

# UNIT 5

# The Nervous and Endocrine Systems

## General Outcomes

### In this unit, you will

- explore how the nervous system regulates physiological processes in the body
- explain how the endocrine system contributes to homeostasis in the body

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## Focussing Questions

- 1 How does the human body react to changes in its internal and external environment? How does the nervous system regulate these reactions to change?
- 2 How do the senses enable us to detect sensory information and perceive our environment?
- 3 What are the roles of hormones in the human body? How do environmental factors and technologies affect hormone regulation? What societal issues are related to these effects?



**I**magine that you are a wildland firefighter, battling a blaze like the 2003 fire at Lost Creek, which burned 21 000 ha of land in the Crowsnest Pass area of Alberta. You are sweating and breathing hard. The swiftly moving flames are over 50 m high and as hot as 1000 °C. A series of 16 h shifts of digging and hauling heavy equipment have taken their toll, and you are hungry, thirsty, and near exhaustion. Then the team leader radios your crew to warn you that the firestorm—the heart of the fire—is almost on top of you. You look up and see flames leaping through the treetops. You feel a rush of adrenaline. Your heart pumps faster, and you find the energy to run.

Even in an extreme situation like this, physiological processes regulate the body systems in order to maintain homeostasis—the narrow parameters of internal conditions that the body requires to survive. In Unit 5, you will learn how the nervous system and the endocrine system (a system of chemical messengers) work together to maintain homeostasis.



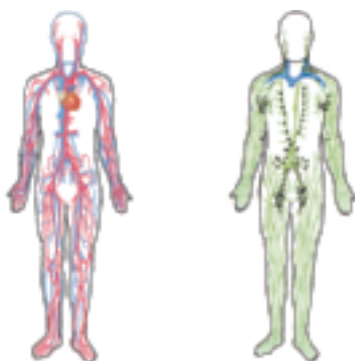
## Prerequisite Concepts

This unit draws and builds upon your understanding of human systems, homeostasis, and the flow of matter in living systems from your Biology 20 studies.

## Organization of Systems in the Human Body

The trillions of cells that make up your body can be organized into about one hundred different types. Similarly specialized cells that perform a common function make up a tissue. Tissues of different types are organized as organs, which themselves are organized structurally and functionally as systems that work together to perform functions necessary to sustain and maintain the human organism. These functions may be divided into groups with a common purpose.

### Transport



Circulatory system

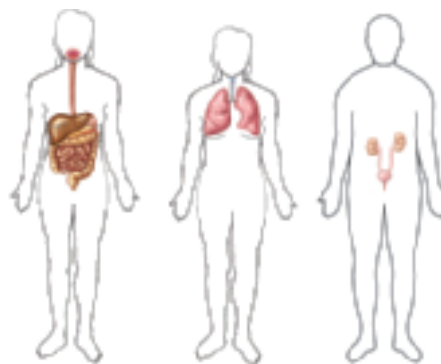
Lymphatic and immune systems

The circulatory system consists of the heart and the blood vessels, which pump and carry blood through the body. Blood transports nutrients and oxygen to cells and removes waste molecules excreted by cells. While blood is moving throughout the body, it distributes heat produced by the muscles.

The lymphatic system consists of lymphatic vessels, lymph, and lymph nodes. Lymphatic vessels absorb fat from the digestive system and collect excess tissue fluid, which is returned to the blood and, thus, the circulatory system.

The circulatory system and the lymphatic system are also involved in protecting the body against disease and substances that are foreign to the body. Certain blood cells—white blood cells (leukocytes and lymphocytes) and platelets—are part of the body’s immune system.

### Maintenance of the Body



Digestive system

Respiratory system

Excretory system

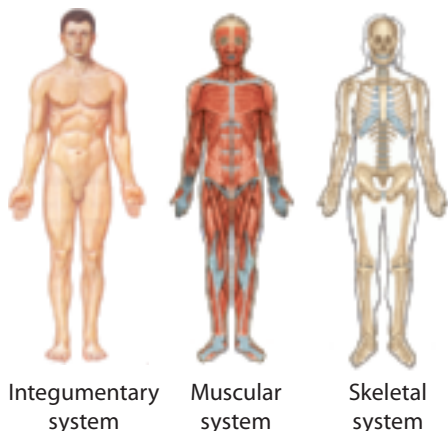
Three systems—the digestive, respiratory, and excretory systems—add and/or remove substances from the blood.

The digestive system consists of the digestive tract and various organs that directly or indirectly process food into nutrient molecules that enter the blood.

The respiratory system consists of the lungs and tubes that take air to and from the lungs. This system brings oxygen into the body and removes carbon dioxide from the body. It also exchanges gases with the blood.

The excretory (urinary) system includes the kidneys and the urinary bladder, along with tubes that process and transport urine. This system rids the body of wastes and helps regulate the fluid level and chemical content of the blood.

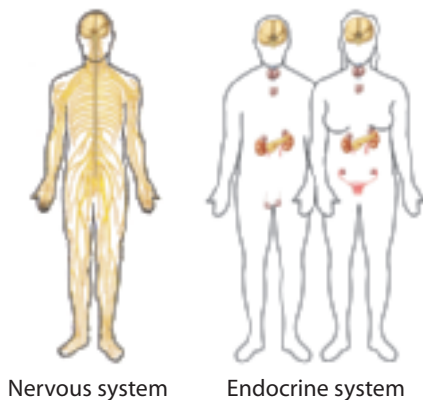
## Sensory Input and Motor Output



The integumentary system consists of the skin and its accessory structures. The sensory receptors in the skin, and in organs such as the eyes and ears, are sensitive to certain external stimuli and communicate with the brain and spinal cord via nerve fibres.

The muscular and the skeletal systems include the muscles and the bones to which they are attached. This system enables the body and its parts to move. The motor system, along with the integumentary system, also protects and supports the internal environment of the body.

## Control



The nervous system consists of the brain, spinal cord, and associated nerves that

conduct nerve impulses from receptors to the brain the spinal cord. Nerves also conduct impulses from the brain and spinal cord to the muscles and glands, allowing the body to respond to both external and internal stimuli.

The endocrine system consists of the hormonal glands that secrete chemicals that serve as messengers between body cells. Both the nervous and the endocrine systems coordinate and regulate the functions of the body's other systems.

You will be studying these two systems in greater detail in Unit 5.

## Reproduction



The reproductive system involves different organs in the male and the female. The male system consists of the testes and other glands, as well as ducts, that conduct semen to and through the penis. The testes produce sex cells called sperm. The female system consists of the ovaries, oviducts, uterus, vagina, and external genitals. The ovaries produce sex cells called eggs or ova. When a sperm fertilizes an egg, an offspring begins development.

You will be studying the male and female reproductive systems in greater detail in Unit 6.

**Chapter Concepts****11.1 Structures and Processes of the Nervous System**

- Homeostasis is maintained in the human body by the various parts of the nervous system.
- Neural transmission occurs along axons, due to an action potential that causes depolarization of the neuron.
- Electrochemical communication occurs between cells at the synapse.

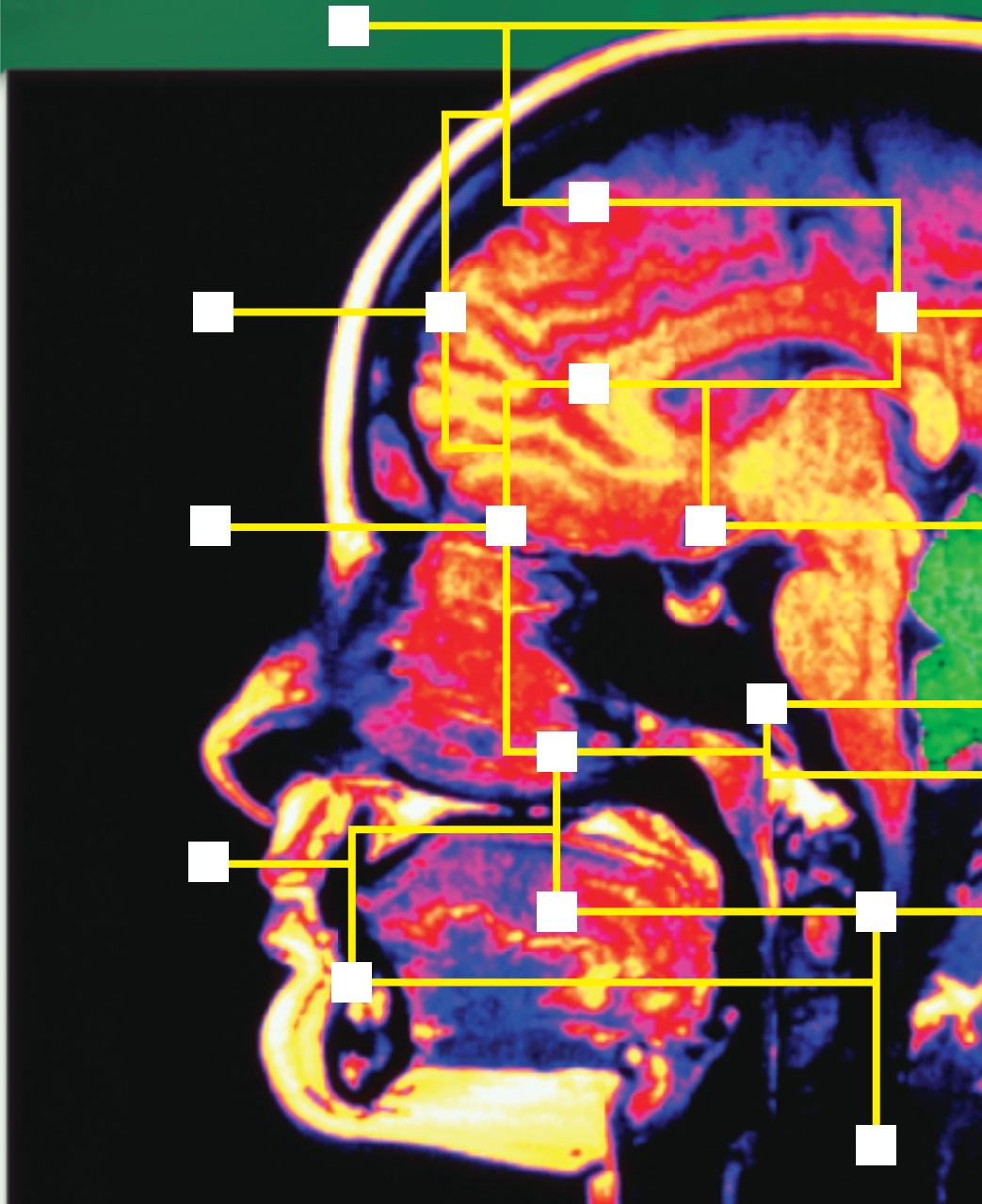
**11.2 The Central Nervous System**

- The central nervous system is the body's control centre. It consists of the brain and spinal cord.
- The brain includes centres that control involuntary responses and voluntary responses.
- The cerebrum is the largest part of the brain. It contains four pairs of lobes, each of which is associated with particular functions.

**11.3 The Peripheral Nervous System**

- The peripheral nervous system is comprised of the somatic (voluntary) system and the autonomic (involuntary) system.
- The autonomic system is divided into the sympathetic and parasympathetic nervous systems.

# The Nervous System



**F**or thousands of years, humans have aspired to create intelligent machines that can interact with their surroundings. More recently, engineers have created sophisticated robots by mimicking aspects of the human nervous system. Modern robots can collect sensory information, use complex signalling networks, and respond to various situations. Even the most advanced robot, however, is about as complex as an insect and processes information at a rate of only 500 million instructions per second. Superimposed on the image of the human brain, shown above, the robotic neural network looks relatively simple. The human nervous system allows us not only to interpret sensory information, but also to learn, reason, imagine, and experience emotions. In addition, the nervous system enables the body to maintain homeostasis.

## Launch Lab

### You, Robot?

Modern robots are designed to mimic basic human nervous system processing, which includes sensory input, integration (sorting and putting together information), and motor output. However, modern robots cannot match the capabilities of the human nervous system. This activity is designed to reduce your neural capabilities to those of a fairly advanced robot. How will this affect your ability to perform simple motor output tasks?

### Materials

- new ear plugs or cotton batting
- 2 pairs of pliers
- tongue depressor
- blindfold
- masking tape
- shoes with laces
- heavy gloves
- stopwatch

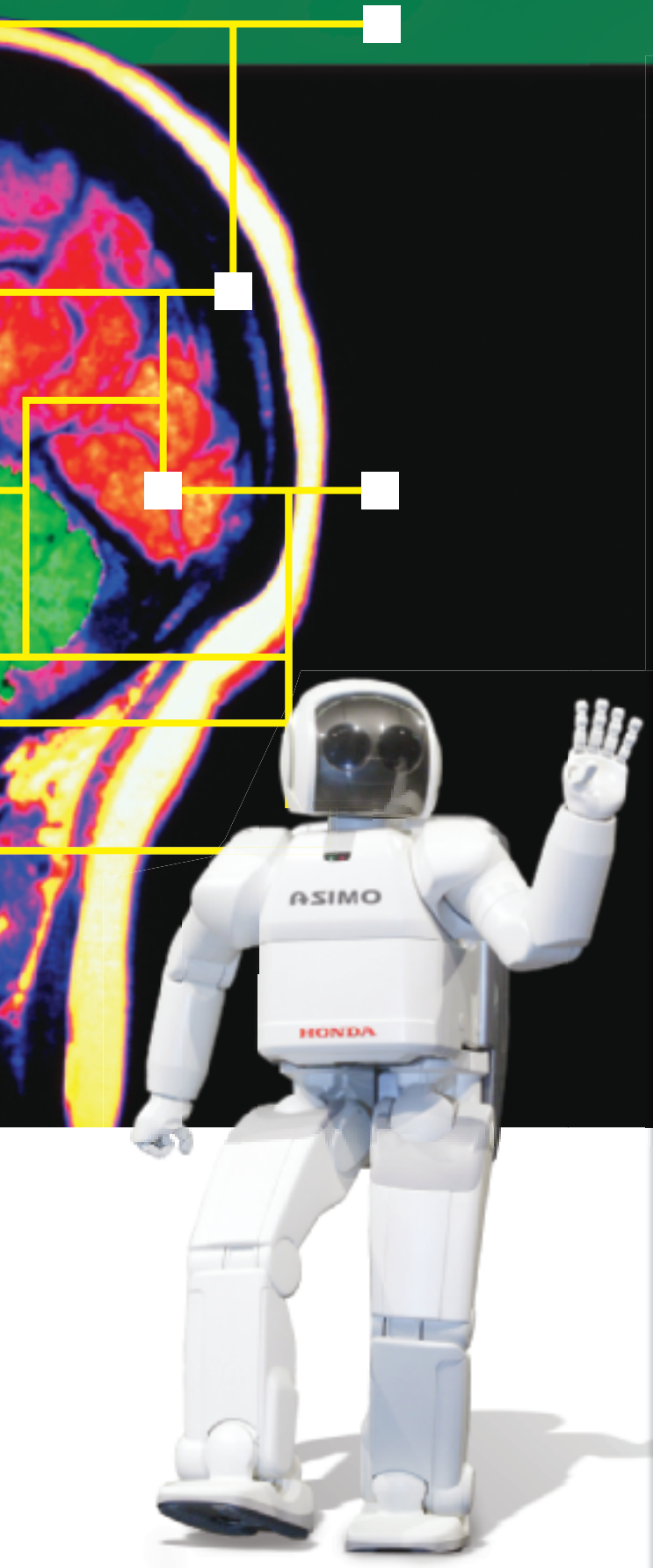
### Procedure

1. Make a data table in your notebook to record the trial times.
2. Work with a partner. With untied shoes, Partner A should sit on a chair in front of Partner B.
3. Time how long Partner B takes to tie Partner A's shoelaces.
4. Repeat step 3 with Partner B wearing a blindfold and earplugs.
5. Now repeat step 3 with Partner B wearing heavy gloves.
6. Now repeat step 3 with tongue depressors taped to Partner B's forefingers and thumbs.
7. Have Partner B hold a pair of pliers in each hand. Repeat step 3 with Partner B using the pliers to untie the shoelaces. Then repeat the task using only one hand.
8. Switch places and repeat steps 3 to 7.

### Analysis

1. Describe how each sense impairment affected the ability to integrate (sort, interpret, and determine responses to) and process sensory information.
2. For each trial, how did impairing the senses affect the ability to perform a simple motor output task?
3. Describe your impressions of the human nervous system's role, based on the results of this activity.

The Asimo project began in 1986. The first fully independent walking humanoid prototype was finished in 1997.



## SECTION 11.1

# Structures and Processes of the Nervous System

### Section Outcomes

In this section, you will

- **describe** the role of the nervous system in homeostasis
- **describe** and **observe** the organization of neurons into nerves
- **describe** the structure and function of a reflex arc, and **design** and **perform** an investigation to study reflex arcs
- **explain** the transmission of an action potential along a neuron and from one neuron to another, and **perform** investigations that demonstrate the structure and function of neurons
- **analyze** and **explain** the effects of various drugs on the nervous system

### Key Terms

homeostasis  
nervous system  
central nervous system  
peripheral nervous system  
neurons  
glial cells  
nerves  
reflex arcs  
dendrites  
cell body  
axon  
myelin sheath  
Schwann cells  
membrane potential  
resting membrane potential  
polarization  
sodium-potassium exchange pump  
depolarization  
nodes of Ranvier  
action potential  
threshold potential  
repolarization  
refractory period  
synapse  
neuromuscular junction  
neurotransmitters  
acetylcholine  
cholinesterase



**Figure 11.1** This child is wearing the same kind of clothing that her people, the Inuit, have traditionally made and worn to protect them against the extremes of their Arctic environment. How is her nervous system adapted to enable her body to maintain homeostasis while living in a harsh climate?

The human nervous system is equipped to sense and respond to continuous change within the body and in its external environment. As you may recall from your previous studies of human systems, **homeostasis** is a state of relative stability within the body. Homeostasis is critical for survival, because the body can only survive within a narrow range of conditions. The nervous system regulates body structures and processes to maintain homeostasis despite fluctuations in the internal and external environment.

For example, the child in Figure 11.1 lives in what many people consider to be an inhospitable environment, with winter temperatures often falling to  $-50^{\circ}\text{C}$  and lower. For the Arctic Inuit, maintaining a constant internal temperature, while keeping blood and heat flowing to the extremities, is crucial. Researchers have discovered that the nervous systems of people living in warmer climates act to constrict blood flow to an extremity (and thus conserve body heat) when the extremity is cooled. In Inuit people who have lived for generations in the far North, however, the nervous system fluctuates the

constriction and dilation of blood vessels to cooled extremities. This has the effect of conserving body heat, but it also allows for continued blood flow to prevent frostbite. In this way, homeostasis is maintained.



**Figure 11.2** Dissections allow researchers to learn about the human body. This dissection of the human nervous system was donated to the Smithsonian Institution in 1935 from the Kirksville College of Osteopathic Medicine.

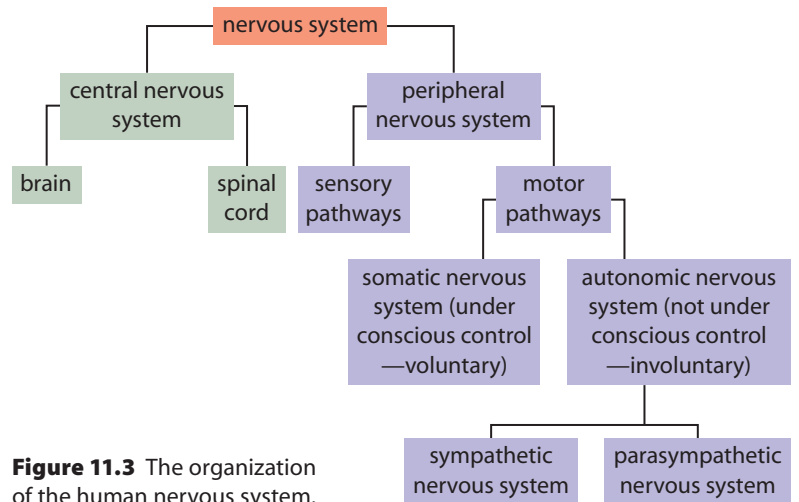
To maintain homeostasis, the human body must react to differences in temperature as well as respond to various internal and external stimuli, and it must regulate these responses. The human nervous system can regulate tens of thousands of activities simultaneously. In ways that scientists do not fully understand, it is intimately connected with human consciousness, intelligence, and creativity. The nervous system monitors and controls most body processes, from automatic functions (such as breathing) to activities that involve fine motor coordination, learning, and thought (such as playing a musical instrument). The brain and spinal cord, and the nerves that emerge from them and connect them to the rest of the body, make up the human **nervous system** (Figure 11.2).

