Chapter 45

Hormones and the Endocrine System

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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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 are equipped to respond.
- Insect metamorphosis is regulated by hormones.

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- 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.

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What role do hormones play in transforming a caterpillar into a butterfly?

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

- **Chemical signals bind to receptor proteins on target cells**.
- Only target cells respond to the signal.

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Types of Secreted Signaling Molecules

- ***Secreted chemical signals*** include
  - *Hormones*
  - *Local regulators*
  - *Neurotransmitters*
  - *Neurohormones*
  - *Pheromones*

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Hormones

- Endocrine signals (hormones) are secreted into extracellular fluids and travel via the bloodstream.
- **Endocrine glands** are ductless and secrete hormones directly into surrounding fluid.
- ***Hormones mediate responses to environmental stimuli*** *and* ***regulate growth, development,*** *and* ***reproduction.***
- **Exocrine glands** have ducts and secrete substances onto body surfaces or into body cavities (for example, tear ducts).

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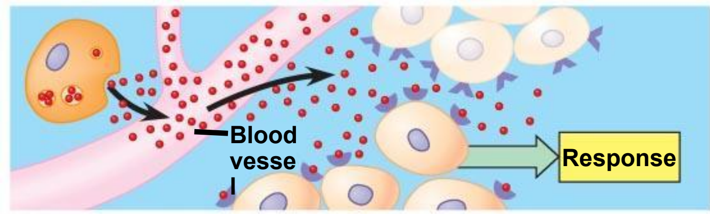
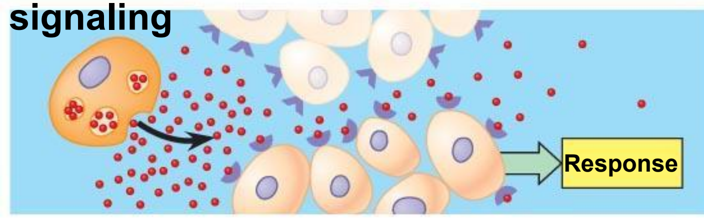
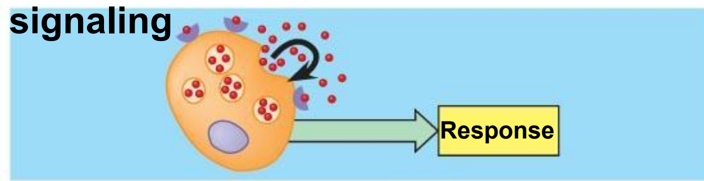
Intercellular communication by secreted molecules



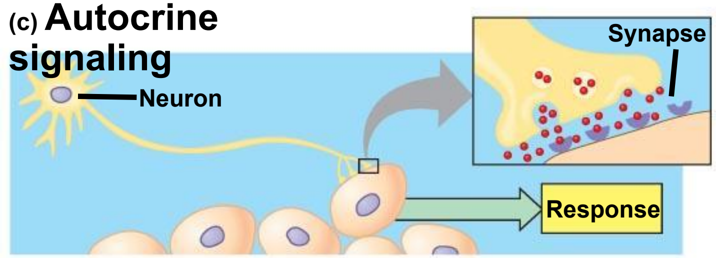
(a) **Endocrine signaling**



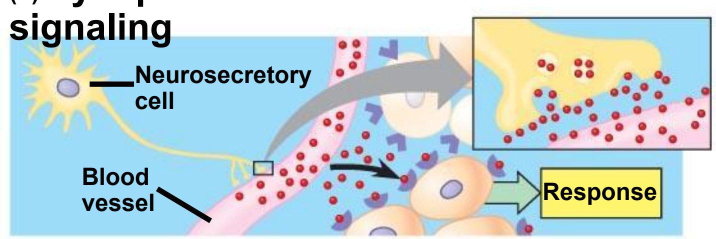
(b) **Paracrine signaling**



(c) **Autocrine signaling**



(d) **Synaptic signaling**



(e) **Neuroendocrine signaling**

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Local Regulators = Short Distance Chemical Signals

- ***Local regulators*** are chemical signals that travel over *short distances* by diffusion.
- Local regulators help regulate blood pressure, nervous system function, and reproduction.
- Local regulators are divided into two types:
  - ***Paracrine*** signals act on cells near the secreting cell.
  - ***Autocrine*** signals act on the secreting cell itself.

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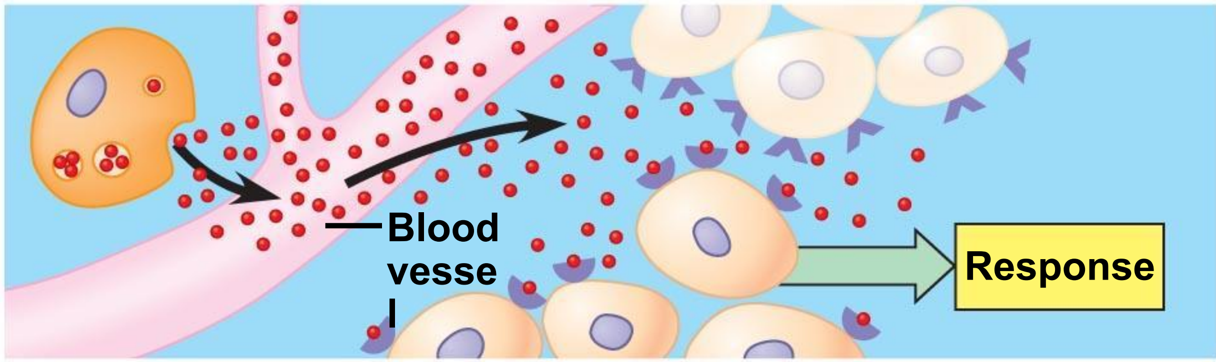
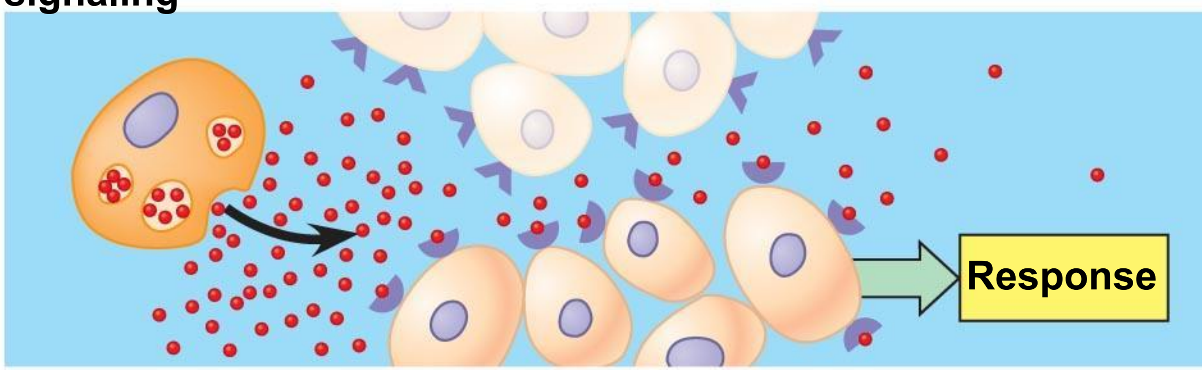
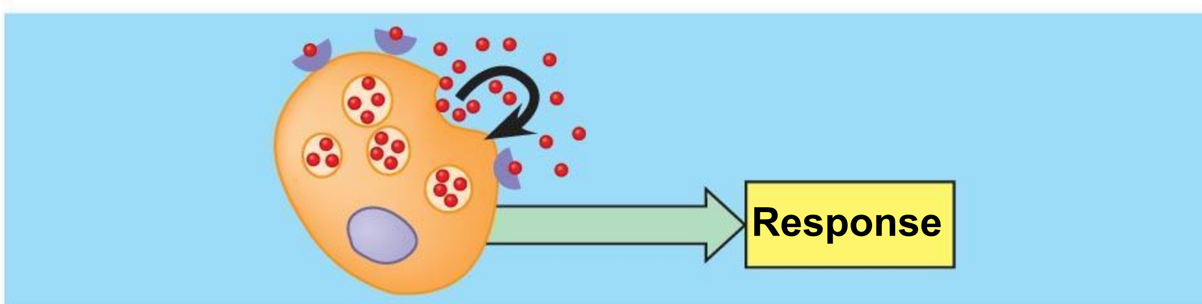
Intercellular communication by secreted molecules



(a) ***Endocrine*** **signaling**



(b) ***Paracrine*** **signaling**



(c) ***Autocrine*** **signaling**

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Neurotransmitters and Neurohormones

- ***Neurons*** *(nerve cells)* ***contact target cells at synapses***.
- *At synapses*, neurons often ***secrete chemical signals*** *called* ***neurotransmitters*** that diffuse a short distance to bind to receptors on the target cell. Neurotransmitters play a role in sensation, memory, cognition, and movement.
- ***Neurohormones*** are a class of hormones that originate *from neurons in the brain* and diffuse through the *bloodstream*.

