39–1 The Endocrine System

If you had to get a message to just one or two of your friends, what would you do? You might use the telephone. Wires running from your house to theirs would carry the message almost instantaneously. The telephone is a good way to reach a small number of people, but what if you wanted to get that same message to thousands of people? You might decide to broadcast it on the radio, sending the message in a way that made it possible to contact thousands of people at once.

Your nervous system works much like the telephone: Many impulses move swiftly over a system of wirelike neurons that carry specific messages from one cell to another. But another system, the endocrine system, does what the nervous system generally cannot. **The endocrine system is made up of glands that release their products into the bloodstream. These products deliver messages throughout the body.** In the same way that a radio broadcast can reach thousands or even millions of people in a large city, the chemicals released by the endocrine system can affect almost every cell in the body. In fact, the chemicals released by the endocrine system affect so many cells and tissues that the interrelationships of other organ systems to one another cannot be understood without taking the endocrine system into account.

Guide for Reading

Key Concepts
- What is the function of the endocrine system?
- How does the endocrine system maintain homeostasis?

Vocabulary
hormone
target cell
exocrine gland
endocrine gland
prostaglandin

Reading Strategy: Making Comparisons
As you read, list the differences and similarities between types of glands, and between types of hormones.

Hormones

The chemicals that "broadcast" messages from the endocrine system are called hormones. **Hormones** are chemicals released in one part of the body that travel through the bloodstream and affect the activities of cells in other parts of the body. Hormones do this by binding to specific chemical receptors on those cells. Cells that have receptors for a particular hormone are called **target cells.** If a cell does not have receptors or the receptors do not respond to a particular hormone, the hormone has no effect on it.

In general, the body's responses to hormones are slower and longer-lasting than the responses to nerve impulses. It may take several minutes, several hours, or even several days for a hormone to have its full effect on its target cells. A nerve impulse, on the other hand, may take only a fraction of a second to reach and affect its target cells.

Figure 39–1 The endocrine system releases hormones that affect the activities of other cells. Much of the increase in heart rate and breathing that the people are experiencing on this ride is due to the actions of hormones.

SECTION RESOURCES

Print:
- ***Teaching Resources,*** Lesson Plan 39–1, Adapted Section Summary 39–1, Adapted Worksheets 39–1, Section Summary 39–1, Worksheets 39–1, Section Review 39–1
- ***Reading and Study Workbook A,*** Section 39–1
- ***Adapted Reading and Study Workbook B,*** Section 39–1

Technology:
- ***iText,*** Section 39–1
- ***Transparencies Plus,*** Section 39–1

Section 39–1

1 FOCUS

Objectives
39.1.1 ***State*** the function of the endocrine system.
39.1.2 ***Describe*** hormones and glands.
39.1.3 ***Explain*** how the endocrine system maintains homeostasis.

Guide for Reading

Reading Strategy
Explain to students that the prefix *endo-* means "within" and that endocrine glands are glands that secrete substances into the bloodstream within the body. Ask: **If *exo-* means "outside," what do you think exocrine glands are?** *(Glands that secrete substances to the outside)* These substances pass out of the glands into ducts, which lead either directly to the outside of the body (sweat or milk ducts) or into internal structures (saliva and digestive enzymes).

Reading Strategy
Have students study the figures and read the captions to preview the material in the section. Suggest that they write down any questions they have about the material based on the figures and then try to find the answers as they read the section.