- 1 Define homeostasis.
- 2 Explain why the nervous system is critical for maintaining homeostasis.

## Organization of the Nervous System

The human nervous system is perhaps the most complex system of any organism. The human brain alone contains over 100 billion nerve cells, and each nerve cell can have up to 10 000 connections to other nerve cells. This means that a nerve impulse—an electrochemical signal—to or from the brain could travel along  $10^{15}$  possible routes.

The nervous system has two major divisions: the central nervous system (CNS) and the peripheral nervous system (PNS). Early researchers made this distinction based on where nervous tissue was located in the body—centrally or away from the centre (peripherally). Together, the central nervous system and the peripheral nervous system control sensory input, integration, and motor output.



**Figure 11.3** The organization of the human nervous system.

The **central nervous system**, which consists of the brain and spinal cord, integrates and processes information sent by nerves.

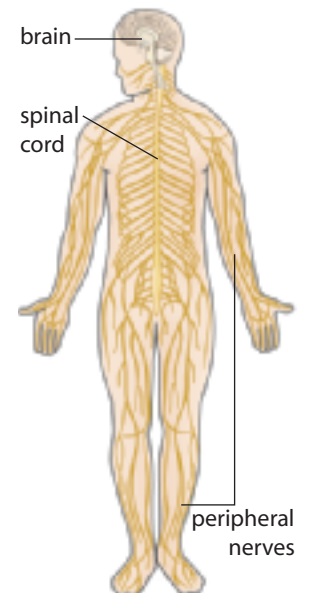
The **peripheral nervous system** includes nerves that carry sensory messages to the central nervous system and nerves that send information from the CNS to the muscles and glands.

The peripheral nervous system is further divided into the somatic system and the autonomic system.

The *somatic system* consists of sensory receptors in the head and extremities, nerves that carry sensory information to the central nervous system, and nerves that carry instructions from the central nervous system to the skeletal muscles.

The *autonomic system* controls glandular secretions and the functioning of the smooth and cardiac muscles.

The *sympathetic* and *parasympathetic* divisions of the autonomic system often work in opposition to each other to regulate the involuntary processes of the body. Involuntary processes, such as heartbeat and peristalsis, are those that do not require or involve conscious control.



- 3 Create a table to identify the different systems in the nervous system and explain the structure and function of each.



## BiologyFile

### FYI

Most nerves are buried deep in the body to protect them from injury, with only small extensions that reach the outer skin. One exception is the ulnar nerve at the elbow, which runs close to the surface of the skin. This is why a slight knock to your elbow sends an unpleasant tingling sensation throughout your arm!

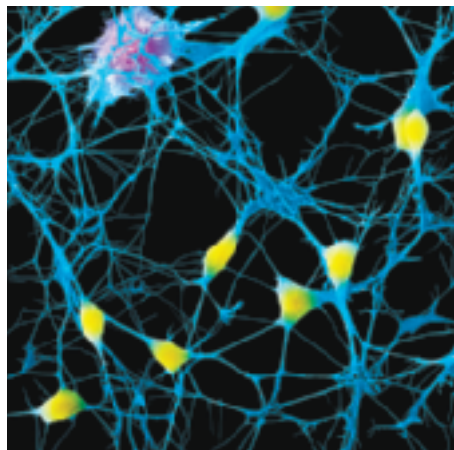
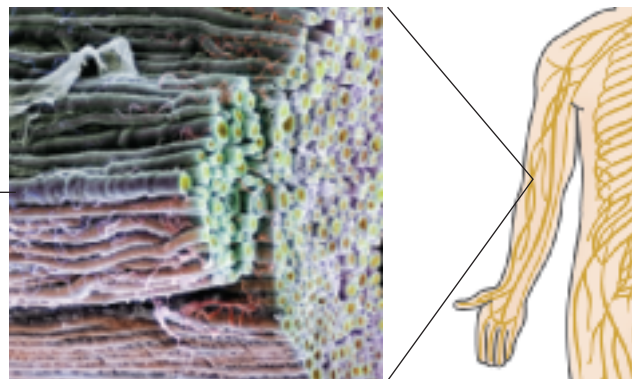
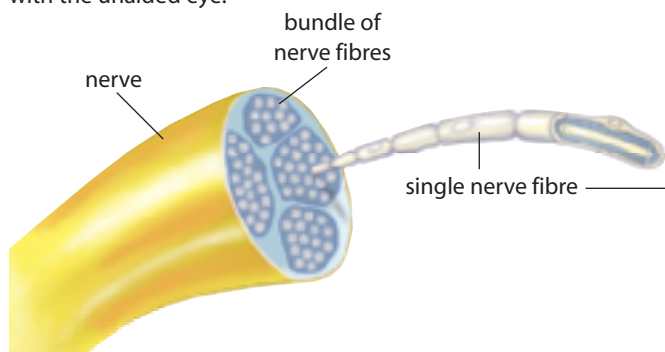
## Cells of the Nervous System

The nervous system is composed of only two main types of cells: neurons and cells that support the neurons, which are called glial cells. **Neurons** are the basic structural and functional units of the nervous system. They are specialized to respond to physical and chemical stimuli, to conduct electrochemical signals, and to release chemicals that regulate various body processes.

The activity of neurons is supported by another type of cells called glial cells. (The word glial comes from a Greek word that means “glue.”) **Glial cells** outnumber neurons by about 10 to 1, and they account for about half of the volume of the nervous system. Collectively, glial cells nourish the neurons, remove their wastes, and defend against infection. Glial cells also provide a supporting framework for all the nervous-system tissue. Figure 11.4 shows a small sample of this tissue.

Individual neurons are organized into tissues called **nerves**. Figure 11.5 shows how hundreds of individual neurons are grouped into nerve bundles and surrounded by protective connective tissue. Like optical fibre cables, which carry many individual wires from one part of a network to another, the nerves extend the neurons throughout the peripheral nervous system. Some nerves consist of neurons that carry information from sensory receptors. Other nerves consist of neurons that carry information to the muscles or glands.

**Figure 11.5** Neurons are bundled together into nerves in the peripheral nervous system and into tracts in the central nervous system. Nerves are macroscopic structures. Neurons, however, are microscopic structures. Even a neuron that is over 1 m long cannot be seen with the unaided eye.

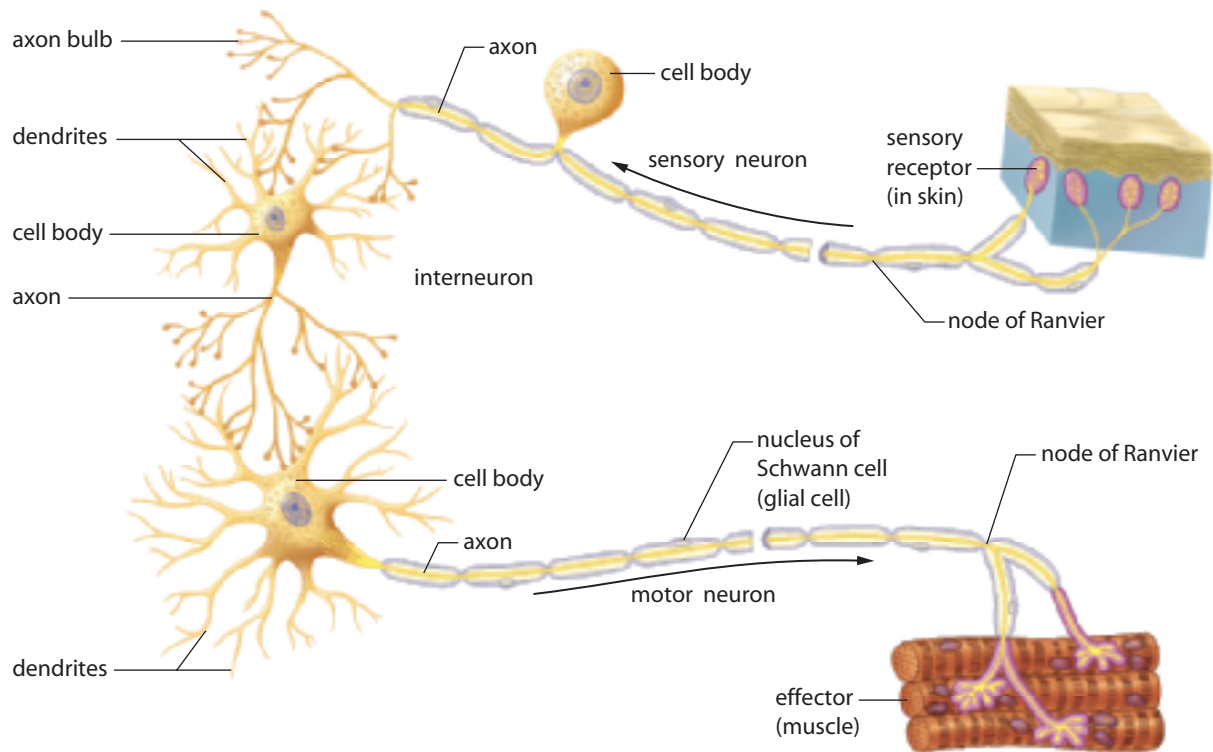


Magnification: 295 x

**Figure 11.4** This electron micrograph shows interconnecting neurons with their cell bodies (yellow) and a supporting glial cell (purple).

Neurons vary considerably in size and appearance, depending on their position and function in the body. Three main types of neurons, however, form the basic impulse-transmission pathway of the entire nervous system (Figure 11.6). This pathway, summarized in Table 11.1, depends on three overlapping functions: sensory input, integration, and motor output.

- 1. Sensory input:** Sensory neurons gather information from the sensory receptors (senses) and transmit these impulses to the central nervous system (brain and spinal cord).
- 2. Integration:** Interneurons are found entirely within the central nervous system. They act as a link between the sensory and motor neurons. They process and integrate incoming sensory information, and relay outgoing motor information.



**Figure 11.6** This diagram shows how a sensory neuron, an interneuron, and a motor neuron are arranged in the nervous system. (The breaks indicate that the axons are longer than shown).

**Table 11.1** Structures of the General Neural Impulse Transmission Pathway

Structure	Function
sensory receptors	receive stimuli and form a nerve impulse
sensory neurons	transmit impulses from the sensory receptors to the interneurons
interneurons	are found in the brain and spinal cord; act as an integration centre
motor neurons	conduct impulses from the interneurons to the effectors
effectors	muscles, glands, and other organs that respond to impulses from the motor neurons

**3. Motor output:** Motor neurons transmit information from the central nervous system to the muscles, glands, and other organs (effectors).

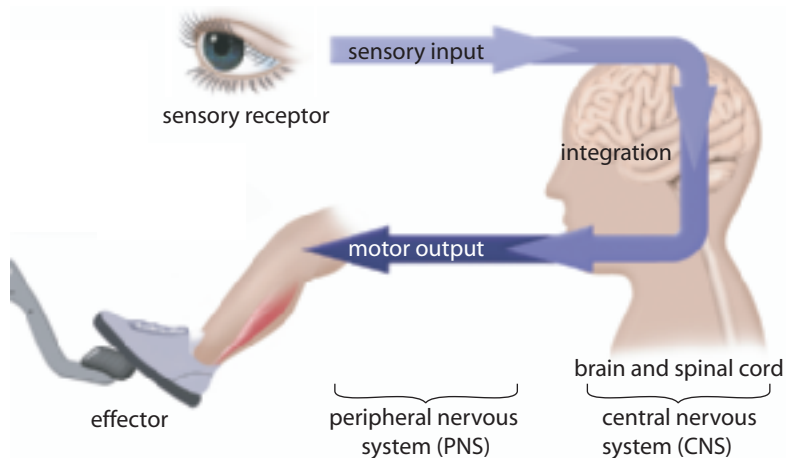
Figure 11.7 on page 370 provides an example of a basic neural transmission pathway. Suppose that you are driving a car, and a cat darts onto the road in front of you. Your eyes collect sensory information (the sight of the cat on the road), and sensory neurons transmit

this information by conducting electrochemical signals to the brain and spinal cord. Here the information is integrated by interneurons. Motor neurons then carry motor output signals to the muscles (effectors), causing you to extend your foot and press the brake.

### The Reflex Arc

Some neurons are organized to enable your body to react rapidly in times of danger, even before you are consciously aware of the threat. These sudden, unlearned, involuntary responses to certain stimuli are called reflexes. Examples of reflexes are jerking your hand away from a hot or sharp object, blinking when an object moves toward your eye, or vomiting in response to food that irritates your stomach. **Reflex arcs** are simple connections of neurons that explain reflexive behaviours. They can be used to model the basic organization of the nervous system.

Reflex arcs use very few neurons to transmit messages. As a result, reflexes can be very rapid, occurring in about 50 ms (milliseconds). Withdrawal reflexes, for example, depend on only



**Figure 11.7** An overview of the neurons in a nerve impulse pathway

three neurons. Figure 11.8 illustrates a typical neural circuit, as well as a withdrawal reflex from a potentially dangerous situation. Receptors in the skin sense the pressure of the cactus needle and initiate an impulse in a sensory neuron. The impulse carried by the sensory neuron then activates the interneuron in the spinal cord. The interneuron signals the motor neuron to instruct the muscle to contract and withdraw the hand.

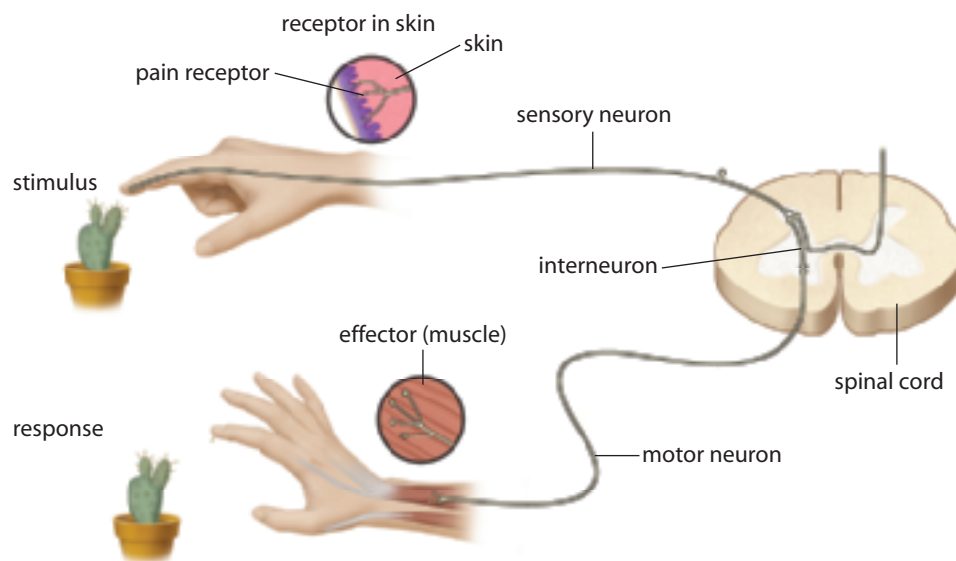
A reflex arc moves directly to and from the brain or spinal cord, before the brain centres involved with voluntary control have time to process the sensory

information. This is why, after stepping on a stone, you would not feel pain or cry out until *after* your foot was withdrawn, once the brain has had time to process the information. You can test your reflexes in Investigation 11.A.

- 4 Compare the basic function of neurons and glial cells.
- 5 List the three types of neurons, and identify their primary functions.
- 6 Identify the basic neural pathway that is involved as you dodge a wayward tennis ball. Compare this pathway with a withdrawal reflex.

## The Structure of a Neuron

Neurons have many of the same features as other body cells. In addition, neurons have specialized cell structures that enable them to transmit nerve impulses. Different types of neurons are different shapes and sizes. In general, however, they share four common features: dendrites, a cell body (soma), an axon, and branching ends (Figure 11.9).



**Figure 11.8** A withdrawal reflex. Receptors in the skin perceive the stimulus. Sensory information is conducted from the senses into the spinal cord. Motor information is then conducted away from the spinal cord to the muscles and glands.

Performing an experiment to investigate the physiology of reflex arcs

Identifying a reflex arc not discussed in the textbook, and designing an experiment to investigate the physiology of this reflex arc

## Move Fast! Reflex Responses

Reflexes are rapid, involuntary neural pathways that help to protect the body. The knee-jerk (patellar) reflex is an example of the numerous stretch adjustments your body makes every second to unconsciously maintain your balance and coordination. (Your teacher may add others.) Try to initiate the following three common reflexes. Then design an experiment to test a fourth reflex.

### Question

How does a reflex arc help to protect the body from harm?

### Safety Precautions

Do *not* use excessive force when testing the knee-jerk reflex.

### Materials

- cotton balls
- room light
- 20 cm by 20 cm clear plastic sheet
- chair

### Procedure

#### Part 1: Pupillary Reflex

1. Work with a partner. Dim the lights in the room for a few minutes. Look at the pupils in your partner's eyes.
2. Turn on the lights. Check the size of the pupils.

#### Part 2: Blink Reflex

1. Have your partner hold a piece of clear plastic in front of the face.
2. Without warning, quickly throw a cotton ball at your partner's eyes. Your partner should blink, demonstrating the blink reflex.

#### Part 3: Knee Jerk (Patellar) Reflex

1. Have your partner sit in a chair with legs crossed, so the top leg can swing freely.
2. Hit the top leg softly, just below the knee, with the side of your hand. The leg should kick out immediately, demonstrating the patellar reflex.

### Analysis

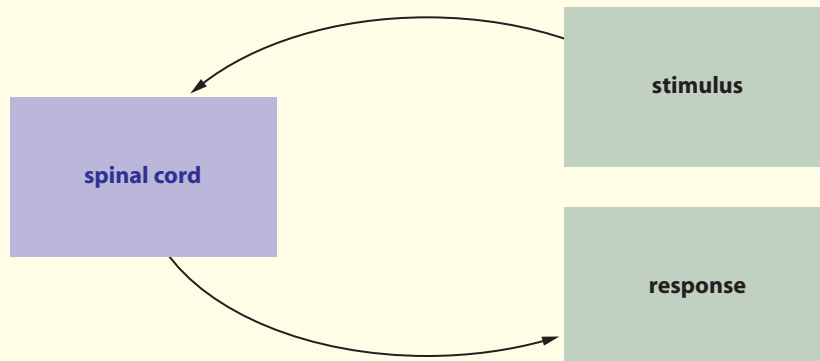
1. Copy the diagram below into your notebook. Use it as a model to represent and summarize each of the reflex responses that you tested and observed in this investigation.
2. Explain why reflexes are important for the body.

### Conclusion

3. Describe how the three reflexes tested in this investigation might protect the body.

### Applications

4. A student puts her hand on hot glassware, but withdraws her hand *before* she feels the pain. Explain how and why her awareness of the pain is delayed.
5. Design a procedure to test one of the other reflexes of the body. Hypothesize what the reflex arc might look like for the reflex you are testing, and suggest a way in which this reflex would help to protect the body. Obtain your teacher's approval before carrying out your procedure.



## BiologyFile

### FYI

Researchers at the Max Planck institute have interfaced actual living neurons with microchip transistors, as shown in the photo. They succeeded in sending a signal from a microchip, through two neurons, to another microchip that turned on a silicon switch. They plan to expand their work to understand more about the elaborate communication systems involved in the nerve pathways of the brain.



**Dendrites** are short, branching terminals that receive nerve impulses from other neurons or sensory receptors, and relay the impulse to the cell body. The dendrites are numerous and highly branched, which increases the surface area available to receive information. The **cell body** contains the nucleus and is the site of the cell's metabolic reactions. The cell body also processes input from the dendrites. If the input received is large enough, the cell body relays it to the axon, where an impulse is initiated.

