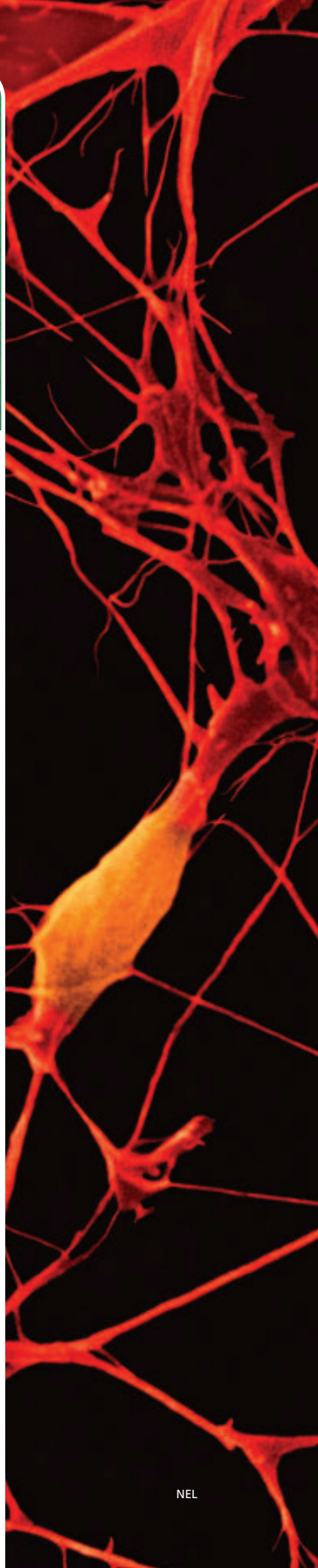
unit

30 A Nervous and Endocrine Systems



Organs do not work independently; rather, they work in coordinated systems that continuously respond and adjust to changing environments. The nervous system senses changes in the internal and external environment, and relays this information through neurons, such as those shown here. The body then responds to these messages. In many cases, it is the endocrine that responds, by changing levels of hormones.

Researchers are investigating artificial substitutes for many human organs and cells. Artificial cells that mimic the biological processes of natural cells could one day be used to help build artificial kidneys and livers. Synthetic fabric could temporarily serve as artificial skin for burn victims. A bioartificial pancreas that is currently being tested in animals at the University of Alberta could one day provide a cure for diabetes. To be able to function properly, an artificial organ must also be able to communicate with and act together with the body's own cells. What characteristics do these substitutes need to function effectively in the body? In this unit, you will study how the nervous and endocrine systems work together to coordinate the functions of all the organs of the body and help maintain homeostasis, the body's attempt to adjust to a fluctuating external environment.

As you progress through the unit, think about these focusing questions:

- How does the human body maintain equilibrium between its internal and external environments?
- What physiological processes and control systems are involved in maintaining homeostasis?

UNIT 30 A PERFORMANCE TASK

Determining the Effects of Caffeine on Homeostasis

Caffeine is one of the world's most widely used drugs. In this Performance Task, you will investigate the effects caffeine has on human systems and demonstrate how the homeostatic feedback adjustment works. You will use an invertebrate or a protist as a model to provide information that may be applicable to human physiological systems. At the end of this unit, you may apply your skills and knowledge to complete this Performance Task.

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GENERAL OUTCOMES

In this unit, you will

- explain how the nervous system controls physiological processes
- explain how the endocrine system contributes to homeostasis

Unit 30 A
Nervous and Endocrine Systems

ARE YOU READY?

These questions will help you find out what you already know, and what you need to review, before you continue with this unit.

Prerequisites

Concepts

- cellular structures and functions
- kidney function
- immune response

Skills

- ask questions about observed relationships
- plan investigations of questions, ideas, and problems
- analyze data and apply mathematical concepts and conceptual models to develop and assess possible solutions

You can review prerequisite concepts and skills on the Nelson Web site and in the Appendices.

A Unit Pre-Test is also available online.

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Knowledge

1. Place the following terms from smallest to largest and provide an example of each term:
   - chromosome
   - tissue
   - organ system
   - cell
   - gene
   - organ

2. Which statement is the best description of negative feedback?
   (a) A series of receptors that respond to changes in the internal environment of the body by inhibiting the release of hormones.
   (b) A control system that prevents imbalances in the body by compensating for any changes with a new change in the opposite direction.
   (c) A mechanism that responds to changes in the internal and external environments of the body by stimulating the release of hormones.
   (d) A biological system that prevents the body from responding to changes in the external environment, releasing hormones, or using nerves to shut down organs.

3. Use the diagram of negative feedback in **Figure 1** to explain how the body maintains homeostasis when water intake decreases. (*Hint:* The excretory system was covered in your Biology 20 studies.)

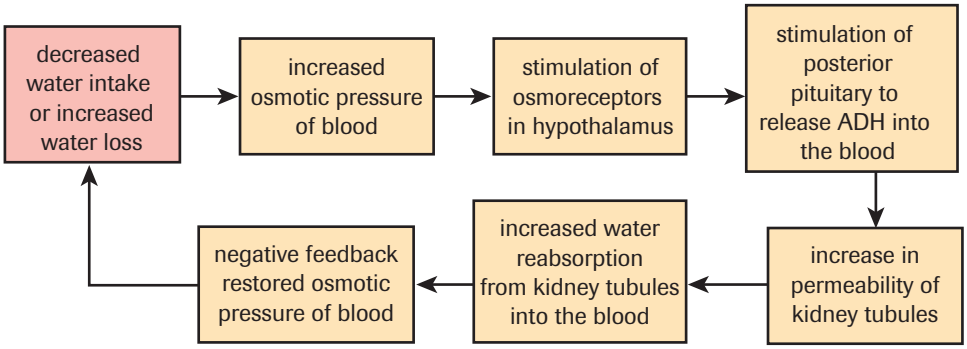

Figure 1

4. From the physiology you studied in Biology 20, provide an example of how cells communicate with each other to protect the body from invading microbes.

5. From the physiology you studied in Biology 20, provide an example of how cells in one part of the body communicate with cells in another part of the body to release hormones.

Skills and STS Connections

6. A cell is placed in a beaker and the concentration of Na^+ ions and sugar ($C_6H_{12}O_6$) is monitored after 10 s and 60 s (**Figure 2**).
   (a) By examining both the cell and the beaker after 10 s, what evidence supports the hypothesis that the cell membrane is permeable to sugar?
   (b) By examining both the cell and the beaker after 10 s, what evidence supports the hypothesis that Na^+ ions move by diffusion?
   (c) By examining both the cell and the beaker after 60 s, what evidence supports the hypothesis that sugar is actively transported?
   (d) By examining both the cell and the beaker after 60 s, provide a hypothesis that helps explain why the total number of sugar molecules has decreased.

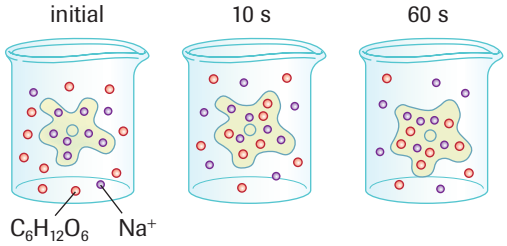

Figure 2

7. A research team wishes to show the negative effects of consuming alcohol on driving. Knowing that alcohol impairs reaction times, the researcher needs to design an investigation that will test their hypothesis.
   (a) Create a hypothesis for the experiment.
   (b) Present the experimental design.
   (c) Write a multi-step procedure for the experiment.
   (d) Identify the independent and dependent variables for the experiment.
   (e) What variables must be controlled to get reliable results?
   (f) Design a data table for the experiment.
   (g) Would you expect identical data from different subjects? Explain your answer.
   (h) What practical information could be provided by the experiment?

chapter

13 Nervous System

In this chapter

In 1998, Michael J. Fox (**Figure 1**) announced that he was leaving a popular television sitcom because of Parkinson's disease. Fox was diagnosed with early stages of Parkinson's disease in 1991, when he noticed a twitch in a finger. Over the next seven years the disease progressed, making acting very difficult.

Parkinson's disease is a progressive degenerative nerve disorder that affects muscle activity. Cells in two areas of the brain, the substantia nigra and the locus cerulus, degenerate and die. These cells secrete dopamine and norepinephrine. Any reduction in these chemicals affects muscle movement. Early symptoms include muscle tremors, slow body movements, rigidity in the joints, and an inability to regain one's balance. As the disease progresses, the symptoms become more pronounced and daily activities become extremely difficult.

The cause of the disease is not known. In about 15 % of cases, heredity plays a role. A person can inherit one of two genes that produce proteins that destroy the brain cells. In the remaining 85 % of cases, scientists believe that a dormant gene is triggered. Unfortunately, the actual trigger and how the gene is triggered is unknown. Although the disease usually occurs in people over 50, Parkinson's can also affect younger adults.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Do nerves carry electrical current? Explain.
2. Does a nerve that carries information from your eye, function any differently from a nerve that sends information to a muscle?
3. A woman touches a hot object and quickly moves her finger away. Does the brain coordinate the movement of the finger away from the hot object?
4. A cougar jumps from behind a bush and startles a man standing nearby. The information is passed to the man's brain. Explain how the nervous system, endocrine system, and urinary system prepare his body for stress.
5. Endurance athletes, such as Alex Decoteau (**Figure 2**, next page), a great long-distance runner from the Red Pheasant reserve in Saskatchewan, have to endure a lot of pain. He was able fight back the pain and win four races in one day. What allows one person to withstand more pain than another person?

Career Connections:
Mental Health Worker; Chiropractor

Figure 1
Canadian actor Michael J. Fox

Figure 2
In 1910, Alex Decoteau won the half-mile, one mile, two mile, and five mile races at a meet in Fort Saskatchewan.

Exploration — Stimulus and Response in Invertebrates

Invertebrates such as worms and leeches have a distinct top and bottom, front and back, and head and tail. In this activity, you will observe the response of an invertebrate to a simple stimulus.

Materials: medicine dropper, invertebrate, microscope slide, paper towel

- Gently touch the head of the invertebrate with a piece of paper towel and note its response.
  (a) Explain why the invertebrate responded as it did.
  (b) What can you infer about the nervous system of the invertebrate?
  (c) How do you think an invertebrate would respond to a concentration of salt added to its environment?

13.1 The Importance of the Nervous System

Prisoners have often been isolated and placed in dark rooms as a means of punishment. Imagine how you would be affected if you didn't know whether it was day or night, or if you couldn't hear a sound for days.

Even in these extreme conditions, however, your nervous system remains active. Information about your depth of breathing, the physical condition of the breathing muscles, and the amount of water contained in the respiratory tract is continually relayed to the brain for processing and storage. Other nerve cells detect air temperature, light intensity, and odours. Pressure receptors in the skin—known as baroreceptors—inform you of the fit of your clothes and can detect an insect scurrying across your leg. Blinking your eyes or scratching your nose requires coordinated nerve impulses. Memories of happy times and hopes for your future reside in the nervous system.

The nervous system is an elaborate communication system that contains more than 100 billion nerve cells in the brain alone. That number exceeds the number of visible stars in the Milky Way galaxy.

central nervous system (CNS) the body's coordinating centre for mechanical and chemical actions; made up of the brain and spinal cord

peripheral nervous system (PNS) all parts of the nervous system, excluding brain and spinal cord, that relay information between the central nervous system and other parts of the body

Organization of the Nervous System

The nervous system has two main divisions: the **central nervous system (CNS)** and the **peripheral nervous system (PNS)** (**Figure 1**). The central nervous system consists of the nerves of the brain and spinal cord and acts as a coordinating centre for incoming and outgoing information. The peripheral nervous system consists of nerves that carry information between the organs of the body and the central nervous system.

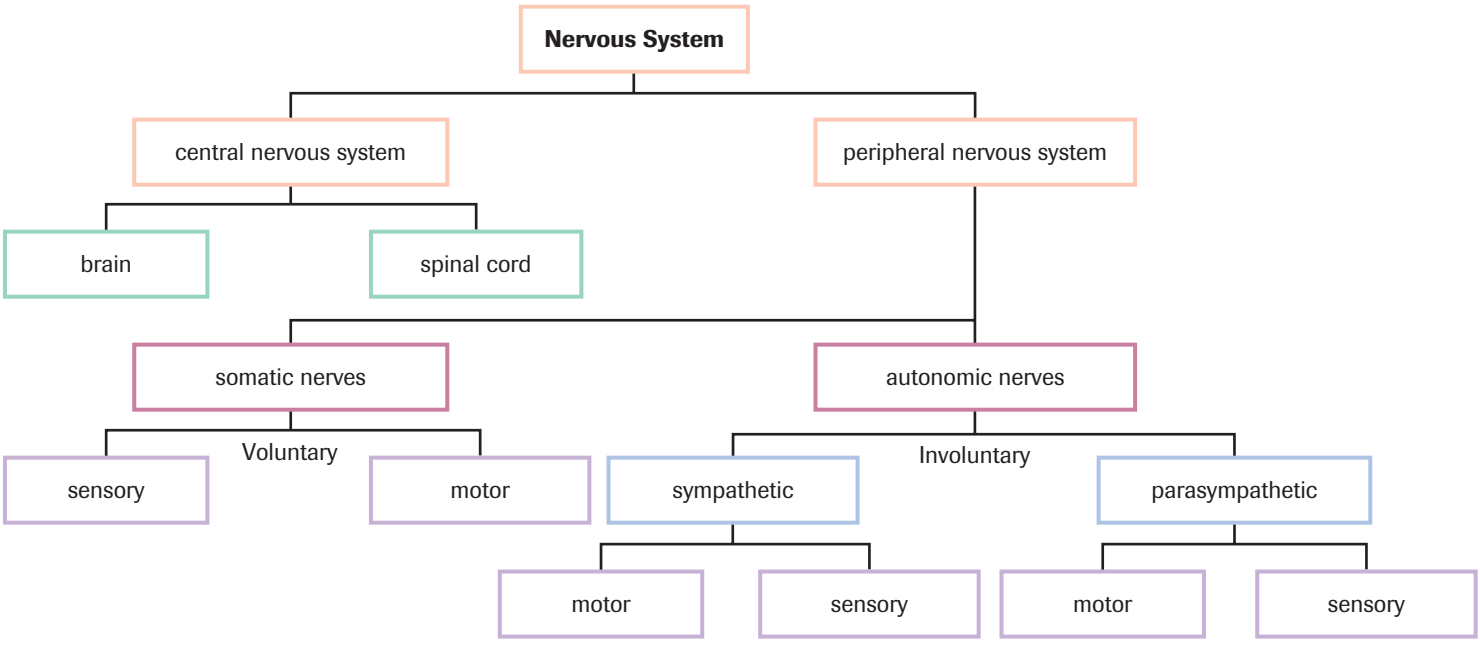

Figure 1
The main divisions of the nervous system

The peripheral nervous system can be further subdivided into somatic and autonomic nerves. The somatic nervous system controls the skeletal muscle, bones, and skin. Sensory somatic nerves relay information about the environment to the central nervous system, while motor somatic nerves initiate an appropriate response. The autonomic nervous system contains special motor nerves that control the internal organs of the body. The two divisions of the autonomic system—the sympathetic nervous system and the parasympathetic nervous system—often operate as "on–off" switches. These two systems will be discussed later in the chapter.

Anatomy of a Nerve Cell

Two different types of cells—glial cells and neurons—are found in the nervous system. **Glial cells**, often called neuroglial cells, are nonconducting cells and are important for the structural support and metabolism of the nerve cells. **Neurons** are the functional units of the nervous system (**Figure 2**). All neurons contain dendrites, cell bodies, and axons. The **dendrites** receive information, either from the environment or from other neurons. Like all living cells, neurons contain a nucleus (in a neuron, the nucleus is within the cell body). Dendrites conduct nerve impulses toward the cell body. An extension of cytoplasm, called the **axon**, conducts nerve impulses away from the cell body. A neuron has only one axon, though it may form many branches. In humans, the axon is extremely thin; more than 100 axons could be placed inside the shaft of a single human hair. The axon carries the nerve impulse toward other neurons or to effectors. A close examination of most nerves shows that they are comprised of many axons held together by connective tissue (**Figure 3**, next page).

glial cell nonconducting cell important for structural support and metabolism of the nerve cells

neuron nerve cell that conducts nerve impulses

dendrite projection of cytoplasm that carries impulses toward the cell body

axon extension of cytoplasm that carries nerve impulses away from the cell body

Many axons are covered with a glistening white coat of a fatty protein called the **myelin sheath**, which acts as insulation for the neurons. Axons that have a myelin covering are said to be myelinated. Formed by special glial cells called **Schwann cells**, the myelin sheath insulates by preventing the loss of charged ions from the nerve cell. The areas between the sections of myelin sheath are known as the **nodes of Ranvier**. Nerve impulses jump from one node to another, thereby speeding the movement of nerve impulses. Not surprisingly, nerve impulses move much faster along myelinated nerve fibres than nonmyelinated ones. The speed of the impulse along the nerve fibre is also affected by the diameter of the axon. Generally, the larger the diameter of the axon, the faster the speed of the nerve impulse.

myelin sheath insulated covering over the axon of a nerve cell

Schwann cell special type of glial cell that produces the myelin sheath

nodes of Ranvier regularly occurring gaps between sections of myelin sheath along the axon

All nerve fibres found within the peripheral nervous system have a thin outer membrane called the **neurilemma**, which surrounds the axon. The neurilemma is formed by the Schwann cells and promotes the regeneration of damaged axons. This explains why feeling gradually returns to your finger following a paper cut—severed neurons can be rejoined. However, not all nerve cells that have a myelin sheath have a neurilemma. Nerves within the brain that contain myelinated fibres are called white matter because the myelinated axons are whitish in appearance. Other nerve cells within the brain and

neurilemma delicate membrane that surrounds the axon of some nerve cells

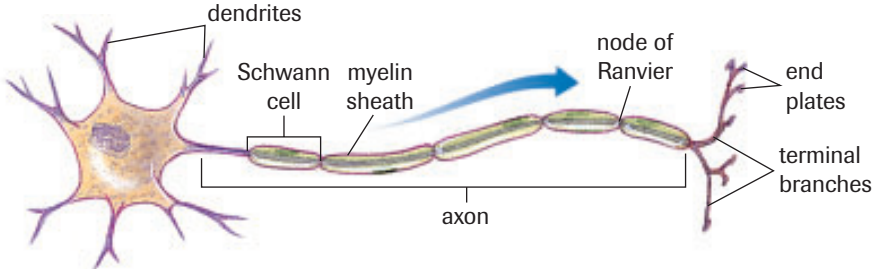

Figure 2
Structure of a neuron. The arrow shows the direction in which a nerve impulse travels.

DID YOU KNOW ?

Multiple Sclerosis

Multiple sclerosis is caused by the destruction of the myelin sheath that surrounds the nerve axons. The myelinated nerves in the brain and spinal cord are gradually destroyed as the myelin sheath hardens and forms scars, or plaques. This scarlike tissue prevents normal impulse transmission. Often referred to as MS, multiple sclerosis can produce symptoms of double vision, speech difficulty, jerky limb movements, and partial paralysis of the voluntary muscles. First identified by a French neurologist in 1868, MS is the most common neurological disease affecting young adults in Canada.

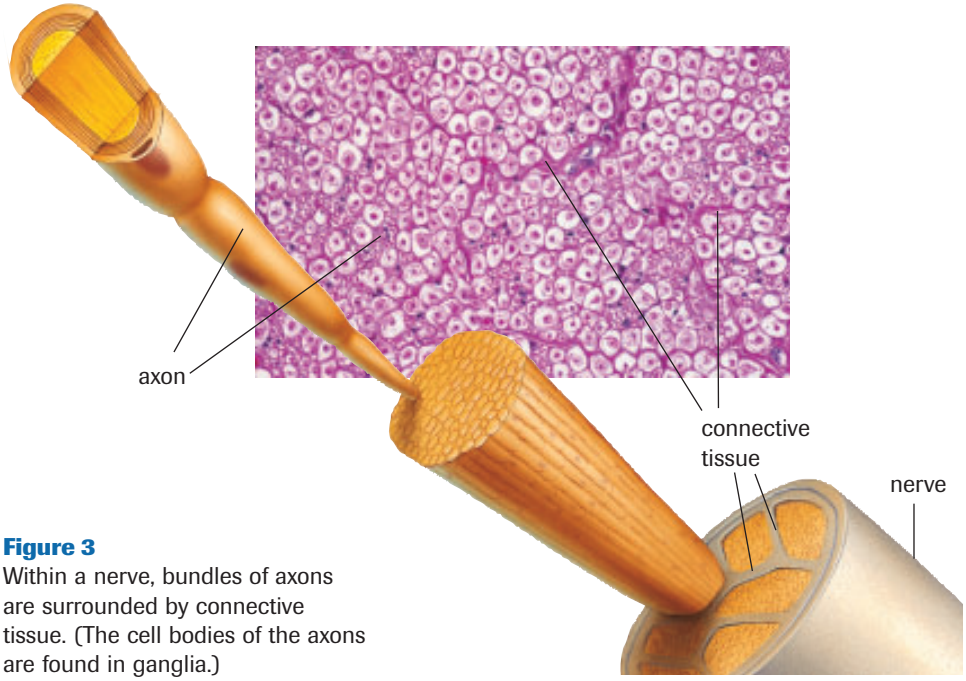

Figure 3
Within a nerve, bundles of axons are surrounded by connective tissue. (The cell bodies of the axons are found in ganglia.)

sensory neuron neuron that carries impulses to the central nervous system; also known as afferent neuron

sensory receptor highly modified dendrites of a sensory neuron that are activated by an environmental stimulus

ganglion (plural **ganglia**) collections of nerve cell bodies located outside the central nervous system

interneuron a neuron of the central nervous system that connects with sensory, motor, and other interneurons to integrate sensory input with motor output; also known as association neuron

motor neuron neuron that carries impulses from the central nervous system to an effector; also known as efferent neuron

effector a cell or organ that produces a physiological response when stimulated by a nerve impulse

spinal cord, referred to as the grey matter, lack a myelin sheath. Cells of the white and grey matter of the central nervous system lack neurilemmas. That is why damage to the central nervous system tends to be permanent.

Neurons are categorized into three groups: the sensory neurons, interneurons, and motor neurons. **Sensory neurons** (also known as afferent neurons) relay information (or stimuli) received by **sensory receptors** about the external or internal environment to the central nervous system for processing. The cell bodies of sensory neurons are located in clusters called **ganglia** (singular, **ganglion**) located outside of the spinal cord.

Interneurons, as the name suggests, link neurons to other neurons. Found only in the brain and spinal cord, the interneurons (also known as association neurons) integrate and interpret the sensory information and connect sensory neurons to outgoing motor neurons. **Motor neurons** (also known as efferent neurons) relay information to the **effectors**, which is the cell or organ that responds to the stimulus. Muscles, organs, and glands are classified as effectors because they produce responses.

Practice

1. Differentiate between the peripheral nervous system (PNS) and central nervous system (CNS).
2. Differentiate between sensory nerves and motor nerves.
3. Briefly describe the function of the following parts of a neuron: dendrites, myelin sheath, Schwann cells, cell body, and axon.
4. What is the relationship between the speed of a nerve impulse and the size of the axon along which it travels?

Repairing Damaged Nerves

For years, scientists have been puzzled about why the central nervous system does not support nerve growth in the same way as the peripheral nervous system. New surgical procedures, the identification of factors that inhibit nerve cell regeneration in the central nervous system, and emerging work with stem cells provide hope for the many people who are paralyzed by spinal cord injury (SCI) (**Figure 4**).

In Norrtalje, Sweden, 25-year-old Thomas Westburg sustained a serious spinal cord injury while snowmobiling. Four nerves were torn from the spinal cord in the area of the neck. The injury left Westburg's left shoulder, arm, and hand completely paralyzed. Surgeons at the Karolinska Hospital in Stockholm reattached two of the nerves. Remarkably, the repair job provided a channel along which new nerves began to grow from cell bodies in Westburg's spinal cord. The slow growth of nerve cells finally connected the spinal cord with muscles that move the arm. In Westburg's case, about 40 % of mobility was restored.

Some promising research comes from the use of stem cells. Stem cells are cells that have not yet specialized into tissue cells, such as skin, bone, muscle, or nerve cells. Scientists are experimenting with the possibility of replacing cells that have been damaged by disease or trauma, such as in cases of spinal cord injury or Parkinson's disease.

In October 2000, scientists announced that they had reconnected severed nerves in the spinal cords of rats using spore-like cells from the nervous system of adult rats. Only 3 μm (micrometres) in diameter, these repair cells are so small that some researchers first regarded them as cellular debris. The spore-like cells can be frozen for more than a month and still be retrieved for use. Properly incubated, they grow easily and can withstand a decrease in nutrients and changes of temperature. Placed in the body of a mammal, they are able to survive with limited amounts of oxygen for several days until blood vessels grow into the area. These spore-like cells can only transform into cells associated with nerve conduction.

Scientists harvested the spore-like nerve cells from the spines of healthy adult rats and seeded them into the spinal cords of injured rats. Quickly the new cells began to grow in the area of the severed cord. After 10 days, researchers recorded small twitches in the toes of the rats. Within three months, some of the rats could stand on their hind legs. The use of adult stem cells has also been proposed for this purpose. However, further research is required to determine whether these cells could be used to treat neurological diseases and injuries.

The Reflex Arc

If you accidentally touch a hot stove, you probably do not think about how your nervous system tells you that it is hot. The sensation of heat is detected by specialized temperature receptors in your skin, and a nerve impulse is carried to the spinal cord. The sensory neuron passes the impulse on to an interneuron, which, in turn, relays the impulse to a motor neuron. The motor neuron causes the muscles in the hand to contract and the hand to pull away. All this happens in less than a second, before the information even travels to the brain. Very quickly, the sensation of pain becomes noticeable and you may let out a scream.

Reflexes are involuntary and often unconscious. Imagine how badly you could burn yourself if you had to wait for the sensation of pain before removing your hand from the hot stove. The damage would be much worse if you had to go through the process of

Figure 4
Snowmobile accidents account for a high number of spinal cord injuries in Canada.

DID YOU KNOW?

Spinal Cord Injury in Canada

According to the Canadian Paraplegic Association (CPA), about 1000 new injuries a year result in some level of permanent paralysis or neurological deficit. Spinal cord injury is most common in males in the 15–34 age group.

EXTENSION

CBC radio ONE

QUIRKS & QUARKS

Brain Band-Aid

Dr. Rutledge Ellis-Behnke (professor in the Department of Brain and Cognitive Sciences at the Massachusetts Institute of Technology) and colleagues have been working to overcome the body's natural defence systems that prevent damaged neurons from growing back and repairing. In research trials in hamsters, severed nerves have been regrown and function has been restored.

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gauging the intensity of the pain and then contemplating the appropriate action. Even the small amount of time required for nerve impulses to move through the many circuits of the brain and back to the muscle would increase the damage.

reflex arc neural circuit through the spinal cord that provides a framework for a reflex action

The simplest nerve pathway is the **reflex arc**. Most reflexes occur through a reflex arc, which do not involve coordination by the brain. Reflex arcs contain five essential components: the sensory receptor, the sensory neuron, the interneuron (most often found in the spinal cord, but in some reflex arcs, in the brain), the motor neuron, and the effector (**Figure 5**).

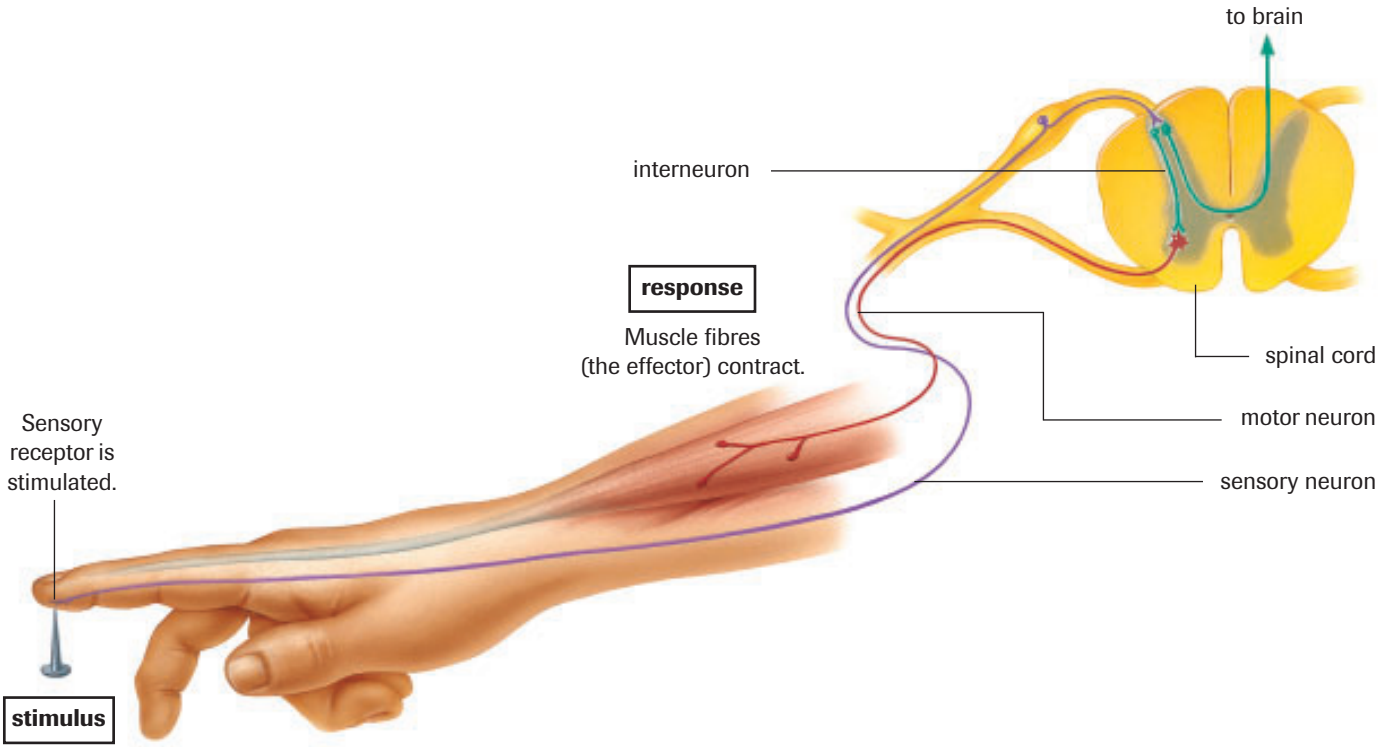

Figure 5
A reflex arc begins when the touch receptor in the finger senses the tack. Sensory information is relayed from the sensory neuron (purple) to the spinal cord. Interneurons in the spinal cord (green) receive the information from the sensory neuron and relay it to the motor neuron (red). The motor neuron activates the muscle cell (the effector), causing it to contract. The brain also receives sensory information from a sensory neuron, which registers as pain. This step is not part of the reflex arc.

Physicians may stimulate a reflex arc to test the health and functioning of parts of the nervous system. For example, the patellar reflex is stimulated by gently tapping the tendon below the kneecap. Sensory receptors detect the slight stretching of the tendon and relay an impulse to a sensory neuron (**Figure 6**, next page). The impulse travels down the sensory neuron to the spinal cord. The message has now travelled from the peripheral nervous system to the central nervous system. The central nervous system then relays a message back out to the peripheral nervous system, along two motor neurons that connect with the muscles on the upper and lower thigh (the quadriceps and hamstrings, respectively). The impulses from these motor neurons simultaneously cause the quadriceps to contract and the hamstrings to relax. As a result, the lower leg rises. This all takes place so quickly as to seem instantaneous.

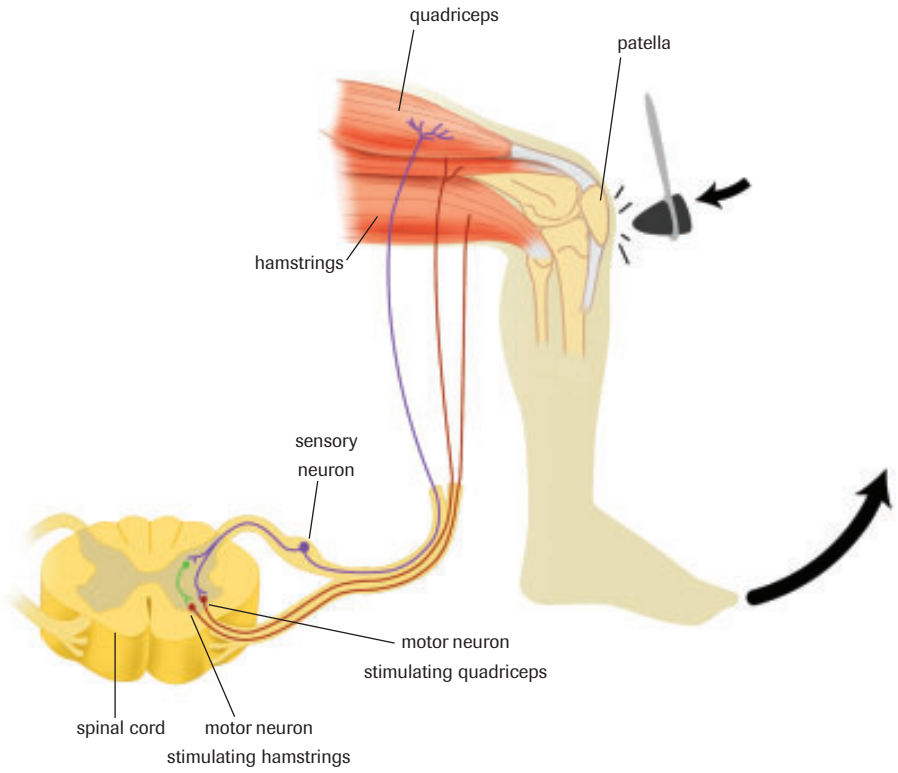

Figure 6
The patellar reflex is commonly known as the "knee-jerk response." Tapping on the ligament under the knee cap causes the lower leg to raise in response.

You may have experienced a physician quickly shining a small penlight in one eye during an examination. In this exam, the physician is looking for your pupils to constrict (become smaller) in response to the light. (This should never be done with a bright light, since it could damage the eye.) This is called the pupillary reflex. Sensors in the eye detect the light and pass an impulse to a sensory neuron. In this case, the impulse is carried to the brain. This is the point at which the message is relayed from the peripheral nervous system to the central nervous system in this reflex arc. As with the patellar reflex, the central nervous system relays a message to two motor neurons in the peripheral nervous system, one for each eye. These neurons carry an impulse to muscles in the eye that cause the pupil to contract. As a result, when a light is shone in one eye of a person with a healthy nervous system, the pupils of both eyes will respond simultaneously.

INVESTIGATION 13.1 *Introduction*

Reflex Arcs

Reflex arcs provide a framework for reflex actions. Simple physical tests can be performed to test reflexes. In this investigation, you will observe the presence and strength of a number of reflex arcs. You will also design an experiment to investigate a reflex arc.

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

To perform this investigation, turn to page 436.

SUMMARY The Importance of the Nervous System

Table 1 Parts of the Nervous System

Structure	Function
neuron	• nerve cell that conducts nerve impulses
sensory neuron (afferent neuron)	• carries impulses to the central nervous system
interneuron	• carries impulses within the central nervous system
motor neuron (efferent neuron)	• carries impulses from the central nervous system to effectors
dendrite	• projection of cytoplasm that carries impulses toward the cell body
axon	• extension of cytoplasm that carries nerve impulses away from the cell body
myelin sheath	• covering over the axon of a nerve cell that is composed of Schwann cells and insulates the axon
nodes of Ranvier	• regularly occurring gaps between sections of myelin sheath that speed transmission of nerve impulses
neurilemma	• delicate membrane surrounding the axons of some nerve cells that promotes nerve regeneration
reflex arc	• neural circuit that travels through the spinal cord • provides a framework for a reflex action

Section 13.1 Questions

1. Name the essential components of a reflex arc and the function of each.
2. What would happen if neuron I in **Figure 7** was severed?
3. In **Figure 7**, what is the order in which an impulse travels along a reflex arc?
4. Primitive sporelike repair cells have been extracted from adult rats. Discuss some of the benefits of using mature repair cells.
5. The incidence of multiple sclerosis (MS) varies among different regions of Canada. Provide a possible explanation for different distributions of the disease.
6. A study on severed optic nerves showed that neurons from the peripheral nervous system grafted into the stalk of the optic nerve regrew approximately 10 % of the retinal ganglions. No reconnections were seen when severed optic-nerve neurons were left alone. What do these findings suggest?

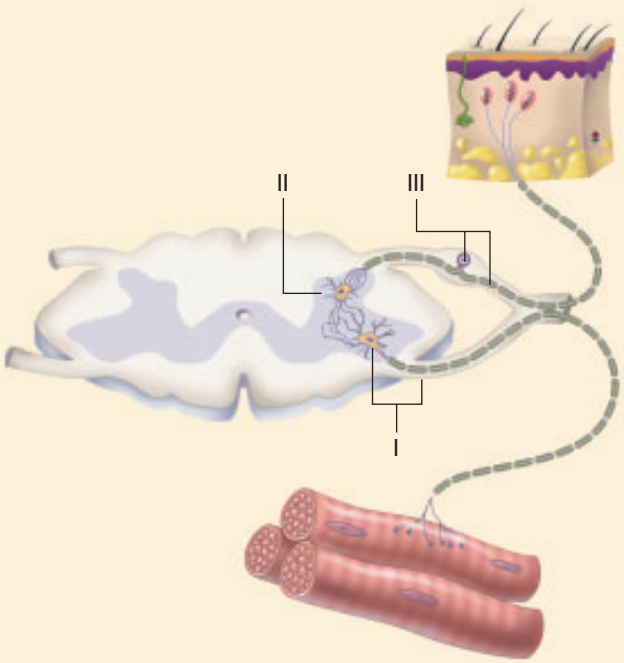

Figure 7
Reflex arc

Electrochemical Impulse 13.2

As early as 1900, German physiologist Julius Bernstein suggested that nerve impulses were an electrochemical message created by the movement of ions through the nerve cell membrane. Evidence supporting Bernstein's theory was provided in 1939 when two researchers at Columbia University, K.S. Cole and H.J. Curtis, placed a tiny electrode inside the large nerve cell of a squid (**Figure 1**). A rapid change in the electrical potential difference—commonly called the potential—across the membrane was detected every time the nerve became excited. The resting membrane normally had a potential somewhere near −70 mV (millivolts); however, when the nerve became excited, the potential on the inside of the membrane registered +40 mV. This reversal of potential is described as an **action potential**. Cole and Curtis noticed that the +40 mV did not last more than a few milliseconds (ms) before the potential on the inside of the nerve cell returned to −70 mV, the **resting potential**.

action potential the voltage difference across a nerve cell membrane when the nerve is excited

resting potential voltage difference across a nerve cell membrane when it is not transmitting a nerve impulse (usually negative)

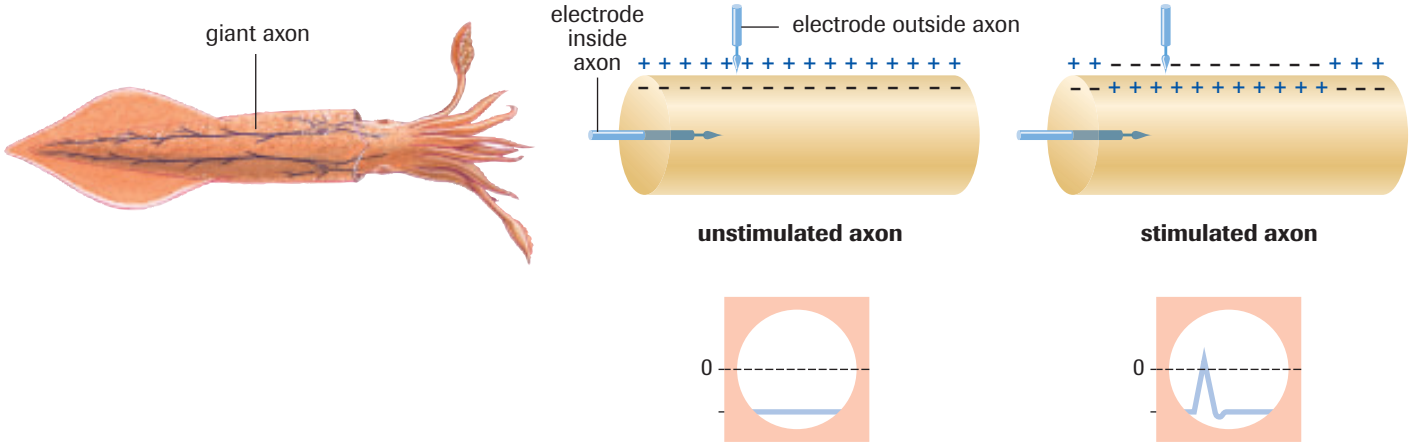

Figure 1
A miniature electrode is placed inside the giant axon of a squid. The inside of the resting membrane is negative with respect to the outside of the membrane. When stimulated, the charges across the nerve membrane temporarily reverse.

The Resting Potential

The plasma membrane of almost all cells has an electrical potential of about –70 mV. In neurons, this electrical potential is called the resting potential. What gives plasma membranes this electrical potential? If we examine the neuron on a molecular level, we can find the answer. Like almost all cells, neurons have a rich supply of positive and negative ions on both sides of the cell membrane (**Figure 2**). There is a higher concentration of potassium ions (K^+) inside the cell and a higher concentration of sodium ions (Na^+) outside the cell. The movement of K^+ is mainly responsible for creating the electrical potential.

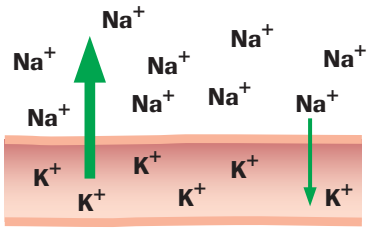

Figure 2
The K^+ concentration is higher inside the cell and the Na^+ concentration is higher outside the cell.

facilitated diffusion transport of substances across cell membrane down a concentration gradient by a carrier in the membrane; does not use energy

gated ion channel a pore in the cell membrane that allows ions to move in and out of the cell by opening and closing

sodium-potassium pump a transporter in the cell membrane that moves potassium ions into the cytoplasm while simultaneously removing sodium ions from the cytoplasm to the extracellular fluid

active transport movement of substances across cell membranes that uses energy; often moves substances against a concentration gradient

The plasma membrane of all cells, including neurons, is composed of a phospholipid bilayer. Plasma membranes are selectively permeable; ions cannot cross the bilayer by simple diffusion. Instead, they enter cells by **facilitated diffusion**, passing through **gated ion channels** that span the bilayer. Ion channels are specific to particular ions, such as K^+ or Na^+ ions.