2 INSTRUCT

Hormones

Build Science Skills
Using Analogies Help students understand the endocrine system by comparing it with familiar human relationships in which one person directs the actions of others—such as coach and team, conductor and orchestra members, traffic officer and motorists, and movie director and actors. Ask: **How are these relationships similar to those of the endocrine system?** *(An endocrine gland is like a director, the hormones are like verbal or visual directions, and cells are like the people being directed.)* L1

Demonstration

Demonstrate hormone-target cell interactions with a model. Have students use an empty egg carton to model a tissue. First, they should create "target cells" by cutting small holes in the top of the carton over a few of the sections. Then, they should pour water over the egg carton to model a circulating hormone. Ask: **Which cells in your model contain hormone?** *(Just the target cells)* **What effect did the hormone have on the other cells?** *(none)* L1 L2

Glands

Build Science Skills

Inferring Call on students at random to compare and contrast endocrine and exocrine glands. *(Endocrine glands release their hormones into the bloodstream; exocrine glands release their products through ducts into open spaces.)* Then, ask: **Based on how they release their hormones, what can you infer about the effects on the body of hormones released by endocrine glands and products released by exocrine glands?** *(Hormones released by endocrine glands can affect cells throughout the body, whereas products released by exocrine glands tend to have local effects.)* L2

Use Visuals

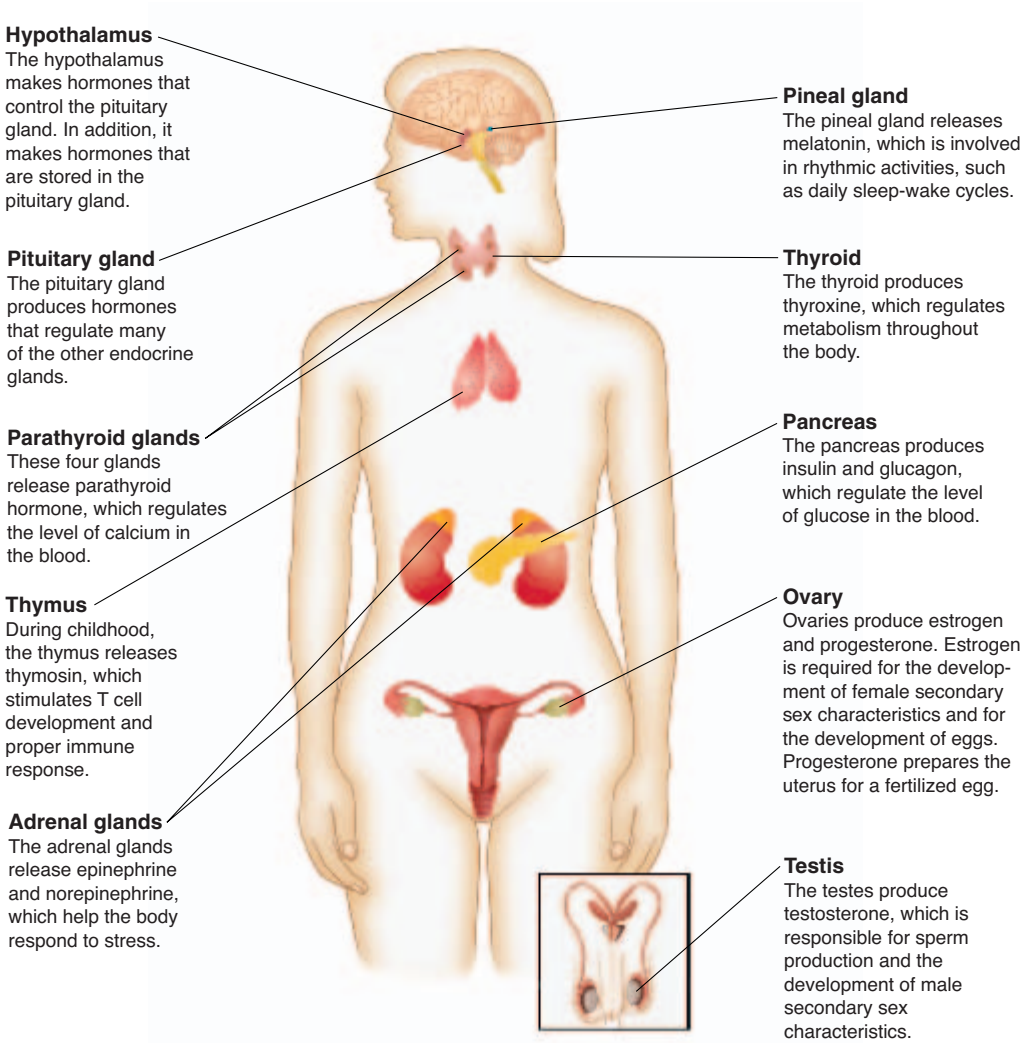
Figure 39–2 Call students' attention to the figure. Make sure they understand that the ovaries are found only in females and the testes only in males. Name several different glands, and have students locate them in the figure. As students locate each gland, ask: **What hormones does the gland produce, and what roles do the hormones play in the body?** *(Students should identify the hormones and roles of the glands by reading the appropriate labels in the figure.)* L1

