LECTURE PRESENTATIONS

For CAMPBELL BIOLOGY, NINTH EDITION

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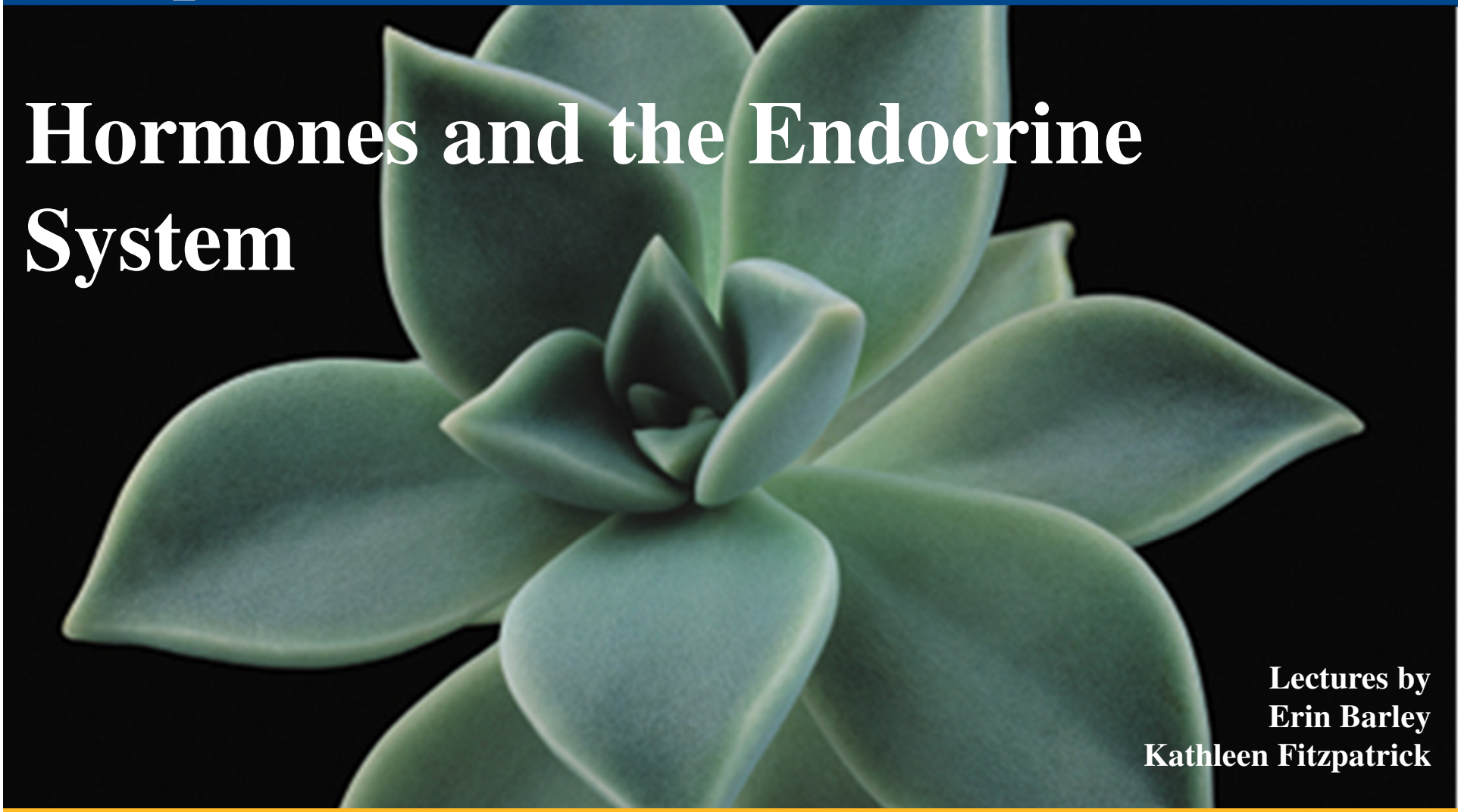
Chapter 45

Hormones and the Endocrine System



Lectures by
Erin Barley
Kathleen Fitzpatrick

Overview: The Body's Long-Distance Regulators

- Animal **hormones** are chemical signals that are secreted into the circulatory system and communicate regulatory messages within the body
- Hormones reach all parts of the body, but only target cells have receptors for that hormone
- Insect metamorphosis is regulated by hormones

- Two systems coordinate communication throughout the body: the endocrine system and the nervous system
- The **endocrine system** secretes hormones that coordinate slower but longer-acting responses including reproduction, development, energy metabolism, growth, and behavior
- The **nervous system** conveys high-speed electrical signals along specialized cells called neurons; these signals regulate other cells

Figure 45.1

Figure 45.UN01

Concept 45.1: Hormones and other signaling molecules bind to target receptors, triggering specific response pathways

- Endocrine signaling is just one of several ways that information is transmitted between animal cells

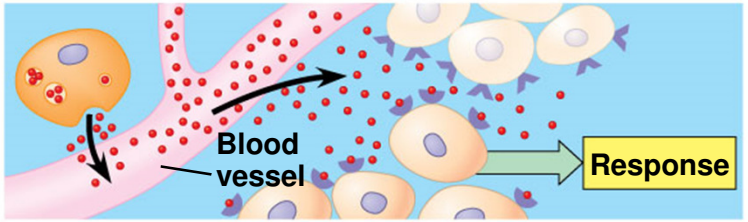
Intercellular Communication

- The ways that signals are transmitted between animal cells are classified by two criteria
  - The type of secreting cell
  - The route taken by the signal in reaching its target

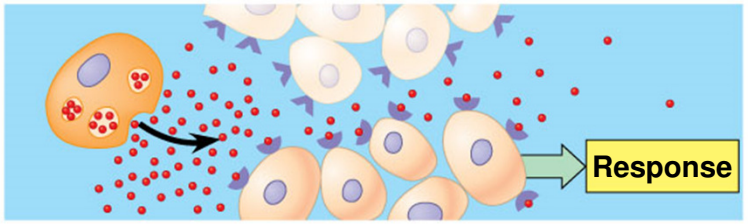
Endocrine Signaling

- Hormones secreted into extracellular fluids by endocrine cells reach their targets via the bloodstream
- Endocrine signaling maintains homeostasis, mediates responses to stimuli, regulates growth and development

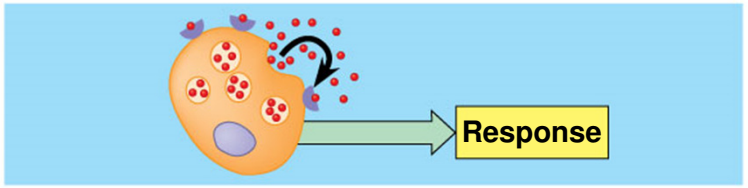
Figure 45.2



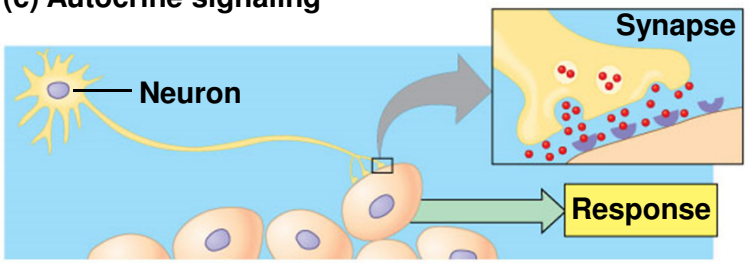
(a) Endocrine signaling



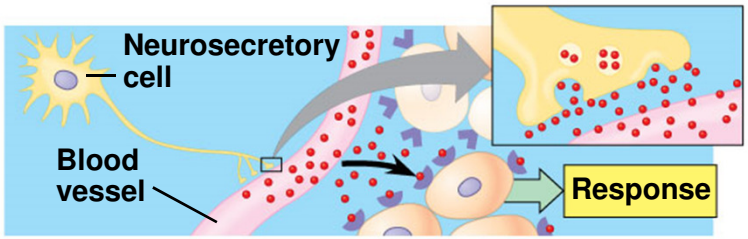
(b) Paracrine signaling



(c) Autocrine signaling



(d) Synaptic signaling

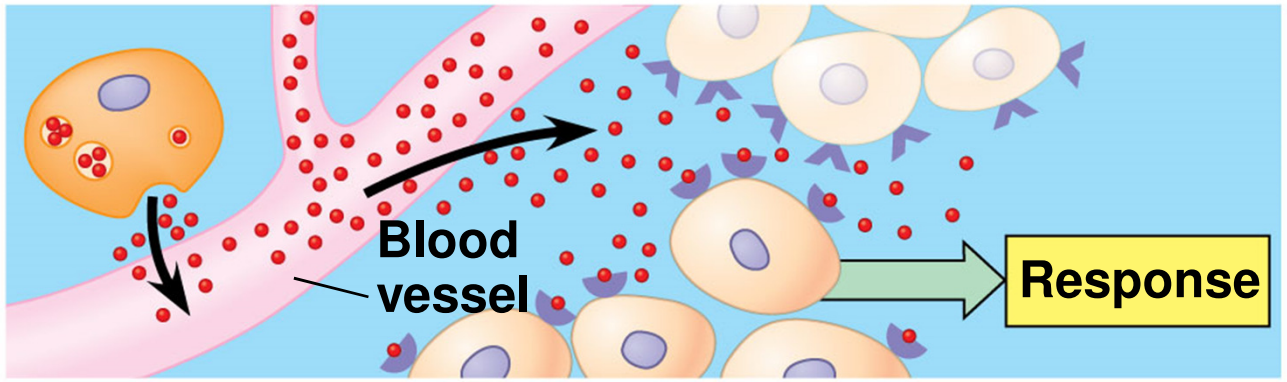


(e) Neuroendocrine signaling

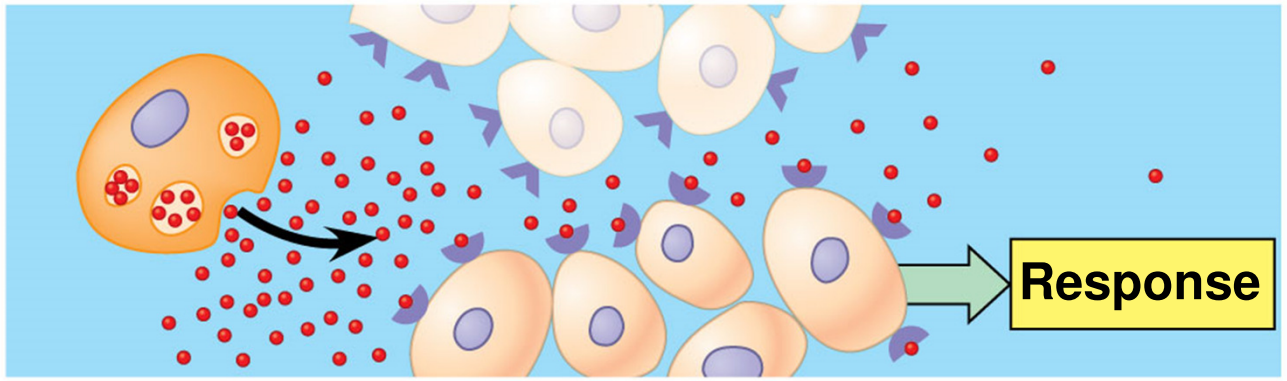
Paracrine and Autocrine Signaling

- **Local regulators** are molecules that act over short distances, reaching target cells solely by diffusion
- In **paracrine signaling**, the target cells lie near the secreting cells
- In **autocrine signaling**, the target cell is also the secreting cell