There are many more K^+ channels than Na^+ channels in the membrane, so more K^+ diffuse out of the cell than Na^+ diffuse in (**Figure 3**). As K^+ leaves the cell, it transfers its positive charge outside the cell. The negatively charged ions are trapped inside the cell, and so an electrical charge builds up across the membrane, creating an electrical gradient. (If ion concentrations were determined only by diffusion, eventually the concentrations of sodium and potassium would equalize across the membrane. This does not happen because the **sodium-potassium pump** in the membrane moves potassium back into the cell and sodium back out of the cell through **active transport**.)

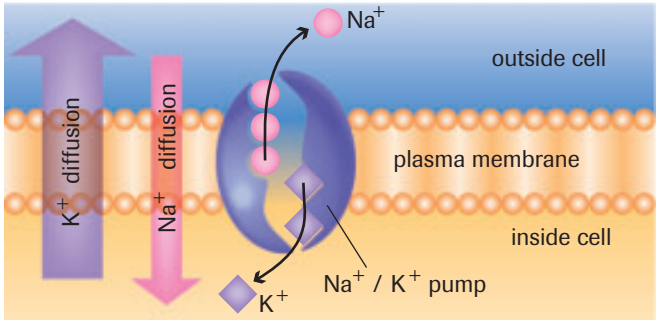

Figure 3
As potassium and sodium diffuse down their concentration gradients across the cell membrane through facilitated diffusion, the sodium-potassium pump actively transports them against the gradients.

CHEMISTRY CONNECTION

Electrolytes

An electrolyte is an aqueous electrical conductor. As in nerve cells, it is the ions in an electrolyte solution that transfer electric charge within an electric cell. Your *Chemistry 20–30* textbook will provide more information on ions and electric cells.

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Excess positive ions accumulate along the outside of the nerve membrane, while excess negative ions accumulate along the inside of the membrane. The resting membrane is said to be charged and is called a **polarized membrane**. The separation of electrical charges by a membrane has the potential to do work, which is expressed in millivolts (mV). A charge of −70 mV indicates the difference between the number of positive charges found on the inside of the nerve membrane relative to the outside. (A charge of −90 mV on the inside of the nerve membrane would indicate even fewer positive ions inside the membrane relative to the outside.)

polarized membrane membrane charged by unequal distribution of positively charged ions inside and outside the nerve cell

The Action Potential

A nerve impulse is an action potential. When a neuron receives a stimulus, the cell membrane becomes more permeable to sodium than potassium. Scientists believe that sodium channels are opened in the membrane, while potassium channels close. The highly concentrated sodium ions rush into the cell by diffusion and by charge attraction. The rapid inflow of sodium reverses the charge on both sides of the membrane.

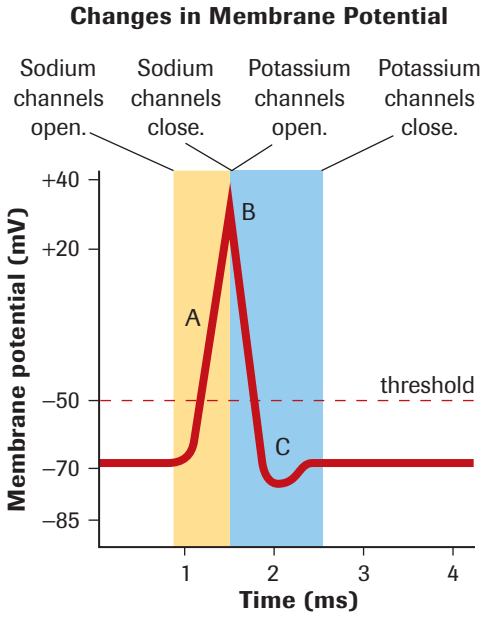

Figure 4
The phases of an action potential

This charge reversal is referred to as **depolarization** (**A** on **Figure 4**). Once the voltage inside the cell becomes positive, the sodium channels slam closed, stopping the inflow of sodium. The potassium channels then open and potassium ions diffuse out of the cell and the charge outside the cell becomes positive again. The process of restoring the original polarity of the nerve membrane is called **repolarization** (**B**). However, the potassium gates close relatively slowly and the outside of the cell becomes even more positively charged than the resting membrane (and the inside more negatively charged) as more and more potassium ions move out of the cell. This is called **hyperpolarization** (**C**). The sodium-potassium pump restores the condition of the resting membrane by transporting sodium ions out of, and potassium ions into, the cell. The time taken for the membrane to return to the resting potential after repolarization is called the **refractory period**, which lasts 1 to 10 ms. The membrane must return to the resting potential before it can generate another action potential.

Movement of the Action Potential

An action potential happens at a specific point on the nerve cell membrane. But how does it move along the cell membrane? In fact, an action potential does not move. Many action potentials are generated one after another along the cell membrane, causing a wave of depolarization. It is similar to a falling domino. When the first domino falls, it causes the domino next to it to fall, and so on.

The first action potential is generated as sodium ions rush into the cell, causing a depolarization of the membrane. The positively charged ions that rush into the nerve cell are then attracted to the adjacent negative ions, which are aligned along the inside of the nerve membrane (**Figure 5**). Similarly, the positively charged sodium ions on the outside of the resting membrane are attracted to the negative charge that has accumulated along the outside of the membrane in the area of the action potential.

depolarization diffusion of sodium ions into the nerve cell resulting in a charge reversal

repolarization process of restoring the original polarity of the nerve membrane

hyperpolarization condition in which the inside of the nerve cell membrane has a greater negative charge than the resting membrane; caused by excessive diffusion of potassium ions out of the cell

refractory period recovery time required before a neuron can produce another action potential

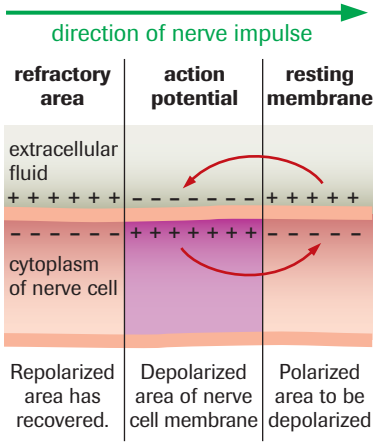

Figure 5
The movement of a nerve impulse. Red arrows indicate ions attracted to adjacent ions with opposite charges.

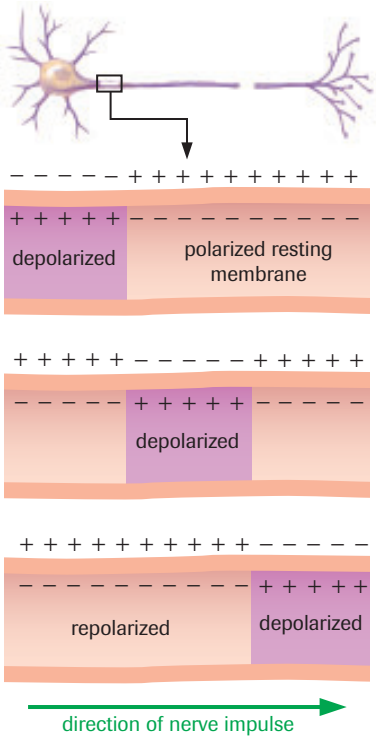

Figure 6
Successive action potentials along a section of axon cause a wave of depolarization along the cell membrane.

The flow of positively charged ions from the depolarized area toward the adjacent resting membrane causes an electrical disturbance. This electrical stimulus causes the sodium channels in the adjacent resting membrane to open, triggering an action potential next to the first action potential. The cycle keeps repeating and the action potentials cause a wave of depolarization along the membrane (**Figure 6**).

What stops the action potentials from going backwards along the cell membrane? Recall that the membrane can only produce another action potential when it is at the resting potential. Thus, during the refractory period right after an action potential, the cell membrane cannot produce another action potential because it is hyperpolarized. So, a new action potential can only be triggered at the leading edge of the first depolarized area.

When axons are myelinated, nerve impulses travel by **saltatory conduction**. In myelinated axons, the gated ion channels are concentrated at the nodes of Ranvier. The flow of ions across the cell membrane can only happen at the nodes and so action potentials have to "jump" from node to node. This causes a nerve signal to be transmitted down an axon much faster (**Figure 7**).

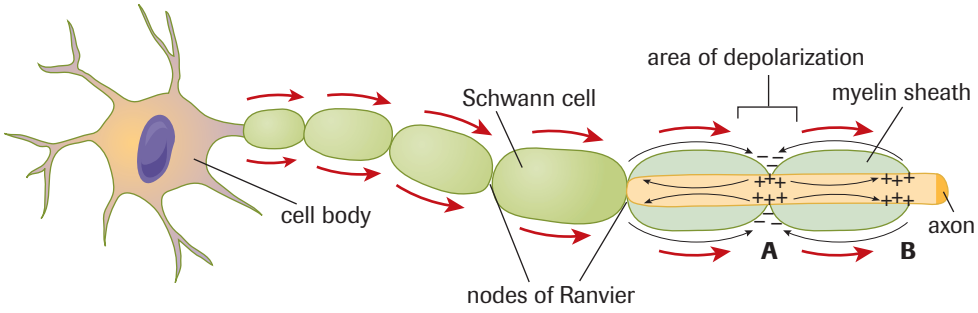

Figure 7
In myelinated axons, depolarization happens only at the nodes (**A**) and an action potential jumps to the next node (**B**). The red arrows show the direction of the nerve impulse and the black arrows show the flow of ions.

saltatory conduction generation of action potentials only at nodes of Ranvier in myelinated axons, resulting in rapid transmission of nerve impulses

Practice

1. What is a polarized membrane?
2. What causes the inside of a neuron to become negatively charged?
3. Why does the polarity of a cell membrane reverse during an action potential?
4. Why do nerve impulses move faster along myelinated nerve fibres?

Threshold Levels and the All-or-None Response

In a classic experiment, a single neuron leading to a muscle is isolated and a mild electrical shock is applied to the neuron. A special recorder measures the strength of muscle contraction. **Figure 8**, on the next page, shows sample data for this experiment. In this example, stimuli of less than 2 mV does not produce any muscle contraction. A potential stimulus must be above a critical value to produce a response. The critical intensity of the stimulus is known as the **threshold level**. Stimuli below threshold levels do not initiate a response. In **Figure 8**, although a threshold level of 2 mV is required to produce a response, threshold levels are different for each neuron.

threshold level minimum level of a stimulus required to produce a response

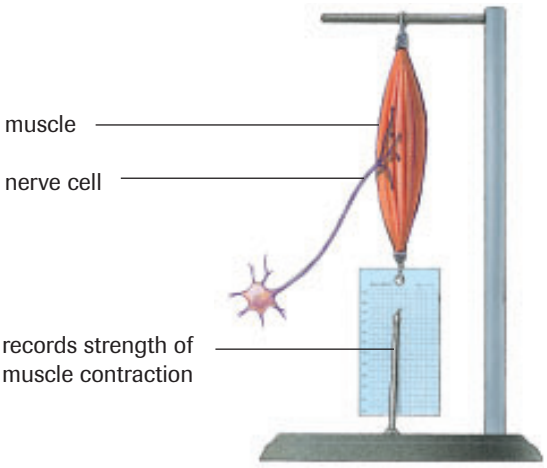

Table 1 Stimulus Strength and Force of Muscle Contraction

Strength of stimuli	Force of contraction
1 mV	–
2 mV	3 N
3 mV	3 N
10 mV	3 N

Figure 8
The threshold level for this neuron is 2 mV. Different neurons have different threshold levels.

EXTENSION

The Threshold Potential of a Neuron

Listen to this audio discussion of the reaction of a neuron to stimulus once its membrane potential has reached the threshold level.

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A second, but equally important, conclusion can be drawn from the experimental data in **Table 1**. Increasing the intensity of the stimuli above the critical threshold value will not produce an increased response—the intensity of the nerve impulse and speed of transmission remain the same. In what is referred to as the **all-or-none response**, neurons either fire maximally or not at all.

all-or-none response a nerve or muscle fibre responds completely or not at all to a stimulus

How do animals detect the intensity of stimuli if nerve fibres either fire completely or not at all? Experience tells you that you are capable of differentiating between a warm object and one that is hot. To explain the apparent anomaly, we must examine the manner in which the brain interprets nerve impulses. Although stimuli above threshold levels produce nerve impulses of identical speed and intensity, variation with respect to frequency does occur. The more intense the stimulus, the greater the frequency of impulses. Therefore, when a warm glass rod is placed on your hand, sensory impulses may be sent to the brain at a slow rate. A hot glass rod placed on the same tissue also causes the nerve to fire, but the frequency of impulses is greatly increased—a difference the brain recognizes.

The different threshold levels of neurons provide a second way for the intensity of stimuli to be detected. Each nerve is composed of many individual nerve cells or neurons. A glass rod at 40 °C may cause a single neuron to reach threshold level, but the same glass rod at 50 °C will cause two or more neurons to fire (**Figure 9**). The second neuron has a higher threshold level. The greater the number of impulses reaching the brain, the greater the intensity of the response.

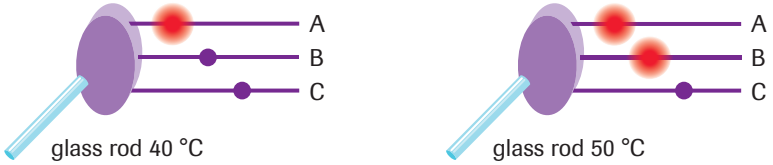

Figure 9
Neuron B has a higher threshold level than neuron A and will not fire until the glass rod is heated above 40 °C. The brain interprets both the number of neurons excited and the frequency of impulses.

Synaptic Transmission

synapse a region between neurons, or between neurons and effectors; also known as the synaptic cleft

neurotransmitter chemical messenger released by the presynaptic neuron that binds to receptors on the postsynaptic neuron

presynaptic neuron neuron that carries impulses to the synapse

postsynaptic neuron neuron that carries impulses away from the synapse

Small spaces between neurons, or between neurons and effectors, are known as **synapses**. The terminal branches of a single neuron allow it to join with many different neurons (**Figure 10**). Synapses rarely involve just two neurons. Small vesicles containing chemicals called **neurotransmitters** are located in the end plates of axons. The impulse moves along the axon and releases neurotransmitters from the end plate. The neurotransmitters are released from the **presynaptic neuron** and diffuse across the synapse, or synaptic cleft, creating a depolarization of the dendrites of the **postsynaptic neuron** when the neurotransmitters bind to receptors. Although the space between neurons is very small—approximately 20 nm (nanometres)—the nerve transmission slows across the synapse. Diffusion is a slow process. Not surprisingly, the greater the number of synapses over a specified distance, the slower the speed of transmission. This may explain why you react so quickly to a stimulus in a reflex arc, which has few synapses, while solving biology problems, which involves many more synapses, requires more time.

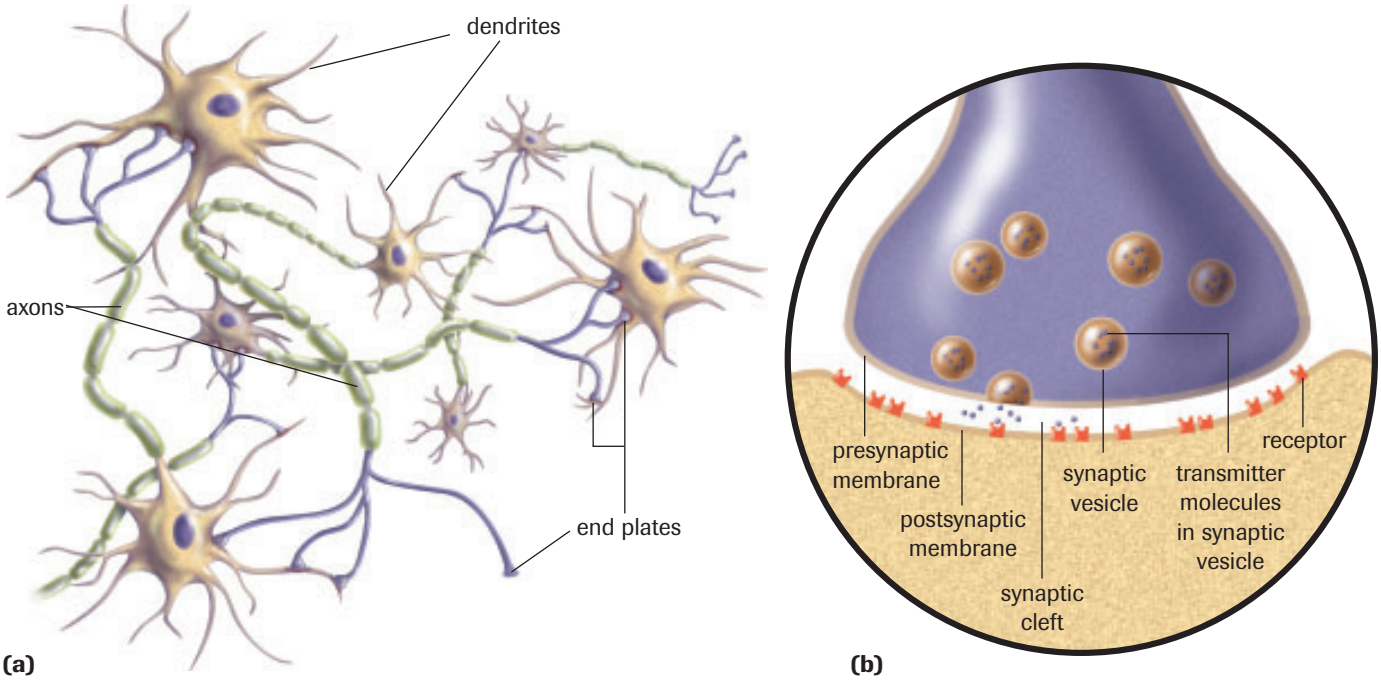

Figure 10

(a) The end plates of terminal branches synapse with the cell bodies and dendrites of many different neurons.

(b) Synaptic vesicles in the end plate of the presynaptic neuron release neurotransmitters into the synaptic cleft. The neurotransmitters attach themselves to receptors on the postsynaptic membrane, causing it to depolarize. The action potential continues along the postsynaptic neuron.

Practice

5. Some people report they have a high pain tolerance. Explain this in terms of threshold levels.

6. What is the all-or-none response?

7. Describe the path of a nerve impulse across a synapse.

mini Investigation Examining Neurons

1. Using a light microscope, examine a longitudinal view of a neuron.
   (a) Describe the appearance of the neuron.
   (b) Estimate the diameter of the neuron.
2. Follow the nerve cell to the synapse.
   (a) Describe the appearance of the synapse and draw a diagram of it.
   (b) Estimate the distance between the presynaptic neuron and the postsynaptic neuron.
3. Refer to the Nelson Web site to view different scientific models of synapses and photomicrographs of synapses taken from scanning electron microscopes and electron microscopes.

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   (a) What additional information about synapses is revealed by observing these high-magnification, high-resolution photomicrographs?
   (b) How do the scientific models help explain the functioning of the synapse?

EXTENSION

Calculation of Scale

Listen to this review of calculation of scale in microscopic measurements.

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Neurotransmitters

Neurotransmitters alter the membrane potentials of postsynaptic neurons. **Acetylcholine** is a neurotransmitter found in the end plates of many nerve cells. Acetylcholine acts as an excitatory neurotransmitter on many postsynaptic neurons by opening the sodium ion channels. Once the channels are opened, the sodium ions rush into the postsynaptic neuron, causing depolarization. The reversal of charge causes the action potential. However, the continued presence of acetylcholine also presents a problem. With the sodium channels open, the postsynaptic neuron would remain in a constant state of depolarization. How can the nerve respond to the next impulse if it never recovers? The presynaptic membrane releases the enzyme **cholinesterase**, which destroys acetylcholine. Once acetylcholine is destroyed, the sodium channels close, and the neuron begins its recovery phase. Many insecticides take advantage of the synapse by blocking cholinesterase. The heart of an insect, unlike the human heart, is totally under nerve control. An insecticide causes the insect's heart to respond to the nerve message by contracting but never relaxing.

acetylcholine neurotransmitter released from vesicles in the end plates of neurons, which makes the postsynaptic membranes more permeable to Na^+ ions

cholinesterase enzyme, which breaks down acetylcholine, that is released from presynaptic membranes in the end plates of neurons shortly after acetylcholine

Not all neurotransmitters are excitatory. For example, although acetylcholine can act as an excitatory neurotransmitter on some postsynaptic membranes, it can act as an inhibitory neurotransmitter on others. Inhibitory neurotransmitters make the postsynaptic membrane more permeable to potassium. By opening even more potassium gates, the potassium ions inside the neuron follow the concentration gradient and diffuse out of the neuron. The rush of potassium out of the cell increases the number of positive ions outside the cell relative to the number found inside the cell, and the cell membrane becomes hyperpolarized, inhibiting any action potentials. As the name suggests, these inhibitory neurotransmitters prevent postsynaptic neurons from becoming active.

Figure 11, on the next page, shows a model of a typical neural pathway. Neurotransmitters released from neurons A and B are both excitatory, but neither neuron is capable of causing sufficient depolarization to initiate an action potential in neuron D. However, when both neurons A and B fire at the same time, a sufficient amount of neurotransmitter is released to cause depolarization of the postsynaptic membrane. The production of an action potential in neuron D requires the sum of two excitatory neurons. This principle is referred to as **summation**.

DID YOU KNOW?

Myasthenia Gravis

Drugs that temporarily keep the enzyme cholinesterase from working are used to treat myasthenia gravis, a disease of progressive fatigue and muscle weakness caused by the impaired transmission of nerve impulses.

summation effect produced by the accumulation of neurotransmitters from two or more neurons

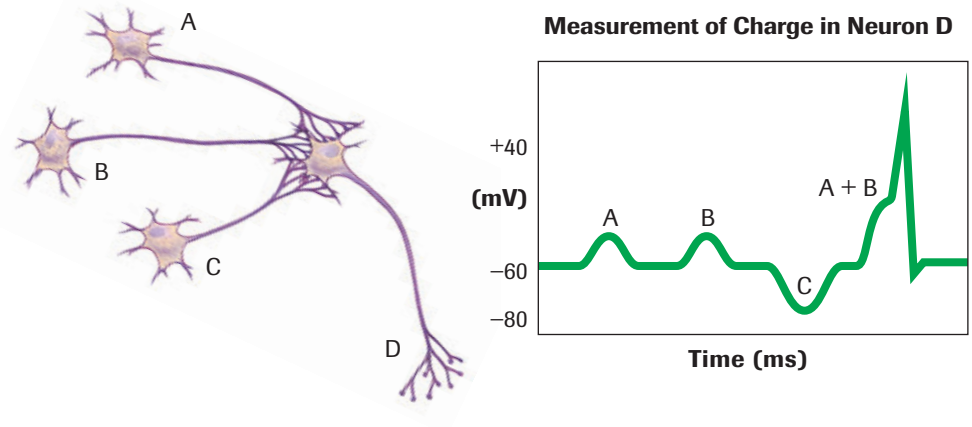

Figure 11
Action potentials must occur simultaneously in A and B to reach the threshold level in D.

The neurotransmitter released from neuron C produces a dramatically different response. Neuron D becomes more negatively charged when neuron C is activated. You may have already concluded that neuron C must release an inhibitory neurotransmitter.

The interaction of excitatory and inhibitory neurotransmitters is what allows you to throw a ball. As the triceps muscle on the back of your upper arm receives excitatory impulses and contracts, the biceps muscle on the front of your arm receives inhibitory impulses and relaxes. By coordinating excitatory and inhibitory impulses, the two muscles of the arm do not pull against each other.

Many different neurotransmitters have been identified in the nervous system. Some common ones are summarized in **Table 1**.

Table 1 Common Neurotransmitters

Neurotransmitter	Action	Secretion sites	Major effects
acetylcholine	excitatory to skeletal muscles; excitatory or inhibitory at other locations	neuromuscular functions; CNS, PNS	skeletal muscle contraction
norepinephrine	excitatory or inhibitory	CNS, PNS	wakefulness
dopamine	generally excitatory	CNS, PNS	voluntary movement and emotions
serotonin	generally inhibitory	CNS	sleep
GABA (gamma-aminobutyric acid)	inhibitory	CNS	motor behaviour

Inhibitory impulses in your central nervous system are very important. Sensory information is received by the brain and is prioritized. Much of the less important information is ignored so that you can devote your attention to the more important sensory information. For example, during a biology lecture, your sensory information should be directed at the sounds coming from your teacher, the visual images that appear on the chalkboard, and the sensations produced as you move your pen across the page. Although your temperature receptors may signal a slight chill in the air and the pressure receptors in your skin may provide the reassuring information that you are indeed wearing clothes, the information from these sensory nerves is suppressed. Inhibitory impulses help you prioritize information. That is why the inhibitory neurotransmitter GABA is the most abundant neurotransmitter in the brain.

Various disorders have been associated with neurotransmitters. Parkinson's disease, characterized by involuntary muscle contractions and tremors, is caused by inadequate production of dopamine. Alzheimer's disease, associated with the deterioration of memory and mental capacity, has been related to decreased production of acetylcholine.

CAREER CONNECTION

Mental Health Worker

Mental health workers must have an extensive knowledge about how the nervous system works. Chemical imbalances in neurotransmitters may contribute to mental health issues, such as depression and other disorders, so these health care providers must be able to identify potential problems and assess patient needs. If helping people and diagnosing problems interests you, becoming a mental health worker might be the career for you.

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Case Study

Drugs and the Synapse

Psychoactive drugs are a group of legal and illegal drugs that exert their effect on the nervous system, disrupting its ability to receive information about the external or internal environment. Because the nervous system is the primary way in which your body receives information about changes in your internal and external environment, anything that distorts the nervous system's operation will create problems.

Under normal circumstances, impulses are relayed between nerve cells in the brain by neurotransmitters. A neurotransmitter released from the presynaptic neuron attaches to receptor sites on the postsynaptic neuron. When enough receptor sites have been filled by the transmitter chemicals, the nerve cell membrane is disrupted and an impulse is initiated—the nerve cell fires. Psychoactive drugs interfere with either the movement of these transmitter molecules or their attachment to the receptor sites.

Depressants, such as tranquillizers, opiates, barbiturates, and alcohol, are a group of psychoactive drugs that slow down the action of the central nervous system. Some depressants delay the effect of transmitter chemicals by slowing the reaction of connecting nerves. Stimulants, such as cocaine, nicotine, amphetamines, and caffeine, are psychoactive drugs that speed up the action of the central nervous system. Some stimulants prevent the neurotransmitters from being broken down or recycled once they have left the receptors. The neurotransmitters remain longer than they normally would and they keep the receptor sites on the postsynaptic neuron full, resulting in more frequent firing of the neuron.

Different drugs act at different points in the normal sequence of events to affect neurotransmission. They may have stimulant or depressant effects by any of the mechanisms listed below.

Effects of a Stimulant on Neurotransmission

(a) A drug mimics the neurotransmitter and stimulates the receptor at the receptor site ((**2**) in **Figure 12**).
(b) A drug decreases the rate of breakdown or diffusion of the neurotransmitter from the receptor site.
(c) A drug increases the rate of release of the neurotransmitter from storage at the presynaptic neuron (**1**).

Effects of a Depressant on Neurotransmission

(a) A drug blocks the receptor site and so the normal neurotransmitter cannot interact with the receptor (**2**) and send an impulse.
(b) A drug decreases synthesis and storage of the neurotransmitter at the presynaptic neuron (**5**).
(c) A drug increases the rate of breakdown of the neurotransmitter on the postsynaptic membrane (**3**) or in the synaptic cleft (**4**).

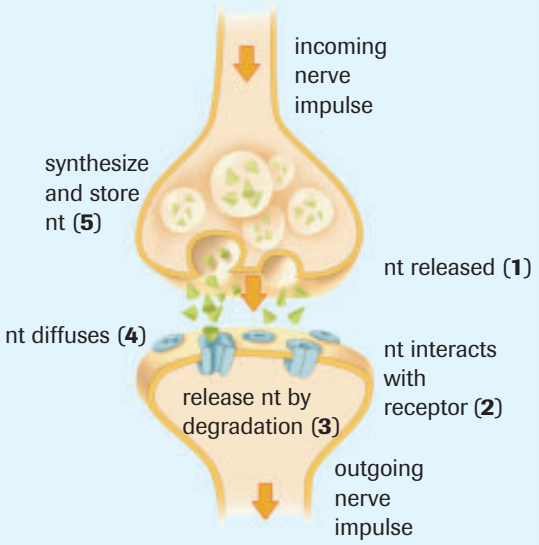

Figure 12
The path of neurotransmitters (nt) in the synapse

Opiates

In the 1970s, scientists discovered that the brain had receptors for opiates such as codeine, morphine, and heroin. These receptors were located in parts of the brain important for breathing, pain, and emotions. Scientists wondered why the brain had these receptors. Later it was discovered that opiates have a similar chemical structure to endorphins, naturally occurring painkillers that the brain manufactures. Endorphins are always in the brain, but they are released in greater amounts when a person is in pain or under stress. Pain is interpreted by specialized cells in the dorsal part of the spinal cord. When stimulated, these cells produce a neurotransmitter that "informs" the injured area of the damage. Increasing the amount of the pain neurostransmitter released increases the perception of pain. Endorphins block the production of pain neurotransmitters and so can block feelings of pain or stress. When people take opiates, the main effect is relief from pain.

In addition to pain relief, opiates cause other effects: euphoria, drowsiness, and reduced anxiety. Not all of the mechanisms by which opiates produce these effects are known. It is generally believed that opiates stimulate the reward pathway in the brain (**Figure 13**, next page). The reward pathway is designed to reinforce behaviours that are essential to survival, such as drinking when thirsty. Stimulating neurons in these pathways brings on pleasant, happy feelings that encourage repetition of the behaviour that led to the stimulation of the pathway. The neurons in the reward pathway use the neurotransmitter dopamine. One theory is that stimulating opiate receptors inhibits the release of the neurotransmitter GABA, which normally inhibits the release of dopamine, so dopamine release is increased in the reward pathway.

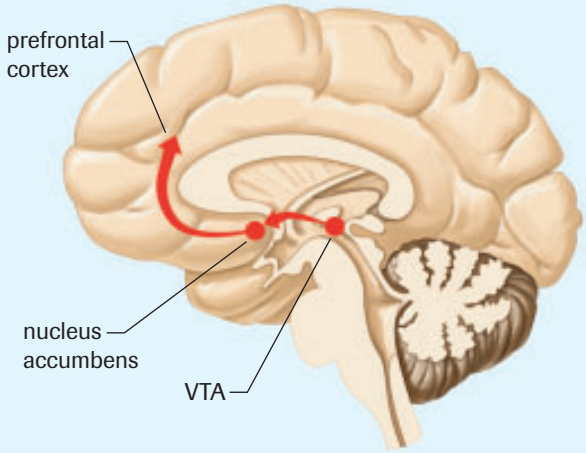

Figure 13
The reward pathway involves three different parts of the brain: the ventral tegmental area (VTA), nucleus accumbens, and the prefrontal cortex.

Alcohol

Alcohol, a depressant, is one of the most widely used and abused of the psychoactive drugs. It affects the central nervous system in many different ways. It enhances the effects of the neurotransmitter GABA, which is an inhibitory transmitter. It also weakens the effect of the neurotransmitter glutamine, which is an excitatory transmitter. Weakening an excitatory transmitter has the same effect as enhancing an inhibitory transmitter: both make a person sluggish. Alcohol does this by interacting with receptors for these neurotransmitters on the postsynaptic membrane. Alcohol also increases the production of endorphins.

Alcohol affects different areas of the brain. In the cerebral cortex, alcohol depresses behavioural inhibitory centres, slows down the processing of information from the senses, and inhibits thought processes. Alcohol affects the hippocampus, causing exaggerated emotions. By acting on the cerebellum, which controls fine motor movement, alcohol inhibits coordination.

Nicotine

Nicotine is one of the most widely used, and most addictive, stimulants. A component of the tobacco plant, it is commonly taken in with cigarette smoke. When inhaled, nicotine reaches the brain in approximately 10 seconds. Nicotine mimics acetylcholine and binds to acetylcholine receptors. This leads to an increase in energy level, heart rate, and breathing rate. When nicotine binds to certain receptor sites, it stimulates the production of endorphins, which promotes the release of the neurotransmitter dopamine in the reward pathway.

Cocaine

Made from a plant called *Erythroxylon coca*, cocaine is a stimulant. It can be taken by chewing on coca leaves, smoked, inhaled ("snorted"), or injected. When cocaine reaches the brain, it causes feelings of euphoria, excitement, reduced hunger, and strength. It also increases heart rate and blood pressure. Cocaine prevents the reuptake of norepinephrine, seratonin, and dopamine, so these remain in the synaptic cleft for a longer time.

Cocaine stimulates neurons in the reward pathway, among other areas of the brain. By stimulating the reward pathway, the user has a feeling of well-being, which reinforces use of the drug.

Addiction

Prolonged use of all these drugs can lead to **addiction**. Addiction is a behavioural phenomenon: a person who is addicted loses self-control. Addicts focus their attention on the drug over all other things, even when they are harming themselves. Addiction also involves two other physical phenomena: physical dependence and tolerance. Physical dependence means that if a person suddenly stops taking the drug, she or he goes through withdrawal. Tolerance means that, over time, a person needs an increased amount of the drug in order to produce the desired effect.

Case Study Questions

1. (a) Provide a diagram that shows how a psychoactive drug interferes with receptor sites on the postsynaptic neuron.
   (b) Why are such diagrams, known as scientific models, useful?
2. Alcohol also decreases the production of acetylcholine. Link decreased production of acetylcholine production to decreased reaction times.
3. Describe the behaviour of a person who has had too much to drink and relate each symptom to events in the central nervous system.
4. Why might someone take opiates?
5. Draw a diagram that shows how an opiate affects the synapse.
6. What is the result of having increased levels of dopamine in the synapses of the reward pathway?
7. During the mid-1990s, the death of two elite basketball players was linked to the use of cocaine. Explain why using a stimulant prior to exercise is dangerous.
8. How might an understanding of the effects of depressants and stimulants affect a person's decisions about whether to take these kinds of drugs?
9. Amphetamines are drugs that are often abused. Find out how amphetamines affect the synapse and the effects they have on the brain.

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SUMMARY Electrochemical Impulse

- Nerves conduct electrochemical impulses from the dendrites along the axon to the end plates of the neuron.
- Active transport and diffusion of sodium and potassium ions establish a polarized membrane.
- An action potential is caused by the inflow of sodium ions.
- Nerve cells exhibit an all-or-none response.
- Neurotransmitters allow the nerve message to move across synapses.

EXTENSION

In Pursuit of Ecstasy

This brief video shows how the recreational drug ecstasy affects neurotransmitters in the brain, and how these changes can have serious side-effects, including permanent changes in brain chemistry and, in a few cases, death.

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Section 13.2 Questions

1. Why was the squid axon particularly appropriate for nerve research?
2. What changes take place along a nerve cell membrane as it moves from a resting potential to an action potential to a refractory period?
3. In **Figure 14**, which area(s) of the graph indicate(s) the opening of Na^+ ion channels and the diffusion of Na^+ ions into the nerve cells? Explain your answer.

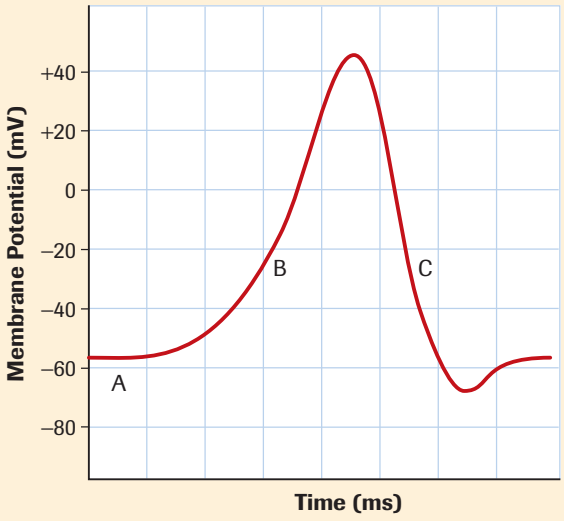

Figure 14
Action potential

4. In **Figure 14**, repolarization occurs in which areas? Explain your answer.
5. Use the synapse model in **Figure 15** to explain why nerve impulses move from neuron A to neuron B, but not from neuron B back to neuron A.

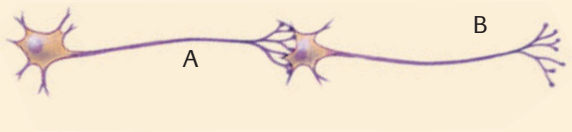

Figure 15
Nerve pathway

6. Explain the functions of acetylcholine and cholinesterase in the transmission of nerve impulses.
7. The action of many psychoactive drugs can be explained in terms of neurotransmitters. Valium, a depressant, interacts with gamma-amino-butyric acid (GABA) transmitter–receptor sites on postsynaptic membranes. The greater the number of receptor sites that are occupied, the more effective the neurotransmitter. LSD and mescaline, both hallucinogenic drugs, are thought to interact with the receptor sites of serotonin.
   (a) Draw a diagram that shows how Valium and hallucinogenic drugs work.
   (b) What dangers exist from taking drugs that interfere with naturally produced neurotransmitter chemicals?
8. The neurotransmitter serotonin is normally involved in temperature regulation, sensory perception, and mood control. A class of compounds known as selective serotonin reuptake inhibitors (SSRIs) has proven highly successful in the treatment of depression, anxiety, and obsessive-compulsive disorder (OCD). (The drug Prozac is a commonly prescribed SSRI.) How do these therapeutic drugs affect serotonin? Are there any risks involved? Search for information in newspapers, periodicals, CD-ROMs, and on the Internet.

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13.3 The Central Nervous System

The central nervous system consists of the brain and spinal cord. The brain is formed from a concentration of nerve tissue in the anterior portion of animals and acts as the coordinating centre of the nervous system. Enclosed within the skull, the brain is surrounded by a tough three-layer protective membrane known as the **meninges**. The outer membrane is called the *dura mater*, the middle layer is the *arachnoid mater*, and the inner layer is the *pia mater*. These three membrane layers protect the brain.

meninges protective membranes that surround the brain and spinal cord

Cerebrospinal fluid circulates between the innermost and middle meninges of the brain and through the central canal of the spinal cord. The cerebrospinal fluid acts both as a shock absorber and a transport medium, carrying nutrients to brain cells while relaying wastes from the cells to the blood. Physicians can extract cerebrospinal fluid from the spinal cord to diagnose bacterial or viral infection. The technique, referred to as a lumbar puncture or spinal tap, is used to identify poliomyelitis and meningitis.

cerebrospinal fluid cushioning fluid that circulates between the innermost and middle membranes of the brain and spinal cord; it provides a connection between neural and endocrine systems

The Spinal Cord

The spinal cord carries sensory nerve messages from receptors to the brain and relays motor nerve messages from the brain to muscles, organs, and glands. Emerging from the skull through an opening called the foramen magnum, the spinal cord extends downward through a canal within the backbone (**Figure 1**). A cross section of the spinal cord reveals the two types of nerve tissue introduced earlier in this chapter: white matter and grey matter. Although the central grey matter consists of nonmyelinated interneurons, the surrounding white matter is composed of myelinated nerve fibres from the sensory and motor neurons. The interneurons are organized into nerve tracts that connect the spinal cord with the brain. A dorsal root brings sensory information into the spinal cord, while a ventral root carries motor information from the spinal cord to the peripheral muscles, organs, and glands (effectors).

DID YOU KNOW ?

Meningitis

Meningitis is caused by a bacterial or viral infection of the outer membranes of the brain. Its symptoms include fever, vomiting, an intense headache, and a stiff neck. If left untreated, bacterial meningitis can lead to death.

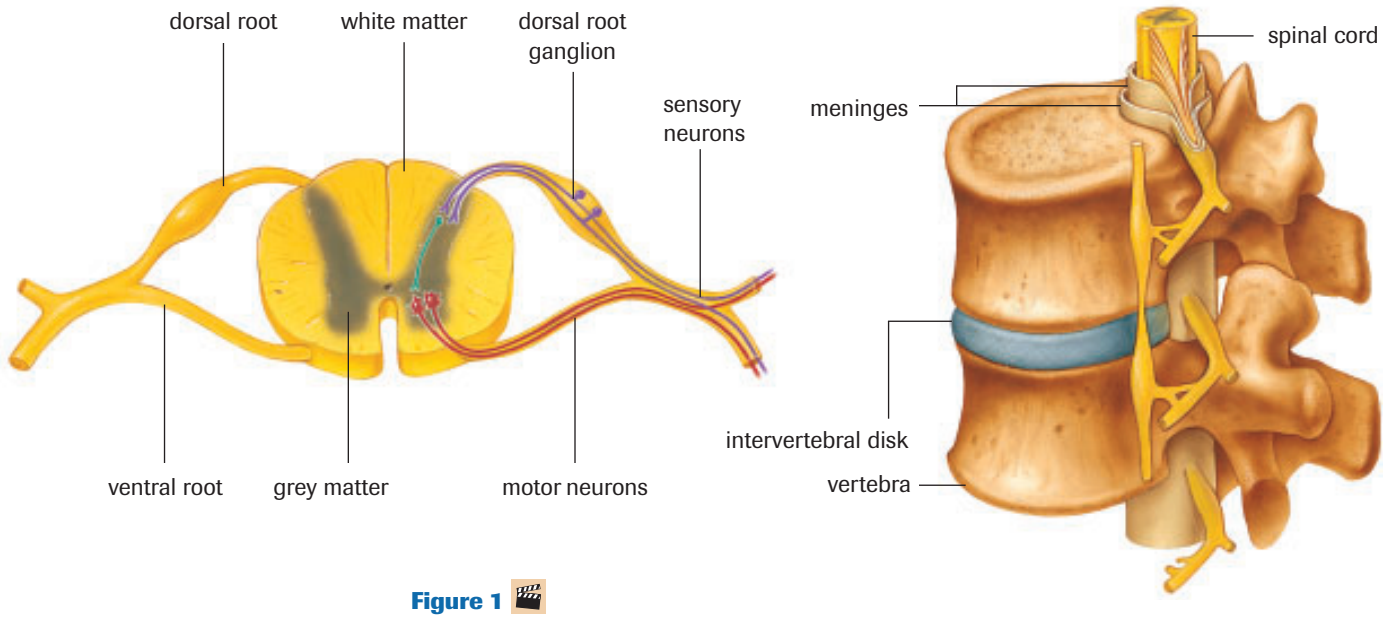

Figure 1
The spinal cord is protected by the vertebral column. Sensory nerves enter the spinal cord through the dorsal root, and motor nerves leave through the ventral root.

WEB Activity

Web Quest—Spinal Cord Research

Spinal cord injuries can be devastating, although most individuals go on to live very complete and active lives. Thanks to advances in spinal cord research, people living with these injuries have more technology and research than ever to support them. This Web Quest takes you deep into the world of spinal cord injury research. You will be required to come up with a persuasive argument for increased funding in one of several remarkable directions, including healing damaged spinal columns, re-growing new cells and even changing the way the body uses the spinal cord.