Glands

A gland is an organ that produces and releases a substance, or secretion. **Exocrine glands** release their secretions, through tubelike structures called ducts, directly to the organs that use them. Exocrine glands include those that release sweat, tears, and digestive juices. Unlike exocrine glands, **endocrine glands** release their secretions (hormones) directly into the bloodstream. **Figure 39–2** shows the location of the major endocrine glands in the human body.

CHECKPOINT *What are exocrine glands?*

▼ **Figure 39–2** Endocrine glands produce hormones that affect many parts of the body. **Interpreting Graphics** *What is the function of the pituitary gland?*



UNIVERSAL ACCESS

Inclusion/Special Needs

Help students understand hormone action. First, guide them in creating two parallel flowcharts, one showing how a steroid hormone interacts with a target cell and the other showing how a nonsteroid hormone interacts with a target cell. Then, after the flowcharts are completed, have students identify differences between the two types of hormone action by comparing the flowcharts, step by step. L1

Advanced Learners

Challenge students to learn more about prostaglandins. Ask them to find out how prostaglandins were discovered, how they differ from other hormones, and the roles played by specific prostaglandins, such as those in the uterus, blood vessels, or bronchioles. Urge students to share what they learn with the class in a PowerPoint® presentation. L3

Hormone Action

Hormones may be classified as belonging to two general groups—steroid hormones and nonsteroid hormones. Steroid hormones are produced from a lipid called cholesterol. Nonsteroid hormones include proteins, small peptides, and modified amino acids. The two basic patterns of hormone action are shown in **Figure 39–3.**

Steroid Hormones Because they are lipids, steroid hormones can cross cell membranes easily, passing directly into the cytoplasm and even into the nuclei of target cells.

1. A steroid hormone enters a cell by passing directly across its cell membrane.
2. Once inside, it binds to a steroid receptor protein (found only in its target cells) to form a hormone-receptor complex.
3. The hormone-receptor complex enters the nucleus of the cell, where it binds to a DNA control sequence.
4. This binding initiates the transcription of specific genes to messenger RNA (mRNA).
5. The mRNA moves into the cytoplasm and directs protein synthesis.

Hormone-receptor complexes work as regulators of gene expression—they can turn on or turn off whole sets of genes. Because steroid hormones affect gene expression directly, they can produce dramatic changes in cell and organism activity.

Nonsteroid Hormones Nonsteroid hormones generally cannot pass through the cell membrane of their target cells.

1. A nonsteroid hormone binds to receptors on the cell membrane.
2. The binding of the hormone activates an enzyme on the inner surface of the cell membrane.
3. This enzyme activates secondary messengers that carry the message of the hormone inside the cell. Calcium ions, cAMP (cyclic adenosine monophosphate), nucleotides, and even fatty acids can serve as second messengers.
4. These second messengers can activate or inhibit a wide range of other cell activities.

