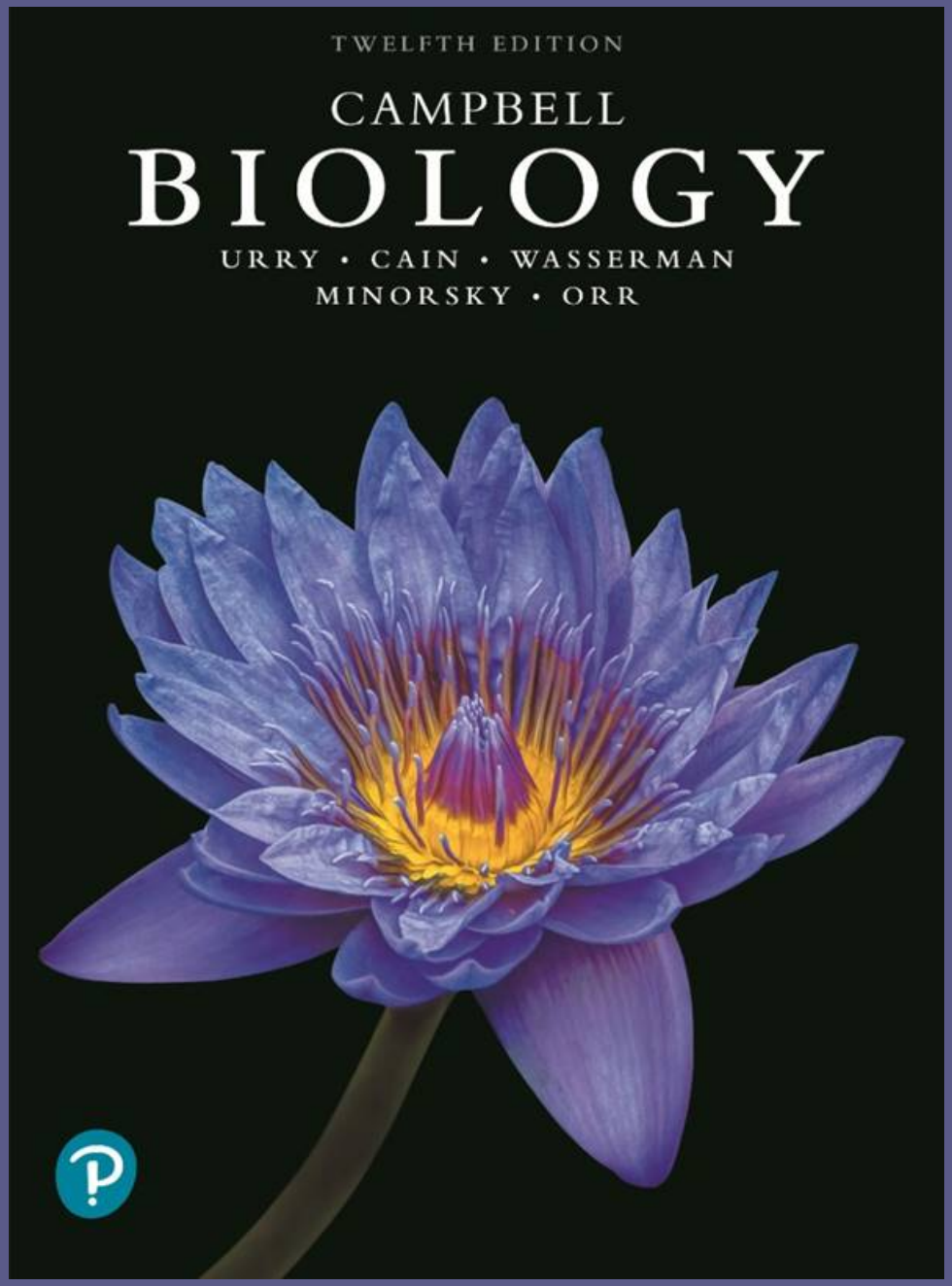


Chapter 45

Hormones and the Endocrine System

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

Figure 45.1a

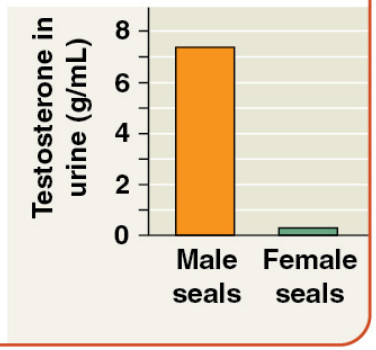
CONCEPT 45.1: Hormones and other signaling molecules bind to target receptors, triggering specific response pathways

- A **hormone** is a secreted molecule that circulates through the body and stimulates specific cells
- Hormones reach all parts of the body, but only target cells have receptors for that hormone

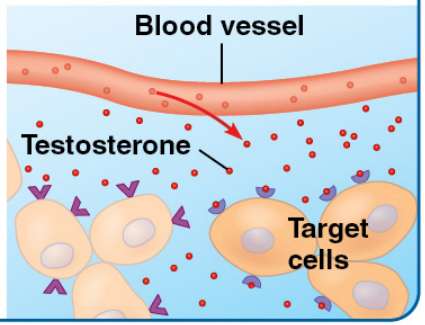
Figure 45.1b

What variables shape a hormone's effect on an animal's body and behavior?

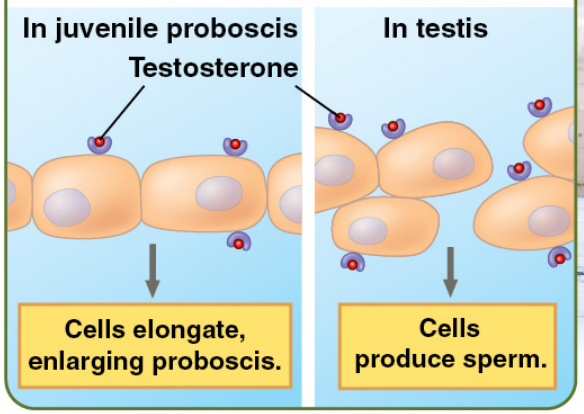
Concentration of the hormone in the body



Presence of the hormone receptor in a cell



Response of the cell when the receptor binds the hormone



▼ Male elephant seals sparring

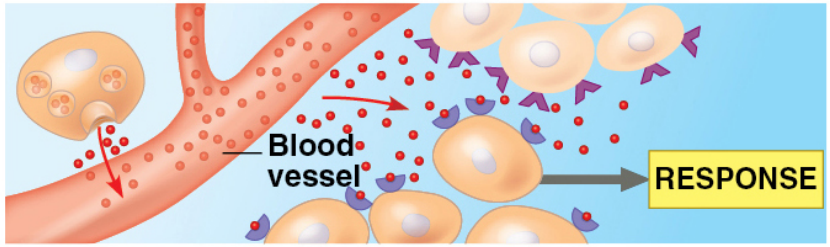
CONCEPT 45.1: Hormones and other signaling molecules bind to target receptors, triggering specific response pathways

- Chemical signaling by hormones is the function of the **endocrine system**
- The **nervous system** is a network of specialized cells—neurons—that transmit signals along dedicated pathways
- The nervous and endocrine systems often overlap in function

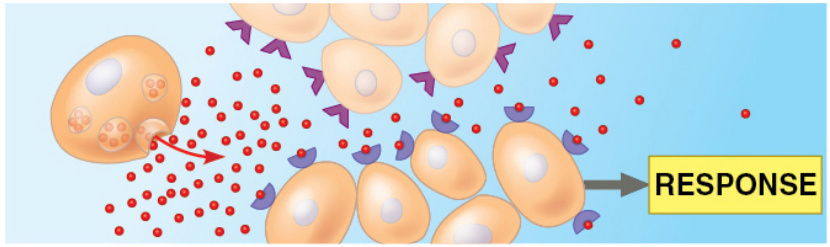
Intercellular Information Flow

- Communication between animal cells through secreted signals can be classified by two criteria:
  - The type of secreting cell
  - The route taken by the signal in reaching its target

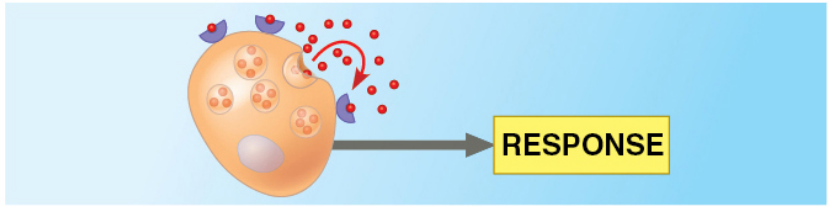
Figure 45.2



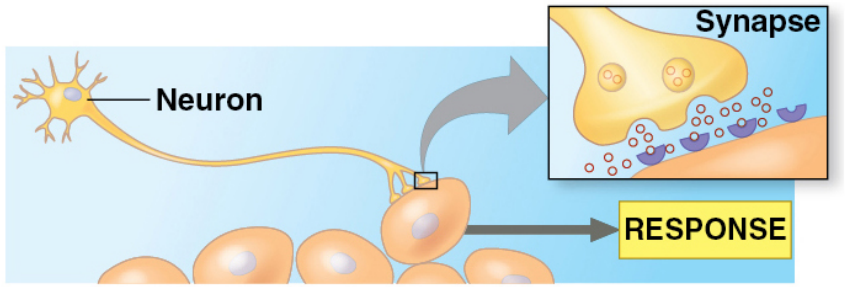
(a) Endocrine signaling



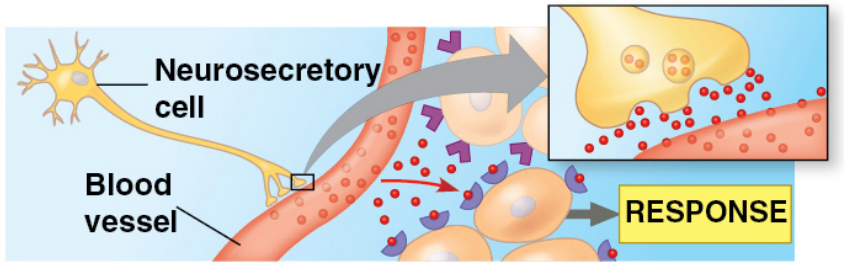
(b) Paracrine signaling



(c) Autocrine signaling



(d) Synaptic signaling



(e) Neuroendocrine signaling

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
  - triggers changes underlying sexual maturity and reproduction

Paracrine and Autocrine Signaling

- **Local regulators** are molecules that act over short distances, reaching target cells solely by diffusion
- Paracrine and autocrine signaling play roles in processes such as blood pressure regulation, nervous system function, and reproduction

- In **paracrine** signaling, the target cells lie near the secreting cells
- In **autocrine** signaling, the target cell is also the secreting cell
- Local regulators that mediate such signaling include the **prostaglandins**
- Prostaglandins function in the immune system and blood clotting

- Some local regulators, such as **nitric oxide** (**NO**) are gases
- When the level of oxygen in the blood falls, cells in blood vessel walls release NO
- After diffusing into the surrounding smooth muscle cells, NO activates an enzyme that relaxes the cells
- This vasodilation increases blood flow to tissues

Synaptic and Neuroendocrine Signaling

- Neurons communicate with target cells via specialized junctions called synapses
- At synapses, secreted molecules called **neurotransmitters** diffuse short distances and bind to receptors on target cells
- In neuroendocrine signaling, specialized neurosecretory cells secrete **neurohormones** that diffuse from nerve endings into the bloodstream

Signaling by Pheromones

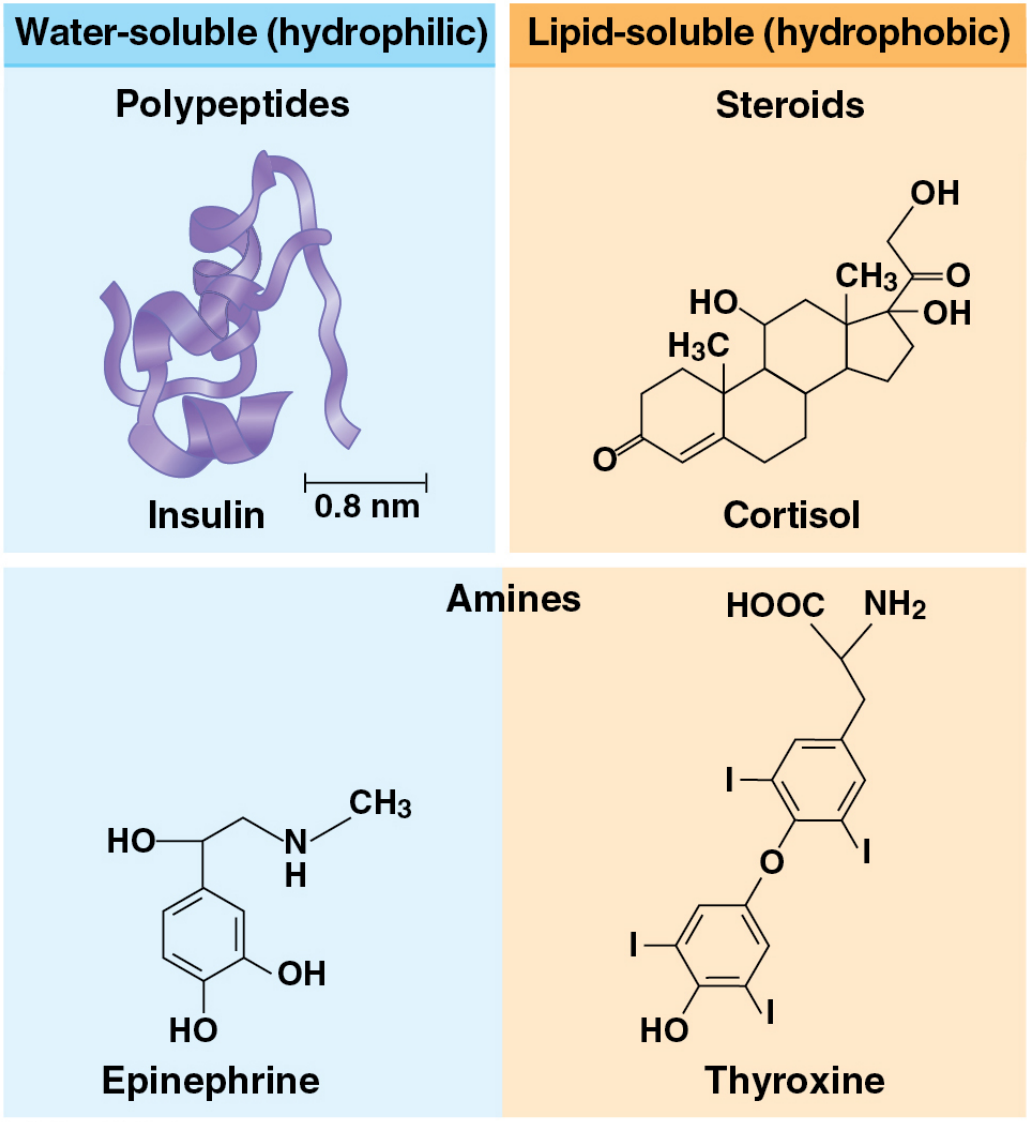
- Members of some animal species may communicate with **pheromones**, chemicals that are released into the environment
- Pheromones serve many functions, including marking trails leading to food, defining territories, warning of predators, and attracting potential mates