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Brain Structure and Function

What makes *Homo sapiens* unique is intellect and the reasoning functions of the brain. However, despite its apparent uniqueness, the human brain has developmental links with other chordates (**Figure 2**). As in primitive vertebrates, the human brain comprises three distinct regions: the forebrain, the midbrain, and the hindbrain.

fish (salmon) **reptile** (alligator) **mammal** (dog)

Figure 2
The greatest evolutionary changes in the human brain have occurred in the forebrain. Coloured in blue, the forebrain is the site of reason, intellect, memory, language, and personality.

In humans, the forebrain is greatly enlarged and is comprised of many regions. The **cerebrum** forms the largest part of the forebrain and is divided into left and right hemispheres. These two giant hemispheres act as the major coordinating centre from which sensory information and accompanying motor actions originate. Speech, reasoning, memory, and even personality reside within these paired cerebral hemispheres. The surface of the cerebrum is known as the **cerebral cortex**. Composed of grey matter, the cortex has many folds that increase surface area. The deep folds are known as fissures.

cerebrum largest and most highly developed part of the human brain, which stores sensory information and initiates voluntary motor activities

cerebral cortex outer layer of the cerebral hemispheres

Each hemisphere can be further subdivided into four lobes (**Figure 3**, next page): the frontal lobe, the temporal lobe, the occipital lobe, and the parietal lobe. **Table 1**, on the next page, lists the functions of each of the lobes.

Stimulation of the motor cortex by electrical probes can trigger muscles in various parts of the body. Not surprisingly, the number of nerve tracts leading to the thumb and fingers is greater than the number leading to the arms or legs, since the thumb and fingers are capable of many delicate motor movements. Wrist and arm movements, by contrast, are limited and, therefore, regulated by fewer nerves. **Figure 4**, on the next page, shows parts of the human body drawn in proportion to the number of motor nerves that control them. Note the size of the tongue and mouth. Human speech depends on subtle changes in the position of the tongue and mouth.

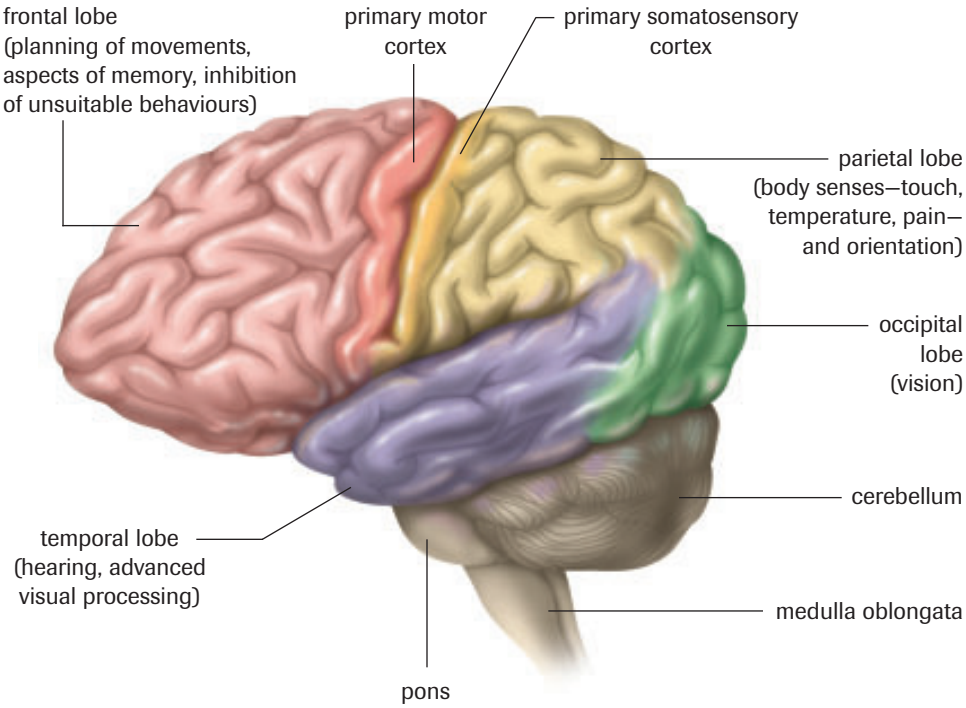

Figure 3
Primary receiving and integrating centres of the human cerebral cortex. Primary cortical areas receive signals from receptors on the body's periphery. Association areas coordinate and process sensory input from different receptors.

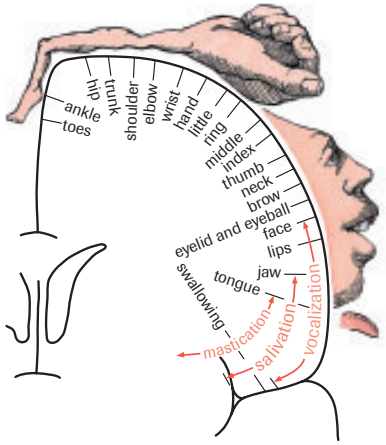

Figure 4
Regions of the body are drawn in proportion to the area of the motor cortex required to control the region.

Table 1 The Lobes of the Cerebrum

Lobe	Function
frontal lobe	• Motor areas control movement of voluntary muscles (e.g., walking and speech). • Association areas are linked to intellectual activities and personality.
temporal lobe	• Sensory areas are associated with vision and hearing. • Association areas are linked to memory and interpretation of sensory information.
parietal lobe	• Sensory areas are associated with touch and temperature awareness. • Association areas have been linked to emotions and interpreting speech.
occipital lobe	• Sensory areas are associated with vision. • Association areas interpret visual information.

corpus callosum nerve tract that joins the two cerebral hemispheres

thalamus area of brain that coordinates and interprets sensory information and directs it to the cerebrum

hypothalamus area of the brain that coordinates many nerve and hormone functions

Research has demonstrated that information stored in one side of the brain is not necessarily present in the other. The right side of the brain has been associated with visual patterns or spatial awareness; the left side of the brain is linked to verbal skills. Your ability to learn may be related to the dominance of one of the hemispheres. A bundle of nerves called the **corpus callosum** (**Figure 5**, next page) allows communication between the two hemispheres.

The thalamus, hypothalamus, and olfactory bulbs are also part of the forebrain. The **thalamus** acts as a relay station, directing incoming sensory information to the appropriate parts of the cerebrum for interpretation. The **hypothalamus** is a small part of the brain but it plays a large role in maintaining the body's internal equilibrium. A direct connection between the hypothalamus and the pituitary gland unites the nervous system with the endocrine system. (The role of the hypothalamus and the endocrine system

will be discussed in greater detail in chapter 15.) Located on the bottom of the temporal lobes, the **olfactory bulbs** receive and interpret information about smell.

olfactory bulb area of the brain that processes information about smell; one bulb in each hemisphere

The midbrain lies just below the thalamus. Consisting of four spheres of grey matter, the midbrain acts as a relay centre for some eye and ear reflexes. The hindbrain, as the name suggests, is found posterior to the midbrain and joins with the spinal cord. The cerebellum, pons, and medulla oblongata are the major regions of the hindbrain. The **cerebellum**, located immediately beneath the two cerebral hemispheres, is the largest section of the hindbrain. The cerebellum controls limb movements, balance, and muscle tone. Have you ever considered the number of coordinated muscle actions required to pick up a pencil? The hand must be opened before it touches the pencil; the synchronous movement of thumb and fingers requires coordination of both excitatory and inhibitory nerve impulses.

cerebellum part of the hindbrain that controls limb movements, balance, and muscle tone

The **pons**, meaning "bridge," is largely a relay station that passes information between the two regions of the cerebellum and between the cerebellum and the medulla. The posterior region of the hindbrain is the **medulla oblongata**. Nerve tracts from the spinal cord and higher brain centres run through the medulla, which acts as the connection between the peripheral and central nervous systems. The medulla oblongata controls involuntary muscle action. Breathing movements, the diameter of the blood vessels, and heart rate are but a few things regulated by this area of the hindbrain. The medulla oblongata also acts as the coordinating centre for the autonomic nervous system.

pons region of the brain that acts as a relay station by sending nerve messages between the cerebellum and the medulla

medulla oblongata region of the hindbrain that joins the spinal cord to the cerebellum; one of the most important sites of autonomic nerve control

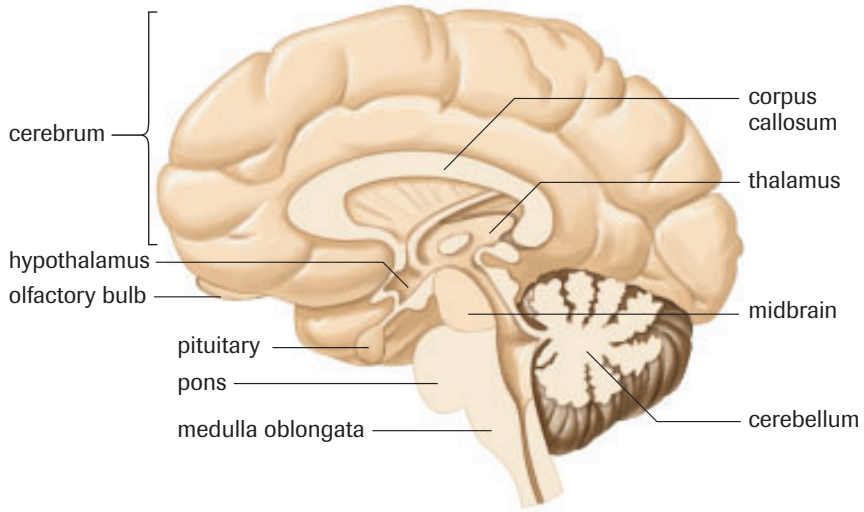

Figure 5
The human brain cut lengthwise between the two cerebral hemispheres

Practice

1. List the parts of the forebrain.
2. List the parts of the hindbrain.
3. What is the structure that connects the two cerebral hemispheres?
4. What is the function of the pons?

INVESTIGATION 13.2 *Introduction*

Brain Dissection

In this investigation you will perform a dissection of a sheep's brain to identify principal brain structures and relate them to human brain structures.

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

To perform this investigation, turn to page 437.

Figure 6
In the 1940s and early 1950s, Dr. Wilder G. Penfield studied brain structure and function in living humans using a surgical procedure.

WEB Activity

Canadian Achievers—Dr. Wilder G. Penfield

Dr. Wilder G. Penfield (1891–1976), founder of the Montreal Neurological Institute, was the foremost pioneer in brain mapping. Using electrical probes, Penfield (**Figure 6**) located three speech areas within the cerebral cortex. Interestingly, the predominant speech areas reside on the left side of the brain. Penfield's finding dismissed the once-held notion that the two hemispheres were mirror images of each other. Penfield also spent a great deal of his time mapping the cerebral cortex of people with epilepsy. Penfield developed a surgical technique that involved removing a section of the skull and probing the brain with electrodes to locate the diseased area. Find out more about Dr. Penfield and how his research improved understanding and treatment of this brain disorder.

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Case Study

Phineas Gage

In September 1848, a thunderous explosion shook the ground near the small town of Cavendish, Vermont. Phineas Gage, the 25-year-old foreman of a railway construction crew, lay on the ground impaled by a tamping iron. Apparently Gage had accidentally set off blasting caps by tamping them with a large iron bar. A closer examination revealed that the metre-long bar had entered his skull immediately below the left eye and exited through the top of the skull (**Figure 7**). Incredible as it may seem, Phineas Gage recovered from the explosion and lived for another 12 years. He showed no signs of physical impairment. His vision, hearing, balance, and speech remained intact. However, he did experience one change: the once quiet and thoughtful Phineas became irresponsible and short-tempered. Spontaneous temper tantrums would send him into a fit of profanity. What could have triggered such changes?

Case Study Questions

1. Which lobe of Gage's brain was damaged?
2. Provide a hypothesis to explain why Phineas Gage's personality changed. How would you test your hypothesis?
3. In 1949, Portuguese neurologist Antonio Egas Moniz received the Nobel Prize for his surgical procedure—known as prefrontal leukotomy—in which some of the nerve tract between the thalamus and the frontal lobes is severed. Why might a physician attempt such an operation?

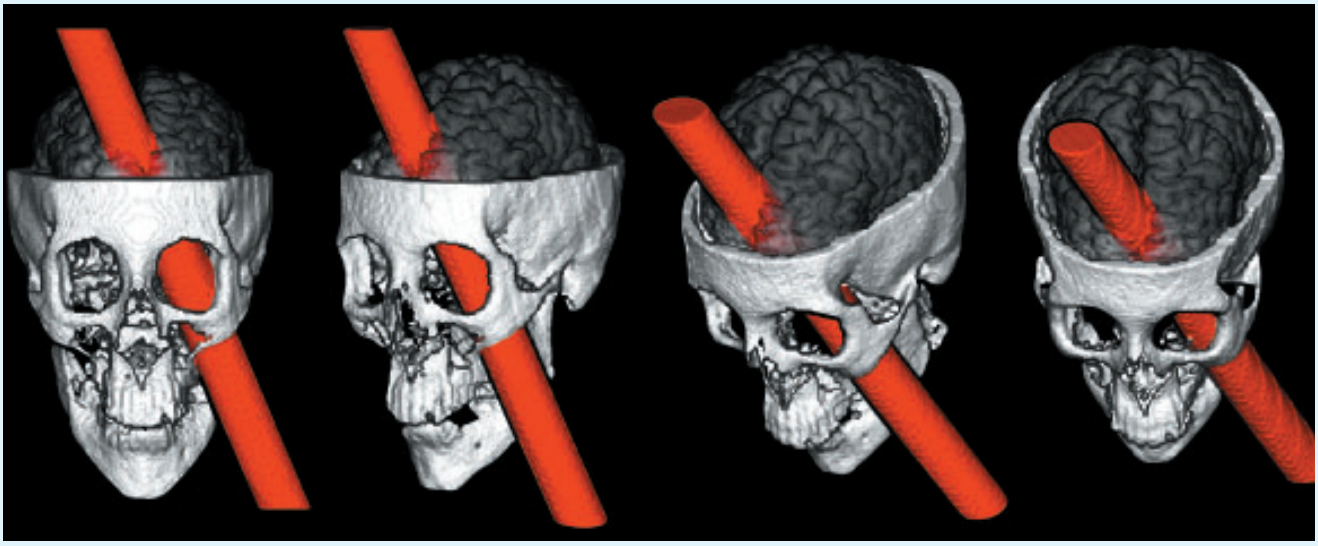

Figure 7
Computer model of the skull of Phineas Gage shown from four angles

WEB Activity

Case Study—Neuroimaging

Non-invasive imaging techniques are now available to researchers studying normal body functions and to physicians diagnosing various disorders, including cancer. These techniques are especially useful in neuroimaging—viewing the brain. Visit the Nelson Web site to learn more about positron-emission tomography (PET scans) and magnetic resonance imaging (MRI) (**Figure 8**) and other techniques. How do these techniques work and what can they reveal about the brain?

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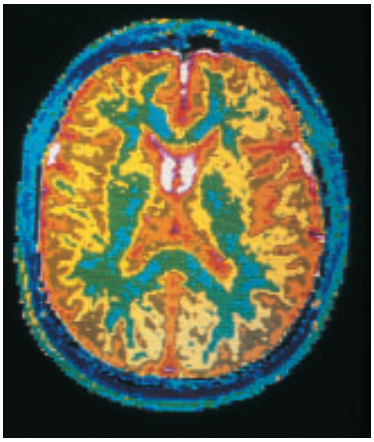

Figure 8
MRI image of a normal human brain

Research into Treatments for Alzheimer's Disease

Alzheimer's disease is a progressive, degenerative neurological disease often linked with aging. The most common symptoms are deterioration of thinking and of memory. Although it is more common in people over 65 years of age, it can affect people in their 40s. The cause of Alzheimer's disease is unknown. While family history puts individuals at a slightly higher risk, there is no clear genetic cause. Scientists currently believe that environmental factors, such as water or air pollution, may play a greater role in the development of the disease. In 2005, an estimated 280 000 Canadians over the age of 65 had Alzheimer's disease. By the year 2031, experts predict that the number will rise to 509 000.

One of the characteristics of brain tissue of Alzheimer's patients is the production of plaques and tangles (**Figure 9**). Plaques are created when a normal process goes awry. Healthy brains have microscopic deposits that contain a protein called beta amyloid. The beta amyloid has been split off from a larger protein by enzymes called secretases. In the brain of an Alzheimer's patient, secretases appear to work too well and produce too much beta amyloid. The large amounts of beta amyloid are deposited as amyloid plaques, which destroy neurons. Tangles form when healthy neurons begin to grow and behave abnormally. These tangles eventually choke and kill the neuron. As more neurons die, the patient loses brain tissue.

Knowing the biological basis of the disease gives researchers ideas about how to treat it. One of the most ambitious research efforts has been directed toward finding a vaccine to prevent the disease. By injecting antibodies against beta amyloids, researchers hope to reduce abnormal levels in Alzheimer's patients.

EXTENSION

Profile: Erich Jarvis

The work of neuroscientist Erich Jarvis demonstrates the power of open-mindedness in the lab. Find out why he chose a career in science over dance, why he calls himself a scientific artist, and why he finds bird brains so interesting by viewing this *NOVA* video.

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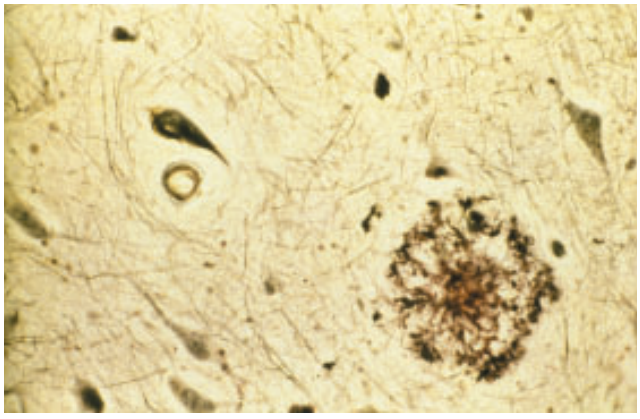

Figure 9
The large dark patch, lower right, is a beta amyloid plaque. The dark triangle, upper left, is a neuron filled with tangles.

EXTENSION

Secrets of the Mind: Probe the Brain

Canadian brain surgeon Wilder Penfield mapped the brain's motor cortex by applying mild electric currents to the exposed brains of patients.

In this *NOVA* simulation, you will apply a virtual electric probe to an exposed brain. You will apply small shocks and observe how the body responds.

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SUMMARY The Central Nervous System

Table 2 Function of the Main Structures of the Central Nervous System

Structure	Function
meninges	• protective membranes that surround the brain and spinal cord
cerebrospinal fluid	• circulates between the innermost and middle membranes of the brain and spinal cord • acts as a transport medium and shock absorber (cushion)
cerebrum	• the largest and most highly developed part of the human brain • stores sensory information and initiates voluntary motor activities
cerebral cortex	• the outer layer of the cerebral hemispheres
corpus callosum	• a nerve tract that allows communication between the two cerebral hemispheres
cerebellum	• the region of the brain that coordinates muscle movement
hypothalamus	• maintains the body's internal equilibrium
pons	• the region of the brain that acts as a relay station by sending nerve messages between the cerebellum and the medulla
medulla oblongata	• the hindbrain region that joins the spinal cord to the cerebellum • the site of autonomic nerve control

Section 13.3 Questions

1. List the four regions of the cerebral cortex and state the function of each.
2. Name the different areas of the brain labelled on **Figure 10** and indicate the functions of the different areas.

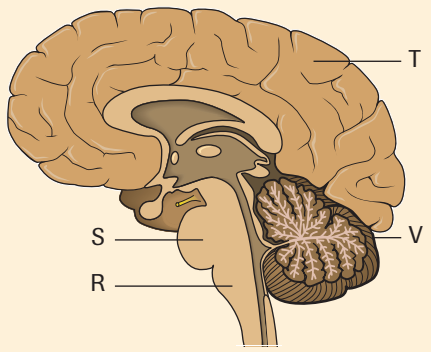

Figure 10
Human brain

3. A physician makes an incision completely through the corpus callosum. How might this affect the patient?
4. Compare the evolutionary development of the human brain to that of a fish's brain. What special advancements are noted in the human brain?
5. The old saying that "an elephant never forgets" seems to have some basis. What area of the brain would you examine to begin researching this question? Explain why.
6. Studies have been conducted to attempt to demonstrate the mental or reasoning superiority of some people based on skull size. Critique these studies.
7. Conduct an information search on strokes, including the causes, risk factors, warning signs, and effects on the various body systems. Include statistics on the incidence of strokes in Canada and on some lifestyle strategies for reducing the risk of stroke. Prepare a poster summarizing your research results in the form of charts, graphs, and tables. Be prepared to share your findings with your class. Search for information in newspapers, periodicals, CD-ROMs, and on the Internet.

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8. The EEG has been used to legally determine death. Although the heart may continue to beat, the cessation of brain activity signals legal death. Ethical problems arise when some brain activity remains despite massive damage. Artificial resuscitators can assume the responsibilities of the medulla oblongata and regulate breathing movements. Feeding tubes can supply food, and catheters can remove wastes when voluntary muscles can no longer be controlled. The question of whether life should be sustained by artificial means has often been raised. Should a machine like the EEG be used to define the end of life? Explain your answer.

The Peripheral Nervous System 13.4

The peripheral nervous system is composed of two divisions, the sensory-somatic and the autonomic nervous system. Both of these systems are composed of sensory neurons, which run from stimulus receptors to the central nervous system (CNS), and motor neurons, which run from the CNS to muscles or organs that take action. The sensory-somatic nervous system senses and responds to external stimuli, and the autonomic nervous system responds to internal stimuli (**Figure 1**).

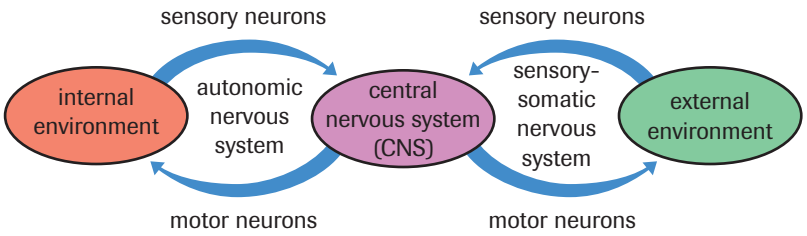

Figure 1
Both divisions of the peripheral nervous system interact with the central nervous system.

The Sensory-Somatic System

The sensory-somatic nervous system brings information about the external environment to the CNS and sends information back to the skeletal muscles. The sensory-somatic nervous system is considered to be under voluntary (somatic) control because you can, for the most part, control the movement of your muscles. However, reflex arcs, which are involuntary, also fall under the sensory-somatic nervous system.

This system is composed of 12 pairs of cranial nerves (nerves that originate in the brain) and 31 pairs of spinal nerves. Some of these nerves have only sensory neurons, others have motor neurons, and others have both sensory and motor neurons. The cranial nerves control vision, hearing and balance, taste and smell, facial and tongue movements, and muscles of the head and neck among other things. The spinal nerves innervate the skeletal muscles for the rest of the body. All our conscious awareness of our surroundings and all our actions to cope with them operate through the sensory-somatic nervous system.

The Autonomic Nervous System

The autonomic nervous system brings information about the body's internal environment to the CNS and carries signals back to regulate the internal environment. So the autonomic nervous system controls smooth muscle, cardiac muscle, the internal organs, and glands. Unlike the sensory-somatic nervous system, this control is involuntary. For example, rarely do you consciously direct your breathing movements. Blood oxygen levels are monitored throughout the body. If levels fall below the normal range, autonomic nerves act to restore oxygen levels by increasing your breathing rate and heart rate.

The autonomic nervous system also differs anatomically from the sensory-somatic nervous system. It uses two groups of motor neurons to stimulate the target effectors (muscles, organs, or glands). The first group, the preganglionic neurons, run from the CNS to a ganglion where they connect with a second group, the postganglionic neurons, which then run to the target organ, muscle, or gland.

DID YOU KNOW?

How Polygraphs Work

Lie detectors (also known as polygraphs) monitor changes in the activity of the sympathetic nervous system. One component of a lie detector, the galvanic skin response, checks for small changes in perspiration. In theory, a stressful situation, such as lying, would cause the stimulation of sympathetic nerves, which, in turn, would activate the sweat glands. Increased breathing and pulse rates are also monitored by lie detectors. Because lie detectors cannot always differentiate between lying and other stressful situations, they are not considered 100 % accurate.

sympathetic nervous system
nerve cells of the autonomic nervous system that prepare the body for stress

parasympathetic nervous system
nerve cells of the autonomic nervous system that return the body to normal resting levels after adjustments to stress

The autonomic system is made up of two distinct, and often opposing, units, the **sympathetic nervous system** and **parasympathetic nervous system** (**Figure 2**). The sympathetic system prepares the body for stress, while the parasympathetic system reverses the effects of the sympathetic nervous system and restores the body to normal. **Table 1**, on the next page, summarizes the effects of the autonomic nervous system. Sympathetic and parasympathetic nerves also differ in anatomy. Sympathetic nerves have a short preganglionic nerve and a longer postganglionic nerve; the parasympathetic nerves have a long preganglionic nerve and a shorter postganglionic nerve. The preganglionic nerves of both systems release acetylcholine, but the postganglionic nerve from the sympathetic system releases norepinephrine. The postganglionic nerves from the parasympathetic system release acetylcholine and nitric oxide. The sympathetic nerves

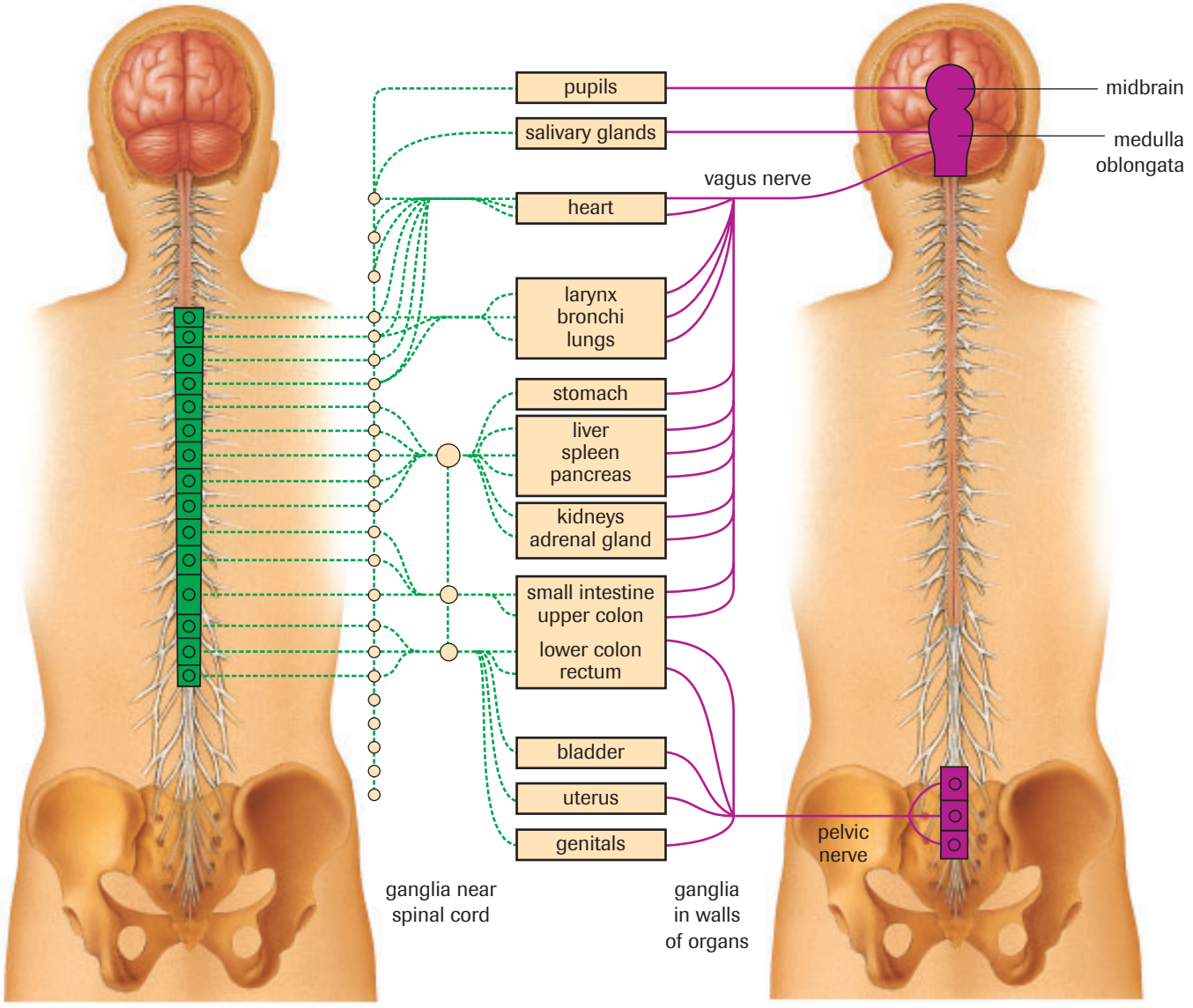

Figure 2
The sympathetic nerves are shown in green, and the parasympathetic nerves are shown in purple.

Table 1 Some Effects of the Autonomic Nervous System

Organ	Sympathetic	Parasympathetic
heart	increases heart rate	decreases heart rate
digestive tract	decreases peristalsis	increases peristalsis
liver	increases the release of glucose	stores glucose
eyes	dilates pupils	constricts pupils
bladder	relaxes sphincter	contracts sphincter
skin	increases blood flow	decreases blood flow
adrenal gland	causes release of epinephrine	no effect

CAREER CONNECTION

Chiropractor

Chiropractors treat disorders of the musculoskeletal system by manipulating the spinal column. They often work with massage therapists, physiotherapists, and physicians and may interpret X-rays, make diagnoses, and develop treatment plans.

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come from the thoracic vertebrae (ribs) and lumbar vertebrae (small of the back). The parasympathetic nerves exit directly from the brain or from either the cervical (the neck area) or caudal (tailbone) sections of the spinal cord. An important cranial nerve of the parasympathetic system is the **vagus nerve** (*vagus* meaning "wandering"). Branches of the vagus nerve innervate the heart, bronchi of the lungs, liver, pancreas, and the digestive tract.

vagus nerve major cranial nerve that is part of the parasympathetic nervous system

SUMMARY The Peripheral Nervous System

- The peripheral nervous system is made up of the sensory-somatic and the autonomic nervous systems. Together they sense and respond to external and internal stimuli.
- The autonomic nervous system consists of the sympathetic and parasympathetic systems. The sympathetic system prepares the body for stress; the parasympathetic system returns the body to a resting state.

Section 13.4 Questions

1. State the similarities and differences between the two divisions of the peripheral nervous system.
2. State the two divisions of the autonomic nervous system and compare their structures and functions.
3. What are the functions of the vagus nerve?
4. How do sympathetic and parasympathetic nerves differ from one another?
5. Many prescription drugs affect the autonomic nervous system. **Table 2** describes the action of four different drugs.
   (a) Which drug should not be taken by someone who has high blood pressure? Give reasons for your answer.
   (b) A patient who has taken too much neostigmine is admitted to hospital. What symptoms would be displayed?

Table 2 Drug Actions

Drug	Action
pilocarpine	produces effects similar to the parasympathetic nervous system
resperine	inhibits the activity of the sympathetic nervous system
ephedrine	stimulates the release of norepinephrine from postganglionic nerves
neostigmine	blocks the action of cholinesterase at synapses

INVESTIGATION 13.1

Reflex Arcs

Reflex arcs make up the neural circuit that travels through the spinal cord, providing a framework for reflex actions. Simple physical tests are used to check reflexes. In this investigation, you will observe the presence and strength of a number of reflex arcs and design an investigation about the blink reflex. Read through the investigation, then write a prediction on what will happen in each part of the procedure. Then, formulate and record a hypothesis to explain your predictions. Make sure you make clear notes of all your observations as you gather evidence for the investigation.

Report Checklist

- ● Purpose
- ○ Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

Problem

What is the advantage of being able to test different reflexes?

Materials

rubber reflex hammer
penlight

Procedure

Part 1: Knee Jerk

1. Find a partner. You will act as each other's subjects.
2. Have your subject sit on a chair with his or her legs crossed. The subject's upper leg should remain relaxed.
3. Locate the position of the kneecap and find the large tendon below the midline of the kneecap.
4. Using a reflex hammer, gently strike the tendon below the kneecap.
5. Ask the subject to clench a book with both hands, then strike the tendon of the upper leg once again.

Part 2: Achilles Reflex

6. Have the subject remove a shoe. Ask your subject to kneel on a chair so that his or her feet hang over the edge of the chair. Push the toes toward the legs of the chair and then lightly tap the Achilles tendon with the reflex hammer.

Part 3: Babinski Reflex

7. Now ask the subject to remove a sock. Have the subject sit in a chair, then place the heel of the bare foot on another chair for support. Quickly slide the reflex hammer along the sole of the subject's foot, beginning at the heel and moving toward the toes.

Part 4: Pupillary Reflex

8. Have the subject close one eye for approximately 1 min. Ask him or her to open the closed eye. Compare the size of the pupils.
9. Ask the subject to close both eyes for 1 min, then open both eyes. Shine a penlight in one of the eyes.
10. Select a student with light-coloured eyes to be the subject. With at least two observers carefully watching the subject's eyes, gently stroke the fine hairs on the nape of the subject's neck.

Part 5: The Blink Reflex

11. The eye blinks when an object moves toward the eye. Design an experiment to investigate conditions that initiate the reflex. Consider any of the following questions.
    - What size of object is required to initiate the blink reflex?
    - At what speed must the object move to cause the reflex?
    - At what distance from the eye is the reflex initiated?

(a) Present your design to your teacher for approval prior to conducting your investigation.

Caution: Be careful when moving objects close to the eyes to avoid injury.

Analysis

(b) From your observations, formulate a hypothesis about the sequence of events that occur in the nervous system in each part of the procedure.

(c) How does the knee-jerk reflex change when the subject is clenching the book? Why do you think this is?

(d) What is the purpose of testing different reflexes?

(e) What conclusions, if any, can you draw from the data from your investigation of the blink reflex?

INVESTIGATION 13.1 *continued*

Synthesis

(f) Explain why the knee-jerk and Achilles reflexes are important in walking.

(g) A person touches a stove, withdraws his or her hand, and then yells. Why does the yelling occur after the hand is withdrawn? Does the person become aware of the pain before the hand is withdrawn?

INVESTIGATION 13.2

Report Checklist

● Purpose	● Design	● Analysis
○ Problem	● Materials	○ Evaluation
○ Hypothesis	○ Procedure	○ Synthesis
○ Prediction	● Evidence	

Brain Dissection

An examination of the preserved brain of a sheep or any other mammal will provide enough similarities to be useful for structural and general functional comparisons to be made between it and the human brain. The main difference between the human and most other mammalian brains is the larger human cerebrum.

Purpose

To examine the structures of a mammalian brain and relate those structures to the functions of the human brain.

Materials

safety goggles
lab apron
latex gloves
dissecting tray
forceps
scalpel
probe
model of human brain and diagrams showing different sheep brain views

See Appendix B2 for notes on lab safety during a dissection. Take particular care when using a scalpel.

Procedure

Part 1: External Structure

1. Obtain a sheep brain, examine the dorsal, lateral, and ventral views (**Figure 1**), and identify the three major structures that are easily seen:

- The large cerebrum is composed of the two cerebral hemispheres. They form the largest part of the brain and also make up the largest part of the forebrain.
- The cerebellum is the highly convoluted structure behind the cerebrum and above the brain stem. The cerebellum is part of the hindbrain.
- The brain stem extends from the spinal cord (the cut region) through the base and part of the central interior of the brain. Because the brain stem extends the length of the brain, it includes a portion of the hindbrain, the forebrain, and all of the midbrain.

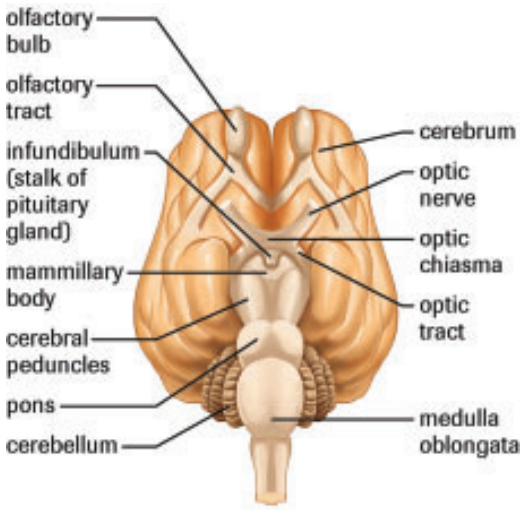

Figure 1
Sheep's brain, ventral view

INVESTIGATION 13.2 *continued*

2. Examine the cerebrum and note the convoluted appearance of its surface. A membrane called the meninges covers the surface of the cerebrum. (Depending on the preservation technique, the meninges may or may not be present.)

(a) Name and describe the functions of the three membranes that make up the meninges.

3. The convolutions are formed by the raised areas or ridges, called gyri, and the depressed areas, called fissures. The major fissures divide the important lobes of the cerebrum. The mammalian cerebrum is much more convoluted than the brains of other vertebrates, such as birds, reptiles, amphibians, and fish.

(b) What is the significance of these convolutions? How do they provide mammals with an advantage?

4. Refer to a model or diagrams of the human brain to help you locate the corresponding fissures and lobes of the sheep cerebrum. Note any differences and similarities in the cerebrums.
   - The longitudinal fissure divides the two cerebral (right and left) hemispheres.
   - The central fissure extends from the top of each cerebral hemisphere to the lateral fissure.
   - The parieto-occipital fissure is not visible externally, but is found near the back of the cerebrum deep in each cerebral hemisphere.
   - The frontal lobe is in front of the central fissure and the parietal lobe is behind this fissure, extending to the region of the parieto-occipital fissure.
   - Behind the parieto-occipital fissure is the occipital lobe.
   - Below the lateral fissure and extending to the occipital lobe is the temporal lobe.

(c) List the cerebral lobes and describe the major human functions located in each. Gently move the cerebral hemispheres apart to expose the corpus callosum.

(d) Describe the function of the corpus callosum.

5. Locate the highly convoluted cerebellum, which lies posterior to the cerebral hemispheres. Compare the cerebellum of the sheep brain with a model or diagrams of the human brain. Note that the sheep brain is not divided longitudinally, as is the human cerebellum.

(e) What is the function of the cerebellum?

6. Examine the ventral surface of the sheep brain and locate the medulla oblongata, which begins where the spinal cord widens, just below the cerebellum. The medulla oblongata contains regions where motor nerves from the right side of the cerebrum cross over to the left side of the spinal cord, and vice versa. Some sensory nerves travelling to the brain also cross over in the medulla, and others cross over where the nerve enters the spinal cord.

(f) What centres that control vital autonomic functions are located in the medulla oblongata?

7. While holding the occipital lobes, gently pull down and back on the cerebellum. In the cavity toward the centre of the brain a small, bulbous mass will be seen. This is the pineal gland of the forebrain, which secretes the hormone melatonin. The pineal gland has nerve connections with the eyes. Melatonin regulates reproductive functions related to light and changes in the seasons, marked by the amount of daylight. The precise role of melatonin and the pineal gland and how they regulate biological rhythms associated with reproduction in humans is uncertain.

(g) Research the role of melatonin and the pineal gland in their regulation of biological rhythms in other vertebrates.

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8. Just below the pineal gland are four rounded structures of the midbrain called the corpora quadrigemina. The two upper structures carry nerve impulses from the eyes and are involved with reflex responses to visual stimuli. The lower two structures relay impulses from the ears to the auditory areas of the cerebrum.

9. Examine the ventral surface of the brain. Moving forward from the spinal cord, note that just in front of the medulla oblongata is a rounded structure called the pons.

(h) What is the function of the pons?

Anterior to the pons are the rounded cerebral peduncles, which carry nerve tracts to and from the medulla oblongata and the cerebral hemispheres. The mammillary body is a rounded structure in front of the cerebral peduncles and below the hypothalamus. In the sheep brain, the mammillary body is a single structure, whereas in humans it is double. The mammillary body is a relay station for olfactory neurons.

INVESTIGATION 13.2 *continued*

(i) Describe the functions of the hypothalamus.

Below the hypothalamus and in front of the mammillary body is the infundibulum, the stalk to which the pituitary gland is attached. The pituitary gland may not be present, as it is sometimes broken off during preparation of the brain.

10. The optic chiasma forms an X in front of the infundibulum.

(j) Explain the significance of the optic chiasma in relation to the right and left retinas and the right and left occipital lobes.

Locate the olfactory bulbs in front of the optic chiasma, at the base of the frontal lobes of the cerebrum.

(k) Describe the function of the olfactory bulbs.

Part 2: Internal Structure

11. Observe the internal view (**Figure 2**) of a sheep brain that has been dissected in the sagittal plane. If the brain has not already been dissected, use your scalpel to cut vertically down the midline of the brain. Locate the following structures that were seen in the dorsal and ventral views of the whole brain: cerebrum, corpus callosum, cerebellum, medulla oblongata, spinal cord; pineal gland, corpora quadrigemina; pons, cerebral peduncle, mammillary body, infundibulum, optic chiasma, and olfactory bulb.

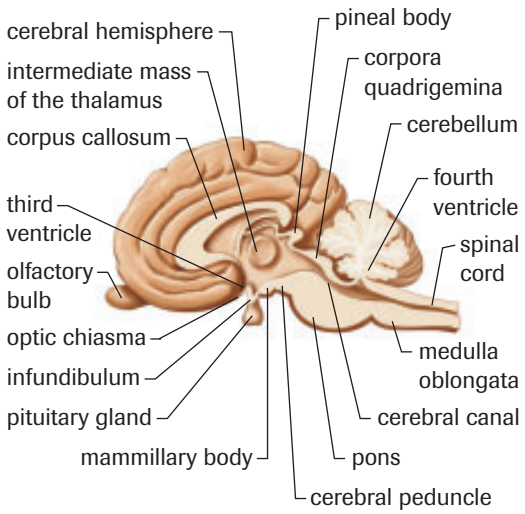

Figure 2
Sheep's brain, internal view

12. Note the difference in colour of the outer and inner regions of the cerebellum. Note also how this colour difference follows the convolutions. This is also characteristic of the cerebrum.

(l) Explain the significance of the difference in colour and its relationship to the convolutions.

(m) Explain why the corpus callosum is only one colour.

13. Locate the four ventricles of the brain. These ventricles develop from an enlargement of the cavity in the embryonic neural tube. The ventricles are filled with cerebrospinal fluid, which also surrounds the brain and the spinal cord beneath the meninges.

(n) Describe the composition of the cerebrospinal fluid.