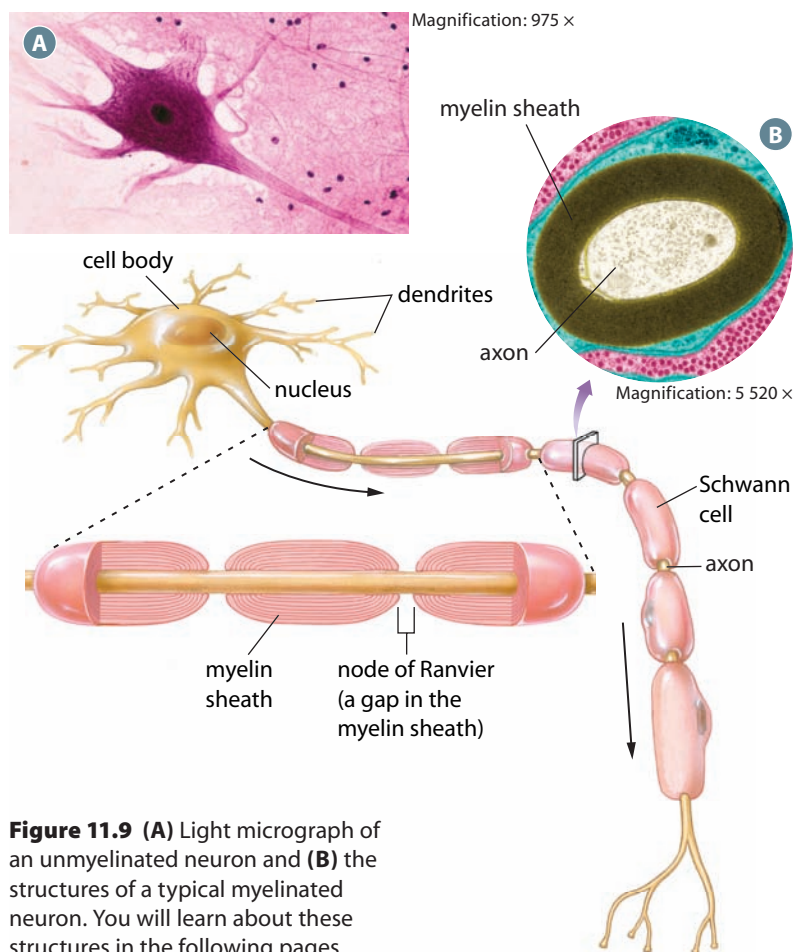
A neuron typically has one **axon**, which conducts impulses away from the cell body. Axons range in length from 1 mm to 1 m, depending on the neuron's location in the body. For example, the sciatic nerve in the leg contains neuronal axons that extend from the spinal cord all the way to the muscles in the foot, a distance of over 1 m. The terminal end of an axon branches into many fibres. To communicate with adjacent neurons,

glands, or muscles, the axon terminal releases chemical signals into the space between it and the receptors or dendrites of neighbouring cells.

The axons of some neurons are enclosed in a fatty, insulating layer called the **myelin sheath**, which gives the axons a glistening white appearance. These axons are said to be myelinated. Axons without a myelin sheath are said to be unmyelinated (Figure 11.9).

The myelin sheath protects myelinated neurons and speeds the rate of nerve impulse transmission. **Schwann cells**, a type of glial cell, form myelin by wrapping themselves around the axon. In the central nervous system, myelinated neurons form what is known as *white matter*, and unmyelinated neurons form the *grey matter*. Most neurons in the peripheral nervous system are myelinated.

- 7 Draw a neuron, label its basic structures, and identify their functions.
- 8 Describe the structure of a myelinated neuron.



**Figure 11.9** (A) Light micrograph of an unmyelinated neuron and (B) the structures of a typical myelinated neuron. You will learn about these structures in the following pages.

## Unmyelinated Nerve Impulse

A taser is a non-lethal weapon that some police officers use to immobilize threatening people. A taser sends 25 000 to 150 000 V (volts) of electricity through the human nervous system. This overloads the motor neurons of the somatic system, momentarily incapacitating the body. The electrical jolt interferes with the nervous system because neuron function depends on the cells' ability to conduct electrochemical impulses.

Neurons are able to establish a voltage difference between the inside and outside of the cell membrane. They use this voltage difference to generate a neural impulse. In the remainder of this section, you will focus on how these impulses are generated in neurons and how these electrical signals are transmitted along the length of a neuron.

## The Electrical Nature of Nerves

Luigi Galvani (1737–1798), an Italian physician and anatomist, discovered the electrical nature of nerve tissue in a simple experiment. Using two metal rods and some wire, he was able to activate a nerve within a frog's leg and cause the leg to twitch. No detailed information about the mechanisms by which nervous tissue transmitted electrical information was obtained until 1952. At that time, A.L. Hodgkin and A.F. Huxley performed experiments on the giant axon of the squid of the genus *Loligo*, shown in Figure 11.10. This squid has giant neurons used for rapid tail movements, with axons that reach from the head of the squid into its tail. A squid giant axon is up to 10 cm long and about 1 mm in diameter, or 100 to 1000 times the diameter of a human axon. The size of the axon allows scientists to measure the potential difference across the cell membrane quite easily, by inserting tiny electrodes into the axon and then reading the potential difference from a specialized voltmeter. This technique has provided extensive information about how a voltage is established across the axon membrane and how a neural impulse is generated.

Although neurons can conduct neural impulses from one area of the body to another, this process differs from electrical conduction along a wire. Nerve conduction is more complex and considerably slower. Unlike the movement of electrons along an electrical wire, nerve conduction depends on the movement of ions across the cell membrane of the axon.

### Resting Membrane Potential

When microelectrodes are inserted in an inactive, or resting, neuron, measurements from a voltmeter indicate an electrical potential difference (voltage) across the neural membrane (Figure 11.11). The electrical potential difference across the membrane can be likened to the electric potential of a flashlight battery or car

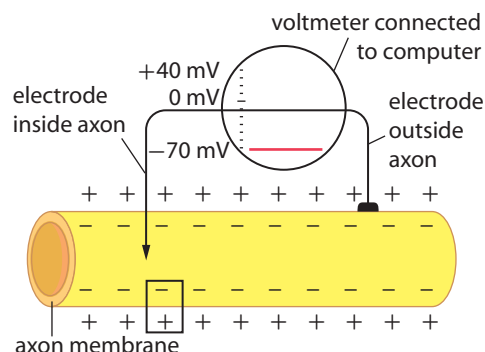


**Figure 11.10** *Loligo opalescens*, one of the species of *Loligo* studied by neurobiologists. What unique feature of this squid genus has helped scientists learn about the human nervous system?

battery. The chemical reactions maintain a separation of charges between the positive and negative poles. Similarly, in a resting neuron, the cytoplasmic side of the membrane is negative, relative to the extracellular side. The charge separation across the membrane is a form of potential energy, or **membrane potential**.

The potential difference across the membrane in a resting neuron is called the **resting membrane potential**. The resting membrane potential of most unstimulated neurons is  $-70$  mV (millivolts), and it is negative on the inside, relative to the outside. The resting membrane potential provides energy for the generation of a nerve impulse in response to an appropriate stimulus.

The process of generating a resting membrane potential of  $-70$  mV is called **polarization**. Neurons become polarized as a result of several mechanisms at work at the same time. Large protein molecules that are negatively charged are present in the intracellular fluid but not outside of the cell. These proteins are so large that they cannot pass through the cell



**Figure 11.11** A diagram of a specialized voltmeter and a neuron with a resting membrane potential of  $-70$  mV.

membrane. As well, the membrane is nearly impermeable to some smaller negatively charged ions such as chloride ions. Their presence in the intracellular fluid further contributes to the negative charge inside the cell.

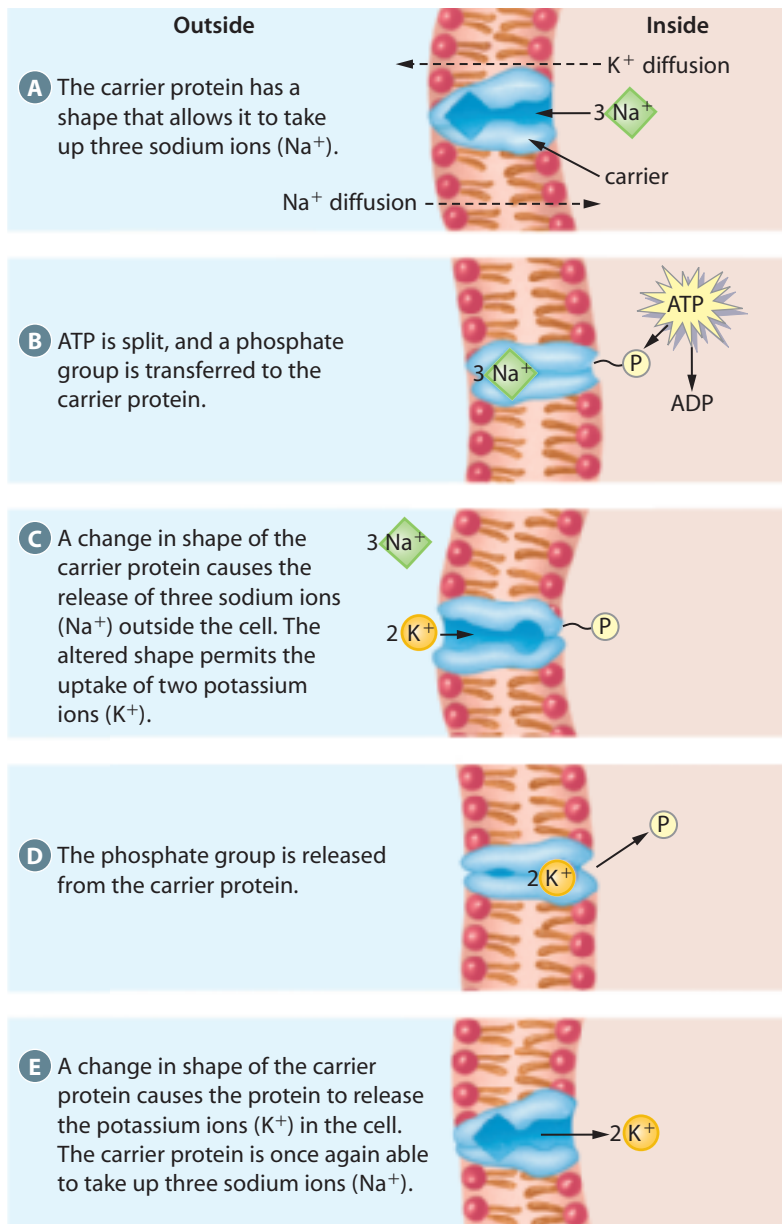
The most important contributor to the separation of charge and the resulting electrical potential difference across the membrane is the **sodium-potassium exchange pump** (Figure 11.12). This system uses the energy of ATP to transport sodium ions out of the cell and potassium ions into the cell.

The sodium-potassium exchange pump exchanges three sodium ions for

two potassium ions. As a result, an excess of positive charge accumulates outside of the cell. The cell membrane is not totally impermeable to sodium and potassium ions, so they leak slowly by diffusion across the membrane in the direction of their concentration gradient. However, potassium ions are able to diffuse out of the cell more easily than sodium ions can diffuse into the cell. The overall result of the active transport of sodium and potassium ions across the membrane, and their subsequent diffusion back across the membrane, is a constant transmembrane potential of  $-70$  mV.

You might wonder why the  $-70$  mV potential difference across the neuronal membrane is called the *resting* membrane potential when the sodium-potassium pump is constantly using energy to transport these ions. The term *resting* means that no nerve impulses are being transmitted along the axon. The resting potential maintains the axon membrane in a condition of readiness for an impulse to occur. The energy for any eventual impulses is stored in the electrochemical gradient across the membrane.

**Figure 11.12** The sodium-potassium exchange pump actively transports three sodium ions ( $\text{Na}^+$ ) outside of the cell for every two potassium ions ( $\text{K}^+$ ) moved inside the cell. Small amounts of  $\text{Na}^+$  and  $\text{K}^+$  also diffuse (“leak”) slowly across the cell membrane, following their concentration gradient.



- 9 Explain what the resting membrane potential is, and why it is significant to the functioning of neurons.
- 10 Identify and explain the three factors that contribute to the resting membrane potential.

## Action Potential

A nerve impulse consists of a series of action potentials. To understand an impulse, you first need to focus on an individual action potential taking place on one tiny segment of the axon membrane. In myelinated neurons, action potentials occur only at **nodes of Ranvier** (see Figure 11.9) because the myelin sheath insulates the axonal membrane that it encircles.

## Target Skills

Gathering and analyzing data from a model of a neuron

Working as a team to carry out experimental procedures and assess results

## Modelling Resting Membrane Potential

In this investigation, you will build a simple model of the neural membrane to demonstrate how the resting membrane potential is established.

### Question

How does the resting neural membrane generate an electric potential?



### Safety Precautions

Wash your hands after completing this investigation, or immediately if your skin is exposed to the solutions used. Wear goggles to protect your eyes against accidental splashes. The solutions used are irritating to the eyes.

### Materials

- 3 mol/L sodium chloride solution
- 22 cm of moistened dialysis tubing
- string
- elastic band
- pen
- 3 mol/L potassium chloride solution
- 2 strips of uninsulated copper wire, each 40 cm long
- DC millivolt meter
- 400 mL beaker

### Procedure

1. Create a table to record the data collected.
2. With your group, take the two 40-cm strips of copper wire and tightly wind one end of each around a pen in order to form a coil of about 8 cm.
3. Attach the uncoiled ends to the millivolt meter, as shown below. Each wire will serve as an electrode.



4. Pour about 300 mL of the sodium chloride solution into the 400 mL beaker. Take the copper electrode attached to the positive terminal of the meter, and immerse the free end in the solution.
5. Tie off one end of moistened dialysis tubing. Fill two thirds of the tubing with potassium chloride solution. Place the free end of the other copper electrode in the solution in the tubing. Secure the end of the tubing around the wire with an elastic band.
6. While another group member observes the needle on the millivolt meter, place the dialysis tubing in the beaker that contains the solution of sodium chloride. (If sensor probes are available, these can be used to measure and monitor the electric potential.)
7. Leave the dialysis tubing in the beaker, and continue to monitor the electric potential every 5 min, until a trend is established. Record each value in your data table.

### Analysis

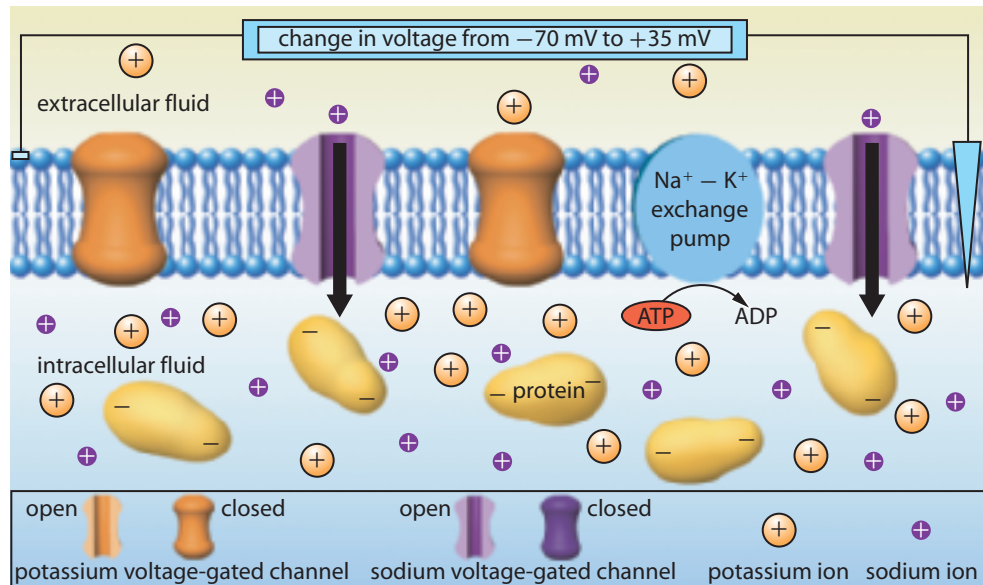
1. Graph the data from your data table.
2. Explain what the dialysis tubing, potassium chloride solution, and sodium chloride represent in this model of a resting neuron.
3. Compare the electric potential created in this model with a resting membrane potential in a neuron.
4. Compare your results with the results of other groups in your class. Provide a reason for any differences.
5. Hypothesize how you might be able to increase the electric potential across the dialysis tubing.

### Conclusions

6. a) Describe what happened to the magnitude of the electric potential over time, and explain why this happened.  
b) If this occurred in a neuron, what would happen?
7. a) How did your model illustrate the mechanism of ion channel diffusion?  
b) Summarize all the factors that establish resting membrane potential in a neuron, including the mechanism of ion channel diffusion illustrated by your model.



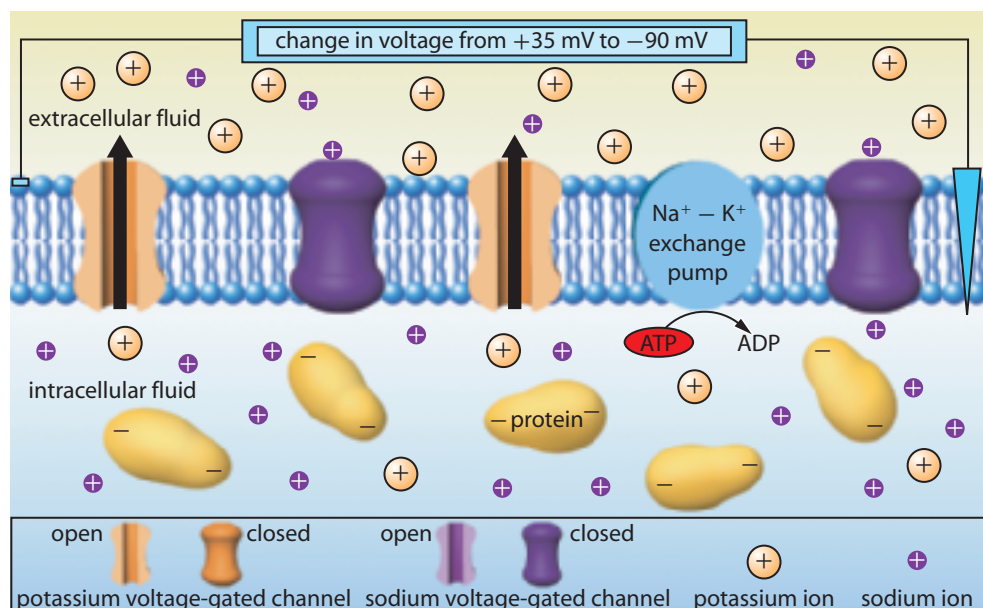
**Figure 11.13** Summary of the events in an action potential.



A neuronal membrane is said to be **depolarized** if the transmembrane potential is reduced to less than the resting potential of  $-70$  mV. If, for any reason, the membrane at a node of Ranvier becomes depolarized to  $-55$  mV, a dramatic change occurs in the membrane. This change is called an **action potential**. (As you will see later, this depolarization is usually caused by an action potential that has just occurred at an adjacent node of Ranvier.) An action potential is called an “all-or-none” event because a depolarization to between  $-70$  mV and  $-55$  mV has no effect. Any depolarization

to  $-55$  mV, or any other amount up to 0, will produce identical action potentials. The potential difference of  $-55$  mV is therefore called the **threshold potential**. Threshold potentials can vary slightly, depending on the type of neuron, but they are usually close to  $-55$  mV.

When the transmembrane potential at a node of Ranvier reaches threshold, special structures in the membrane called voltage-gated sodium channels open and make the membrane very permeable to sodium ions. The sodium ions on the outside of the axon suddenly rush into the axon, driven by their



**Figure 11.14** The repolarization of a neuron. Why must the neuron be repolarized before it can be stimulated again?

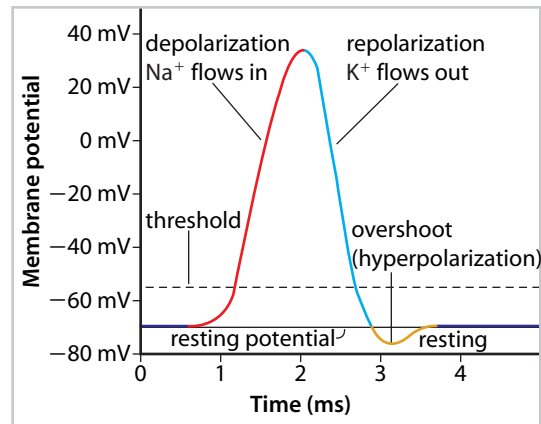
concentration gradient and the potential difference across the membrane as shown in Figure 11.13. Within a millisecond or less, enough positively charged sodium ions have crossed the membrane to make the potential difference across the membrane in that tiny region of the axon +35 mV.

As a result of the change in membrane potential, the sodium channels close and voltage-gated potassium channels open. As shown in Figure 11.14, the potassium ions now move down their concentration gradient (toward the outside of the axon), carrying positive charge out of the neuron. As a result, the membrane is **repolarized**—that is, returned to its previous polarization. In fact, the membrane potential overshoots to nearly  $-90$  mV. At that point, the potassium channels close. The sodium-potassium exchange pump and the small amount of naturally occurring diffusion quickly bring the membrane back to its normal resting potential of  $-70$  mV. For the next few milliseconds after an action potential, the membrane cannot be stimulated to undergo another action potential. This brief period of time is called the **refractory period** of the membrane.

Figure 11.15 summarizes the changes in the transmembrane potential that occur during an action potential. Notice that all of these events occur within a period of a few milliseconds. As well, they occur in one small region of the axon membrane.

- 11 Explain the difference between depolarization of a neuron and an action potential.
- 12 Describe the “all-or-none” response.
- 13 Describe the process of repolarization in the neuron, and explain its importance in the transmission of a neural impulse.