Figure 45.3

Chemical Classes of Hormones

- Hormones fall into three major chemical classes
  - Polypeptides
  - Steroids
  - Amines
- Polypeptides and most amines are water-soluble
- Steroid hormones and other largely nonpolar hormones are lipid-soluble

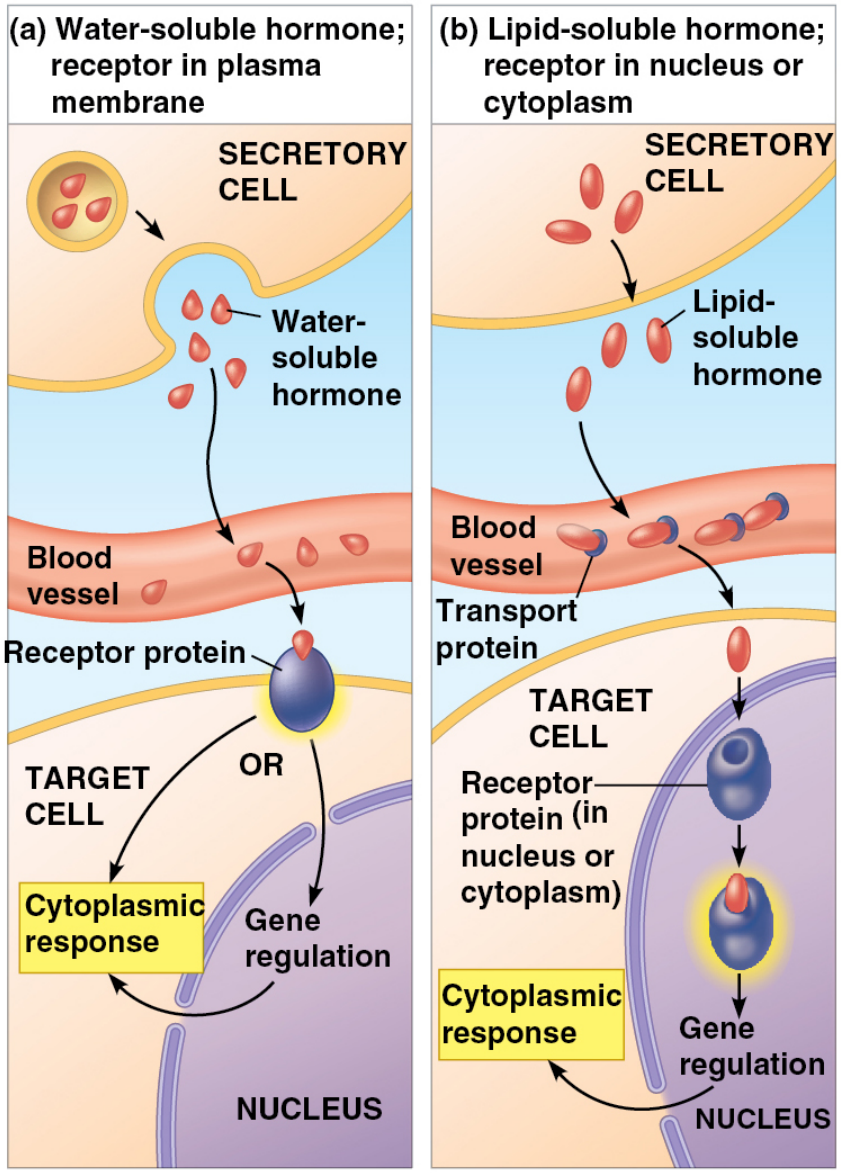
Figure 45.4


Water-soluble (hydrophilic)
Lipid-soluble (hydrophobic)
Polypeptides
Steroids
Insulin
0.8 nm
Cortisol
Amines
Epinephrine
Thyroxine

Cellular Hormone Response Pathways

- 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
- They bind to receptors in the cytoplasm or nucleus of the target cells

Figure 45.5


(a) Water-soluble hormone; receptor in plasma membrane
SECRETORY CELL
Water-soluble hormone
Blood vessel
Receptor protein
TARGET CELL
OR
Cytoplasmic response
Gene regulation
NUCLEUS
(b) Lipid-soluble hormone; receptor in nucleus or cytoplasm
SECRETORY CELL
Lipid-soluble hormone
Blood vessel
Transport protein
TARGET CELL
Receptor protein (in nucleus or cytoplasm)
Cytoplasmic response
Gene regulation
NUCLEUS

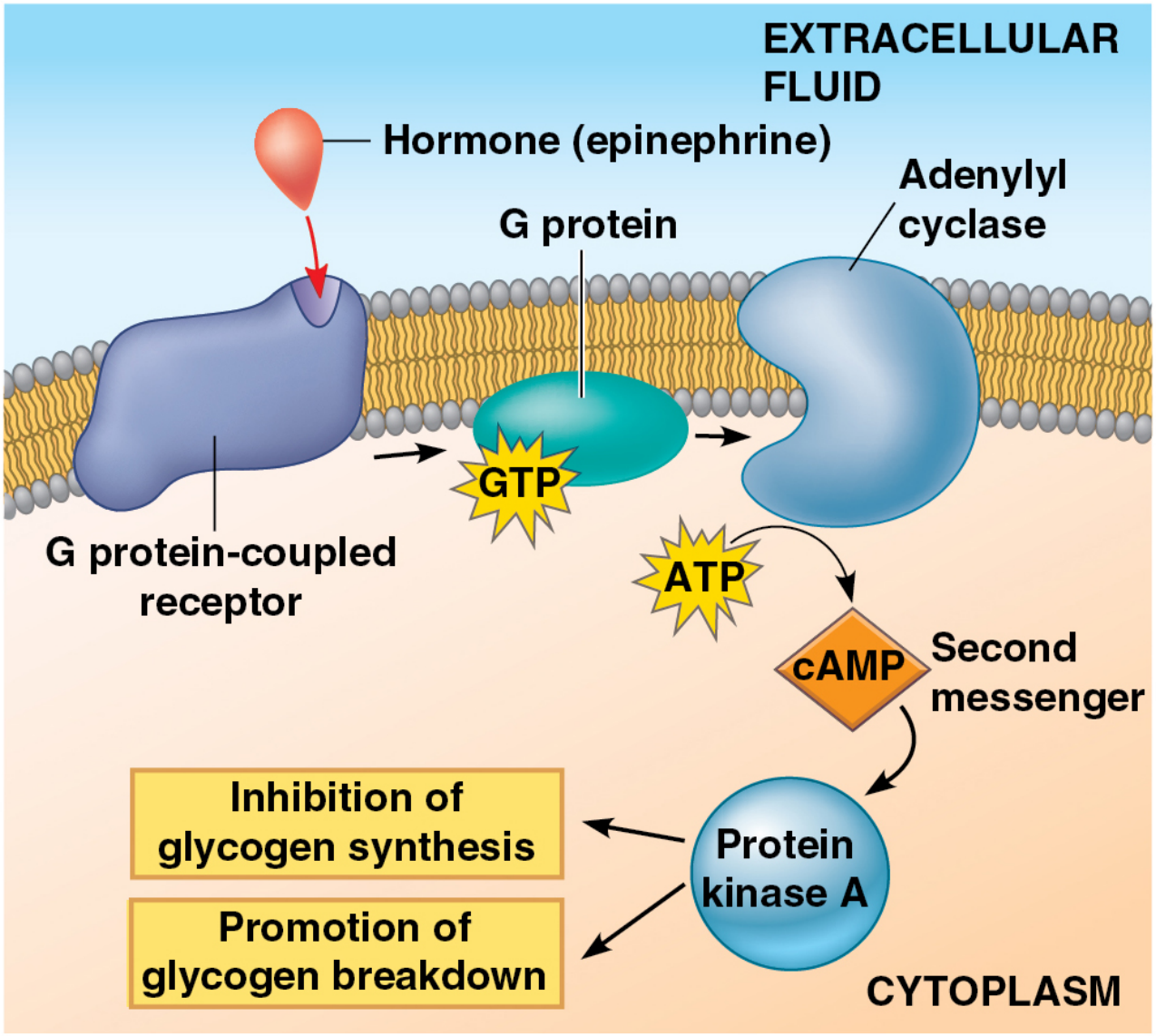
Mastering Biology Animation: Binding of Hormones

Response Pathway for Water-Soluble Hormones

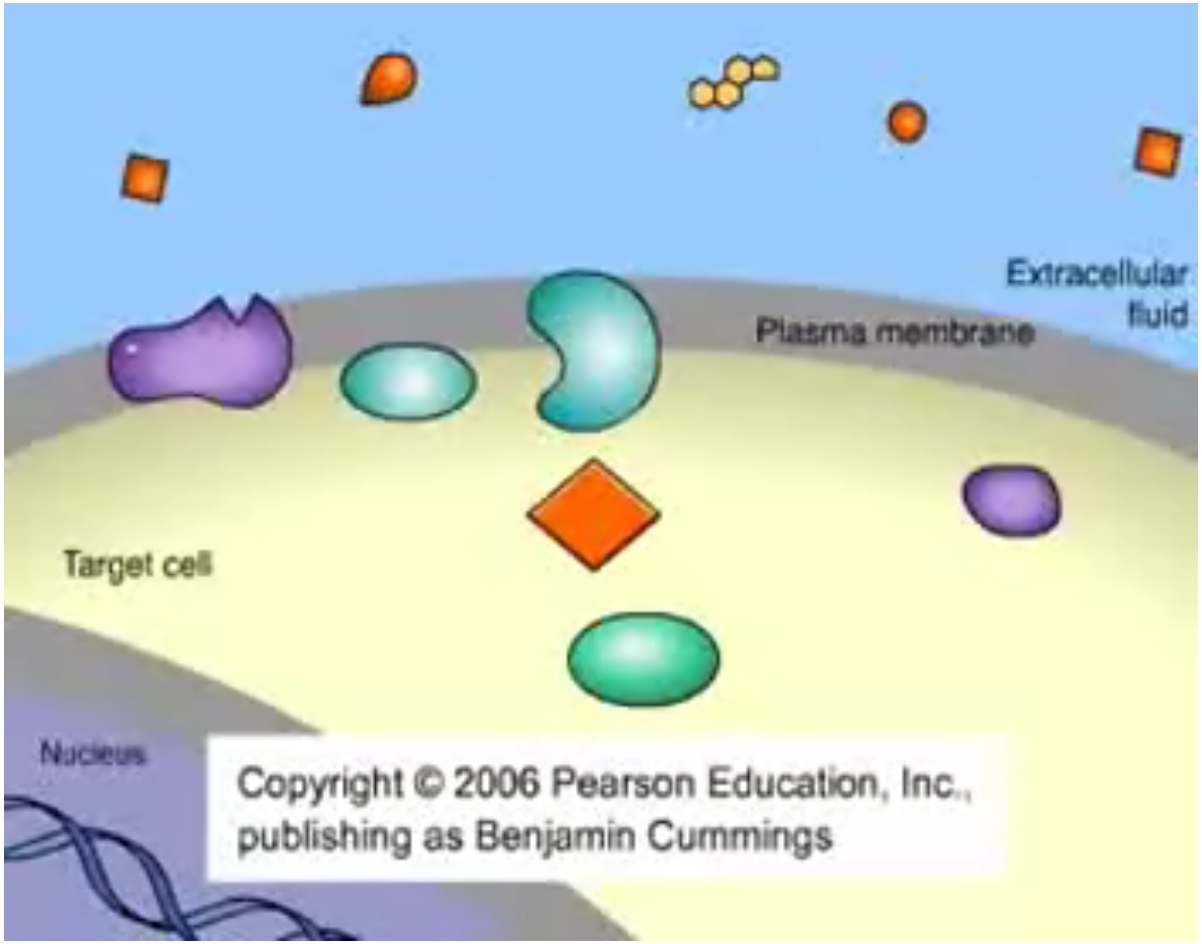
- Binding of a hormone to its receptor initiates a cellular response
- The chain of events that converts the chemical signal to an intracellular response is called **signal transduction**
- The response may be activation of an enzyme, change in uptake or secretion of certain molecules, or rearrangement of the cytoskeleton
- In some cases, the signal may initiate changes in transcription of certain genes

- The hormone **epinephrine** (or adrenaline) regulates many organs in response to stressful situations
- Epinephrine binds to G protein-coupled receptors on the plasma membrane of target cells
- This triggers a cascade of events involving synthesis of cyclic AMP (cAMP)
- This leads to activation of enzymes responsible for (for example) the breakdown of glycogen into glucose

Figure 45.6


EXTRACELLULAR FLUID
Hormone (epinephrine)
Adenylyl cyclase
G protein
GTP
G protein-coupled receptor
ATP
cAMP
Second messenger
Inhibition of glycogen synthesis
Protein kinase A
Promotion of glycogen breakdown
CYTOPLASM