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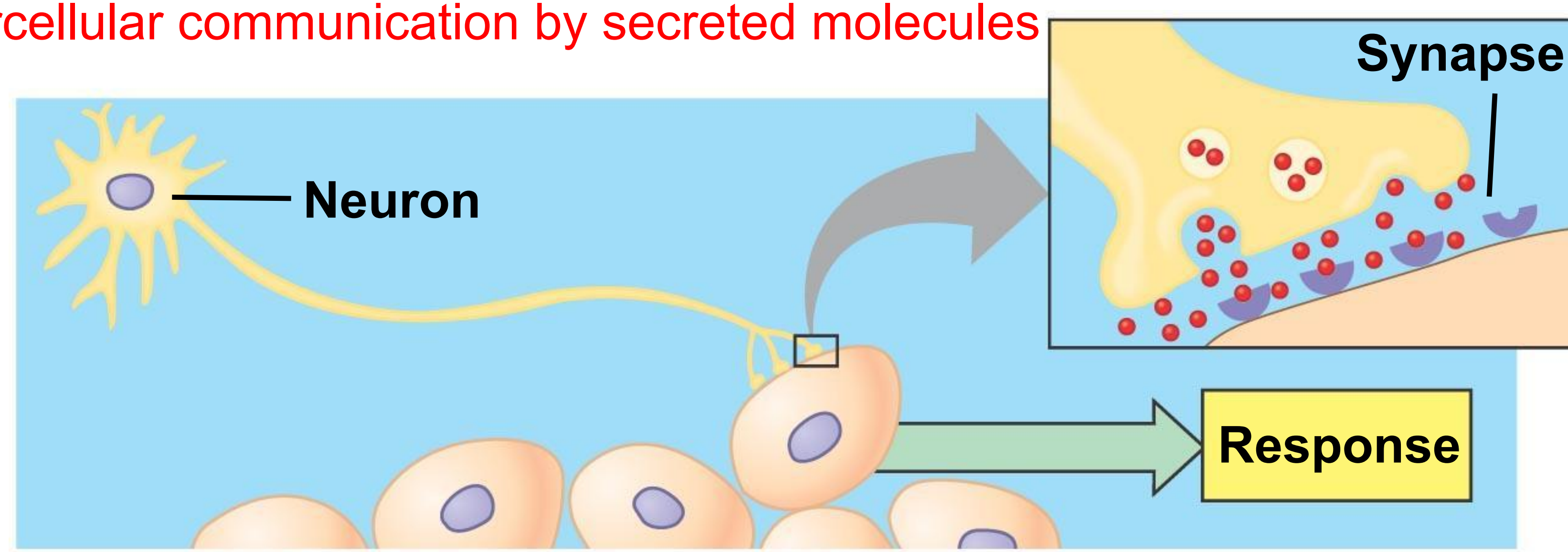
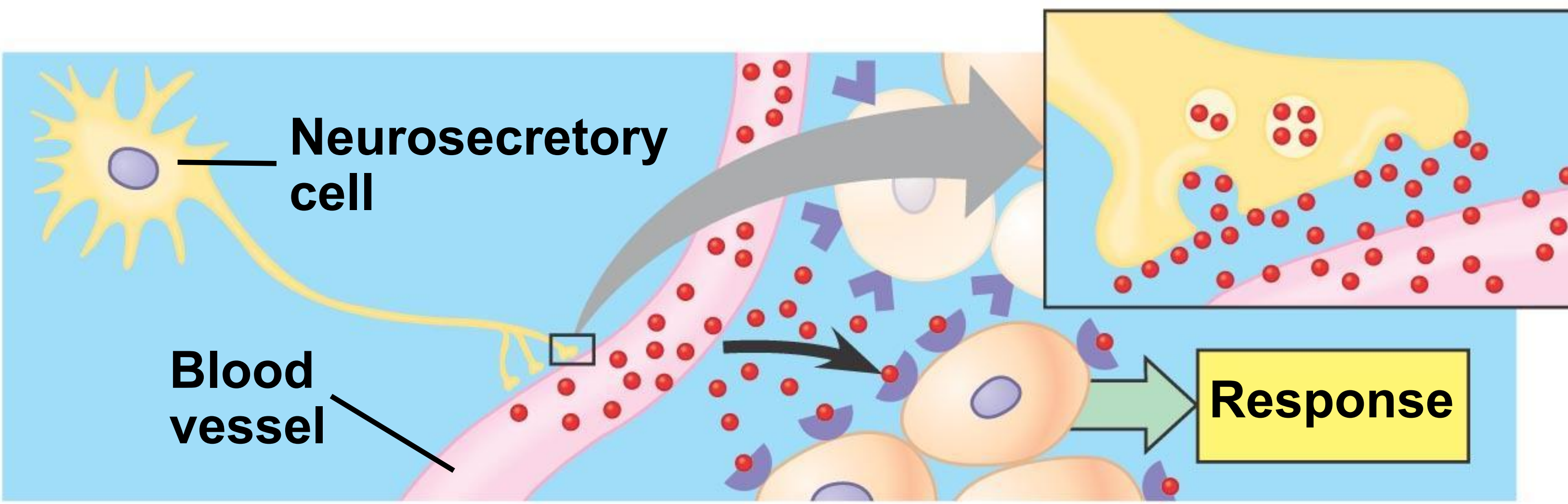
Intercellular communication by secreted molecules



(d) Synaptic signaling - neurotransmitters



(e) Neuroendocrine signaling

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Pheromones

- ***Pheromones*** are chemical signals that are released from the body and used to *communicate with other individuals in the species*.
- Pheromones mark trails to food sources, warn of predators, and attract potential mates.

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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

  Polypeptides and amines are water-soluble.

  Steroids are lipid-soluble.