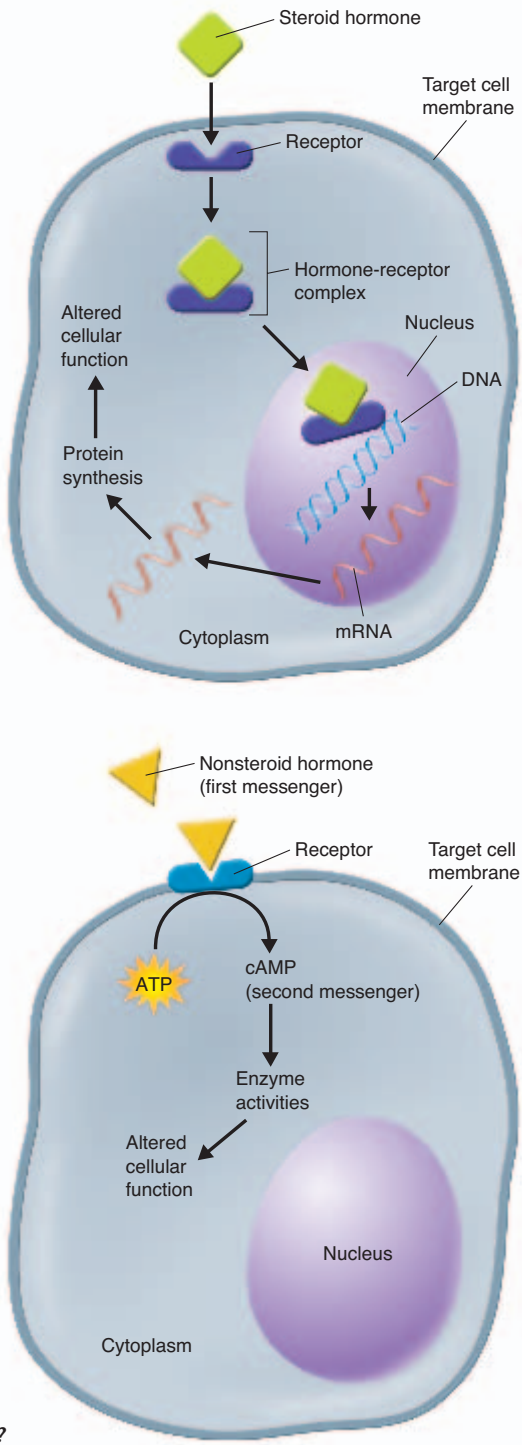


Figure 39–3 The two main types of hormones are steroid hormones (top) and nonsteroid hormones (bottom). **Comparing and Contrasting** ***How are steroid hormones different from nonsteroid hormones?***

Hormone Action

Build Science Skills

Comparing and Contrasting Work with the class to compare and contrast the two types of hormone action. On the board or an overhead projector, make a two-column table called Hormone Action, with one column headed Steroid Hormones and the other headed Nonsteroid Hormones. Then, challenge students to brainstorm similarities and differences between the two types of hormones. *(Examples of similarities include: both bind to receptors; both affect the activity of the receptor cell. Examples of differences include: steroid hormones are lipids, whereas nonsteroid hormones are proteins; steroid hormones enter cells and go to the cell nucleus, whereas nonsteroid hormones stay outside of the cell and work via a secondary messenger.)* As the similarities and differences are identified, record them in the table. Suggest that students copy the table into their class notes. L1 L2

Use Visuals

Figure 39–3 Ask: **Why does the green hormone enter the top cell whereas the yellow hormone stays outside the bottom cell?** *(The green hormone is a steroid hormone, and it can cross cell membranes. The yellow hormone is a nonsteroid hormone, so it cannot cross cell membranes.)* **Why does the steroid hormone exert a greater influence on cell activity?** *(It enters the nucleus of the cell, where it regulates gene expression directly.)* L1 L2

TEACHER TO TEACHER

To demonstrate the second messenger mechanism, I use a model. Prior to class, I arrange for another teacher to send a student from his or her class to my class with a message, such as "turn out the lights." The message is placed in an envelope with my name on it and the name of a student in my class. The student from the other class enters my classroom and hands the envelope to me. I hand the envelope to my student whose name is also on the envelope. This student opens the envelope and responds to the message. Then, I challenge students to tell me who represented the first messenger *(the student from the other class)*, the receptor *(me)*, and the second messenger *(my student)*.