### Action Potential



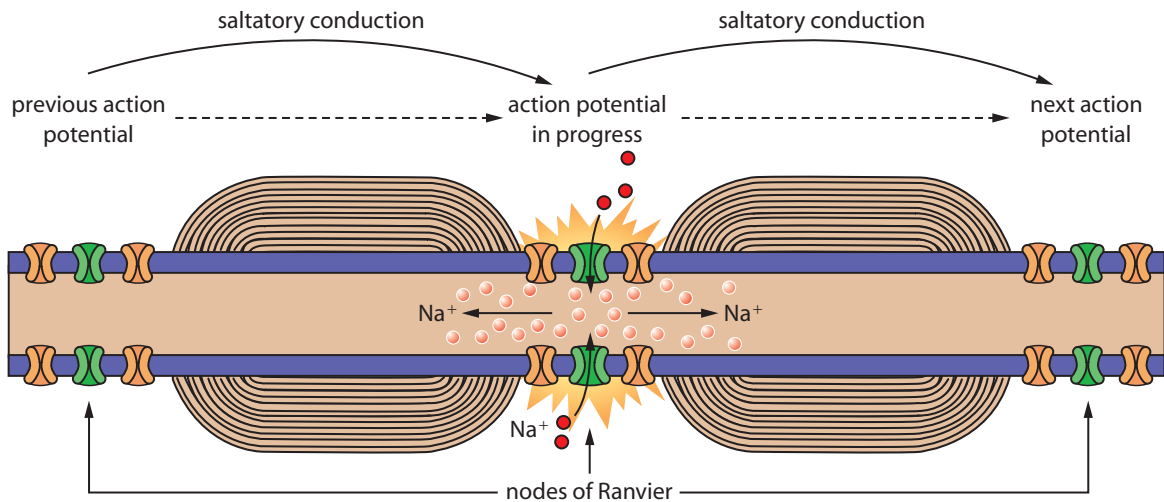
**Figure 11.15** The changes in the transmembrane potential of the axon are a result of sodium ions flowing into the axon and potassium ions flowing out. An action potential lasts only a few milliseconds.

### Myelinated Nerve Impulse

A nerve impulse consists of a series of action potentials. How does one action potential stimulate another? Examine Figure 11.16 on page 378. As you know, when an action potential occurs at a node of Ranvier, sodium ions flow into the axon. After the sodium channels close, there is still a relatively high concentration of sodium inside the axon at that node. Since particles such as ions always diffuse from an area of higher concentration to an area of lower concentration, the sodium ions inside the axon cannot diffuse out. Instead, they diffuse in both directions along the axon.

When the sodium ions reach neighboring nodes of Ranvier, the positive charges reduce the net negative charge inside the axonal membrane. The presence of the positively charged sodium ions causes the membrane at the nodes of Ranvier to become depolarized to threshold. Since an action potential just occurred at the node to the left (in the figure), that membrane is refractory, which means that it cannot be stimulated to undergo another action potential yet. This mechanism prevents impulses from going backwards. The membrane of the node of Ranvier to the right is not refractory so the depolarization initiates an action potential at this node.

The same process occurs at each node until it reaches the end of the neuron. This process of one action potential stimulating the production



**Figure 11.16** Sodium ions that accumulate inside an axon during an action potential diffuse in both directions along the inside of the axon.

of another one at the next node constitutes the nerve impulse.

Because action potentials are forced to “jump” from one node of Ranvier to the next due to the myelin sheath, the conduction of an impulse along a myelinated neuron is called *saltatory conduction*. (The word “saltatory” comes from a Latin word that means to jump or leap.) A similar process occurs in unmyelinated neurons. In these neurons, however, action potentials can occur at all locations along a membrane. Therefore, they occur beside one another. As a result of so many action potentials occurring all along the axon, the transmission of an impulse along an unmyelinated axon is much slower than the saltatory conduction along a myelinated axon (about 0.5 m/s, compared with as much as 120 m/s in a myelinated axon).

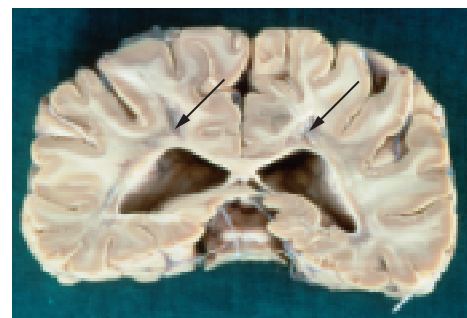
The nervous system disorder called multiple sclerosis is caused by the breakdown of the myelin sheath surrounding the axons in the central nervous system (Figure 11.17). The neurons can no longer efficiently carry electrochemical signals between the brain and the body. Multiple sclerosis is thought to be an autoimmune disease, in which the body’s own immune system breaks down the myelin. The symptoms of multiple sclerosis can include blurred vision, loss of balance, muscle weakness, fatigue, and slurred speech. Most people

with multiple sclerosis experience periods of remission and periods of progression of the disease.

In Investigation 11.C, you will examine myelinated and unmyelinated neural tissue.

## Signal Transmission across a Synapse

The simplest neural pathways have at least two neurons and one connection between the neurons. Other neural pathways can involve thousands of neurons and their connections as an impulse travels from the origin of the stimulus, through the sensory neurons to the brain, and back through motor neurons to the muscles or glands. The connection between two neurons, or a neuron and an effector, is called a **synapse**. A **neuromuscular junction** is a synapse between a motor neuron and a muscle cell.



**Figure 11.17** In this person, who has multiple sclerosis, the myelin sheath in the white matter of the brain has been destroyed, leaving lesions. Arrows show the affected areas of the brain.

## BiologyFile

### Web Link

View an on-line animation of neural impulse propagation. In what way is a neural impulse like a wave?



An impulse travels the length of the axon until it reaches the far end, called the synaptic terminal. Most neurons are not directly connected, but have a gap between them called the synaptic cleft. These neurons are not close enough for the impulse to jump from one to the other. How, then, does the impulse proceed from the presynaptic neuron, which sends out information, to the postsynaptic neuron, which receives the information?

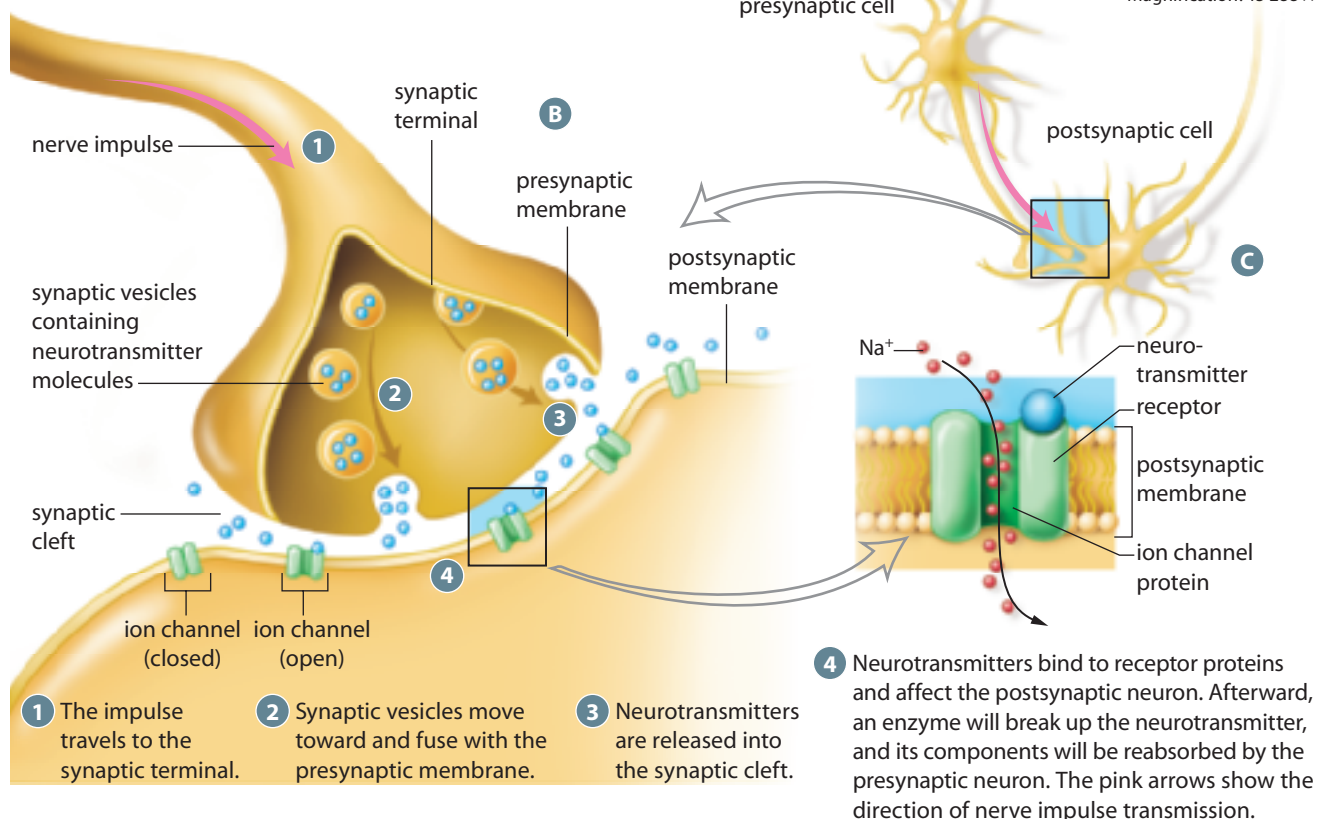
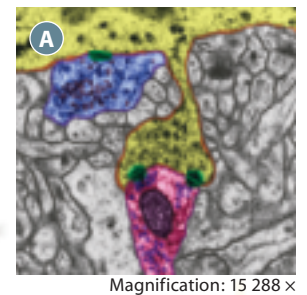
Chemical messengers called **neurotransmitters** carry the neural signal from one neuron to another. Neurotransmitters can also carry the neural signal from a neuron to an effector, such as a gland or muscle fibre. Figure 11.18 summarizes the events in the movement of an impulse across a synapse. When an action potential arrives at the end of a presynaptic neuron, the impulse causes sacs that contain neurotransmitters to fuse with the membrane of the axon. These sacs, called synaptic vesicles, release their contents into the synaptic cleft by exocytosis. The neurotransmitters then diffuse across

the synapse, taking about 0.5 to 1 ms to reach the dendrites of the postsynaptic neuron, or cell membrane of the effector.

Upon reaching the postsynaptic membrane, the neurotransmitters bind to specific receptor proteins in this membrane. As Figure 11.18 illustrates, the receptor proteins trigger ion-specific channels to open. This depolarizes the postsynaptic membrane and, if the threshold potential is reached, initiates an action potential. The impulse will travel along the postsynaptic axon to its terminal and to the next neuron or an effector.

Neurotransmitters have either excitatory or inhibitory effects on the postsynaptic membrane. If the effect is excitatory, the receptor proteins will trigger ion channels that open to allow positive ions, such as sodium, to flow into the postsynaptic neuron. As a result, the membrane becomes slightly depolarized. The membrane of the neuron cannot experience an action potential but the slight depolarization spreads throughout the nerve cell, lowering its threshold level.

**Figure 11.18** (A) An electron micrograph of a neural synapse. Note in green the synaptic vesicles in the axon terminal of the presynaptic neuron. (B) Neurotransmitters bind to receptor proteins. (C) Synaptic transmission.



## BiologyFile

### Web Link

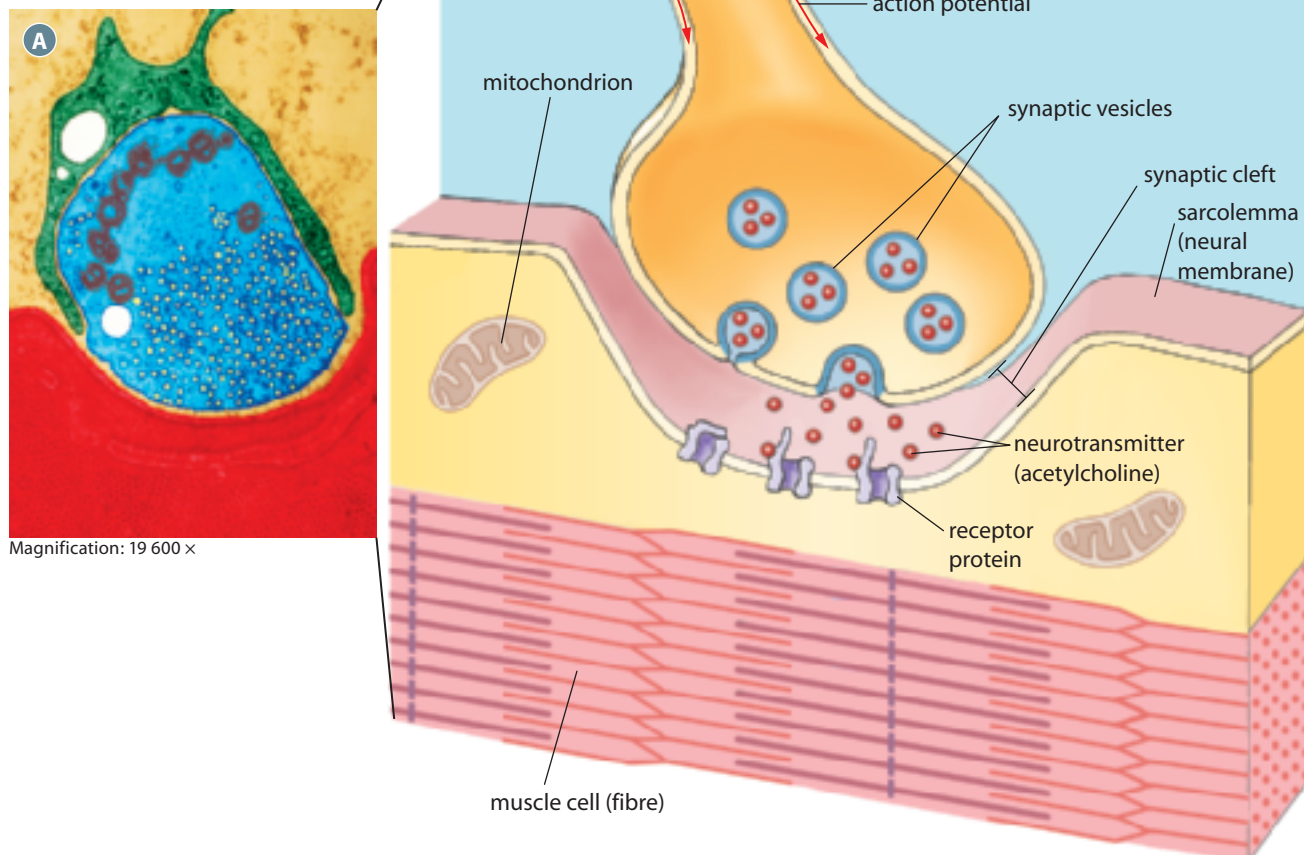
View an on-line animation of neurotransmitters in action. Describe the role of the cell membrane in neurotransmitter release.

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WWW

If the neurotransmitter is inhibitory, the receptor will trigger potassium channels to open, allowing potassium ions to flow out. This results in a more negative transmembrane potential, resulting in hyperpolarization. A single cell body may be receiving signals from many presynaptic neurons at the same time. Some can be excitatory and others can be inhibitory. One of the functions of the cell body is to integrate all of the incoming signals. The combined effect of all of the stimuli spreads across the cell body. If the excitatory stimuli are strong enough, the depolarization will reach the point at which the axon is connected to the cell body and an impulse will be generated. The postsynaptic neuron will then return to resting potential.

After the neurotransmitter has had its effect, enzymes break it down and inactivate it so that its components can be reabsorbed by the presynaptic cell.

**Figure 11.19 (A)** An electron micrograph and **(B)** a diagram showing a neuromuscular junction. Notice the axon of the motor neuron connecting (across a synapse) with muscle fibres in red.



- 14 Summarize the events that occur as an impulse is propagated along the length of the neuron.
- 15 Summarize the events involved in impulse transmission from the presynaptic neuron to the postsynaptic neuron.
- 16 Identify the function of neurotransmitters in the nervous system.

### Neurotransmitters in Action

**Acetylcholine** is a neurotransmitter that crosses a neuromuscular junction (Figure 11.19). Acetylcholine excites the muscle cell membrane, causing depolarization and contraction of the muscle fibre. Consider what would happen if acetylcholine remained in

Observing neurons and neuromuscular junctions with a microscope

Identifying the principal structures in different types of neurons, and relating these structures to their functions

## Examining Neural Tissue

In this investigation, you will examine microscope slides of neural tissue, along with some corresponding photographs. As you observe the tissues and make diagrams, identify the specialized structures that allow neurons to carry out their functions.

### Question

How does the structure of different neurons relate to their functions?



### Safety Precautions

Handle the microscope slides with care, so they do not break and cut you.

### Materials

- microscope
- prepared neural slides similar to, but not limited to, the ones shown below

### Procedure

Observe each slide provided by your teacher, as well as the micrographs below, and identify any key neural structures.

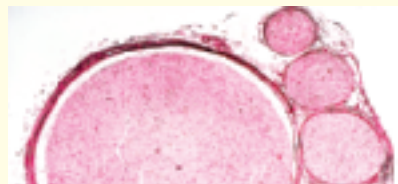
### Analysis

1. Slide and micrograph 1 show a cross-section of the brain. Sketch your observations, and label the white and grey matter. Describe the structural differences between the two types of neural tissue.
2. Slide and micrograph 2 show a cross-section of a nerve. Sketch your observations, and label the nerve bundles and neurons. Explain the basic function of a neuron.
3. Slide and micrograph 3 show a cross-section of the spinal cord. Sketch your observations, and label a sensory neuron, a motor neuron, and an interneuron. (**Hint:** See Figure 11.6.) Explain the function of each neuron, and trace the neural pathway.
4. Slide and photograph 4 show several unmyelinated neurons. Sketch one neuron that you can see, and label the basic structures. Indicate the direction of impulse transmission down the neuron.
5. Slide and micrograph 5 show a longitudinal view of a myelinated axon. Sketch your observations, and label the axon, the myelin sheath, a Schwann cell, and a node of Ranvier. Describe the functions of the myelin sheath.
6. Slide and micrograph 6 show a view of the neuromuscular junction between the dendrites of a motor neuron and the receptors on a muscle fibre. Sketch your observations, and label the motor neuron, muscle fibre, and synapse. Hypothesize how the impulse coming from the motor neuron might reach the muscle fibre (effector).
7. Observe and sketch any additional slides provided by your teacher.



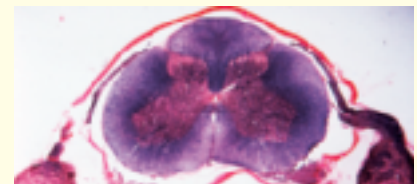
Magnification: 7 ×

1 White and grey matter



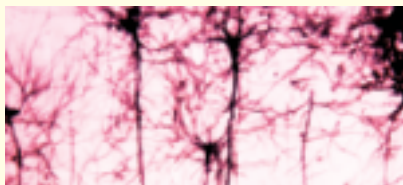
Magnification: 6,125 ×

2 Cross-section of nerve



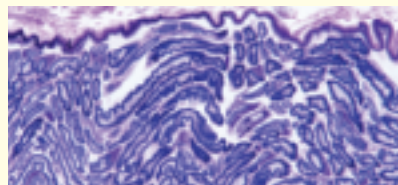
Magnification: 0.5 ×

3 Cross-section of spinal cord



Magnification: 39 ×

4 Unmyelinated neurons



Magnification: 228 ×

5 Myelinated axons



Magnification: 28 ×

6 Neuromuscular junction

## BiologyFile

### FYI

Acupuncture is a traditional Chinese medical practice in which needles are inserted at specific points on the body. Based on Western scientific thinking, it is hypothesized that the resulting stimulation of these points triggers the brain to release endorphins, neurotransmitters that ease the sensation of pain. Traditional Eastern scientific thinking explains acupuncture in terms of rebalancing the body's *chi*—its life-force energy.

the synapse. The muscle fibre cell could not repolarize and would remain in a state of excitation (contraction).

Normally, an enzyme called **cholinesterase** is released into a synapse, where it breaks down acetylcholine. Cholinesterase is one of the fastest acting enzymes. It breaks down acetylcholine so that it can be removed from the protein receptors, thus allowing the ion channels to close and the membrane to repolarize in a fraction of a second. A nerve gas called sarin destroys this function by blocking the release of cholinesterase into the neuromuscular junction. With the buildup of acetylcholine, critical muscles, such as the heart and diaphragm, enter a state of constant contraction or paralysis. Some insecticides affect insects in the same way and kill them.