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

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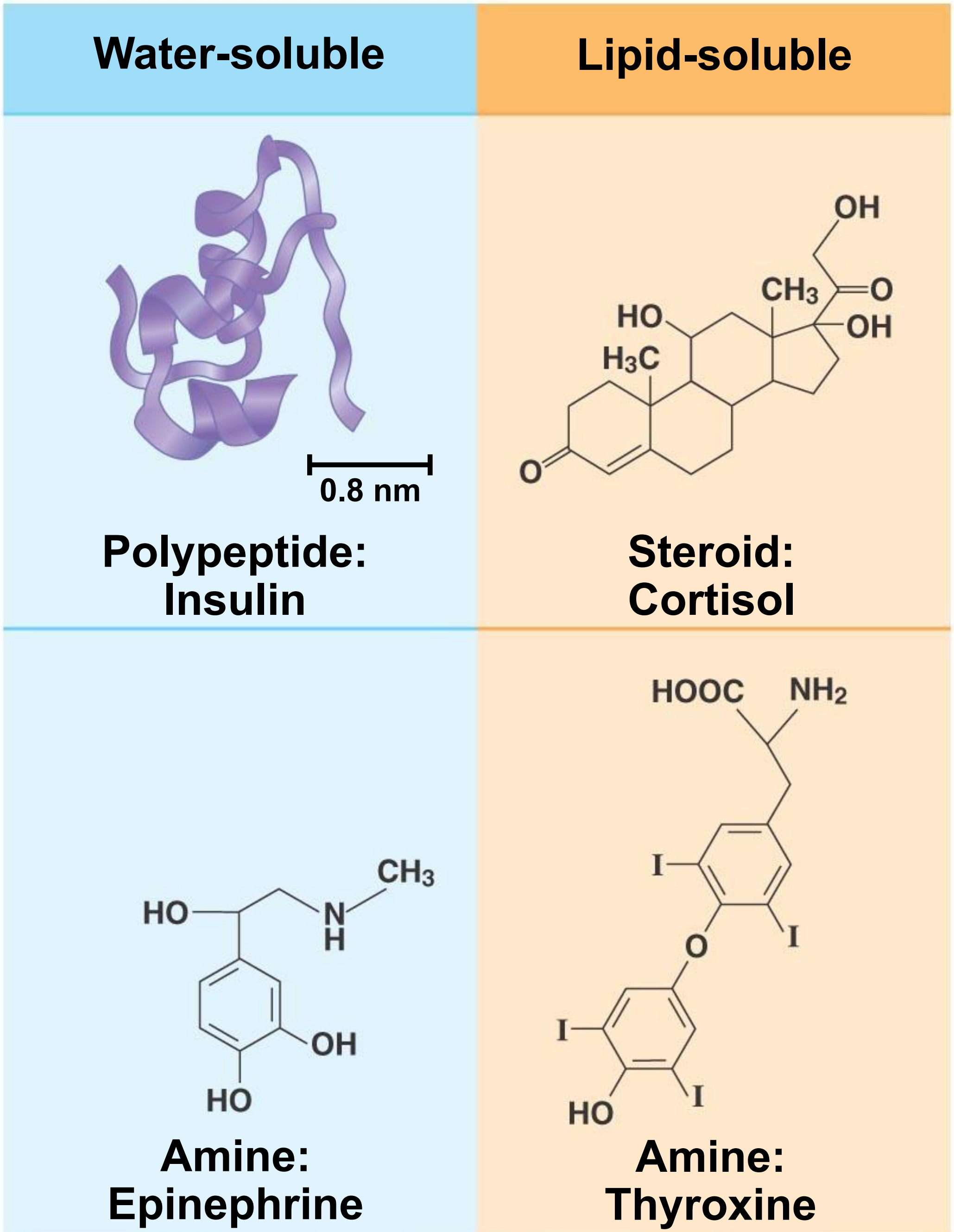
Hormones differ in form and solubility



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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 plasma *membrane* of target cells.

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signal transduction pathway

- ***Signaling*** by any of these hormones involves three key events:
  - ***Reception***
  - ***Signal transduction***
  - ***Response***
- 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.

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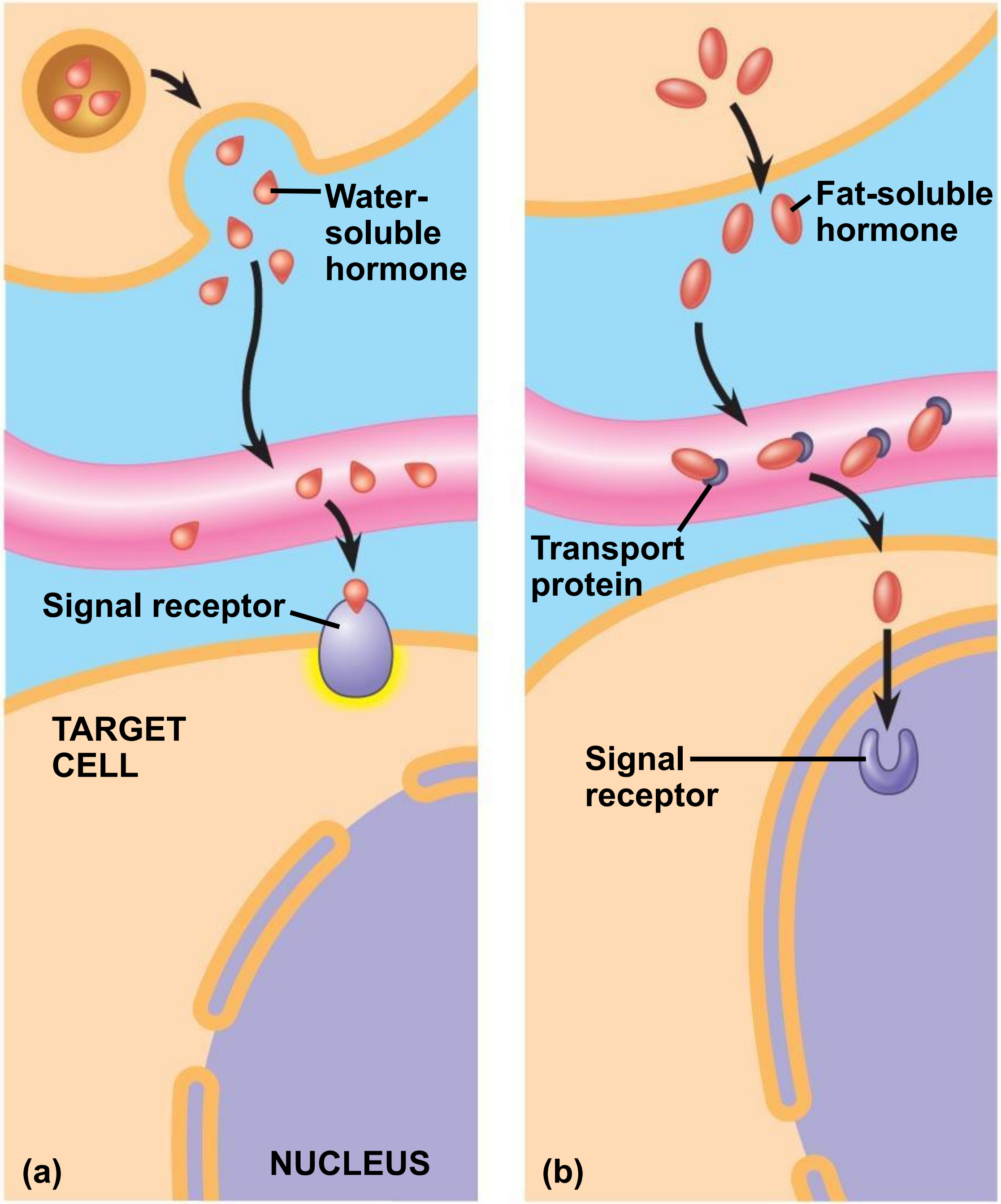
Receptor location varies with hormone type