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Answers to . . .

CHECKPOINT *Glands that release their secretions into local tissues through ducts*

Figure 39–2 *The pituitary produces hormones that regulate the activity of many other endocrine glands.*

Figure 39–3 *Steroid hormones can cross cell membranes. Nonsteroid hormones generally cannot cross cell membranes.*

Prostaglandins

Build Science Skills

Inferring Point out that prostaglandins are called "local hormones" because they affect only nearby cells and tissues. Ask: **What advantage might this give prostaglandins over endocrine hormones?** *(Prostaglandins might work more quickly because they do not have to travel to another part of the body and the response is localized.)* L2

Control of the Endocrine System

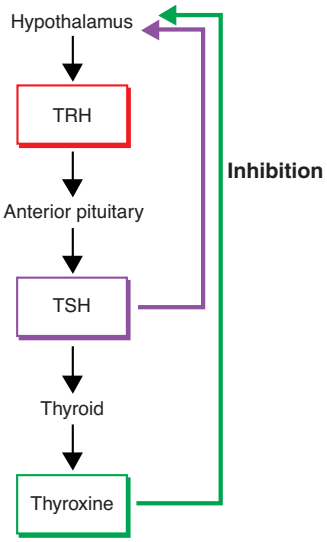
Use Visuals

Figure 39–4 Check students' comprehension of the inhibition mechanism in the figure. Have them find the arrows that connect TSH and thyroxine to the hypothalamus. Then, ask: **How do TSH and thyroxine affect the hypothalamus?** *(Increased levels of TSH and thyroxine inhibit TRH secretion by the hypothalamus.)* L1 L2

Build Science Skills

Using Analogies Help students better understand the feedback mechanisms that control the endocrine system by extending the thermostat analogy in the text. Ask: **How does a thermostat control a furnace?** *(When the temperature falls below a set point, a sensor in the thermostat signals the furnace to switch on and produce heat; when the temperature rises above a set point, the sensor signals the furnace to switch off.)* Tell students that the thyroid gland is like a furnace because it can increase or decrease its output of the hormone thyroxine, which changes the rate of metabolism and, consequently, core body temperature. Ask: **If the thyroid is a furnace, what is the thermostat?** *(The hypothalamus, because it senses changes in the level of thyroxine or changes in internal body temperature and signals the anterior pituitary to release TSH)* L1 L2

▼ Figure 39–4 **One way the endocrine system is regulated by internal feedback mechanisms is by maintaining the rate of metabolism.** When the hypothalamus senses that the level of thyroxine in the blood is low, it secretes TRH. TRH stimulates the anterior pituitary to secrete TSH. TSH stimulates the thyroid to release thyroxine. Increased levels of TSH and thyroxine inhibit TRH secretion by the hypothalamus.



Prostaglandins

Until recently, the glands of the endocrine system were thought to be the only organs that produced hormones. However, except for red blood cells, all cells have been shown to produce small amounts of hormonelike substances called **prostaglandins** (prahs-tuh-GLAN-dinz). Prostaglandins get their name from a gland in the male reproductive system, the prostate, in which they were first discovered. Prostaglandins are modified fatty acids that are produced by a wide range of cells. They generally affect only nearby cells and tissues, and thus are known as "local hormones."

Some prostaglandins cause smooth muscles, such as those in the uterus, bronchioles, and blood vessels, to contract. One group of prostaglandins causes the sensation of pain in most headaches. Aspirin helps to stop the pain of a headache because it inhibits the synthesis of these prostaglandins.