Mastering Biology Animation: Water-Soluble Hormone Pathway



Response Pathway for Lipid-Soluble Hormones

- In most cases, the response to a lipid-soluble hormone is a change in gene expression
- When a steroid hormone binds to its cytosolic receptor, a hormone-receptor complex forms that moves into the nucleus
- There, the receptor part of the complex acts as a transcriptional regulator of specific target genes

- The steroid hormone receptors that bind to estrogens are well-characterized
- In female birds and frogs, estradiol, a form of estrogen, binds to a cytoplasmic receptor in liver cells
- The estradiol-bound receptor activates transcription of the vitellogenin gene, needed to produce egg yolk

- Thyroxine, vitamin D, and other lipid soluble hormones that are not steroids typically have receptors in the nucleus
- These hormone molecules diffuse across the plasma membrane and the nuclear envelope
- Once bound to a hormone, the receptor binds to sites in the cell's DNA and stimulates transcription of specific genes

Mastering Biology Animation: Steroid Hormone Pathway

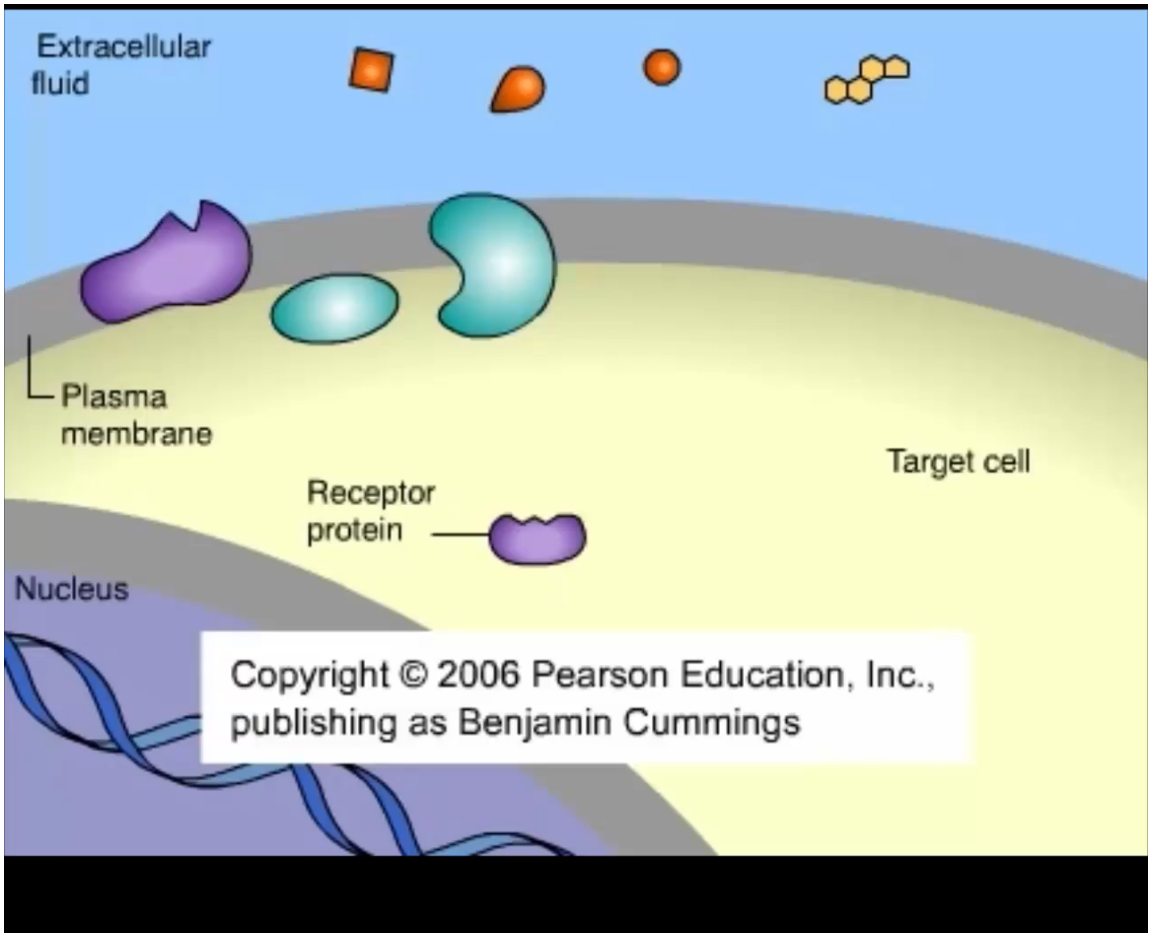
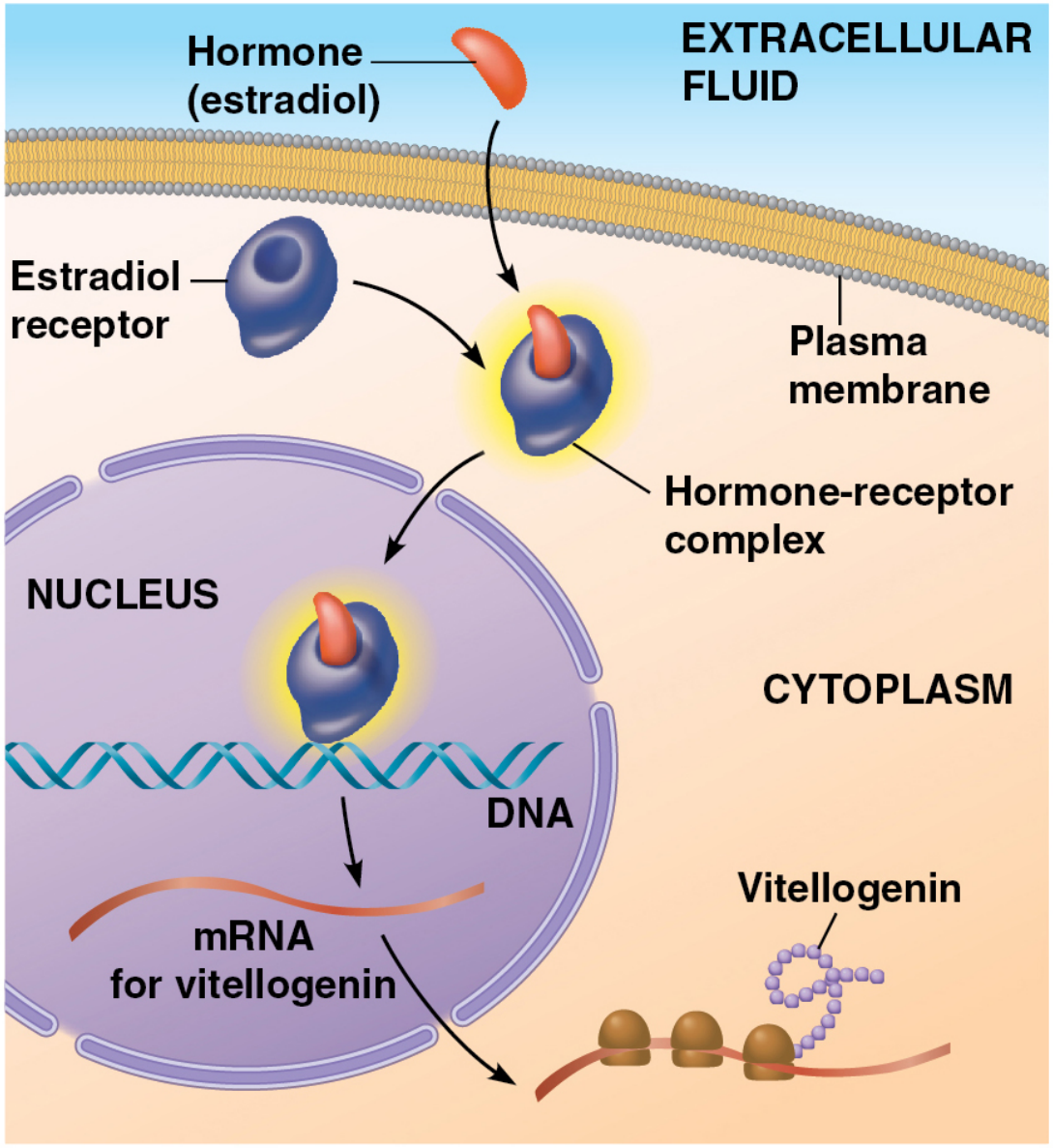
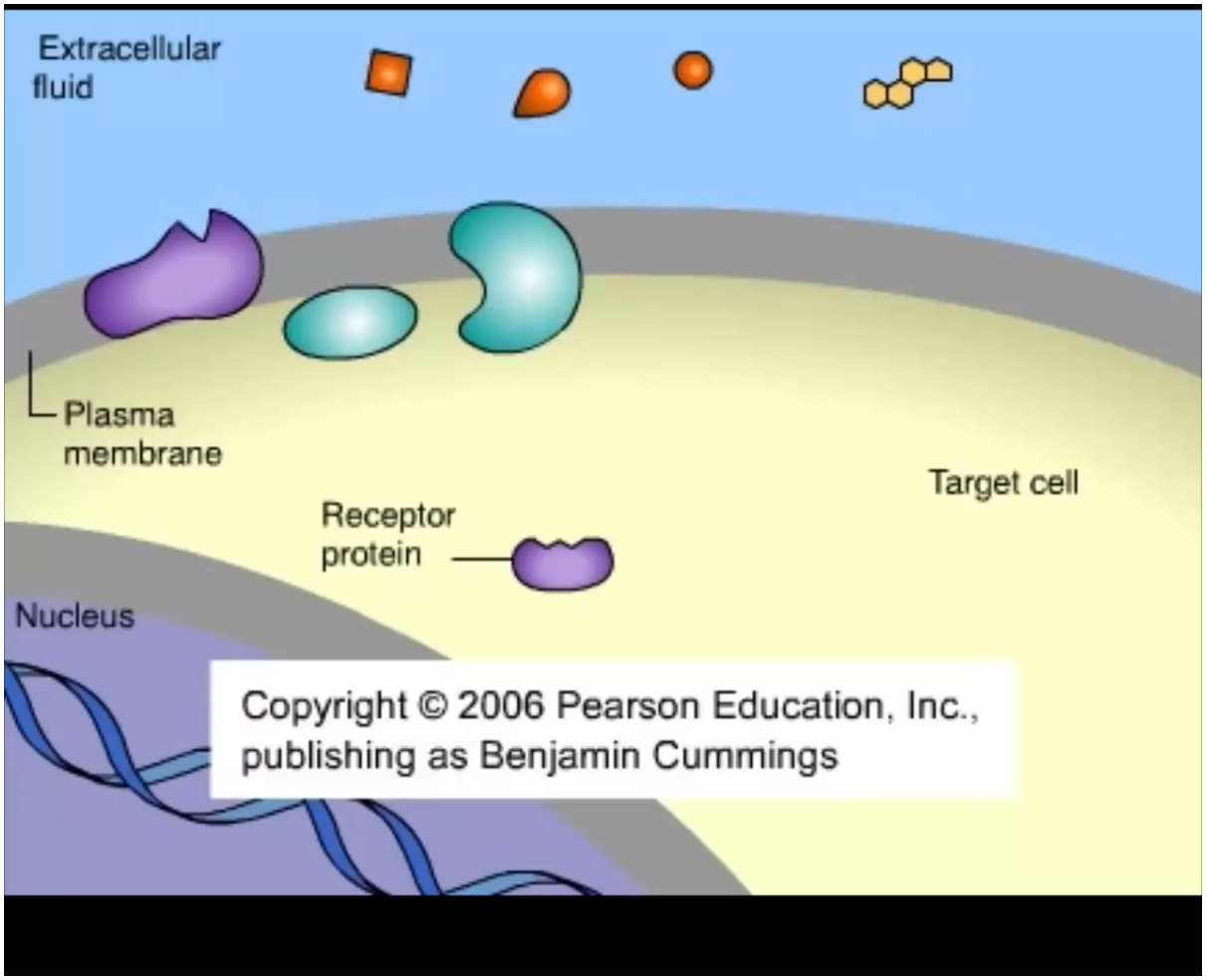


Figure 45.7


Hormone (estradiol)
EXTRACELLULAR FLUID
Estradiol receptor
Plasma membrane
Hormone-receptor complex
NUCLEUS
CYTOPLASM
DNA
mRNA for vitellogenin
Vitellogenin