There are more than 50 substances in the human body that can act as neurotransmitters. Table 11.2 lists some common neurotransmitters and their functions. The functions vary depending on where in the body the neurotransmitter acts. Several neurological disorders have been linked to neurotransmitter deficiencies or excessive production. In addition, certain drugs can alter the proper action of neurotransmitters, as described in Thought Lab 11.1.

17 Compare the excitatory and inhibitory effects of neurotransmitters on the postsynaptic membrane.

18 Compare and relate the functions of acetylcholine and cholinesterase.

## Section 11.1 Summary

- The human nervous system is a complex system composed of many subsystems that all work together to maintain homeostasis in the body.
- The nervous system gathers and processes information from the external and internal environments and then relays a response to the necessary areas of the body.
- The neuron is the functional unit of the nervous system.
- There are three kinds of neurons: sensory neurons, interneurons, and motor neurons.
- Neurons allow the nervous system to relay sensory information to the brain and spinal cord for integration, and to produce a response, as needed, by the effectors.
- All cells have a membrane potential, but the neuron is unique in that it can change the potential of its membrane to generate an impulse. An impulse is

**Table 11.2** Selected Neurotransmitters and Their Functions

Neurotransmitter	Function	Effects of abnormal production
dopamine	affects the brain synapses in the control of body movements; is linked to sensations of pleasure, such as eating	excessive production linked to schizophrenia, a disorder in which the individual's perception of reality is greatly distorted; inadequate production linked to Parkinson's disease, a progressive disorder that destroys neurons, causing tremors, slurred speech, and other coordination problems
serotonin	regulates temperature and sensory perception; is involved in mood control	inadequate amounts in the brain synapses linked to depression
endorphins	act as natural painkillers in synapses in the brain; also affects emotional areas of the brain	deficiency linked to an increased risk of alcoholism
norepinephrine	is used by the brain and some autonomic neurons; complements the actions of the hormone epinephrine, which readies the body to respond to danger or other stressful situations	overproduction linked to high blood pressure, anxiety, and insomnia; deficiency linked to hunger cravings and exhaustion

Analyzing and explaining how different drugs affect neural impulses

Working cooperatively to investigate the effects of a drug on neurons or neural synapses

Hypothesizing what might make some drugs addictive

A drug is a non-food substance that changes the way the body functions. Most drugs, legal or illegal, affect the neurons and synapses by either promoting or decreasing the action of a neurotransmitter. Research has shown that many addictive drugs stimulate the brain's natural reward and pleasure centres, often by artificially elevating the levels of neurotransmitters, such as dopamine or endorphins. The table briefly describes the major effects of some commonly abused addictive drugs.

### Procedure

- Working with a partner, use the information in the table to create a drug information pamphlet about one of the drugs presented. If possible, research the drug further using Internet or library resources. Your information pamphlet should include
  - a detailed explanation of how the drug affects the nervous system and other body functions
  - hazards to the nervous system and the entire body from short-term and long-term use of the drug
- Present your pamphlet to another group or to the rest of the class.






### Analysis

- Hypothesize what might make the drug you investigated addictive. Suggest a possible mechanism, based on how the drug affects the nervous system, that explains why the body could become addicted to the drug.

### Extension

- Debate the effects of drug use on society as a whole.

### Effects of Selected Drugs on Human Systems

Drug	Effects on nervous system and body
nicotine 	<ul style="list-style-type: none"> <li>is derived from the tobacco plant</li> <li>is one of the main addictive ingredients in cigarettes and chewing tobacco, which cause cancer, respiratory problems, and other problems after long-term use</li> <li>rapidly stimulates the reward centre of the brain to release dopamine, which promotes feelings of euphoria</li> <li>stimulates certain areas of the body by mimicking the actions of acetylcholine, causing increased heart rate and blood pressure</li> </ul>
marijuana 	<ul style="list-style-type: none"> <li>is harvested from the flowers and leaves of certain types of <i>Cannabis</i> plant</li> <li>when smoked, active ingredient (THC) interferes with synapses in the brain, including the reward centres</li> <li>produces feelings of euphoria, and reduces concentration and muscle coordination</li> </ul>
ecstasy (MDMA) 	<ul style="list-style-type: none"> <li>affects neurons in the brain, causing overproduction of serotonin</li> <li>in the short term, produces feelings of pleasure</li> <li>can cause cardiac arrest, dangerously elevated body temperature, and rapid and permanent brain damage</li> </ul>
cocaine 	<ul style="list-style-type: none"> <li>is naturally found in leaves of <i>Erythroxylon coca</i>, a species of coca plant</li> <li>targets neurons in the reward centre of the brain and prevents the re-uptake of dopamine</li> <li>increases energy levels and produces feelings of euphoria</li> <li>is highly addictive and can cause strokes and heart attacks</li> </ul>
methamphetamine (meth, crystal meth) 	<ul style="list-style-type: none"> <li>enters the neuron by passing directly through neuron membranes</li> <li>causes excessive release of dopamine and blocks the dopamine transporter from pumping dopamine back into the transmitting neuron</li> <li>increases energy levels and produces feelings of euphoria</li> <li>often leads to extreme aggressiveness, delusions, and psychosis (greatly distorted perception of reality)</li> </ul>

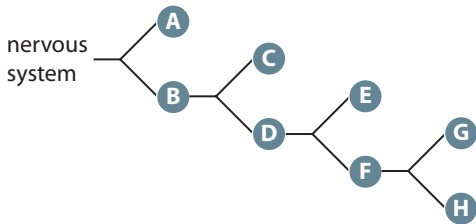


transmitted from one neuron to the next through a synapse.

- Many substances, such as drugs, painkillers, chemicals, and neurotoxins, can interfere with the functions of synapses and neurotransmitters.

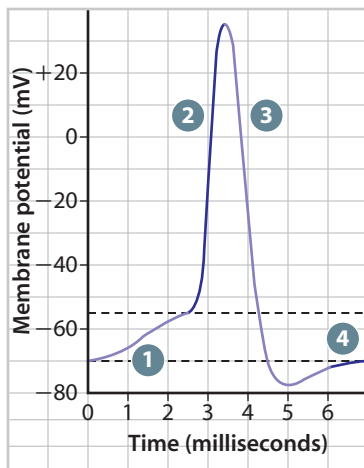
## Section 11.1 Review

1. Copy the letters A through H into your notebook. Identify the division of the nervous system that is represented by each letter.



2. Analyze the following statement: “The neuron conducts impulses in the same way as electricity moves through a wire.” Is a nerve impulse like electricity? Prepare a table that compares a nerve impulse to the movement of an electric current along a wire.
3. Compare the structure and functions of myelinated neurons and unmyelinated neurons.
4. Using a diagram, explain how a neuron establishes the resting membrane potential. What is the value of this in mV?
5. Examine the graph below, and answer the questions that follow.

**Action Potential**



- a) In your notebook, indicate the specific events that are occurring at 1, 2, 3, and 4.
  - b) At which area of the graph are sodium ions rapidly entering the neuron?
  - c) At which area of the graph are potassium ions rapidly leaving the neuron?
  - d) At which area of the graph is the sodium ion concentration higher outside than inside the neuron?
6. Hypothesize how overproduction of cholinesterase might affect the body. Explain your answer.
  7. Use word processing or spreadsheet software to construct a table to compare an excitatory response with an inhibitory response. Give an example of where these responses are complementary in the body. **ICT**
  8. Cocaine affects a synapse by blocking the re-uptake of the neurotransmitter dopamine by the presynaptic neurons. Therefore, the levels of dopamine continue to build in the synapse, causing certain effects on the body.
    - a) Use word processing software to make a flowchart summarizing the usual events in the transmission of an impulse between the presynaptic and postsynaptic neurons. **ICT**
    - b) Explain how cocaine interferes with neural transmission across the synapse.
    - c) Describe the natural role of dopamine in the brain.
    - d) Formulate a hypothesis about how cocaine could be addictive after only one use.

## SECTION 11.2

# The Central Nervous System

### Section Outcomes

In this section, you will

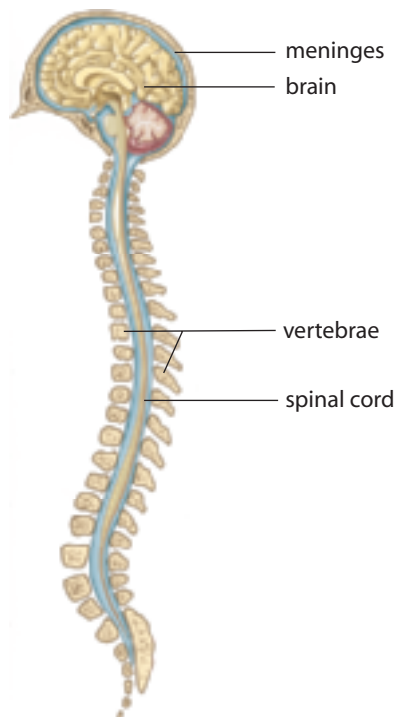
- **identify** the principal structures of the central nervous system
- **explain** the functions of the spinal cord and various regions of the brain
- **observe** the principal features of the mammalian brain
- **explain** how technological advances in neuroscience can provide solutions to practical problems

### Key Terms

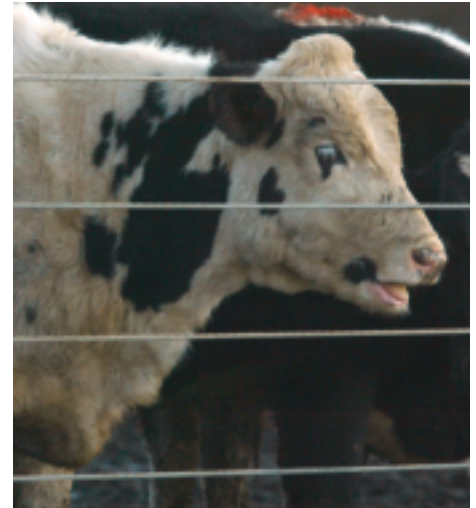
grey matter  
white matter  
meninges  
cerebellum  
medulla oblongata  
pons  
midbrain  
thalamus  
hypothalamus  
cerebrum  
blood-brain barrier  
cerebrospinal fluid  
cerebral cortex  
corpus callosum  
occipital lobes  
temporal lobes  
parietal lobes  
frontal lobes  
Broca's area  
Wernicke's area

The central nervous system (Figure 11.20) is the structural and functional centre for the entire nervous system. The site of neural integration and processing, the central nervous system receives information from the senses, evaluates this information, and initiates outgoing responses to the body. Damage to the central nervous system can therefore affect temperament, motor control, and homeostasis. For example, the beef steer in Figure 11.21 has bovine spongiform encephalopathy (BSE), a disease that produces sponge-like holes in the brain. Also called “mad cow disease,” BSE initially causes nervousness and over-sensitivity to touch. Affected animals then develop an unsteady gait and lose the ability to walk, and eventually die.

As you learned in Section 11.1, the central nervous system is composed of two types of nervous tissue: grey matter and white matter. **Grey matter** is grey because it contains mostly cell bodies, dendrites, and short, unmyelinated



**Figure 11.20** The central nervous system



**Figure 11.21** This cow has BSE, a progressive neurological disorder in cattle. Like chronic wasting disease in elk and some forms of sheep scrapie, BSE is caused by an infectious protein.

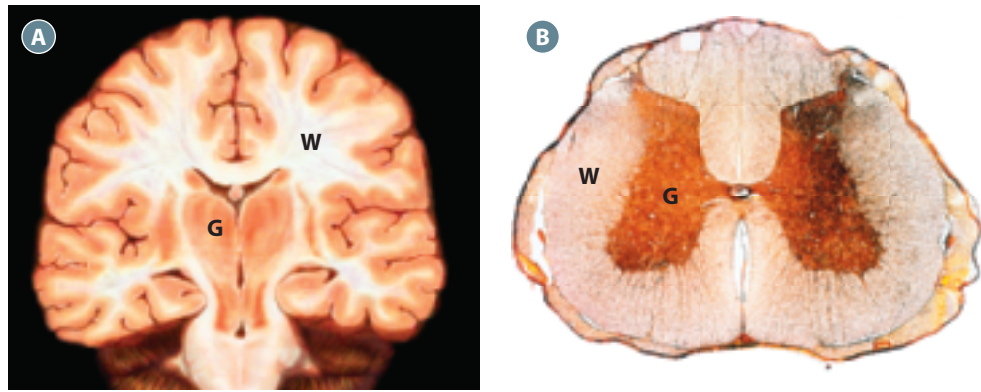
axons (nerve fibres). Grey matter is found around the outside areas of the brain and forms the H-shaped core of the spinal cord. **White matter** is white because it contains myelinated axons that run together in tracts. White matter forms the inner region of some areas of the brain, and the outer area of the spinal cord.

### The Spinal Cord

The spinal cord is a column of nerve tissue that extends out of the skull from the brain, and downward through a canal within the backbone (see Figures 11.20 and 11.23 on page 386). The spinal cord is a vital communication link between the brain and the peripheral nervous system. Within the spinal cord, sensory nerves carry messages from the body to the brain for interpretation, and motor nerves relay messages from the brain to the effectors. The spinal cord is also the primary reflex centre, coordinating rapidly incoming and outgoing neural information.

A cross section of the spinal cord reveals both white matter and grey matter (Figure 11.22 on page 386). The outer

**Figure 11.22 (A)** Cross section of human brain showing right and left side. **(B)** Cross section through human spinal cord. The central nervous system is composed of both white matter (W) and grey matter (G).



white matter consists of myelinated nerve fibres. The butterfly-shaped core is made up of grey matter, which contains unmyelinated neurons as well as the cell bodies and dendrites of many spinal neurons.

The delicate tissues of the spinal cord are protected by cerebrospinal fluid, soft tissue layers, and the spinal column, a series of backbones (vertebrae). Injury to the spinal column can also damage the spinal cord, resulting in paralysis.

### The Brain

The ancient Egyptians were among the first neuroscientists, and were the first known civilization with a written word for “brain.” The Greek philosopher

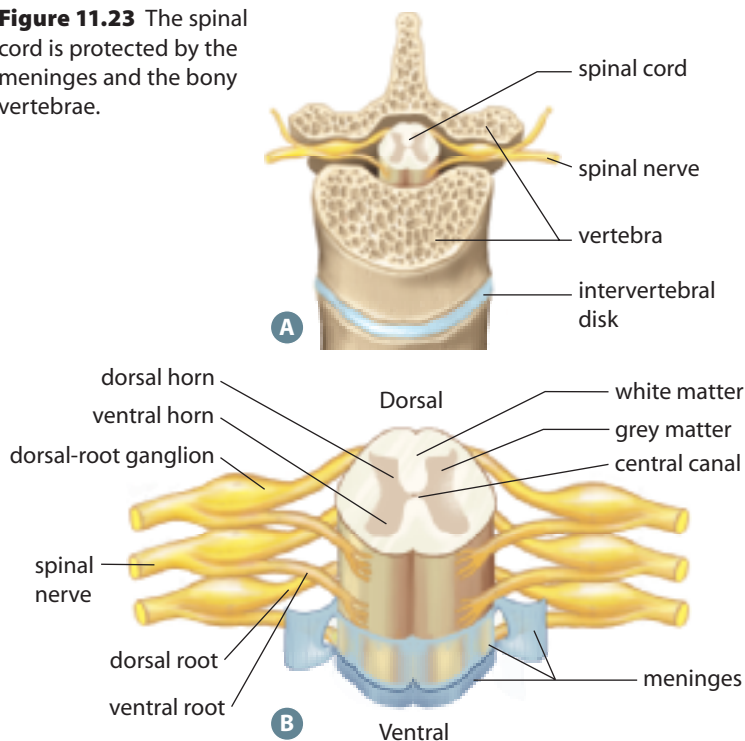
Aristotle (384–322 B.C.E.) knew that directly touching the brain did not cause any sensation to the owner. Like many other anatomists through the centuries, Aristotle concluded that the heart must therefore be in control of human intelligence, sensations, and body functions.

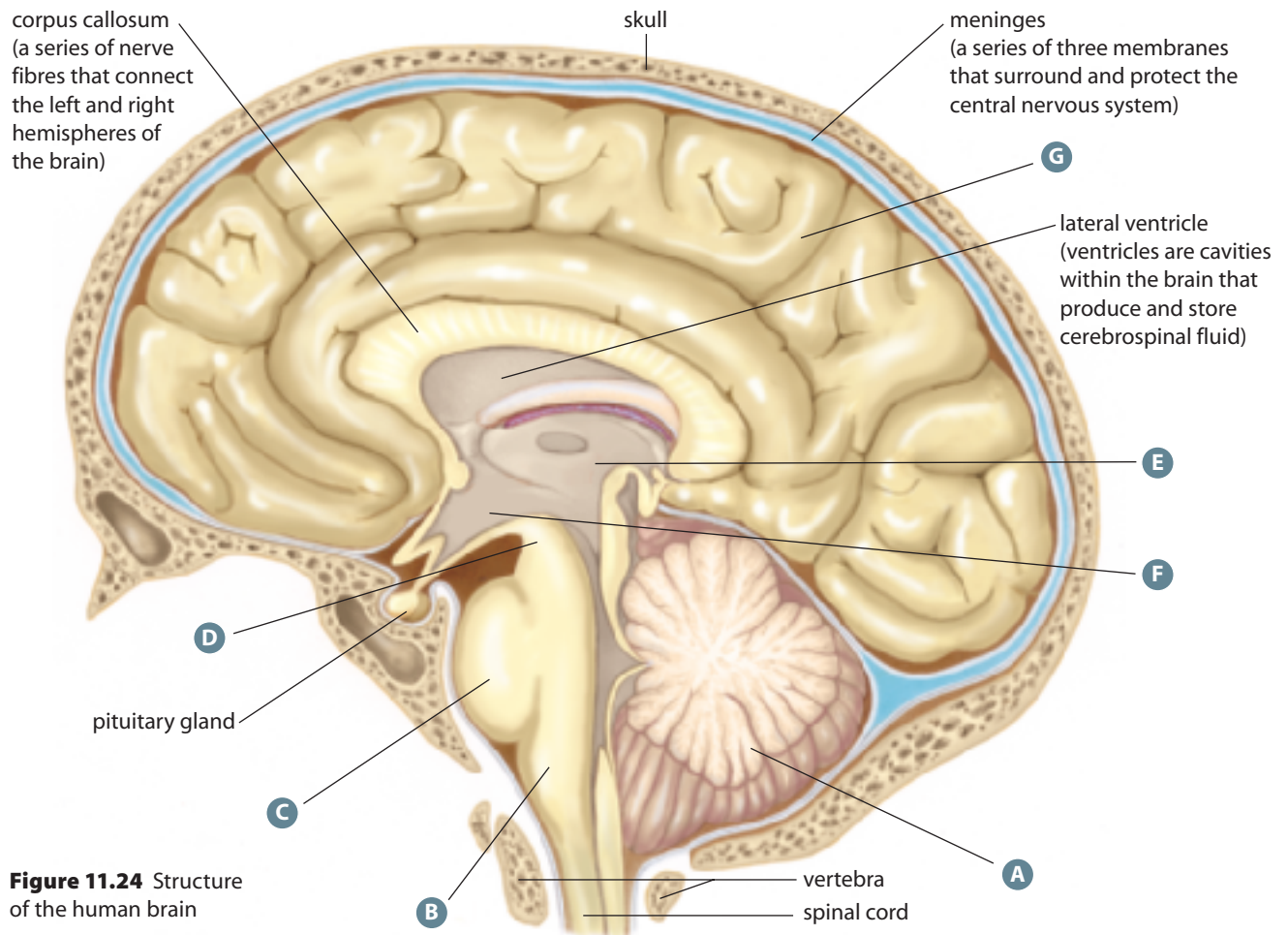
It has only been in the last two centuries that researchers have begun to unravel the intricate workings of the human brain. Scientists have discovered the brain’s central role in maintaining homeostasis and have identified the brain as the centre for intelligence, consciousness, and emotion. Yet, in many ways, researchers are just beginning to understand the relationship between the brain’s structures and functions. Despite its relatively small size, scientists estimate that there are more neurons in the human brain than stars in the Milky Way Galaxy.

As shown in Figure 11.24, the brain can be subdivided into three general regions: the hindbrain, the midbrain, and the forebrain.

Despite its central importance, the brain is fragile and has a gelatin-like consistency. The skull, however, forms a protective bony armour around the brain. In addition, the **meninges**, three layers of tough, elastic tissue within the skull and spinal column, directly enclose the brain and spinal cord (Figure 11.25 on page 388). One way to visualize the brain, meninges, and skull is to think of a peanut, wrapped in its red skin, and inside its shell.