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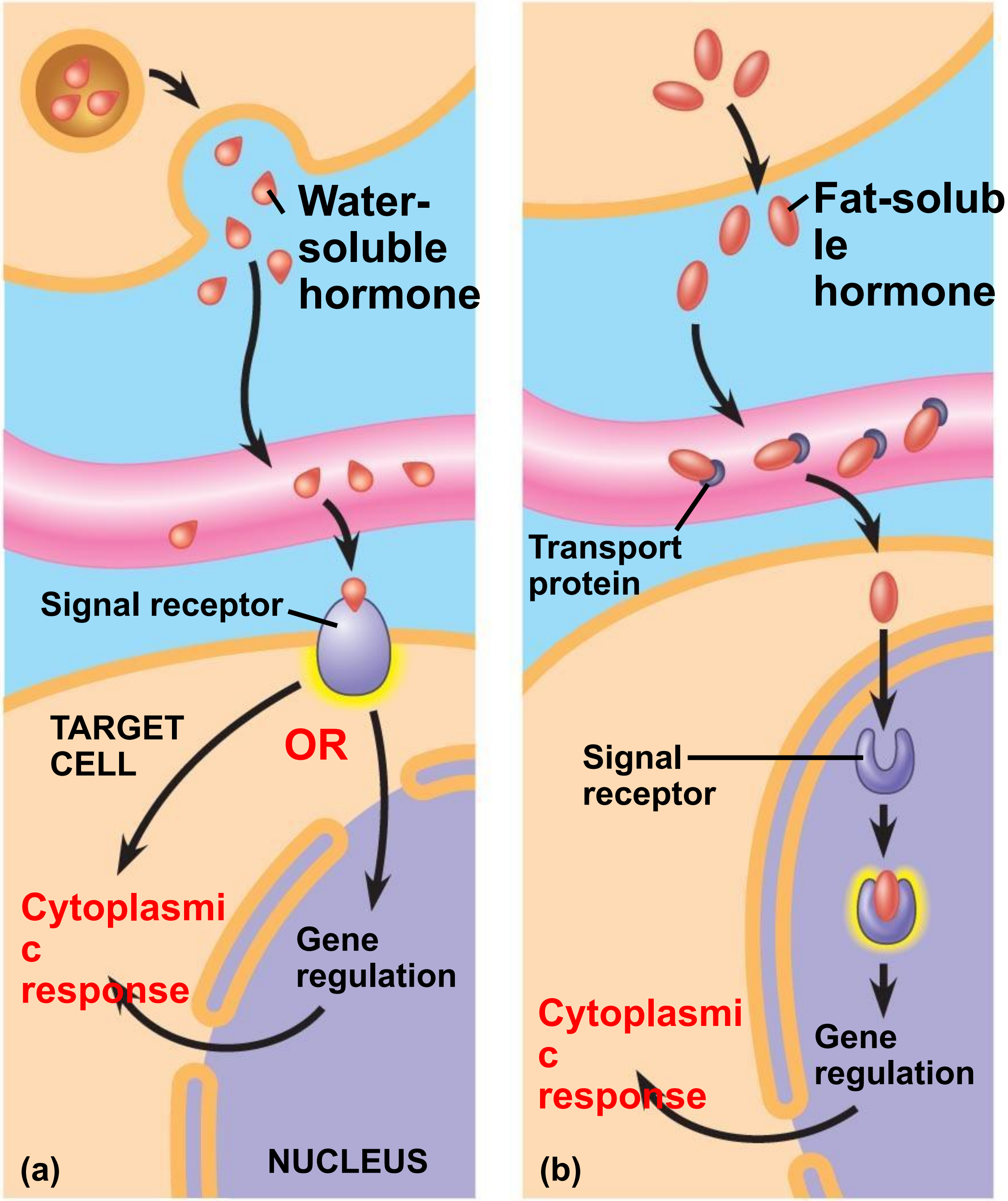
Receptor location varies with hormone type



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Pathway for Water-Soluble Hormones

- 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.

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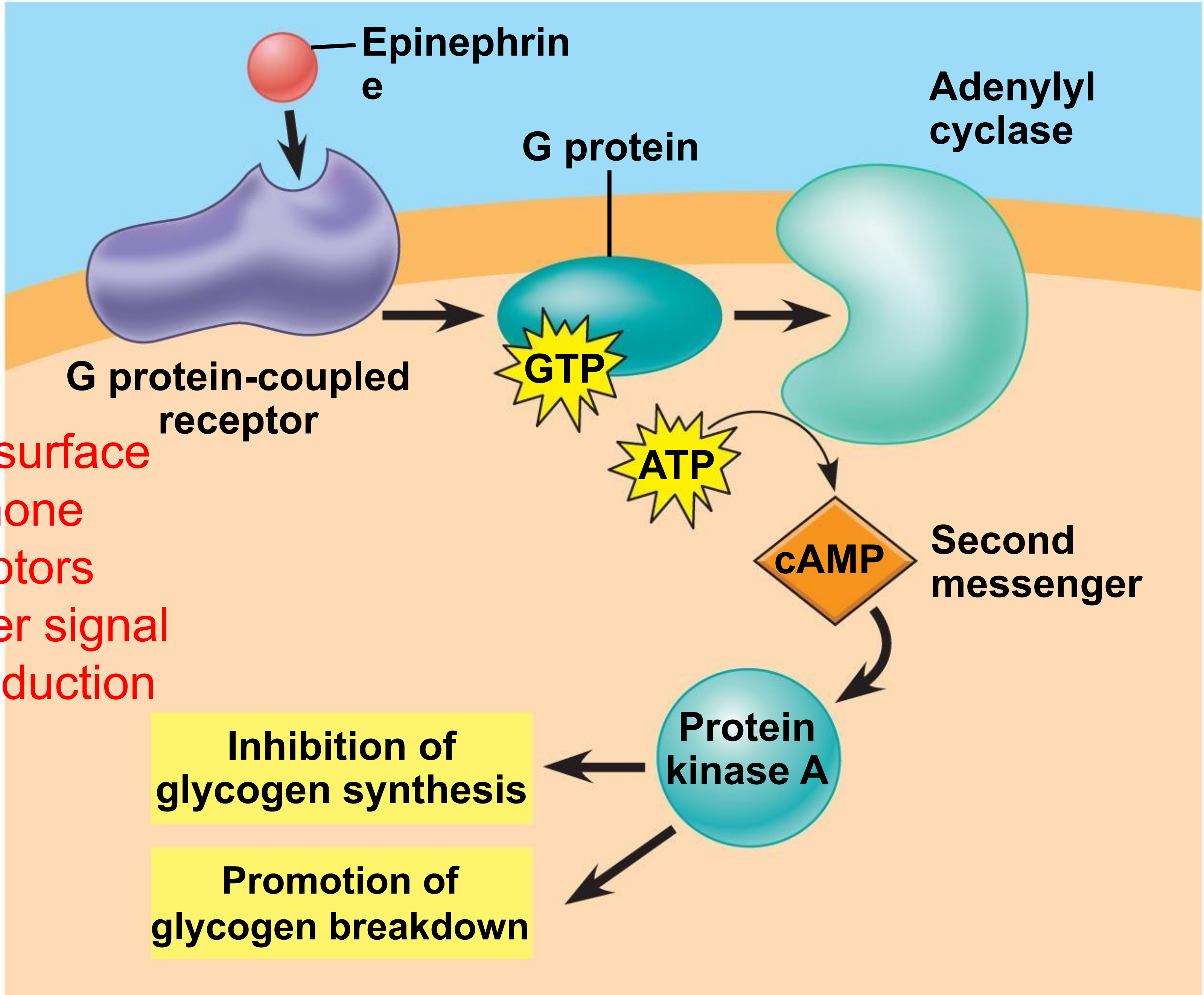

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Cell-surface hormone receptors trigger signal transduction

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.