Animation: Lipid-Soluble Hormone



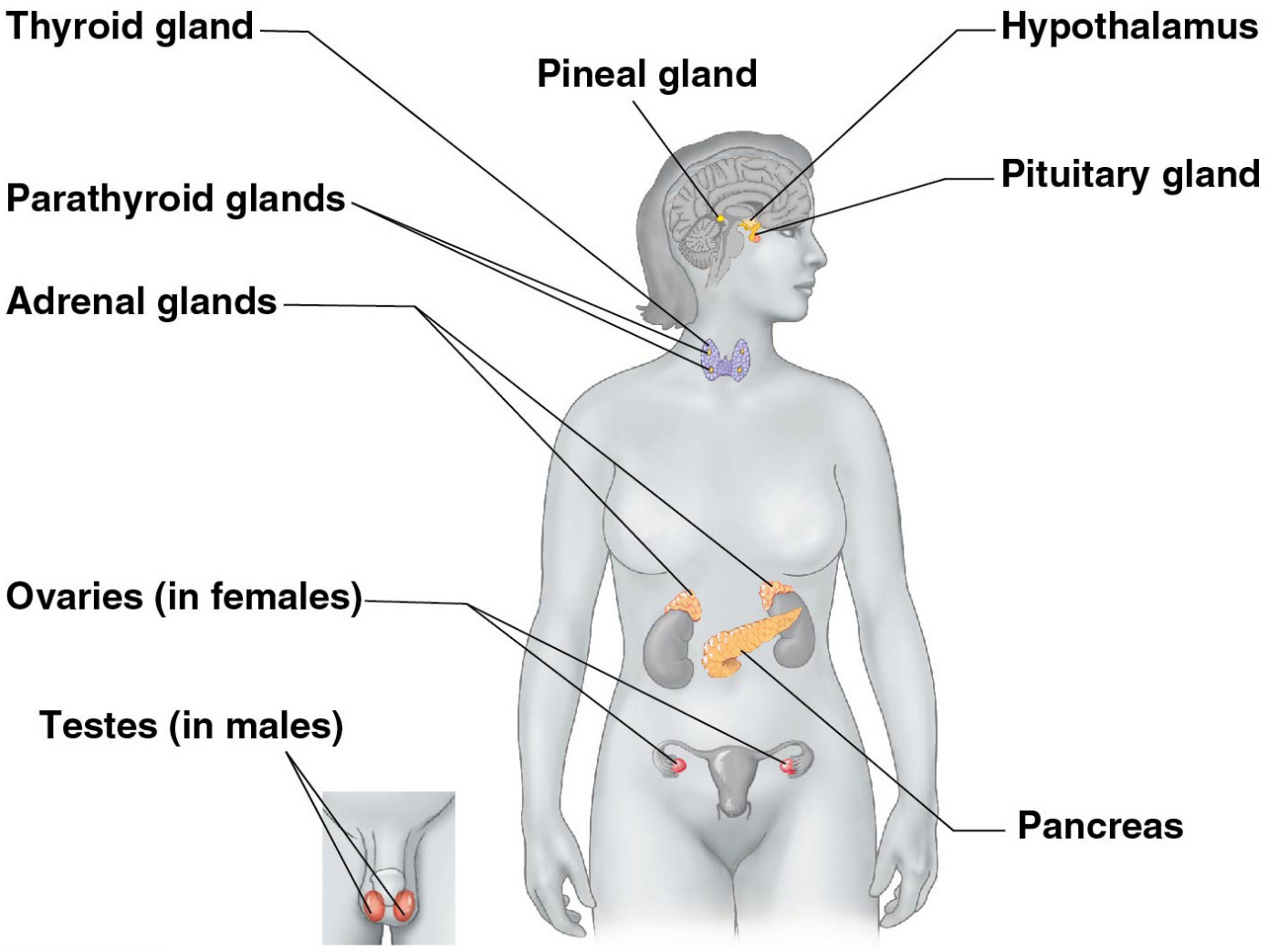
Multiple Responses to a Single Hormone

- The same hormone may have different effects on target cells that have
  - Different receptors for the hormone
  - Different signal transduction pathways
- For example, the hormone epinephrine has multiple effects that form the basis of the “fight-or-flight” response, a rapid response to stress

Endocrine Tissues and Organs

- Endocrine cells are often grouped in ductless organs called **endocrine glands**, such as the thyroid and parathyroid glands and testes or ovaries
- In contrast, exocrine glands, such as salivary glands, have ducts to carry secreted substances onto body surfaces or into body cavities

Figure 45.8


Thyroid gland
Pineal gland
Hypothalamus
Pituitary gland
Parathyroid glands
Adrenal glands
Ovaries (in females)
Testes (in males)
Pancreas

CONCEPT 45.2: Feedback regulation and coordination with the nervous system are common in hormone pathways

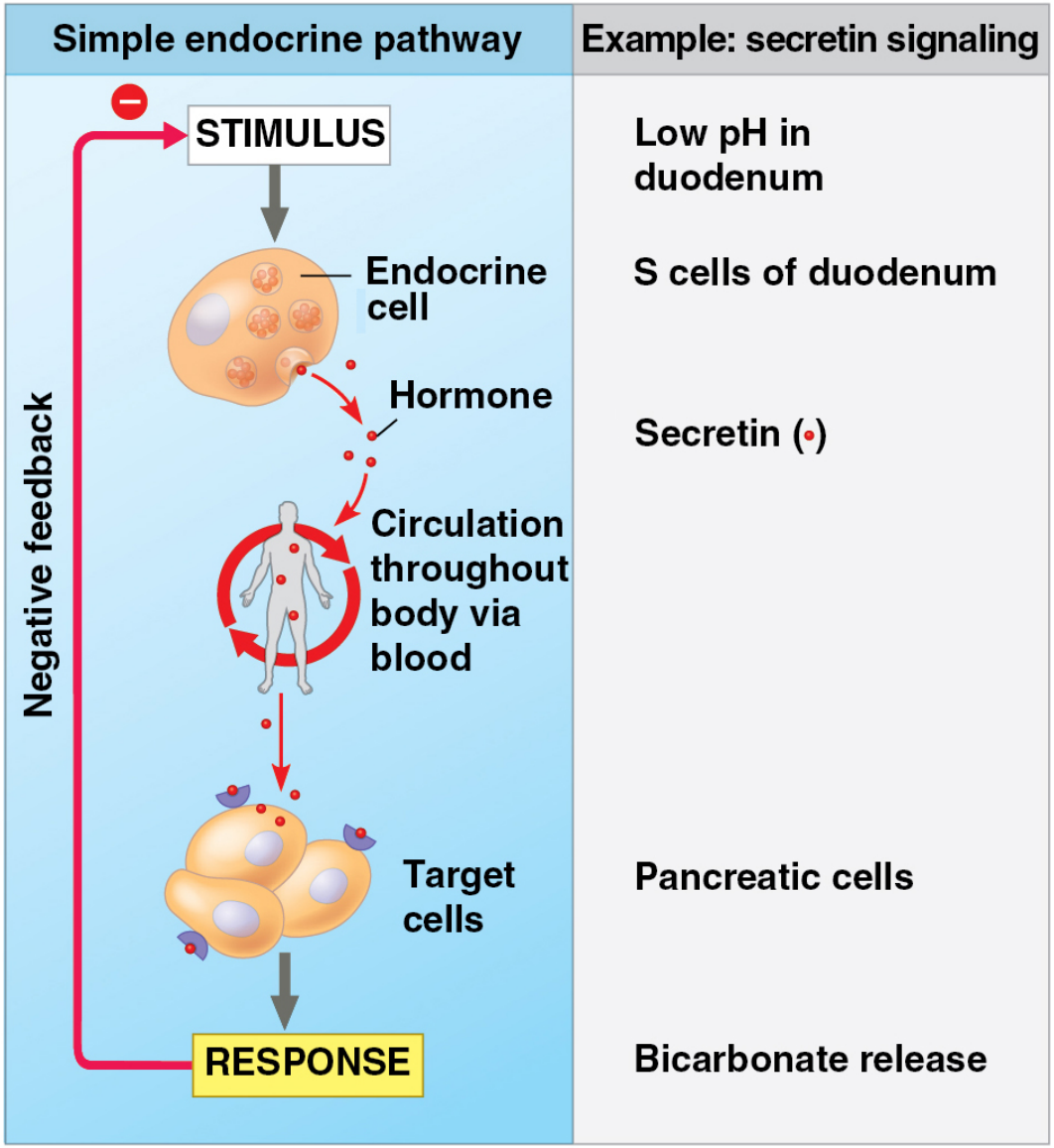
- Hormones are assembled into regulatory pathways

Simple Endocrine Pathways

- In a simple endocrine pathway, endocrine cells respond directly to a stimulus by secreting a particular hormone
- The hormone travels in the bloodstream to target cells, where it interacts with its specific receptors
- Signal transduction within target cells brings about a physiological response

- 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 to secrete bicarbonate into ducts that lead to the duodenum
- This causes a raise the pH in the duodenum

Figure 45.9

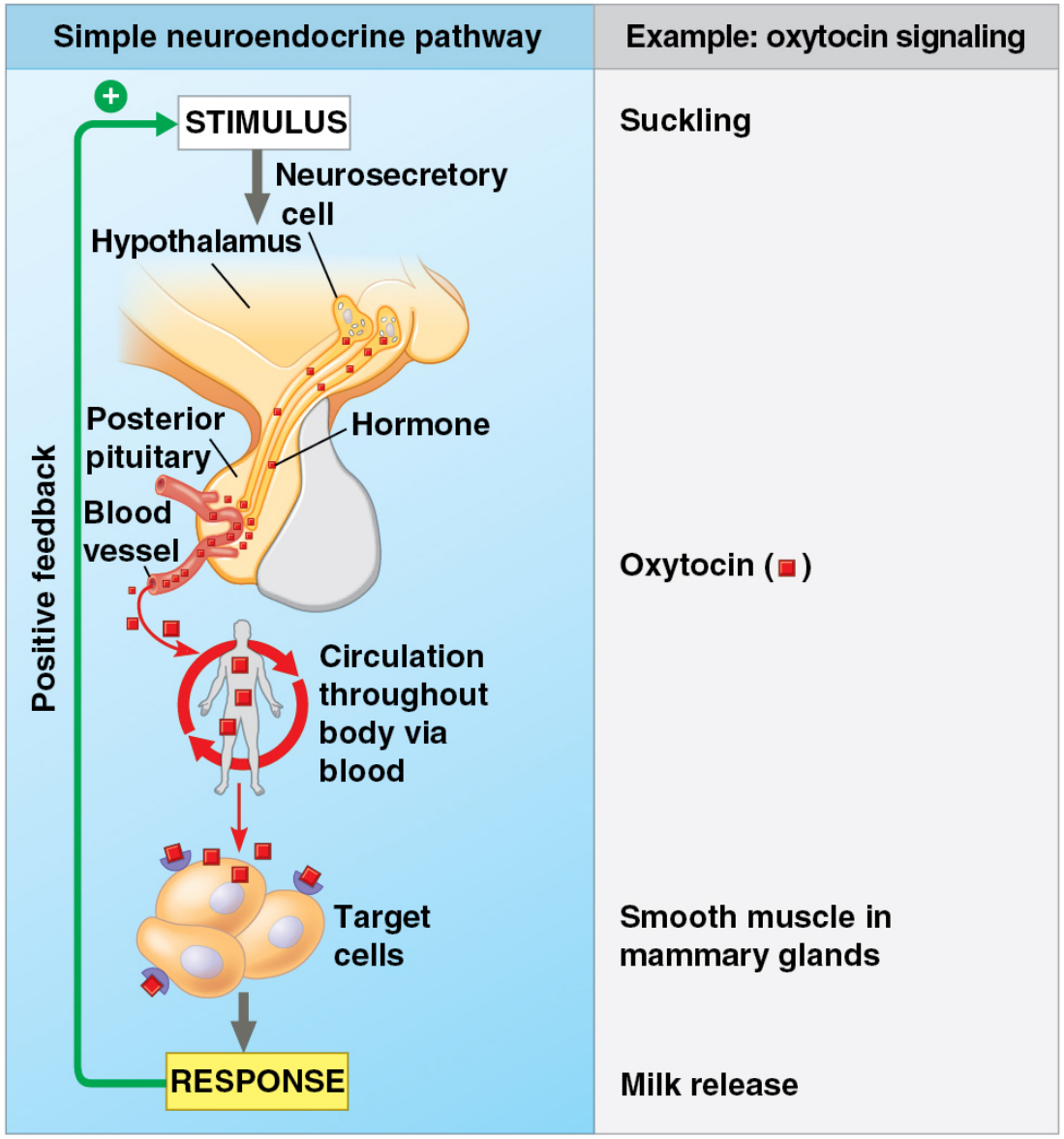

Simple endocrine pathway
Example: secretin signaling
STIMULUS
Low pH in duodenum
Endocrine cell
S cells of duodenum
Hormone
Secretin (•)
Circulation throughout body via blood
Target cells
Pancreatic cells
RESPONSE
Bicarbonate release
Negative feedback

Simple Neuroendocrine Pathways

- 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

- For example, the suckling of an infant stimulates signals in the nervous systems of the mother, that reach the hypothalamus
- Nerve impulses from the hypothalamus trigger the release of **oxytocin** from the posterior pituitary
- This causes the mammary glands to secrete milk

Figure 45.10


Simple neuroendocrine pathway
Example: oxytocin signaling
STIMULUS
Neurosecretory cell
Hypothalamus
Posterior pituitary
Hormone
Blood vessel
Positive feedback
Circulation throughout body via blood
Target cells
RESPONSE
Suckling
Oxytocin (■)
Smooth muscle in mammary glands
Milk release

Feedback Regulation

- In a **negative feedback** loop, the response reduces the initial stimulus
- For example, the increase in pH in the intestine caused by secretin release shuts off further secretin release
- **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

Coordination of Endocrine and Nervous Systems

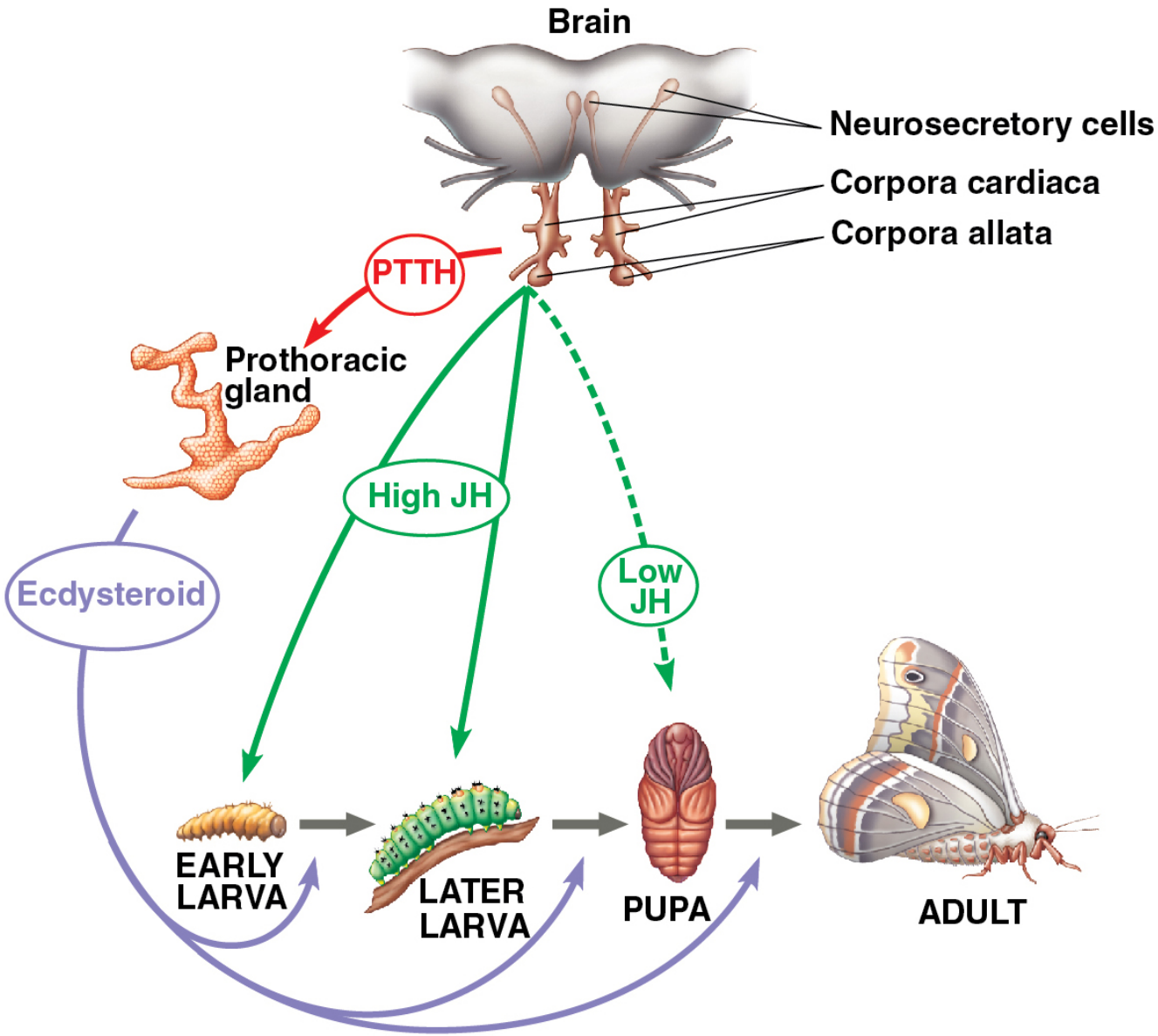
- In a wide range of animals, endocrine organs in the brain integrate function of the endocrine system with that of the nervous system

