 35–7 An impulse begins when a neuron is stimulated by another neuron.

Go Online **active art**
For: Nerve Impulse activity
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Web Code: cbp-0352

Use Visuals

Figure 35–7 Help students integrate the visuals with the text. Ask: **In part B of the figure, what causes the action potential to occur?** *(Positively charged Na^+ ions flow inside the cell membrane, causing the inside of the membrane to become more positive than the outside.)* **In part C, what causes the resting potential to occur again?** *(K^+ ions flow out of the cell membrane, causing the inside of the membrane to become negative again.)* L2

Demonstration

Use the domino analogy mentioned in the text to simulate the movement of an action potential down an axon. Arrange dominoes on end in a row, and then knock them down by giving the first one a gentle push. Ask: **Why did all the dominoes fall when only the first domino was pushed?** *(Because kinetic energy was passed from domino to domino)* **What was the source of the kinetic energy that was transmitted down the line of dominoes?** *(Some was provided by the push on the first domino, some by the position of the dominoes—standing on end, they were easily toppled by gravity when gently bumped.)* **What would you have to do in order to get the dominoes to topple again?** *(Return them to the starting position and provide an initial input of energy.)* L1 L2

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Students interact with the art online.

BIO INSIGHTS — BACKGROUND

All or nothing
A nerve impulse usually is described as an all-or-nothing phenomenon. This means that there is a threshold level below which a stimulus cannot trigger an action potential. Any stimulus at or above the threshold level triggers exactly the same response. However, if a neuron has just fired, this picture changes. There is a period of a few milliseconds, called the absolute refractory period, during which no stimulus can produce a response, even a stimulus above the threshold level. Then, for a slightly longer period, the relative refractory period, an intense stimulus well above the threshold level is needed to provoke a response. The closer the neuron is to complete recovery, the less intense the stimulus must be to provoke a response. When the neuron is completely recovered, it responds in the all-or-nothing way once again.

Answers to . . .

CHECKPOINT *The difference in electrical charge across the cell membrane of a resting neuron*

Figure 35–6 *Active transport*

35–2 (continued)

The Synapse

Make Connections

Health Science Explain that many mental illnesses appear to be associated with abnormal levels of certain neurotransmitters. For example, depression is associated with lower-than-normal levels of serotonin and norepinephrine, and schizophrenia is associated with higher-than-normal levels of dopamine. Ask: **How do you think abnormal levels of neurotransmitters affect the functioning of the nervous system?** *(Students might say they would either decrease or increase the transmission of nerve impulses.)* L2

3 ASSESS

Evaluate Understanding

Call on students at random to define each of the Vocabulary terms. Call on other students to correct any errors.

Reteach

Provide students with copies of Figure 35–5 without the labels, and have them label each part of the neuron.

Thinking Visually

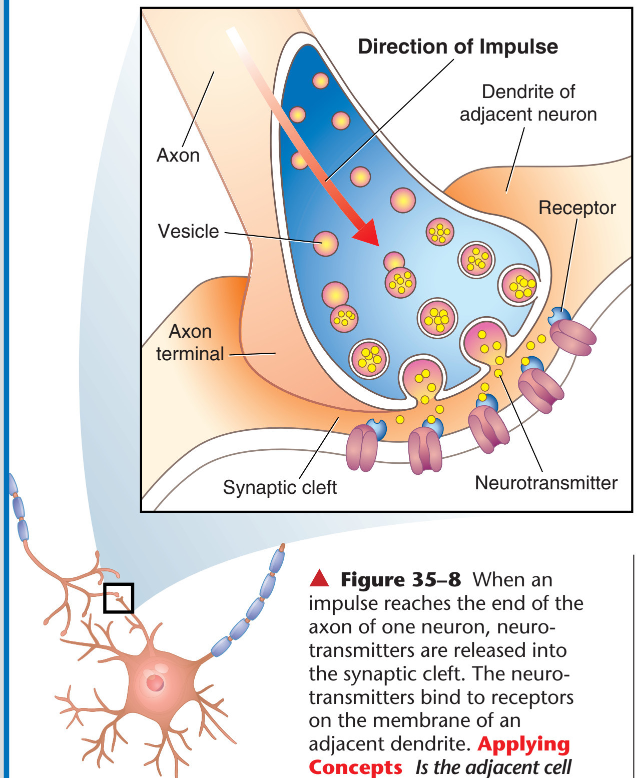
Students' flowcharts should include the following events: arrival of the nerve impulse at an axon terminal; release of neurotransmitters into the synaptic cleft; diffusion of neurotransmitters across the gap and attachment to receptors on a neighboring cell membrane; and movement of positive ions across that cell's membrane, causing stimulation of the neighboring cell.

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 35–2.

Answer to . . .

Figure 35–8 *No; a motor neuron passes an impulse to a muscle cell.*



▲ **Figure 35–8** When an impulse reaches the end of the axon of one neuron, neurotransmitters are released into the synaptic cleft. The neurotransmitters bind to receptors on the membrane of an adjacent dendrite. **Applying Concepts** *Is the adjacent cell always another neuron?*

The Synapse

At the end of the neuron, the impulse reaches an axon terminal. Usually the neuron makes contact with another cell at this location. The neuron may pass the impulse along to the second cell. Motor neurons, for example, pass their impulses to muscle cells.

The location at which a neuron can transfer an impulse to another cell is called a **synapse** (SIN-aps). As shown in **Figure 35–8,** a space, called the synaptic cleft, separates the axon terminal from the dendrites of the adjacent cell, in this case a neuron. The terminals contain tiny sacs, or vesicles, filled with neurotransmitters (noo-roh-TRANZ-mit-urs). **Neurotransmitters** are chemicals used by a neuron to transmit an impulse across a synapse to another cell.

When an impulse arrives at an axon terminal, the vesicles release the neurotransmitters into the synaptic cleft. The neurotransmitter molecules diffuse across the synaptic cleft and attach themselves to receptors on the membrane of the neighboring cell. This stimulus causes positive sodium ions to rush across the cell membrane, stimulating the second cell. If the stimulation exceeds the cell's threshold, a new impulse begins.

Only a fraction of a second after binding to their receptors, the neurotransmitter molecules are released from the cell surface. They may then be broken down by enzymes, or taken up and recycled by the axon terminal.

35–2 Section Assessment

1. **Key Concept** Describe the functions of the nervous system.
2. **Key Concept** What happens when a neuron is stimulated by another neuron?
3. Name and describe the three types of neurons.
4. Describe the role of the myelin sheath.
5. **Critical Thinking Applying Concepts** How can the level of pain you feel vary if a stimulus causes an all-or-none response?

Thinking Visually

Creating a Flowchart
Create a flowchart to show the events that occur as a nerve impulse travels from one neuron to the next. Include as much detail as you can. Use your flowchart to explain the process to a classmate.

35–2 Section Assessment

1. The human nervous system controls and coordinates functions throughout the body and responds to internal and external stimuli.
2. If the stimulus is large enough, an impulse begins that travels rapidly along the axon toward the axon terminals, where the impulse is passed on to another cell.
3. Sensory neurons, motor neurons, and interneurons
4. The myelin sheath insulates the axon and greatly increases the speed of transmission of nerve impulses.
5. There are two possible factors: the number of sensory neurons activated by a stimulus and the frequency of the stimulation.