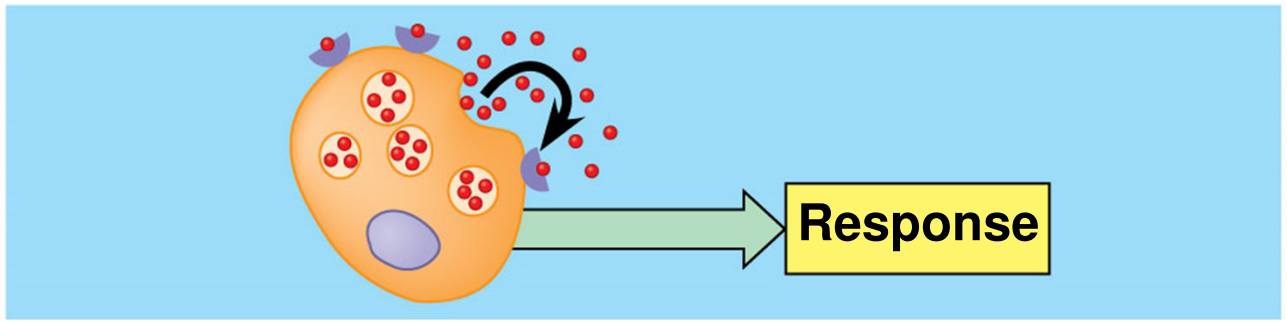
Figure 45.2a



(a) Endocrine signaling



(b) Paracrine signaling

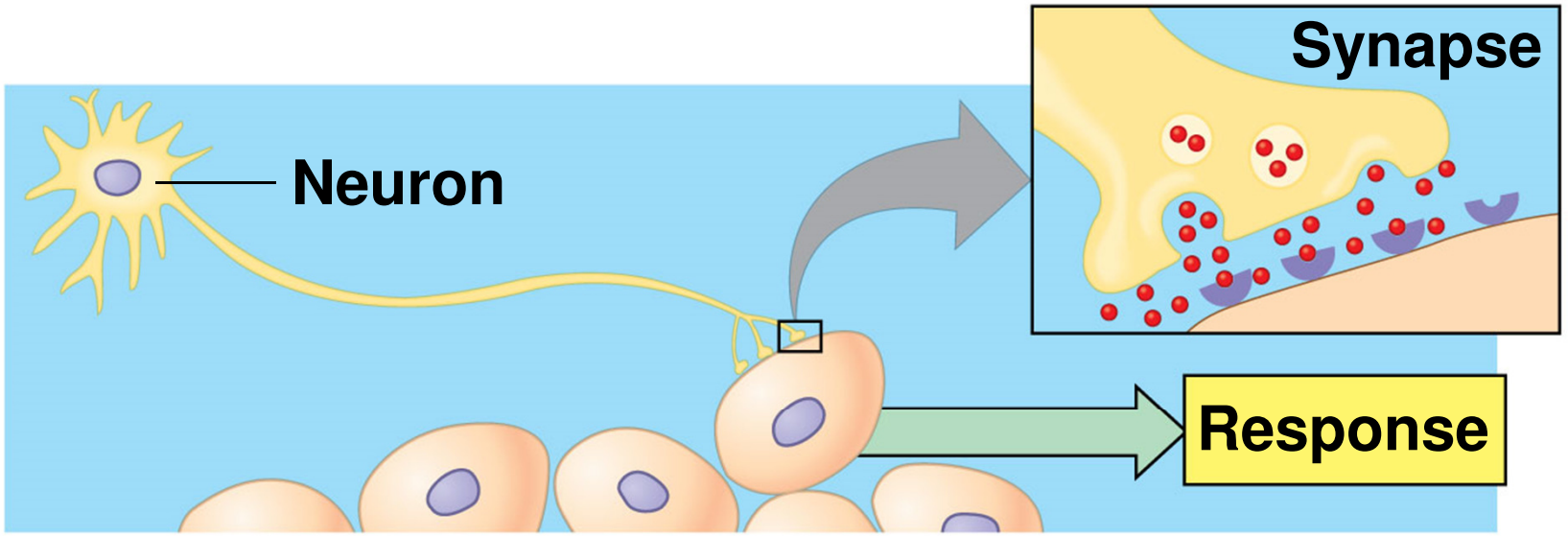


(c) Autocrine signaling

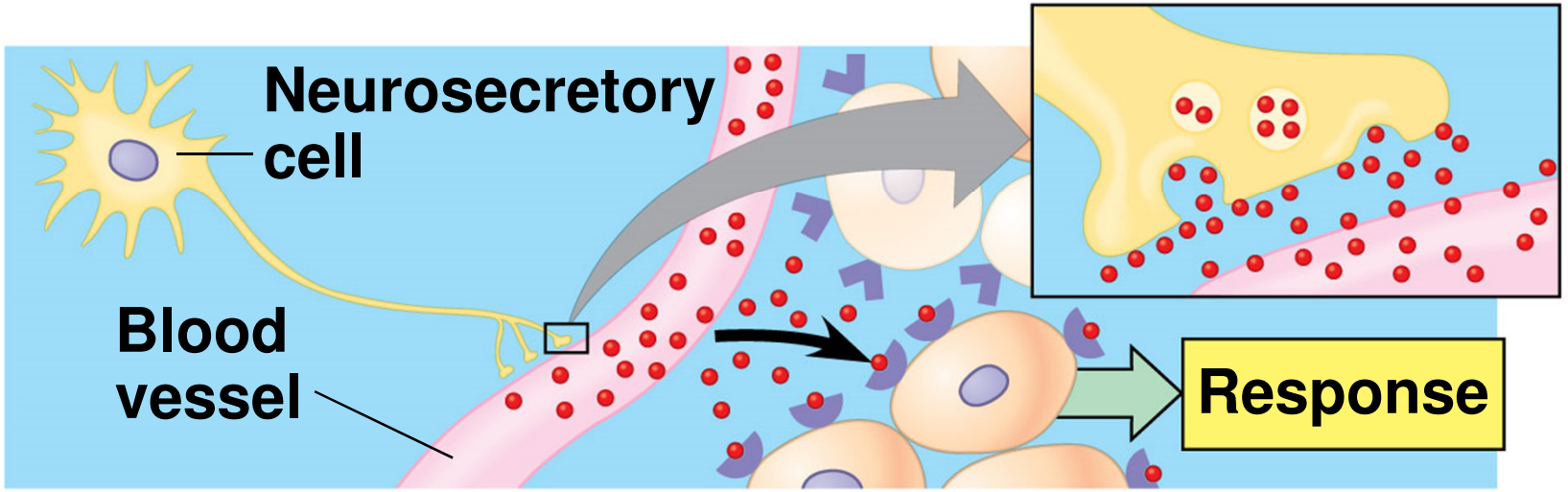
Synaptic and Neuroendocrine Signaling

- In synaptic signaling, neurons form specialized junctions with target cells, called synapses
- At synapses, neurons secrete molecules called **neurotransmitters** that diffuse short distances and bind to receptors on target cells
- In neuroendocrine signaling, specialized neurosecretory cells secrete molecules called **neurohormones** that travel to target cells via the bloodstream

Figure 45.2b



(d) Synaptic signaling



(e) Neuroendocrine signaling

Signaling by Pheromones

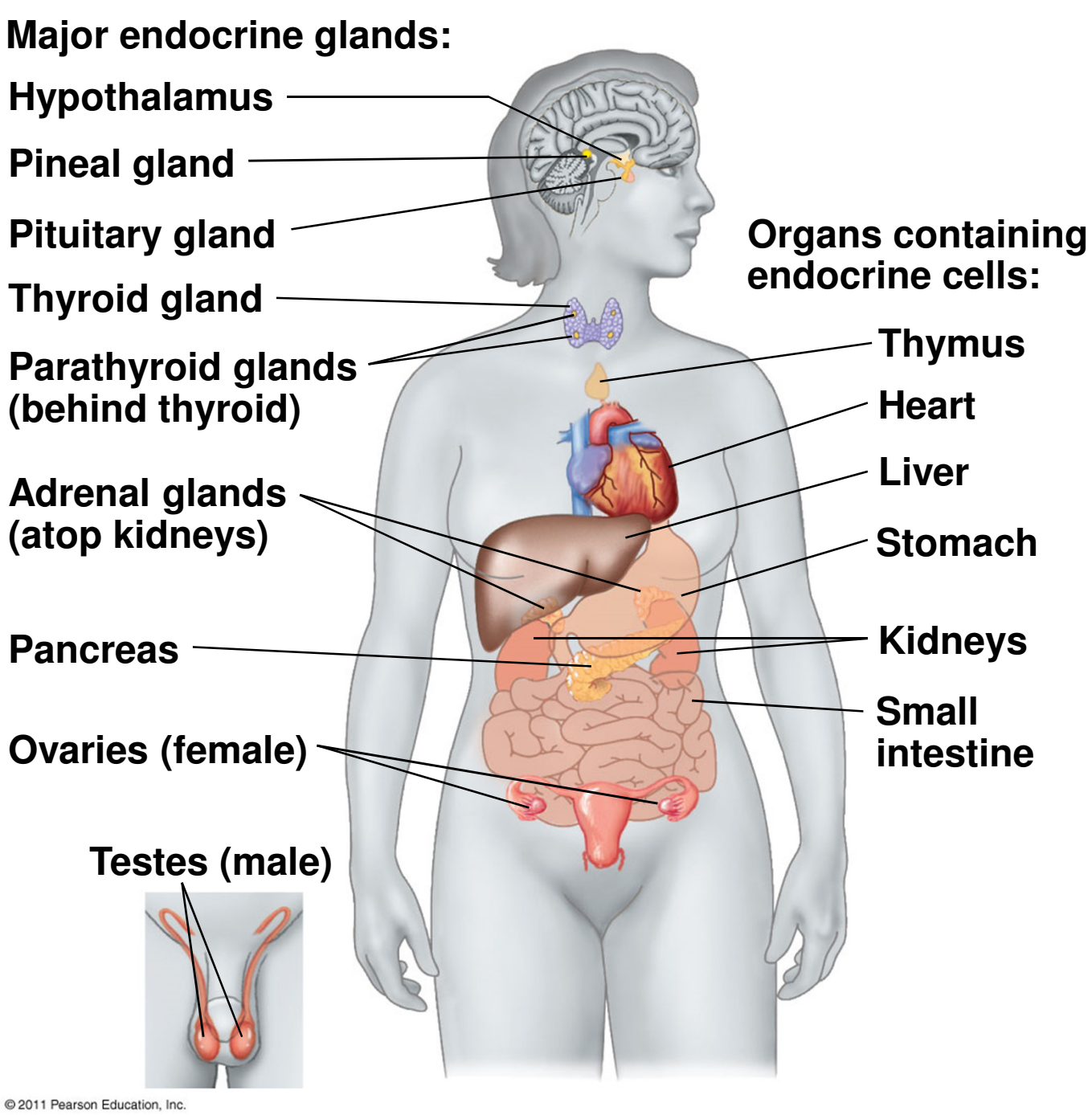
- Members of the same animal species sometimes communicate with **pheromones**, chemicals that are released into the environment
- Pheromones serve many functions, including marking trails leading to food, defining territories, warning of predators, and attracting potential mates

Figure 45.3

Endocrine Tissues and Organs

- In some tissues, endocrine cells are grouped together in ductless organs called **endocrine glands**
- Endocrine glands secrete hormones directly into surrounding fluid
- These contrast with exocrine glands, which have ducts and which secrete substances onto body surfaces or into cavities

Figure 45.4

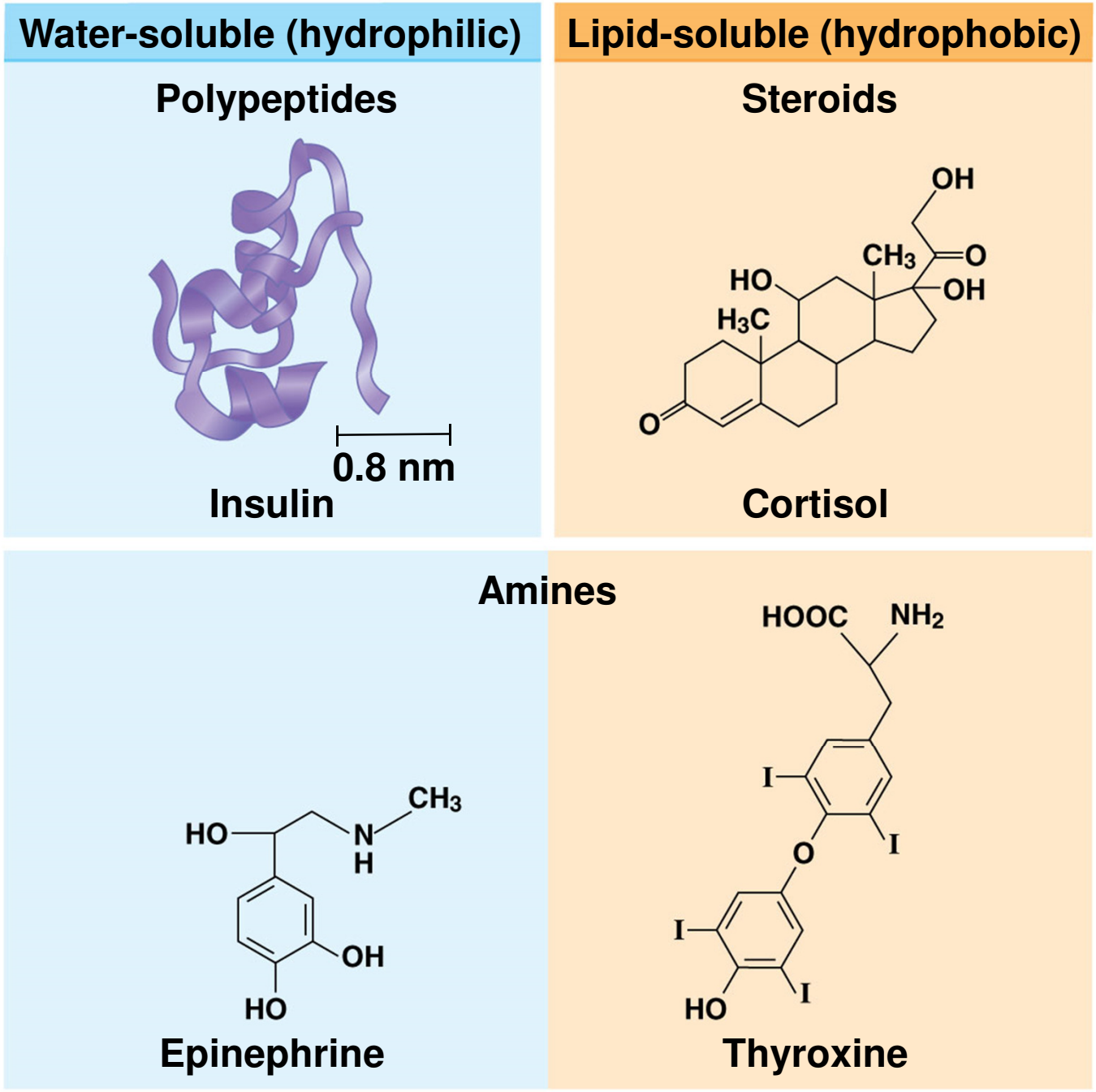


Chemical Classes of Hormones

- Three major classes of molecules function as hormones in vertebrates
  - Polypeptides (proteins and peptides)
  - Amines derived from amino acids
  - Steroid hormones

- Lipid-soluble hormones (steroid hormones) pass easily through cell membranes, while water-soluble hormones (polypeptides and amines) do not
- The solubility of a hormone correlates with the location of receptors inside or on the surface of target cells

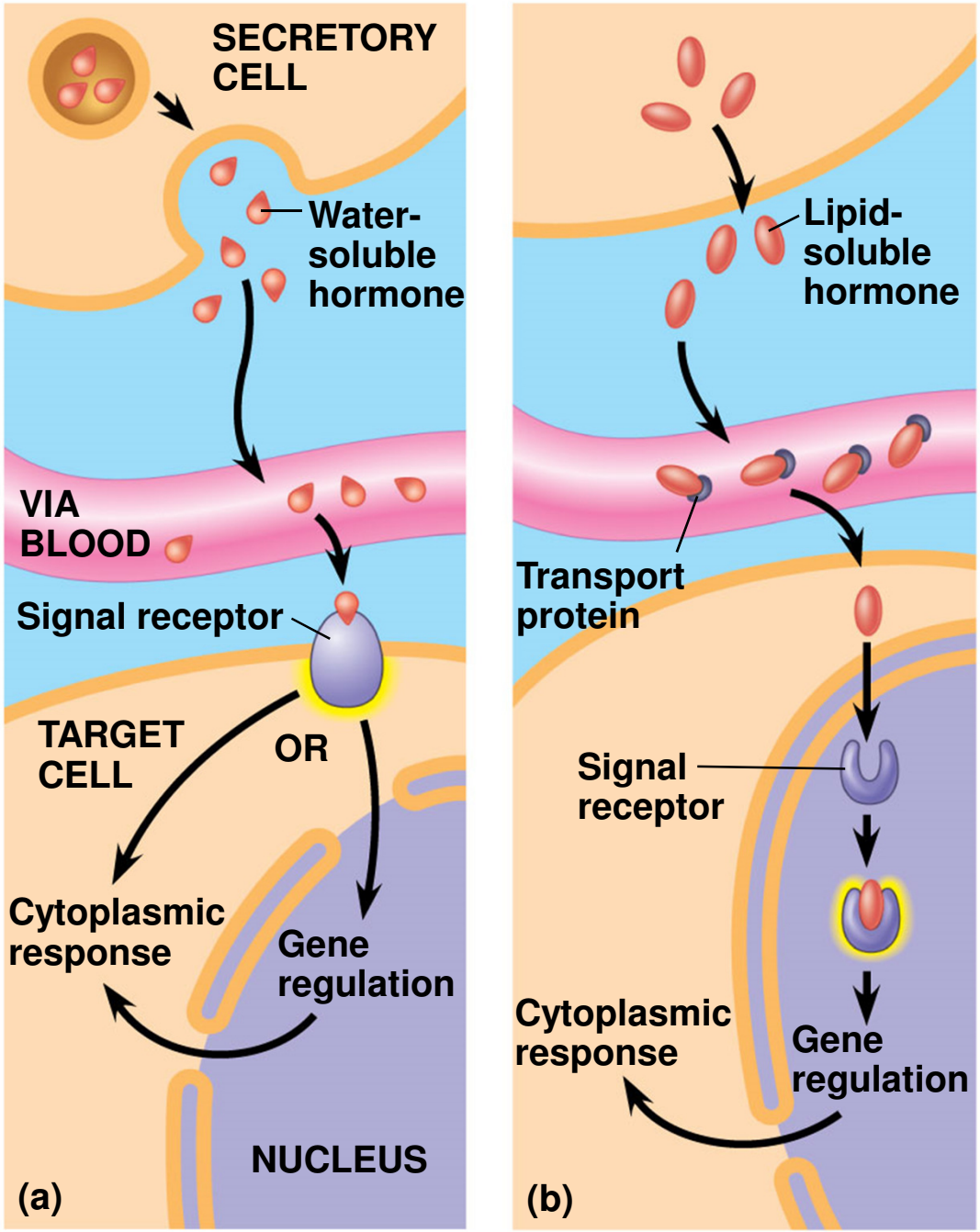
Figure 45.5



Cellular Response Pathways

- Water- and lipid-soluble hormones differ in their paths through a body
- Water-soluble hormones are secreted by exocytosis, travel freely in the bloodstream, and bind to cell-surface receptors
- Lipid-soluble hormones diffuse across cell membranes, travel in the bloodstream bound to transport proteins, and diffuse through the membrane of target cells