Invertebrates

- The endocrine pathway that controls the molting of larva originates in the larval brain, where neurosecretory cells produce PTTH
- In the prothoracic gland, PTTH directs the release of ecdysteroid
- Bursts of ecdysteroid trigger each successive molt as well as metamorphosis
- Metamorphosis is not triggered until the level of another hormone, JH (juvenile hormone), drops

Figure 45.11

Figure 45.12

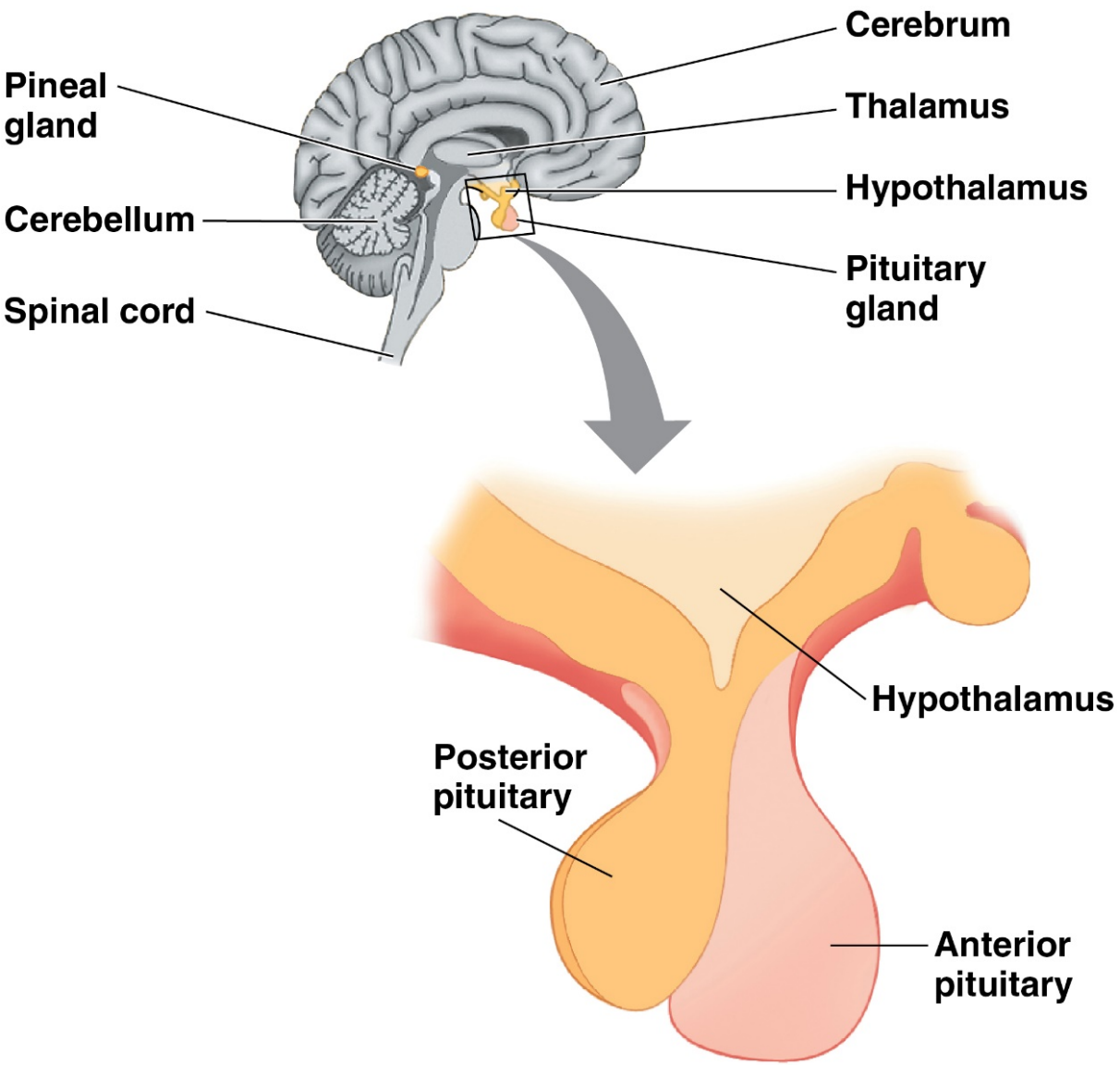

Brain
Neurosecretory cells
Corpora cardiaca
Corpora allata
PTTH
Prothoracic gland
High JH
Low JH
Ecdysteroid
EARLY LARVA
LATER LARVA
PUPA
ADULT

Vertebrates

- The **hypothalamus** coordinates endocrine signaling
- It receives information from nerves throughout the body and initiates appropriate neuroendocrine signals
- Signals from the hypothalamus travel to 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

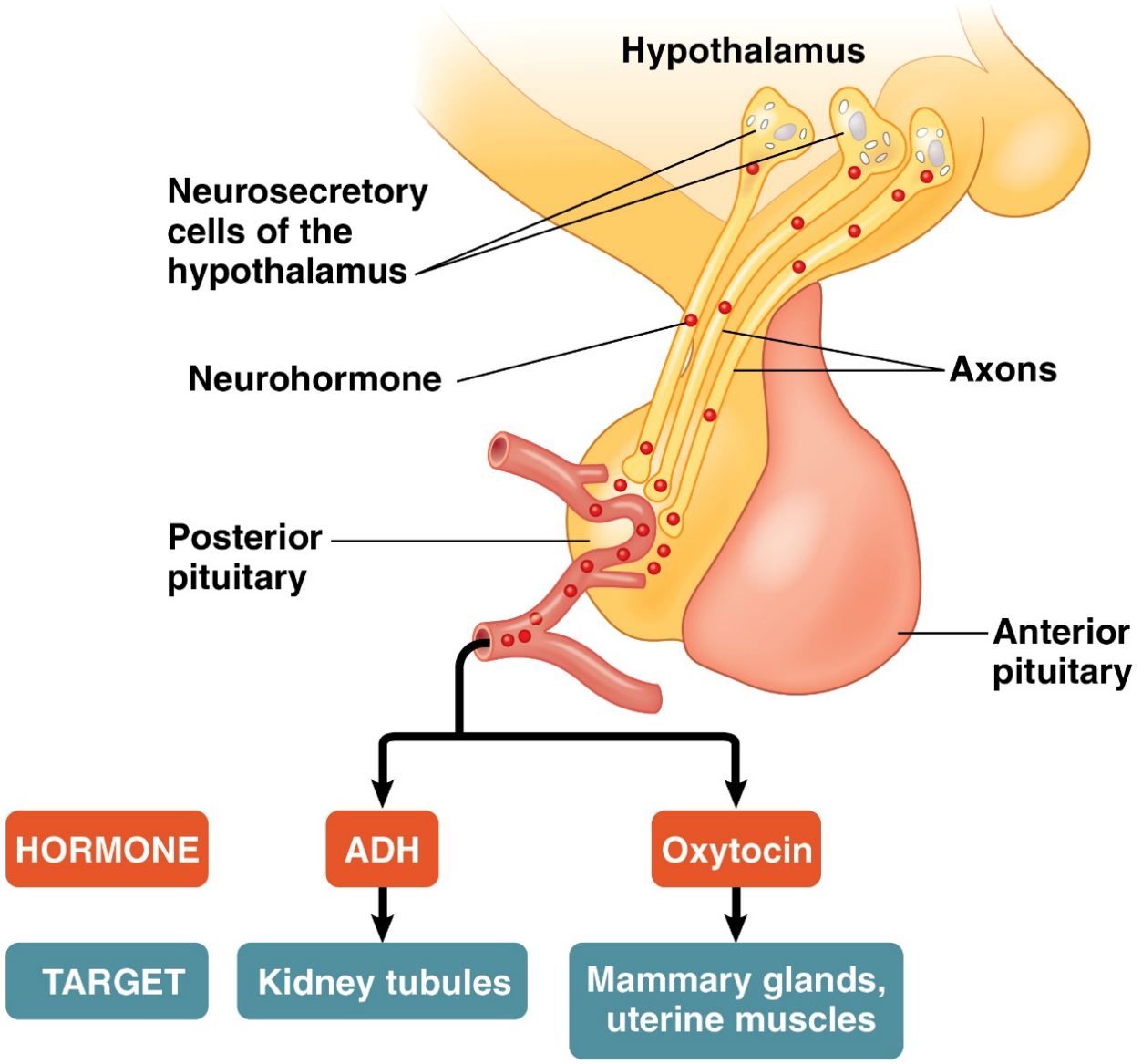
Figure 45.13


Cerebrum
Pineal gland
Thalamus
Hypothalamus
Cerebellum
Pituitary gland
Spinal cord
Hypothalamus
Posterior pituitary
Anterior pituitary

Posterior Pituitary Hormones

- Neurosecretory cells of the hypothalamus synthesize the two posterior pituitary hormones
  - **Antidiuretic hormone** (**ADH**) regulates physiology and behavior
  - Oxytocin regulates milk secretion by the mammary glands

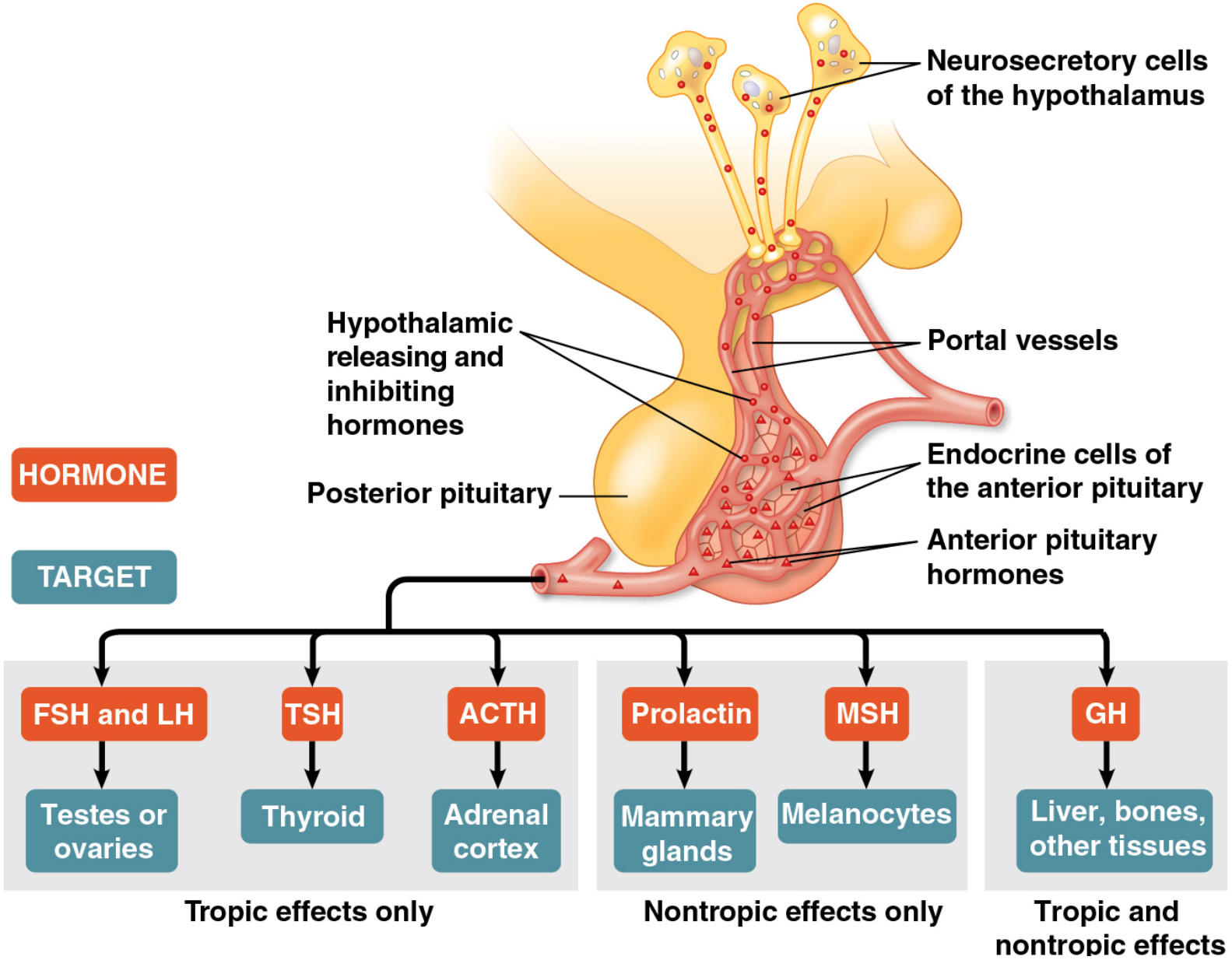
Figure 45.14


Hypothalamus
Neurosecretory cells of the hypothalamus
Neurohormone
Axons
Posterior pituitary
Anterior pituitary
HORMONE
ADH
Oxytocin
TARGET
Kidney tubules
Mammary glands, uterine muscles