Control of the Endocrine System

As powerful as they are, hormones are monitored by the body in order to keep the functions of different organs in balance. Even though the endocrine system is one of the master regulators of the body, it too must be controlled. **Like most systems of the body, the endocrine system is regulated by feedback mechanisms that function to maintain homeostasis.**

Recall that feedback inhibition occurs when an increase in any substance "feeds back" to inhibit the process that produced the substance in the first place. Heating and cooling systems, controlled by thermostats, are examples of mechanical feedback loops. The hormones of the endocrine system are biological examples of the same type of process.

Controlling Metabolism

To see how an internal feedback mechanism regulates the activity of the endocrine system, let's look at the thyroid gland and its principal hormone, thyroxine. Thyroxine affects the activity of cells throughout the body, increasing their rate of metabolism. Recall that metabolism is the sum of all of the chemical reactions that occur in the body. A drop in thyroxine decreases the metabolic activity of cells.

Does the thyroid gland determine how much thyroxine to release on its own? No, instead the activity of the thyroid gland is controlled by the hypothalamus and the anterior pituitary gland. When the hypothalamus senses that the thyroxine level in the blood is low, it secretes thyrotropin-releasing hormone (TRH), a hormone that stimulates the anterior pituitary to secrete thyroid-stimulating hormone (TSH). TSH stimulates the release of thyroxine by the thyroid gland. High levels of thyroxine in the blood inhibit the secretion of TRH and TSH, which stops the release of additional thyroxine. This feedback loop, shown in **Figure 39–4,** keeps the level of thyroxine in the blood relatively constant.

BIO INSIGHTS

FACTS AND FIGURES

Fast-acting hormones

In humans and most other animals, endocrine hormones bring about relatively slow changes, sometimes taking hours or even days to achieve their full effects. In some small animals, however, certain hormones produce a more immediate change. Examples are the hormones that cause vertebrates such as chameleons to change their color and pattern so they are camouflaged in their environment. The hormones that lead to such color changes usually produce their full effects in a matter of seconds. The effects are brought about by special color-containing cells in the skin, which change in size to produce a different color pattern. The color-containing cells are controlled by endocrine hormones that are produced in response to light patterns entering the eye of the animal.

Recall that the hypothalamus is also sensitive to temperature. When the core body temperature begins to drop, even if the level of thyroxine is normal, the hypothalamus produces extra TRH. The release of TRH stimulates the release of TSH, which stimulates the release of additional thyroxine. Thyroxine increases oxygen consumption and cellular metabolism. The increase in metabolic activity that results helps the body maintain its core temperature despite lower temperatures.

CHECKPOINT *What process does thyroxine control?*

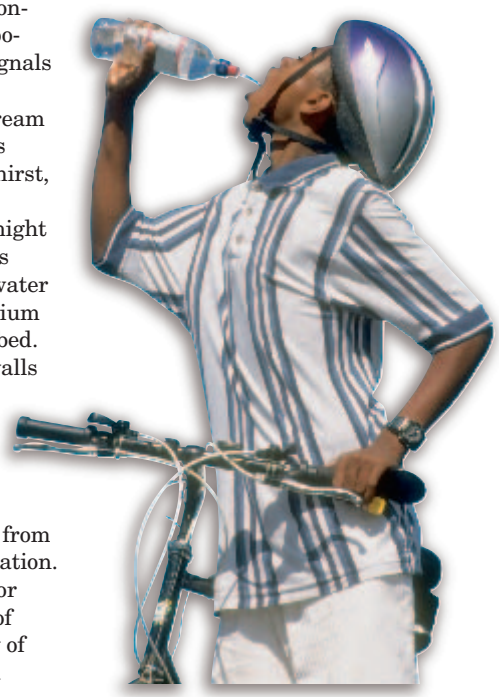
Maintaining Water Balance Homeostatic mechanisms regulate the levels of a wide variety of materials dissolved in the blood and in extracellular fluids. These include minerals such as sodium, potassium, and calcium, and soluble proteins such as serum albumin, which is found in blood plasma. Most of the time, homeostatic systems operate so smoothly that we are scarcely aware of their existence. However, that is not the case with one of the most important homeostatic processes, the one that regulates the amount of water in the body.