Figure 45.6-2

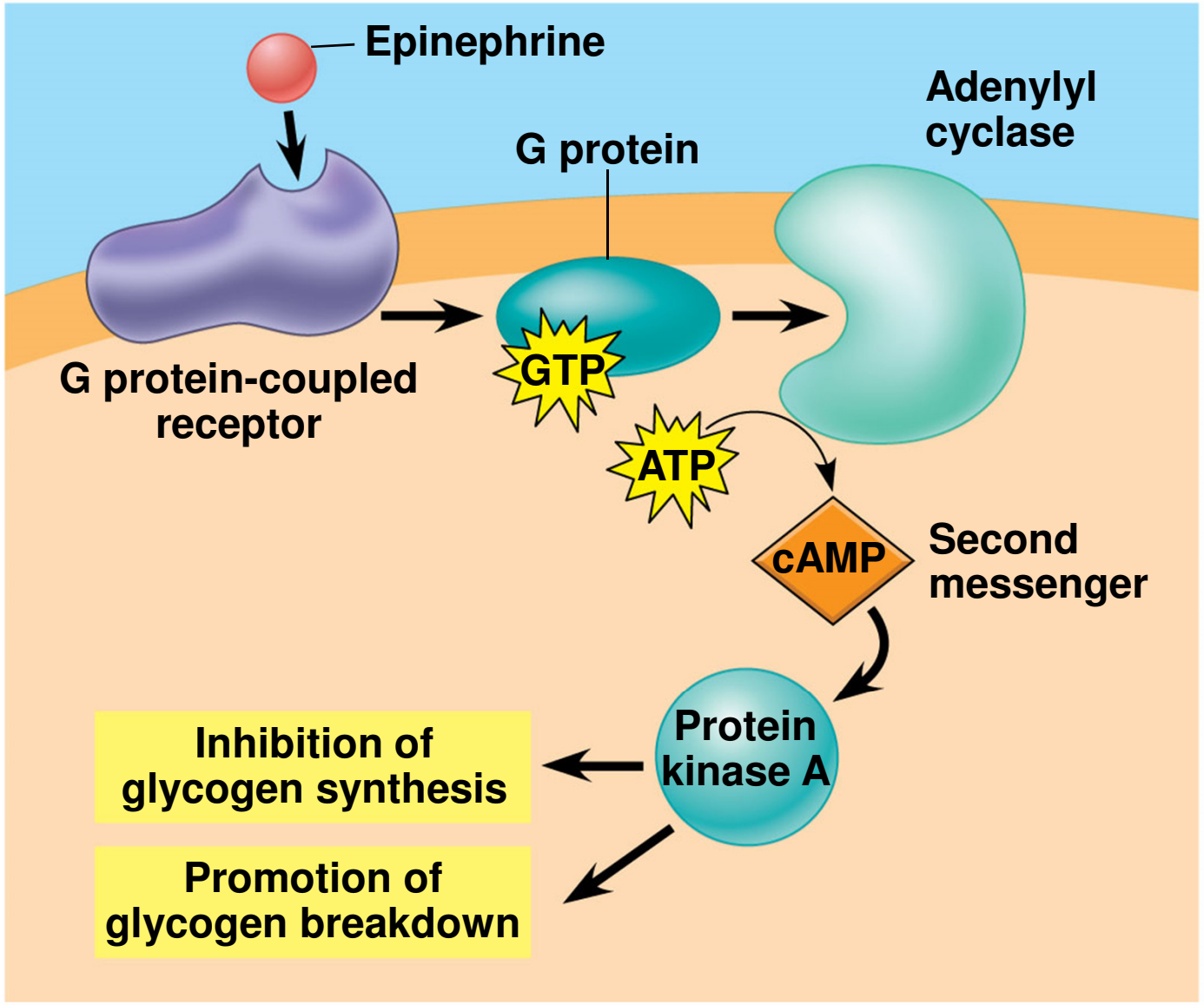


Pathway for Water-Soluble Hormones

- Binding of a hormone to its receptor initiates a **signal transduction** pathway leading to responses in the cytoplasm, enzyme activation, or a change in gene expression

- The hormone **epinephrine** has multiple effects in mediating the body's response to short-term stress
- Epinephrine binds to receptors on the plasma membrane of liver cells
- This triggers the release of messenger molecules that activate enzymes and result in the release of glucose into the bloodstream

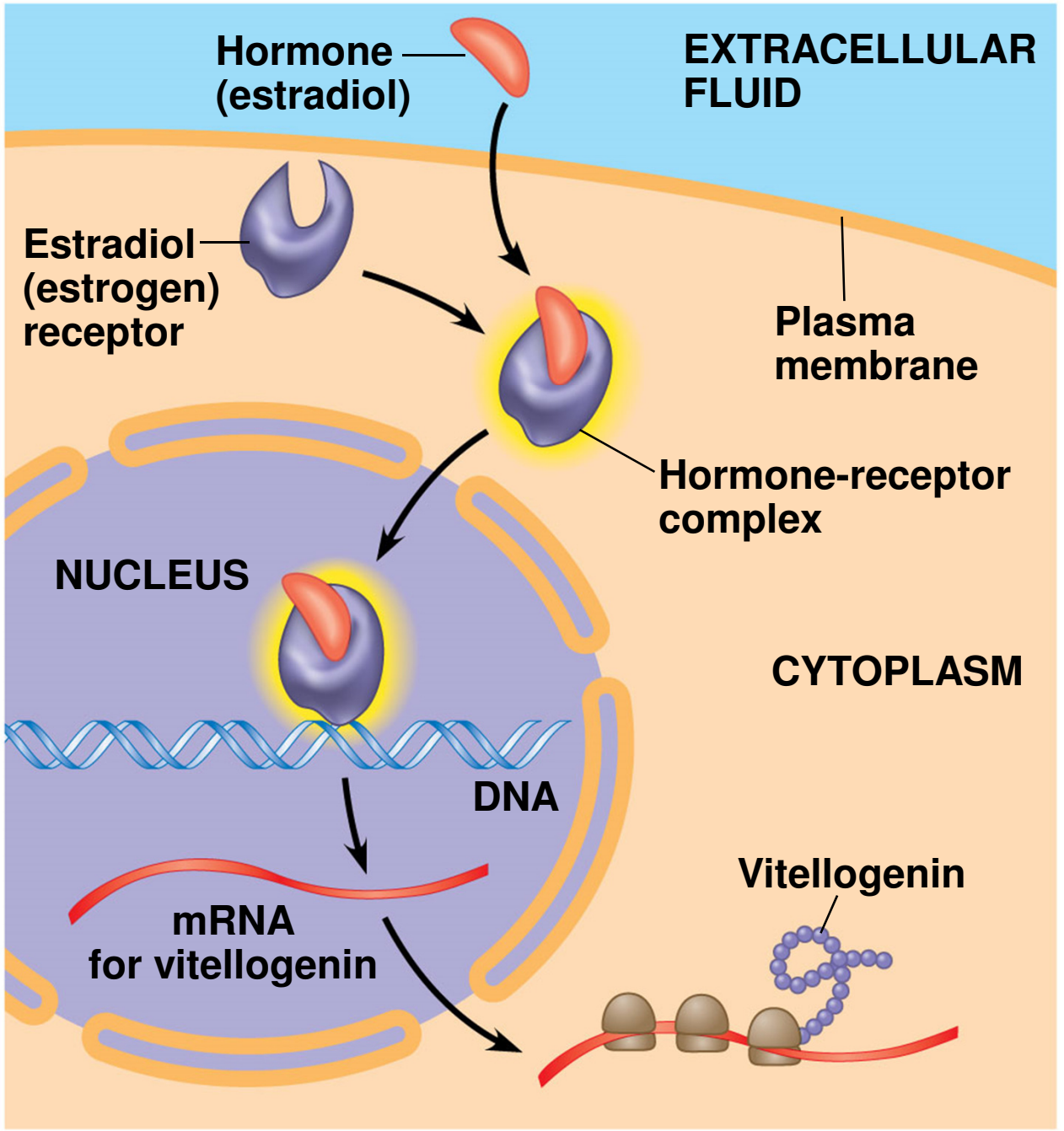
Figure 45.7-2



Pathway for Lipid-Soluble Hormones

- The response to a lipid-soluble hormone is usually a change in gene expression
- Steroids, thyroid hormones, and the hormonal form of vitamin D enter target cells and bind to protein receptors in the cytoplasm or nucleus
- Protein-receptor complexes then act as transcription factors in the nucleus, regulating transcription of specific genes

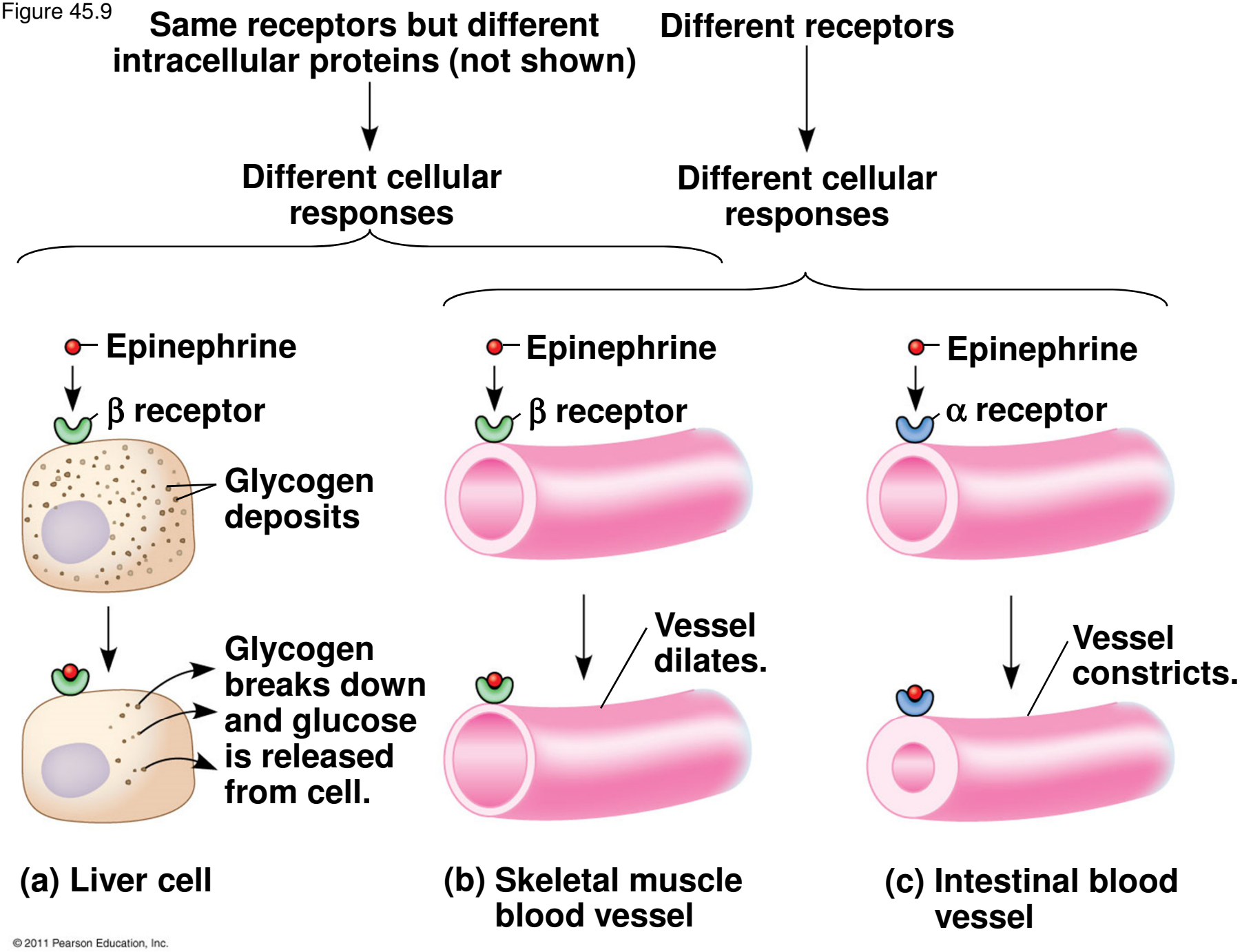
Figure 45.8-2



Multiple Effects of Hormones

- The same hormone may have different effects on target cells that have
  - Different receptors for the hormone
  - Different signal transduction pathways

Figure 45.9



Signaling by Local Regulators

- Local regulators are secreted molecules that link neighboring cells or directly regulate the secreting cell
- Types of local regulators
  - **Cytokines** and **growth factors**
  - **Nitric oxide (NO)**
  - **Prostaglandins**