Anterior Pituitary Hormones

- The anterior pituitary controls diverse processes, such as metabolism, osmoregulation, and reproduction
- Hormones secreted by the hypothalamus control release of all anterior pituitary hormones
- For example, prolactin-releasing hormone from the hypothalamus stimulates the anterior pituitary to secrete **prolactin** (**PRL**), which has a role in milk production

Figure 45.15

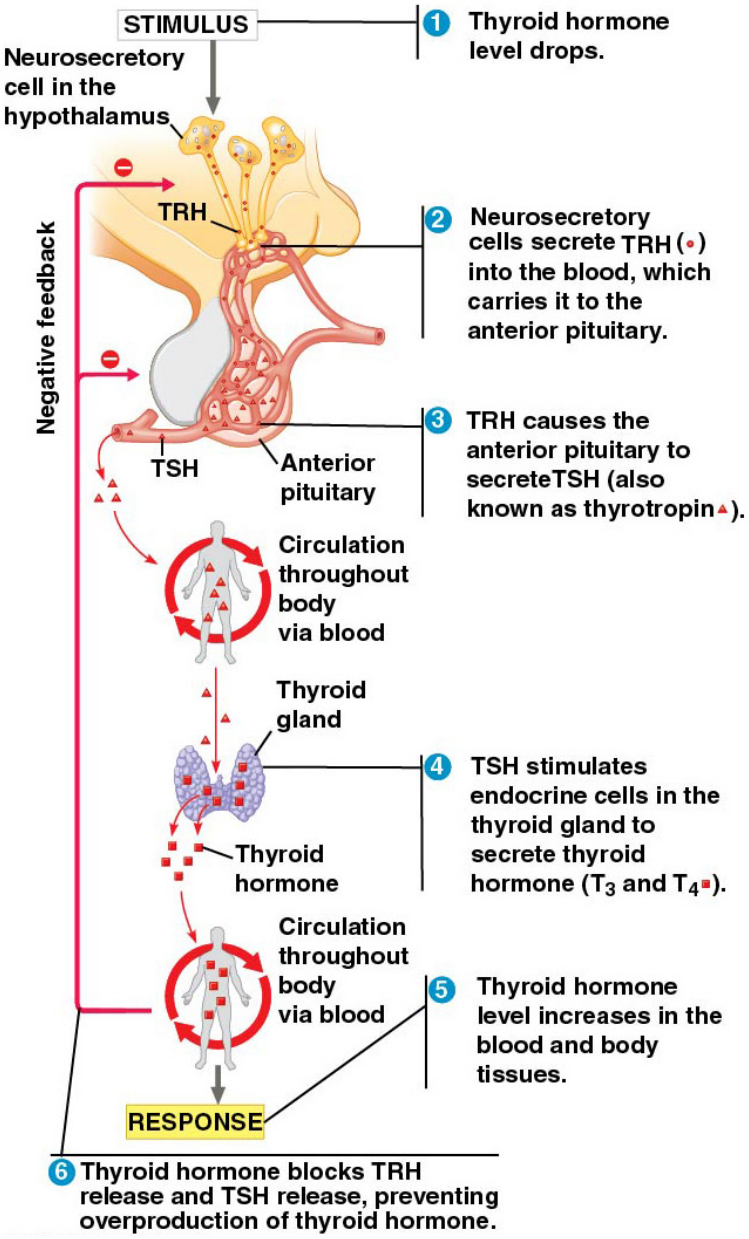

Neurosecretory cells of the hypothalamus
Hypothalamic releasing and inhibiting hormones
Portal vessels
Endocrine cells of the anterior pituitary
Posterior pituitary
Anterior pituitary hormones
HORMONE
TARGET
FSH and LH
TSH
ACTH
Prolactin
MSH
GH
Testes or ovaries
Thyroid
Adrenal cortex
Mammary glands
Melanocytes
Liver, bones, other tissues
Tropic effects only
Nontropic effects only
Tropic and nontropic effects

- Sets of hormones from the hypothalamus, anterior pituitary, and a target endocrine gland are often organized into a hormone cascade
- The anterior pituitary hormones in these pathways are called tropic hormones

Thyroid Regulation: A Hormone Cascade Pathway

- In mammals, **thyroid hormone** regulates many functions
- If thyroid hormone level drops in the blood, the hypothalamus secretes thyrotropin-releasing hormone (TRH), causing the anterior pituitary to secrete thyroid-stimulating hormone (TSH)
- TSH stimulates release of thyroid hormone by the **thyroid gland**

Figure 45.16


STIMULUS
1 Thyroid hormone level drops.
Neurosecretory cell in the hypothalamus
Negative feedback
TRH
2 Neurosecretory cells secrete TRH (•) into the blood, which carries it to the anterior pituitary.
3 TRH causes the anterior pituitary to secreteTSH (also known as thyrotropin▲).
TSH
Anterior pituitary
Circulation throughout body via blood
Thyroid gland
4 TSH stimulates endocrine cells in the thyroid gland to secrete thyroid hormone (T_3 and T_4■).
Thyroid hormone
Circulation throughout body via blood
5 Thyroid hormone level increases in the blood and body tissues.
RESPONSE
6 Thyroid hormone blocks TRH release and TSH release, preventing overproduction of thyroid hormone.

Disorders of Thyroid Function and Regulation

- Disruption of thyroid hormone production and regulation can result in serious disorders
- Thyroid hormone is the only iodine-containing molecule synthesized in the body
- With low levels of thyroid hormone, due to insufficient iodine, the pituitary continues to secrete TSH
- This causes the thyroid to enlarge, resulting in a goiter, a marked swelling of the neck

Hormonal Regulation of Growth

- **Growth hormone** (**GH**) is secreted by the anterior pituitary gland, and has tropic and nontropic effects
- The liver, a major target, responds to GH by releasing insulin-like growth factors (IGFs)
- These stimulate bone and cartilage growth
- An excess of GH can cause gigantism, while a lack of GH can cause dwarfism

Figure 45.17

CONCEPT 45.3: Endocrine glands respond to diverse stimuli in regulating homeostasis, development, and behavior

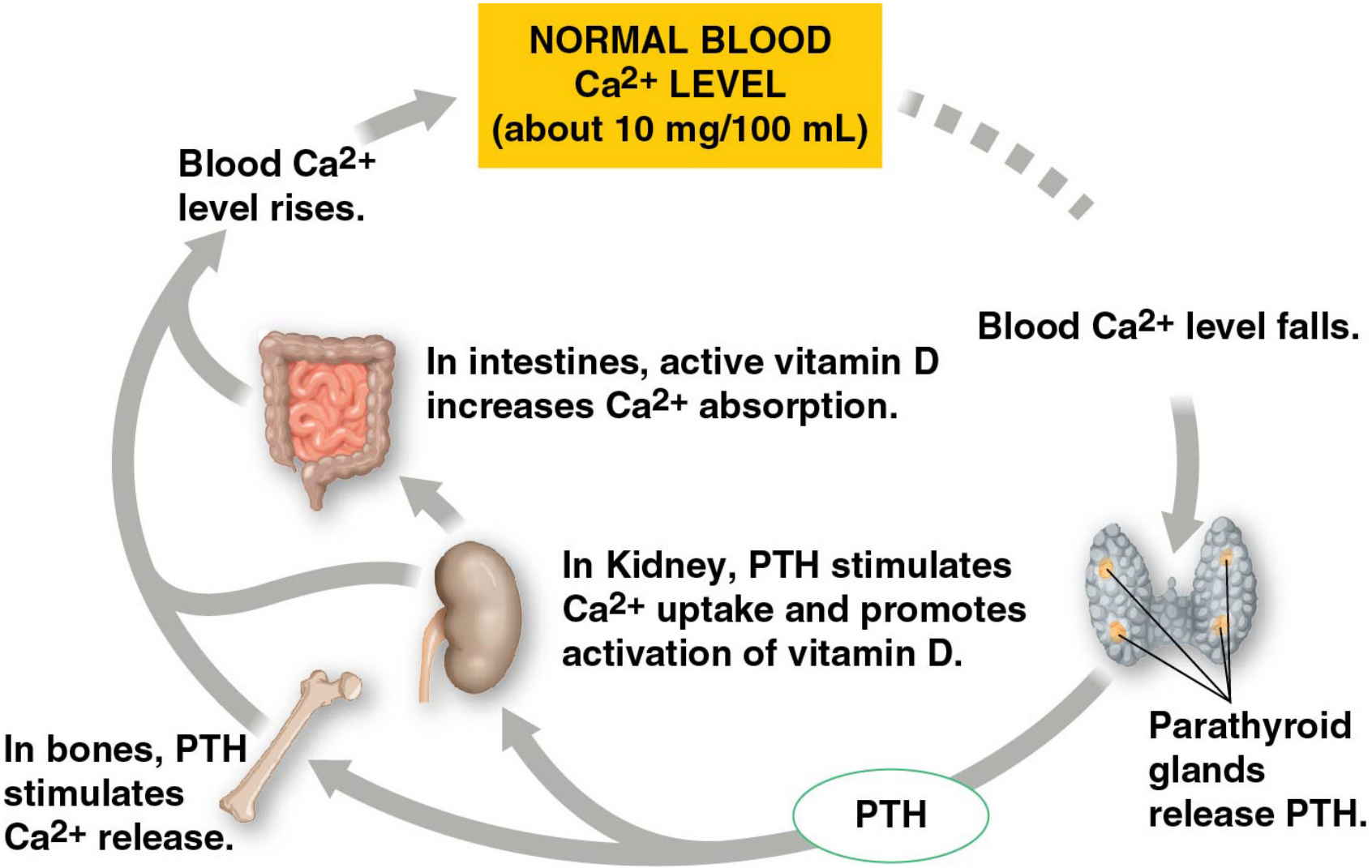
- Endocrine signaling regulates homeostasis, development, and behavior

Parathyroid Hormone and Vitamin D: Control of Blood Calcium

- Homeostatic regulation of calcium (Ca^{2+}) in the blood is vital
- In mammals, **parathyroid hormone** (**PTH**) is released by the **parathyroid glands** when Ca^{2+} levels fall below a set point

- PTH raises the level of blood Ca^{2+}
  - It releases Ca^{2+} from bone and stimulates reabsorption of Ca^{2+} in the kidneys
  - It indirectly affects Ca^{2+} by promoting production of vitamin D
- **Calcitonin** decreases the level of blood Ca^{2+}
  - It stimulates Ca^{2+} deposition in bones and secretion by kidneys

Figure 45.18


NORMAL BLOOD
Ca2+ LEVEL
(about 10 mg/100 mL)
Blood Ca2+
level rises.
Blood Ca2+ level falls.
In intestines, active vitamin D
increases Ca2+ absorption.
In Kidney, PTH stimulates
Ca2+ uptake and promotes
activation of vitamin D.
In bones, PTH
stimulates
Ca2+ release.
PTH
Parathyroid
glands
release PTH.

Adrenal Hormones: Response to Stress

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

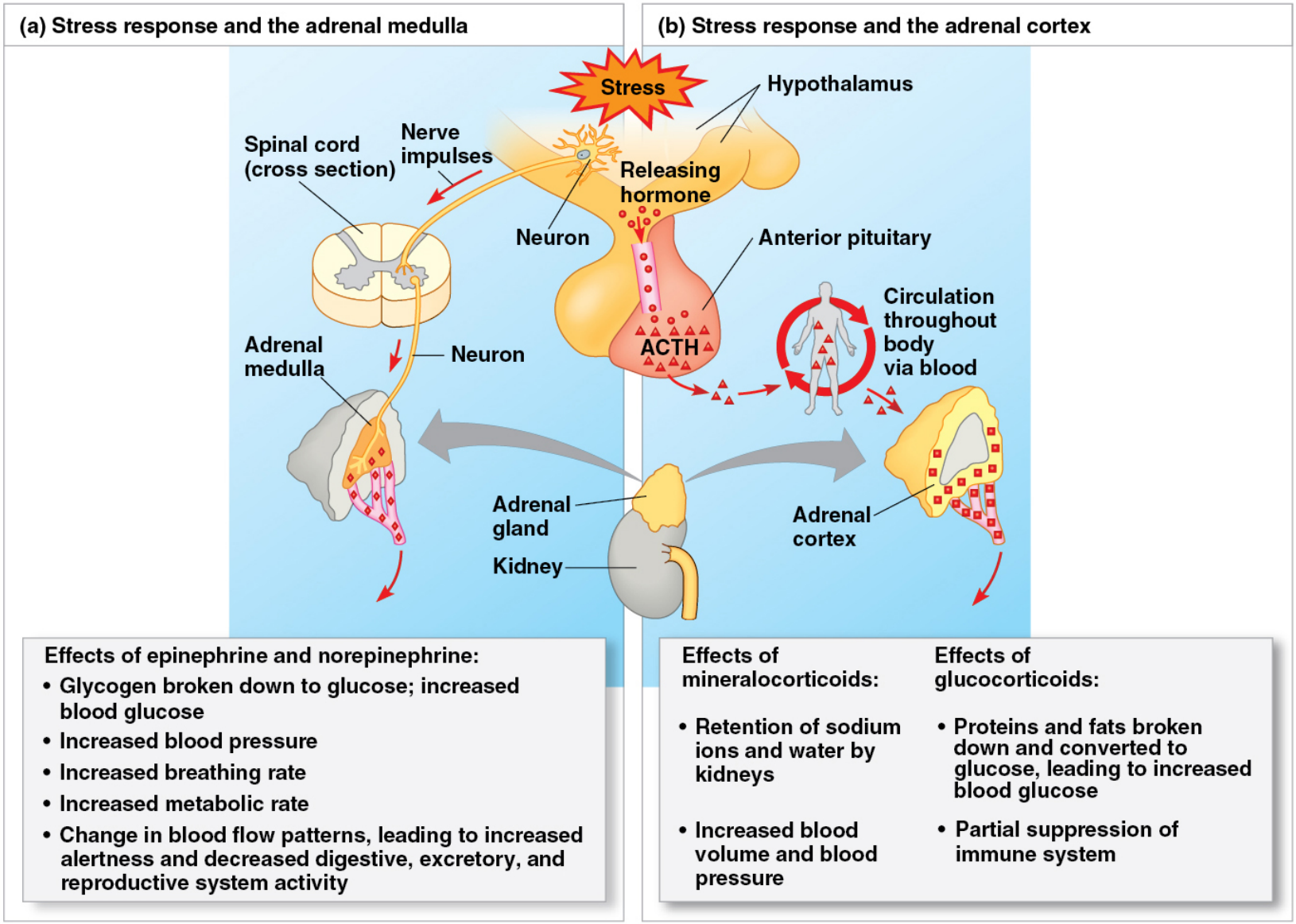
The Role of the Adrenal Medulla

- The adrenal medulla secretes epinephrine (adrenaline) and **norepinephrine** (noradrenaline)
- These hormones are members of a class of compounds called catecholamines
- They coordinate a set of physiological responses that comprise the “fight-or-flight” response