**Figure 11.23** The spinal cord is protected by the meninges and the bony vertebrae.





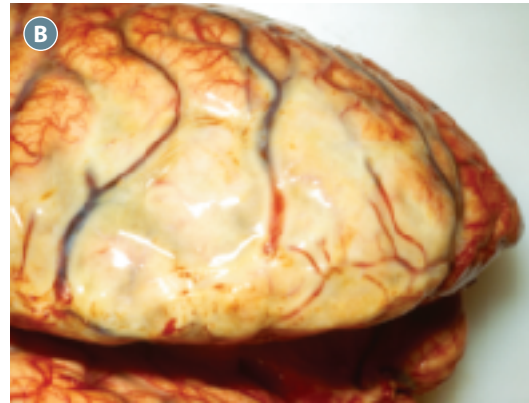
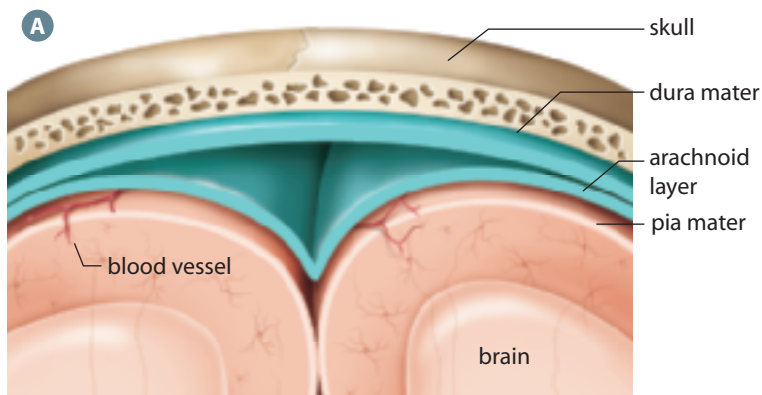
**Figure 11.24** Structure of the human brain

## HINDBRAIN

- A** The **cerebellum** is a walnut-shaped structure located below (inferior to) and largely behind (posterior to) the cerebrum, described below. The word *cerebellum* comes from the Latin word for “little brain.” This part of the brain is involved in the unconscious coordination of posture, reflexes, and body movements, as well as fine, voluntary motor skills, such as those used to hit a tennis ball, ride a bicycle, or write. The cerebellum receives information from specialized sensors, called proprioceptors, located within skeletal muscles and joints.
- B** The **medulla oblongata** sits at the base of the brainstem, where it connects the brain with the spinal cord. The medulla oblongata contains centres that control automatic, involuntary responses, such as heart rate, constriction or dilation of blood vessels to control blood pressure, and the rate and depth of breathing, swallowing, and coughing.
- C** The **pons** is found above (superior to) and in front of (anterior to) the medulla oblongata in the brainstem. The pons serves as a relay centre between the neurons of the right and left halves of the cerebrum, the cerebellum, and the rest of the brain.
- D** The **MIDBRAIN** is found above the pons in the brainstem. It relays visual and auditory information between areas of the hindbrain and forebrain. As well, it plays an important role in eye movement and control of skeletal muscles.

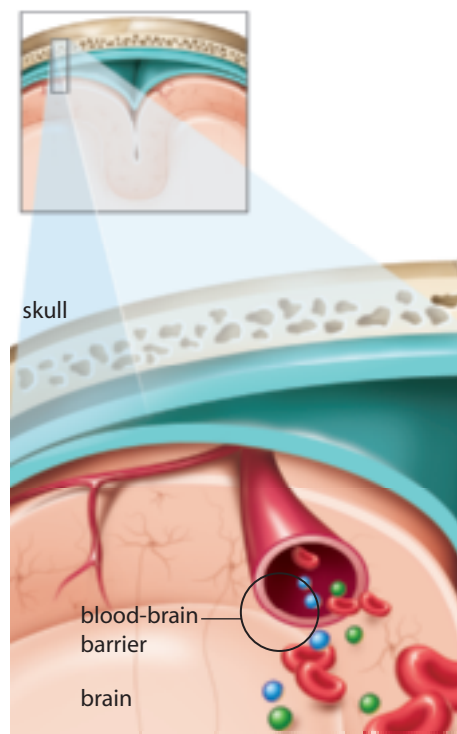
## FOREBRAIN

- E** The **thalamus** sits at the base of the forebrain. It consists of neurons that provide connections between various parts of the brain. These connections are mainly between the forebrain and hindbrain, and between areas of the sensory system (except for the sense of smell) and cerebellum. The thalamus is often referred to as “the great relay station of the brain.”
- F** The **hypothalamus**, which lies just below the thalamus, helps to regulate the body’s internal environment, as well as certain aspects of behaviour. The hypothalamus contains neurons that control blood pressure, heart rate, body temperature, and basic drives (such as thirst and hunger) and emotions (such as fear, rage, and pleasure). Brain damage or a tumour that affects the hypothalamus can cause a person to display unusual, even violent behaviour. The hypothalamus is also a major link between the nervous and endocrine (hormone) systems (which you will study in Chapter 13). The hypothalamus coordinates the actions of the pituitary gland, by producing and regulating the release of certain hormones.
- G** The **cerebrum** is the largest part of the brain and accounts for more than four fifths of the total weight of the brain. The cerebrum is divided into right and left cerebral hemispheres, which contain the centres for intellect, memory, consciousness, and language; it interprets and controls the response to sensory information.



**Figure 11.25** (A) Three layers of tissue, called the meninges, surround and protect the brain and spinal cord. (B) The dark brown-yellow patches on the meninges reveal a meningitis infection. Meningitis, or inflammation of the meninges, is caused by a bacterial or viral infection that can spread to underlying brain tissue. Meningitis can be life threatening and is diagnosed by examining a sample of the fluid surrounding the brain and spinal cord.

The meninges protect the central nervous system by preventing the direct circulation of blood through the cells of the brain and spinal cord. This separation of the blood and central nervous system is called the **blood-brain barrier** (Figure 11.26). Scientists discovered this barrier when they injected blue dye into the bloodstream of an animal and all the body tissues turned blue except for the brain and spinal cord. The brain, however, requires a constant supply of nutrients and oxygen. In fact, the brain, which



**Figure 11.26** The blood-brain barrier. Only certain substances can pass through the tight seal formed by the blood-brain barrier.

comprises only 2 percent of the body's total weight, uses at least 20 percent of the body's oxygen and energy supplies. If the oxygen supply to the brain is disrupted for even a few minutes, massive damage can occur in the brain. For example, a stroke occurs when arteries that supply the brain with blood are blocked.

The blood-brain barrier both protects the brain and supplies the brain with nutrients and oxygen. The blood capillaries that lead to the brain are made up of tightly fused epithelial cells. Thus, the capillary walls form a barrier that blocks many toxins and infectious agents. Some substances, such as glucose and oxygen, can still pass through the barrier by special transport mechanisms. Other, lipid-soluble substances, are able to pass directly through the lipid bilayer of the cell membrane. This is why caffeine, nicotine, alcohol, heroin, and other lipid-soluble substances have such rapid effects on brain function. Why might researchers have difficulty treating neurological disorders with drugs that are not lipid soluble?

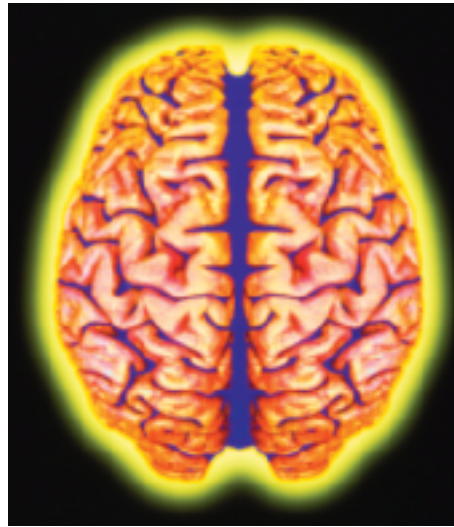
Circulating throughout the spaces, or ventricles, within the brain and spinal cord is the **cerebrospinal fluid**. The total volume of cerebrospinal fluid in an adult human is about 150 mL at any one time. The fluid is replaced about four times each day, and the total amount of fluid

produced each day is about 500 mL. The cerebrospinal fluid transports hormones, white blood cells, and nutrients across the blood-brain barrier for cells of the brain and spinal cord. It also circulates between two layers of the meninges, the arachnoid and pia mater, and therefore acts as a shock absorber to cushion the brain.

- 19 Identify the main structures of the central nervous system, and describe its general functions.
- 20 Explain how the blood-brain barrier and the cerebrospinal fluid protect the brain and spinal cord.
- 21 Identify five homeostatic functions of the brain.
- 22 Identify the major structures in the hindbrain, midbrain, and forebrain, and the functions of these structures.

## The Structure and Function of the Cerebrum

Each half of the cerebrum consists of an internal mass of white matter and a thin, outer covering of grey matter, called the **cerebral cortex**. Compared to a falcon with its keen eyesight or a dog with its sense of smell, humans lack many sensory capabilities. Due to the evolution of the cerebral cortex, however, humans are considered to have the most sophisticated intellect and behaviour of all animals. The cerebral cortex is responsible for language, memory, personality, vision, conscious thought, and other activities that are associated with thinking and feeling. The cerebral cortex is about 5 mm thick and, as shown in Figure 11.27, is highly convoluted. This allows it to fit a high concentration of grey matter within the confines of the skull. Relative to a smooth surface, the convolutions and fissures greatly increase the surface area, so that the cerebral cortex covers about 0.5 m<sup>2</sup>, or about the area of an open newspaper.



**Figure 11.27** The human cerebrum. What are the functions of the right and left sides? Why are there so many folds along the surface of the cerebrum?

The right and left halves of the cerebrum are called the cerebral hemispheres. They are linked by a bundle of white matter called the **corpus callosum**. The corpus callosum sends messages from one cerebral hemisphere to the other, telling each half of the brain what the other half is doing. Surgical isolation of the hemispheres is sometimes used to treat epilepsy, a condition that causes uncontrollable seizures. Scientists think that epilepsy can be caused by an overload of neurological electrical activities, so the corpus callosum is cut to prevent the spread of the epileptic seizures from one hemisphere to the other.

Research indicates that, while every cognitive function contains right-brain and left-brain components, some functions seem to have a dominant hemisphere. In general, the right-brain, or right cerebral hemisphere, is associated with holistic and intuitive thinking, visual-spatial skills, and artistic abilities. The left-brain, or left cerebral hemisphere, is linked to segmental, sequential, and logical ways of thinking, and to linguistic and mathematical skills. This is why people who are right-brain dominant process and learn information differently from people who are left-

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### Try This

Take two eggs and two plastic containers that are just large enough to contain the eggs. Fill one of the containers with water, and place one egg inside. Put the other egg in the other container, without water. Tightly close the lid of each container, and shake the containers. Which egg broke? How does this model demonstrate the function of the cerebrospinal fluid?

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### FYI

In the 1800s, several scientists promoted the common misconception that humans use only 10 percent of their brains. Researchers now know that the destruction of even small areas of the brain can have devastating effects on behaviour and physiology. On the other hand, sometimes a different part of the brain is able to compensate for, or take over, the functions of the injured part. This can occur when someone has a stroke that damages the parts of the brain that are predominantly involved in speech. Other, usually less active parts may take over the speech functions.

<b>YELLOW</b>	<b>BLUE</b>	<b>ORANGE</b>
<b>BLACK</b>	<b>RED</b>	<b>GREEN</b>
<b>PURPLE</b>	<b>YELLOW</b>	<b>RED</b>
<b>ORANGE</b>	<b>GREEN</b>	<b>BLACK</b>
<b>BLUE</b>	<b>RED</b>	<b>PURPLE</b>
<b>GREEN</b>	<b>BLUE</b>	<b>ORANGE</b>

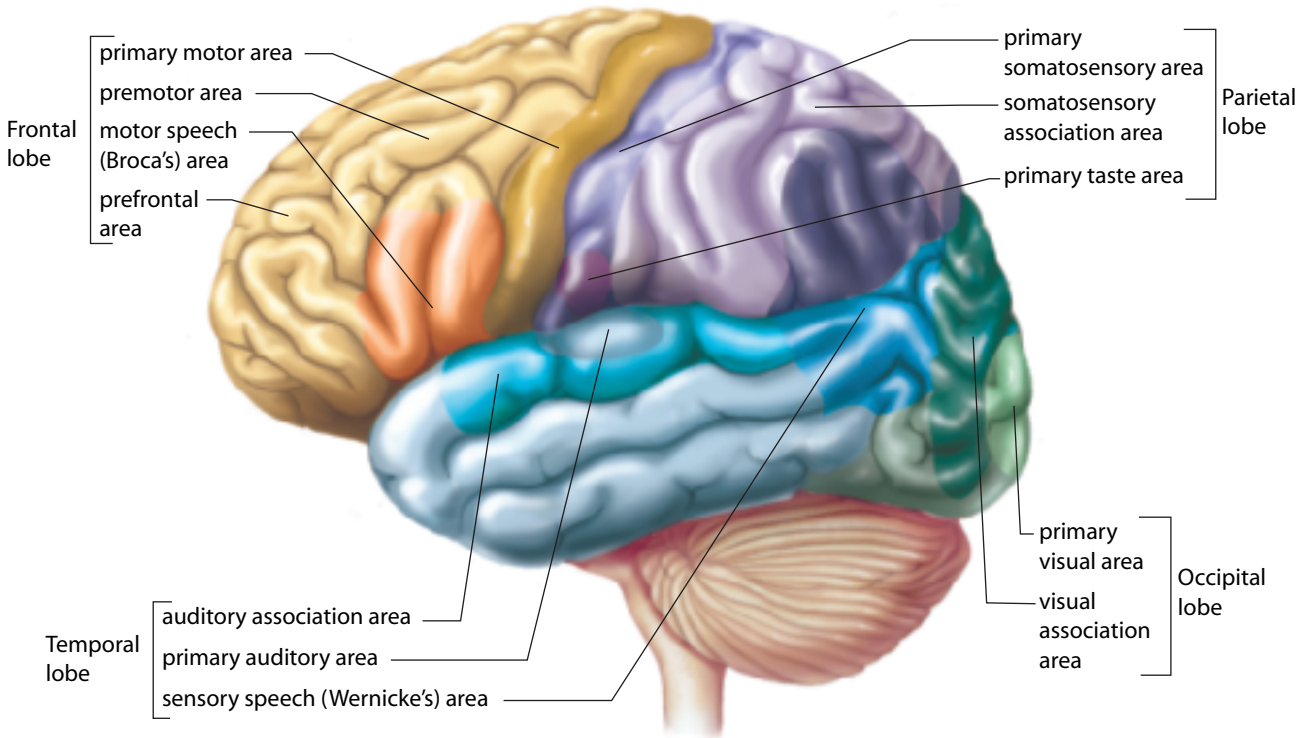
**Figure 11.28** The Stroop effect. The right brain identifies the colour, while the left brain insists on reading the word.

brain dominant. One way to illustrate the difference between right-brain and left-brain processing is the Stroop effect. Try to say the actual colours shown in Figure 11.28, rather than the words themselves. This is difficult because, as one theory suggests, one side of the brain may dominate in word recognition, while the other side may dominate in colour recognition. In other words, this leads to a right-left brain conflict!

**The Cerebral Cortex Consists of Four Pairs of Functional Lobes**

Figure 11.29 shows the division of each hemisphere of the cerebral cortex into four pairs of lobes. Each pair of lobes is associated with a different function.

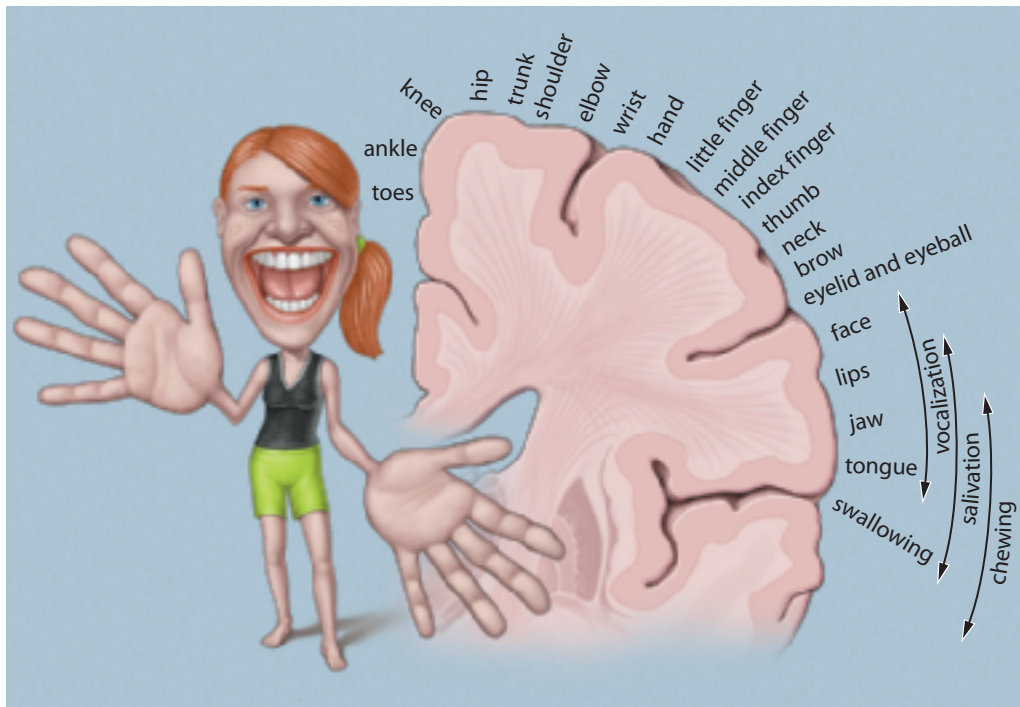
**Figure 11.29** The cerebral cortex is divided into four pairs of lobes: frontal, temporal, parietal, and occipital.



The **occipital lobes** receive and analyze visual information. If the occipital lobes are stimulated by surgery or trauma, the individual will see light. The occipital lobes are also needed for recognition of what is being seen. Damage to the occipital lobes can result in a person being able to see objects, but not able to recognize them.

The **temporal lobes** share in the processing of visual information, although their main function is auditory reception. These lobes are also linked to understanding speech and retrieving visual and verbal memories.

The **parietal lobes** receive and process sensory information from the skin. The primary sensory areas extend in a band from the right to left side of the cerebrum. The proportion of a parietal lobe devoted to a particular part of the body is related to the importance of sensory information for this part of the body. The highest concentrations of sensory receptors occur in the face, hands, and genitals, making these areas of the body highly sensitive. The parietal lobes also help to process information about the body's position and orientation.



**Figure 11.30** Based on this map of the motor cortex, which areas of the body have the greatest muscle control?

The **frontal lobes** are named for their location at the front of the cerebrum. This is the part of the head that some people may hit in jest with the palm of their hand when they finally remember something! The frontal lobes integrate information from other parts of the brain and control reasoning, critical thinking, memory, and personality. The Broca's area of the frontal lobes is associated with language use.

The frontal lobes also contain motor areas that control various aspects of precise, voluntary motor movement, such as playing a piano. Figure 11.29 identified the primary motor area in the frontal lobes of the cerebrum. Similar to the sensory areas in the parietal lobes, the proportion of motor area in the frontal lobes devoted to a particular part of the body correlates with the degree of complexity of movement that body structure can make. The stylized illustration in Figure 11.30 shows the disproportionate size of certain areas of the brain in relation to the amount of motor area devoted to them. The nerves leading from the right and left frontal lobes cross over in the brainstem, so that

each side of the brain controls muscles on the opposite side of the body.

Table 11.3 summarizes the functions of the principal structures in the brain.

**Table 11.3** Major Structures and Functions of the Human Brain

Structure	Major functions
<b>Hindbrain</b>	
cerebellum	controls muscle coordination and balance
medulla oblongata	controls subconscious activities, such as heart rate, blood pressure, breathing, swallowing, and vomiting
pons	relays information between the cerebellum and cerebral cortex
<b>Midbrain</b>	receives specific sensory input; connects the hindbrain to the forebrain
<b>Forebrain</b>	
thalamus	connects various parts of the brain; relays information from the senses
hypothalamus	regulates the pituitary gland, heart rate, blood pressure, and temperature; controls drives such as hunger, thirst, and sexual desire
<i>Cerebrum</i>	
frontal lobes	associated with conscious thought, intelligence, memory, and personality; control voluntary muscle movements
temporal lobes	involved in auditory reception
parietal lobes	receive sensory information from the skin, and process information about body position
occipital lobes	process visual information
corpus callosum	connects the right and left cerebral hemispheres through nerve tracts



## BiologyFile

### Try This

While sitting at your desk, lift your right foot off the floor and make clockwise circles. While doing this, draw the number 6 in the air with your right hand. Your foot should change direction! Why does this happen?