The two lateral ventricles (the first and second ventricles) extend mostly into the parietal lobe and partly into the frontal and occipital lobes of the cerebral hemispheres, beginning from a region beneath the corpus callosum. Insert a blunt probe into the small opening below the corpus callosum to explore one of the lateral ventricles. A thin membrane on the surface of each ventricle contains a network of capillaries called the choroid plexus. These membranes and the choroid plexus capillaries produce the cerebrospinal fluid. This fluid drains from the lateral ventricles into the third ventricle, which is between the right and left masses of the thalamus. The thalamus is above the mammillary body and the hypothalamus. The hypothalamus forms the floor of the third ventricle. The third ventricle drains posteriorly through a narrow canal above the cerebral peduncle. This canal enlarges between the medulla oblongata and the cerebellum to form the fourth ventricle. Continuing posteriorly, the fourth ventricle forms a narrow canal called the central spinal canal. Where this canal begins is considered to be the beginning of the spinal cord. The cerebrospinal fluid also flows from the fourth ventricle along the dorsal surface of the spinal cord and around to its ventral surface. From the ventral surface it then begins to flow anteriorly until it reaches the brain. As the cerebrospinal fluid flows over the brain, it is reabsorbed into blood capillaries in the arachnoid layer of the meninges.

(o) Describe the functions of the ventricles and the cerebrospinal fluid.

Chapter 13 SUMMARY

Outcomes

Knowledge

- describe a neuron and myelin sheath, explaining the formation and transmission of an action potential and the transmission of a signal across a synapse and the main chemicals and transmitters involved (13.1, 13.2)
- identify structures of the central and peripheral nervous systems and explain their functions in regulating the voluntary (somatic) and involuntary (autonomic) systems, (13.1, 13.3, 13.4)
- describe the organization of neurons into nerves and simple reflex arcs (13.1)

STS

- explain that scientific knowledge and theories develop through hypotheses, collection of experimental evidence and by providing explanations (13.1)
- explain that scientific investigation includes analyzing evidence and providing explanations based on scientific theories and concepts (13.2)
- explain that the goal of technology is to provide solutions to practical problems (13.3)

Skills

- conduct investigations and record data by: investigating the physiology of reflex arcs (13.1); observing neurons and synapses (13.3); and observing a mammalian brain and identifying structures (13.3)
- analyze data and apply concepts (13.1, 13.3)
- work as members of a team (all)

Key Terms

13.1

central nervous system (CNS)
peripheral nervous system (PNS)
glial cell
neuron
dendrite
axon
myelin sheath
Schwann cell
nodes of Ranvier
neurilemma
sensory neuron
sensory receptor
ganglion
interneuron
motor neuron
effector
reflex arc

13.2

action potential
resting potential
facilitated diffusion
gated ion channel
sodium-potassium pump
active transport
polarized membrane
depolarization
repolarization
hyperpolarization
refractory period
saltatory conduction
threshold level
all-or-none response
synapse
neurotransmitter
presynaptic neuron
postsynaptic neuron
acetylcholine
cholinesterase
summation
addiction

13.3

meninges
cerebrospinal fluid
cerebrum
cerebral cortex
corpus callosum
thalamus
hypothalamus
olfactory bulb
cerebellum
pons
medulla oblongata

13.4

sympathetic nervous system
parasympathetic nervous system
vagus nerve

MAKE a summary

1. Construct a mind map of the nervous system by linking key terms. Begin with **Figure 1**, page 408, in Section 13.1.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 13
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

EXTENSION

Mirror Neurons

A recently discovered system in the brain may help explain why we humans can get so worked up watching other people. Watch this *NOVA* video to find out some explanations of this phenomenon.

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Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. The nervous and endocrine systems are similar, in that they both
   A. regulate body movement
   B. have prolonged effects on target organs
   C. respond to changes in equilibrium to maintain homeostasis
   D. respond to changes in the external environment, but do not respond to changes in the internal environment

2. The primary function of the myelin sheath is to
   A. supply nutrients to the axon
   B. increase the speed at which nerve impulses travel
   C. conduct active transport of potassium ions
   D. regulate the diffusion of sodium ions across the synapse

Use the following information to answer questions 3 and 4.

Figure 1 shows a reflex arc. The neurons that make up the arc are labelled with roman numerals.

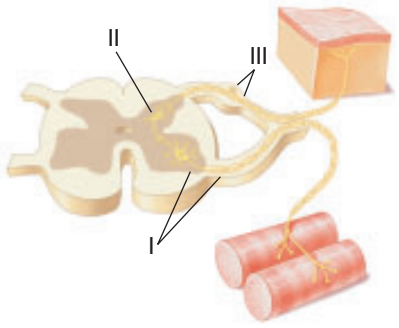

Figure 1

3. If neuron I were severed,
   A. the sensory receptor would detect touch, but the muscle would not contract
   B. the muscle would still be capable of contracting, but sensory information would not be relayed to the CNS
   C. the reflex arc would not work because sensory information is not received by the CNS
   D. it would be impossible for the information received by the sensory neuron to travel to the brain

4. The order in which an impulse travels along the reflex arc is
   A. I, II, and III
   B. II, I, and III
   C. III, II, and I
   D. III, I, and II

5. An impulse can move from one neuron to an adjacent neuron because
   A. the axon of one neuron always touches the axon of the adjacent neuron
   B. dendrites of one neuron always touch the axon of the adjacent neuron
   C. chemical transmitters are released from the dendrites of one neuron and diffuse to the axon terminal of the adjacent neuron
   D. chemical transmitters are released from the axon terminal of one neuron and diffuse to the dendrites of the adjacent neuron

Use the following information to answer questions 6 and 7.

Figure 2 shows the change in the membrane potential of a neuron as it undergoes an action potential.

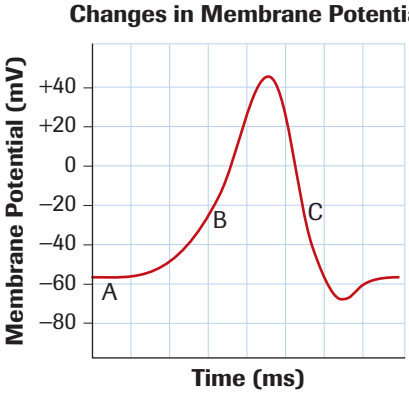

Figure 2

6. The area of the graph that indicates the opening of Na^+ ion channels and the diffusion of Na^+ ions into the nerve cells is
   A. area A, which represents polarization of the membrane
   B. area B, which represents depolarization of the membrane
   C. area C, which represents repolarization of the membrane
   D. areas B and C, which represent depolarization of the membrane

7. Repolarization occurs in
   A. area B because more K^+ ions enter the cell than Na^+ leave
   B. area B because more Na^+ ions enter the cell than K^+ leave
   C. area C because of diffusion of K^+ ions out of the axon
   D. area C because of diffusion of Na^+ ions out of the axon

8. A stroke results in a loss of speech, difficulty in using the right arm, and an inability to solve mathematical equations. Which area of the brain is damaged?
   A. left cerebellum
   B. right cerebellum
   C. left cerebral hemisphere
   D. right cerebral hemisphere

9. NR Place the following events involved in nerve transmission across a synapse in the order in which they occur. (Record all four digits of your answer.)
   1. Cholinesterase attaches to acetylcholine.
   2. Acetylcholine is released from the vesicles in the presynaptic neuron.
   3. The electrochemical impulse reaches the end plate of the presynaptic neuron.
   4. Sodium channels are opened along the postsynaptic neuron.

10. NR In **Figure 3**, which number represents the segment of the neuron that is: depolarized, polarized (resting membrane), repolarized (refractory period), and more permeable to Na^+ ions? (Record all four digits of your answer.)

_____	_____	_____	_____
depolarized	polarized	repolarized	more permeable to Na^+ ions

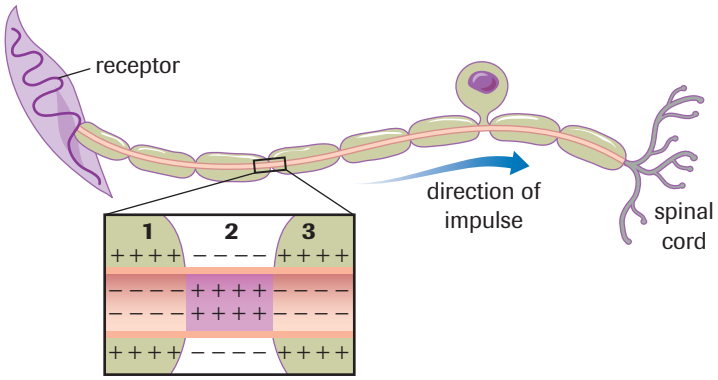

Figure 3
Myelinated neuron

11. NR From the list, identify the statements about the synapse that are correct. (Record all four digits of your answer in lowest-to-highest numerical order.)
   1. Nerve impulses speed up as they cross the synapse.
   2. Synapses occur only between two neurons.
   3. Destruction of the synaptic vesicles in neuron #1 will prevent depolarization in neuron #2.
   4. Neurotransmitters released from neuron #1 attach to the postsynaptic membrane of neuron #2.
   5. Neurotransmitters diffuse across the synapse.
   6. All neurotransmitters cause the depolarization of the postsynaptic membrane.
   7. Neurotransmitters from neuron #1 are destroyed by enzymes.

Part 2

12. Use what you have learned about threshold levels to **explain why** some individuals can tolerate more pain than others.

13. In **Figure 4**, the neurotransmitter released from neuron X causes the postsynaptic membrane of nerve Y to become more permeable to sodium. However, the neurotransmitter released from nerve W causes the postsynaptic membrane of nerve Y to become less permeable to sodium but more permeable to potassium. **Explain why** the stimulation of neuron X produces an action potential in neuron Y, but the stimulation of neuron X and W together fails to produce an action potential.

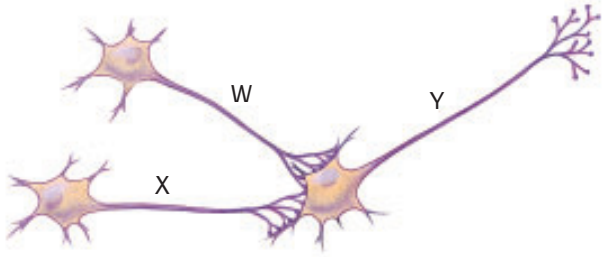

Figure 4
Nerve pathway

14. Botulism (a toxin produced by bacteria that causes food poisoning) and curare (a natural poison) inhibit the action of acetylcholine. **Describe** the symptoms you would expect to find in someone exposed to botulism or curare. **Explain** the symptoms.

15. A patient complains of losing his sense of balance. A marked decrease in muscle coordination is also mentioned. **Identify** which area of the brain a physician might look at for the cause of the symptoms.

Use the following information to answer questions 16 and 17.

A nerve cell that synapses in a muscle is stimulated by electrical current. The strength of the stimulus is increased and the force of muscle contraction is recorded. The results are recorded in **Table 1**.

Table 1 Stimulus Strength and Force of Muscle Contraction

Trial	Strength of stimulus (mV)	Force of contraction of muscle (N)
1	0	none
2	10	none
3	20	4
4	30	not measured

16. **Predict** the force of muscle contraction in trial 4. Give your reasons. DE

17. **Identify** the threshold level from the experiment. DE

Use the following information to answer questions 18 and 19.

Three different neurons synapse on a single neuron, as shown in **Figure 5**. The experimental data is recorded in **Table 2**.

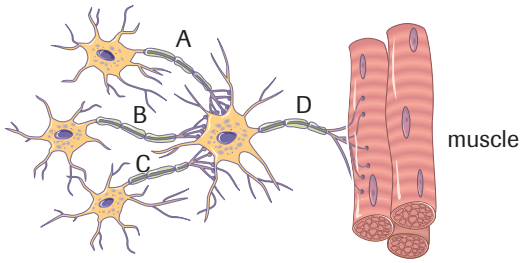

Figure 5

Table 2 Effects of Stimulating Neurons A, B, and C

Neuron stimulated	Effect on muscle
A	contraction
A and B	no contraction
B	no contraction
A and C	contraction
C	no contraction
B and C	no contraction

18. From the experimental data, **infer** which neuron releases an inhibitory neurotransmitter. DE

19. **Explain** the principle of summation using the experimental data. DE

20. During World War I, physicians noted a phenomenon called "phantom pains." Soldiers with amputated limbs complained of pain or itching in the missing limb. Use your knowledge of sensory nerves and the central nervous system to **explain** this phenomenon.

21. Scientists continue to look for chemical factors that both stimulate and inhibit the growth of new nerve cells. One such factor is myelin-associated glycoprotein (MAG), which is abundant in the myelin sheath of neurons in the central nervous system, but is scarce in the myelin of peripheral nervous system neurons. Write a unified response addressing the following aspects of research into MAG: DE
    - **Predict** whether MAG is a growth stimulator or growth inhibitor? **Justify** your answer.
    - **Why** might scientists be interested in developing drugs that would turn on or turn off MAG?

22. People with Parkinson's disease have low levels of the neurotransmitter dopamine. Researchers have been able to coax rat embryonic stem cells to develop into dopamine neurons. When these neurons were implanted into rats with a rodent version of Parkinson's, the characteristic tremor of the disease disappeared. Conduct research to **identify** the latest information concerning treatment of Parkinson's disease.

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23. For hundreds of years, people in China have believed that drinking herbal tea can improve one's memory. Researchers have isolated a compound from the tea that inhibits the action of cholinesterase. The compound, called huperzine A, is believed to be the active ingredient. Researchers are now exploring whether huperzine A affects symptoms of Alzheimer's disease. Write a unified response addressing the following aspects of huperzine A and Alzheimer's disease: DE
    - **Why** are researchers exploring the use of huperzine A for Alzheimer's patients?
    - **Why** do you think that some Western scientists have been reluctant to research medicinal effects of herbal teas?
    - **How** do you think the research into herbal teas will be received once the action of hyperzine A is known?

24. Individuals with spinal cord injuries often report loss of sensation and muscle paralysis. Recently, researchers have found that Id proteins, proteins in cancer cells which promote tumour growth, may be used to help re-grow damaged axons in the CNS. Investigate Id proteins and their potential to regenerate axons.
    (a) **Explain why** a person with a spinal cord injury might experience a loss of sensation.
    (b) **Describe** the significance of using Id proteins to stimulate the repair of damaged axons.
    (c) **Why** is it unlikely that the Id proteins might cause brain cancer if introduced into neurons?

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25. Use what you know about the transmission of nerve impulses to **hypothesize** (formulate a hypothesis) about how local and general anaesthetics work.

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chapter

14 The Senses

In this chapter

David Hume, the great Scottish philosopher, once concluded that humans are nothing more than the sum of their experiences. Elders in Aboriginal societies are revered because of their experiences. Our experiences, or what some philosophers call reality, exist because of a sensory nervous system. Environmental stimuli such as the flash of lightning (**Figure 1**), the sound of thunder, the chill of a cold day, and the smells of food are relayed to the brain by sensory neurons.

As you learned in the previous chapter, sensory neurons supply the central nervous system with information about the external environment and our internal environment. Whether it is information gathered by the sensory receptors of the eye or from those of the ear, it is carried to the brain along neurons as electrochemical impulses. Different parts of the brain process auditory information and visual information. How sensory information is perceived depends on which part of the brain receives the impulse. For example, if a visual sensory neuron were instead routed to the processing site for auditory information, you might hear lightning!

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Imagine if neurons carrying sensory information about sound were surgically moved from the sound interpreting area in the temporal lobe to the vision interpreting area in the occipital lobe.
   (a) How would the brain interpret a loud sound?
   (b) Would moving the nerve ending to another part of the visual area of the occipital lobe cause a different interpretation of the stimulus? Explain why or why not.
2. When you first walk into a kitchen where fish is cooking, the smell is strong and distinctive, yet after a few minutes the smell disappears.
   (a) Why does the smell seem to disappear?
   (b) What advantage is gained from having the smell disappear?
3. Predict which of the following areas of the body are most sensitive to touch by placing them in order. Provide reasons for the order you have chosen.
   - back of the neck
   - lips
   - face
   - fingertips
   - palms of hand
   - shoulder

Career Connections:
Optometrist; Audiologist

Figure 1
The central nervous system processes environmental stimuli.

Exploration Detecting Temperature Changes

Heat and cold receptors, rather than detecting specific temperatures as does a thermostat, are adapted to signal *changes* in environmental temperatures.

Materials: 3 bowls or large beakers, warm water, room-temperature water, cold water

- Fill three bowls or large beakers with water—one with warm, one with room-temperature, and one with cold water.
- Place your right hand in the cold water and your left hand in the warm water (**Figure 2**). Allow your hands to adjust to the temperature and then transfer both hands to the bowl that contains room-temperature water.
  (a) Describe what happens.
  (b) Explain why you might feel a chill when you step out of a warm shower even though room temperature is comfortable.

(c) Explain the following observations: When a frog is placed in a beaker of water above 40 °C, the frog will leap out immediately. When the frog is placed in room-temperature water and the temperature is slowly elevated, the frog will remain in the beaker.

Figure 2

14.1 Sensory Information

Figure 1
In order for us to see, visual receptors in the eye must be stimulated by light.

Sensory neurons supply the central nervous system with information about the external environment and the quality of our internal environment. Light-sensitive receptors within the retina of the eye are stimulated by light, not sound (**Figure 1**). A group of specialized temperature receptors in the skin identify cold, while other ones identify heat. Specialized chemoreceptors in the carotid artery provide the central nervous system with information about blood carbon dioxide and oxygen levels. Special osmoregulators in the hypothalamus monitor water concentration in the blood, and highly modified stretch receptors monitor blood pressure in arteries. How do different receptors respond to different stimuli? How are different stimuli converted into electrochemical events? How do you identify the intensity of different stimuli? How does the brain interpret stimuli?

A stimulus is a form of energy. Sensory receptors convert one source of energy into another. For example, taste receptors in your tongue convert chemical energy into a nerve action potential, a form of electrical energy. Light receptors in the eye convert light energy into electrical energy. Balance receptors of the inner ear convert gravitational energy and mechanical energy into electrical energy.

As you learned in Section 13.1, sensory receptors are highly modified dendrites of sensory neurons. Often, different sensory receptors and connective tissues are grouped within specialized sensory organs, such as the eye or ear. This grouping of different receptors often amplifies the energy of the stimulus to ensure that the stimulus reaches threshold levels. **Table 1** lists different types of sensory receptors found within the body, classified by the type of stimulus to which they respond.

Table 1 The Body's Sensory Receptors

Receptor Type	Stimulus	Information provided
taste	chemical	presence of specific chemicals (identified by taste buds)
smell	chemical	presence of chemicals (detected by olfactory cells)
pressure	mechanical	movement of the skin or changes in the body surface
proprioceptor	mechanical	movement of the limbs
balance	mechanical	body movement
audio	sound	sound waves
visual	light	changes in light intensity, movement, and colour
thermoreceptor	temperature changes	flow of heat

A network of touch, heat, cold, pressure, and pain receptors are found throughout the skin (**Figure 2**, next page). Pain receptors have naked dendrites in the epidermis. Pain receptors are extremely important because the sensation of pain makes you move away from whatever is causing the stimulus, which protects you from harm. A simple experiment indicates that sensations occur in the brain and not the receptor itself. This phenomenon is supported by brain-mapping experiments. When the neurotransmitter released by the sensory neuron is blocked, the sensation stops. Thus the brain registers and interprets the sensation. When the sensory region of the cerebral cortex is excited by mild electrical shock at the appropriate spot, the sensation returns even in the absence of the stimulus.

DID YOU KNOW?

Seeing Stars

Occasionally a sensory receptor can be activated by stimuli that it was not designed to detect. Boxers who receive a blow to the eye often see stars. The pressure of the blow stimulates the visual receptors at the back of the eye, and the blow is interpreted as light. Similarly, a blow near the temporal lobe can often be interpreted as a bell ringing.

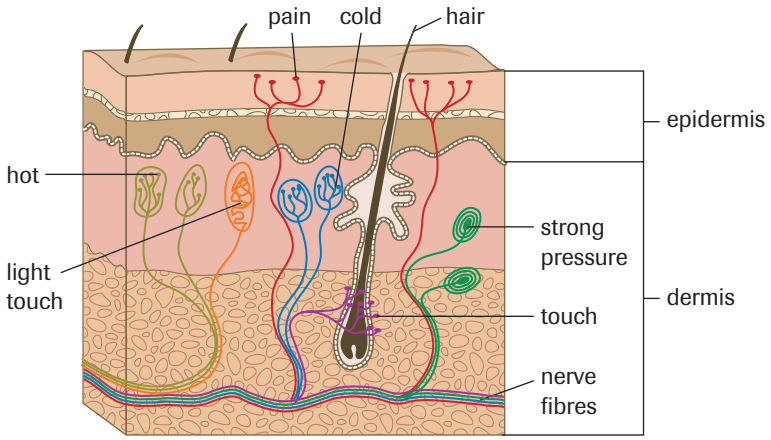

Figure 2
Each sensory receptor in the skin has dendrites modified in a different way.

Despite an incredible collection of specialized sensory receptors, much of your environment remains undetected. What you detect are stimuli relevant to your survival. For example, consider the stimuli from the electromagnetic spectrum. You experience no sensation from radio waves, or from infrared or ultraviolet wavelengths. Humans can only detect light of wavelengths between 350 nm and 800 nm. Your range of hearing, compared with that of many other species, is also limited.

Thermoreceptors do not act as thermometers, which detect specific temperatures. Hot and cold receptors are adapted to signal changes in environmental temperatures. Most animals can tolerate a wide range of temperatures, but are often harmed by rapid temperature changes. For example, a rapid change in temperature of 4 °C will kill some fish. Humans have also died from an unexpected plunge in very cold or very hot water. This principle was introduced in the Exploration at the start of Chapter 14 with the description of the "hot frog" experiment. If a frog is placed in a beaker of water above 40 °C, the frog will leap out immediately. However, if the frog is placed in room-temperature water, and the temperature is slowly elevated, it will remain in the beaker. The frog's thermoreceptors have had time to adjust.

sensory adaptation occurs once you have adjusted to a change in the environment; sensory receptors become less sensitive when stimulated repeatedly

Sensory adaptation occurs once the receptor becomes accustomed to the stimulus. The neuron ceases to fire even though the stimulus is still present. The adaptation seems to indicate that the new environmental condition is not dangerous. The same principle of adaptation can be applied to touch receptors in the skin. Generally, the receptors are only stimulated when clothes are put on or taken off. Sensory information assuring you that your clothes are still on your body is usually not required.

Taste and Smell

Taste receptors allow you to differentiate between things that are edible and things that are inedible. Taste receptors are found in different locations in different species. For example, octopuses have taste receptors on their tentacles. In humans, taste receptors are concentrated in the taste buds on the tongue (**Figure 3**). Specific chemicals dissolve on the tongue and stimulate receptors in the taste buds. There are five main types of taste: sweet, sour, salt, bitter, and savoury (also called umami). Each is associated with molecular shapes or charges. For example, salty taste is associated with the positive sodium ion, and savoury taste is associated with salts of glutamic acid. For example, table salt (sodium chloride) is a common salty food enhancer in foods such as potato chips and canned foods, and monosodium glutamate is a common savoury food enhancer in Asian cuisine and processed foods. A taste bud contains 1 to 200 cells. Each cell can

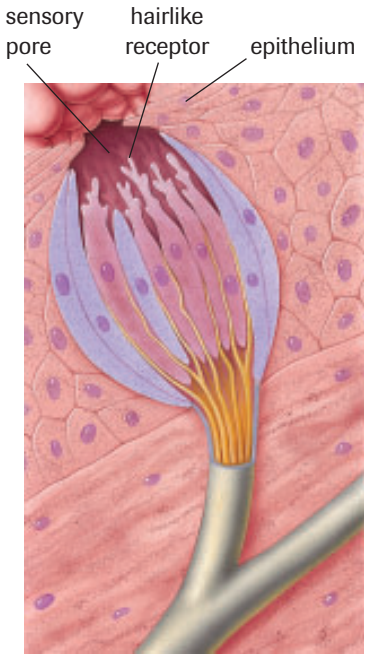

Figure 3
Dissolved chemicals enter the taste pore where they are detected by receptor cells. There are more than 10 000 taste buds in a human mouth.

DID YOU KNOW ?

Taste + Smell + Irritation = Flavour

When you describe how a food "tastes" you are really describing its flavour, which is actually the combination of its taste, smell, and chemical irritation. Chemical irritants, such as the burn of chili peppers or the cool of menthol, add to the way things feel in your mouth.

respond to chemicals responsible for all the taste types, but it tends to be more responsive to one particular chemical. When you bite into an orange slice, the brain processes information from all the different cells and perceives a complex flavour.

Experience tells you that your sense of taste and smell (olfaction) work together. Have you ever noticed that when you have a cold, your ability to taste food is reduced? Clogged nasal passages reduce the effectiveness of olfactory cells (located in the nasal cavity). Since you use both types of receptors to experience food, the diminished taste you experience is actually the result of your reduced capacity to smell the food. The main difference between taste and smell is that smell detects airborne chemicals and taste detects dissolved chemicals.

INVESTIGATION 14.1 *Introduction*

Mapping Sensory Receptors

Sensory receptors are specialized structures designed to respond to specific stimuli from the internal or external environment. Receptors convert information about changing environments to electrochemical impulses, which are transmitted to the central nervous system. In this investigation you will map the position of several sensory receptors in the skin.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

To perform this investigation, turn to page 462.

SUMMARY *Sensory Information*

- Sensory receptors are highly modified dendrites of sensory neurons that detect information about the external or internal environment.
- Sensory receptors convert one form of energy into another. For example, the eye converts light energy into an electrochemical impulse.
- Taste receptors detect dissolved chemicals; olfactory receptors detect airborne chemicals. Taste and olfactory receptors act together to create the perception of taste.

Section 14.1 Questions

1. Identify a sensory receptor for each of the following stimuli: chemical energy, mechanical energy, heat, light energy, and sound energy.
2. Do sensory receptors identify all environmental stimuli? Give examples to back up your answer.
3. Explain the concept of sensory adaptation by using examples of olfactory stimuli and auditory stimuli.
4. Explain why you are less able to taste food when you have a cold.

The Structure of the Eye 14.2

One of the primary ways humans gather information about their environment is through the visual information supplied by the sensory receptors in the eye. The structure of the eye allows for sensory information to be gathered and transmitted to the brain efficiently. The eye comprises three separate layers: the sclera, the choroid layer, and the retina (**Figure 1**). The **sclera** is the outermost layer of the eye. Essentially a protective layer, the white fibrous sclera maintains the eye's shape. The front of the sclera is the clear, bulging **cornea**, which acts as the window to the eye by bending light toward the pupil. Like all tissues, the cornea requires oxygen and nutrients. However, the cornea is not supplied with blood vessels, which would cloud the transparent cornea. Most of the oxygen is absorbed from gases dissolved in tears. Nutrients are supplied by the **aqueous humour**, a transparent fluid in a chamber behind the cornea.

sclera outer covering of the eye that supports and protects the eye's inner layers; usually referred to as the white of the eye

cornea transparent part of the sclera that protects the eye and refracts light toward the pupil of the eye

aqueous humour watery liquid that protects the lens of the eye and supplies the cornea with nutrients

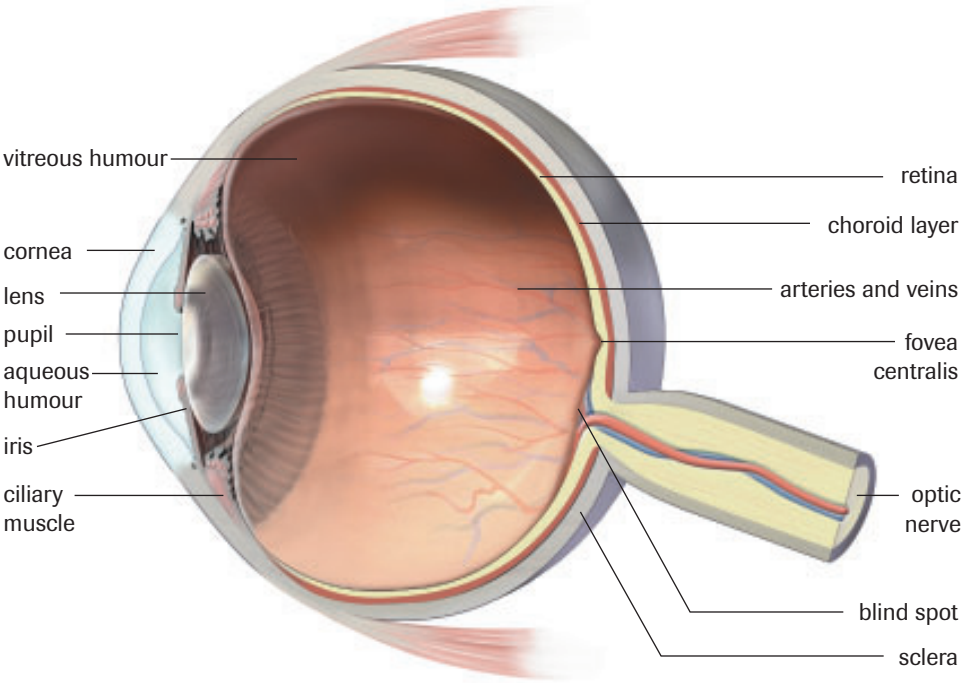

Figure 1
Simplified diagram of the human eye

EXTENSION

Focusing Light on the Retina
Listen to this description of the structures of the eye that actively and passively refract light so that it can be focused with high resolution on the surface of the retina.

www.science.nelson.com GO

The middle layer of the eye is called the **choroid layer**. Toward the front of the choroid layer is the **iris**. The iris is composed of a thin circular muscle that acts as a diaphragm, controlling the size of the pupil, the opening formed by the iris that allows light into the eye. The lens, which focuses the image on the retina, is found in the area immediately behind the iris. Ciliary muscles, attached to ligaments suspended from the dorsal and ventral ends of the lens, alter the shape of the lens. A large chamber behind the lens, called the vitreous humour, contains a cloudy, jellylike material that maintains the shape of the eyeball and permits light transmission to the retina.

choroid layer middle layer of tissue in the eye that contains blood vessels that nourish the retina

iris opaque disk of tissue surrounding the pupil that regulates amount of light entering the eye

retina innermost layer of tissue at the back of the eye containing photoreceptors

rods photoreceptors that operate in dim light to detect light in black and white

cones photoreceptors that operate in bright light to identify colour

The innermost layer of the eye is the **retina**, which comprises four different layers of cells: pigmented epithelium, light-sensitive cells, bipolar cells, and cells of the optic nerve. The pigmented epithelium is positioned between the choroid layer and the light-sensitive cells. Pigmented granules in this layer prevent light that has entered the eye from scattering. There are two different types of light-sensitive cells: the **rods** and the **cones** (**Figure 2**). The rods respond to low-intensity light; the cones, which require high-intensity light, identify colour. Both rods and cones act as the sensory receptors. Once excited, the nerve message is passed from the rods and cones to the bipolar cells, which, in turn, relay the message to the cells of the optic nerve. The optic nerve carries the impulse to the central nervous system (**Figure 3**).

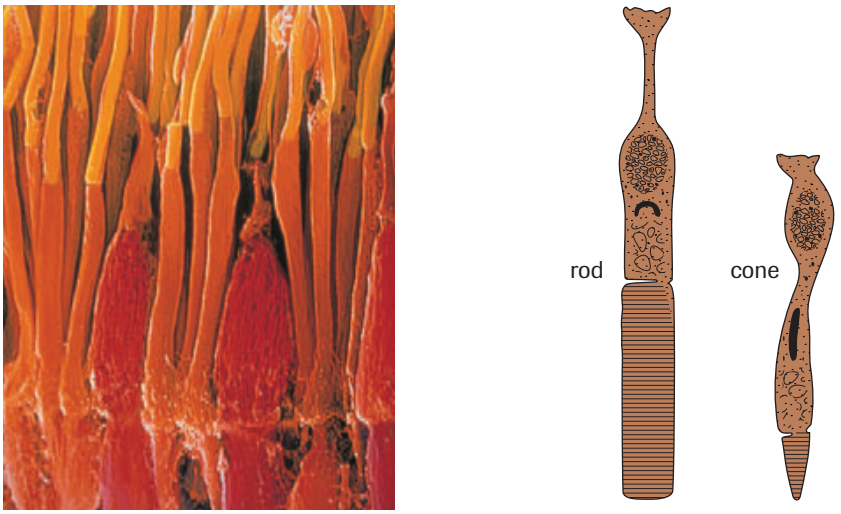

Figure 2
In humans, there are about 18 times as many rods (orange) as cones (red) in the retina.

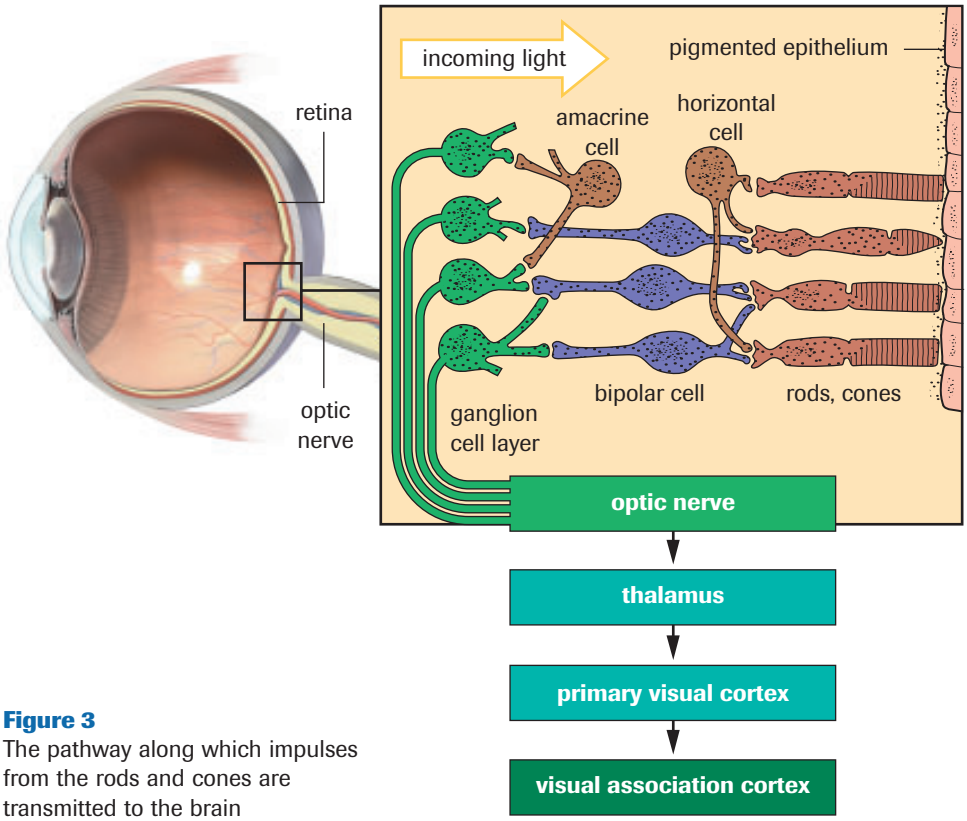

Figure 3
The pathway along which impulses from the rods and cones are transmitted to the brain

Rods and cones are unevenly distributed on the retina. In the centre of the retina is a tiny depression referred to as the **fovea centralis**. The most sensitive area of the eye, it contains cones packed very close together. When you look at an object, most of the light rays fall on the fovea centralis. Rods surround the fovea, which could explain why you may see an object from the periphery of your visual field without identifying its colour. There are no rods or cones in the area in which the optic nerve comes in contact with the retina. Because of this absence of photosensitive cells, this area is appropriately called the blind spot. **Table 1** summarizes the different parts of the eye.

fovea centralis area at centre of retina where cones are most dense and vision is sharpest

Table 1 Parts of the Eye

Structure	Function
sclera	• supports and protects delicate photocells
cornea	• refracts light toward the pupil
aqueous humour	• supplies cornea with nutrients and refracts light
choroid layer	• contains blood vessels that nourish the retina
iris	• regulates the amount of light entering the eye
vitreous humour	• maintains the shape of the eyeball and permits light transmission to the retina
lens	• focuses the image on the retina
pupil	• the opening in the iris that allows light into the eye
retina	• contains rods used for viewing in dim light and cones used for identifying colour
fovea centralis	• most light-sensitive area of the retina • contains only cones
blind spot	• where the optic nerve attaches to the retina

CAREER CONNECTION

Optometrist

Does the biology of the eye fascinate you? Understanding how the complex parts of the eye work together to produce vision is essential for treating eye and health-related disorders, such as glaucoma. Optometrists are eye specialists who conduct examinations, diagnose disease, evaluate eye structure, and prescribe drugs, eyeglasses and contact lenses. Find out more about this career choice.

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EXTENSION

Simulation—Principal Features of the Eye

In this animation, you will observe the structure of the human eye while listening and reading about the function of each structure. At the end of the animation, you will complete an interactive quiz to test your understanding.

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Practice

1. List the three layers of the eye and describe the function of each layer.
2. Compare rods and cones in terms of location, structure, and function.

INVESTIGATION 14.2 *Introduction*

Report Checklist

- ○ Purpose
- ● Problem
- ○ Hypothesis
- ○ Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ○ Evaluation
- ○ Synthesis

Eye Dissection

The eyes of most mammals have very similar anatomy. Dissection of a cow eye can therefore help you better understand the structures of the human eye. In this investigation, you will dissect a cow eye and describe the structures you observe.

To perform this investigation, turn to page 463.

Chemistry of Vision

An estimated 160 million rods surround the colour-sensitive cones in the centre of the retina. The rods contain a light-sensitive pigment called **rhodopsin**, or "visual purple." The cones contain similar pigments, but they are less sensitive to light. Rhodopsin is composed of a form of vitamin A and a large protein molecule called opsin. When a single photon, the smallest unit of light, strikes a rhodopsin molecule, it divides into

rhodopsin the pigment found in the rods of the eye

two components: retinene, the pigment portion, and opsin, the protein portion. This division alters the cell membrane of the rods and produces an action potential. Neurotransmitters are released from the end plates of the rods, and the nerve message is conducted across synapses to the bipolar cells and to a neuron of the optic nerve. For the rods to continue to work, rhodopsin levels must be maintained. A long-term vitamin A deficiency can permanently damage the rods.

The extreme sensitivity of rhodopsin to light creates a problem. In bright light, rhodopsin breaks down faster than it can be restored. The opsins used for colour vision are much less sensitive to light and, therefore, operate best with greater light intensity. Since only the rods are active during periods of limited light intensity, images appear as shades of grey. Not surprisingly, the rods are most effective at dusk and dawn.

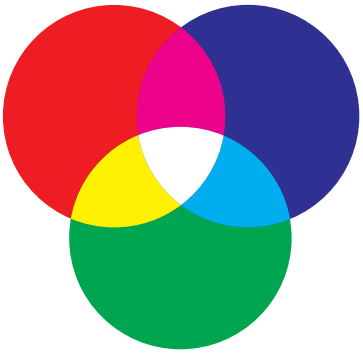

Figure 4
The three primary colours for source light are red, blue, and green. Each cone is sensitive to one of these three colours.

Colour Perception

The cones are responsible for colour vision. Each cone is sensitive to one of the three primary colours of source light: red, blue, and green. (Do not confuse the primary colours of source light with the primary colours of reflected light: magenta, cyan, and yellow.) When combinations of cones are stimulated by incoming light, the brain perceives different colours (**Figure 4**). For example, yellow is perceived when cones sensitive to both green and red wavelengths are stimulated. Purple is perceived when cones sensitive to both red and blue wavelengths are stimulated. Cyan (blue-green) is perceived when cones sensitive to blue and green wavelengths are stimulated. White is perceived when cones sensitive to all three wavelengths are stimulated. The three types of cones firing in different combinations allow humans to see millions of different shades of colour.

Colour blindness occurs when one or more types of cones are defective. The most common type of colour blindness, red-green colour blindness, occurs when the cones containing the red-sensitive pigment fail to work properly. The defect is genetic and more common in males than females.

DID YOU KNOW ?

Seeing Ultraviolet Light

The lens of the eye is not clear. A slight yellow coloration blocks out rays from the ultraviolet end of the electromagnetic spectrum. As you age, your lenses become thicker and more yellow, making you less able to see wavelengths from the ultraviolet end of the spectrum.

Afterimages

Have you ever noticed a trailing blue or green line that stays in your vision after you look into a camera flash? What you see is an afterimage. There are two different types of afterimages: positive and negative. The positive afterimage occurs after you look into a bright light and then close your eyes. The image of the light can still be seen even though your eyes are closed. The more dramatic negative afterimage occurs when the eye is exposed to bright coloured light for an extended period of time.

mini Investigation — Afterimages

Stare at the cross in **Figure 5** with one eye for 30 s, and then stare at a bright white surface for at least 30 s. The colours will reverse. The afterimage is believed to be caused by fatigue of that particular type of cone in that area of the retina. The horizontal red cones become fatigued, but the complementary green cones continue to fire. The opposite effect occurs for the vertical bar.

Figure 5
The red bar produces a green afterimage; the green bar produces a red afterimage.

Focusing the Image

As light enters the eye, it is first bent toward the pupil by the cornea. Light waves normally travel in straight lines and slow down when they enter more dense materials like the cornea. The slowing of light by a denser medium causes bending, which is called refraction. The cornea directs light inward toward the lens, resulting in further bending. Because the lens is thicker in the centre than at its outer edges, light is bent to a focal point. An inverted image is projected on the light-sensitive retina.

Ciliary muscles control the shape of the lens, and suspensory ligaments maintain a constant tension. When close objects are viewed, the ciliary muscle contracts, and the lens becomes thicker. The thicker lens provides additional bending of light for near vision. For objects that are farther away, relaxation of the ciliary muscles causes the lens to become thinner. The adjustment of the lens to objects near and far is referred to as **accommodation**. Objects 6 m from the viewer need no accommodation.

The importance of the accommodation reflex becomes more pronounced with age. Layers of transparent protein covering the lens increase throughout your life, making the lens harder. As the lens hardens, it loses its flexibility. By the time you reach age 40, near-point accommodation has diminished and may begin to hinder reading.

A secondary adjustment occurs during the accommodation reflex. When objects are viewed from a distance, the pupil dilates in an attempt to capture as much light as possible. When objects are viewed close up, the pupil constricts in an attempt to bring the image into sharp focus. Test this for yourself by looking at the print on this page with one eye. Move your head toward the book until the print gets very blurry. Now crook your finger until you have a small opening and look through it. Gradually make the opening smaller. The image becomes sharper. Light passes through a small opening and falls on the most sensitive part of the retina, the fovea centralis. Inuit were aware of this principle when they made eyeglasses by drilling holes in whalebone. Light passing through the narrow openings resulted in a sharper focus.

EXTENSION

Hyperpolarization

In this Audio Clip, you will hear about a mechanism called hyperpolarization, which is involved in creating a nerve impulse that plays a role in detection of light in the retina.