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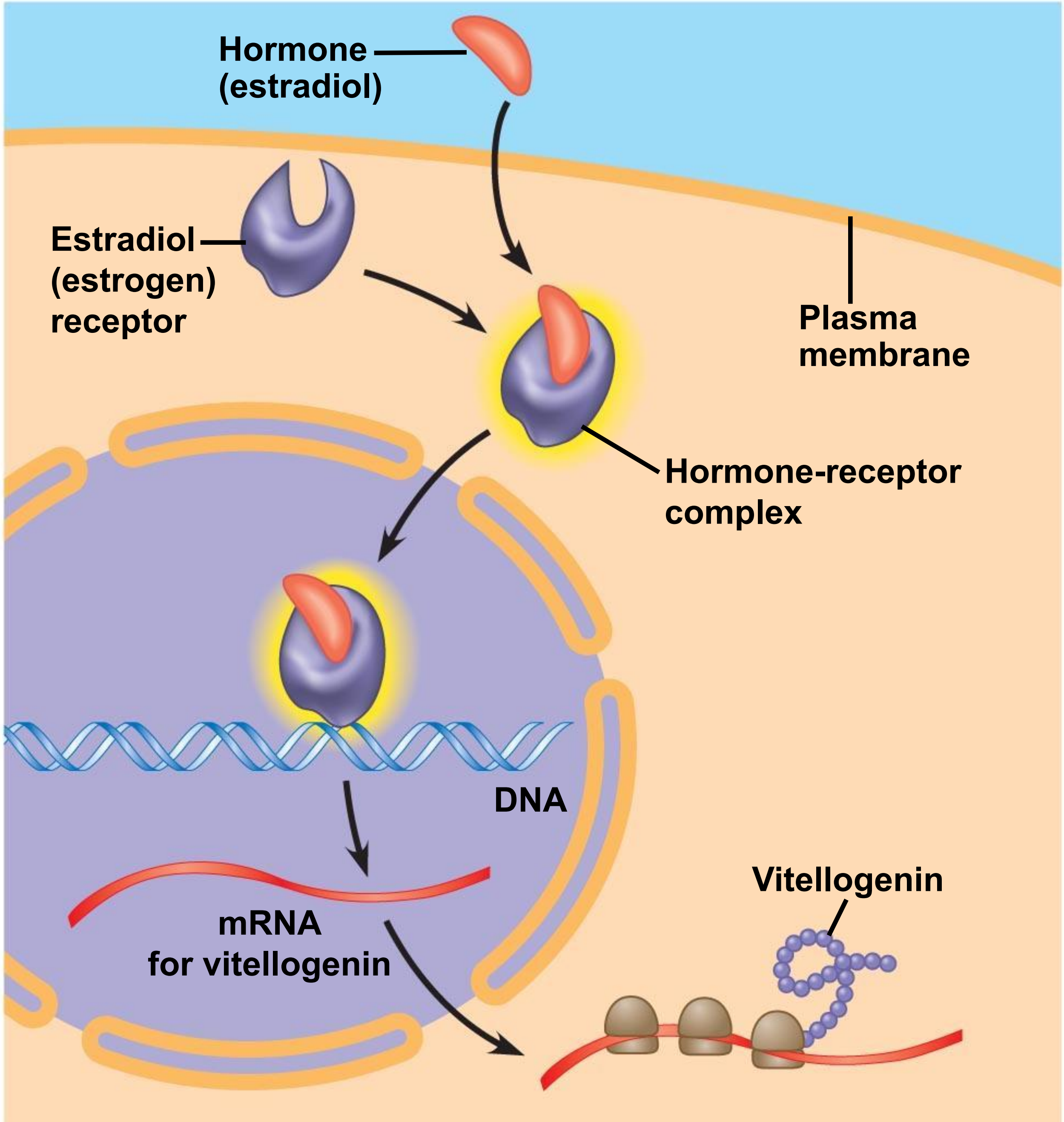
Steroid hormone receptors are inside the cell and directly regulate gene expression



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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*
  - *Different proteins* for carrying out the response.
- A hormone can also have different effects in different species.

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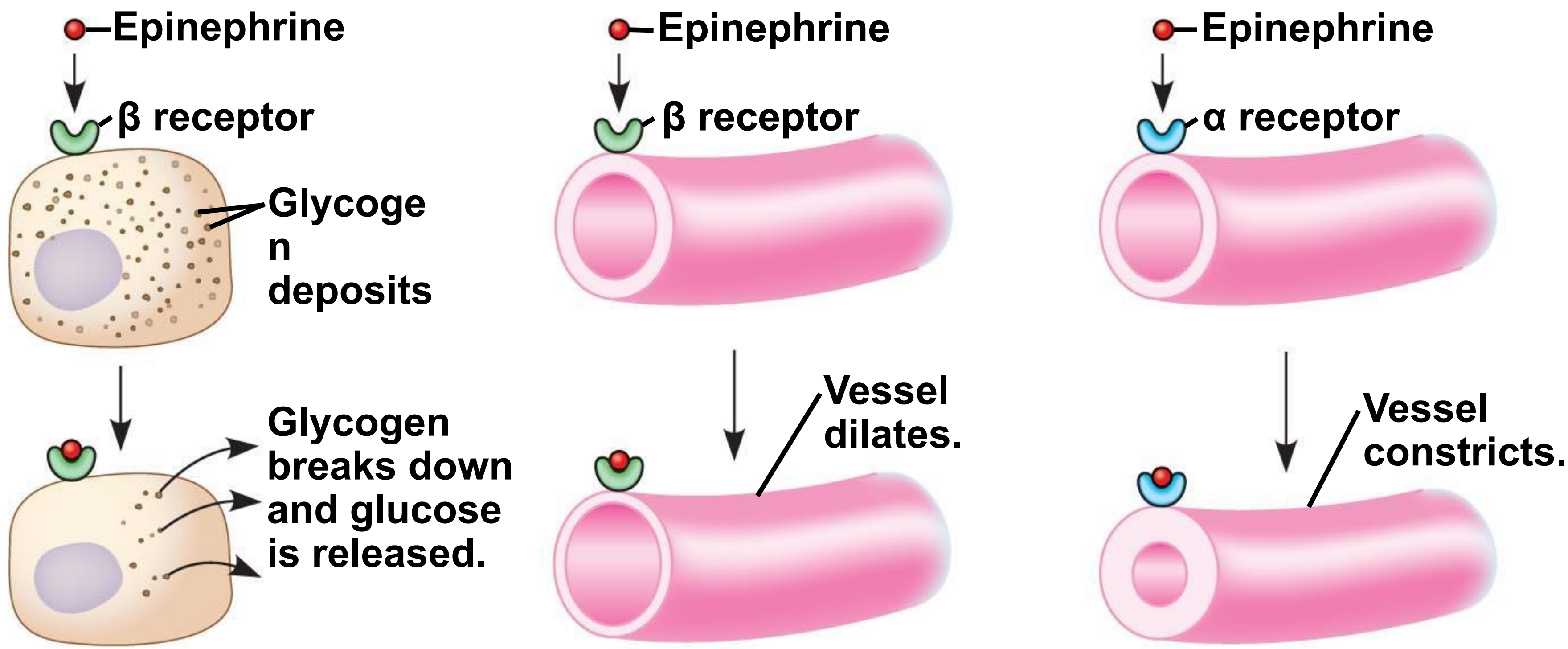
One hormone, different effects