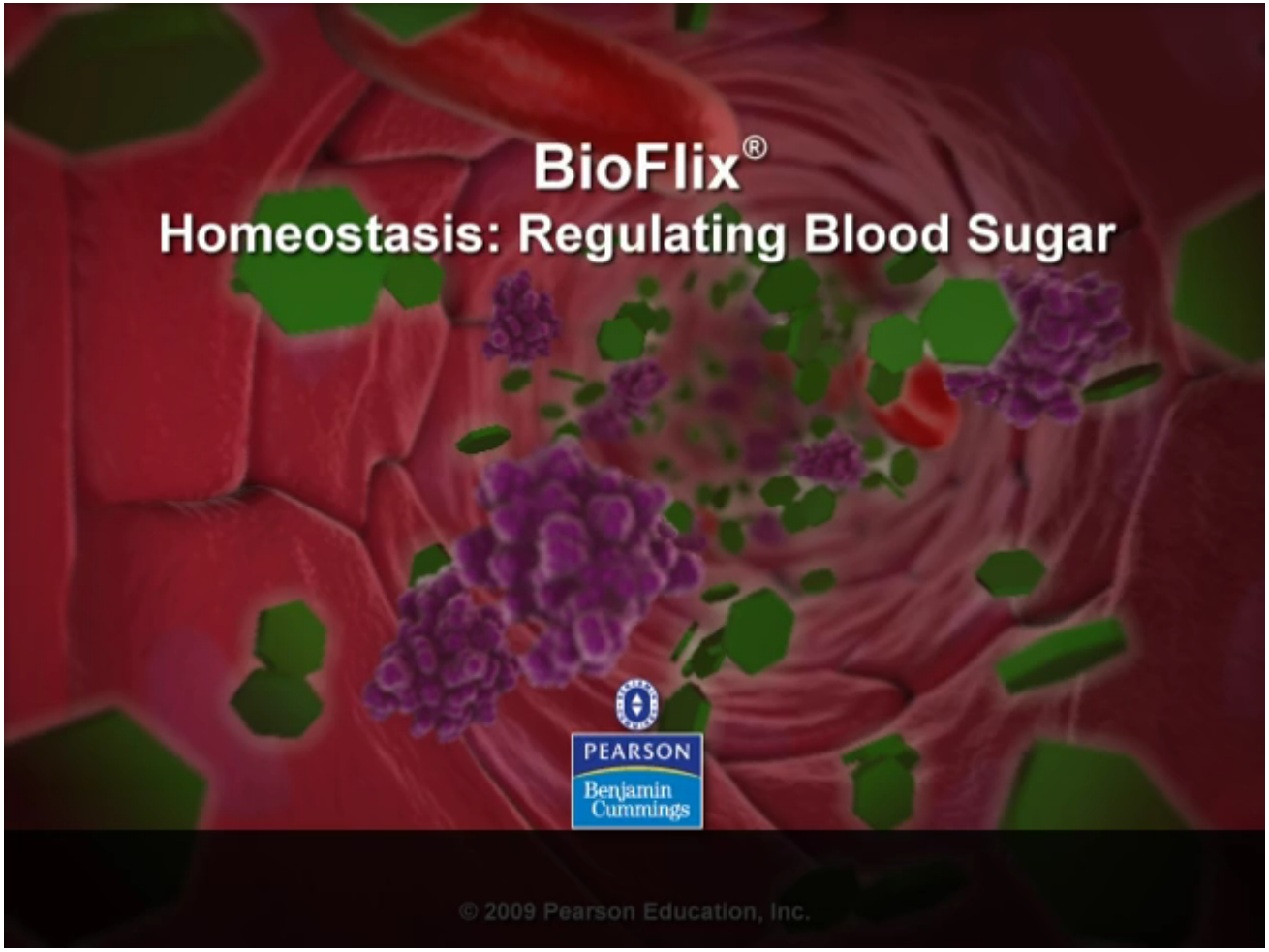
- Epinephrine and norepinephrine
  - Increase the rate of glycogen breakdown in liver cells
  - Trigger the release of glucose and fatty acids into the blood
  - Raise the rate of oxygen delivery to body cells
  - Direct blood toward heart, brain, and skeletal muscles and away from skin, digestive system, and kidneys

Animation: Hormonal Response to Stress

Figure 45.19


(a) Stress response and the adrenal medulla
(b) Stress response and the adrenal cortex
Stress
Hypothalamus
Spinal cord (cross section)
Nerve impulses
Releasing hormone
Neuron
Anterior pituitary
Circulation throughout body via blood
ACTH
Adrenal medulla
Neuron
Adrenal gland
Kidney
Adrenal cortex
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

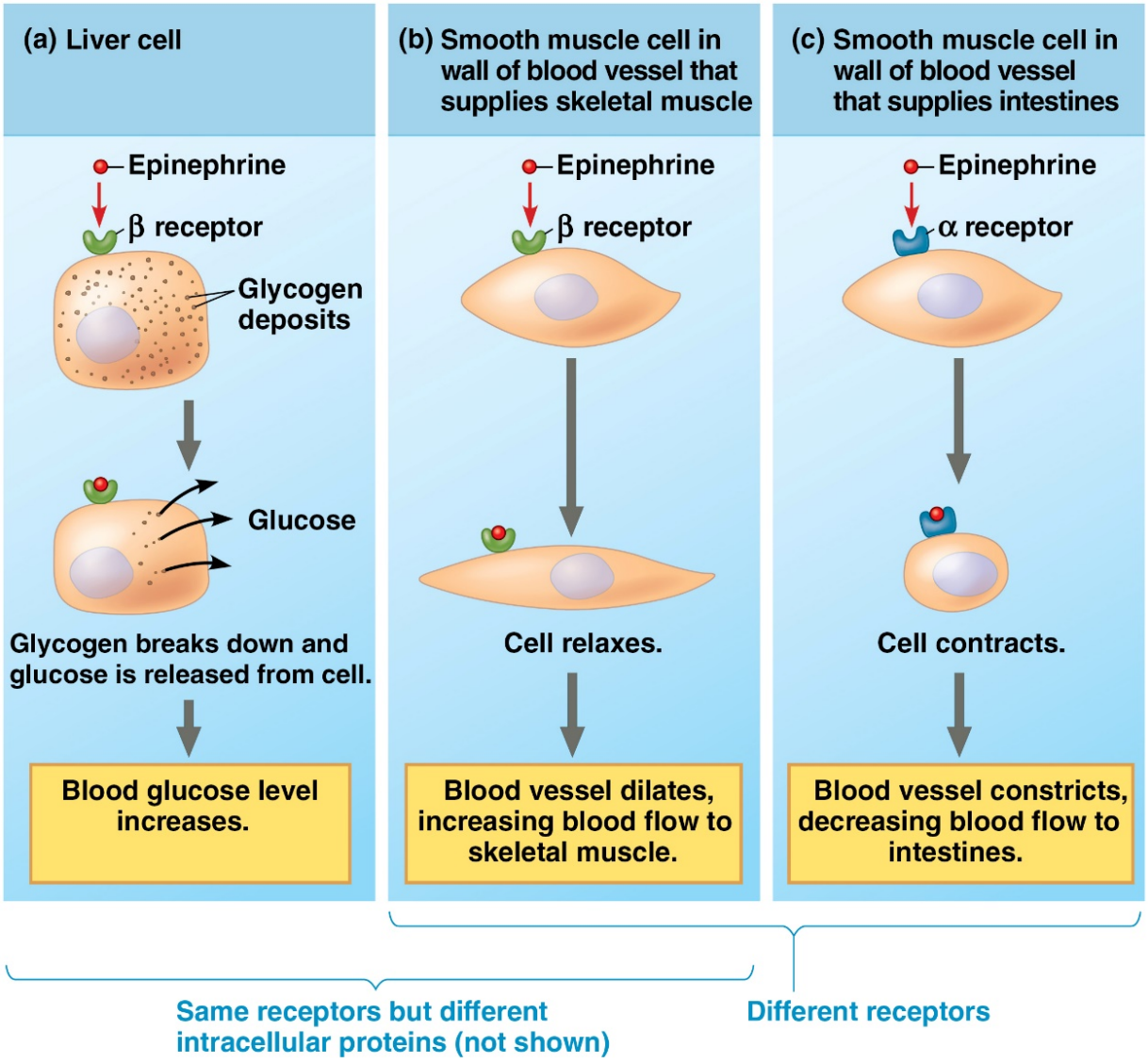
BioFlix® Animation: Homeostasis



Epinephrine's Multiple Effects: A Closer Look

- Epinephrine coordinates a response in a range of target cells
  - In liver cells, it binds to a receptor that activates protein kinase A, which regulates glycogen metabolism
  - In smooth muscle cells lining blood vessels supplying skeletal muscle, it leads to vasodilation to increase blood supply
  - In smooth muscle of blood vessels of the intestines, it leads to vasoconstriction and reduced blood flow

Figure 45.20


(a) Liver cell
(b) Smooth muscle cell in wall of blood vessel that supplies skeletal muscle
(c) Smooth muscle cell in wall of blood vessel that supplies intestines
Epinephrine
β receptor
Glycogen deposits
Glucose
Glycogen breaks down and glucose is released from cell.
Blood glucose level increases.
Epinephrine
β receptor
Cell relaxes.
Blood vessel dilates, increasing blood flow to skeletal muscle.
Epinephrine
α receptor
Cell contracts.
Blood vessel constricts, decreasing blood flow to intestines.
Same receptors but different intracellular proteins (not shown)
Different receptors

The Role of the Adrenal Cortex

- The adrenal cortex becomes active under stressful conditions including low blood sugar, decreased blood volume and pressure, and shock
- A series of hormonal signals lead to production and secretion of a family of steroids called corticosteroids
- Humans produce two types of corticosteroids: glucocorticoids and mineralocorticoids

- **Glucocorticoids**, such as cortisol, influence glucose metabolism and the immune system
- **Mineralocorticoids**, such as aldosterone, affect salt and water balance

Sex Hormones

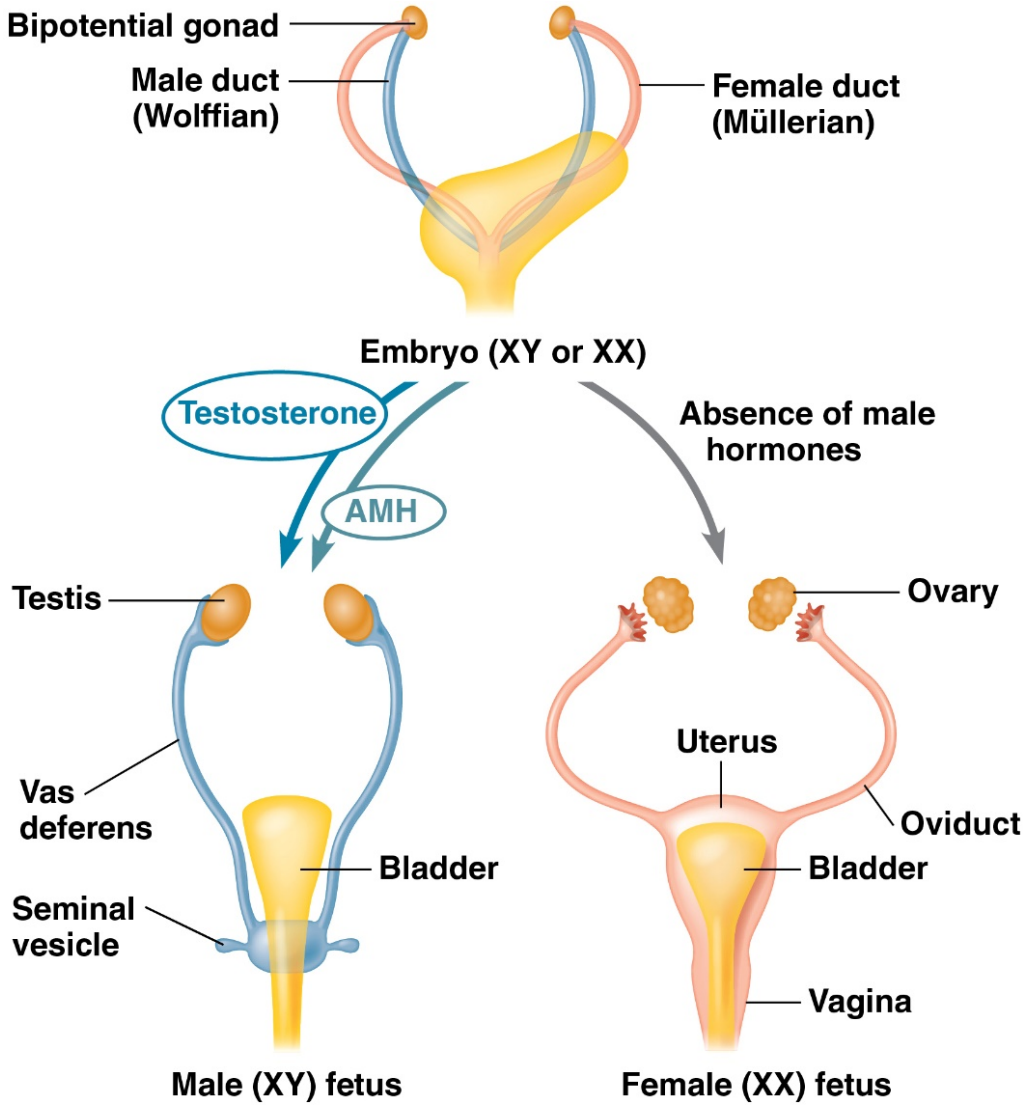
- The gonads, testes and ovaries, produce most of the sex hormones: androgens, estrogens, and progesterone
- All three types are found in both males and females, but in different proportions