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accommodation adjustments made by the lens and pupil of the eye for near and distant objects

EXTENSION

Visual Accommodation

Watch the eye change during accommodation in this interactive animation.

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Vision Defects

Glaucoma is caused by a buildup of aqueous humour in the anterior chamber of the eye. Although a small amount of the fluid is produced each day, under normal conditions tiny ducts drain any excess. When these drainage ducts become blocked, fluid builds up in the anterior chamber. As the fluid builds up, the pressure inside the eye rises. The retinal ganglion cells slowly die from this increased pressure, which leads to vision loss.

glaucoma disease of the eye in which increased pressure within the eyeball causes a gradual loss of sight

Problems may arise with the lens. Occasionally, the lens becomes opaque and prevents some of the light from passing through. The condition is known as a **cataract**. A traditional solution to the problem has been to remove the lens and to fit the patient with strong eyeglasses.

cataract condition that occurs when the lens or cornea becomes opaque, preventing light from passing through

In most people, the lens and cornea are symmetrical. Incoming light is refracted along identical angles for both the dorsal (back) and ventral (front) surfaces, forming a sharp focal point. In some individuals, however, the lens or cornea is irregularly shaped. This condition is called **astigmatism**.

astigmatism vision defect caused by abnormal curvature of surface of the lens or cornea

mini Investigation — Testing for Astigmatism

The chart in **Figure 6** will help you determine whether you have astigmatism. Cover one eye and look at the chart. If you have cornea astigmatism, the lines along one plane will appear sharp, but those at right angles will appear fuzzy. Repeat the test with the other eye.

(a) In your own words, describe what causes astigmatism.

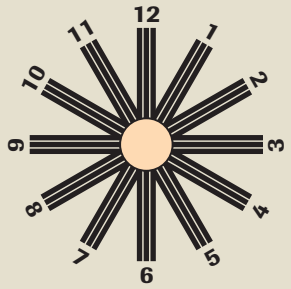

Figure 6
A test for corneal astigmatism

nearsightedness condition that occurs when the image is focused in front of the retina

farsightedness condition that occurs when the image is focused behind the retina

Two of the more common vision defects are **nearsightedness** (also known as myopia) and **farsightedness** (hyperopia). Nearsightedness occurs when the eyeball is too long. Since the lens cannot flatten enough to project the image on the retina, the distant image is instead brought into focus in front of the retina. Someone who is nearsighted is able to focus on close objects, but has difficulty seeing objects that are distant. Glasses that contain a concave lens can correct nearsightedness (**Figure 7**). Farsightedness is caused by an eyeball that is too short, causing distant images to be brought into focus behind the retina, instead of on it. A farsighted person is able to focus on distant objects, but has trouble seeing objects that are close up. Farsightedness can be corrected by glasses that have a convex lens.

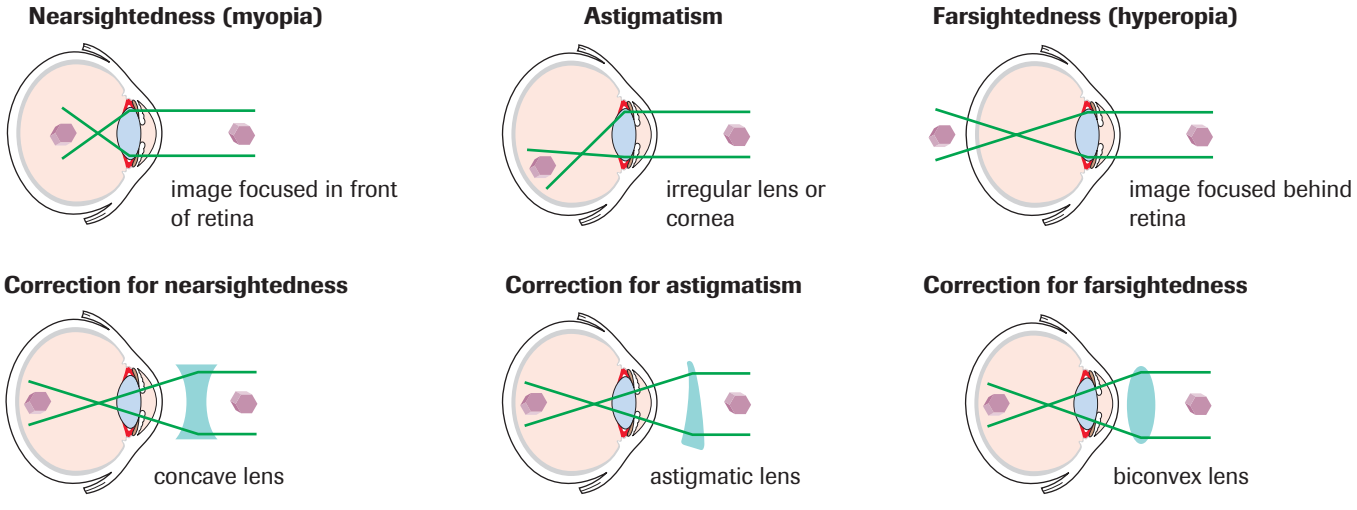

Figure 7
Visual defects can be improved with corrective lenses.

WEB Activity

Case Study—Corneal Surgery

Surgery for treating nearsightedness was first developed in Russia in the mid-1970s by Dr. Svyatoslav Fyodorov. He was inspired by a Russian teenager whose glasses had shattered during a fight, badly cutting his cornea. Remarkably, the eye healed and the boy's myopia seemed cured. An alteration of the cornea had corrected the myopia. Dr. Fyodorov soon developed a procedure called radial keratotomy for correcting myopia.

With the development of laser surgery in the early 1980s, new, less invasive, procedures were developed, including photorefractive keratotomy (PRK) and laser in-situ keratomileusis (LASIK) (**Figure 8**). Find out how these procedures work. Also, investigate corneal ring implants and implantable contact lenses. What are the pros and cons of these two new procedures?

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Figure 8
Laser eye surgery

SUMMARY The Structure of the Eye

- Images are displayed on the retina. Rods are photosensitive receptors that detect images in dull light. Cones are photosensitive receptors that distinguish colour in bright light.
- Ciliary muscles change the shape of the lens. A thicker lens permits the greater bending of light for viewing near objects, while a more flattened lens is used to view distant objects.

Section 14.2 Questions

1. Indicate the function of each of the following parts of the eye: vitreous humour, aqueous humour, cornea, pupil, iris, rods, cones, fovea centralis, and blind spot.
2. What are accommodation reflexes?
3. Why do rods not function effectively in bright light?
4. Identify the causes for each of the following eye disorders: glaucoma, cataract, astigmatism, nearsightedness, and farsightedness.
5. Illustrate how corrective lenses provide for normal vision.
6. Laser surgery can provide a cure for myopia (shortsightedness), but skeptics argue that surgery has risks and that shortsightedness can be corrected with glasses. A "halo effect" (circles of light that can distort night vision) may result from laser surgery.
   (a) Research the halo effect. How often does it occur after laser surgery?
   (b) Should people who experience the halo effect be allowed to drive at night? Why or why not?
   (c) Do you believe that surgery should be attempted? Explain your answer.
   (d) Do you think this surgery should be covered by medicare? Justify your answer.
7. Nearsightedness, or myopia, is experienced by up to about one-third of the population. Nearsighted people have difficulty reading highway signs and seeing other objects at a distance, but can see for up-close tasks such as reading.
   (a) Draw a diagram of an eye for a person with myopia.
   (b) Refractive surgery can reduce or even eliminate the need for glasses or contacts. The most common procedures are performed with a laser. The laser removes a layer of corneal tissue, which flattens the cornea and allows light rays to focus closer to or even on the retina. Refer to the Nelson website to research different laser techniques that can be used.

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8. Hawks and eagles depend upon their excellent vision for hunting. In addition to the central fovea found in most birds, hawks and eagles have a second "lateral" fovea placed to one side of the central fovea. Explain how having a lateral fovea might help hawks and eagles hunt.

14.3 Hearing and Equilibrium

DID YOU KNOW?

The Smallest Bones

The ear ossicles are the smallest bones in the body. They are fully developed at birth.

The ear (**Figure 1**) is associated with two separate functions: hearing and equilibrium. The ear can be divided into three sections for study: the outer ear, the middle ear, and the inner ear. The outer ear comprises the **pinna**, the external ear flap, which collects the sound, and the **auditory canal**, which carries sound to the eardrum. The auditory canal is lined with specialized sweat glands that produce earwax, a substance that traps foreign particles and prevents them from entering the ear.

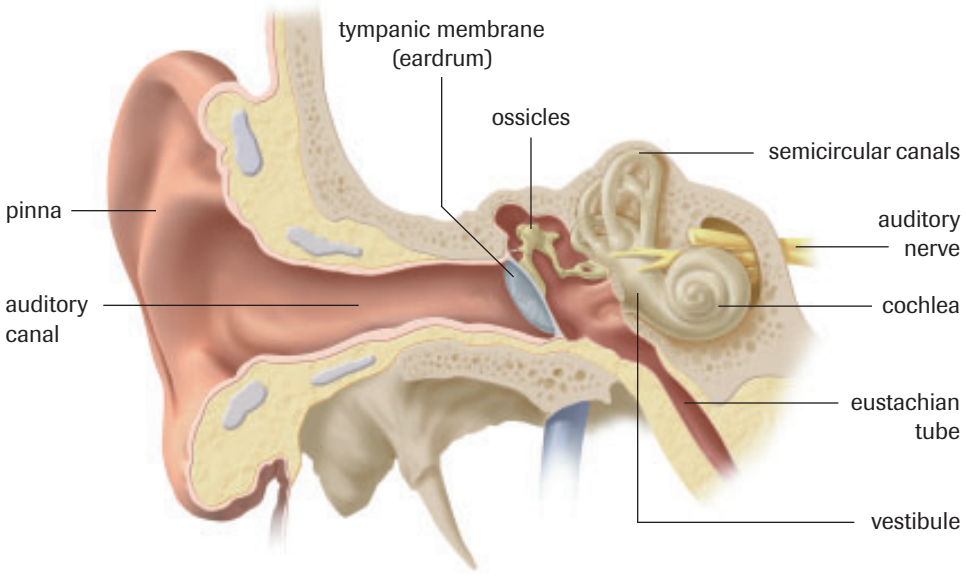

Figure 1
Anatomy of the human ear

pinna outer part of the ear that acts like a funnel, taking sound from a large area and channelling it into a small canal

auditory canal carries sound waves to the eardrum

tympanic membrane thin layer of tissue that receives sound vibrations, also known as the eardrum

ossicles tiny bones that amplify and carry sound in the middle ear

oval window oval-shaped hole in the vestibule of the inner ear, covered by a thin layer of tissue

eustachian tube air-filled tube of the middle ear that equalizes pressure between the external and internal ear

vestibule chamber found at the base of the semicircular canals that provides information about static equilibrium

semicircular canals fluid-filled structures within the inner ear that provide information about dynamic equilibrium

cochlea coiled structure of the inner ear that responds to various sound waves and converts them into nerve impulses

The middle ear begins at the **tympanic membrane**, and extends toward the oval and round windows. The air-filled chamber of the middle ear contains three small bones, called **ossicles**, which include the malleus (the hammer), the incus (the anvil), and the stapes (the stirrup). Sound vibrations that strike the eardrum are first concentrated within the solid malleus, and then transmitted to the incus, and finally to the stapes. The stapes strikes the membrane covering the **oval window** in the inner wall of the middle ear. Sound is amplified by concentrating the sound energy from the large tympanic membrane to the smaller oval window.

The **eustachian tube** extends from the middle ear to the mouth and the chambers of the nose. Approximately 40 mm in length and 3 mm in diameter, the eustachian tube permits the equalization of air pressure on either side of the eardrum. Have you ever noticed how your ears seem to pop when you go up in a plane? Yawning, swallowing, and chewing gum allow air to leave the middle ear through the eustachian tube. An ear infection can block the eustachian tube and create inequalities in air pressure. Discomfort, temporary deafness, and poor balance can result.

The inner ear has three distinct structures: the vestibule and the semicircular canals, which are involved with balance, and the cochlea, which is connected with hearing (**Figure 2**, next page). The **vestibule**, connected to the middle ear by the oval window, houses two small sacs, the utricle and saccule, which establish head position. There are three **semicircular canals**, arranged at different angles, and the movement of fluid in these canals helps you identify body movement. The **cochlea** is shaped like a spiralling snail's shell and contains rows of specialized hair cells that run the length of the inner canal. The hair cells respond to sound waves and convert them into nerve impulses.

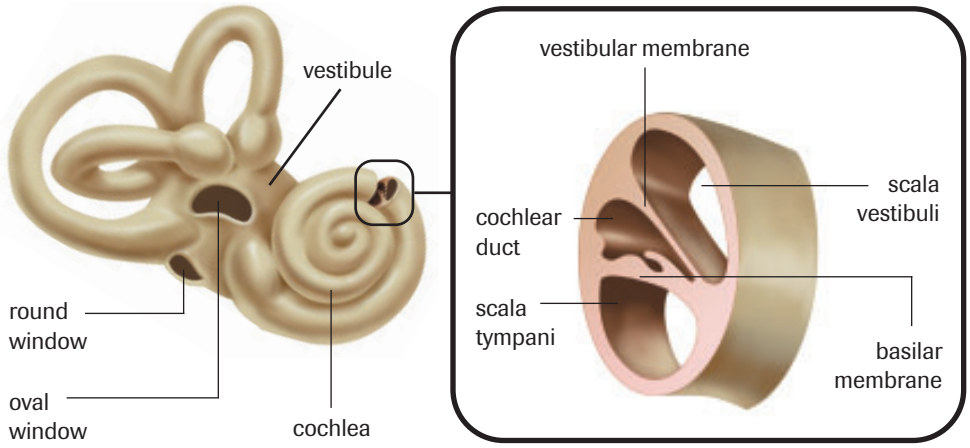

Figure 2
Sound waves are transformed into membrane vibrations in the cochlea.

Hearing and Sound

Sound is a form of energy. Like light, thermal energy, and various forms of chemical energy, sound energy must be converted into an electrical impulse before you can interpret it. The sensitivity of the ear can be illustrated by the fact that you can hear a mosquito outside your window, even though the energy reaching your ear is less than one quadrillionth of a watt. The average light in a house uses 60 W of energy.

Hearing begins when sound waves push against the eardrum, or tympanic membrane. The vibrations of the eardrum are passed on to the three bones of the middle ear: the malleus, the incus, and the stapes. Arranged in a lever system, the three bones are held together by muscles and ligaments. The bones concentrate and amplify the vibrations received from the tympanic membrane. The ossicles can triple the force of vibration from the eardrum; they move a shorter distance but exert greater force by concentrating the energy in a very small area.

Muscles that join the bones of the middle ear act as a safety net protecting the inner ear against excessive noise. Intense sound causes the tiny muscles—the smallest in your body—to contract, restricting the movement of the malleus and reducing the intensity of movement. At the same time, a second muscle contracts, pulling the stapes away from the oval window, thereby protecting the inner ear from powerful vibrations. Occasionally, the safety mechanism doesn't work quickly enough. The sudden blast from a firecracker can send the ossicles into wild vibrations before the protective reflex can be activated.

The oval window receives vibrations from the ossicles. As the oval window is pushed inward, the round window, located immediately below the oval window, moves outward. This triggers waves of fluid within the inner ear. The cochlea receives the fluid waves and converts them into electrical impulses, which you interpret as sound. The hearing apparatus within the cochlea is known as the **organ of Corti** and comprises a single inner row and three outer rows of specialized hair cells (**Figure 3**, next page), anchored to the **basilar membrane**. The hair cells respond to vibrations of the basilar membrane. Vibrations in the fluid on either side of the basilar membrane cause the membrane to move, and the hairs on the cells bend as they brush against the tectorial membrane. The movement of the hair cells, in turn, stimulates sensory nerves in the basilar membrane. Auditory information is then sent to the temporal lobe of the cerebrum via the auditory nerves.

The inner ear is able to identify both pitch and loudness because of the structure of the cochlea. Close to the oval window, the basilar membrane is narrow and stiff. Further into the cochlea, the basilar membrane widens and becomes more flexible. The narrowest area is activated by high-frequency sound waves, which contain enough energy

CAREER CONNECTION

Audiologist
Audiologists work with people who have hearing, balance, and related ear problems. Employment opportunities are expected to grow rapidly—as the population ages, more people will have hearing problems. What type of work do audiologists do? Why is the work important? What academic requirements must be met?

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organ of Corti primary sound receptor in the cochlea

basilar membrane anchors the receptor hair cells in the organ of Corti

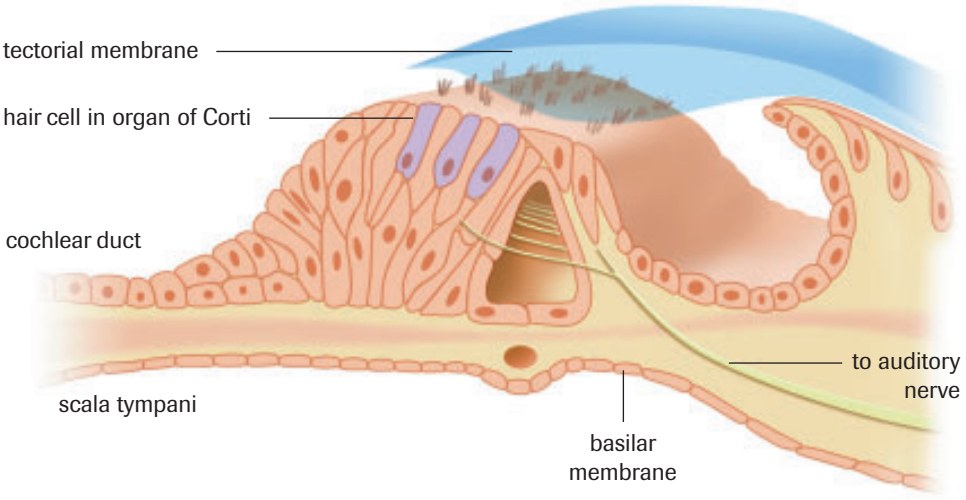

Figure 3
The organ of Corti is a ridge of cells that runs along the basilar membrane. The top of the organ of Corti meets the tectorial membrane.

to move the membrane. The high-frequency waves are transformed into basilar membrane vibrations, which, in turn, cause the hair cells to move. The hair cells trigger an action potential, which is carried to the area of the brain that registers high-pitched sounds. The high-frequency waves caused by a police siren die out quickly in the narrow, rigid part of the cochlea. However, low-frequency waves move farther along the cochlea, causing the hair cells in the wider, more elastic area to vibrate (**Figure 4**). The stimulation of nerve cells in different parts of the cochlea enables you to differentiate sounds of different pitch. Each frequency or pitch terminates in a specific part of the auditory section in the temporal lobe of the brain.

In addition to responding directly to sound energy, the basilar membrane can respond directly to mechanical stimulation. A jarring blow to the skull sets up vibrations that are passed on toward the cochlea. Aside from the sound created by the blow, the resulting mechanical vibrations of the skull can also be interpreted as sound.

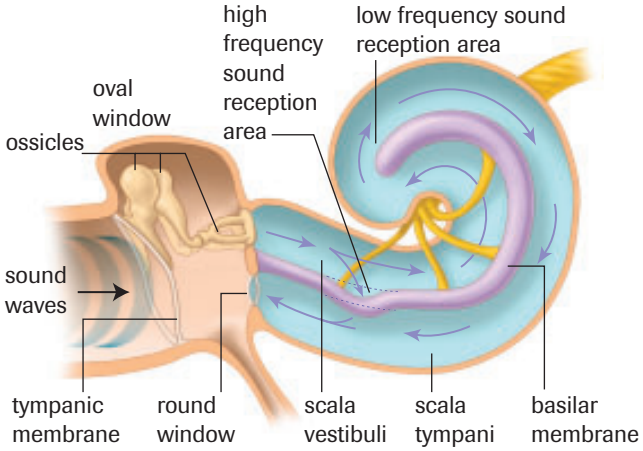

Figure 4
Here the cochlea has been uncoiled. High-frequency sounds are picked up at the base of the cochlea and low-frequency sounds are picked up towards the tip of the cochlea.

Practice

1. What function do the tympanic membrane, ossicles, and oval window serve in sound transmission?
2. Categorize the following structures of the inner ear according to whether their functions relate to balance or hearing: organ of Corti, cochlea, vestibule, saccule, ampulla, semicircular canals, oval window, and round window.

Equilibrium

Balance consists of two components: static equilibrium and dynamic equilibrium. Static equilibrium involves movement along one plane, such as horizontal or vertical. Head position is monitored by two fluid-filled sacs called the saccule and the utricle. Tiny hair cells line the saccule and utricle. Cilia from the hair cells are suspended in a gelatinous material that contains small calcium carbonate granules called **otoliths**. When the head is in the normal position, the otoliths do not move; however, when the head is bent forward, gravitational force acts on the otoliths, pulling them downward. The otoliths cause the gelatinous material to shift, and the cilia to bend (**Figure 5**). The movement of the cilia stimulates the sensory nerve, and information about head position is relayed to the cerebellum for interpretation.

otoliths tiny stones of calcium carbonate embedded in a gelatinous coating within the saccule and utricle

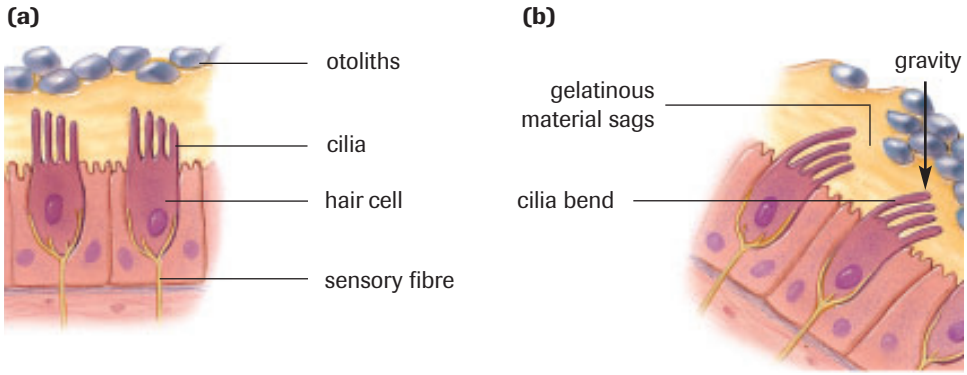

Figure 5
(a) When the head is in the erect position, the cilia from the hair cells remain erect.
(b) Movement of the head causes movement of the hair cells. Any movement of the cilia from the hair cells initiates nerve impulses.

The second aspect of balance, referred to as dynamic equilibrium, provides information during movement. While you are moving, balance is maintained by the three fluid-filled semicircular canals (**Figure 6**). Each of the canals is equipped with a pocket called an ampulla, which holds a cupula. Rotational stimuli cause the fluid in the semicircular canals to move, bending the cilia attached to hair cells in the cupulas. Once the hair cells bend, they initiate nerve impulses, which are carried to the cerebellum. It is believed that rapid continuous movement of the fluids within the semicircular canals is the cause of motion sickness.

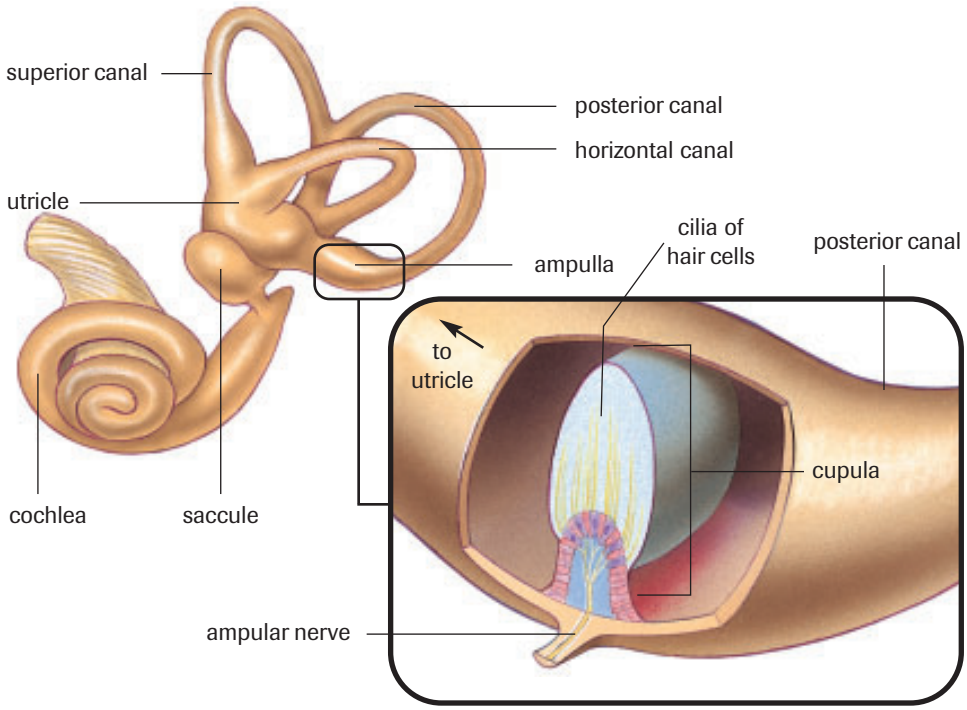

Figure 6
Three semicircular canals provide information about motion. Cilia attached to hair cells in the cupula respond to the movement of fluid in the semicircular canals.

INVESTIGATION 14.3 *Introduction*

Hearing and Equilibrium

Have you ever wondered how good your hearing actually is? Do you have trouble with motion sickness? Investigation 14.2 will help you learn more about hearing and equilibrium.

Report Checklist

● Purpose	● Design	● Analysis
○ Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

To perform this investigation, turn to page 464.

Treatments for Hearing Loss

One type of hearing loss is conductive hearing loss. In this type, sound waves have trouble entering the inner ear. This can be caused by wax buildup in the outer ear, middle ear infections, or a punctured eardrum. Conductive hearing loss can often be corrected by medical or surgical procedures. Another type of hearing loss is sensorineural hearing loss, where the auditory nerve is severed or damaged or the hair cells of the cochlea are damaged or dead. It can be caused by aging, exposure to loud noises, head trauma, or genetic conditions. Often hearing loss can be a mixture of the two types.

A large variety of hearing aids exist but they all work on the same principle: they all amplify sound and transmit it to the eardrum. Hearing aids have a microphone to pick up sound, an amplifier to increase the loudness of the sound, and a speaker to transmit the sound to the eardrum. However, no amount of amplification will help if the hair cells or the auditory nerve are not working, since no vibrations are being transmitted to the brain.

Cochlear implants are devices that can restore a type of hearing to those with severe sensorineural hearing loss. A cochlear implant does not make sounds louder or clearer. The device bypasses the damaged parts of the inner ear and converts sounds into electrical impulses that are sent directly to the auditory nerve (**Figure 7**). A cochlear implant has a microphone that picks up sounds from the environment and a speech processor that selects and arranges sounds. A transmitter and a receiver/stimulator receive signals from the speech processor and convert them into electrical impulses. Electrodes then send the electrical impulses to the auditory nerves. The nerves send the coded signals to the brain, where they are interpreted as sound. Rather than restoring normal hearing by replicating the same exact sounds, the implant provides the person with sounds that enable them to interpret the environment around them. Over time the person learns to decipher what the different impulses mean and can eventually understand speech.

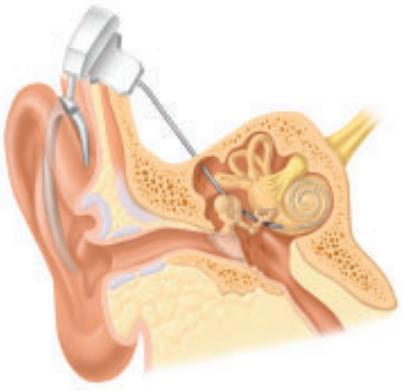

Figure 7
Unlike conventional hearing aids, cochlear implants have to be surgically implanted into the skull. Electrodes are placed in the cochlea (the grey line in the cochlea) and are connected to an external microphone placed above the ear.

WWW *WEB Activity*

Simulation—Ear Structure and Function

In this simulation, you will follow sound as it travels from the outside environment through the structures of the human ear. You will look at the structures in the inner ear and how they translate the pressure changes due to sound waves into action potentials. At the end of the animation, you will complete an interactive quiz to test your understanding.

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SUMMARY Hearing and Equilibrium

Table 1 Parts of the Ear

Structure	Function
External ear	
pinna	• outer part of the external ear amplifies sound by funnelling it from a large area into the narrower auditory canal
auditory canal	• carries sound waves to the tympanic membrane
Middle ear	
ossicles	• tiny bones that amplify and carry sound in the middle ear
tympanic membrane	• also called the eardrum, it receives sound waves
oval window	• receives sound waves from the ossicles
eustachian tube	• air-filled tube of the middle ear that equalizes pressure between the outer and middle ear
Inner ear	
vestibule	• chamber at the base of the semicircular canals that provides information concerning static equilibrium
semicircular canals	• fluid-filled structures that provide information concerning dynamic equilibrium
cochlea	• coiled tube within the inner ear that receives sound waves and converts them into nerve impulses

Section 14.3 Questions

1. Briefly outline how the external ear, middle ear, and inner ear contribute to hearing.
2. Differentiate between static and dynamic equilibrium.
3. How do the saccule and utricle provide information about head position?
4. Describe how the semicircular canals provide information about body movement.
5. A scientist replaces ear ossicles with larger, lightweight bones. Would this procedure improve hearing? Support your answer.
6. Cochlear implants are expensive. The surgery to insert cochlear implants is covered by public health-care plans, but the cochlear implant device is not. Should patients be required to pay for their own devices?
7. Should individuals who refuse to wear ear protection while working around noisy machinery be eligible for medical coverage for the cost of hearing aids? What about rock musicians or other individuals who knowingly play a part in the loss of their own hearing? Justify your position.
8. In 1660, Robert Boyle discovered that sound cannot travel in a vacuum. Research and describe his famous experiment.

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9. Research motion sickness, including its probable causes and some current solutions. You can begin your research on the Internet.

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10. Frequency is the number of vibrations produced per second and is measured in hertz. One hertz is equal to one vibration per second. Low-frequency sounds have low pitches and high-frequency sounds have high pitches. The hearing ranges for different species are listed in **Table 1**.

Table 1 Hearing Range of Various Species

Species	Approximate range (HZ)
human	64–23,000
dog	67–45,000
cat	45–64,000
horse	55–33,000
beluga whale	1000–123,000
goldfish	20–3000

(a) Which animal has the greatest hearing range?
(b) Provide a hypothesis as to why this animal has such a large range.

INVESTIGATION 14.1

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

Mapping Sensory Receptors

Your ability to feel objects is determined by the information that touch receptors provide your brain. Areas that are very sensitive have a great number of touch receptors. To distinguish between the touch of two pinpoints in an area, that area must contain two touch receptors. The body has different receptors for both hot and cold. Many times these receptors are very close to each other, but occasionally you may find one area that has only one of the receptors.

Purpose

To map touch receptors in different parts of the body and to map the hot and cold receptors in a given area of the body

Materials

divider
ruler
two 50 mL beakers
10 finishing nails
ice
red and blue felt markers
paper towel

Part 1: Touch Discrimination

Procedure

1. Using a ruler, move the points on the divider 20 mm apart and place the points on the back of a subject's hand (**Figure 1**).

Figure 1

Caution: The points on the divider are sharp. Be careful when placing the divider on skin. Do not press too hard as it may cause injury.

(a) Can the subject feel both points?

2. Have the subject look away from the area being investigated. Progressively decrease the distance between the points. Occasionally, touch with only one of the points to keep the results reliable.

(b) Record the minimum distance at which the subject can still distinguish two different points.

3. Predict which of the following areas of the body has the greatest number of touch receptors. (For example, predict minimum distance between two points that can be detected on the fingertip, and then test your prediction.)
   - palm of hand
   - fingertip
   - back of hand
   - calf
   - back of neck
   - lips

Analysis

(c) Compare your predicted and observed results.

(d) Explain why the fingertips are more sensitive than the back of the hand.

(e) Explain why the body part that you found to have the greatest number of receptors has that many receptors.

Synthesis

(f) Not every touch by an object can be felt. Design an investigation to measure the minimum pressure necessary to stimulate a touch receptor. If your lab has the necessary equipment, conduct your experiment after having your procedure approved by your teacher.

EXTENSION

Action Potentials

In this simulation, observe the relationship between different amounts of pressure and the frequency of action potentials from pressure sensors in the human hand.

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INVESTIGATION 14.1 *continued*

Part 2: Temperature Receptors

Prediction

(g) Predict whether you are more sensitive to hot or cold. Do you believe you have more hot or more cold receptors?

Procedure

4. Fill a beaker with warm water and another with iced water. Place five finishing nails in each beaker. Allow the nails to sit in the cold or warm water for at least 2 min between tests.
5. Draw a square 5 cm by 5 cm on the back of a subject's hand. While the subject looks away from the test area, remove one of the nails, wipe off excess water, and lightly touch the point of the nail on the skin inside the test area. Ask the subject whether the nail is hot or cold. Then return the nail to the beaker.
6. If the subject identifies the temperature correctly, place a small dot where the nail touched the hand. Use a blue water-soluble marker for cold receptors and red water-soluble marker for heat receptors.
7. Alternate between hot and cold nails when conducting your test. (And occasionally, change the order.) Map the area within the square. Do at least 20 trials for each temperature.

Analysis

(h) Compare your observed data to the prediction that you made. What conclusions can you draw from the evidence?

Synthesis

(i) Air temperatures usually range between −30 °C and +35 °C. Body temperature is about 37 °C. Using this information, explain why temperature receptors are not evenly distributed.

INVESTIGATION 14.2

Eye Dissection

The eyes of most mammals have very similar anatomy. By dissecting a cow eye, you can therefore better understand the structures of the human eye. Use the diagram in **Figure 1** on page 449 to help you to identify the structures. As you perform the dissection, record your observations in written notes and/or in biological drawings. Refer to Appendix A4 for a review of biological drawings.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	○ Evaluation
○ Hypothesis	○ Procedure	○ Synthesis
○ Prediction	● Evidence	

Purpose

To observe the principal features of a mammalian eye and identify the major structures

Materials

cow eye
safety goggles
lab apron
dissecting gloves
scissors
forceps
dissecting tray
hand lens
a sheet of newspaper

Wear safety goggles and an apron at all times. When you have finished the activity, clean your work area, wash your hands thoroughly, and dispose of all specimens and materials as instructed by your teacher.

Procedure, Evidence, and Analysis

1. Examine the outside of the eye.

(a) Identify as many structures as possible.

2. Using scissors and forceps, remove as much fat and muscle from the eye as possible.
3. Identify the sclera and the iris. With the scissors, carefully cut into the sclera, in a circle along the outside of the iris.

(b) Note and record how the sclera feels as you cut it.

4. Remove the front part of the eye.

(c) Identify and describe the aqueous humour and the vitreous humour.

5. Using forceps, remove the lens from the eye. Place the lens on the sheet of newspaper.

(d) Describe your observations.

INVESTIGATION 14.2 *continued*

6. Locate the ciliary muscles. These can be found where the lens was and appear black or very dark in colour and have ridges. The layer inside of the eye is the choroids layer.

(e) Describe the choroids layer.

7. Using forceps, remove the retina from the back of the eye.

(f) Describe the appearance of the retina, and the location of the blind spot in the retina.

INVESTIGATION 14.3

Hearing and Equilibrium

Report Checklist

● Purpose	● Design	● Analysis
○ Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

In this investigation, you will test the effects of environmental factors on both hearing and equilibrium. Begin by reading over the procedure, then predict what will happen in each Part. Formulate a hypothesis and explain your predictions. In Part I, gather evidence by recording the direction from which the sound seems to come and describing any changes in the intensity of the sound. In Part 2, record the direction in which the subject leans and his or her description of any sensations when standing after the chair has stopped.

Problem

What effect will environmental factors have on hearing? on equilibrium?

Materials

tuning fork
rubber hammer
metre stick
swivel chair

Procedure

Part 1: Factors That Affect Hearing

1. Strike a tuning fork with a rubber hammer and listen to the sound. Holding the tuning fork in your left hand, place the *stem* (not the prongs!) of the tuning fork on your forehead. Place the palm of your right hand over your right ear.
2. Repeat the procedure, but this time hold the tuning fork in your right hand and place your left hand over your left ear.
3. Repeat the procedure a third time, but ask your lab partner to cover both of your ears.
4. Strike the tuning fork with a rubber hammer and hold it approximately 1 m from your ear.
5. Ask your lab partner to place a metre stick gently on the bony bump immediately behind your ear. Then, ask him or her to place the stem of the tuning fork on the metre stick.

Part 2: Equilibrium

6. Ask your lab partner to sit in a swivel chair. Have your partner elevate his or her legs and begin slowly rotating the chair in a clockwise direction. After 20 rotations, have the subject stand. (Be prepared to support your partner!)
7. After 3 min, repeat the process, but rotate the swivel chair in a counterclockwise direction.
8. Ask your lab partner to tilt his or her head to the right, and begin a clockwise rotation of the swivel chair. After 20 rotations, ask the subject to hold his or her head erect and to stand up. (Again, be prepared to catch your lab partner.)

Analysis and Evaluation

(a) Provide explanations for the data collected.

(b) Using the data collected, provide evidence to suggest that sound intensity is greater in fluids than in air.

(c) Provide evidence that the fluid in the semicircular canals continues to move even after rotational stimuli cease.

(d) What causes the falling sensation produced in step 8?

(e) Describe the manner in which the semicircular canals detect changes in motion during a roller-coaster ride.

Chapter 14 SUMMARY

Outcomes

Knowledge

- describe the structure and function of the human eye (i.e., cornea, lens, sclera, choroid, retina, rods and cones, pupil, iris, and optic nerve) (14.2)
- describe the structure and function of the human ear (i.e., pinna, auditory canal, tympanum, ossicles, cochlea, organ of Corti, auditory nerve, utricle and saccule, semicircular canals, and eustachian tube) (14.3)
- explain other ways that human organisms sense their environment and spatial orientation (14.1, 14.3)

STS

- explain that scientific knowledge and theories develop through hypotheses, collection of evidence through experimentation, and provision of explanations (14.2)
- explain that the goal of technology is to provide solutions to practical problems (14.2, 14.3)

Skills

- ask questions and plan investigations by designing an experiment to investigate heat, cold, pressure, and touch receptors (14.1)
- conduct investigations and gather and record data and information by performing experiments to measure the ability to discriminate objects visually and to hear a range of sounds (14.2, 14.3) and by observing the principal features of an ear and eye and identifying the major visible structures of those organs (14.2, 14.3)
- analyze data and apply mathematical and conceptual models (all)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

14.1

sensory adaptation

14.2

sclera
cornea
aqueous humour
choroid layer
iris
retina
rods
cones
fovea centralis
rhodopsin
accommodation
glaucoma
cataract
astigmatism
nearsightedness
farsightedness

14.3

pinna
auditory canal
tympanic membrane
ossicles
oval window
eustachian tube
vestibule
semicircular canals
cochlea
organ of Corti
basilar membrane
otoliths

MAKE a summary

1. Imagine a cougar or bear suddenly walks in your path. Create a flow chart or diagram that shows how your nervous system would respond to this stressful situation. Label the diagram with as many key terms as possible.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To www.science.nelson.com

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 14
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

EXTENSION

CBC radio ONE QUIRKS & QUARKS

Blind, Naked, and Feeling No Pain

Listen to this interview with Dr. Tom Park, who has discovered that naked mole-rats don't feel pain through their skin. The animals otherwise seem to have normal sensation in their skin. Studying mole-rats may help us to better understand pain.

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Chapter 14 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. The *action* and *purpose* of sensory receptors, respectively, is to
- A. increase the energy of the stimulus above the threshold level and to provide the CNS with information about the external environment only
- B. decrease the energy of the stimulus below the threshold level and to provide the CNS with information about the external environment only
- C. convert the energy of a response into an action potential and to provide the CNS with information about changes in the external environment or within the internal environment
- D. convert the energy of a stimulus into an action potential and to provide the CNS with information about changes in the external environment or within the internal environment

Use the following information to answer questions 2 and 3.

Figure 1 shows a cross section of a human eye. Structures are labelled with a letter.

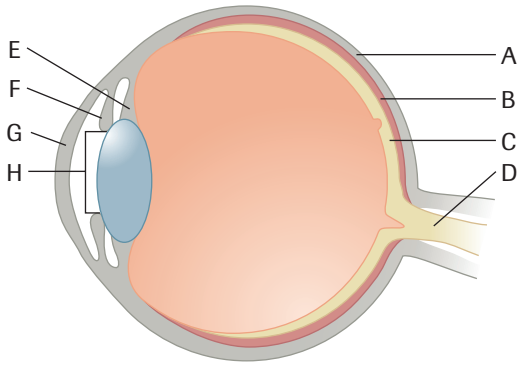

Figure 1

2. Which choice gives all three labels correctly for the given structures?
- A. A = sclera, C = retina, G = cornea
- B. B = sclera, C = retina, H = cornea
- C. C = sclera, G = retina, D = cornea
- D. F = sclera, E = retina, H = cornea

3. Identify the statement that is incorrect.
- A. Light enters through structure G on the diagram.
- B. Light enters through structure H on the diagram.
- C. Structure B on the diagram prevents light from scattering.
- D. Structure A on the diagram prevents light from scattering.

Use the following information to answer questions 4 and 5.

Figure 2 shows the internal structures of the human ear. The structures are labelled with a number.

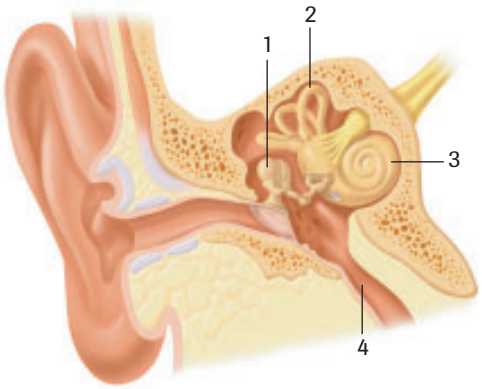

Figure 2

4. NR Match the following structures with the labels shown on **Figure 2**. (Record all four digits of your answer.)

_____	_____	_____	_____
eustacian tube	semicircular canals	ossicles	cochlea

5. The structure that is primarily responsible for maintaining dynamic equilibrium is labelled with which number?
- A. 1
- B. 2
- C. 3
- D. 4

6. A person who has colour blindness would have a gene defect expressed in this part of the eye.
- A. optic nerve
- B. vestibule
- C. cones
- D. cornea

7. NR Place the following structures in order as light passes through the eye. (Record all four digits of your answer.)
1. aqueous humor
2. lens
3. cornea
4. fovea

8. Should the curvature of the cornea along the horizontal axis of the eye be greater than the curvature along the vertical axis, the result would be
   A. glaucoma
   B. night blindness
   C. astigmatism
   D. farsightedness

9. Sensorineural deafness may be caused by
   A. the blockage of the eustachian tube
   B. damage to the basilar membrane
   C. damage to the ossicles
   D. damage to the tympanic membrane

10. NR Place the following events in the correct sequence after the initial event. (Record all four digits of your answer.)