Same receptors but different intracellular proteins

Different receptors



(a) Liver cell

(b) Skeletal muscle blood vessel

(c) Intestinal blood vessel

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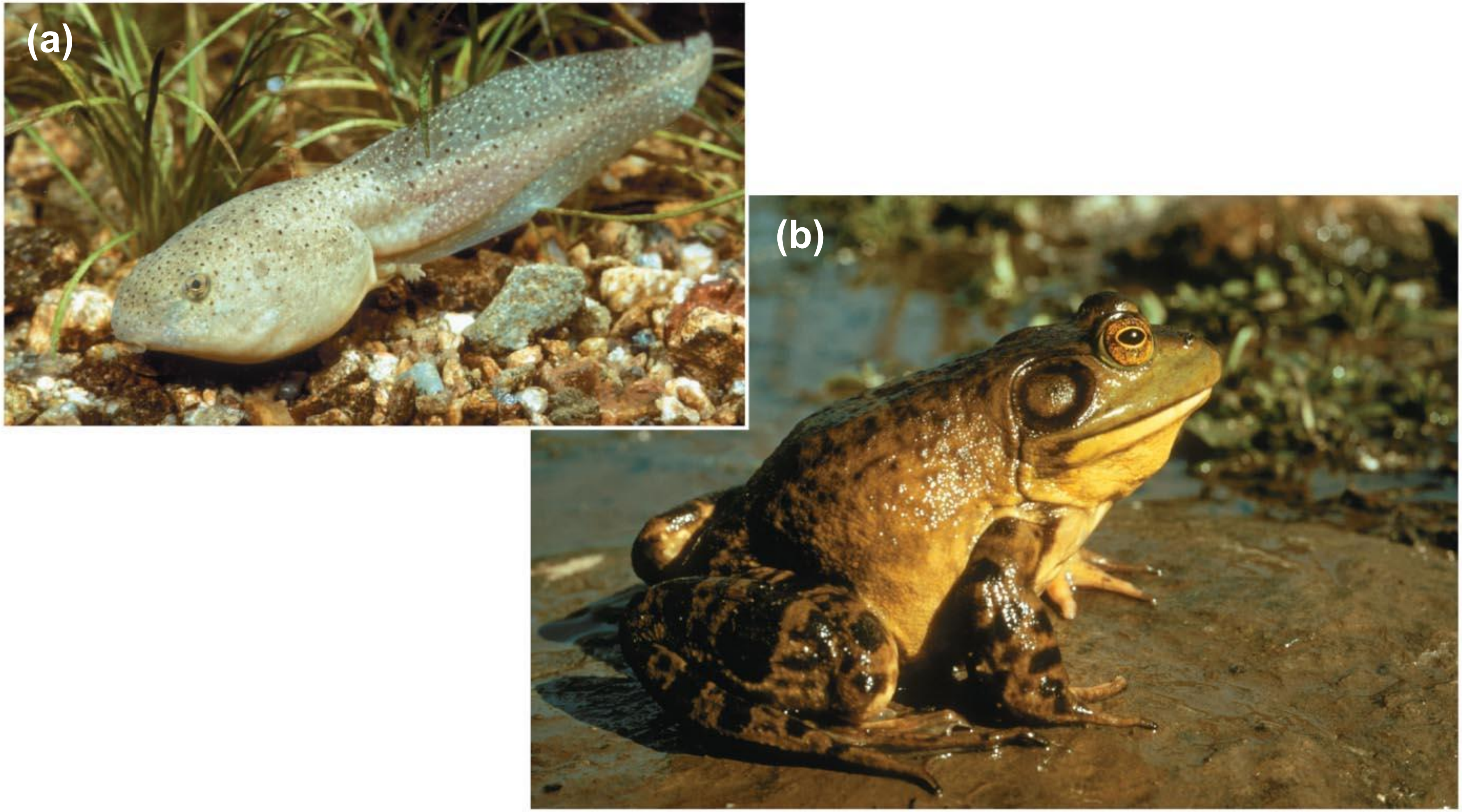
Specialized role of a hormone in frog metamorphosis



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Signaling by Local Regulators

- In paracrine signaling, nonhormonal chemical signals called local regulators elicit responses in nearby target cells.
- Types of local regulators:
  - **Cytokines** and **growth factors**
  - **Nitric oxide (NO)**
  - **Prostaglandins -** help regulate aggregation of platelets, an early step in formation of blood clots.

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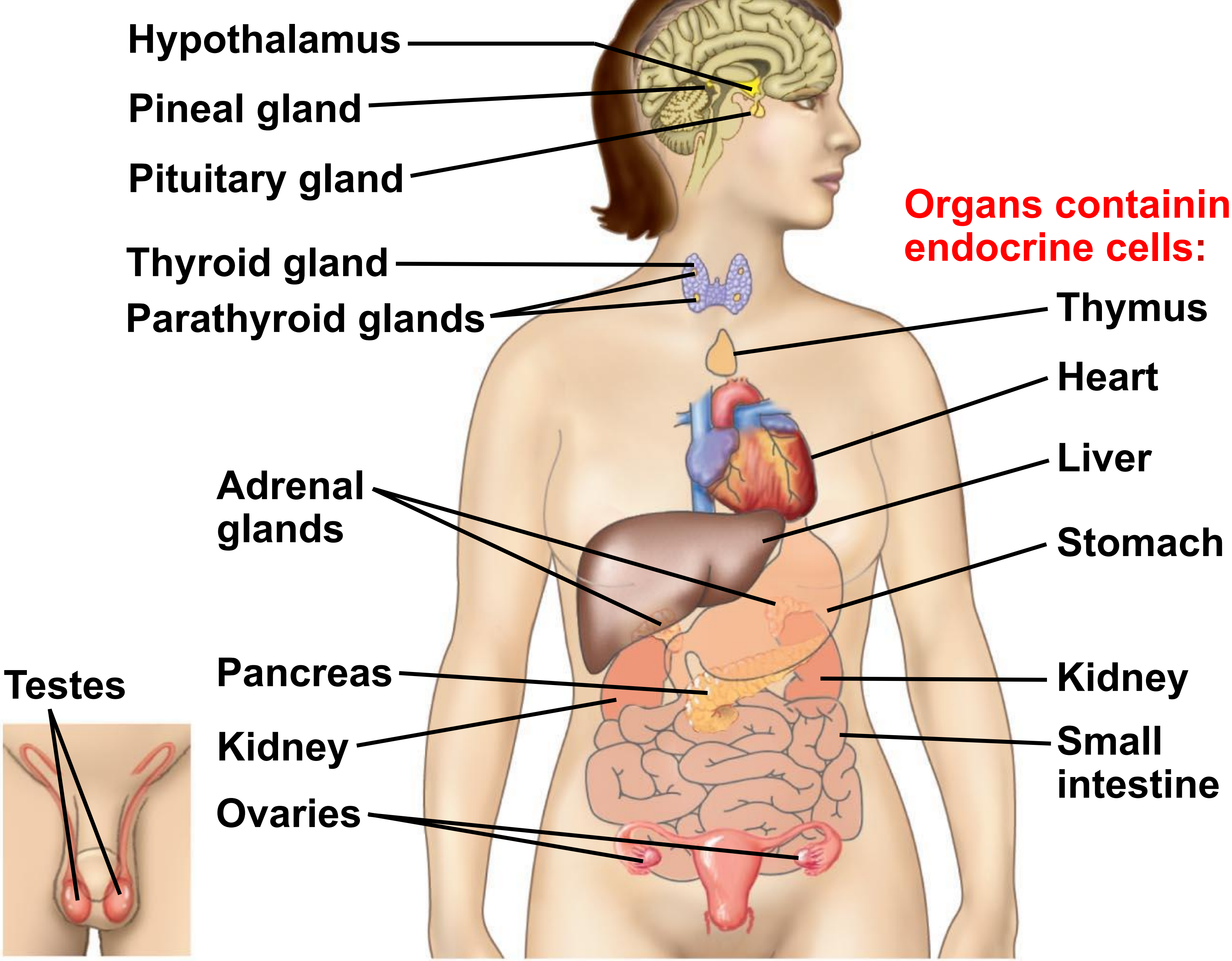
Major endocrine glands:



Organs containing endocrine cells:

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Simple Hormone Pathways

- Negative feedback and antagonistic hormone pairs are common features of the endocrine system.
- Hormones are assembled into regulatory pathways.
- ***Hormones*** *are released from an* ***endocrine*** *cell, travel through the* ***bloodstream****, and interact with the* ***receptor*** *or a* ***target cell*** *to cause a* ***physiological response***.