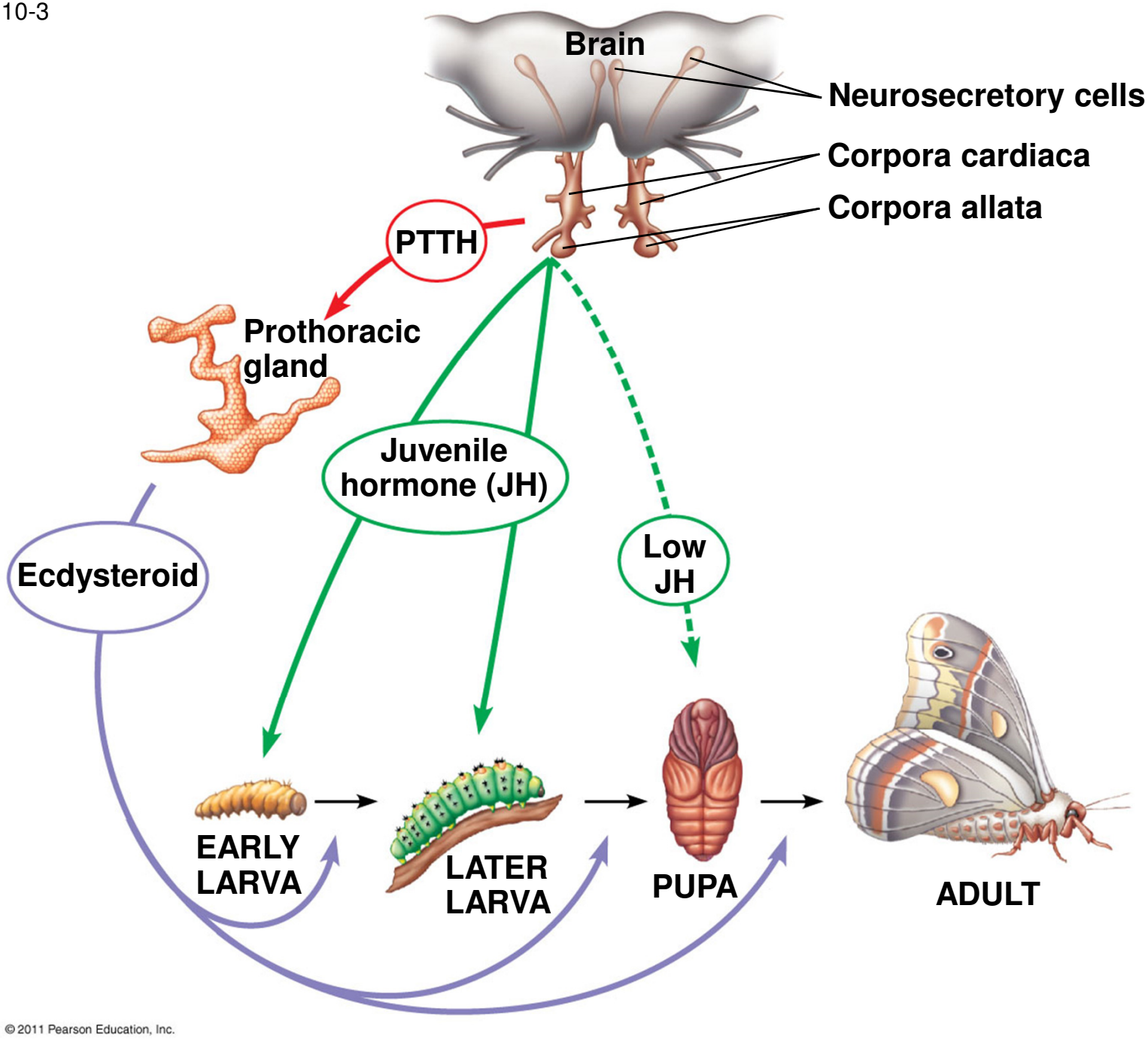
- In the immune system, prostaglandins promote fever and inflammation and intensify the sensation of pain
- Prostaglandins help regulate aggregation of platelets, an early step in formation of blood clots

Coordination of Neuroendocrine and Endocrine Signaling

- The endocrine and nervous systems generally act coordinately to control reproduction and development
- For example, in larvae of butterflies and moths, the signals that direct molting originate in the brain

- In insects, molting and development are controlled by a combination of hormones
  - A brain hormone (PTTH) stimulates release of ecdysteroid from the prothoracic glands
  - Juvenile hormone promotes retention of larval characteristics
  - Ecdysone promotes molting (in the presence of juvenile hormone) and development (in the absence of juvenile hormone) of adult characteristics

Figure 45.10-3



Concept 45.2: Feedback regulation and antagonistic hormone pairs are common in endocrine systems

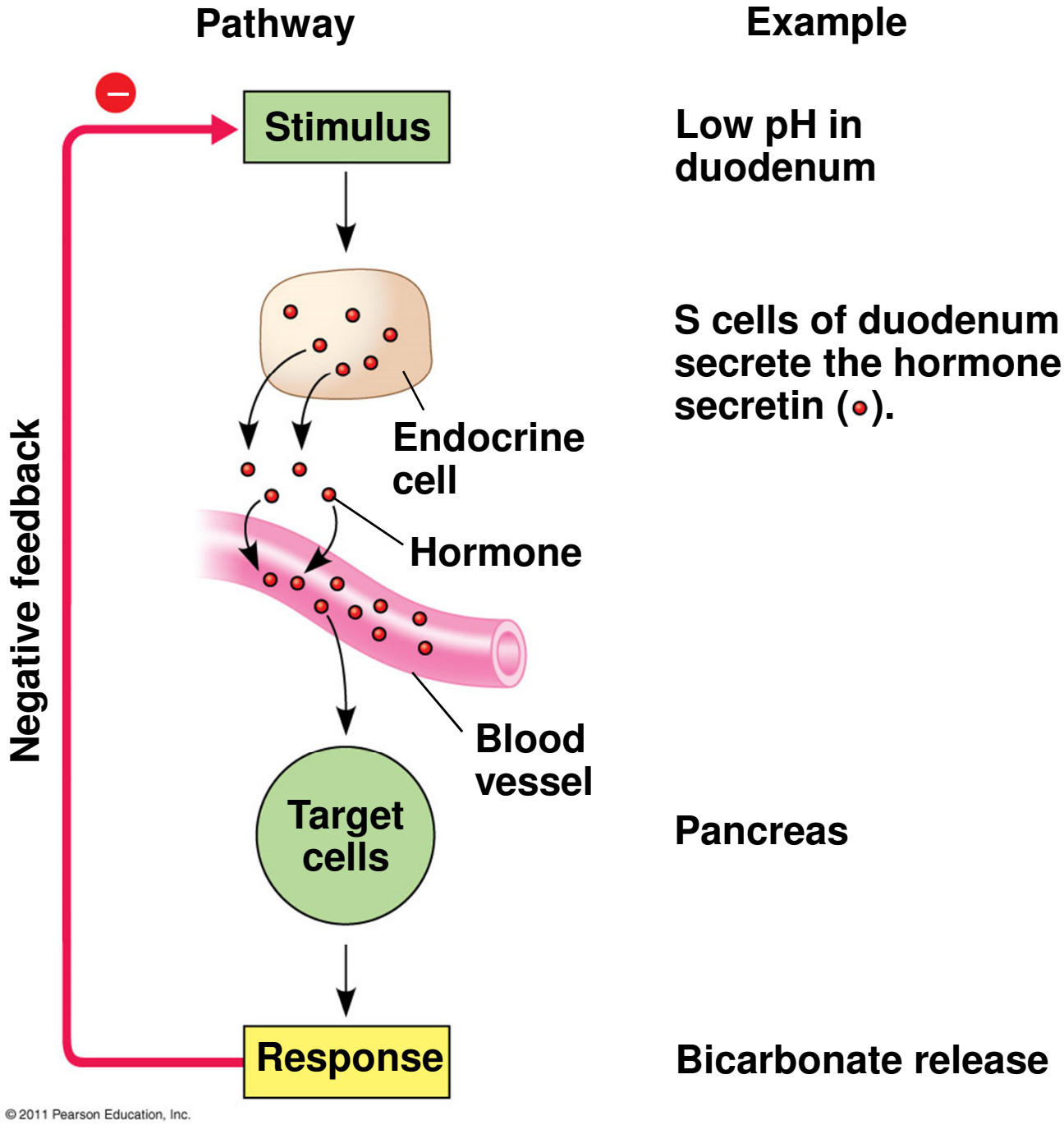
- Hormones are assembled into regulatory pathways

Simple Hormone Pathways

- Hormones are released from an endocrine cell, travel through the bloodstream, and interact with specific receptors within a target cell to cause a physiological response

- For example, the release of acidic contents of the stomach into the duodenum stimulates endocrine cells there to secrete secretin
- This causes target cells in the **pancreas**, a gland behind the stomach, to raise the pH in the duodenum

Figure 45.11


Pathway
Example
Stimulus
Low pH in duodenum
S cells of duodenum secrete the hormone secretin (•).
Endocrine cell
Hormone
Blood vessel
Target cells
Pancreas
Response
Bicarbonate release
Negative feedback
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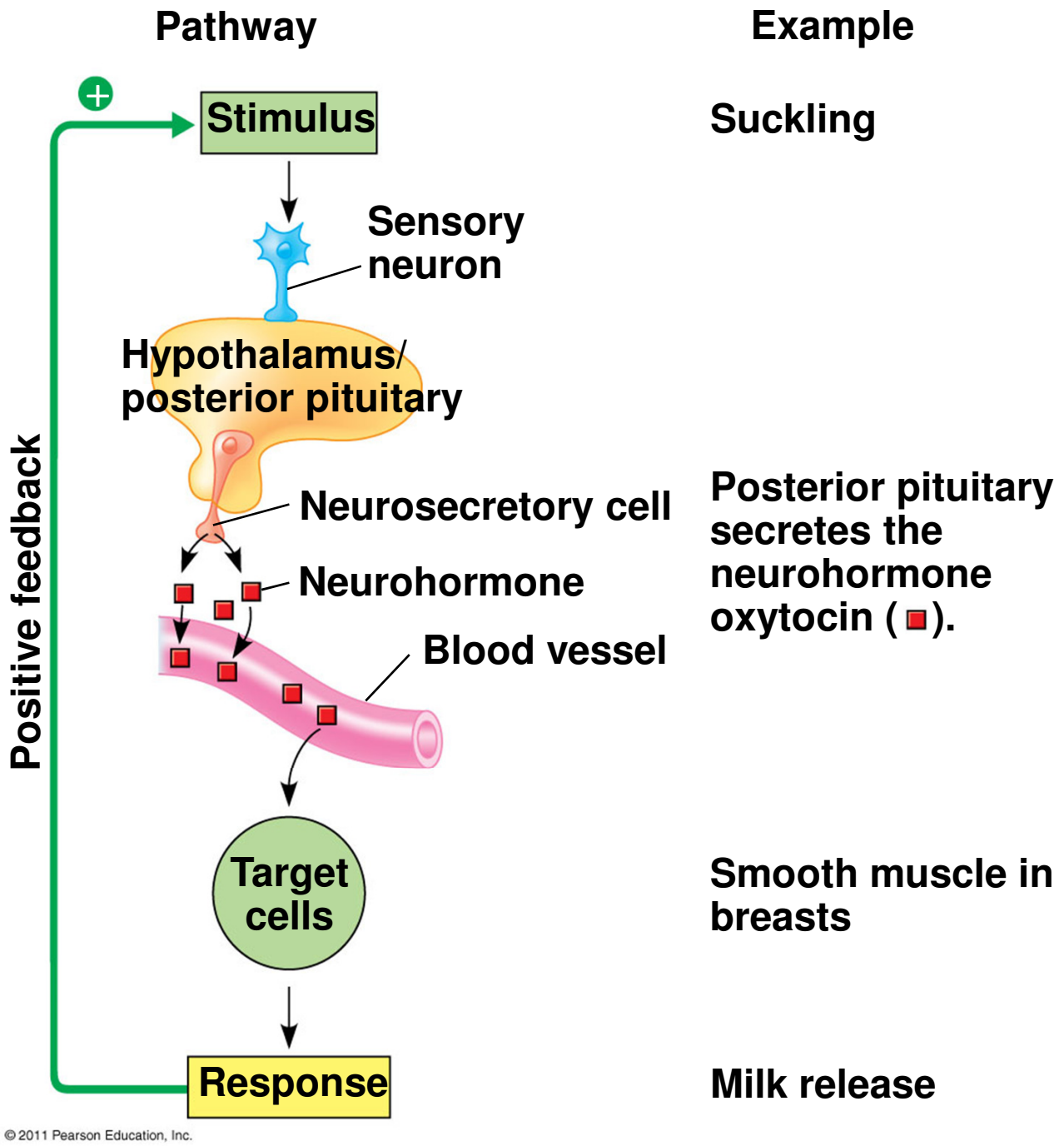
- In a simple neuroendocrine pathway, the stimulus is received by a sensory neuron, which stimulates a neurosecretory cell
- The neurosecretory cell secretes a neurohormone, which enters the bloodstream and travels to target cells

Figure 45.12



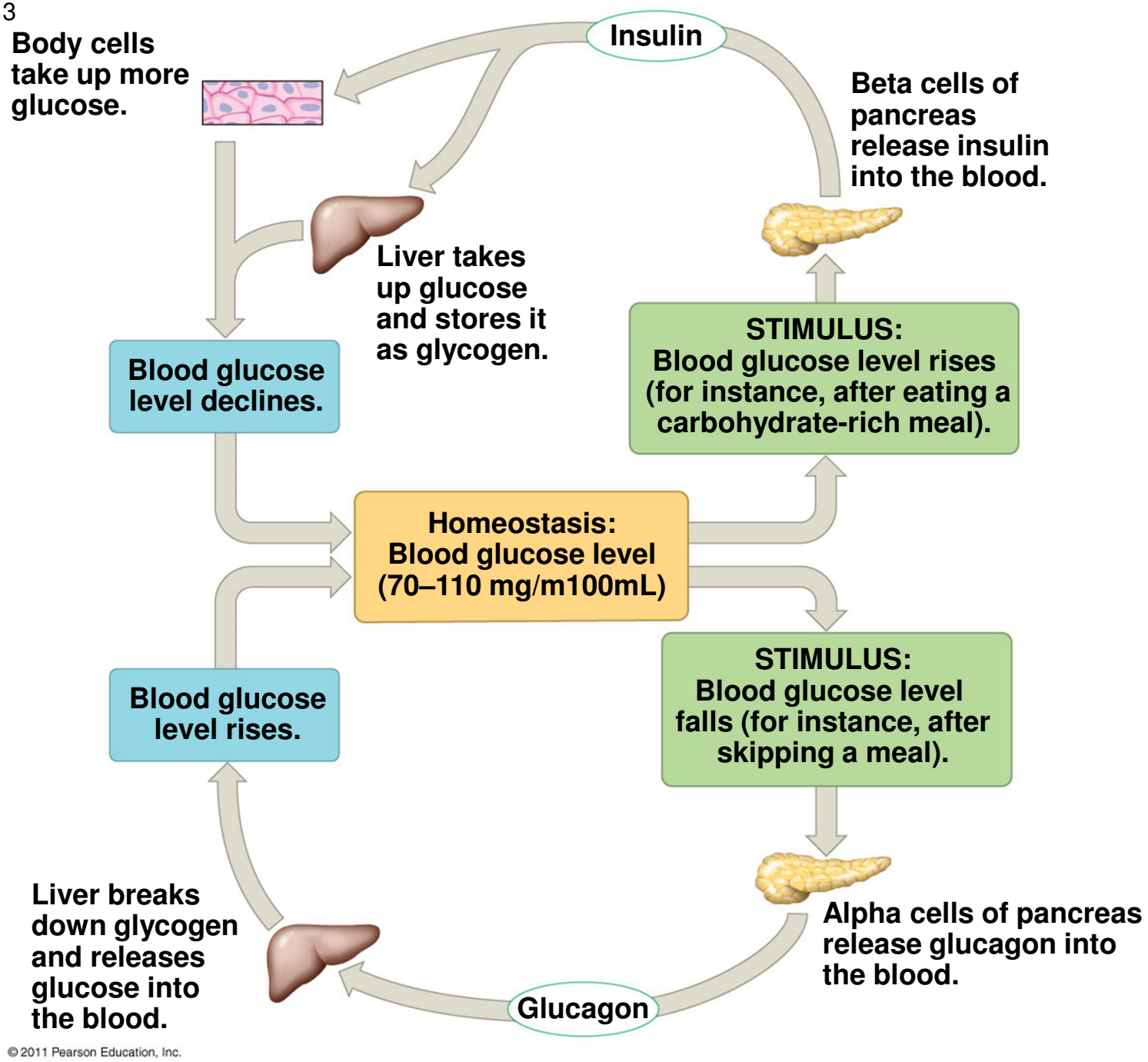
Feedback Regulation

- A **negative feedback** loop inhibits a response by reducing the initial stimulus, thus preventing excessive pathway activity
- **Positive feedback** reinforces a stimulus to produce an even greater response
- For example, in mammals oxytocin causes the release of milk, causing greater suckling by offspring, which stimulates the release of more oxytocin