When you exercise strenuously, you lose water as you sweat. If this water loss continued, your body would soon become dehydrated. Generally, that doesn't happen because your body's homeostatic mechanisms swing into action.

The hypothalamus contains cells that are sensitive to the concentration of water in the blood. As you lose water, the concentration of dissolved materials in the blood rises. The hypothalamus responds in two ways. First, the hypothalamus signals the pituitary gland to release a hormone called antidiuretic hormone (ADH). ADH molecules are carried by the bloodstream to the kidneys, where the removal of water from the blood is quickly slowed down. Later, you experience a sensation of thirst, a signal that you should take a drink to restore lost water.

When you finally get around to taking that drink, you might take in as much as 1 or 2 liters of fluid. Most of that water is quickly absorbed into the bloodstream. But this volume of water added to the blood would dilute it so much that the equilibrium between the blood and the cells of the body would be disturbed. Large amounts of water would diffuse across blood vessel walls into the tissues. The cells of the body would swell with the excess water.

Needless to say, this doesn't happen, because the same homeostatic mechanism intervenes. When the water content of the blood rises, the pituitary releases less ADH. In response to lower ADH levels, the kidneys remove water from the bloodstream, restoring the blood to its original concentration. This homeostatic system sets both upper and lower limits for blood water content: A water deficit stimulates the release of ADH, causing the kidneys to conserve water; an oversupply of water causes the kidneys to eliminate the excess water as a component of urine.



▼ **Figure 39–5** When exercising on a hot day, it is important to replenish lost liquid. **Applying Concepts** *Explain why people who are exercising should drink fluids before they are thirsty.*

Demonstration

Remind students of the discussion of feedback inhibition in Section 35–1. Point out that the endocrine system is regulated by feedback inhibition mechanisms and that feedback inhibition is sometimes referred to as negative feedback. Demonstrate the difference between a positive- and a negative-feedback mechanism by dividing the class into two groups. Tell members of one group to take turns saying the word *positive*, with each student saying it louder than the previous person. Then, instruct members of the other group to take turns saying the word *negative*, with students alternating between saying it louder and saying it softer than the previous person. Conclude by asking: **How did negative feedback affect the volume?** *(It kept the volume more or less constant.)* **How did positive feedback affect the volume?** *(It steadily increased the volume.)* **When would a positive-feedback mechanism be useful?** *(Positive feedback intensifies a response until the condition that stimulated the response is under control. For example, the signal for formation of a blood clot will be amplified until the bleeding is under control and the signal is no longer produced.)* L1 L2

Build Science Skills

Using Models To help students understand how the body maintains water balance, create two flowcharts on the chalkboard, one illustrating a water deficit and one illustrating an oversupply of water. Call on students to fill in the steps for each flowchart. *(Deficit: hypothalamus signals pituitary → pituitary releases ADH → blood carries ADH to kidneys → kidneys decrease removal of water. Oversupply: water content of blood rises → pituitary releases less ADH → kidneys increase removal of water from blood)* L1 L2

BIO INSIGHTS

FACTS AND FIGURES

The power of hormones

The endocrine glands, despite their tremendous importance in the body, are amazingly small. The pituitary gland, which produces nine different hormones and controls most of the other endocrine glands, is only as large as a pea. All of the body's endocrine tissues combined would fit in the palm of one hand. The quantity of hormones produced by this small amount of glandular tissue is also slight. For example, the average woman produces only about 5 mL, or a teaspoonful, of the steroid hormone estrogen in her entire lifetime. Obviously, to have the far-reaching effects on the body that they do, hormones must be very powerful. In fact, most hormones are so potent that they are effective at concentrations as low as one part per million.

Answers to . . .