    Initial event: Sound waves push against the eardrum or tympanic membrane.

    1. Tiny hair-like cells in the organ of Corti respond to vibrations by stimulating nerve cells in the basilar membrane.
    2. Vibrations are passed along to three bones in the middle ear: the malleus, incus, and stapes.
    3. The cochlea receives waves within the inner ear.
    4. The oval window receives vibrations from the ossicles.

Part 2

Use the following information to answer questions 11 to 14.

In an experiment, skin was exposed to different temperatures. The frequency of firing of action potentials from temperature receptors was recorded. The average frequency was then used to sketch the graph in **Figure 1**.

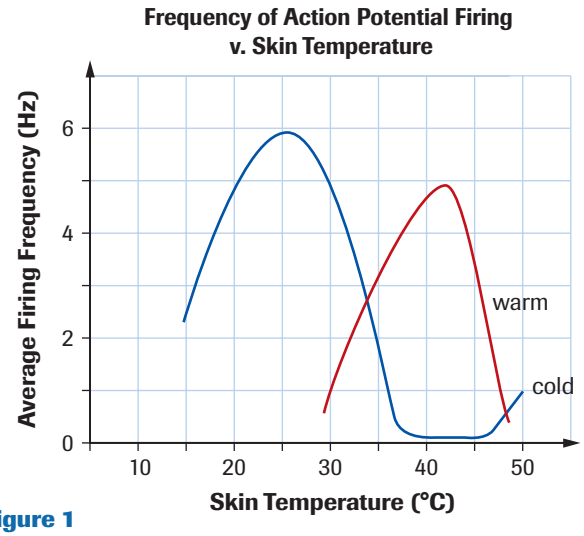

Figure 1

11. DE **Identify** the temperature at which cold temperature receptors fire most frequently.

12. DE **Identify** the temperature at which hot temperature receptors fire most frequently.

13. DE **Conclude** whether the body is more sensitive to warm or cold stimuli. **Justify** your conclusion.

14. DE **Hypothesize** why cold temperature receptors show an increased sensitivity at 50 °C.

15. The retina of a chicken is composed of many cones very close together. **Explain** the advantages and disadvantages associated with this type of eye.

16. DE Myopia is thought to be caused by a combination of genetic and environmental factors, but there are some differences in opinion. Write a unified response addressing the following aspects of myopia.
    - It was once believed that excessive reading might cause myopia. **How** might this theory be tested?
    - **How** might the link between myopia and genetics be established?

17. **Why** do people often require reading glasses after they reach the age of 40?

18. When the hearing of a rock musician was tested, the results revealed a general deterioration of hearing as well as total deafness for particular frequencies. **Why** is the loss of hearing not equal for all frequencies?

19. One theory suggests that painters use less purple and blue in their paintings as they age because layers of protein build up on the lens in their eyes. As the buildup gradually becomes thicker and more yellow, the shorter ultraviolet wavelengths from the ultraviolet end of the spectrum are filtered. **How** would you test the theory?

Use the following information to answer questions 20 to 23.

The data in **Table 1** were collected from an experiment.

Table 1 Changes in Near-point Accommodation with Age

Age	Near-point accommodation (cm)
10	7.5
20	10.2
30	11.3
40	17.2
50	56.8
60	87.3

20. DE **Identify** the problem that was being investigated in the experiment.

21. DE **Hypothesize** how the variables under investigation are related.

22. DE **Conclude** the age at which near-point accommodation is most affected.

23. DE **Explain** what causes the change in near-point accommodation. How does it affect people?

chapter

15 Endocrine System

In this chapter

Olga Yegorova upset reigning 5000 m champion Gabriela Szabo at the 2001 World Track and Field Championships held in Edmonton. The usually polite Canadian audience booed Yegorova as she crossed the finish line. The Russian distance runner was booed for what was perceived to be an unfair advantage—taking the banned chemical hormone, erythropoietin (EPO). Following a competition in Paris, Yegorova had tested positive for erythropoietin, but she had been reinstated just before the world championships on a technicality. Although EPO was detected in Yegorova's urine, the Paris track meet organizers failed to do the required follow-up blood test. By the time Yegorova was tested again, abnormally high levels of EPO could no longer be identified.

Erythropoietin is a naturally occurring hormone produced by the kidneys. It boosts red blood cell production, increasing oxygen transport to the tissues. More oxygen means greater energy for endurance athletes. Tests have shown that athletic enhancement gained by using EPO for four weeks matches that of several years of training. But EPO is dangerous. Increased red blood cell production makes the blood thicker and more difficult to pump. Very high red blood cell counts can increase blood clotting and overwork the heart. According to some doping experts, the deaths of 20 European cyclists between 1988 and 1998 can be linked directly to EPO use.

Since the body produces EPO, it is difficult to detect. New tests that analyze blood for abnormally high red blood cell volume and analyze for unusually high EPO levels are being used to detect its use. Unfortunately, athletes can still avoid getting caught by stopping EPO treatments a few weeks before the tests.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Explain how hormones help the body adjust to stress.
2. Antidiuretic hormone (ADH) and aldosterone are hormones that affect the kidney. Explain why the regulatory systems for osmotic pressure of fluids and for body fluid volumes are controlled by chemicals carried by blood, rather than by nerves.

Career Connections:
Licensed Practical Nurse; Pharmacist

Figure 1
Gabriela Szabo of Romania leads Olga Yegorova in a race.

Exploration — Chemical Signals and Sports

Find out more about the use of banned drugs in sports.

(a) Choose one banned drug and explain the unfair advantage it provides.

(b) What are some of the health risks associated with its use?

(c) Identify some of the technologies used to detect whether an athlete is using the drug.

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15.1 Homeostasis, Hormones, and the Endocrine System

The human body works best at a temperature of 37 °C, with a 0.1 % blood glucose level and a blood pH of 7.35. However, the external environment does not always provide the ideal conditions for life. Air temperatures in Canada can fluctuate between –40 °C and +40 °C. Rarely do foods consist of 0.1 % glucose and have a pH of 7.35. You also place different demands on your body when you take part in various activities, such as playing racquetball, swimming, or digesting a large meal. Your body systems must adjust to these variations to maintain a stable internal environment. **Homeostasis** refers to the body's attempt to adjust to a fluctuating environment. The body maintains a constant balance, or steady state, through a series of adjustments. This system of balance requires constant monitoring and feedback about body conditions (**Figure 1**). An increase in heart rate during exercise and the release of glucose from the liver to restore blood sugar levels are a couple of examples of the adjustments made. The concept of homeostasis is central to how the endocrine system operates.

homeostasis the process by which a constant internal environment is maintained despite changes in the environment

DID YOU KNOW ?

Discovering Homeostasis

The word *homeostasis* was coined in 1932 when Walter Cannon, a physiology professor at Harvard University, published the book *Wisdom of the Body*. Aided by new X-ray equipment, Cannon was able to mix food with barium sulfate and follow it toward the stomach. He noted that the waves of contraction that pushed along the digestive tract could be suspended if the animal were frightened. Cannon surmised that higher mammals have a complex system of self-regulatory mechanisms that keep the body stable under various physical and emotional circumstances.

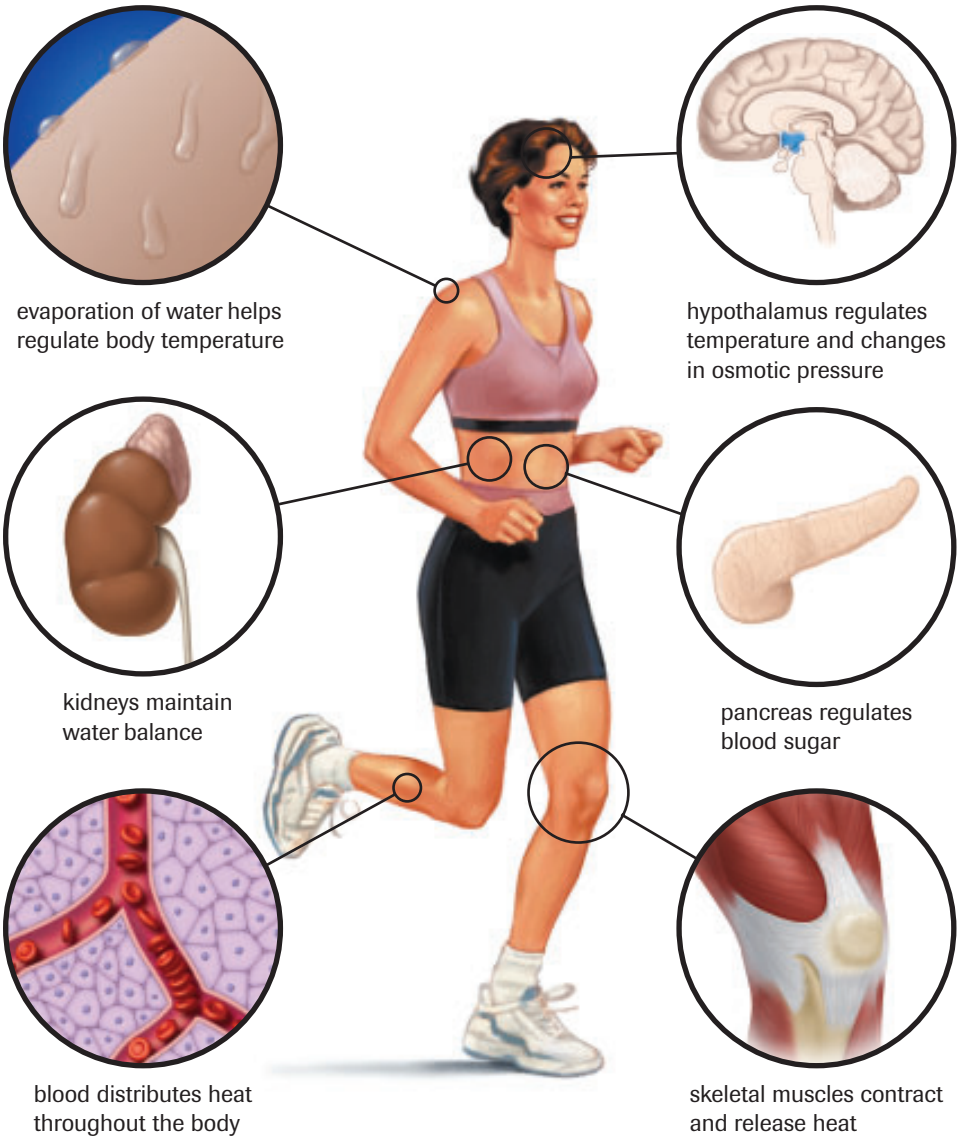

Figure 1
Homeostasis requires the interaction of several regulatory systems. Information about blood sugar, fluid balance, body temperature, oxygen levels, and blood pressure is relayed to a nerve coordinating centre. Once their levels move outside the normal limits, regulators bring about the needed adjustments.

All homeostatic control systems have three functional components: a receptor, a coordinating centre, and an effector (**Figure 2**). Special receptors located in the organs of the body signal a coordinating centre once an organ begins to operate outside its normal limits. The coordinating centre relays the information to the appropriate effector, which helps to restore the normal balance. For example, when carbon dioxide levels increase during exercise, chemical receptors in the brainstem are stimulated. Nerve cells from the brain then carry impulses to effector muscles, which increase the depth and rate of breathing. The increased breathing movements help flush excess carbon dioxide from the body.

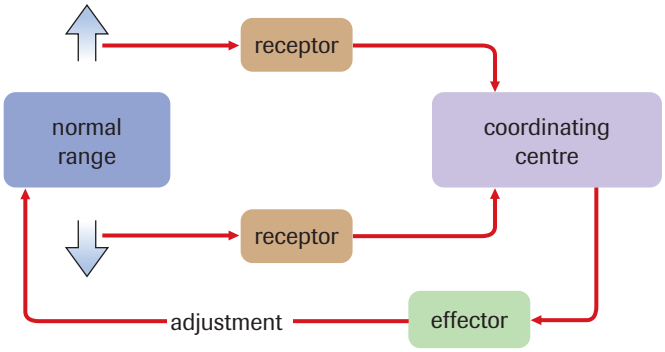

Figure 2
A schematic diagram of a control system

A group of chemical receptors in the arteries in the neck can detect low levels of oxygen in the blood. A nerve is excited and sends a message to the brain, which relays the information by way of another nerve to the muscles that control breathing movements. This system ensures that oxygen levels are maintained within an acceptable range. Homeostasis is often referred to as a **dynamic equilibrium**. Although there are fluctuations in blood glucose, body temperature, blood pressure, and blood pH, the homeostatic mechanism ensures that all body systems function within an acceptable range to sustain life (**Figure 3**).

dynamic equilibrium a state of stability within fluctuating limits

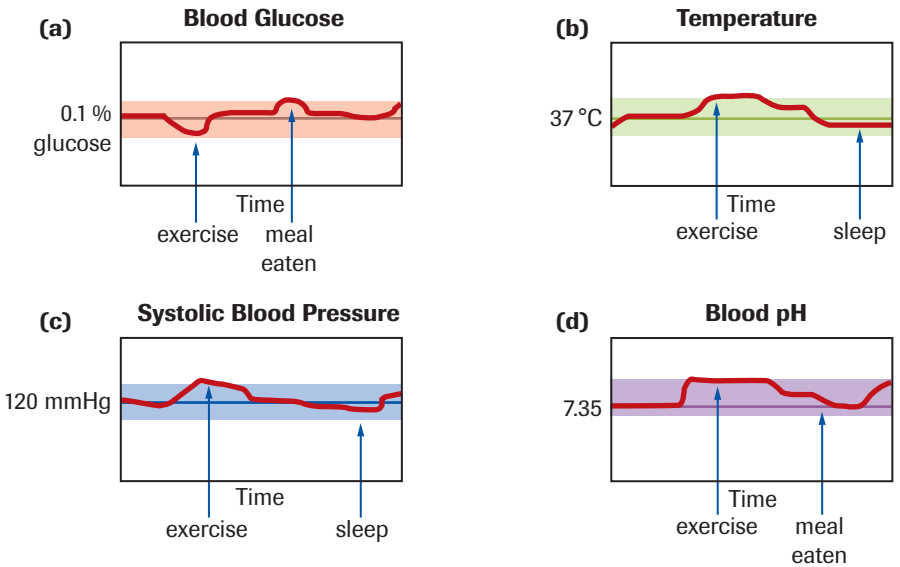

Figure 3
Blood glucose **(a)** is maintained within a narrow range and movement outside of the range can signal disease. Body temperature **(b)** can fluctuate by +2 °C with exercise and −2 °C with sleep. Systolic blood pressure **(c)** is usually near 120 mmHg but can move as high as 240 mmHg in a very fit athlete for a limited time during strenuous exercise. Blood pH **(d)** operates within a narrow range, and changes of ±0.2 can lead to death.

Homeostasis and Feedback Systems

negative feedback the process by which a mechanism is activated to restore conditions to their original state

Mechanisms that make adjustments to bring the body back within an acceptable range are referred to as **negative feedback** systems. The household thermostat is an example of such a system (**Figure 4**). In this case, the coordinating centre, called a thermostat, also contains the receptor (a thermometer). When the room temperature falls below a set point, say 20 °C, the thermostat switches on the effector (the furnace). When the thermometer detects a temperature above the set point, the thermostat switches off the furnace. This type of control circuit is called negative feedback because a change in the variable being monitored (e.g., temperature) triggers the control mechanism to counteract any further change in the same direction. Negative feedback mechanisms prevent small changes from becoming too large. Most homeostatic mechanisms in animals operate on this principle of negative feedback.

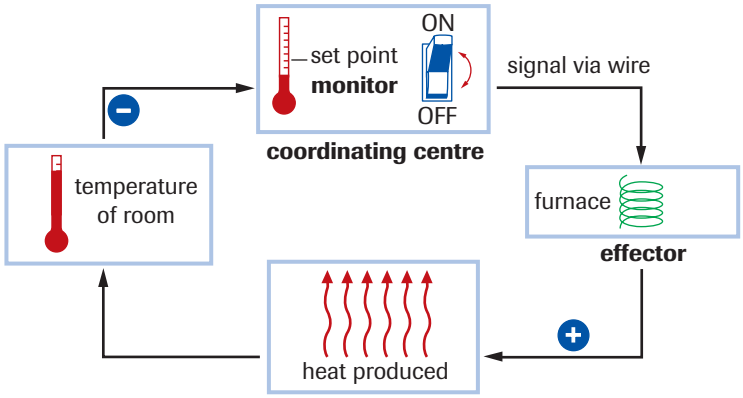

Figure 4
The household thermostat illustrates a negative feedback system. When the variable (temperature) exceeds the set point, the coordinating centre turns the effector off. The + indicates "stimulation" or "activation," and the − indicates "inhibition" or "turning off."

positive feedback the process by which a small effect is amplified

Positive feedback systems are less common in the body. Whereas negative feedback systems are designed to resist change, positive feedback systems reinforce change. Positive feedback systems move the controlled variable away from a steady state. The value of a positive feedback system is that it allows a discrete physiological event to be accomplished rapidly. Once this event is accomplished, the feedback system stops.

Practice

1. Define homeostasis.
2. Use the example of a thermostat to explain homeostasis.
3. Explain the negative feedback system shown in **Figure 5**.

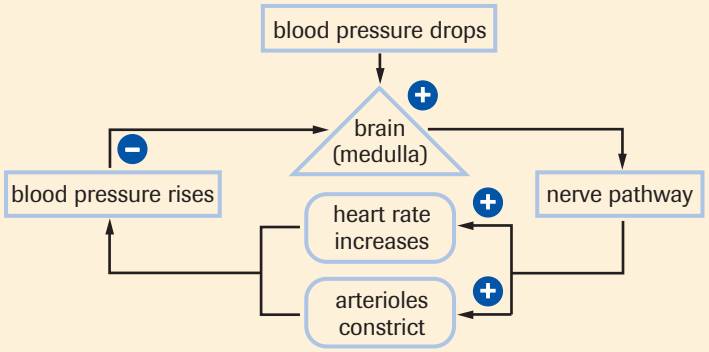

Figure 5

Hormones

The trillions of cells of the body all interact with each other—no cell operates in isolation. The integration of body functions depends on chemical controls. **Hormones** are chemical regulators produced by cells in one part of the body that affect cells in another part of the body. The word *hormone* comes from the Greek *hormon*, meaning "to excite or set into motion." Hormones serve as regulators, speeding up or slowing down certain bodily processes. Only a small amount of a hormone is required to alter cell metabolism. Chemicals produced by endocrine glands (**Figure 6**) and secreted directly into the blood are referred to as **endocrine hormones** (**Figure 7**). The circulatory system carries these hormones to the various organs of the body.

Figure 7
Endocrine hormones are chemical controls involved in the regulation of growth, development, and homeostasis. This sequence of photos is a computer simulation of the aging process based on statistical data.

Hormones can be classified according to their activation site. Some hormones are called nontarget hormones. They affect many cells or tissues throughout the body. For example, **insulin** makes practically all cells in the body permeable to glucose and makes liver cells to convert glucose to glycogen. **Human growth hormone (hGH)** and **epinephrine** are also non-target hormones. Other hormones affect specific cells or target tissues. For example, gastrin stimulates only certain stomach cells, which then produce digestive enzymes.

Chemical Control Systems

Along with the nervous system, the endocrine system provides integration and control of the organs and tissues to maintain homeostasis. The nervous system enables the body to adjust quickly to changes in the environment. The endocrine system is designed to maintain control over a longer duration. Hormones such as growth hormone and the various hormones involved in reproduction, for example, regulate and sustain development for many years.

The division between the nervous system and endocrine system is most subtle in the hypothalamus. The hypothalamus regulates the pituitary gland through nerve stimulation as well as by releasing hormones. However, the endocrine glands, stimulated by the pituitary, secrete chemicals that affect the nerve activity of the hypothalamus.

Hormones do not affect all cells. Cells may have receptors for one hormone, but not another. The number of receptors on individual cells may also vary. For example, liver cells and muscle cells have many receptor sites for the hormone insulin, but less active cells such as bone and cartilage cells have fewer receptors.

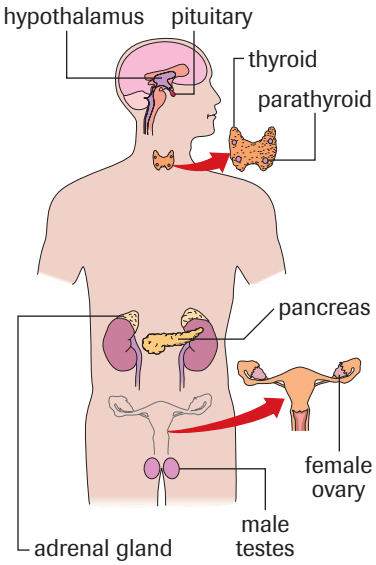

Figure 6
The location and appearance of some important endocrine glands in the human body. Hidden within the thyroid gland are four small glands—the parathyroid glands.

hormones chemicals released by cells that affect cells in other parts of the body

endocrine hormones chemicals secreted by endocrine glands directly into the blood

insulin hormone produced by the islets of Langerhans in the pancreas; insulin is secreted when blood sugar levels are high

human growth hormone (hGH) hormone produced by the pituitary gland that stimulates growth of the body; also known as somatotropin (STH)

epinephrine (adrenaline) hormone, produced in the adrenal medulla that accelerates heart rate and body reactions during a crisis (the fight-or-flight response)

Hormones may also be classified by their chemical nature. Most hormones are water-soluble, and are proteins, peptides, or amino acid derivatives. Water-soluble hormones act from outside the cell by binding to receptor sites on the cell membrane, which activates enzymes in the cytoplasm to carry out specific functions (**Figure 8 (a)**). The second class of hormones is fat-soluble hormones, which are also called steroids. Steroids act from inside the cell, by diffusing into a specific cell and binding with receptor molecules in the cytoplasm, which signals the cell to produce a specific protein (**Figure 8 (b)**). You will learn more about specific members of these two classes in the rest of this unit and in Unit 30 B.

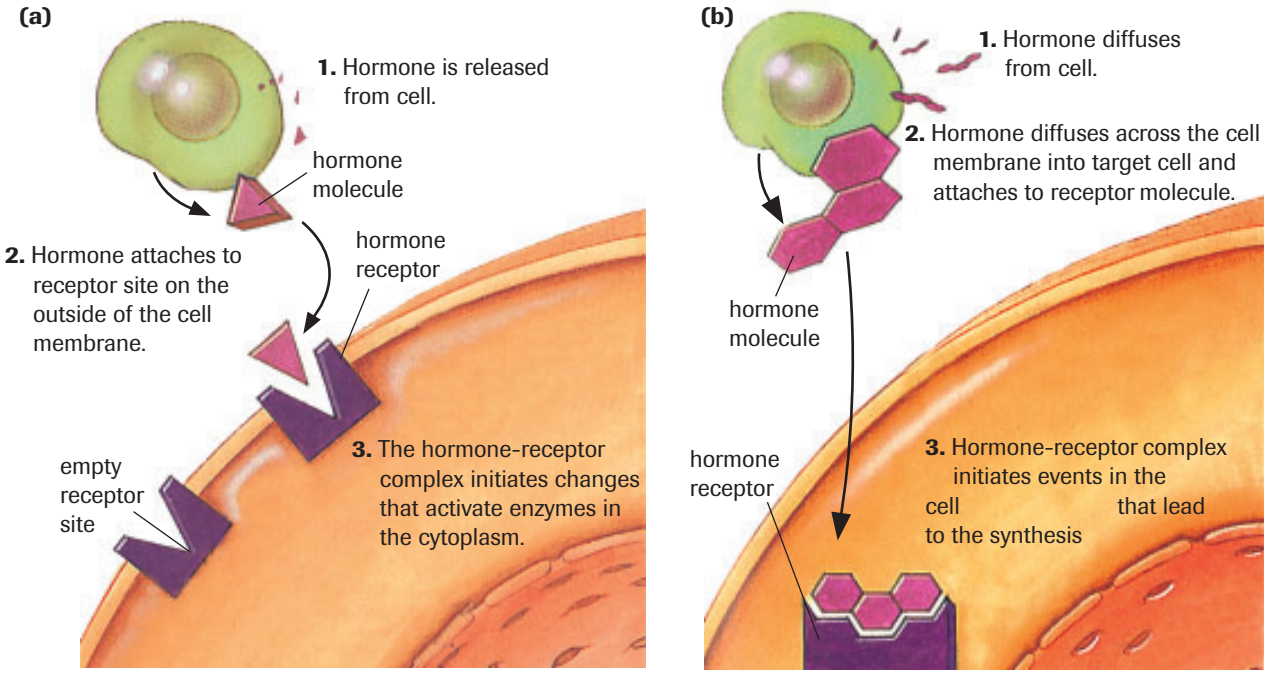

Figure 8
(a) A water-soluble hormone molecule combines with its receptor on the cell membrane. This triggers events in the cell that lead to the activation of enzymes in the cytoplasm.
(b) A fat-soluble (steroid) hormone molecule passes through the cell membrane of the target cell and combines with its receptor in the cytoplasm. This triggers events in the cell that lead to the production of a specific protein.

DID YOU KNOW?

Exocrine Glands

Exocrine glands, unlike the endocrine glands, are glands that secrete substances through ducts or tubes onto a body surface or into a cavity. Most of the body's glands are exocrine glands. Digestive, mucous, sebaceous, and sweat glands are included in this category. The pancreas is considered both an exocrine gland and an endocrine gland.

Regulating Hormones

Hormone production must be regulated. Once a hormone produces the desired effect, production of that hormone must be decreased to maintain normal body functioning.

Consider, for example, the hormone epinephrine (adrenaline). Epinephrine enables the body to respond to stressful situations. Among other responses, the hormone causes pulse and breathing rates to accelerate and blood sugar levels to rise. All actions are designed to allow the body to respond to stress in what has come to be known as the "flight-or-fight" response. However, once the stressful situation is gone, the body returns to normal resting levels. Once again, negative-feedback action is required to restore homeostasis. Throughout this chapter, you will study other specific examples of negative feedback.

Practice

4. Define an endocrine hormone.
5. Do hormones affect every cell in the body? Explain why or why not.
6. Explain why hormones must be regulated.

The Pituitary Gland: The Master Gland

The **pituitary gland** is often referred to as the "master gland," because it exercises control over other endocrine glands. This small, sac-like structure is connected by a stalk to the hypothalamus, the area of the brain associated with homeostasis. The interaction between the nervous system and endocrine system is evident in the hypothalamus–pituitary complex (**Figure 9**, next page). The pituitary gland produces and stores hormones. The hypothalamus stimulates the release of hormones by the pituitary gland by way of nerves and by releasing hormones.

Releasing hormones (also called releasing factors) are peptides that stimulate the pituitary to release a stored hormone.

The posterior lobe of the pituitary does not synthesize hormones. Instead, it stores and releases hormones that have been synthesized by the hypothalamus, such as antidiuretic hormone (ADH). You learned in Unit 20 D that this hormone acts on the kidneys and helps regulate body water. The ADH travels from the hypothalamus to the pituitary by way of specialized nerve cells (**Figure 9 (a)**, next page). Once at the posterior pituitary lobe, the ADH is stored until it is needed, at which time it is released into the blood.

In contrast, the anterior lobe of the pituitary synthesizes its own hormones. The secretion of the pituitary hormones by the posterior lobe, such as hGH (**Figure 9 (b)**, next page), is governed by factors secreted by the hypothalamus. Releasing factors stimulate the pituitary to secrete its hormones, and **inhibiting factors** stop pituitary secretions. These factors travel from the hypothalamus to the pituitary by a series of blood vessels.

Table 1 summarizes the hormones produced by the pituitary gland. Most of the pituitary hormones will be discussed in detail in the following sections.

Table 1 Pituitary Hormones

Hormone	Target
Anterior lobe	
thyroid-stimulating hormone (TSH)	thyroid gland
adrenocorticotropic hormone (ACTH)	adrenal cortex
human growth hormone (hGH)	most cells
follicle-stimulating hormone (FSH)	ovaries, testes
luteinizing hormone (LH)	ovaries, testes
prolactin (PRL)	mammary glands
melanocyte-stimulating hormone (MSH)	melanocytes in skin
Posterior lobe	
oxytocin	uterus, mammary glands
antidiuretic hormone (ADH)	kidneys

DID YOU KNOW?

Unused Protein Hormones

Protein hormones that do not attach to receptor molecules on target cells are removed from the body by the liver or kidney. The presence of these hormones can be monitored by urinalysis.

pituitary gland gland at the base of the brain that, together with the hypothalamus, functions as a control centre, coordinating the endocrine and nervous systems

releasing hormone a peptide produced by the hypothalamus that stimulates the anterior pituitary gland to release a stored hormone; also called a releasing factor

inhibiting factor chemical that inhibits production of a hormone by the anterior pituitary gland

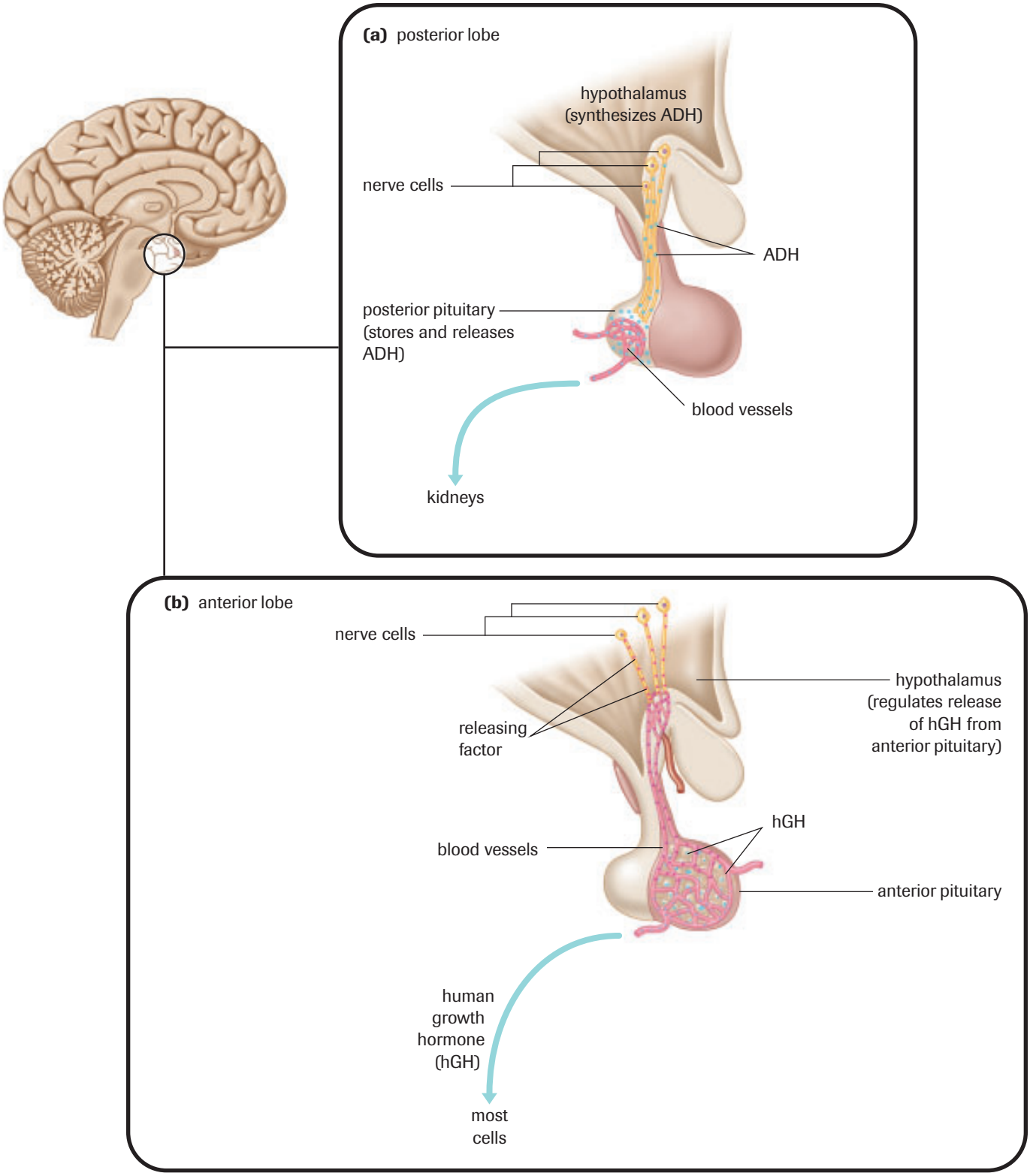

Figure 9

The pituitary gland is composed of two separate lobes: the posterior lobe and the anterior lobe.

(a) In this example, the cells of the hypothalamus synthesize antidiuretic hormone (ADH), which travels from the hypothalamus to the pituitary along specialized nerve cells. The ADH molecules remain in the pituitary gland and are released into the blood when they are needed.

(b) Releasing and inhibiting factors secreted by nerve cells of the hypothalamus travel along blood vessels to the anterior pituitary where they regulate the secretion of hormones such as hGH.

Using Recombinant DNA Technology to Produce Hormones

Genetic engineering involves extracting genes from human chromosomes and inserting them into bacteria, which then synthesize the human gene product. Recombinant DNA technology has been widely used by drug companies to produce human hormones.

Human growth hormone (hGH) can be produced by this technology. Normally produced by the pituitary, hGH primarily promotes the growth of bone and muscle. Lower than normal concentrations can cause dwarfism, extreme fatigue, anxiety, and malaise. One estimate indicates that 3 in 10 000 people have a serious deficiency of hGH.

Humans do not respond to animal growth hormone, and hGH has to be extracted from cadavers, of which there is a limited supply. Only a minute quantity of hGH can actually be extracted from the pituitary of a cadaver. In addition, the brain tissue from a cadaver might have been infected with a disease-causing agent such as the infectious protein that causes Creutzfeldt-Jacob disease, the human equivalent of mad cow disease. In 1985, recombinant DNA human growth hormone (rhGH) first became available.

Although rhGH provides a ready supply of hormone, its use has raised many ethical questions. Should rhGH be available only to children who have dwarfism or to any child that might want to be taller? Should dwarfism be treated as a disease, or viewed as one part of human diversity?

SUMMARY — Homeostasis, Hormones and the Endocrine System

- Homeostasis is the body's attempt to keep all its systems operating within normal limits in a fluctuating environment.
- The endocrine system and nervous system work together to maintain homeostasis.
- All homeostatic control systems have three functional components: a receptor, a coordinating centre, and an effector.
- Negative feedback mechanisms trigger a response that reverses the changed condition; positive feedback mechanisms move the controlled variable even farther away from a steady state.
- The hypothalamus controls the production of pituitary hormones.

Section 15.1 Questions

1. Differentiate between positive and negative feedback systems.
2. Use **Figure 10** to explain homeostasis.

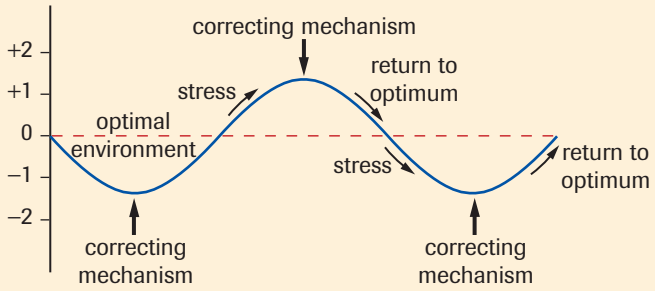

Figure 10

3. What are target tissues or organs?
4. Explain how the nervous system and endocrine system are specialized to maintain homeostasis.
5. Compare water-soluble and fat-soluble hormones.
6. Compare the anterior and posterior lobes of the pituitary. How are they similar and how are they different?
7. Some scientists have speculated that certain young female Olympic gymnasts may have been given growth hormone inhibitors. Why might the gymnasts have been given growth inhibitors? Do you think hormone levels should be altered to regulate growth patterns?
8. Compare the cells of the hypothalamus to cells of the pituitary.

15.2 Hormones That Affect Blood Sugar

islets of Langerhans hormone-producing cells of the pancreas; these cells are part of the endocrine system

glucagon hormone produced by the pancreas; when blood sugar levels are low, glucagon promotes conversion of glycogen to glucose

Two members of the endocrine system affect blood sugar levels in humans: specific cells in the pancreas and the adrenal glands. The pancreas contains two types of cells: one type that produces digestive enzymes and a second type that produces hormones. The hormone-producing cells are located in structures called the **islets of Langerhans**, named after their discoverer, German scientist Paul Langerhans. More than 200 000 tiny islets, each containing thousands of cells, are scattered throughout the pancreas. The islets contain beta and alpha cells that are responsible for the production of two hormones: insulin and **glucagon**.

Insulin is produced in the beta cells of the islets of Langerhans and is released when the blood sugar level increases. After a meal, the blood sugar level rises and an appropriate amount of insulin is released (**Figure 1**). The insulin causes cells of the muscles, the liver, and other organs to become permeable to the glucose. Also, in the liver, glucose is

EXTENSION

Hormones and Blood Glucose Regulation

In this Audio Clip, you can hear a discussion of how specific hormones work together to maintain blood glucose homeostasis.

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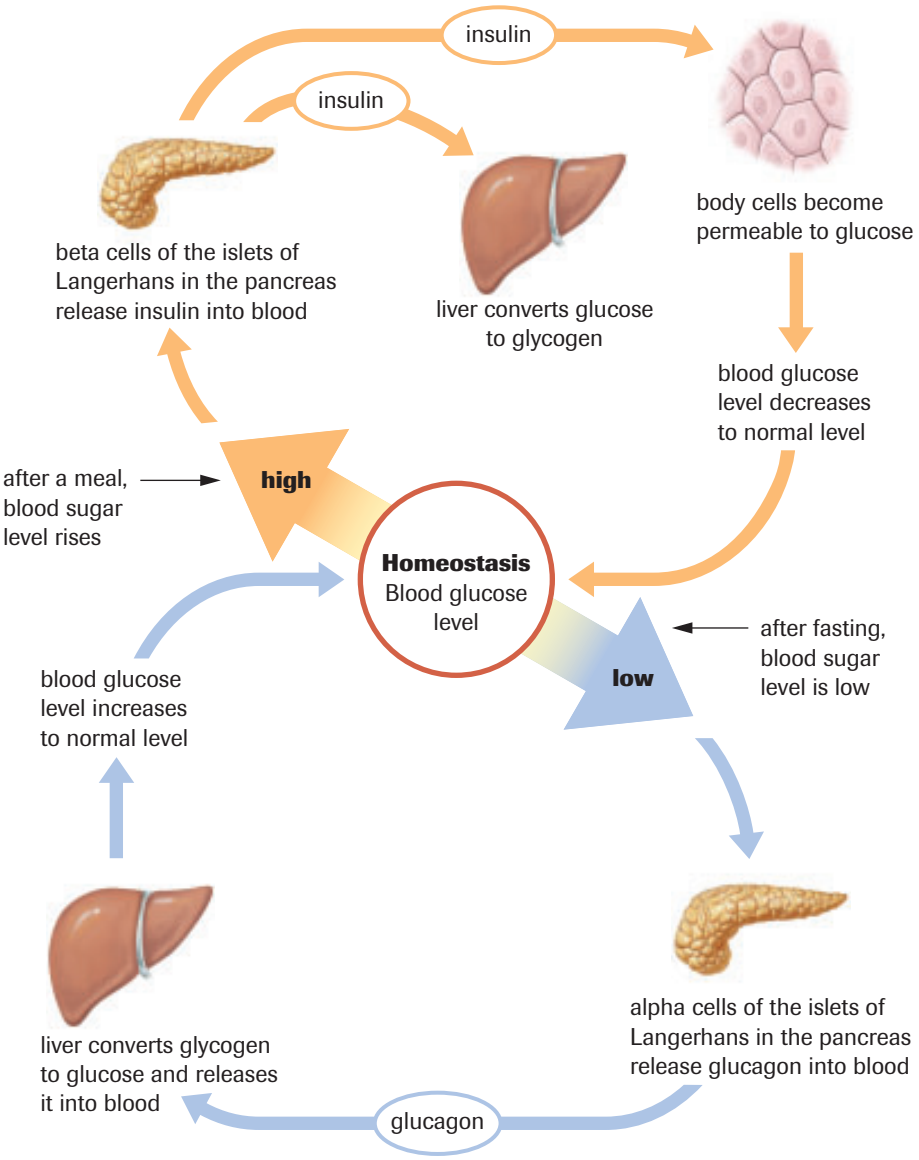

Figure 1
Insulin, released when blood sugar levels are high, increases the permeability of cells to glucose. Glucose is converted into glycogen within the liver, thereby restoring blood sugar levels. Glucagon, released when blood sugar levels are low, promotes the conversion of liver glycogen into glucose, thereby restoring blood sugar levels.

converted into glycogen, the primary storage form for glucose. This enables the blood sugar level to return to normal. In this way, insulin helps maintain homeostasis.

Glucagon and insulin work in a complementary fashion. Insulin causes a decrease in the blood sugar level, and glucagon causes an increase in the blood sugar level. Produced by the alpha cells of the islets of Langerhans, glucagon is released when blood sugar levels are low, such as after periods of fasting. Glucagon promotes the conversion of glycogen to glucose, which is released into the blood. As glycogen is converted to glucose in the liver, the blood sugar level returns to normal.

Diabetes

Diabetes is a chronic disease with no cure that affects more than two million Canadians. It is caused by insufficient production or use of insulin. When left untreated, it can cause blindness, kidney failure, nerve damage, and nontraumatic limb amputation.

diabetes chronic disease in which the body cannot produce any insulin or enough insulin, or is unable to use properly the insulin it does make

Without adequate levels of insulin, blood sugar levels rise very sharply following meals. This condition is known as hyperglycemia, or high blood sugar (from *hyper*, meaning "too much"; *glyco*, meaning "sugar"; and *emia* referring to a condition of the blood). The kidneys are unable to reabsorb all the blood glucose that is filtered through them, so the glucose appears in the urine. Since high concentrations of glucose in the nephrons draw water out of the plasma by osmosis, people with diabetes excrete unusually large volumes of urine and are often thirsty.

People with diabetes often feel tired. Remember that insulin causes cells to become permeable to glucose. Despite the abundance of glucose in the blood, little is able to move into the cells. The cells must turn to other sources of energy. Fats and proteins can be metabolized for energy, but, unlike carbohydrates, they are not an easily accessible energy source. The switch to these other energy sources creates a host of problems. Acetone, an intermediate product of excessive fat metabolism, can be produced. In severe cases, the smell of acetone can be detected on the breath of these people.