Insulin and Glucagon: Control of Blood Glucose

- **Insulin** (decreases blood glucose) and **glucagon** (increases blood glucose) are antagonistic hormones that help maintain glucose homeostasis
- The pancreas has clusters of endocrine cells called pancreatic islets with alpha cells that produce glucagon and beta cells that produce insulin

Figure 45.13



Target Tissues for Insulin and Glucagon

- Insulin reduces blood glucose levels by
  - Promoting the cellular uptake of glucose
  - Slowing glycogen breakdown in the liver
  - Promoting fat storage, not breakdown

- Glucagon increases blood glucose levels by
  - Stimulating conversion of glycogen to glucose in the liver
  - Stimulating breakdown of fat and protein into glucose

Diabetes Mellitus

- **Diabetes mellitus** is perhaps the best-known endocrine disorder
- It is caused by a deficiency of insulin or a decreased response to insulin in target tissues
- It is marked by elevated blood glucose levels

- *Type 1 diabetes mellitus* (insulin-dependent) is an autoimmune disorder in which the immune system destroys pancreatic beta cells
- *Type 2 diabetes mellitus* (non-insulin-dependent) involves insulin deficiency or reduced response of target cells due to change in insulin receptors

Concept 45.3: The hypothalamus and pituitary are central to endocrine regulation

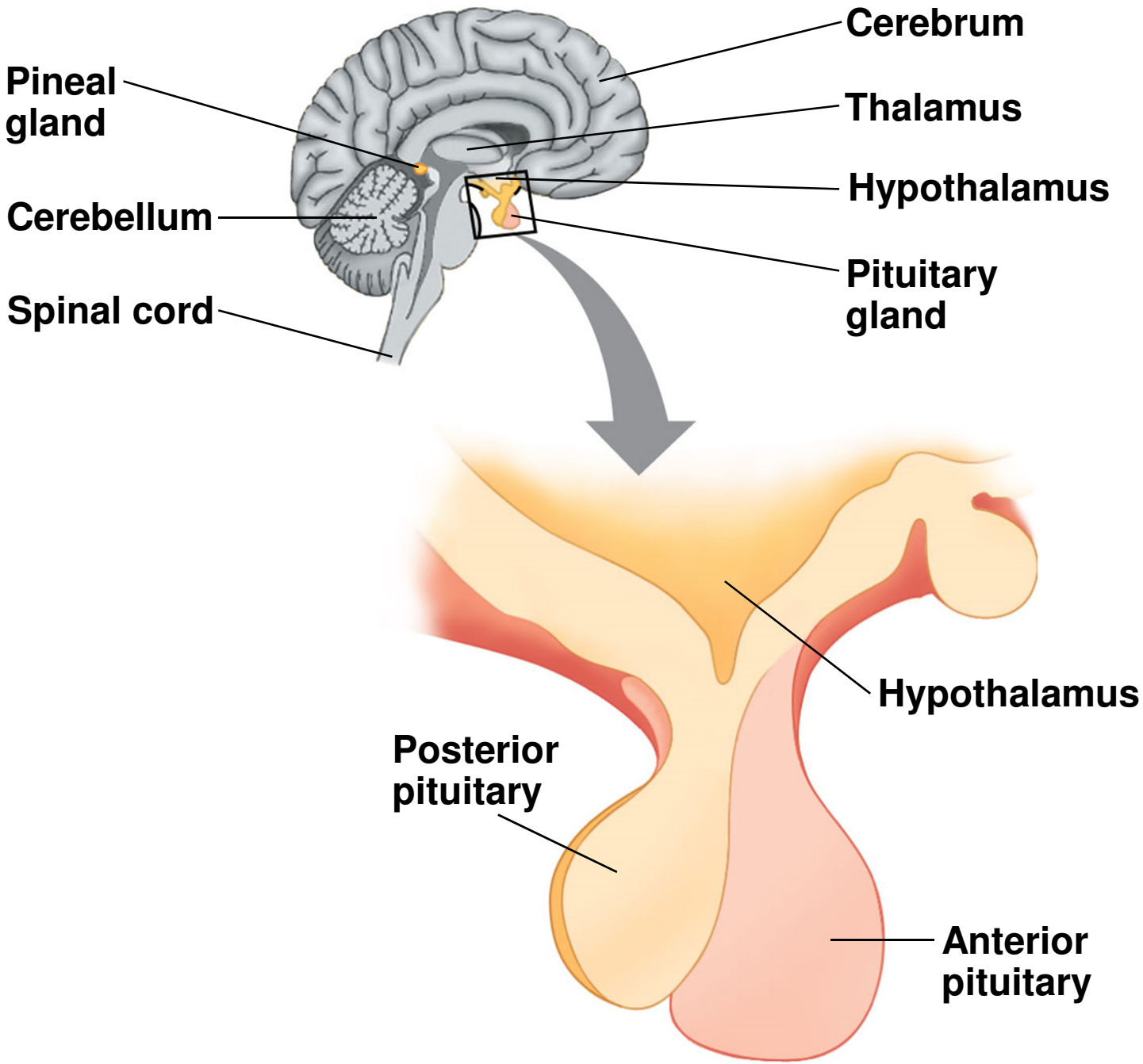
- Endocrine pathways are subject to regulation by the nervous system, including the brain

Coordination of Endocrine and Nervous Systems in Vertebrates

- The **hypothalamus** receives information from the nervous system and initiates responses through the endocrine system
- Attached to the hypothalamus is the **pituitary gland,** composed of the posterior pituitary and anterior pituitary

- The **posterior pituitary** stores and secretes hormones that are made in the hypothalamus
- The **anterior pituitary** makes and releases hormones under regulation of the hypothalamus

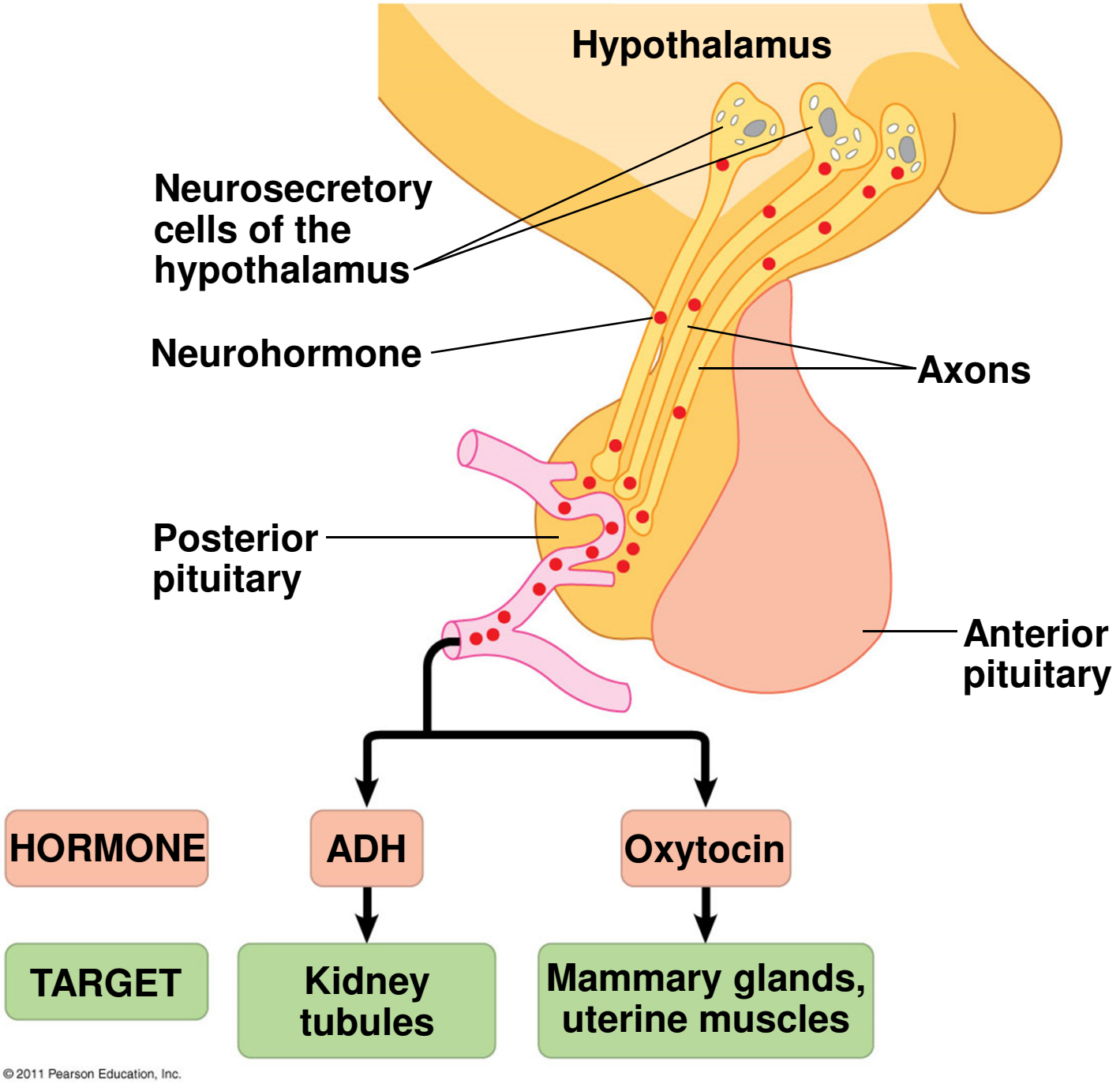
Figure 45.14



Posterior Pituitary Hormones

- The two hormones released from the posterior pituitary act directly on nonendocrine tissues
  - Oxytocin regulates milk secretion by the mammary glands
  - **Antidiuretic hormone (ADH)** regulates physiology and behavior

Figure 45.15



Anterior Pituitary Hormones

- Hormone production in the anterior pituitary is controlled by releasing and inhibiting hormones from the hypothalamus
- For example, prolactin-releasing hormone from the hypothalamus stimulates the anterior pituitary to secrete **prolactin** (**PRL**), which has a role in milk production

Figure 45.16

Tropic effects only:
FSH
LH
TSH
ACTH

Nontropic effects only:
Prolactin
MSH

Nontropic and tropic effects:
GH

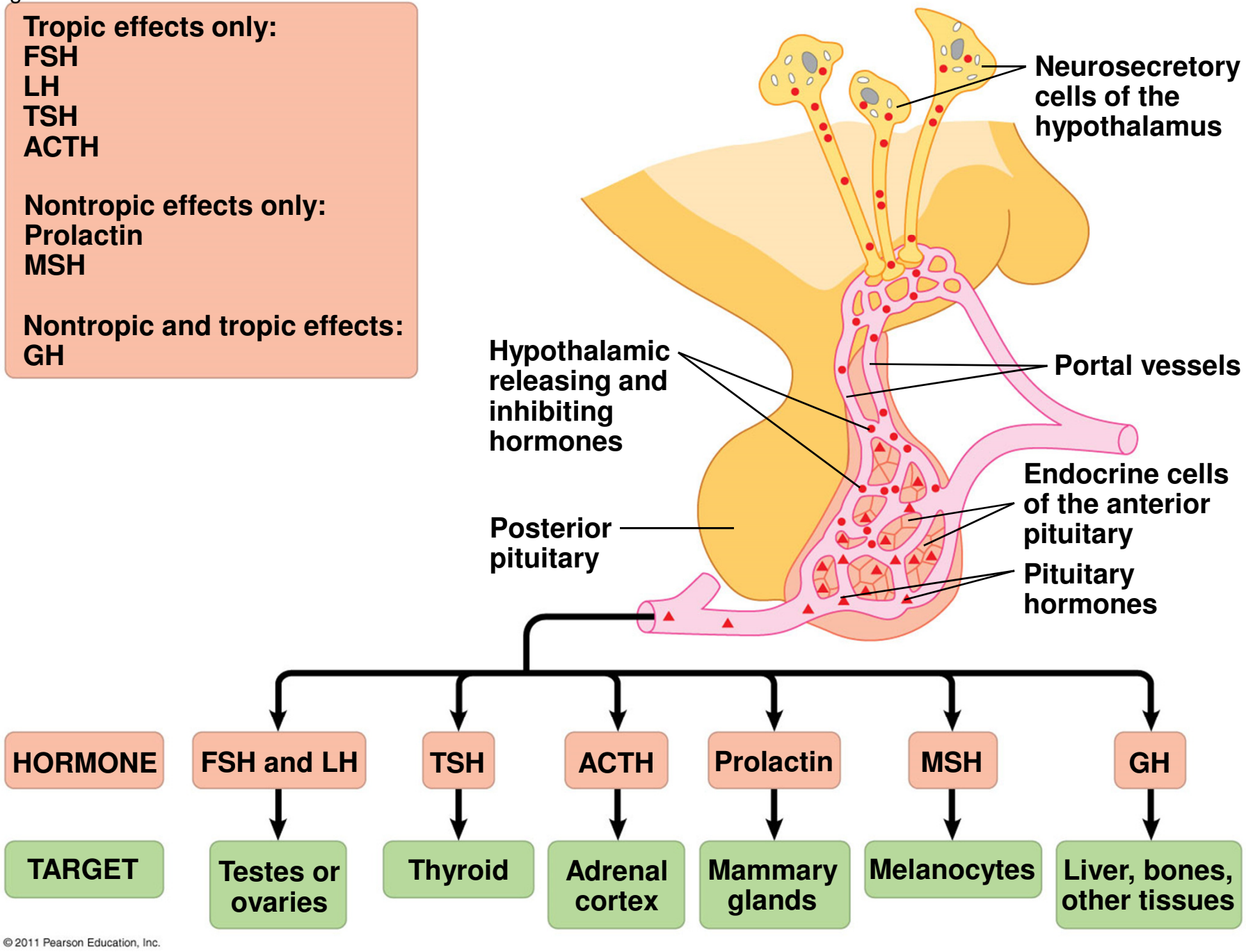


Table 45.1

Table 45.1 Major Human Endocrine Glands and Some of Their Hormones

Gland	Hormone	Chemical Class	Representative Actions	Regulated By
Hypothalamus 	Hormones released from the posterior pituitary and hormones that regulate the anterior pituitary (see below)			
Posterior pituitary gland (releases neurohormones made in hypothalamus) 	Oxytocin	Peptide	Stimulates contraction of uterus and mammary gland cells	Nervous system
	Antidiuretic hormone (ADH)	Peptide	Promotes retention of water by kidneys	Water/salt balance
Anterior pituitary gland 	Growth hormone (GH)	Protein	Stimulates growth (especially bones) and metabolic functions	Hypothalamic hormones
	Prolactin	Protein	Stimulates milk production and secretion	Hypothalamic hormones
	Follicle-stimulating hormone (FSH)	Glycoprotein	Stimulates production of ova and sperm	Hypothalamic hormones
	Luteinizing hormone (LH)	Glycoprotein	Stimulates ovaries and testes	Hypothalamic hormones
	Thyroid-stimulating hormone (TSH)	Glycoprotein	Stimulates thyroid gland	Hypothalamic hormones
	Adrenocorticotropic hormone (ACTH)	Peptide	Stimulates adrenal cortex to secrete glucocorticoids	Hypothalamic hormones
Thyroid gland 	Triiodothyronine (T_3) and thyroxine (T_4)	Amines	Stimulate and maintain metabolic processes	TSH
	Calcitonin	Peptide	Lowers blood calcium level	Calcium in blood
Parathyroid glands 	Parathyroid hormone (PTH)	Peptide	Raises blood calcium level	Calcium in blood
Pancreas 	Insulin	Protein	Lowers blood glucose level	Glucose in blood
	Glucagon	Protein	Raises blood glucose level	Glucose in blood
Adrenal glands				
Adrenal medulla 	Epinephrine and norepinephrine	Amines	Raise blood glucose level; increase metabolic activities; constrict certain blood vessels	Nervous system
Adrenal cortex	Glucocorticoids	Steroids	Raise blood glucose level	ACTH
	Mineralocorticoids	Steroids	Promote reabsorption of Na^+ and excretion of K^+ in kidneys	K^+ in blood; angiotensin II
Gonads				
Testes 	Androgens	Steroids	Support sperm formation; promote development and maintenance of male secondary sex characteristics	FSH and LH
Ovaries 	Estrogens	Steroids	Stimulate uterine lining growth; promote development and maintenance of female secondary sex characteristics	FSH and LH
	Progestins	Steroids	Promote uterine lining growth	FSH and LH
Pineal gland 	Melatonin	Amine	Involved in biological rhythms	Light/dark cycles