## Broca's Area and Wernicke's Area

The process of speech involves several areas of the cerebrum. Two important areas are on the left side of the cerebral cortex: **Broca's area** and **Wernicke's area** (see Figure 11.29). Broca's area coordinates the muscles for speaking and translates thought into speech. Damage to this area results in an inability to speak. It does not, however, affect the understanding of language. Wernicke's area stores the information involved in language comprehension. The ability to utter words is not affected if this area is damaged, but the words make little sense.

- 23 Identify the four lobes of the cerebrum, and describe the function of each.
- 24 Describe the primary areas of the brain that are responsible for the fine motor control of the muscles, as well as the area that processes sensory information from the skin.
- 25 Compare the locations and functions of Broca's area and Wernicke's area in the brain.

## Mapping Brain Functions

Scientists first learned about brain functions by studying the brains of people with brain injuries or diseases. For example, injured soldiers would sometimes have damage to certain areas of the brain, but still survive. Researchers could then link the injured area of the brain to loss of functions in other areas of the body. In 1848, an accidental explosion at a railway site drove a metal bar through the frontal lobes of railway worker, Phineas Gage (Figure 11.31). Although he survived the accident, he experienced a type of personality change that scientists have now come to associate with frontal lobe injuries. Once considered reasonable and conscientious, Phineas

Gage was described after the accident as “thoughtless, irresponsible, and fitful.”

Because the brain itself does not contain any pain receptors, neurosurgeons are able to probe areas of the brain while people are conscious. This provides useful feedback about the functions of different areas of the brain. Canadian Nobel prize recipient Wilder Penfield (1891–1976) contributed greatly to our knowledge of the sensory and motor areas of the brain. Penfield, who operated on people with epilepsy, applied electric currents to the surface of their brains in order to find the problem areas. Since the people were awake during the operations, they could tell Penfield what they were experiencing. Probing different areas triggered different sensations and body movements. From this information, Penfield was able to map the sensory and motor areas of the cerebral cortex. As well, Penfield probed certain areas of the cerebral cortex that triggered whole memory sequences. For one person, Penfield triggered a familiar song that sounded so clear the person thought it was being played in the operating room. When Penfield stopped stimulating this area of the brain, the music ceased immediately.

## Imaging Techniques Used to Study the Brain

Modern imaging techniques provide non-invasive ways for researchers to

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### Web Link

Anatomy students often use computer simulations to complete animal dissections. You can try out a virtual sheep brain dissection online. What are some benefits and drawbacks to using virtual dissections for learning?

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WWW

As Phineas P. Gage, a foreman on the railroad in Cavendish, was yesterday engaged in tamping for a blast, the powder exploded, carrying an iron instrument through his head an inch and a fourth in circumference, and three feet and eight inches in length, which he was using at the time. The iron entered on the side of his face, shattering the upper jaw, and passing back of the left eye, and out at the top of the head.

The most singular circumstance connected with this melancholy affair is, that he was alive at two o'clock this afternoon, and in full possession of his reason, and free from pain.

**Figure 11.31** The news report of Phineas Gage's accident first appeared in the *Free Soil Union* (Ludlow, Vermont) on September 14, 1848.

## Target Skills

Observing and identifying the principal features of a mammalian brain using dissections or other means

Compiling and displaying data in appropriate forms

Working cooperatively as a team to investigate a neurological disorder

## The Brain

The proportions of the areas of the brain differ in different mammals, but the basic locations of the functional areas are similar. In this investigation, you will use models, photographs, and a mammalian brain to learn about the principal structural areas of the brain and their functions. As an alternative to doing the dissection, the photographs in this investigation, or a video or web dissection, could be used.

### Question

What are the principal structures of the brain, and what are their functions?



### Safety Precautions

- Use caution when handling sharp instruments.
- Wash your hands well when finished the dissection.
- Disinfect the equipment and area when finished.

### Materials

- preserved sheep brain
- dissection tray
- paper towel
- dissection kit
- 10 percent bleach solution (to clean the dissection tray)

### Part 1: Lateral View—Whole Brain

#### Procedure

1. Obtain a sheep brain from your teacher. Follow your teacher's instructions for rinsing the brain. Then place the brain in the dissection tray.
2. Examine photograph A, showing a lateral view of the sheep brain. Identify the frontal, parietal, temporal, and occipital lobes of the cerebrum.



**A** Lateral view—whole brain

3. If possible, examine the outer surface (dura mater) of the brain. Notice the convolutions and fissures on the outer surface. Also notice that the cerebrum is divided into a right side and a left side.
4. Sketch and label the outer surface of the brain.

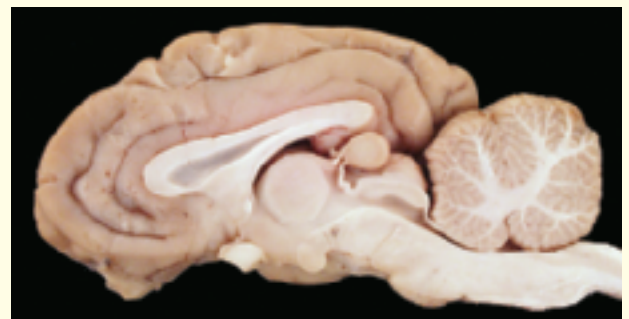
### Analysis

1. Make a table to record the functions of the structures you labelled in your diagram.
2. In humans, the left and right cerebral hemispheres of the brain are associated with different dominant functions. Describe these differences.

### Part 2: Lateral View—Cross-Section

#### Procedure

1. Examine photograph B, showing a cross-section of the sheep brain.
2. Make a gentle incision through the corpus callosum of the sheep brain to separate the right and left hemispheres. Then separate the rest of the brain by cutting through the centre of the mid and hind parts.
3. Using photograph B as a guide, identify, sketch, and label the following structures: spinal cord, cerebellum, medulla oblongata, pons, midbrain, thalamus, hypothalamus, pituitary gland, corpus callosum, and cerebrum. Try to identify the small olfactory bulbs (connected to smell receptors) on the underside of the frontal lobes, as well.



**B** Lateral view—cross-section

*continued on next page*

4. Follow your teacher's instructions to dispose of the sheep brain and wash the dissecting tray.

### Analysis

1. Examine your diagram of the cross-section of the dissected brain. Make a table to record the functions of the structures you labelled in your diagram.

### Conclusion

2. Compare the sheep brain with the human brain shown in Figure 11.29. What similarities and differences can you identify?

### Extension

3. With a partner, build a model of the human brain and present it to the class. Include all the key structures and functions on your model.

see inside an active, human brain. Fundamental discoveries in physics have led to the development of positron-emission tomography (PET) and magnetic resonance imaging (MRI). These two techniques allow researchers to study the brain and help physicians diagnose brain diseases.

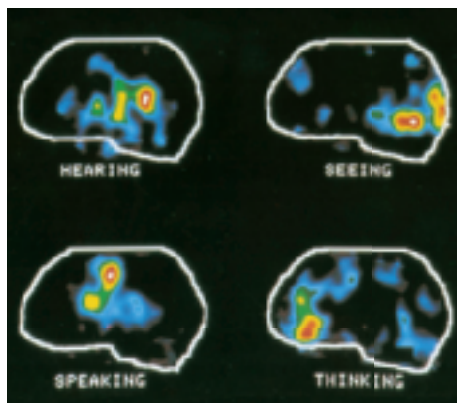
PET is based on the fact that more active areas of the brain have higher energy demands. A person receives an injection of radioactively-labelled glucose, and a scanner monitors glucose consumption in the person's brain. Different colours represent different activity levels in the brain (Figure 11.32). A PET scan can be used to diagnose conditions such as a stroke or Alzheimer's disease, in which the deterioration of the brain leads to memory loss and confusion, and eventual lack of conscious movement.

MRI can produce very clear and detailed images of brain structure (Figure 11.33). A giant magnet surrounds the person's head, and changes in the direction of the magnetic field induce hydrogen atoms in the brain to emit

radio signals. These signals can then be detected, translated, and displayed as a structural or functional image. MRI can also be used to identify various brain disorders, such as brain tumours. Figure 11.33 also shows an MRI image of a human brain affected by Creutzfeldt-Jakob disease. This disease, like BSE, destroys the brain tissue, making it sponge-like.

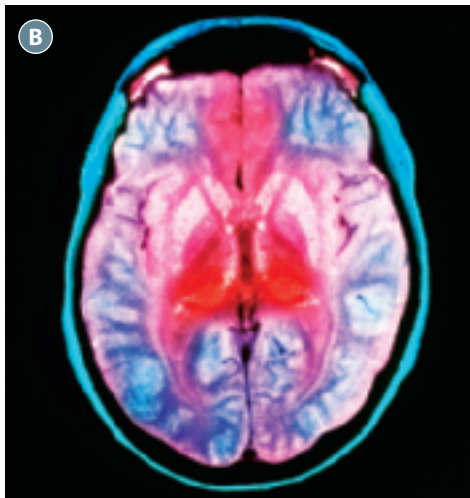
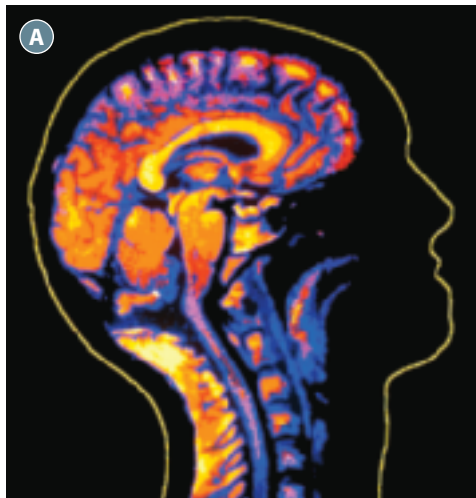
- 26 Describe how early researchers studied brain structure and function.
- 27 Compare the technologies of MRI and PET for studying the brain.

**Figure 11.32** This PET scan shows a cross section of the cerebrum, revealing the activity levels in different areas when the brain is performing certain tasks. Red, orange, and yellow indicate areas of high, medium, and low activity, respectively. What lobes of the cerebral cortex are active in the brain shown here?



## Section 11.2 Summary

- The regulation centre for the nervous system is the central nervous system, which consists of the brain and spinal cord.
- The brain and spinal cord are protected by the cerebrospinal fluid, the meninges, and the skull and spinal column (vertebrae).
- The brain and spinal cord themselves are composed of myelinated neurons (white matter) and unmyelinated neurons (grey matter).
- The hindbrain is composed of the cerebellum (involved in controlling body movements), medulla oblongata (controls many involuntary responses), and pons (relay station between different parts of brain).
- The midbrain is a part of the brain stem.



**Figure 11.33** (A) A detailed magnetic resonance imaging (MRI) of a healthy brain (B) An MRI image of the brain of a person with Creutzfeldt-Jakob's disease. The affected areas are shown at the centre in red. People with Creutzfeldt-Jakob's disease experience memory loss, emotional instability (including inappropriate outbursts), and unsteadiness. These symptoms progress to marked weakness, dementia, and death, often within a year of the onset of the symptoms.

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### Web Link

Research a disorder of the brain, such as Alzheimer's disease or Parkinson's disease. Identify the specific area of the brain that is affected, and describe the resulting loss of function. Include current research findings and the prognosis for people who have these disorders.

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WWW

- The forebrain includes the thalamus and hypothalamus, involved in sensing the external and internal environment, as well as the cerebrum.
- The outer layer of the cerebrum, called the cerebral cortex, is composed of grey matter, and is thought to be the source of human intellect.
- The right and left halves of the cerebral cortex are made of four pairs of lobes,

each of which is associated with particular functions: frontal lobes (conscious thought and movements, speech), parietal lobes (touch, taste), temporal lobes (hearing and speech), and occipital lobes (vision).

- MRI and PET scans are non-invasive tools that can be used to map human brain function and screen for diseases.

## Section 11.2 Review

1. Explain why the brain has elevated requirements for nutrients and oxygen.
2. Describe the three main tissues that support and protect the central nervous system.
3. Explain why a physician takes a sample of cerebrospinal fluid to determine if a person has meningitis.
4. The letters on the diagram indicate possible areas of brain damage. In table format, list the possible areas of brain damage (A to G), and describe the functional problems that might result from damage in each area.
5. Use graphics software to sketch the cerebral cortex. Use it to identify the lobe that would be stimulated in each situation, and explain why. **ICT**
  - a) Seeing this question.
  - b) Thinking about this question.
  - c) Hearing this question read to you by someone else.
  - d) Reading this question to someone else.
  - e) Reading this question using Braille.
6. A stroke has caused damage to certain areas of a person's brain. Upon examination, a doctor notices that the person has difficulty understanding speech and the left side of the body is paralyzed. Identify the specific areas of the brain that are damaged, and explain how this damage might cause the symptoms.
7. Explain how MRI and PET scans can be used to improve our understanding of human brain function.



## SECTION 11.3

# The Peripheral Nervous System

### Section Outcomes

In this section, you will

- **identify** the principal components of the peripheral nervous system
- **explain** the role of the peripheral nervous system in regulating the somatic (voluntary) and autonomic (involuntary) systems
- **compare** the functions of the sympathetic division and the parasympathetic division of the autonomic nervous system

### Key Terms

somatic system  
autonomic system  
sympathetic nervous system  
norepinephrine  
parasympathetic nervous system



**Figure 11.34** The peripheral nervous system is essential for various activities, such as catching a football. What types of motor neurons might be activated in the football player shown here?

As the football player in Figure 11.34 lunges for the ball, sensory nerves enable him to see the ball, feel its texture, hear the roar of the crowd, and gather information about the positions of his muscles and joints. Motor nerves enable the player to maneuver the ball and break free from the defender, and they increase his heart and breathing rates. The peripheral nervous system consists of nerves that link the brain and spinal cord to the rest of the body, including the senses, muscles, glands, and internal organs. Sensory neurons carry information from all parts of the body to the central nervous system, and motor neurons carry information from the central nervous system to the effectors.

The two main divisions of the peripheral nervous systems are the somatic system and the autonomic system.

### The Somatic System

The **somatic system** is largely under voluntary control, and its neurons service the head, trunk, and limbs. Its sensory neurons carry information about the external environment inward, from the receptors in the skin, tendons, and skeletal muscles. Its motor neurons

carry information to the skeletal muscles. Your decision to turn this page in order to continue reading exemplifies the action of the somatic motor nerves.

The somatic system includes 12 pairs of cranial nerves and 31 pairs of spinal nerves, all of which are myelinated. The cranial nerves are largely associated with functions in the head, neck, and face. An exception is the vagus nerve, which connects to many internal organs, including the heart, lung, bronchi, digestive tract, liver, and pancreas.

Figure 11.35 shows the basic divisions of the spinal nerves that emerge from each side of the spinal cord. Each spinal nerve contains both sensory and motor neurons, which service the area of the body where they are found. For example, thoracic nerves control the muscles of the rib cage.

28 What are the major structures involved in the somatic system?

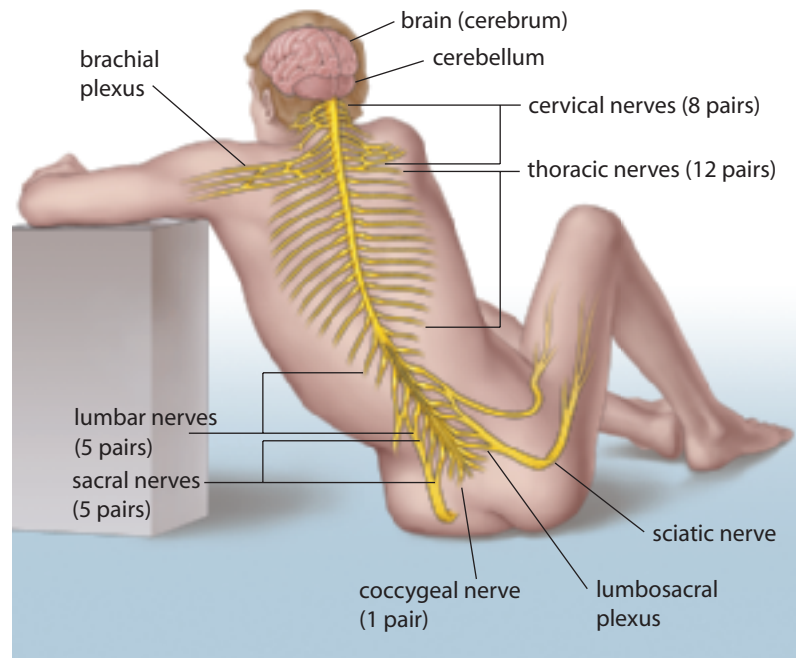
29 What role does the somatic system play in the functioning of the body?

## The Autonomic System

Imagine yourself in a stressful situation. Which systems of your body might be heightened? Which systems might be suppressed? How would these systems return to their initial states? Your internal reactions to the situation would be controlled by a division of the peripheral nervous system, called the **autonomic system**. In contrast to the somatic system, the autonomic system is under automatic, or *involuntary* control. Its nerves either stimulate or inhibit the glands or the cardiac or smooth muscle. The autonomic system maintains homeostasis by adjusting the body to variations in the external and internal environments.

The hypothalamus and medulla oblongata control the autonomic system, which has neurons that are bundled together with somatic system neurons in the cranial and spinal nerves. The sympathetic and parasympathetic divisions of the autonomic system carry information to the effectors. In general, these two divisions have opposing functions (Figure 11.36 on page 398).

The **sympathetic nervous system** is typically activated in stressful situations and is often referred to as the *fight-or-flight* response. The sympathetic neurons release a neurotransmitter called **norepinephrine**, which has an excitatory effect on its target muscles. As well, the sympathetic nerves trigger the adrenal glands to release epinephrine and norepinephrine, both of which also function as hormones that activate the stress response. At the same time, the sympathetic nervous system inhibits some areas of the body. For example, in order to run from danger, the skeletal muscles need a boost of energy. Therefore, blood pressure increases and the heart beats faster, while digestion slows down and the sphincter controlling the bladder constricts. Some of these physiological changes in response to stress are detectable by lie detectors, or polygraphs. Polygraphs monitor changes in heart rate, blood pressure, breathing rate, and



**Figure 11.35** The spinal nerves are named for the region of the body where they are located: cervical, thoracic, lumbar, and sacral.

the sweatiness of palms, all of which tend to increase if someone is telling a lie (Figure 11.37 on page 399).

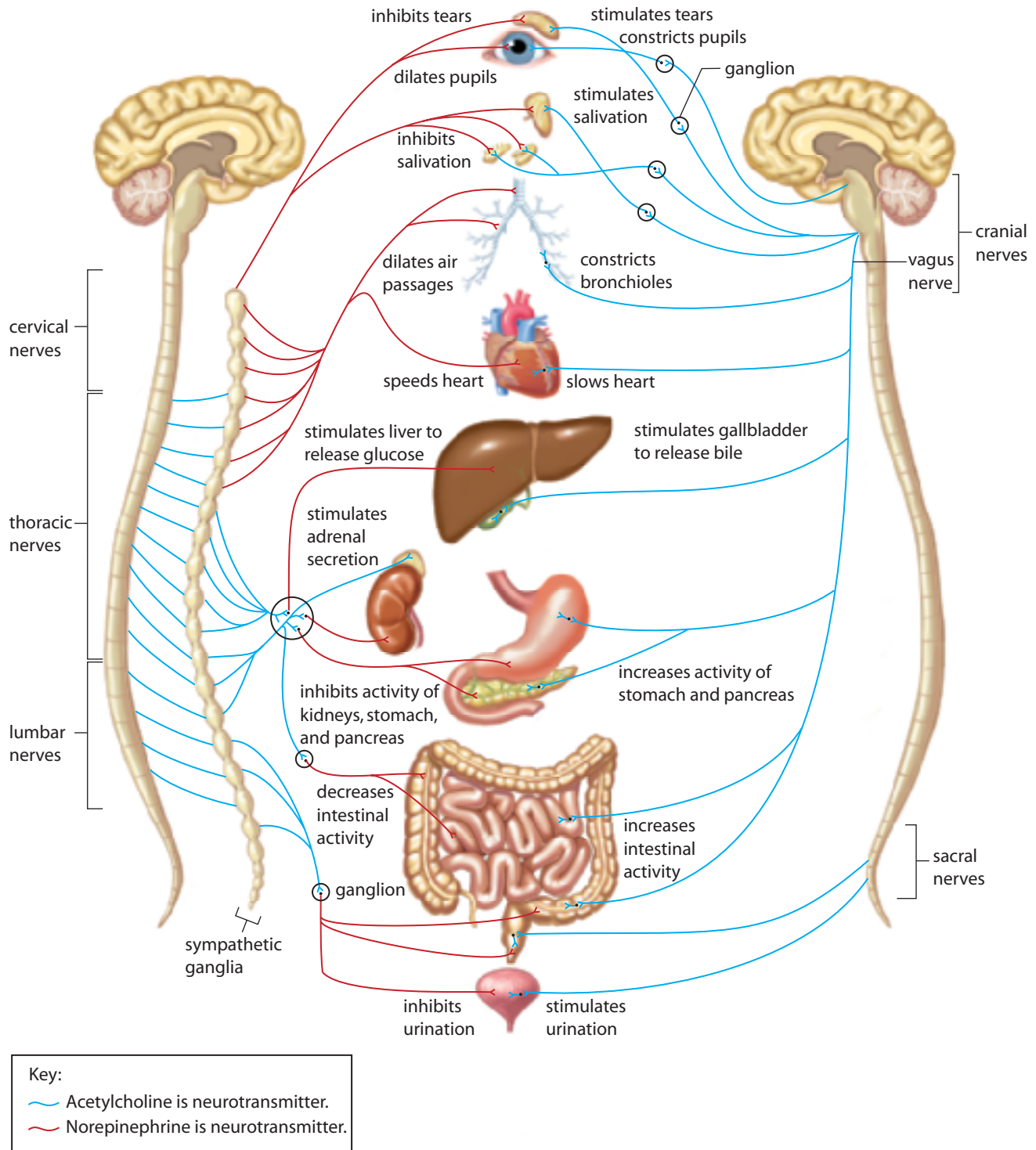
The **parasympathetic nervous system** is activated when the body is calm and at rest. It acts to restore and conserve energy. Sometimes referred to as the *rest-and-digest* response, the parasympathetic nervous system slows the heart rate, reduces the blood pressure, promotes the digestion of food, and stimulates the reproductive organs by dilating blood vessels to the genitals. The parasympathetic system uses a neurotransmitter called acetylcholine to control organ responses.