CHECKPOINT *Thyroxine controls the level of metabolic activity in cells.*

Figure 39–5 *They could become dehydrated before they experience a sensation of thirst.*

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

Complementary Hormone Action

Build Science Skills

Applying Concepts Help students understand how hormones regulate calcium concentration. Ask: **What causes the parathyroid glands to produce PTH?** *(A decrease in the level of calcium in the blood)* **What does PTH do?** *(Stimulates the intestines to absorb more calcium, the kidneys to retain more calcium, and the bones to release calcium)* **What causes the thyroid gland to produce calcitonin?** *(An increase in the level of calcium in the blood)* **What does calcitonin do?** *(Stimulates the bones and kidneys to take up calcium and the intestines not to take up calcium)* L1 L2

3 ASSESS

Evaluate Understanding

Have some students compare steroid and nonsteroid hormones, and have others name examples of each.

Reteach

Guide students in making two Venn diagrams, comparing and contrasting (1) exocrine and endocrine glands and (2) hormones and prostaglandins.

Focus on the BIG Idea

Steroid hormones are lipids, so they can pass through the cell membrane and enter cells. Nonsteroid hormones are not lipids, so they cannot pass through the cell membrane and must act from outside cells.

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 39–1.

Go Online NSTA SCILINKS
For: Links on the endocrine system
Visit: www.SciLinks.org
Web Code: cbn-0391

Complementary Hormone Action

Sometimes two hormones with opposite effects act to regulate part of the body's internal environment. One way to think about how the endocrine system functions is to think about driving a car. A good driver might be able to control a car on an open highway by using only the accelerator pedal. But driving around town, even a good driver would get into trouble using just the accelerator. There are too many situations in which the brake is needed to slow the car down.

In the same way, many endocrine functions depend on the complementary effects of two opposing hormones. Such a complementary system regulates the level of calcium ions in the bloodstream. The level of calcium dissolved in the bloodstream is kept within a narrow range. The two hormones that regulate calcium concentration are calcitonin, from the thyroid gland, and parathyroid hormone (PTH), from the parathyroid glands. Calcitonin decreases the level of calcium in the blood, while PTH increases it.

When blood calcium levels are too high, the thyroid secretes calcitonin. Calcitonin signals the kidneys to reabsorb less calcium as they form urine. Calcitonin also reduces the amount of calcium absorbed in the intestines and stimulates calcium deposition in the bones.

If calcium levels drop too low, PTH is released by the parathyroids. PTH, together with vitamin D, stimulates the intestine to absorb more calcium from food. PTH also causes the kidneys to retain more calcium, and it stimulates bone cells to release some of the calcium stored in bone tissue into the bloodstream.

You may be surprised that the body regulates calcium levels so carefully. This adaptation has evolved because calcium is one of the most important minerals in the body. If calcium levels drop below their normal range, blood cannot clot, muscles cannot contract, and the transport of materials across cell membranes may fail.

39–1 Section Assessment

1. **Key Concept** Describe the function of the endocrine system in the body.
2. **Key Concept** Explain how the endocrine system helps maintain homeostasis.
3. Compare endocrine glands and exocrine glands.
4. What are prostaglandins and why are they called "local hormones"?
5. **Critical Thinking Applying Concepts** What are the advantages of having both a nervous system and an endocrine system?

Focus on the BIG Idea

Cellular Basis of Life Use what you learned in Chapter 7 about diffusion and how materials cross cell membranes to explain the actions of steroid hormones and nonsteroid hormones.

39–1 Section Assessment

1. To produce hormones that affect the activities of cells throughout the body
2. The endocrine system, along with the autonomic nervous system, continually adjusts many body activities, helping the body maintain relatively constant internal conditions.
3. Endocrine glands secrete hormones directly into the bloodstream. Exocrine glands release their secretions through ducts.
4. All cells produce hormonelike substances called prostaglandins, which are called "local hormones" because they affect only nearby cells or tissues.
5. The nervous system broadcasts specific messages quickly to a limited number of cells, whereas the endocrine system broadcasts messages slowly to target cells throughout the body.