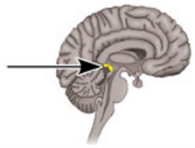
Table 45.1a

Table 45.1 Major Human Endocrine Glands and Some of Their Hormones

Gland		Hormone	Chemical Class	Representative Actions	Regulated By
Hypothalamus		Hormones released from the posterior pituitary and hormones that regulate the anterior pituitary (see below)			
Posterior pituitary gland (releases neurohormones made in hypothalamus)		Oxytocin	Peptide	Stimulates contraction of uterus and mammary gland cells	Nervous system
		Antidiuretic hormone (ADH)	Peptide	Promotes retention of water by kidneys	Water/salt balance
Anterior pituitary gland		Growth hormone (GH)	Protein	Stimulates growth (especially bones) and metabolic functions	Hypothalamic hormones
		Prolactin	Protein	Stimulates milk production and secretion	Hypothalamic hormones
		Follicle-stimulating hormone (FSH)	Glycoprotein	Stimulates production of ova and sperm	Hypothalamic hormones
		Luteinizing hormone (LH)	Glycoprotein	Stimulates ovaries and testes	Hypothalamic hormones
		Thyroid-stimulating hormone (TSH)	Glycoprotein	Stimulates thyroid gland	Hypothalamic hormones
		Adrenocorticotropic hormone (ACTH)	Peptide	Stimulates adrenal cortex to secrete glucocorticoids	Hypothalamic hormones
Thyroid gland		Triiodothyronine (T_3) and thyroxine (T_4)	Amines	Stimulate and maintain metabolic processes	TSH
		Calcitonin	Peptide	Lowers blood calcium level	Calcium in blood
Parathyroid glands		Parathyroid hormone (PTH)	Peptide	Raises blood calcium level	Calcium in blood

Table 45.1b

Table 45.1 Major Human Endocrine Glands and Some of Their Hormones (continued)

Gland		Hormone	Chemical Class	Representative Actions	Regulated By
Pancreas		Insulin	Protein	Lowers blood glucose level	Glucose in blood
		Glucagon	Protein	Raises blood glucose level	Glucose in blood
Adrenal glands					
Adrenal medulla		Epinephrine and norepinephrine	Amines	Raise blood glucose level; increase metabolic activities; constrict certain blood vessels	Nervous system
Adrenal cortex		Glucocorticoids	Steroids	Raise blood glucose level	ACTH
		Mineralocorticoids	Steroids	Promote reabsorption of Na^+ and excretion of K^+ in kidneys	K^+ in blood; angiotensin II
Gonads					
Testes		Androgens	Steroids	Support sperm formation; promote development and maintenance of male secondary sex characteristics	FSH and LH
Ovaries		Estrogens	Steroids	Stimulate uterine lining growth; promote development and maintenance of female secondary sex characteristics	FSH and LH
		Progestins	Steroids	Promote uterine lining growth	FSH and LH
Pineal gland		Melatonin	Amine	Involved in biological rhythms	Light/dark cycles

Thyroid Regulation: A Hormone Cascade Pathway

- A hormone can stimulate the release of a series of other hormones, the last of which activates a nonendocrine target cell; this is called a hormone cascade pathway
- The release of thyroid hormone results from a hormone cascade pathway involving the hypothalamus, anterior pituitary, and thyroid gland
- Hormone cascade pathways typically involve negative feedback

Figure 45.17

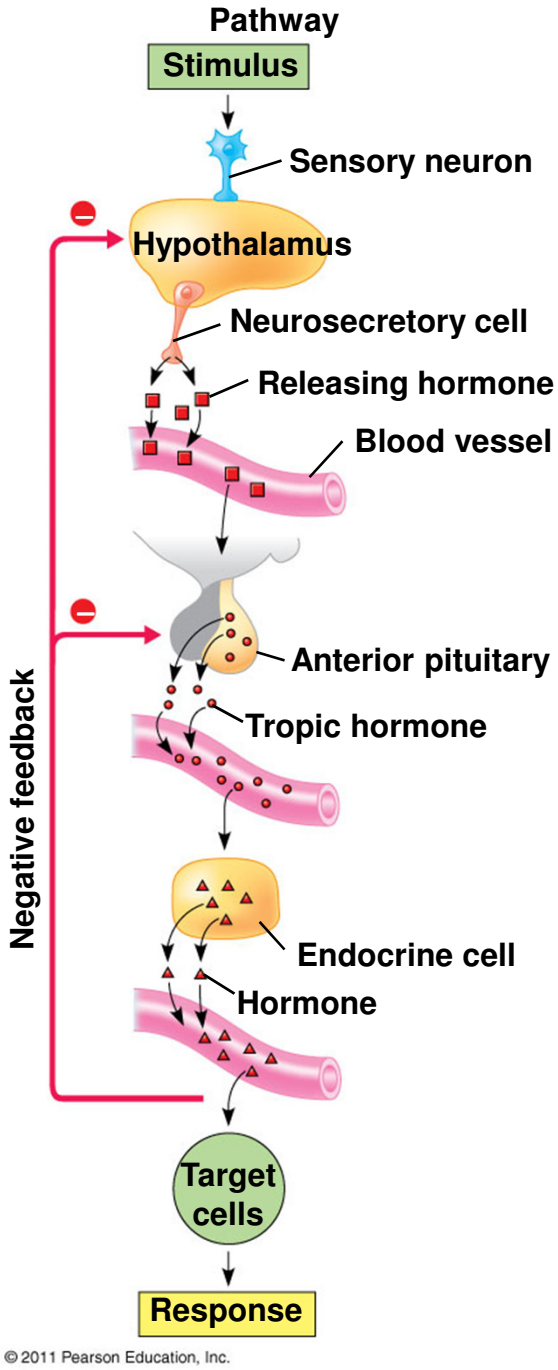

Pathway
Example
Stimulus
Cold
Sensory neuron
Hypothalamus
Hypothalamus secretes thyrotropin-releasing hormone (TRH ■).
Neurosecretory cell
Releasing hormone
Blood vessel
Anterior pituitary
Anterior pituitary secretes thyroid-stimulating hormone (TSH, also known as thyrotropin ●).
Tropic hormone
Endocrine cell
Thyroid gland secretes thyroid hormone (T_3 and T_4 ▲).
Hormone
Negative feedback
Target cells
Body tissues
Response
Increased cellular metabolism
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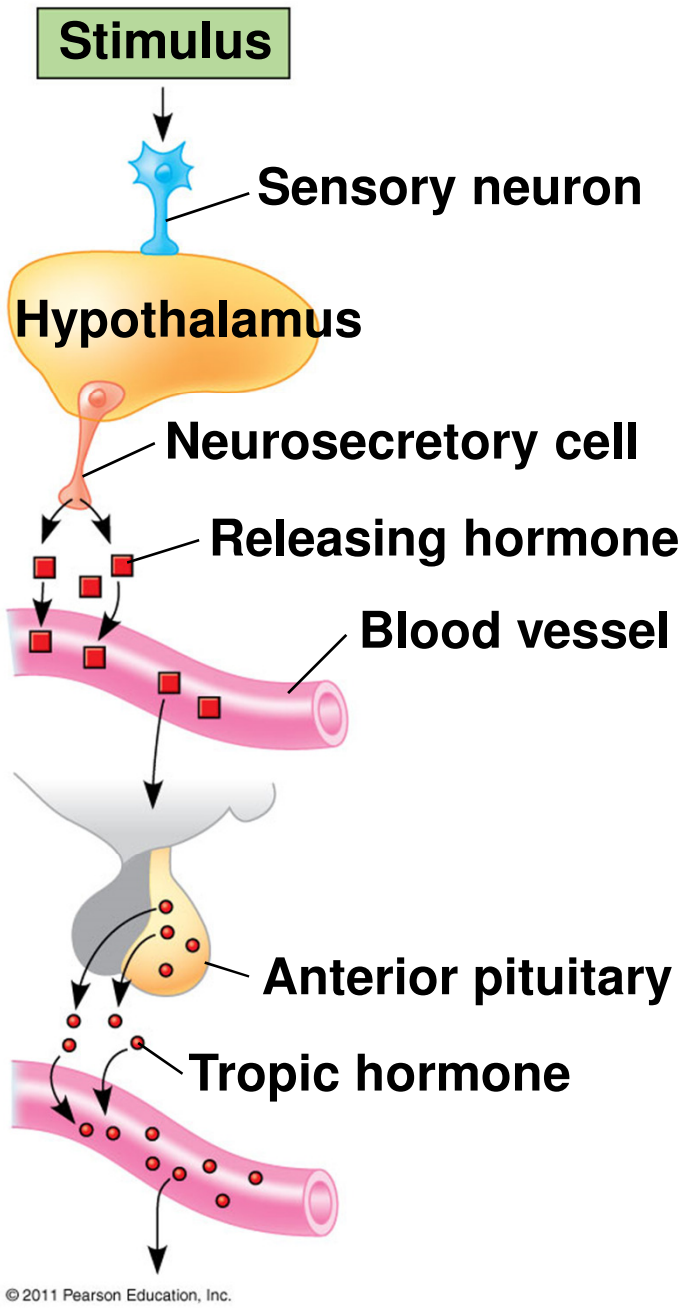
Figure 45.17a



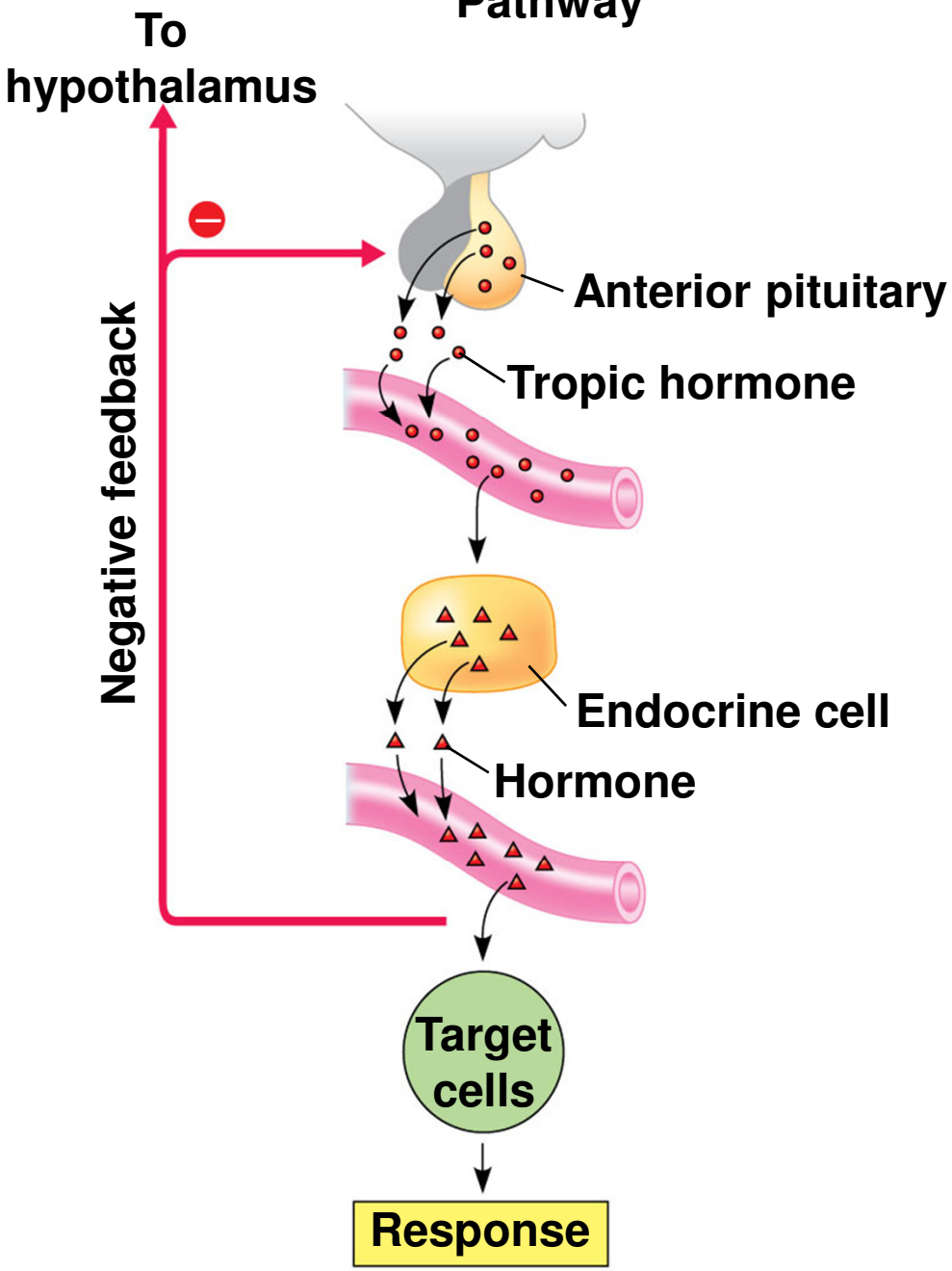
Example

Cold

Hypothalamus secretes thyrotropin-releasing hormone (TRH■).

Anterior pituitary secretes thyroid-stimulating hormone (TSH, also known as thyrotropin●).

Figure 45.17b



Example

Anterior pituitary secretes thyroid-stimulating hormone (TSH, also known as thyrotropin).

Thyroid gland secretes thyroid hormone (T_3 and T_4).