There are three main types of diabetes mellitus. Type 1 diabetes (formerly known as juvenile-onset diabetes) occurs when the pancreas is unable to produce insulin because of the early degeneration of the beta cells in the islets of Langerhans. It is usually diagnosed in childhood, and people who have it must take insulin to live (**Figure 2**). Approximately 10 % of people with diabetes have type 1 diabetes.

Type 2 diabetes (sometimes referred to as adult-onset diabetes) is associated with decreased insulin production or ineffective use of the insulin that the body does produce. It is usually diagnosed in adulthood and can be controlled with diet, exercise, and oral drugs known as sulfonamides (which are ineffective against type 1 diabetes). About 90 % of people with diabetes have type 2 diabetes.

A third type of diabetes, gestational diabetes, is a temporary condition that occurs in 2 % to 4 % of pregnancies. It increases the risk of type 2 diabetes in both mother and child.

DID YOU KNOW?

Hypoglycemia

When the blood sugar level falls below normal, a condition known as hypoglycemia occurs. Hypoglycemia can be caused by too much insulin or too little glucagon.

Figure 2
The pen is the newest way of injecting insulin. It is portable, accurate, and easy to use.

Practice

1. How does insulin regulate blood sugar levels?
2. How does glucagon regulate blood sugar levels?
3. Using a flow chart, show a homeostatic adjustment for a person who has consumed a significant amount of carbohydrates in the past hour.

INVESTIGATION 15.1 *Introduction*

Identification of Hyperglycemia

How is urinalysis used to identify diabetes? In this investigation, you will use simulated urine samples to identify diabetes.

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

To perform this investigation, turn to page 498.

Figure 3
Dr. Charles Best (left) and Dr. Frederick Banting (right)

CAREER CONNECTION

Licensed Practical Nurse

Licensed Practical Nurses provide health care in a variety of community care facilities such as schools, health units, nursing homes, and hospitals. Specialized training can be obtained and combined with clinical experience to further career advancement for these health care professionals.

Do you have a caring attitude with excellent communication and interpersonal skills? Above average employment turnover is expected in this career area!

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WWW WEB Activity

Canadian Achievers—Banting and Best

Working together at the University of Toronto, Dr. Frederick Banting and Dr. Charles Best (**Figure 3**) were able to isolate insulin and to then use the hormone as the first successful treatment of diabetes. Follow the links on the Nelson Web site to learn more about the remarkable work of these two scientists.

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Islet Cell Transplants

Type 1 diabetes is the second leading cause of blindness in Canada. Other side effects of the disease, such as kidney and heart failure, stroke, and peripheral nerve damage, affect more than 50 000 Canadians. Although insulin injections provide some regulation of blood sugar, they do not necessarily prevent many of the serious complications of diabetes.

Transplanted islet cells, however, could replace the body's natural mechanism for monitoring and producing insulin. Unlike insulin therapy, islet cell transplantation holds the potential to reverse the effects of diabetes. One of the main barriers to successful clinical islet transplantation is immune rejection. Current anti-rejection drugs are toxic and harmful to islet function, and immunosuppression leaves the recipients susceptible to invading microbes.

Researchers around the world are searching for solutions. A team of researchers at the University of Alberta has pioneered a treatment—known as the Edmonton Protocol—designed by Dr. James Shapiro, director and head of the Clinical Islet Transplant Program (**Figure 4**, next page). The treatment uses a combination of three drugs to prevent rejection of the transplanted islets and to prevent diabetes from returning. The success of the treatment depends on new methods of isolating and transplanting pancreatic cells.

Unlike other types of transplant surgery, the technique used for islet transplants presents few risks. Islet cells are extracted from the pancreas of a donor and infused into the recipient's liver by way of a large vein. The surgeon uses ultrasound to see the vein leading into the liver, the skin is frozen, and a syringe is used to put the new cells in place. The patient can usually return home the next day. The liver is used because, when damaged, it is able to regenerate itself by building new blood vessels and cells. New blood vessels and nerve cells connect to the transplanted islets in the liver and eventually produce enough insulin to control blood sugar.

Figure 4
Members of the Edmonton Protocol at the University of Alberta. The research team is also working on a procedure that would permit the transplant of islet cells into people with type 1 diabetes before the onset of physical complications, such as renal failure. A challenge regarding these transplants is finding an affordable supply of insulin-producing cells. At present, cadavers provide the only source of cells and the cost of processing islets from donors is formidable.

WEB Activity

Web Quest—Diabetes

Diabetes is on the rise in Canada and is becoming one of the leading causes of death. Having diabetes affects individuals, their families, as well as the health-care system. In this Web Quest, you will design a primer aimed at people recently diagnosed with diabetes. Your completed primer will explore the disease, current treatments, and the latest research.

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Adrenal Glands

The adrenal glands are located above each kidney. (The word adrenal comes from the Latin *ad*, meaning "to" or "at," and *renes*, meaning "kidneys.") Each adrenal gland is made up of two glands encased in one shell. The inner gland, the **adrenal medulla**, is surrounded by an outer casing, called the **adrenal cortex**. The medulla is regulated by the nervous system, while hormones regulate the adrenal cortex.

The adrenal medulla produces two hormones: epinephrine (also known as adrenaline) and **norepinephrine** (noradrenaline). The nervous system and the adrenal medulla are linked by the fact that both produce epinephrine. The hormone-producing cells within the adrenal medulla are stimulated by sympathetic nerves in times of stress.

In a stressful situation, epinephrine and norepinephrine are released from the adrenal medulla into the blood. Under their influence, the blood sugar level rises. Glycogen, a carbohydrate storage compound in the liver and muscles, is converted into glucose, a readily usable form of energy. The increased blood sugar level ensures that a greater energy reserve will be available for the tissues of the body. These hormones also increase heart rate, breathing rate, and cell metabolism. Blood vessels dilate, allowing more oxygen and nutrients to reach the tissues. Even the iris of the eye dilates, allowing more light to reach the retina—in a stress situation, the body attempts to get as much visual information as possible.

The adrenal cortex produces three different types of steroid hormones: the **glucocorticoids**, the **mineralocorticoids**, and small amounts of **sex hormones**. The glucocorticoids are associated with blood glucose levels. One of the most important of the glucocorticoids, **cortisol**, increases the level of amino acids in the blood in an attempt to help the body recover from stress. The amino acids are converted into glucose by the liver, thereby raising the level of blood sugar. Increased glucose levels provide a greater

adrenal medulla found at the core of the adrenal gland, produces epinephrine and norepinephrine

adrenal cortex outer region of the adrenal gland that produces glucocorticoids and mineralocorticoids

norepinephrine also known as noradrenaline, it initiates the fight-or-flight response by increasing heart rate and blood sugar

glucocorticoid any of the steroids produced by the adrenal cortex that help to regulate electrolyte and water balance

mineralocorticoid any of the sterioids produced by the adrenal cortex that regulate carbohydrate, lipid, and protein metabolism and inhibit the release of corticotrophin

sex hormone any hormone that affects the development and growth of sex organs

cortisol hormone that stimulates the conversion of amino acids to glucose by the liver

EXTENSION

Control of Cortisol Secretion

This animation shows how cortisol secretion is regulated by a negative feedback system.

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energy source, which helps cell recovery. Any of the amino acids not converted into glucose are available for protein synthesis. The proteins can be used to repair damaged cells. In addition, fats in adipose tissue are broken down into fatty acids. Thus, a second source of energy is provided, helping conserve glucose in times of fasting. Under the influence of cortisol, blood glucose uptake is inhibited in many tissues, especially in the muscles. The brain is not affected though, since any significant decrease in glucose absorption of the brain would lead to convulsions.

Short-term and long-term stress responses are shown in **Figure 5**. The brain identifies stressful situations. The hypothalamus sends a releasing hormone to the anterior lobe of the pituitary, stimulating the pituitary to secrete **adrenocorticotropic hormone (ACTH)** (also called corticotropin). ACTH is a **tropic hormone**, which is a hormone that targets another endocrine gland. The blood carries the ACTH to the target cells in the adrenal cortex. Under the influence of ACTH, the cells of the adrenal cortex secrete mineralocorticoids and glucocorticoids (among them cortisol), which are

adrenocorticotropic hormone (ACTH) pituitary hormone that promotes cortisol release by the adrenal cortex; also called corticotropin

tropic hormone hormone that stimulates a specific target gland to secrete other hormones

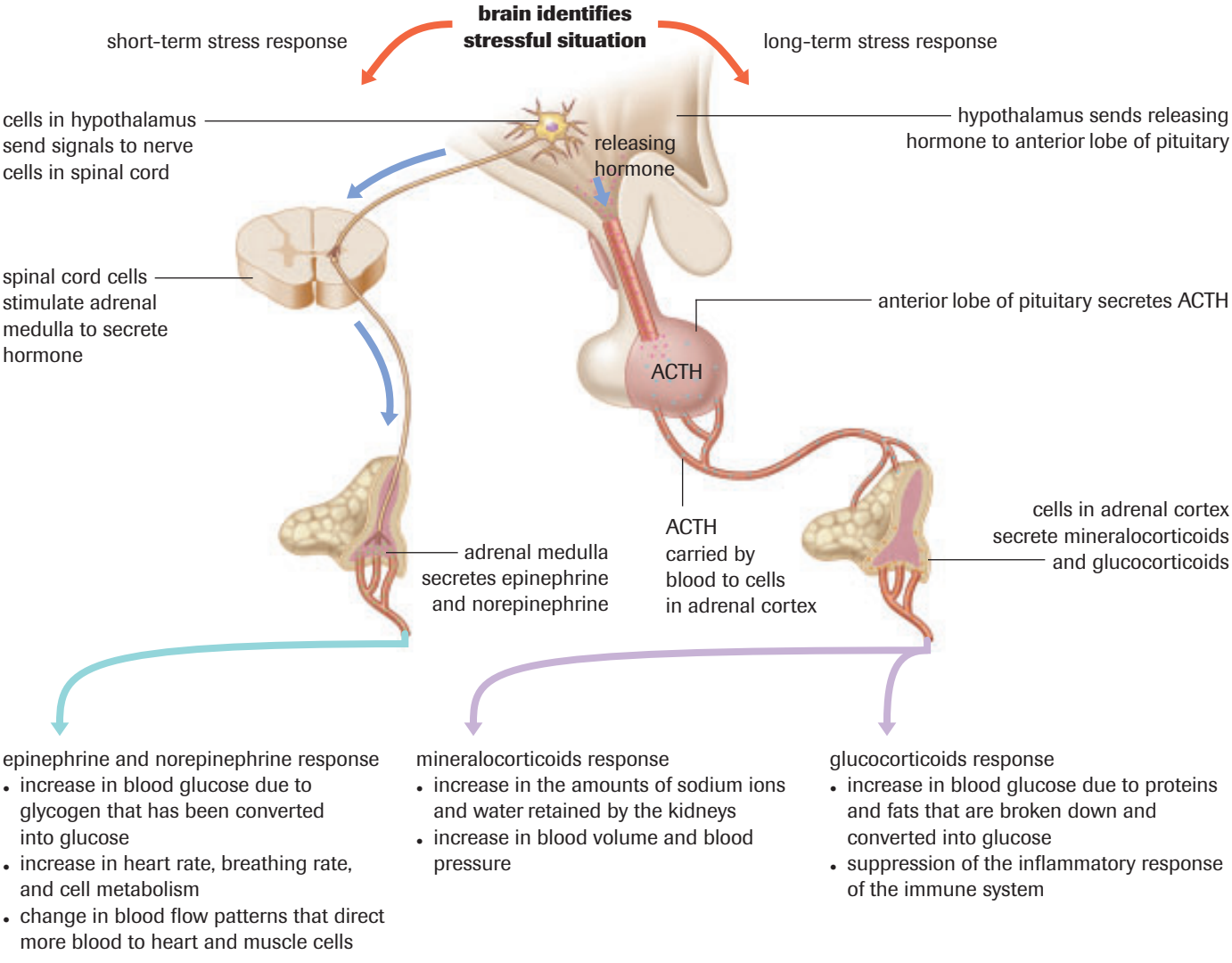

Figure 5
Most of the hormones released by the adrenal cortex in response to stress affect blood sugar levels. However, mineralocorticoids do not. They affect sodium and water levels in the blood.

carried to target cells in the liver and muscles. As cortisol levels rise, cells within the hypothalamus and pituitary decrease the production of regulatory hormones, and, eventually, the levels of cortisol begin to fall. This process is called a long-term stress response. The short-term stress response is regulated by the adrenal medulla, which secretes epinephrine and norepinephrine.

Aldosterone is the most important of the mineralocorticoids. Secretion of aldosterone increases sodium retention and water reabsorption by the kidneys, thereby helping to maintain body fluid levels. You will learn more about this hormone in Section 15.3. (You will explore the third type of hormone secreted by the adrenal cortex, sex hormones, in Unit 30 B.)

aldosterone hormone produced by the adrenal cortex that helps regulate water balance by increasing sodium retention and water reabsorption by the kidneys

Practice

4. What are the similarities and differences of the adrenal cortex and the adrenal medulla?
5. What are the effects of epinephrine and norepinephrine?
6. What is the effect of cortisol?

LAB EXERCISE 15.A

Effects of Hormones on Blood Sugar Levels

Blood sugar levels of a person with diabetes mellitus and a person without were monitored over a period of 12 h. Both ate an identical meal and performed 1 h of similar exercise.

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	○ Evaluation
○ Hypothesis	○ Procedure	○ Synthesis
○ Prediction	○ Evidence	

Evidence

Use the data in **Figure 6** to answer the questions below.

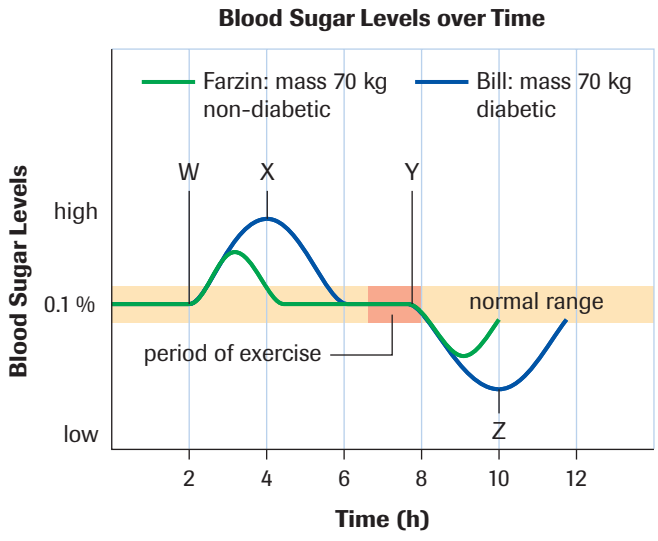

Figure 6
Blood sugar was monitored over 12 h.

Analysis

1. Which hormone injection did Bill receive at the time labelled X? Provide reasons for your answer.
2. What might have happened to Bill's blood sugar level if hormone X had not been injected? Justify your answer.
3. Explain why blood sugar levels rose at time W for Bill and Farzin.
4. Explain why their blood sugar levels begin to fall after time Y.
5. What hormone might Bill have received at time Z? Explain your answer.
6. Why is it important to note that both Farzin and Bill have the same body mass?
7. What differences in blood sugar levels are illustrated by the data collected from Bill and Farzin?
8. Formulate a hypothesis to explain why Bill and Farzin responded differently to the same environmental factors.

SUMMARY Hormones That Affect Blood Sugar

Table 1 Role of Hormones that Regulate Blood Sugar

Hormone	Location of hormone production	Effect
insulin	islets of Langerhans (pancreas)	• increases permeability of cells to glucose; increases glucose uptake • allows for the conversion of glucose to glycogen • brings about a decrease in blood sugar
glucagon	islets of Langerhans (pancreas)	• promotes the conversion of glycogen to glucose • brings about an increase in blood sugar
epinephrine and norepinephrine	adrenal medulla	• promotes the conversion of glycogen to glucose • brings about an increase in blood sugar • brings about an increase in heart rate and cell metabolism
cortisol (a type of glucocorticoid)	adrenal cortex	• promotes the conversion of amino acids to glucose • promotes the breakdown of fats to fatty acids • decreases glucose uptake by the muscles (not by the brain) • brings about an increase in blood sugar in response to stress

Section 15.2 Questions

1. List the hormones released from the pancreas and the adrenal glands, and indicate their control mechanisms.
2. What advantage is provided by increasing blood sugar above normal levels in times of stress?
3. How would high levels of adrenocorticotropic hormone (ACTH) affect secretions of cortisol from the adrenal glands? How would high levels of cortisol affect ACTH?
4. A number of laboratory experiments were conducted on laboratory mice. The endocrine system of mice is similar to that of humans. Brief summaries of the procedures are provided in **Table 2**.
   (a) In procedure 1, identify the gland that was removed and explain why the levels of ACTH increased.
   (b) In procedure 2, identify the hormone that was injected and explain why blood sugar levels decreased.
   (c) In procedure 3, identify the hormone that was affected and explain why urine production increased.
   (d) In procedure 4, identify the hormone that was injected and explain why blood glucose levels increased.
5. The incidence of diabetes in North America has risen dramatically in the last few decades. Research how changes in diet have affected the incidence of diabetes in the Aboriginal population.

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6. The North American lifestyle and diet are believed to be major contributors to type 2 diabetes. Many companies know that foods can be made more palatable to consumers by adding fats and sugars. Discuss the practice of adding fats and sugars to food products to increase sales.
7. Cortisol levels fluctuate throughout the day. Speculate why cortisol levels might be highest in the morning and lowest around midnight.

Table 2 Experiments Conducted on Laboratory Mice

Number	Procedure	Observation
1	gland removed	• urine output increased • Na^+ ion concentration in urine increased • ACTH level increased in blood
2	hormone injected	• blood glucose levels decreased
3	blood flow from the posterior pituitary reduced	• urine production increased
4	hormone injected	• glycogen converted to glucose in the liver • blood glucose increased

Hormones That Affect Metabolism 15.3

In this section, you will explore three different glands that affect metabolism: the **thyroid gland**, which produces the hormones triiodothyronine, thyroxine, and calcitonin; the **parathyroid glands**, which produce parathyroid hormone; and the anterior pituitary gland, which produces growth hormone (among many other regulatory hormones). The thyroid gland helps regulate body metabolism, or the rate at which glucose is oxidized. The parathyroid glands help regulate calcium levels in the blood and lower phosphate levels. Growth hormone (hGH) is one of a multitude of hormones produced by the anterior pituitary gland and influences the growth of long bones and accelerates protein synthesis.

thyroid gland a two-lobed gland at the base of the neck that regulates metabolic processes

parathyroid glands four pea-sized glands in the thyroid gland that produce parathyroid hormone to regulate blood calcium and phosphate levels

Thyroid Gland

Have you ever wondered why some people seem to be able to consume fantastic amounts without any weight change, while others appear to gain weight at the mere sight of food? Thyroid hormones and the regulation of metabolic rate can partly explain this anomaly. Approximately 60 % of the glucose oxidized in the body is released as heat. The remaining 40 % is transferred to ATP, the storage form for cell energy. This added energy reserve is often consumed during activity. Individuals who secrete higher levels of thyroid hormones oxidize sugars and other nutrients at a faster rate. Therefore, these individuals tend not to gain weight and tend to feel warm.

Individuals who have lower levels of thyroid hormones do not oxidize nutrients as quickly, and therefore tend not to break down sugars as quickly. Excess blood sugar is eventually converted into liver and muscle glycogen. However, once the glycogen stores are filled, excess sugar is converted into fat. It follows that the slower the blood sugar is used, the faster the fat stores are built up. People who secrete low amounts of thyroid hormones often experience muscle weakness, cold intolerance, and dry skin and hair. Not all types of weight gain are due to hypothyroidism (low thyroid secretions). In many cases, weight gain reflects a poor diet, lack of exercise, or genetics.

The thyroid gland (**Figure 1**) is located at the base of the neck, immediately in front of the trachea or windpipe. This gland produces two hormones, **thyroxine (T4)** and **triiodothyronine (T3)**, that regulate body metabolism and the growth and differentiation of tissues. Although both hormones appear to have the same function, approximately 65 % of thyroid secretions are thyroxine. In addition to thyroid hormones, the thyroid gland produces **calcitonin**, a hormone that acts on the bone cells to lower the level of calcium found in the blood.

DID YOU KNOW ?

Hyperthyroidism

The overproduction of thyroxine by the thyroid gland results in hyperthyroidism. In hyperthyroidism, the fast oxidation of nutrients causes weight loss, elevated body temperature, and nervous behaviour. The most common cause of hyperthyroidism in Canada is an inherited disorder known as Graves' disease, or thyrotoxicosis. The condition is more common in females than in males.

thyroxine (T4) hormone produced by the thyroid gland that increases metabolism and regulates growth

triiodothyronine (T3) hormone produced by the thyroid gland that increases metabolism and regulates growth; contains three iodine atoms

calcitonin hormone produced by the thyroid gland that lowers calcium levels in the blood

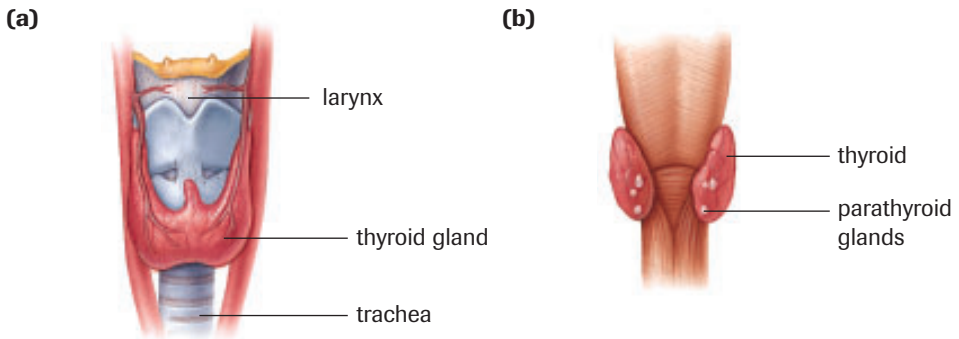

Figure 1
(a) anterior view of thyroid gland
(b) posterior view of thyroid gland

EXTENSION

Hormonal Control of Metamorphosis

In amphibians, thyroid hormones regulate the rate at which metamorphosis occurs. In this activity, you will analyze and evaluate data from five different investigations and draw conclusions about the hormonal control of metamorphosis in three species of amphibian.

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Control of thyroid hormones, like many other hormones, is accomplished by negative feedback (**Figure 2**). Should the metabolic rate decrease, receptors in the hypothalamus are activated. Nerve cells in the hypothalamus secrete thyroid-releasing hormone (TRH), which stimulates the pituitary to release thyroid-stimulating hormone (TSH). Thyroid-stimulating hormone is carried by the blood to the thyroid gland, which, in turn, releases T3 and T4. T3 and T4 raise metabolism by stimulating increased use of sugar by body cells. Higher levels of T3 and T4 and TSH cause the pathway to be "turned off." T3, T4, and TSH inhibit the release of TRH from the hypothalamus, thus turning off the production of TSH from the pituitary.

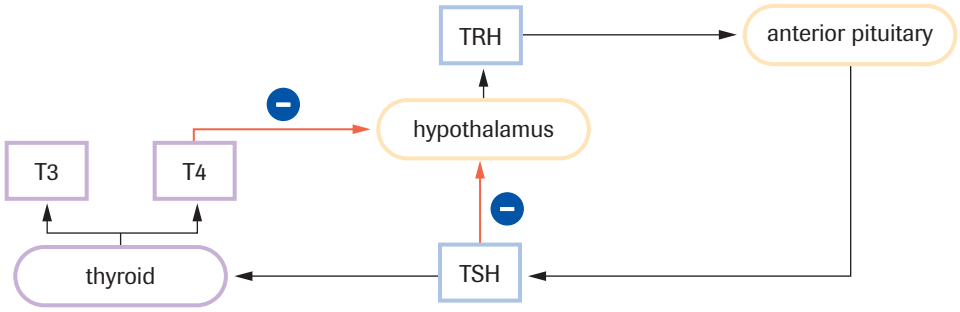

Figure 2
Feedback control loops in the secretion of thyroid hormones

Iodine is an important component of both thyroid hormones. A normal component of the diet, iodine is actively transported from the blood into the follicle cells of the thyroid. The concentration of iodine in the cells can be 25 times greater than that in the blood. Problems arise when iodine levels begin to fall. When inadequate amounts of iodine are obtained from the diet, the thyroid enlarges, producing a **goiter** (**Figure 3**).

goiter disorder that causes an enlargement of the thyroid gland

The presence of a goiter emphasizes the importance of a negative feedback control system. Without iodine, thyroid production and secretion of thyroxine drops. This causes more and more TSH to be produced and, consequently, the thyroid is stimulated more and more. Under the relentless influence of TSH, cells of the thyroid continue to develop, and the thyroid enlarges. In regions where the diet lacks iodine, the incidence of goiter remains high. In many countries, iodine is added to table salt to prevent this condition.

Figure 3
A goiter appears as a swelling in the neck area.

Practice

1. How does thyroxine affect blood sugar?
2. List the symptoms associated with hypothyroidism and hyperthyroidism.

Parathyroid Glands

Four small parathyroid glands are hidden within the larger thyroid gland. Before these glands were discovered, surgeons treating goiters mistakenly removed the parathyroid glands along with sections of a hyperactive thyroid gland. Although the surgery relieved symptoms associated with an overly developed thyroid gland, the patients developed more serious problems. Rapid, uncontrolled muscle twitching, referred to as tetanus, signalled abnormal calcium levels. Tetanus occurs because the nerves become easily excited.

In most cases, nerves or other hormones regulate the endocrine glands. The parathyroid glands are one of the exceptions. The parathyroid glands respond directly to chemical changes in their immediate surroundings. With involvement from the thyroid glands, the parathyroid glands keep calcium levels in homeostasis.

Low calcium levels in the blood stimulate the release of **parathyroid hormone (PTH)** from the parathyroid glands and inhibits release of calcitonin from the thyroid (**Figure 4**). A rise in PTH levels causes the calcium levels in the blood to increase and phosphate levels to decrease. The hormone does this by acting on three different organs: the kidneys, the intestines, and the bones. PTH causes the kidneys and intestines to absorb more calcium while promoting calcium release from bone. (Approximately 98 % of the body's calcium is held in storage by the skeletal system.) The bone cells break down, and calcium is separated from phosphate ions. The calcium is reabsorbed and returned to the blood, while the phosphate is excreted in the urine. This helps conserve much of the body's calcium that is dissolved in plasma. PTH also enhances the absorption of calcium from undigested foods in the intestine. So, as PTH levels increase, the absorption of calcium ions also increases.

parathyroid hormone (PTH)
hormone produced by the parathyroid glands, which will increase calcium levels in the blood and lower the levels of phosphates

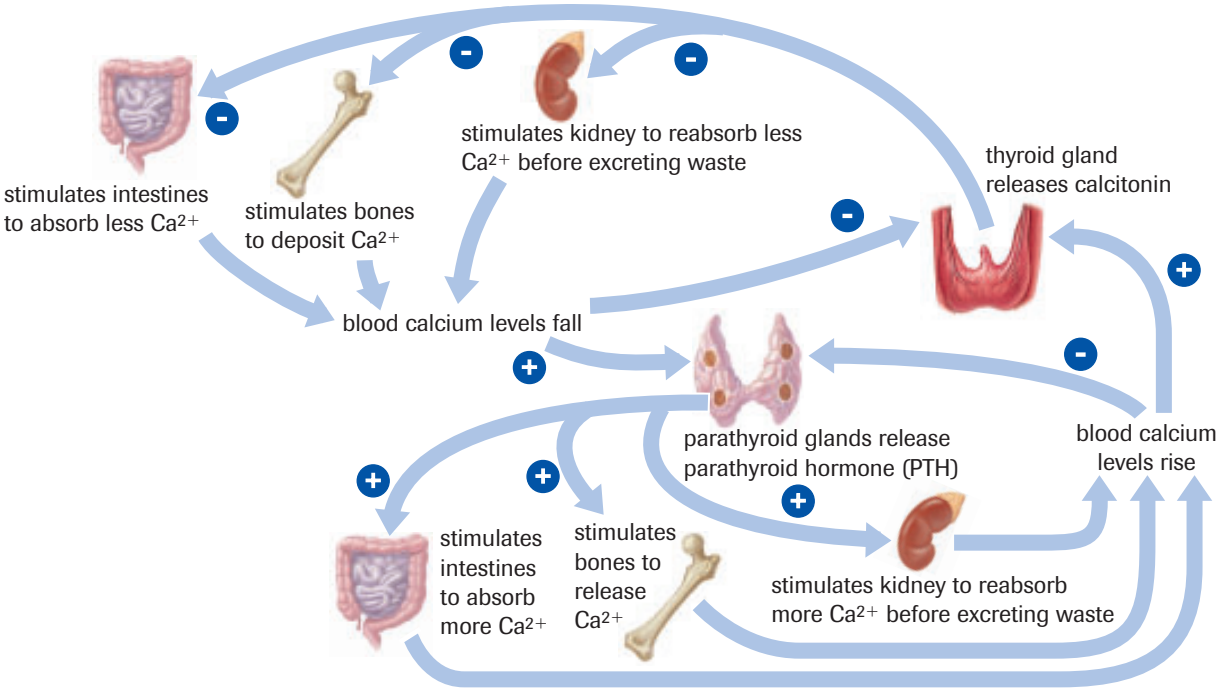

Figure 4
Low levels of blood calcium stimulate release of PTH from the parathyroid glands and inhibits release of calcitonin from the thyroid. PTH causes the kidneys and gut to retain calcium while promoting calcium release from bone. This causes blood calcium levels to rise, which in turn inhibits release of PTH from the parathyroid glands and stimulates release of calcitonin from the thyroid. Calcitonin causes the kidneys and gut to release calcium, while inhibiting calcium release from bone.

Figure 5
Improper bone formation can result from a diet lacking in fruits and vegetables.

Once calcium levels have risen, release of PTH is inhibited and release of calcitonin is stimulated. This causes the intestines, kidneys, and bones to reduce the amount of calcium they release to the blood, and calcium levels then begin to fall. This part of the feedback mechanism involving PTH and calcitonin ensures the blood calcium levels will not increase beyond the body's needs. Abnormally high levels of PTH or low levels of calcitonin can cause health problems. A strong, rigid skeleton is necessary for support, so prolonged breakdown of bone is dangerous. High calcium levels can cause it to collect in blood vessels or to form hard structures in the kidneys called kidney stones.

PTH also helps activate vitamin D. Low levels of vitamin D can cause a disease called rickets (**Figure 5**). With this disease, too little calcium and phosphorus are absorbed from foods and the bones develop improperly.

Growth Hormone (hGH)

Growth hormone (hGH) is produced by the anterior pituatary gland, and stimulates the elongation of the skeleton. The effects are most evident when the body produces too much (hypersecretion) or too little of it (hyposecretion). Hyposecretion of hGH during childhood can result in dwarfism; hypersecretion during childhood can result in gigantism. Hypersecretion in adulthood causes acromegaly, an abnormal bone growth in the hands, feet, and head. Although hGH affects most of the cells of the body, the effect is most pronounced on cartilage cells and bone cells.

Under the influence of growth hormone, cells of soft tissues and bone begin to grow by increasing the number of cells (hyperplasia) and increasing the size of cells (hypertrophy). Growth hormone increases cell size in muscle cells and connective tissues by promoting protein synthesis while inhibiting protein degradation or breakdown. Proteins in many cells, such as muscle, are in a constant state of breakdown and repair. Amino acid uptake increases, which in turn provides the raw materials for protein synthesis. This may help explain the link between declines in growth hormone production and the aging process. As a person ages, hGH production begins to decline and cellular repair and protein replacement are compromised. As the human body ages, protein is often replaced by fat, causing changes in the body's shape.

Growth hormone also has an important role in maintaining homeostasis. It increases fatty acid levels in the blood by promoting the breakdown of fats. Muscles use the fatty acids instead of glucose as a source of metabolic fuel. By switching fuel sources from glucose to fatty acids, growth hormone causes an increase in blood glucose levels. This is especially important for glucose-dependent tissues, such as the brain. The brain is unable to use fat as an energy source. This metabolic pathway is particularly important in times of prolonged fasting where glucose supplies are limited. Growth hormone increases the use of fat stores and promotes protein synthesis, which decreases the amount of fat stored in the body. This may help explain why quick growth spurts are often accompanied by a loss of body fat.

DID YOU KNOW ?

Growth Hormone: Not Just for Growth

Even in adults, growth hormone is the most abundant hormone produced by the anterior pituitary gland. In addition to promoting growth, the hormone helps adjust blood sugar in times of prolonged fasting and enhances the immune system.

SUMMARY Hormones That Affect Metabolism

Table 2 Glands and Hormones Involved in Regulating Metabolism

Gland	Hormone	Effect on metabolism
thyroid	thyroxine (T4) and triiodothyronine (T3)	• regulates the rate at which glucose is oxidized within body cells
thyroid	calcitonin	• lowers calcium levels in the blood
parathyroid glands	parathyroid hormone (PTH)	• raises calcium levels in the blood
anterior pituitary	growth hormone (hGH)	• promotes protein synthesis by increasing the uptake of amino acids by cells • causes a switch in cellular fuels from glucose to fatty acids

Section 15.3 Questions

1. How do the pituitary and hypothalamus interact to regulate thyroxine levels?
2. What is a goiter and why does it create a problem?
3. Symptoms such as weight gain, increased sensitivity to cold, fatigue, and depression can indicate the thyroid gland is not working properly.
   (a) Choose one of the symptoms above and explain how the symptom can be linked to poor thyroid function.
   (b) Explain why eating foods, such as fish, green leafy vegetables, and dairy products, which have higher levels of iodine, may be helpful in preventing thyroid problems.
   (c) Explain why individuals with thyroid problems should avoid foods that block iodine absorption, such as soy and many uncooked vegetables.
4. How does parathyroid hormone (PTH) regulate blood calcium levels?
5. Why would removal of the parathyroid glands lead to tetany?
6. How would hyposecretion of growth hormone affect an individual?
7. The purpose of the parathyroid glands is to regulate the calcium level in our bodies within a very narrow range so that the nervous and muscular systems can function properly.
   (a) A person takes some calcium tablets. Draw a feedback loop showing how PTH regulates that person's calcium levels.
   (b) Hyperparathyroidism occurs when the parathyroids make too much PTH. Explain how this would affect blood calcium levels.
   (c) Explain how would hyperparathyroidism affect a person's bones.
8. Negative feedback control systems influence hormonal levels. The fact that some individuals have higher metabolic rates than others can be explained by the response of the hypothalamus and pituitary to thyroxine. Some feedback systems turn off quickly. Sensitive feedback systems tend to have comparatively lower levels of thyroxine; less sensitive feedback systems tend to have higher levels of thyroxine. One hypothesis attempts to link different metabolic rates with differences in the number of binding sites in the hypothalamus and pituitary. How might the number of binding sites for molecules along cell membranes affect hormonal levels? How would you go about testing the theory?
9. In July 1990, Dr. Daniel Rudman published a study in the prestigious *New England Journal of Medicine* proposing that injections of growth hormone could slow the aging process. Today, antiaging enthusiasts believe that growth hormone could be an antidote to the effects of decades of aging. Although researchers warn that the drug's long-term effects have not been documented and that the drug may not be suitable for everyone, speculation about the potentials of an antiaging drug abounds in both scientific and nonscientific communities. Comment on the social implications of using a drug to slow aging.
10. Bovine somatotropin (BST) is a growth hormone now produced by gene recombination. BST can increase milk production in cows by as much as 20 % by increasing nutrient absorption from the bloodstream into the cow's milk. Should BST be used? Why might some individuals be concerned?

15.4 Hormones Affecting Water and Ion Balance

The body adjusts for increased water intake by increasing urine output. Conversely, it adjusts for increased water loss or decreased water intake by reducing urine output. These homeostatic adjustments involve the nervous system and two different hormones of the endocrine system, antidiuretic hormone (ADH) and aldosterone.

ADH and Water Balance

antidiuretic hormone (ADH) a hormone that causes the kidneys to increase water reabsorption

The main function of **antidiuretic hormone (ADH)** is to conserve body water by reducing urine output. As you have learned previously, diuresis is urine formation and so antidiuresis is the stopping of urine formation, hence the name *antidiuretic* hormone.

osmoreceptors sensory receptors in the hypothalamus that detect changes in the osmotic pressure of the blood and surrounding extracellular fluids (ECF)

How does the body know when to conserve water? There are sensory receptors in the hypothalamus called **osmoreceptors**, which detect changes in osmotic pressure in body fluids.

When you decrease water intake or increase water loss—by sweating, for example—blood solutes become more concentrated. This increases the blood's osmotic pressure. Consequently, water moves into the blood, causing the osmoreceptor cells of the hypothalamus to shrink (**Figure 1**). When this happens, the osmoreceptors stimulate the posterior pituitary gland to release ADH, which is carried by the bloodstream to the kidneys. ADH causes the kidneys to reabsorb more water and thus produce a more concentrated urine. Conserving water prevents the osmotic pressure of the blood from increasing any further.

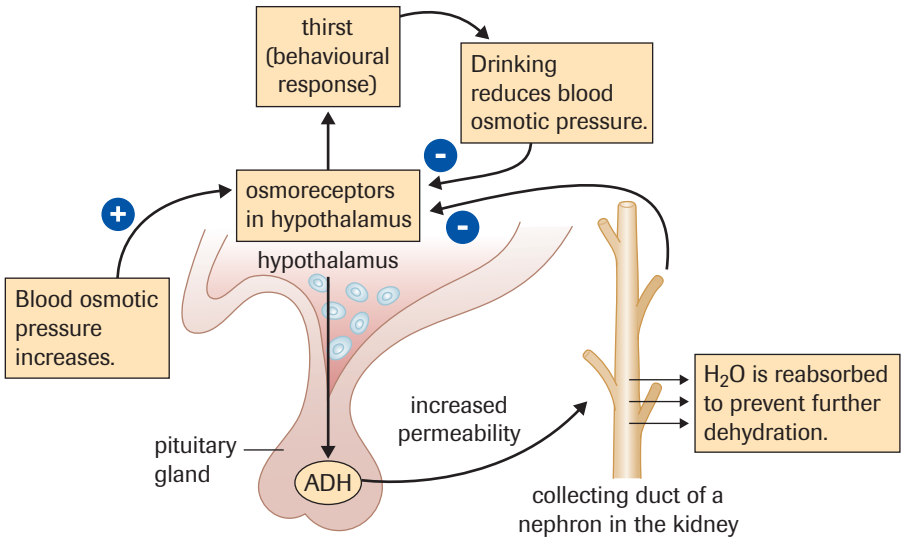

Figure 1
By increasing water reabsorption in the kidneys, ADH helps conserve body water. The osmoreceptors in the hypothalamus initiate the thirst response.

As the osmoreceptors shrink, they also stimulate the sensation of thirst. Drinking water in response to feeling thirsty is a behavioural response rather than a physiological response. As more water is taken in, it is absorbed by the blood and the concentration of solutes in the blood decreases. The greater the volume of water consumed, the lower the osmotic pressure of the blood. As the blood becomes more dilute, fluids move from the blood into the hypothalamus. As a result, the osmoreceptors swell and so they stop stimulating the pituitary gland to release ADH. As ADH levels drop, the tubules in the kidney reabsorb less water. Homeostasis is restored.

DID YOU KNOW?

Alcohol Affects Fluid Levels

Alcohol consumption decreases the release of ADH. Some of the symptoms experienced the day following excessive alcohol consumption can be attributed to increased water loss through urine and decreased body fluid levels.

ADH and the Nephron

Approximately 85 % of the water filtered into the nephron is reabsorbed in the proximal tubule. Although the proximal tubule is very permeable to water, this permeability does not extend to other segments of the nephron (**Figure 1**, previous page). The remaining 15 % of the water filtered into the nephron will be lost if no ADH is present. ADH makes the upper part of the distal tubule and collecting duct permeable to water. When ADH makes the cell membranes permeable, the high concentration of NaCl in the intercellular spaces creates an osmotic pressure that draws water from the upper section of the distal tubule and collecting duct. As water passes from the nephron to the intercellular spaces and the blood, the urine remaining in the nephron becomes more concentrated. It is important to note that the kidneys control only the last 15 % of the water found in the nephron. By varying water reabsorption, the kidneys regulate the osmotic concentrations of body fluids.

Diabetes Insipidus

Diabetes insipidus is the most common disease associated with ADH and its main characteristic is the production of excessive amounts of urine (as much as 16 litres a day). It can be caused by the failure of the posterior pituitary to secrete enough ADH or by the failure of the kidney to respond to ADH. It is not life threatening so long as the person has enough water to drink.

Aldosterone, Blood Pressure and Blood Volume

Conditions that lead to increased fluid loss can decrease blood pressure, reducing the delivery of oxygen and nutrients to tissues. Near the glomerulus is a complex of cells called the **juxtaglomerular apparatus (JGA)**. Blood pressure receptors in the juxtaglomerular apparatus (**Figure 2**, next page) detect changes in blood pressure. When blood pressure is low, specialized cells within the structure release renin, an enzyme that converts angiotensinogen, a plasma protein produced by the liver, into angiotensin.

Angiotensin has two important functions. First, it causes constriction of blood vessels. Blood pressure increases when the diameter of blood vessels is reduced. Second, angiotensin stimulates the release of the hormone aldosterone from the adrenal cortex. Aldosterone is then carried in the blood to the kidneys, where it acts on the cells of the distal tubule and collecting duct to increase Na^+ reabsorption. This causes blood volume and blood pressure to increase. Not surprisingly, as Na^+ reabsorption increases, the osmotic pressure increases and more water moves out of the nephron into the blood by osmosis. This pathway is called the renin-angiotensin-aldosterone system (RAAS).

At first glance, it might appear that the role of ADH is the same as the renin-angiotensin-aldosterone system. Both increase water reabsorption. However, ADH responds to an increase in osmotic pressure of the blood. For example, when the body is dehydrated due to lack of water. The renin-angiotensin-aldosterone system responds when the blood volume is reduced but the osmotic pressure of the blood remains the same. For example, when there is a large loss of body fluid, perhaps from severe diarrhea or from a hemorrhage.

CAREER CONNECTION

Pharmacist

Monitoring and managing a patient's drug therapy is an essential component of pharmacists' work. They also educate caregivers and health professionals about disease management and drug research related to the health and well-being of individuals under the care of a physician. Specialized courses in biology and chemistry are required to become a pharmacist.

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juxtaglomerular apparatus (JGA) a functional unit near a kidney glomerulus that controls renin release in response to changes in blood pressure

EXTENSION

Blood Osmolarity and the Role of Antidiuretic Hormone

Listen to a discussion of blood osmolarity, and the homeostatic interactions that occur among the blood, the hypothalamus, and the collecting ducts of the kidneys.