- The testes primarily synthesize **androgens**, mainly **testosterone**, which promote development of male reproductive structures
- Testosterone is responsible for male secondary sex characteristics

- **Estrogens**, most importantly **estradiol**, are responsible for maintenance of the female reproductive system
- They are also responsible for development of female secondary sex characteristics
- In mammals, **progesterone** is primarily involved in preparing and maintaining the uterus

- Synthesis of the sex hormones is controlled by the gonadotropins, follicle-stimulating hormone and luteinizing hormone from the anterior pituitary
- Gonadotropin secretion is controlled by gonadotropin-releasing hormone from the hypothalamus

Figure 45.21


Bipotential gonad
Male duct (Wolffian)
Female duct (Müllerian)
Embryo (XY or XX)
Testosterone
AMH
Absence of male hormones
Testis
Vas deferens
Seminal vesicle
Bladder
Male (XY) fetus
Ovary
Uterus
Oviduct
Bladder
Vagina
Female (XX) fetus

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

Hormones and Biological Rhythms

- The **pineal gland**, located in the brain, secretes **melatonin**
- Primary functions of melatonin relate to biological rhythms associated with reproduction and with daily activity levels
- The release of melatonin by the pineal gland is controlled by a group of neurons in the hypothalamus called the suprachiasmatic nucleus (SCN)
- The SCN functions as a biological clock

Evolution of Hormone Function

- Over the course of evolution, the functions of particular hormones have diverged
- 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 45.22

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 roles in hunger and metabolism in addition to coloration

Figure 45.UN01

Figure 45.UN02

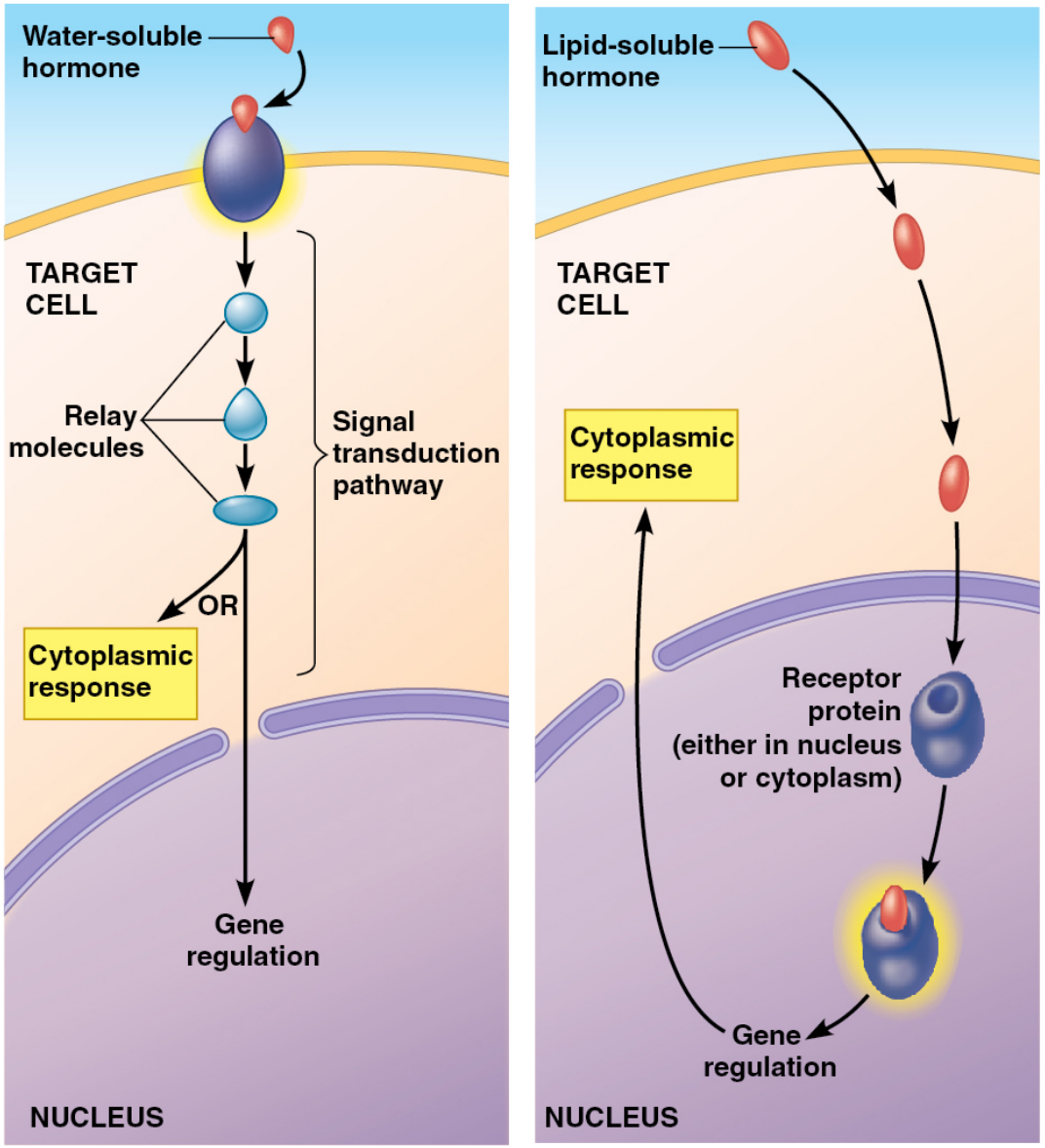


Figure 45.UN03

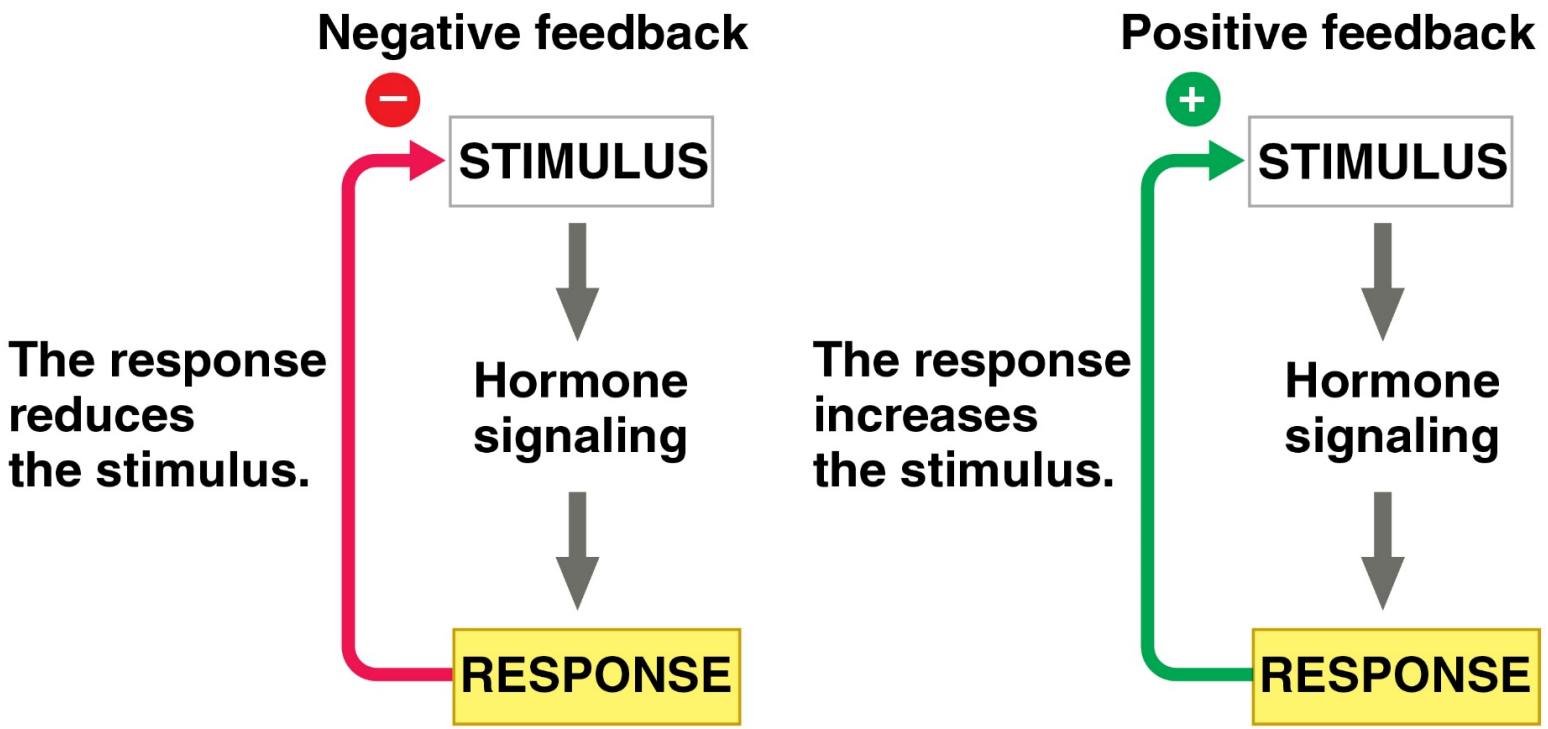


Figure 45.UN04

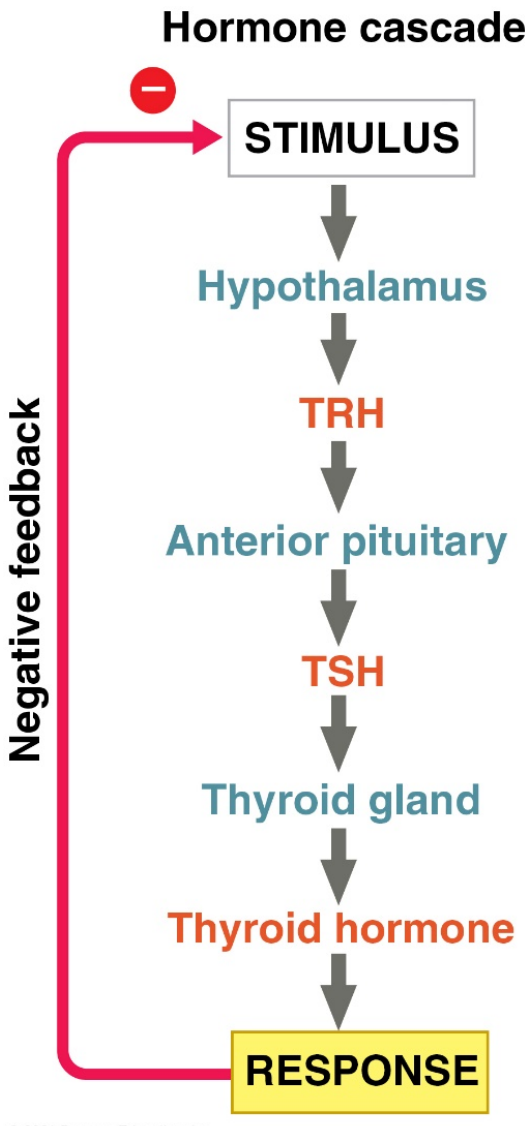


Figure 45.UN05

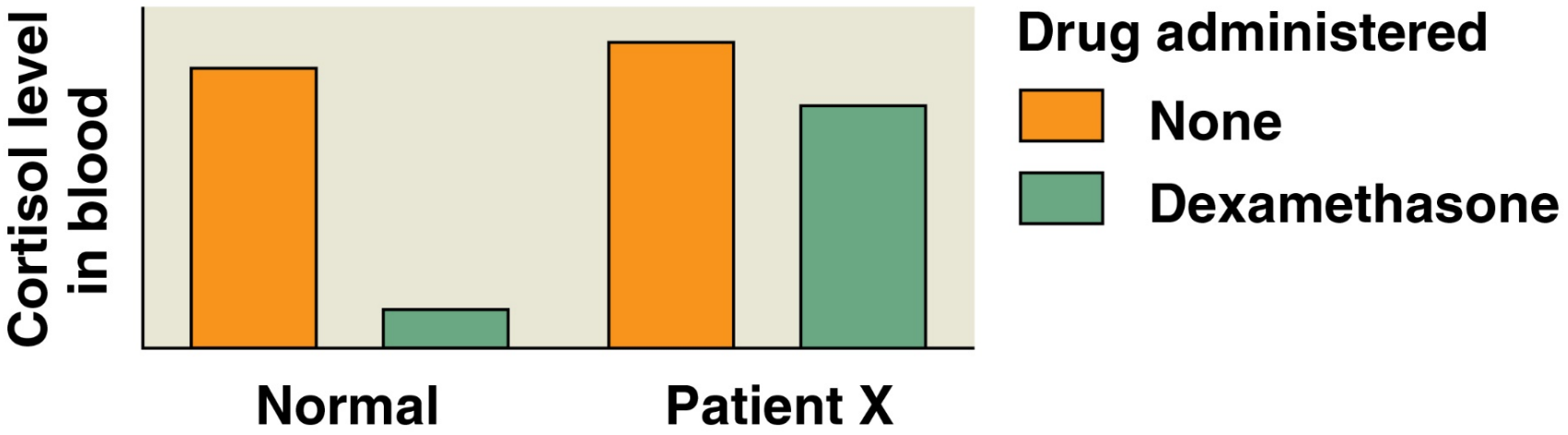


Figure 45.UN06