The two branches of the autonomic system are much like the gas pedal and brake pedal of a car. At a given instant, high levels of sympathetic stimulation might cause the heart to beat faster, while parasympathetic signals would counter this effect and bring the heart rate back down. Depending on the situation and organs involved, the sympathetic and parasympathetic systems work in opposition to each other in order to maintain homeostasis.

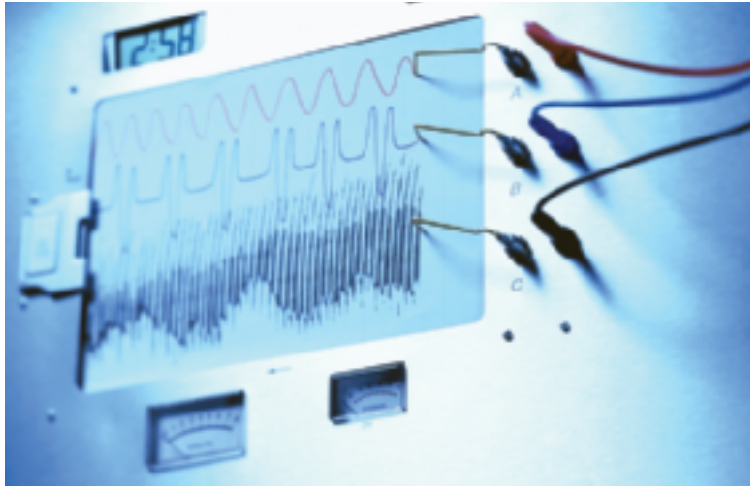
Certain drugs can act as either stimulants or depressants by directly affecting the sympathetic and parasympathetic nervous systems.

**Sympathetic division**

**Parasympathetic division**



**Figure 11.36** The structure and function of the autonomic system: Both the sympathetic and parasympathetic nervous systems regulate the same organs, but with opposing effects.



**Figure 11.37** A polygraph. It can detect some of the physiological changes caused by the sympathetic nervous system when placed in a stressful situation. A racing heart and sweaty palms can be caused by many different factors, however, which is why polygraphs are not totally reliable.

Caffeine, for example, is a commonly used stimulant that causes the sympathetic nervous system to increase the heart rate and blood pressure.

- 30 What type of motor neurons are involved in the autonomic nervous system?
- 31 What generally triggers the sympathetic nervous system, and what are its effects on the body?
- 32 What generally triggers the parasympathetic nervous system, and what are its effects on the body?

### Section 11.3 Summary

- The peripheral nervous system contains components that gather sensory information and then relay this information to the muscles and glands for a voluntary (somatic) or involuntary (autonomic) response.
- Homeostasis is maintained in the body by the often-antagonistic actions of the sympathetic and parasympathetic nervous systems.
- In general, the sympathetic nervous system prepares the body for fight-or-flight, while the parasympathetic system returns the organs to a resting state.

### Section 11.3 Review

1. Compare the general functions of the central nervous system with the functions of the peripheral nervous system.
2. Identify which division of the peripheral nervous system is under voluntary control and which division is under involuntary control. Compare the functions of these two divisions.
3. Imagine that you are hiking in the mountains one afternoon with friends. As you turn a corner, you come across a mother bear and her cubs standing in the middle of the trail.
  - a) Identify the specific division of the nervous system that is responsible for the body's response to this situation.
  - b) Describe at least six physiological responses you might have upon seeing the bears.
  - c) Indicate the division of the nervous system that is responsible for returning the body back to equilibrium after the event is over.
4. Use word processing software to construct a three-column table. Use the following headings: Body structures, Sympathetic stimulation effect, and Parasympathetic stimulation effect. In the first column, list these structures: eyes, salivary glands, bronchioles, heart, liver, adrenal glands, kidneys, stomach, pancreas, intestines, and bladder. Then complete the rest of the table. **ICT**
5. Compare how stimulants and depressants affect the nervous system. Name a common stimulant.



## Neurological Disorders

Humans are not the only members of the animal kingdom that can become victims of neurological and neuromuscular disorders. Symptoms may include seizures, limb weakness or paralysis, balance disorders, vision problems, head, neck or back pain, and swallowing difficulties. Increasing numbers of veterinary practices are dedicated solely to the diagnosis and treatment of neurological disorders. Our love and respect for pets and working and farm animals has spawned a growing industry devoted to implementing unique solutions for specific species and breeds.



### Unique Solutions

Custom wheelchairs for pets were first manufactured about thirty years ago. They were crude and unwieldy, unlike today's streamlined designs that use aluminium tubing, lightweight plastic, neoprene supports, and light pneumatic wheels. 'Doggon' Wheels' has made wheelchairs for pets who are less than a kg to over 100 kg, including cats, rabbits, goats, gerbils, rats, ferrets, pot-bellied pigs, lemurs, and opossums. The majority of pets readily accept the freedom a wheelchair provides. It usually takes only a few days for them to adjust. In addition to wheelchairs, many other devices help those disabled by neurological and neuromuscular disorders.

Harnesses, which fit under an animal and have handles on each end for owners to grasp, provide support for either its front, back end, or middle. Slings and life jackets are used as flotation devices for aqua therapy rehabilitation and for building leg strength. Ramps greatly assist disabled animals in going up or down stairs, getting onto furniture, or into vehicles.

Some potential causes of limb weakness/paralysis include:

- spinal cord diseases (e.g. herniated intervertebral disks, tumours);
- peripheral nerve diseases (e.g. inflammation, degeneration); and
- neuromuscular diseases (e.g. muscle inflammation, metabolic or endocrine disorders).

Pain in the limbs may also be attributed to nerve root or peripheral nerve inflammation or tumours. Back and neck pain may be caused by:

- herniated disks,
- vertebral infections or tumours,
- fractured vertebra,
- arthritis, and/or
- neuritis (nerve root inflammation).

### Neuromuscular Diseases in Horses

Whether horses are used for work, racing performance, riding pleasure, or are simply running wild, effective movement defines their existence. At the Neuromuscular Disease Laboratory at the University of California-Davis Center for Equine Health, veterinarians study, define, and diagnose equine neuromuscular diseases, which have been poorly understood and in many cases not yet identified. The two most commonly diagnosed to date are cervical vertebral malformation and equine protozoal myeloencephalitis. The new Equine Performance Laboratory at UC Davis houses two motorized equine treadmills for evaluating performance problems and implementing new therapeutic approaches for treating them. These treadmills are among the most sophisticated in the world, allowing horses to run uphill, downhill, or on the level and reach racing speeds of over 60 km/h. Because therapeutic options cannot be considered until an accurate definition and diagnosis is made, this research is critical.

...

1. Hold a debate on the following topic: It is a waste of time and money to provide adaptive devices for pets, and working and farm animals when people around the world are in need of help.
2. How could research on neuromuscular diseases in horses provide insight into human health?
3. Neurological disorders can also lead to blindness and deafness. Research to find out what adaptive devices and strategies can be used to help blind or deaf pets.
4. Imagine your pet is unable to use its back legs because of a neurological disorder. Find out the cost of the various adaptive devices required for it to have a continued happy life.

The nervous system plays a key role in maintaining homeostasis in the body. The functional unit of the nervous system is the neuron. This cell is specialized to transmit neural information throughout the nervous system. Bundles of neurons are called nerves.

A neuron can generate a resting membrane potential, which establishes a positive ion charge outside and a negative charge inside the resting neuron. The potential is due to a difference in charge across the membrane. If a stimulus causes sufficient depolarization to reach the threshold potential of the membrane, then an action potential will be sent along the length of the axon in an all-or-none response. The neuron must repolarize before another impulse can be sent.

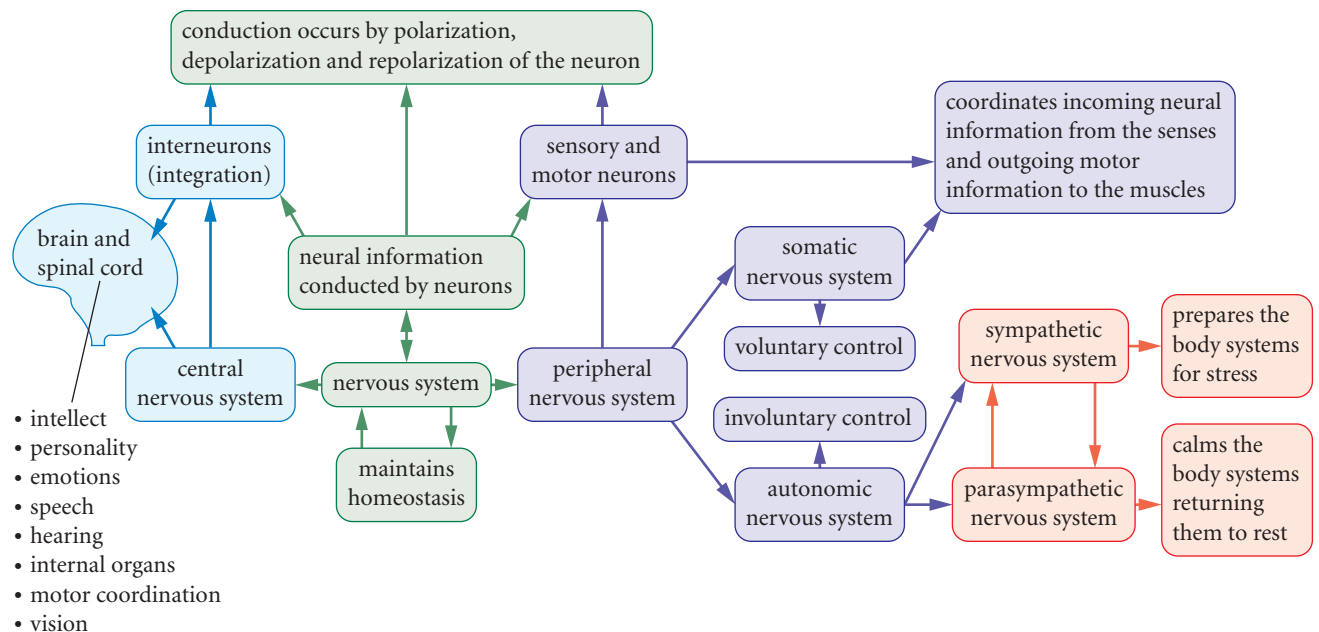
Myelinated neurons make up the white matter of the human nervous system. Their axons are covered with a myelin sheath. The myelination allows for faster impulse conduction and protects nerve cells. The presynaptic neuron can communicate with the postsynaptic neuron or effector by releasing chemicals called neurotransmitters.

There are two main divisions that make up the human nervous system: the central nervous system (CNS) and the peripheral nervous system (PNS).

The central nervous system contains the brain and spinal cord, which function to integrate neural information. The cerebrum is the largest part of the brain. It includes two cerebral hemispheres, or four pairs of lobes. The top layer of the cerebrum is the cerebral cortex. The principal structures of the brain have been mapped to specific functions.

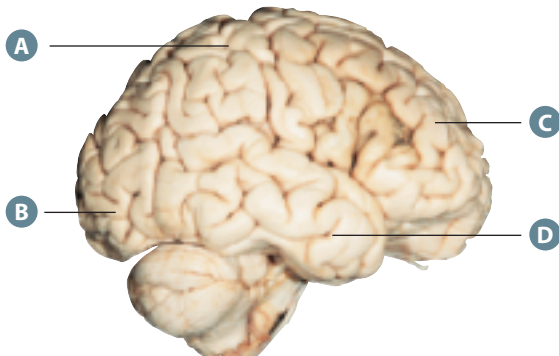
The peripheral nervous system contains sensory neurons that transmit information into the central nervous system and motor neurons that relay neural impulses to the muscles and glands. The peripheral nervous system is further subdivided into the somatic (largely voluntary) and the autonomic (largely involuntary) systems. The reflex arc is structured to carry out rapid responses that do not involve conscious control. The sympathetic and parasympathetic divisions of the autonomic system often act in opposition to each other. The sympathetic system prepares the body for stress, while the parasympathetic system returns the body to a resting state and operates when the body is resting.

## Chapter 11 Graphic Organizer



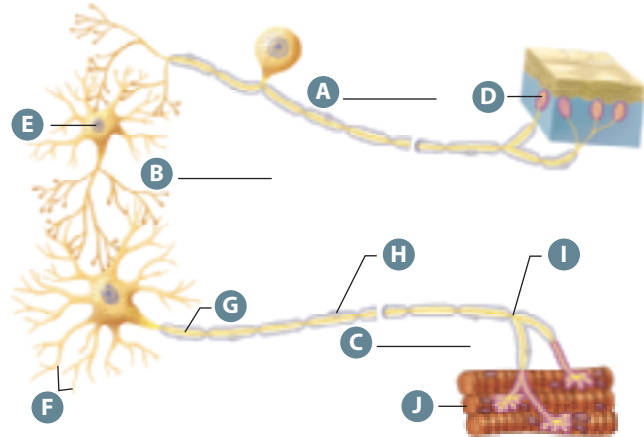
## Understanding Concepts

1. Use word processing software to create a flow diagram showing the main divisions of the nervous system. Describe the key features of each division. **ICT**
2. If the motor area of the right cerebral cortex was damaged in an automobile accident, which side of the body would be affected? Why?
3. If the blood supply to an area of the brain is interrupted, as in a stroke, this part of the brain can be damaged, resulting in a loss of function. In the diagram below, the letters A to D indicate specific lobes of the cerebral cortex that have been damaged due to a stroke. Name the structures that correspond to each letter and describe which brain function would be affected in each case.

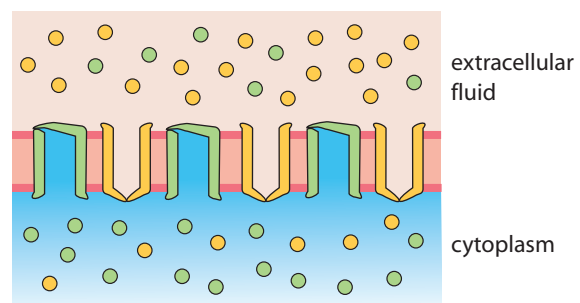


4. Compare the functions of the sympathetic and parasympathetic divisions of the autonomic system. Give specific examples of their physiological effects in the body.
5. A person with epilepsy can have severe epileptic seizures. Explain why severing the corpus callosum is used to treat some cases of epilepsy.
6. Explain the functions of acetylcholine and cholinesterase in the transmission of an impulse and the functioning of the synapse.
7. A person complains of a noticeable decrease in muscle coordination after an injury to the brain. Which area of the brain is most likely affected? Explain.
8. While nailing boards onto a fence, you accidentally hit your hand with a hammer. Use word processing or graphics software to trace the path of neural transmission from the original stimulus to your response as you drop the hammer. Include the types of neurons and their functions. **ICT**
9. In a snowmobile accident, a person receives a severe spinal cord injury. Explain why the person loses all sensation below the injured area.

10. Examine the diagram below, and use word processing software to create a table to record
  - the structures and types of neurons indicated by the letters in the diagram
  - the functions of these structures and neurons
 Under your table, indicate the direction of neuron transmission. **ICT**



11. Compare white matter with grey matter. Identify the location of each, and describe its function.
12. Multiple sclerosis causes the myelin sheath to degenerate over time. Indicate the specific losses of myelinated nerve function caused by this condition.
13. The diagram below indicates different ion concentrations from the inside to the outside of a neuron while the neuron is at rest. Draw this diagram in your notebook, and indicate the sodium ions, potassium ions, sodium ion channels, and potassium ion channels. Also indicate the charge inside and outside the neuron. Explain how the different ion concentrations are established.



14. Using a diagram, explain depolarization, action potential, and repolarization of the neuron. What factors might stimulate an action potential?
15. Explain why saltatory conduction occurs in myelinated neurons but not unmyelinated neurons.

16. Explain how one neuron can inhibit the actions of another neuron.

### Applying Concepts

17. In a classic experiment, the strength of a neural stimulus and the resulting muscle contraction are compared. A single motor neuron that synapses with a muscle fibre is suspended. The other end of the muscle fibre is attached to a mass. If an electrical stimulus is sufficient to cause an impulse in the neuron, the muscle will contract and lift the mass. The following data were obtained from the experiment. Analyze the data, and answer the following questions.

Strength of stimulus (mV)	Mass lifted by muscle contraction (g)
1	0
2	10
3	?
4	?

- a) Define “threshold potential.” What is the minimum size of the stimulus required to reach the threshold potential for this motor neuron?
- b) Explain the all-or-none response. Then predict the mass that could be lifted at 3 mV of stimuli and at 4 mV of stimuli.
- c) Choose a specific example of a sensory neuron, and explain neural stimulation and impulses in terms of the threshold potential and the all-or-none response.
18. One of the tragic consequences of Alzheimer’s disease is progressive memory loss. The memory pathways in the brain are complex and involve several different areas. Name the lobe of the cerebral cortex that is most related to memory, and state three other functions of this lobe.
19. Researchers are experimenting with new technologies that could help people with missing limbs. In one experiment, electrodes implanted in the nervous tissue of a monkey were connected to an artificial hand. The monkey’s nervous system was able to direct the artificial hand to move. This photograph shows the monkey raising a piece of zucchini to its mouth using the thought-controlled robotic arm.



- a) What area of the brain directs the movement of the robotic arm? (Assume that the structure of a monkey brain is similar to the structure of a human brain.)
- b) Using a flowchart, illustrate the basic neural pathway from the sensory stimulus to the motor output.
- c) Compare this artificial pathway with the actual neural pathway to a biologically functional limb.
- d) What are some other potential applications for this technology?
- e) Do the benefits to human life justify this form of animal research?
20. Describe a safeguard that prevents a neuron from carrying an impulse in the wrong direction. What would be the effect of an impulse travelling in both directions in a neuron?
21. One way to model the action potential is to line up several dominoes and initiate a cascade event, in which each successive domino knocks down the next domino.
- a) In this model, the hand provides the initial energy. What provides the initial energy in a neural impulse?
- b) The finger has to contact the first domino just hard enough to get it to fall. Which response does this represent in a real neuron?
- c) Once the dominoes start to fall, they all fall in succession. What does this action represent in the real neuron?
- d) The dominoes always fall in one direction. Contrast this with the direction of impulse transmission in a real neuron.
- e) No matter how many times the dominoes fall, they always move at the same speed and intensity. What principle does this represent in the real neuron?

### Making Connections

22. Meningitis is an infection of the meninges, which cover the brain and spinal cord. It is diagnosed by a spinal tap, which involves analyzing a sample of the cerebrospinal fluid. Explain why the same information could not be determined from a regular blood sample.
23. Based on what you know about threshold potential, explain why some people seem to be more tolerant of pain than others.
24. If food is not preserved properly, *Clostridium botulinum* bacteria can start to reproduce and release a neurotoxin called botulinum toxin. Botulinum toxin inhibits the action of acetylcholine, causing botulism. What symptoms would you expect to observe in someone suffering from botulism? Provide an explanation.