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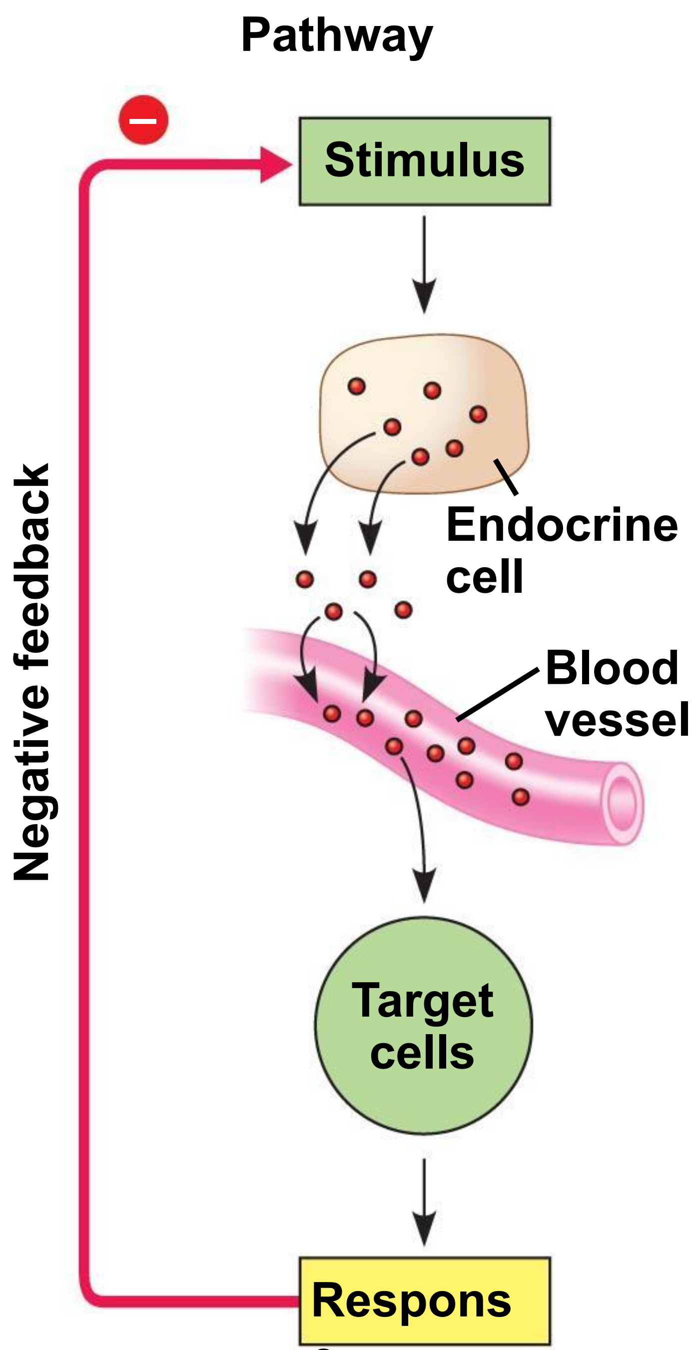
A simple endocrine pathway



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Example

Low pH in duodenum

S cells of duodenum secrete secretin (●)

Pancreas

Bicarbonate release

Insulin and Glucagon: Control of Blood Glucose

- A **negative feedback** loop inhibits a response by reducing the initial stimulus.
- Negative feedback reverses a trend to regulate many hormonal pathways involved in homeostasis.
- **Insulin** and **glucagon** are **antagonistic hormones** that help maintain glucose homeostasis.
- The **pancreas** has endocrine cells called **islets of Langerhans** with *alpha cells* that produce glucagon and *beta cells* that produce insulin.

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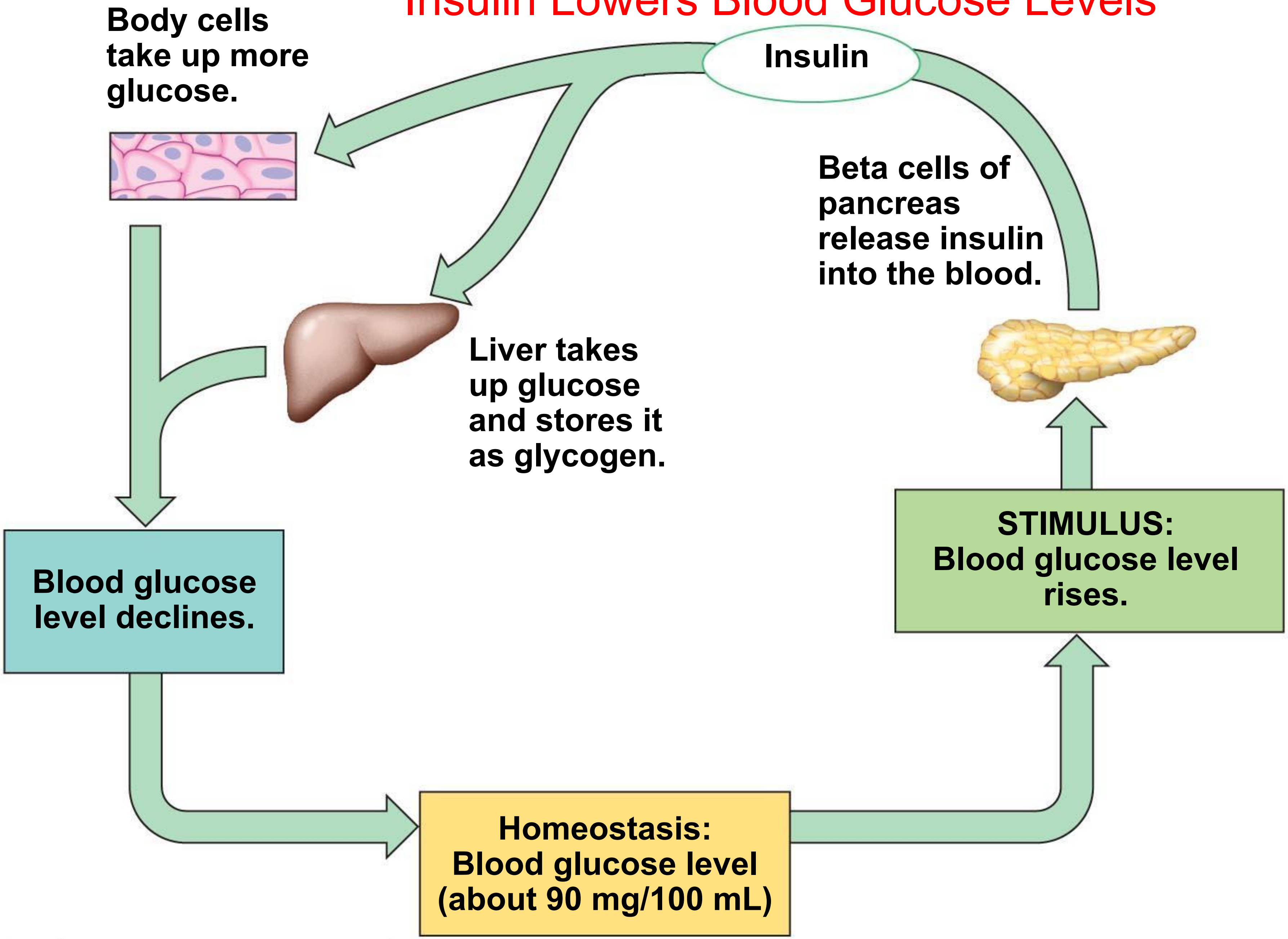
Insulin Lowers Blood Glucose Levels