Body tissues

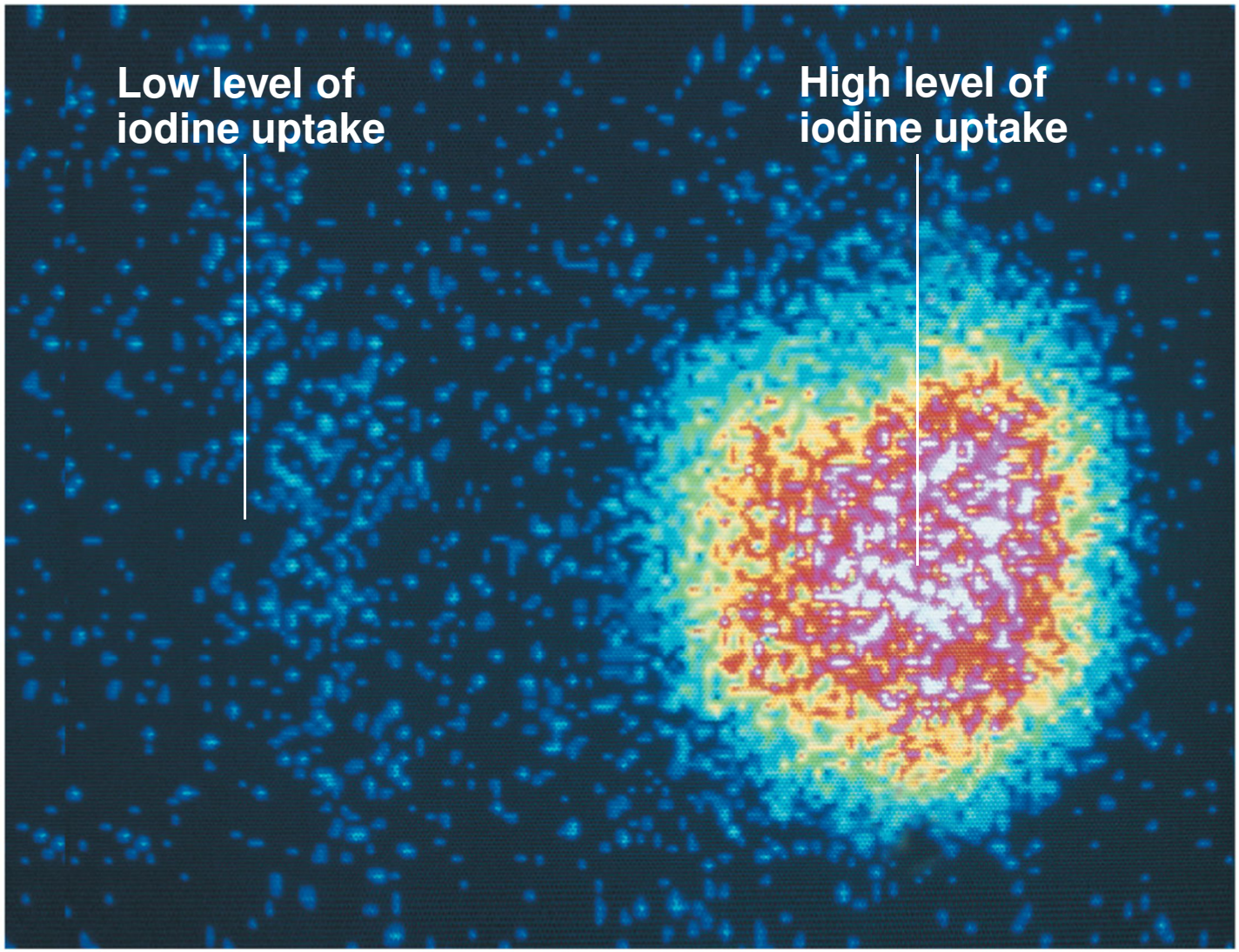
Increased cellular metabolism

Disorders of Thyroid Function and Regulation

- Hypothyroidism, too little thyroid function, can produce symptoms such as
  - Weight gain, lethargy, cold intolerance
- Hyperthyroidism, excessive production of thyroid hormone, can lead to
  - High temperature, sweating, weight loss, irritability, and high blood pressure
- Malnutrition can alter thyroid function

- Graves disease, a form of hyperthyroidism caused by autoimmunity, is typified by protruding eyes
- *Thyroid hormone* refers to a pair of hormones
  - **Triiodothyronin** ($\mathbf{T_3}$), with three iodine atoms
  - **Thyroxine** ($\mathbf{T_4}$), with four iodine atoms
- Insufficient dietary iodine leads to an enlarged thyroid gland, called a goiter

Figure 45.18



Evolution of Hormone Function

- Over the course of evolution the function of a given hormone may diverge between species
- For example, thyroid hormone plays a role in metabolism across many lineages, but in frogs has taken on a unique function: stimulating the resorption of the tadpole tail during metamorphosis
- Prolactin also has a broad range of activities in vertebrates

Figure 45.19

▲ Tadpole

▲ Adult frog

- **Melanocyte-stimulating hormone (MSH)** regulates skin color in amphibians, fish, and reptiles by controlling pigment distribution in melanocytes
- In mammals, MSH plays additional roles in hunger and metabolism in addition to coloration

Tropic and Nontropic Hormones

- A tropic hormone regulates the function of endocrine cells or glands
- Three primarily tropic hormones are
  - **Follicle-stimulating hormone (FSH)**
  - **Luteinizing hormone (LH)**
  - **Adrenocorticotropic hormone (ACTH)**

- **Growth hormone (GH)** is secreted by the anterior pituitary gland and has tropic and nontropic actions
- It promotes growth directly and has diverse metabolic effects
- It stimulates production of growth factors
- An excess of GH can cause gigantism, while a lack of GH can cause dwarfism

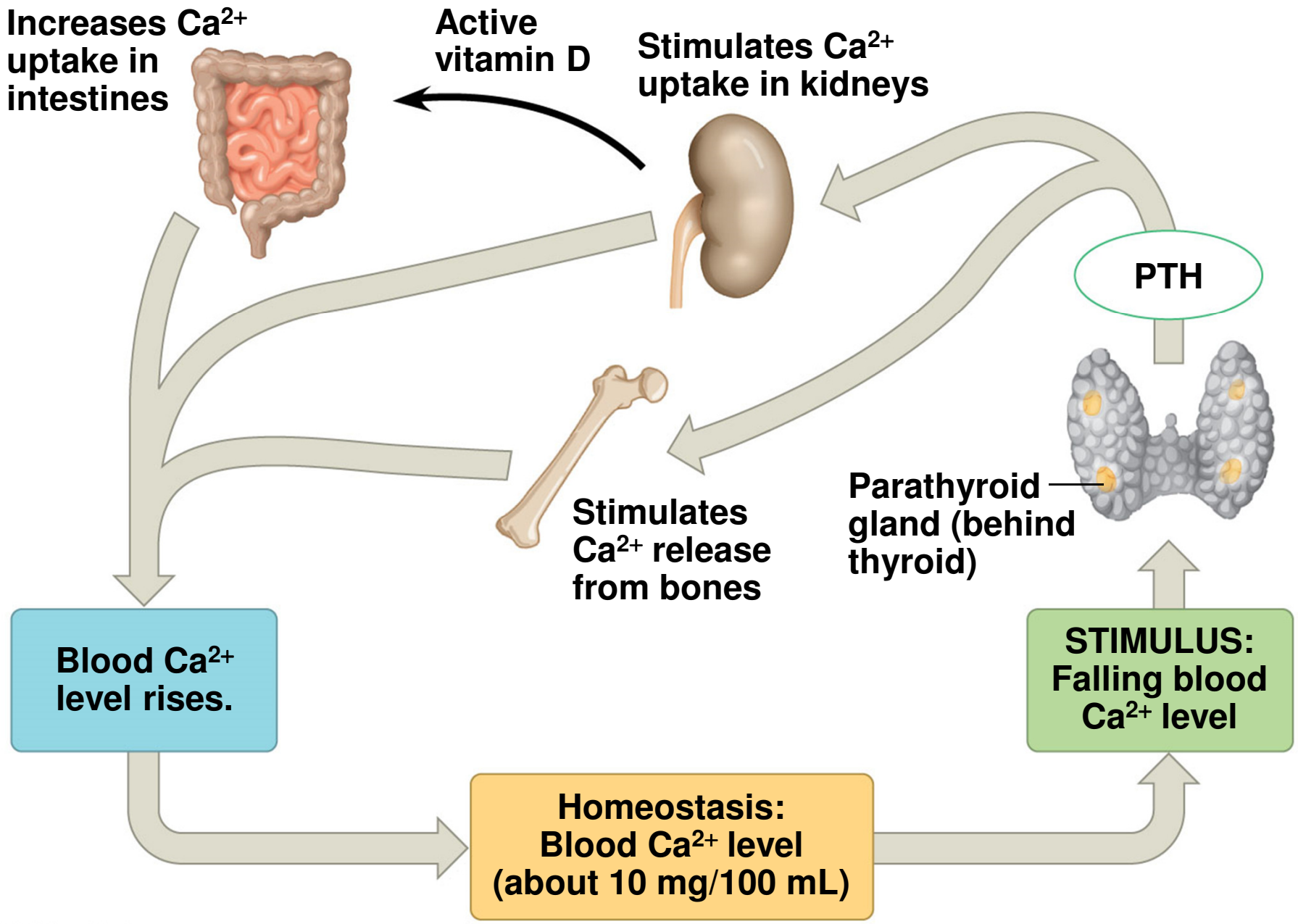
Concept 45.4: Endocrine glands respond to diverse stimuli in regulating homeostasis, development, and behavior

- Endocrine signaling regulates homeostasis, development, and behavior

Parathyroid Hormone and Vitamin D: Control of Blood Calcium

- Two antagonistic hormones regulate the homeostasis of calcium (Ca^{2+}) in the blood of mammals
  - **Parathyroid hormone (PTH)** is released by the **parathyroid glands**
  - **Calcitonin** is released by the thyroid gland

Figure 45.20-2



- PTH increases the level of blood Ca^{2+}
  - It releases Ca^{2+} from bone and stimulates reabsorption of Ca^{2+} in the kidneys
  - It also has an indirect effect, stimulating the kidneys to activate vitamin D, which promotes intestinal uptake of Ca^{2+} from food
- Calcitonin decreases the level of blood Ca^{2+}
  - It stimulates Ca^{2+} deposition in bones and secretion by kidneys

Adrenal Hormones: Response to Stress

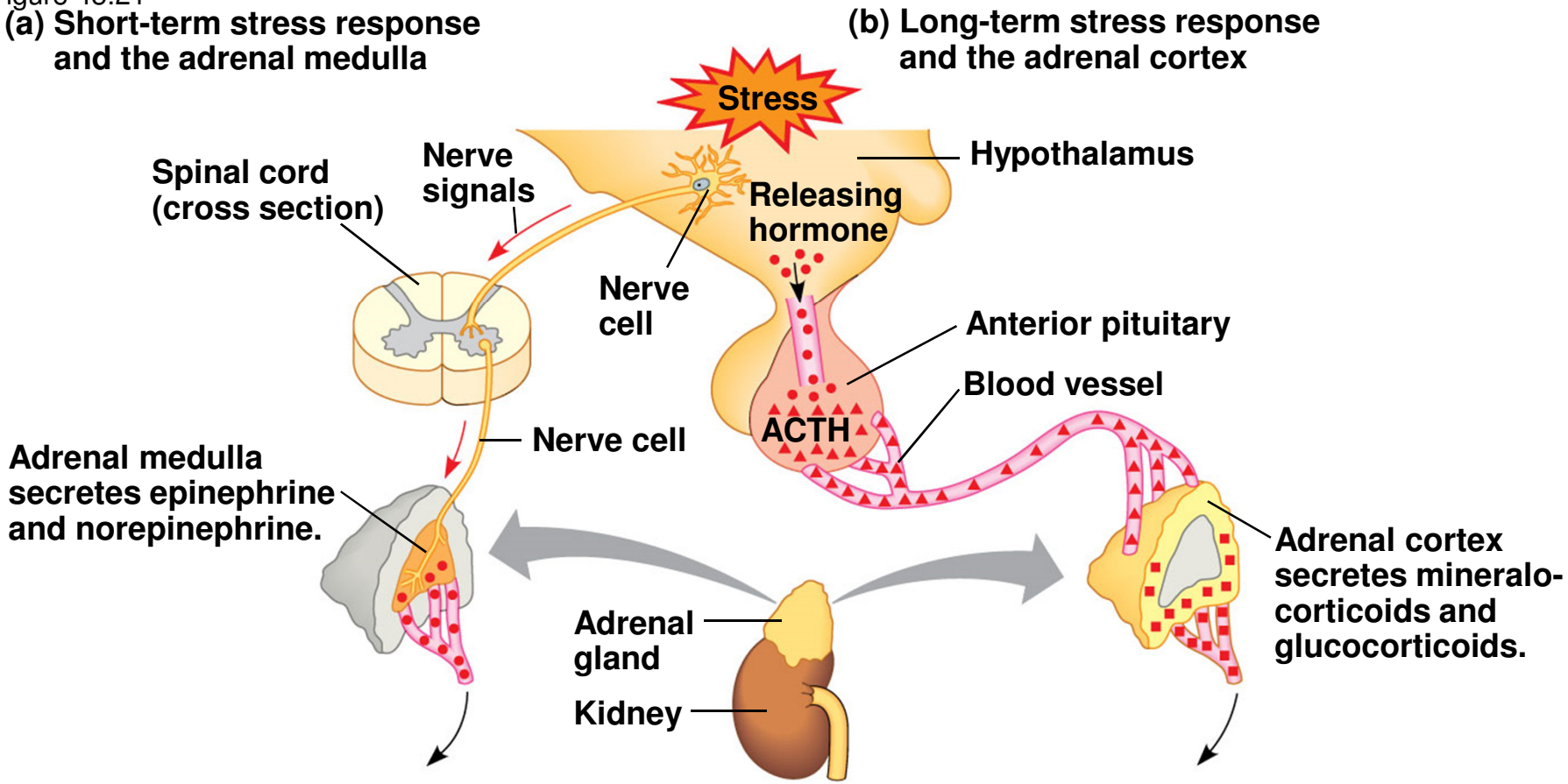
- The adrenal glands are adjacent to the kidneys
- Each **adrenal gland** actually consists of two glands: the *adrenal medulla* (inner portion) and *adrenal cortex* (outer portion)

Catecholamines from the Adrenal Medulla

- The adrenal medulla secretes epinephrine (adrenaline) and **norepinephrine** (noradrenaline)
- These hormones are members of a class of compounds called **catecholamines**
- They are secreted in response to stress-activated impulses from the nervous system
- They mediate various fight-or-flight responses

- Epinephrine and norepinephrine
  - Trigger the release of glucose and fatty acids into the blood
  - Increase oxygen delivery to body cells
  - Direct blood toward heart, brain, and skeletal muscles and away from skin, digestive system, and kidneys
- The release of epinephrine and norepinephrine occurs in response to involuntary nerve signals

Figure 45.21



Effects of epinephrine and norepinephrine:

- Glycogen broken down to glucose; increased blood glucose
- Increased blood pressure
- Increased breathing rate
- Increased metabolic rate
- Change in blood flow patterns, leading to increased alertness and decreased digestive, excretory, and reproductive system activity