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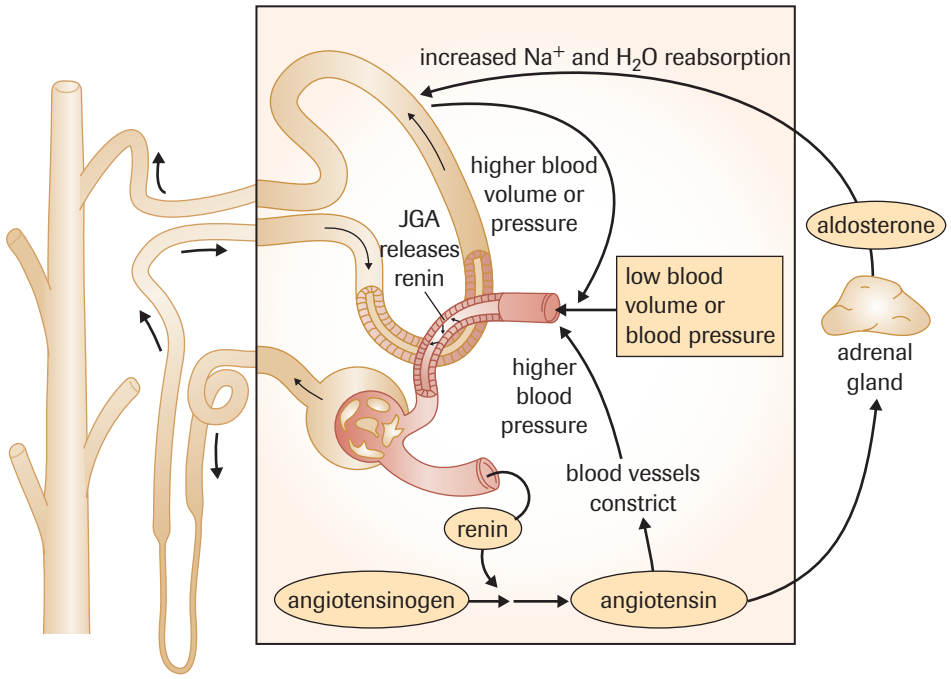

Figure 2
The hormone aldosterone maintains homeostasis by increasing Na^+ and water reabsorption.

WEB Activity

Case Study—Homeostasis and Space Travel

As humans spend more time in space, scientists have found that the microgravity environment changes the ability of the body to maintain homeostasis. Astronauts who spend substantial periods in space are at highest risk of developing hypercationa, a condition that causes kidney stone formation. Aldosterone and ADH work together to adjust urine volume and reabsorption of salts by the kidney. In this activity, you will infer the role of ADH and aldosterone from data on blood and urine composition, and relate it to the changes in homeostasis during space flight.

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SUMMARY *Hormones Affecting Water and Ion Balance*

- Osmoreceptors in the hypothalamus stimulate the release of ADH from the posterior pituitary in response to increased osmotic pressure in the blood.
- ADH causes the distal tubules and collecting ducts of the kidneys to reabsorb more water, which makes the blood less concentrated.
- Aldosterone forms part of the renin-angiotensin-aldosterone system, which is activated by low blood pressure or low blood volume.
- Aldosterone causes the distal tubules to reabsorb more Na^+ ions and water, which increases blood volume and blood pressure.

Section 15.4 Questions

1. In **Figure 3**, labels 1 and 2 represent two hormones that directly affect the permeability of the kidney. Identify these hormones and state their functions.

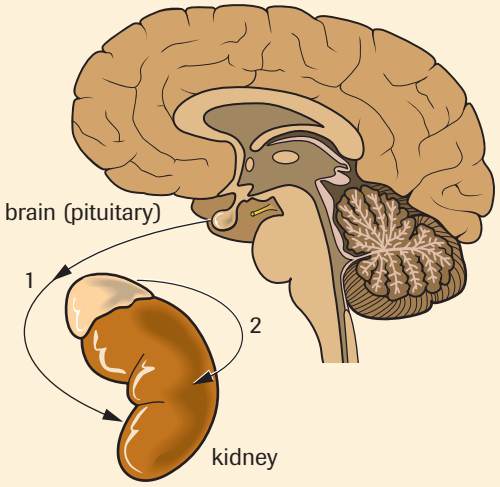

Figure 3

2. Describe the mechanism that regulates the release of ADH.
3. Where is the thirst centre located?
4. Describe the physiological adjustment to increased osmotic pressure in body fluids.
5. Discuss the mechanism by which aldosterone helps to maintain blood pressure.
6. Draw a flow chart that shows why the release of ADH is a negative feedback mechanism.
7. An experiment was performed to determine the effect of a drug, labelled X, on human metabolism. The rate of metabolism can be measured indirectly by monitoring changes in body temperature. Four comparable groups of 50 individuals each were used in the experiment. At the same time each day, all group members were given a dosage of the drug, except for group 4, which was given a placebo that did not contain the drug. Urine output and urea concentrations in urine were monitored one hour after the drug was taken. Each group member was monitored for changes in body temperature and in the volume of secretion from the thyroid gland. The observations are recorded in **Table 1**.
   (a) What controls were used for this experiment?
   (b) Identify the dependent and independent variables for this experiment.
   (c) Using the information provided, does the drug increase metabolic rate? Justify your answer.
   (d) What evidence suggests that drug X exerts a negative feedback response?
   (e) What evidence suggests that ADH and/or aldosterone were released in response to the drug?
   (f) What indirect evidence could you collect that would confirm whether aldosterone was being released?

Table 1 Effects of Different Dosages of Drug X on Metabolism

Group	Dosage of Drug X*	Change in body temp. (°C)	Perspiration	Urea g/100 mL of urine	Urine output mL	Thyroid gland output*
1	1	+0.2	slight increase	1.55	750	0.9
2	10	+0.9	moderate increase	2.01	600	9.8
3	100	+1.2	large increase	2.79	410	97.2
4	placebo	0.0	no change	1.55	810	0.0

* (10^{-6}g/50 kg of body mass)

15.5 Adjustments to Stress

Figure 1
Dr. Hans Selye (1907–1982), the Austrian-born Canadian endocrinologist, was an authority on the link between psychological stress, biochemical changes, and disease.

Dr. Hans Selye (**Figure 1**) was one of the first to identify the human response to long-term stress from a noxious stimulus. According to Selye, a general adaptation syndrome results from exposure to prolonged stress brought on by a disruption of the external and internal environment. When stressful stimulus is identified, both the endocrine system and nervous system make adjustments that enable the body to cope with the problem. The nervous system rapidly adjusts to stress by increasing heart rate and diverting blood to the needed muscles. Although somewhat slower in response, hormones from the endocrine system provide a more sustained response to the stimulus. (See **Figure 5** in Section 15.2, page 482.) **Table 1** summarizes some of the hormonal changes in response to stress.

Table 1 Hormonal Changes in Response to Stress

Hormone	Change	Adjustment
epinephrine	increases	• mobilizes carbohydrate and fat energy stores • increases blood glucose and fatty acids • accelerates heart rate and the activity of the respiratory system
cortisol	increases	• mobilizes energy stores by converting proteins to glucose • elevates blood amino acids, blood glucose, and blood fatty acids
glucagon	increases	• converts glycogen to glucose
insulin	decreases	• decreases the breakdown of glycogen in the liver

Stress hormones provide more blood glucose to cope with the elevated energy requirements brought on by stress. Remember that the primary stimulus for insulin secretion is a rise in blood glucose. If insulin release was not inhibited during a stress response, the hyperglycemia caused by stress would lead to an increased secretion of insulin, which would then lower blood glucose. Consequently, the elevated blood glucose would not be sustained to deal with the continued stress.

In addition to hormones that regulate blood sugar during stress, other hormones regulate blood pressure and blood volume. The nervous system activates the renin–angiotensin–aldosterone pathway in response to reduced blood flow to the kidneys. By increasing Na^+ reabsorption, the kidneys help maintain increased fluid volume. This helps sustain adequate blood pressure during stress. In addition, the stressor activates the hypothalamus, which causes an increased release of antidiurectic hormone (ADH). ADH will further increase water reabsorption from the nephron to help maintain body fluids.

During athletic competition, the accelerated cardiovascular activity provides greater oxygen delivery to the tissues for cellular respiration. Increases in blood sugar and fatty acid levels provide more fuel for metabolic processes. In turn, the greater supply of reactants can provide more ATP for activity.

It is more difficult to adjust to emotional or psychological stress because the increased energy supply is not always used. Although increased nerve activity requires greater energy, the ATP provided by homeostatic adjustment often outstrips demand. Prolonged exposure to high blood glucose, high blood pressure, and an elevated metabolic rate

often causes a readjustment of control systems to permit the higher operating range. As shown in **Table 2**, operating with elevated blood sugar, blood pressure, and heart rate creates more problems for the body.

Table 2 Problems Associated with Long-Term Stress

New operating limit	Problem created
higher blood sugar	• alters osmotic balance between blood and extracellular fluids; can lead to increased fluid uptake by the blood and increased blood pressure • increased water loss from nephron
increased blood pressure	• possible rupture of blood vessels due to higher pressure • increased blood clotting
increased heart rate	• can lead to higher blood pressure • possible destruction of heart muscle

Prostaglandins

Prostaglandins are a group of hormones, but unlike other hormones, they do not travel to other sites in the body. They act on the cells that produced them, and virtually all cells in the body produce them. When a tissue is damaged (stressed), the tissue's cells produce prostaglandins in response. Prostaglandins stimulate inflammation at the damage site, increase blood flow, and stimulate platelets to form clots in damaged blood vessels. They also play a role in producing a fever and cause an increase in the perception of pain.

prostaglandins a group of hormones that act on the cells that produce them in response to cell damage; produced by most cells

Interestingly, aspirin is an effective reducer of fever, pain, and inflammation. It does this by blocking enzyme involved in prostaglandin production. Because aspirin reduces prostaglandin production, blood does not clot as easily. Thus aspirin is often prescribed to prevent clotting in people with heart disease. One of the downsides of aspirin is that if a person is injured while taking it, they may bleed more profusely.

Chemically Enhanced Sports Performance

Strenuous exercise places stress on body systems, which compensate by delivering more fuel and oxygen to the tissues. Long before they were used in sport, ancient people documented how different drugs could mirror hormones produced by the body to affect heart rate, breathing rate, and blood pressure. Caffeine, for example, was found to produce many of the same effects as epinephrine (adrenaline), by increasing heart rate, blood pressure, and alertness.

The quest to gain an advantage began in the 1950s when weight lifters began injecting themselves with **anabolic steroids**. Anabolic steroids are designed to mimic many of the muscle-building traits of the sex hormone testosterone. Although still controversial, some have reported that anabolic steroids can provide athletes with greater lean muscle development and increased strength and, therefore, are advantageous for weightlifting and shorter sprints. However, anabolic steroids do not provide increased agility or skill level, nor do they enhance the ability of the cardiovascular system to deliver oxygen. In fact, they would be detrimental to athletes who need to sustain a high level of aerobic activity over a longer duration, such as marathon runners or cyclists. Although some athletes claim that steroids provide faster recovery from injury, and, therefore, allow more rigorous training, these claims have not been conclusively proven by laboratory studies. Whether advantageous or not, these types of drugs have been banned from competitive sports. During the 1988 Olympics, Canadian sprinter Ben Johnson was disqualified and stripped of a gold medal for using Stanozolol, an anabolic steroid.

anabolic steroids substances that are designed to mimic many of the muscle-building traits of the sex hormone testosterone

A number of health risks have been linked to the extended use of large dosages of anabolic steroids (**Figure 2**). Of particular interest to teens is that anabolic steroids prematurely fuse growth plates in the long bones, thereby reducing the height potential of the individual. Psychological effects, such as mood swings and feelings of rage, have also been documented.

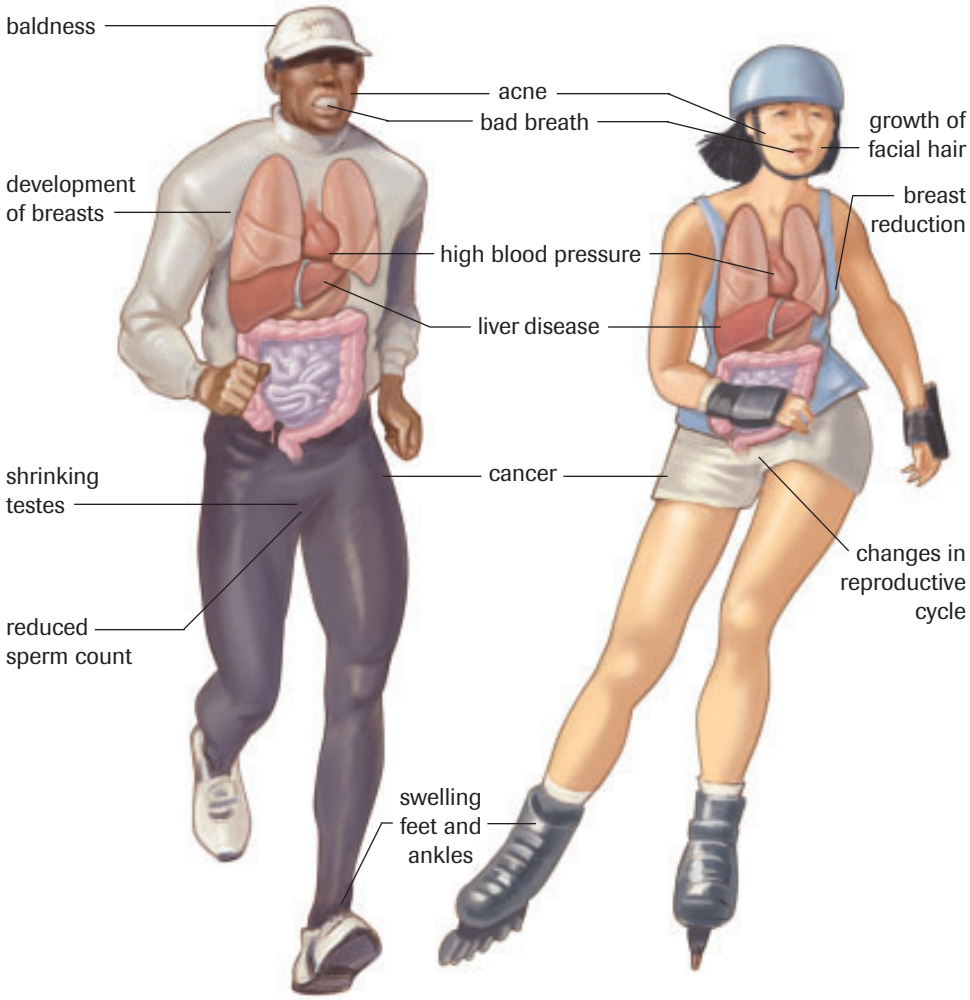

Figure 2
Effects of prolonged anabolic steroid use

Today, athletes have access to a myriad of drugs that do more than just increase strength. Sharpshooters and archers have used beta blockers to slow the heartbeat, which helps to steady their aim and calm jangled nerves. Endurance athletes can gain an advantage by taking erythropoietin (EPO). Human growth hormone decreases fat mass and promotes protein synthesis for muscle development; the enhancement of repair and growth increases strength and permits more vigorous training.

Because the body naturally produces hGH and EPO, they are difficult to detect with standard testing methods. More sophisticated methods must be used to detect small chemical differences between natural and artificial growth hormone. (Artificial growth hormone is synthesized by genetically modified bacteria.) Esters of testosterone are another group of muscle-building drugs that are difficult to detect. The esters slow the metabolism of testosterone by the body, keeping it in the body longer. Normally, testosterone would be metabolized in a few hours. The ester and testosterone raise little suspicion when testing is performed because both occur naturally in the body.

EXPLORE an issue

Protecting Athletes

Winning high-profile sporting competitions such as the Tour de France or Olympic events can be worth millions of dollars in endorsements to the winner (in addition to the fame and adoration they receive in their home countries). It is not surprising that athletes will do almost anything to gain an advantage over their competitors.

Drug testing began at the 1968 Olympics, a year after a British cyclist died of heart failure at the Tour de France after taking a stimulant. The International Olympic Committee (IOC) banned the use of anabolic steroids in 1975. But detection methods did not keep pace with masking agents. A sensitive test for steroids was finally developed in 1983. In 1990, the IOC added testosterone and caffeine to its banned substance list.

Today the most prevalent banned substances are synthetic hormones such as erythropoietin (EPO) (mentioned in the Chapter 15 introduction, page 468). A recombinant version of EPO was originally developed to treat renal failure in dialysis patients. However, some athletes now use it to gain a competitive edge. EPO has been linked to deaths of cyclists, cross-country skiers and runners. In 2006, cyclist Floyd Landis was stripped of his title of winner of the Tour de France when tests revealed he had been taking a synthetic form of testosterone.

Issue Checklist

○ Issue	○ Design	● Analysis
● Resolution	● Evidence	● Evaluation

Statement

Not enough is being done to prevent the use of banned substances in sports.

In your group, research the issue. Search for information in newspapers, periodicals, CD-ROMs, DVDs, and on the Internet.

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- Prepare a list of points and counterpoints for your group to discuss. You might consider these questions:
  - (i) Are some countries complicit in helping athletes hide positive drug tests? Are athletes being sacrificed for national glory?
  - (ii) Are organizers of events compromised in their desire to identify users of banned substances by continually pushing for more records?
  - (iii) What improvements could be made to help eliminate banned drugs from athletics?
- Develop and reflect on your opinion.
- Communicate your views in an appropriate manner.

SUMMARY Adjustments to Stress

- The endocrine and nervous systems interact to help the body cope with stress.
- Prostaglandins are produced by cells that have been damaged and they produce a variety of physiological effects in the damaged cells.
- Anabolic steroids are one of many chemicals used to enhance athletic performance.

Section 15.5 Questions

1. Both the nervous system and endocrine system respond to stress. Explain the benefits of each system's response.
2. Explain what advantage is gained by elevating blood sugar and blood pressure in times of stress.
3. Why is the secretion of insulin reduced in times of stress?
4. Explain the roles of the adrenal medulla and adrenal cortex in times of stress.
5. What are prostaglandins?
6. You have received a bad wound on your arm. Describe the effects prostaglandins have on the wounded area.
7. What are anabolic steroids? Outline their benefits to an athlete and their dangerous side effects.
8. Explain why a marathon runner would be unlikely to take growth hormone or anabolic steroids.
9. Why would erythropoietin (EPO) give an athlete competing in an endurance event an unfair advantage?
10. Why is it difficult to detect banned drugs like growth hormone and EPO?
11. The International Olympic Committee has banned performance-enhancing drugs. Research the classes of banned drugs. Describe the advantages and side effects of one drug in each class.

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INVESTIGATION 15.1

Identification of Hyperglycemia

In this investigation, you will use simulated urine samples to determine how urinalysis is used to identify hyperglycemia and diabetes. Before the investigation, record the purpose of the investigation and then predict what colour(s) you expect to observe in the urine samples using Benedict's test and glucose test tape that will indicate diabetes. Outline the criteria you used to make your decision. When you have gathered and recorded the evidence, analyze it and identify any subjects that might have diabetes. Explain any other reasons there may be for a positive test.

Report Checklist

● Purpose	● Design	● Analysis
○ Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

Problem

How is urinalysis used to identify hyperglycemia diabetes?

Materials

safety goggles
laboratory apron
4 test tubes
wax pen
10 mL graduated cylinder
Benedict's solution
medicine dropper
4 samples of simulated urine
test-tube rack
400 mL beaker
beaker tongs
hot plate
test-tube clamp
distilled water
forceps
glucose test tape

Benedict's solution is toxic and an irritant. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 minutes and inform your teacher.

Procedure

Part 1: Benedict's Test

Benedict's solution identifies reducing sugars. Cupric ions in the solution combine with sugars to form cuprous oxides, which produce colour changes (**Table 1**).

Table 1 Benedict's Test Colour Chart

Colour of solution	Glucose concentration
blue	0.0 %
light green	0.15 %–0.5 %
olive green	0.5 %–1.0 %
yellow-green to yellow	1.0 %–1.5 %
orange	1.5 %-2.0 %
red to red-brown	2.0 %+

1. Label the four test tubes A, B, C, and D. Use a 10 mL graduated cylinder to measure 5 mL of Benedict's solution into each test tube.
2. With a medicine dropper, add 10 drops of urine from sample A to test tube A. Rinse the medicine dropper and repeat for samples B, C, and D.
3. Fill a 400 mL beaker with approximately 300 mL of tap water. Using beaker tongs, position the beaker on a hot plate. The beaker will be used as a hot-water bath. Use the test-tube clamp to place the test tubes in the hot-water bath for 5 min.
4. With the test-tube clamp, remove the samples from the hot-water bath. Record the final colours of the solutions.

Part 2: Glucose Test Tape

The reducing sugar in the urine will react with copper sulfate to reduce cupric ions to cupric oxide. The chemical reaction is indicated by a colour change of the test tape. **Table 2** provides quantitative results.

Table 2 Glucose Test Tape Colour Chart

Colour of solution	Glucose concentration
blue	0.0 %
green	0.25 %–0.5 %
green to green-brown	0.5 %–1.0 %
orange	2.0 %+

5. Clean the four test tubes and place 10 drops of distilled water into each of them.
6. Add five drops of urine to each of the appropriately labelled test tubes. Place the test tubes in a test-tube rack.
7. Use forceps to dip test tape into each of the test tubes. Record the final colours of the test tape.

INVESTIGATION 15.1 *continued*

Evaluation

(a) Describe any difficulties you had in carrying out your investigation.

(b) Explain the advantage of conducting two different tests. Which test was more appropriate? Explain your answer.

(c) Today, people with diabetes test their blood to monitor sugar levels. Explain why blood tests are preferred for people with diabetes. Why weren't blood tests carried out in this investigation?

Synthesis

(d) Why is insulin not taken orally?

(e) Explain why people with diabetes experience the following symptoms: low energy levels, large volumes of urine, the presence of acetone on the breath, and acidosis (blood pH becomes acidic).

(f) Why might the injection of too much insulin be harmful?

(g) Explain how you would help someone who had taken too much insulin.

EXTENSION

CBC radioONE QUIRKS & QUARKS

Fixing Diabetes

Dr. Alex Rabinovitch (University of Alberta) has come up with a new solution addressing the main problem of juvenile diabetes—that the insulin-producing cells, called beta cells, have been destroyed. He's found that he can expose a pancreas to certain chemical growth factors and stimulate it to produce more beta cells. This research opens up the possibility that, in the future, a diabetic will be able to stimulate her or his own pancreas to build new beta cells and regain the ability to make insulin.

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Chapter 15 SUMMARY

Outcomes

Knowledge

- identify the principal endocrine glands of the human organism (15.1, 15.2, 15.3)
- describe the function of the hormones of the principal endocrine glands (15.1, 15.2, 15.3, 15.4)
- explain the metabolic roles hormones may play in homeostasis (15.2, 15.3, 15.4, 15.5)
- explain how the endocrine system allows human organisms to sense their internal environment and respond appropriately (15.1, 15.2, 15.3, 15.4, 15.5)
- compare the endocrine and nervous control systems and explain how they act together (i.e., stress and the adrenal gland) (15.2, 15.3, 15.5)
- describe, using an example, the physiological consequences of hormone imbalances (15.2, 15.3, 15.4)

STS

- explain that science and technology are developed to meet societal needs and expand human capability (15.1, 15.2, 15.5)
- explain that science and technology have both intended and unintended consequences for humans and the environment (15.1, 15.3, 15.5)

Skills

- ask questions and plan investigations by formulating a hypothesis, from published data, on an environmental factor that can be detected and responded to by humans (15.4)
- conduct investigations and gather and record data and information (15.2, 15.4)
- analyze data and apply models by: inferring the role of ADH and aldosterone in maintenance of water and ions using data on blood and urine composition (15.4); and, inferring the role of insulin in regulation of blood sugar by investigating the presence of glucose in simulated urine and comparing with normal blood glucose levels (15.2)

Key Terms

15.1

homeostasis
dynamic equilibrium
negative feedback
positive feedback
hormones
endocrine hormones
insulin
human growth hormone (hGH)
epinephrine (adrenaline)
pituitary gland
releasing hormone
inhibiting factor

15.2

islets of Langerhans
glucagon
diabetes
adrenal medulla
adrenal cortex
norepinephrine
glucocorticoid
mineralocorticoid
sex hormone
cortisol
adrenocorticotropic hormone (ACTH)
tropic hormone
aldosterone

15.3

thyroid gland
parathyroid glands
thyroxine (T4)
triiodothyronine (T3)
calcitonin
goiter
parathyroid hormone (PTH)

15.4

antidiuretic hormone (ADH)
osmoreceptors

15.5

prostaglandins
anabolic steroids

MAKE a summary

1. Sketch the human endocrine system and show how the system maintains homeostasis in response to stress. Use as many of the key terms as possible.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To www.science.nelson.com

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 15
- additional Diploma Exam-style Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

UNIT 30 A PERFORMANCE TASK

Determining the Effects of Caffeine on Homeostasis

In this Performance Task, you will investigate the effects caffeine has on an invertebrate and how it affects homeostasis. Go to the 30 A Performance Task link on the Nelson web site to complete this task.

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Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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Part 1

1. Which of the following describes a negative feedback reaction?
   A. Glucagon stimulates the release of glucose from the liver, which increases blood glucose.
   B. Insulin stimulates cells to absorb glucose, which inhibits the release of insulin.
   C. The hypothalamus releases TRH, which travels to the pituitary gland initiating the release of TSH, which stimulates the release of thyroxine from the thyroid gland.
   D. Calcitonin is released from the thyroid gland and blood calcium levels decrease.

2. Glucagon is produced in an organ and affects target cells that are in another part of the body. The organ of production and the location of the target cells are, respectively,
   A. the adrenal medulla and the adrenal cortex
   B. the liver and the pancreas
   C. the pituitary and the adrenal medulla
   D. the pancreas and the liver

3. Two hormones that adjust body systems for short-term stress and long-term stress are, respectively,
   A. thyroxine and PTH
   B. estrogen and growth hormone
   C. epinephrine and cortisol
   D. TSH and epinephrine

4. A hypersecretion of growth hormone (acromegaly) in an adult would result in which of the following symptoms?
   A. decreased growth of the long bones, causing dwarfism
   B. increased growth of the long bones, causing gigantism
   C. decreased heart rate and an increased amount of fat tissue
   D. widening of the fingers and toes and broadening of the facial bones

5. A person with diabetes could be identified by which of the following symptoms?
   A. increased blood sugar and decreased urine output
   B. increased blood sugar and increased urine output
   C. decreased blood sugar and decreased urine output
   D. decreased blood sugar and increased urine output

6. A laboratory animal is accidentally given too much insulin and begins convulsing. To quickly return the animal to a normal blood sugar you could
   A. provide sugar in a fruit drink
   B. increase water intake
   C. inject erythropoietin
   D. cool the animal as rapidly as possible

7. In times of stress, under the influence of cortisol, amino acid levels increase in the blood. Why is an increase in the amino acid level in the blood beneficial as a response to stress?
   A. The amino acids are converted into proteins, which are used to repair cells damaged by the stress.
   B. The amino acids are converted to glucose by the liver, raising blood sugar, thereby providing more energy to deal with stress.
   C. The amino acids are converted into proteins, which provide more energy to deal with stress.
   D. The amino acids are converted to glycogen by the liver, lowering blood sugar, which stimulates the release of insulin.

8. Hypersecretion of the thyroid gland would cause a
   A. tendency not to gain weight, warm peripheral body temperature, and high energy level
   B. tendency to gain weight, cold peripheral body temperature, and high energy level
   C. tendency not to gain weight, cold peripheral body temperature, and low energy level
   D. tendency to gain weight, warm peripheral body temperature, and low energy level

9. NR Humans respond to stress by secreting ACTH, which causes an increase in blood sugar levels. In your notebook, place the correct number from **Figure 1** above the appropriate step. (Record all four digits of your answer.)

_____	_____	_____	_____
Nerve message signals stress.	Gland secretes ACTH.	Target organ for ACTH.	Organ responds to increased blood sugar.

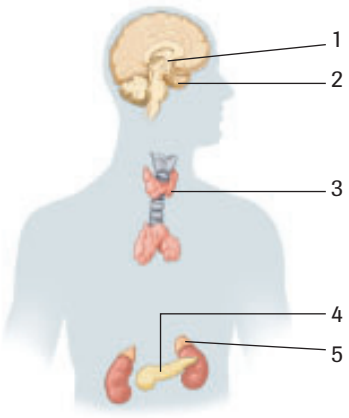

Figure 1

10. The thyroid disorder referred to as goiter is caused by
    A. low levels of TSH, which stimulate thyroid development
    B. low levels of thyroxine, which stimulate thyroid development
    C. decreased thyroxine due to decreased dietary iodine
    D. decreased TSH due to decreased dietary iodine

11. The body responds to a drop in blood pressure by
    A. increasing ADH production and water uptake, and decreasing urine formation
    B. decreasing ADH production and water uptake, and increasing urine formation
    C. increasing Na^+ and water reabsorption, and decreasing urine formation
    D. decreasing Na^+ and water reabsorption, and increasing urine formation

Part 2

12. **List** and **explain** the symptoms experienced by people with diabetes.
13. **Sketch** negative feedback diagrams to **illustrate** how insulin and glucagon regulate blood sugar.
14. With reference to the adrenal glands, **explain** how the nervous system and endocrine system interact in times of stress.
15. **Why** do insulin levels decrease during times of stress?
16. **Explain** the role osmoreceptors play in sensing the body's internal environment.
17. With reference to the importance of negative feedback, provide an example of **why** low levels of iodine in your diet can cause goiters.
18. DE A physician notes that individuals with a tumour on the pancreas secrete unusually high levels of insulin. Unfortunately, insulin in high concentrations causes blood sugar levels to fall below the normal acceptable range. In an attempt to correct the problem, the physician decides to inject the patient with cortisol. Write a unified response that addresses the following aspects of the cortisol treatment.
    - **Why** would the physician give the patient cortisol?
    - **Predict** the problems that might arise from this treatment.
19. A rare virus destroys cells of the anterior lobe of the pituitary. **Predict** how the destruction of the pituitary cells would affect blood sugar. **Explain**.
20. A physician notes that her patient is very active and remains warm on a cold day, even when wearing a light coat. Further discussion reveals that although the patient's daily food intake exceeds that of most people, the patient remains thin. **Why** might the doctor suspect a hormone imbalance? **Identify** which hormone the doctor might suspect.

Use the following information to answer questions 21 to 28.

Caffeine was one of the first performance-enhancing drugs used by athletes. Some people believe that it can increase endurance. Dramatic increases in caffeine levels and high consumption of caffeine have been linked with sleep disorders, impaired fine motor activities, increased fatty acid levels in the blood, and heart attacks. A study was conducted on a group of elite cyclists and a group of high school students to determine whether caffeine provided any marked advantage. Each group pedalled at 80 % maximum capacity for as long as possible. **Table 1** reveals the average amount of time each group was able to pedal after drinking decaffeinated coffee and drinking coffee with caffeine.

Table 1 Cycling Time and Caffeine Consumption in Two Groups

	Average cycling time (min)	
Group	***Decaffeinated coffee (250 mL)***	***Coffee with caffeine (250 mL, 340 mg caffeine)***
elite athletes	82	123
students	41	42

21. DE **Identify** the problem being investigated by the research group.
22. DE **Hypothesize** about the relationship between caffeine consumption and athletic endurance in non-athletes versus elite athletes.
23. DE **Identify** the control for the experiment.
24. DE **Identify** the independent and dependent variables.
25. DE **Infer** conclusions from the evidence in **Table 1**.
26. DE **Why** was neither group told which coffee contained caffeine?
27. DE The procedure does not indicate how much time passed between each exercise test. **Explain** why this is an important factor to know.
28. DE To learn more about how caffeine helps your body adjust to physical stress, you might want to monitor changes in certain hormones during testing. **Identify** hormone levels that you might want to monitor in the blood during the testing and explain what information might be gained by monitoring these hormones.

29. **Compare** the control system of a thermostat to the control system that regulates the body's blood sugar levels.
30. A survey by the Harvard School of Business indicated that CEOs are most often above average height. Another study commissioned by a women's magazine showed that men are attracted to taller women. **Describe** how studies such as these could lead to the misuse of recombinant growth hormone.

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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Part 1

1. Use the data in **Table 1**, which compares plasma components (in g/100 mL of plasma) of several patients, and the key below to answer the following question.

Table 1 Plasma Components of Five Individuals

	Urea	Uric acid	Glucose	Amino acids	Proteins
normal person	0.03	0.004	0.10	0.05	8.00
patient 1	0.03	0.004	0.50	0.05	8.00
patient 2	0.03	0.005	1.70	0.05	8.00
patient 3	0.03	0.050	0.10	0.09	8.00
patient 4	0.07	0.004	0.10	0.06	4.00

According to the data provided, which patient(s) might have diabetes mellitus?

A. patient 1
B. patient 2
C. patient 3
D. patient 4

2. Sound is measured in decibels (dB). A normal conversation registers between 60 dB and 80 dB. Street traffic is about 80 dB and a rock concert can exceed 140 dB. Permanent damage occurs at 85 dB and pain is experienced at 120 dB. Hearing loss occurs when

A. ossicles of the middle ear pierce the tympanic membrane
B. violent wave-like motions cause fluids of the inner ear to tear the round window
C. vibrations tear hair cells from the basilar membrane of the cochlea
D. fluids build up in the Eustachian tube causing great pressure on the oval window

3. Identify the pathway in a simple reflex arc.

A. sensory receptor > sensory neuron > CNS > motor neuron
B. sensory neuron > interneuron > motor neuron > muscle or gland
C. interneuron > motor neuron > muscle or gland > motor receptor
D. motor receptor > sensory receptor > CNS > muscle or gland

Use the following information to answer questions 4 and 5.

During a football game, a receiver collides with a linebacker. Both football players collide and both appear to have received serious injuries. Both athletes are X-rayed upon arriving at the hospital. The linebacker is believed to have a fractured skull resulting in extensive damage to the motor cortex of the left frontal lobe of his brain. The receiver has no broken bones but lost feeling in his lower right leg. During the examination, the doctor uses a needle to gently poke the right leg of the receiver, beginning at the foot and working slowly upward on the leg. Further tests revealed that the loss of feeling in the receiver's leg is the result of a tear in the outer neural tissue at one location of the spinal cord.

4. By poking the receiver's leg with a needle, the physician is most likely

A. trying to locate the area of the leg where muscle damage occurred
B. trying to locate the area of the spinal cord where nerve damage occurred
C. trying to locate the area of the brain where nerve damage occurred
D. trying to locate the area of the leg where muscle and nerve damage occurred

5. Indicate what the prognosis for recovery for the linebacker would be if tests continued to yield memory loss and problems with motor coordination weeks after the initial check.

A. Good: grey matter of the brain has myelinated neurons, which have some capacity for repair.
B. Good: white matter of the brain has unmyelinated neurons, which have some capacity for repair.
C. Poor: grey matter of the brain has unmyelinated neurons, which have little capacity for repair.
D. Poor: white matter of the brain has myelinated neurons, which have little capacity for repair.

6. A fighter jet banks steeply to one side as it changes direction, i.e., one wing is lower than the other. In this situation, a pilot can sometimes become briefly disoriented, thinking that "down" is still toward his or her feet, even though the orientation of the aircraft has changed. How is the disorientation corrected?

A. The otoliths provide information on head position and the direction of gravity while the semicircular canals provide information on movement.
B. The cochlea provides information on head position and the direction of gravity while the semicircular canals provide information on movement.
C. The cochlea provides information on head position and the direction of gravity while the otoliths provide information on movement.
D. The otoliths provide information on head position and the direction of gravity while the cochlear canals provide information on movement.

Use **Figure 1** to answer questions 7 and 8.

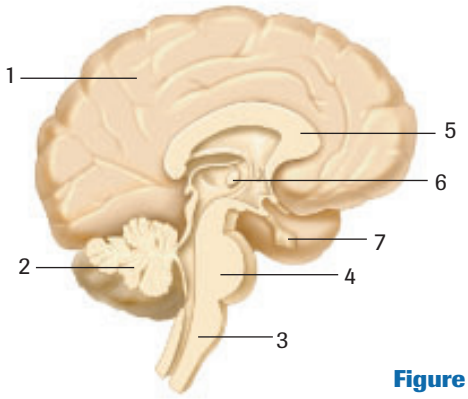

Figure 1

7. NR Identify the areas shown below by number. (Record all four digits of your answer.)

_____	_____	_____	_____
medulla oblongata	cerebellum	corpus callosum	pons

8. The function of the area labelled 5 is to
- A. communicate between the right and left hemisphere
- B. coordinate sensory and motor function from the cerebellum
- C. store sensory information and sequence motor activity
- D. coordinate the autonomic nervous system

9. NR Match each of the descriptions with the appropriate hormone. (Record all four digits of your answer.)
1. Released when blood Ca^{+} levels are low, this hormone causes the kidneys and gut to retain calcium while promoting calcium release from the bone.
2. Released into the blood during stressful situations, this pituitary hormone is carried to the adrenal glands where it stimulates the release of glucocorticoids.
3. Produced by the thyroid, this hormone increases metabolism and regulates growth.
4. Posterior pituitary hormone that acts upon the kidneys to increase water reabsorption.

_____	_____	_____	_____
ADH	thryoxine	PTH	ACTH

Part 2

10. **Illustrate** with a flow chart how the hypothalamus and ADH regulate the water content of blood.

11. **Outline** in a list the organs of the endocrine system.

12. In the homeostatic process of negative feedback, the secretion of most hormones is regulated by other hormones. Using thyroxine as an example, **sketch** a flow chart to **illustrate** this process of regulation by negative feedback.

13. A person's kidneys fail to respond to ADH. **Identify** the disease he or she suffers from and **describe** the physiological consequences of the disease.

14. **Compare** excitatory synapses to inhibitory synapses.

15. **Explain** why two stimuli, applied 0.0001 s apart, would produce only one nerve impulse along the fiber of a specific neuron.

16. Cerebral palsy is a group of disorders that affects body movement and muscle coordination. It is caused by damage to, or malformation of, the brain during development in the womb or in the first few years of life. The effects of cerebral palsy vary widely, from slight awkwardness of movement or hand control to eating difficulties, poor bladder and bowel control, and breathing problems. **Identify** which area(s) of the brain are most likely affected. **Explain** your answer.

17. **Describe** how the kidney senses changes in blood pressure and how it responds to those changes

18. **Describe** how the eye adjusts its focus when changing from looking at an object far away to looking at an object close by. Include the following terms in your description: point of focus, retina, ciliary muscle, suspensory ligaments, and lens.

19. DE **Explain** in a unified response how sounds are heard. In your explanation, include the following items:
- **Describe** the structures through which the sound waves and nerve impulses travel, beginning with the outer ear and ending with the cerebrum.
- **Describe** the function of each structure.

Use the following information to answer questions 20 to 22.

Prior to the work of Banting and Best, patients with type 1 diabetes mellitus usually died within months of the onset of the disease. Today, patients are treated with insulin injections; however, many of these patients do not escape insulin-related disorders brought on by the fluctuations in blood glucose levels. Changes in blood glucose may damage blood vessels, limiting circulation, which in turn can lead to blindness, kidney failure, and the destruction of muscle and nerve tissue in the hands and feet.

20. DE **Explain** why the transplant of islet cells from a donor's pancreas into a diabetic patient is a promising option.

21. DE **Describe** two technological challenges presented by islet transplants.

22. DE **Describe** one societal issue that researchers must face as islet transplants become more common.

Use the following information to answer questions 23 to 27.

On April 26, 1986, a nuclear accident in Chernobyl caused the release of radioactive wastes into the air. The extent of the problem is still unknown, but the effects on children have been the most extreme. One of the most dangerous radioactive materials released was iodine-131, which was absorbed by the thyroid glands of children. Iodine-131 causes inflammation of the thyroid gland and can lead to cancer.

23. **Describe** some possible symptoms of children who had their thyroid glands completely or partially destroyed. DE

24. **Sketch** a feedback loop that **illustrates** how thyroxine levels might be affected. DE

25. **Explain** why children were given non-radioactive iodine. DE

26. Initially, the government tried to suppress information about the nuclear accident. **Describe** what should have been done. DE

27. Nuclear wastes were carried over the European continent with weather. Should surrounding countries be able to demand financial and medical compensation? **Justify** your answer. DE

Use the following information to answer questions 28 to 32.

A laboratory experiment was conducted to determine the effect of thyroxine on metabolic rate. Four groups of adult male rats were used. All groups were maintained in similar environments, designed to provide maximum physical activity. Each group was provided with adequate supplies of water and one of the following diets:

Diet A: food containing all essential nutrients

Diet B: food containing all essential nutrients and an extract of thyroxine

Diet C: food containing all essential nutrients and a chemical that counteracts the effect of thyroxine

Diet D: food containing all essential nutrients, except iodine

The results of the experiment appear in **Table 3**.

Table 3 Metabolism of Four Rats Fed Different Diets

Group	Average initial mass (g)	Average mass after 2 weeks of treatment (g)	Final average oxygen consumption (mL/kg/min)
I (diet A)	310	312	4.0
II (diet ?)	320	309	10.1
III (diet ?)	318	340	2.7
IV (diet ?)	315	400	2.0

28. **Hypothesize** about the relationship between the variables (formulate a hypothesis) for this experiment. DE

29. **Identify** the dependent and independent variables. DE

30. Which group was most likely used as a control? **Explain** your response. DE

31. Diet B was most likely fed to which group(s)? **Explain** your answer. DE

32. Diet D was most likely fed to which group(s)? **Explain** your answer. DE

Use the following information to answer questions 33 to 36.

Serotonin is a naturally occurring neurotransmitter that has a role in determining mood and emotions. A shortage of serotonin has been linked to phobias, schizophrenia, aggressive behaviour, depression, uncontrolled appetite, and migraine headaches. Several types of drugs, shown in **Table 4**, affect serotonin levels.

Table 4 Effects of Various Drugs on Serotonin Levels

Drug	Effect
Prozac, Paxil, Zoloft	serotonin remains longer in the brain
clozapine	prevents serotonin from binding to the postsynaptic membranes
hallucinogens (LSD, ecstasy)	react directly with the serotonin receptors to produce the same effect as serotonin

33. **Why** is Prozac (fluoxetine hydrochloride) prescribed for people with depression? DE

34. **Identify** which drug should not be taken by someone experiencing clinical depression. DE

35. **Sketch** a diagram showing the effect of LSD or ecstasy on serotonin. DE

36. **Explain** how taking hallucinogens over time could reduce serotonin levels. DE

37. The formation of amyloid plaques in the brains of people with Alzheimer's disease can cause acetylcholine levels to drop. **Explain** how an acetylcholine deficiency could cause memory loss, a common symptom of Alzheimer's disease.

38. Review the focusing questions on page 402. Using the knowledge you have gained from this unit, briefly **outline** a response to each of these questions.