Effects of mineralocorticoids:

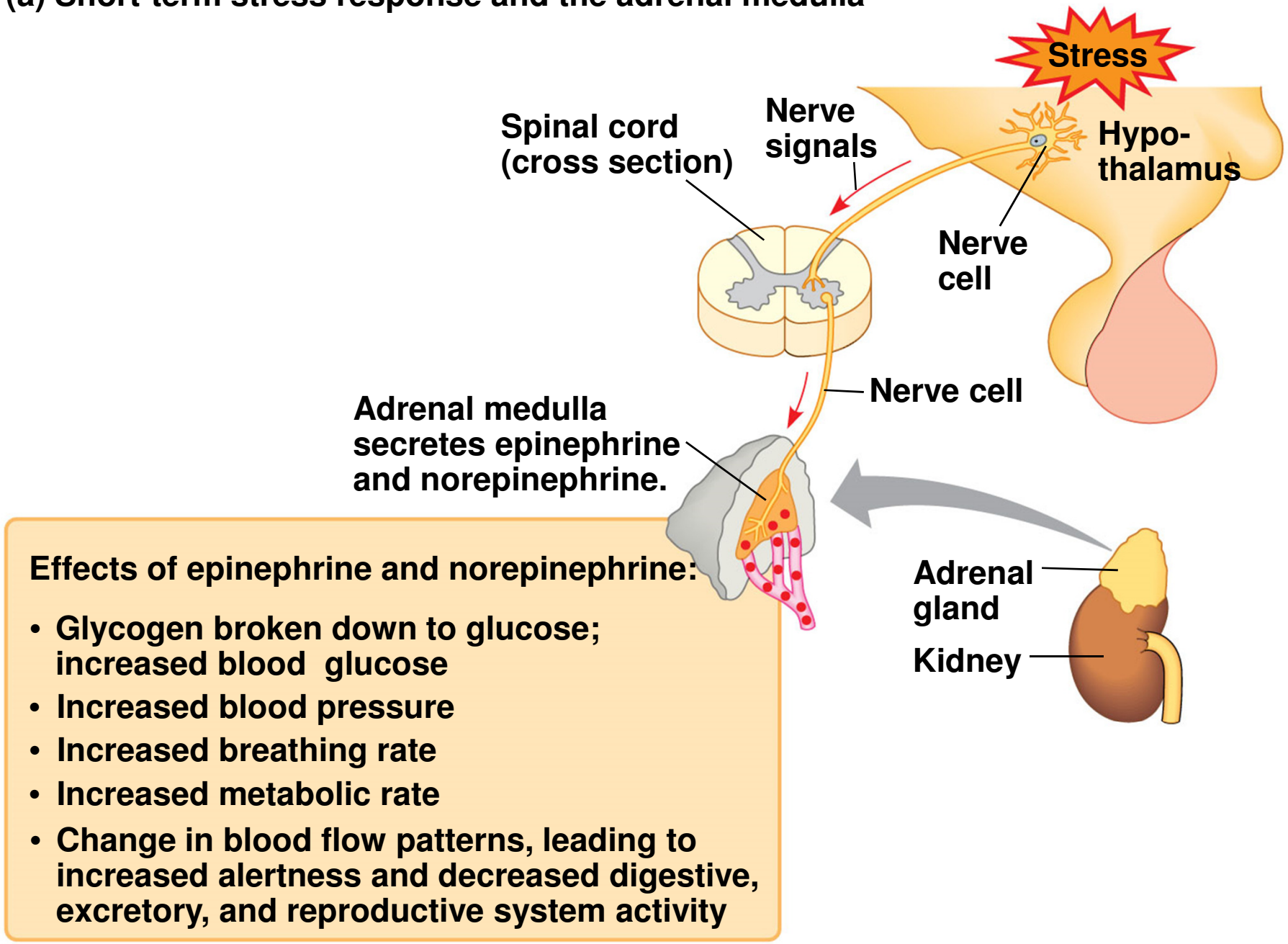
- Retention of sodium ions and water by kidneys
- Increased blood volume and blood pressure

Effects of glucocorticoids:

- Proteins and fats broken down and converted to glucose, leading to increased blood glucose
- Partial suppression of immune system

Figure 45.21a

(a) Short-term stress response and the adrenal medulla

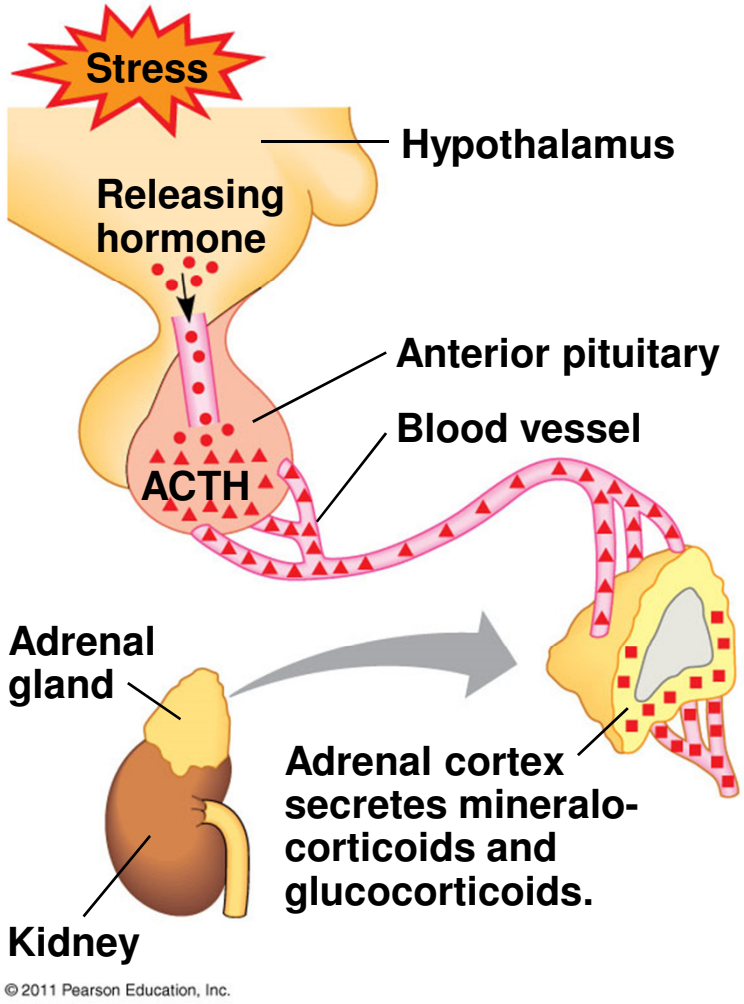


Steroid Hormones from the Adrenal Cortex

- The adrenal cortex releases a family of steroids called **corticosteroids** in response to stress
- These hormones are triggered by a hormone cascade pathway via the hypothalamus and anterior pituitary (ACTH)
- Humans produce two types of corticosteroids: glucocorticoids and mineralocorticoids

Figure 45.21b

(b) Long-term stress response and the adrenal cortex



Effects of mineralocorticoids:

- Retention of sodium ions and water by kidneys
- Increased blood volume and blood pressure

Effects of glucocorticoids:

- Proteins and fats broken down and converted to glucose, leading to increased blood glucose
- Partial suppression of immune system

- **Glucocorticoids**, such as cortisol, influence glucose metabolism and the immune system
- **Mineralocorticoids**, such as aldosterone, affect salt and water balance
- The adrenal cortex also produces small amounts of steroid hormones that function as sex hormones

Gonadal Sex Hormones

- The gonads, testes and ovaries, produce most of the sex hormones: androgens, estrogens, and progestins
- All three sex hormones are found in both males and females, but in significantly different proportions

- The testes primarily synthesize **androgens**, mainly **testosterone**, which stimulate development and maintenance of the male reproductive system
- Testosterone causes an increase in muscle and bone mass and is often taken as a supplement to cause muscle growth, which carries health risks

Figure 45.22

RESULTS

Chromosome Set	Appearance of Genitalia	
	No surgery	Embryonic gonad removed
XY (male)	Male	Female
XX (female)	Female	Female

- **Estrogens**, most importantly **estradiol**, are responsible for maintenance of the female reproductive system and the development of female secondary sex characteristics
- In mammals, progestins, which include **progesterone**, are primarily involved in preparing and maintaining the uterus
- Synthesis of the sex hormones is controlled by FSH and LH from the anterior pituitary

Endocrine Disruptors

- Between 1938 and 1971 some pregnant women at risk for complications were prescribed a synthetic estrogen called diethylstilbestrol (DES)
- Daughters of women treated with DES are at higher risk for reproductive abnormalities, including miscarriage, structural changes, and cervical and vaginal cancers

- DES is an endocrine disruptor, a molecule that interrupts the normal function of a hormone pathway, in this case, that of estrogen

Melatonin and Biorhythms

- The **pineal gland**, located in the brain, secretes **melatonin**
- Light/dark cycles control release of melatonin
- Primary functions of melatonin appear to relate to biological rhythms associated with reproduction

Figure 45.UN02

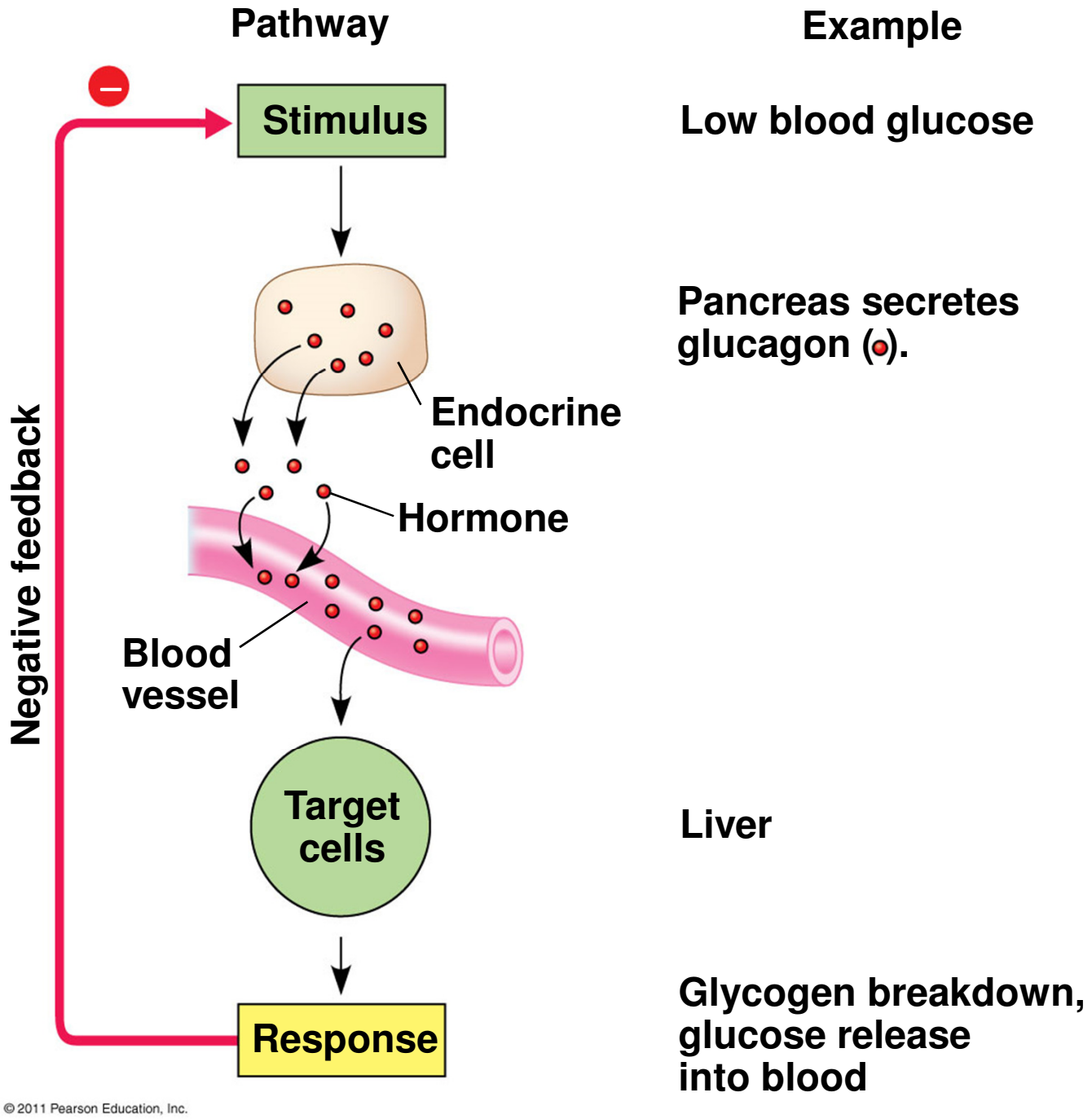


Figure 45.UN03

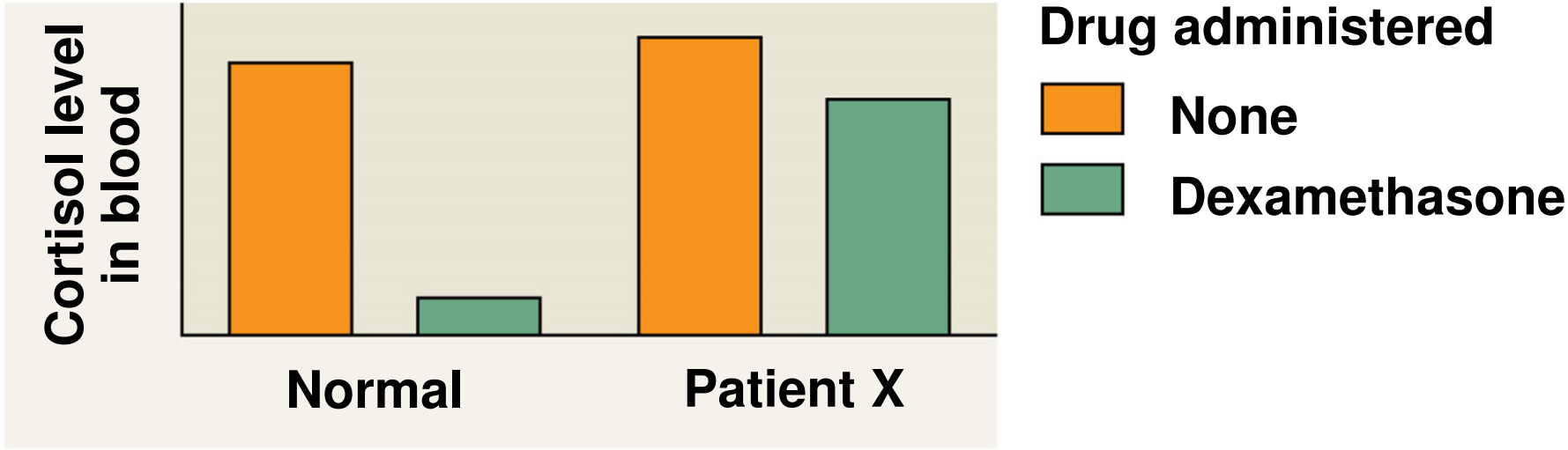


Figure 45.UN04