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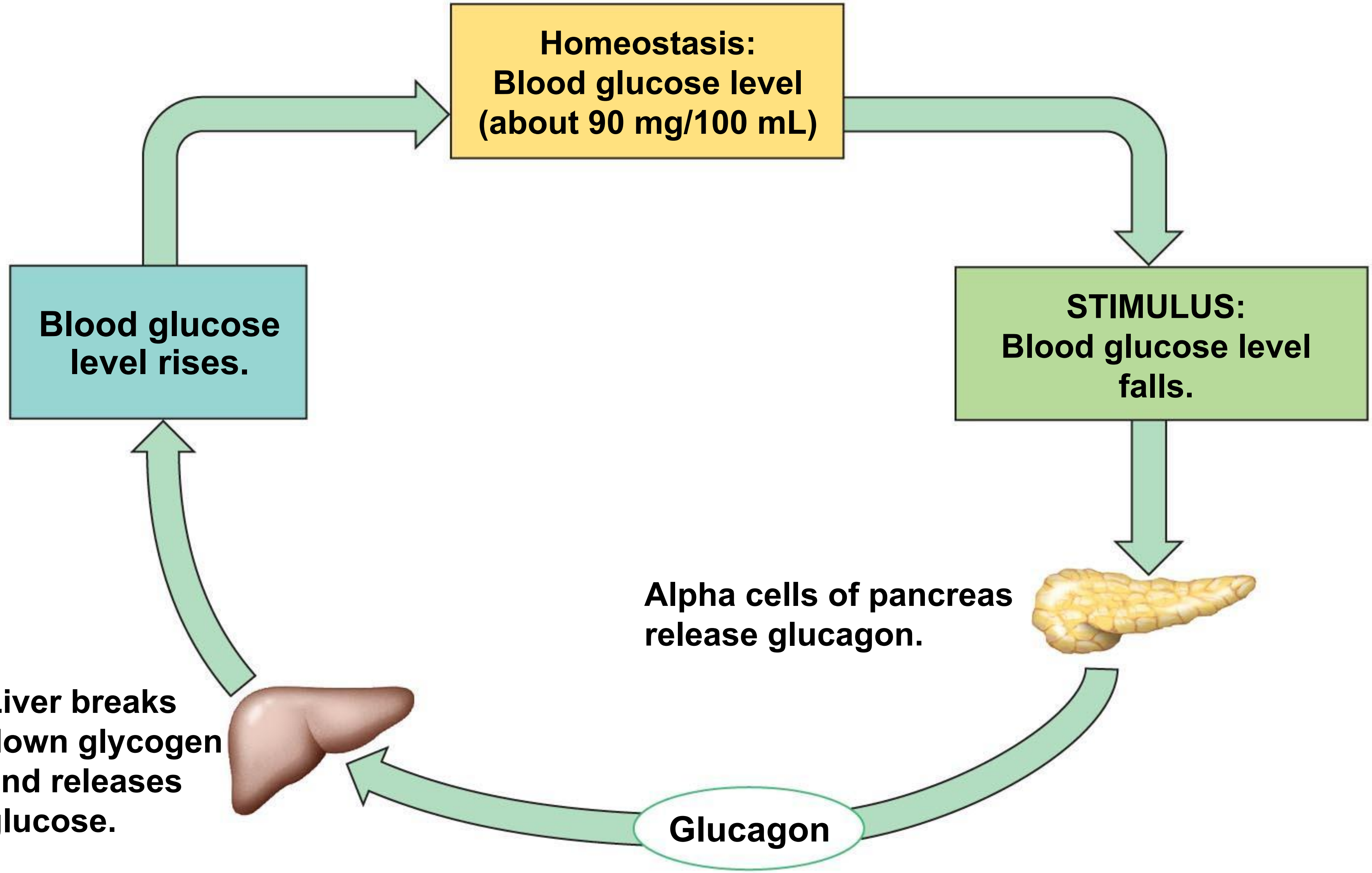
Glucagon Raises Blood Glucose Levels



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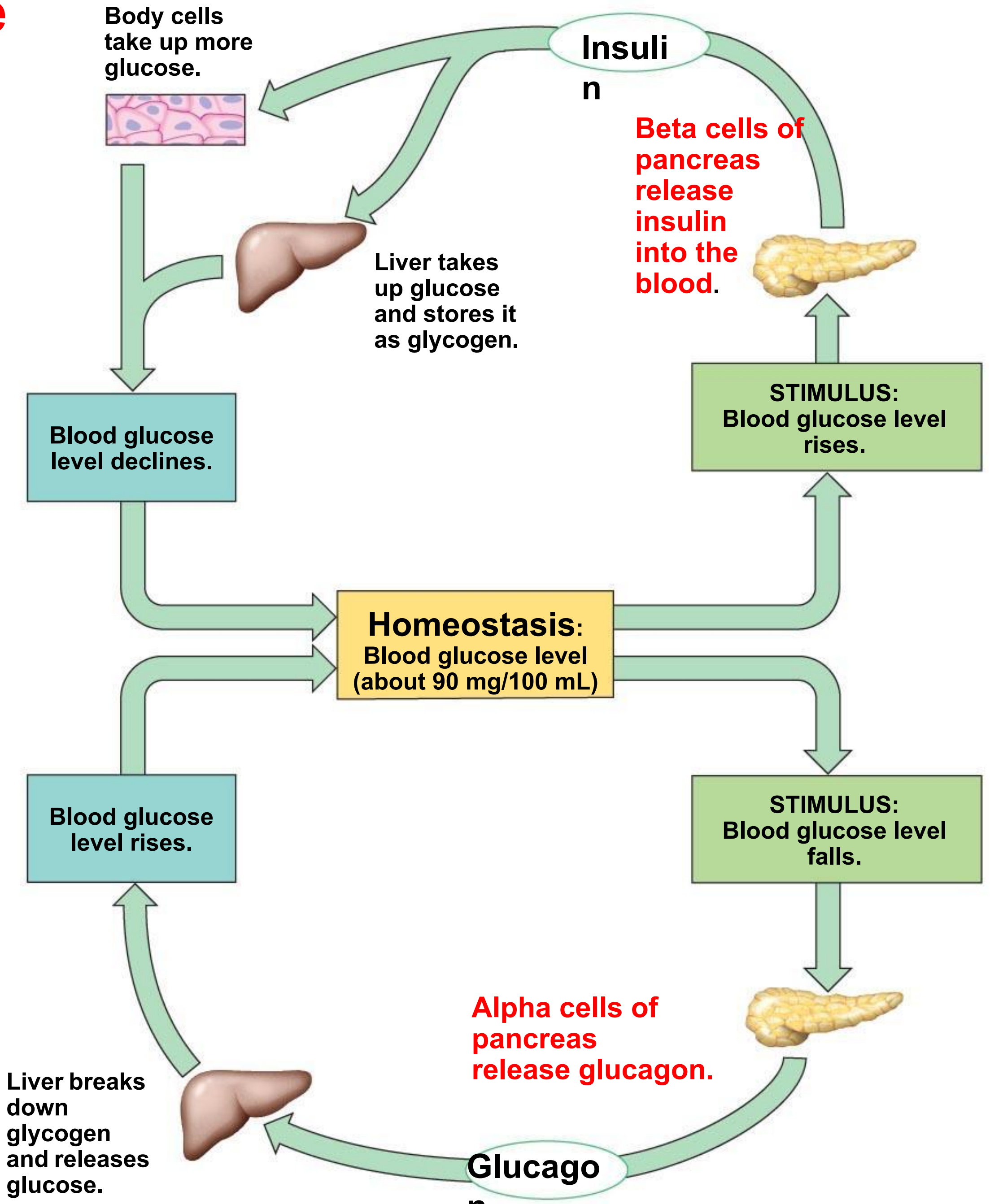
Maintenance of glucose homeostasis by insulin and glucagon



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

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Diabetes Mellitus

- **Diabetes mellitus** is an endocrine disorder caused by a deficiency of insulin or a decreased response to insulin in target tissues.
- It is marked by elevated blood glucose levels.
- *Type I diabetes mellitus* (insulin-dependent) is an autoimmune disorder in which the immune system destroys pancreatic beta cells.
- *Type II diabetes mellitus* (non-insulin-dependent) involves insulin deficiency or reduced response of target cells due to change in insulin receptors.

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The endocrine and nervous systems act individually and together in regulating animal physiology

- ***Signals from the nervous system initiate and regulate endocrine signals***.

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Coordination of Endocrine and Nervous Systems in Invertebrates

- In insects, *molting and development are controlled by a combination of hormones*:
  - A brain hormone stimulates release of **ecdysone** 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

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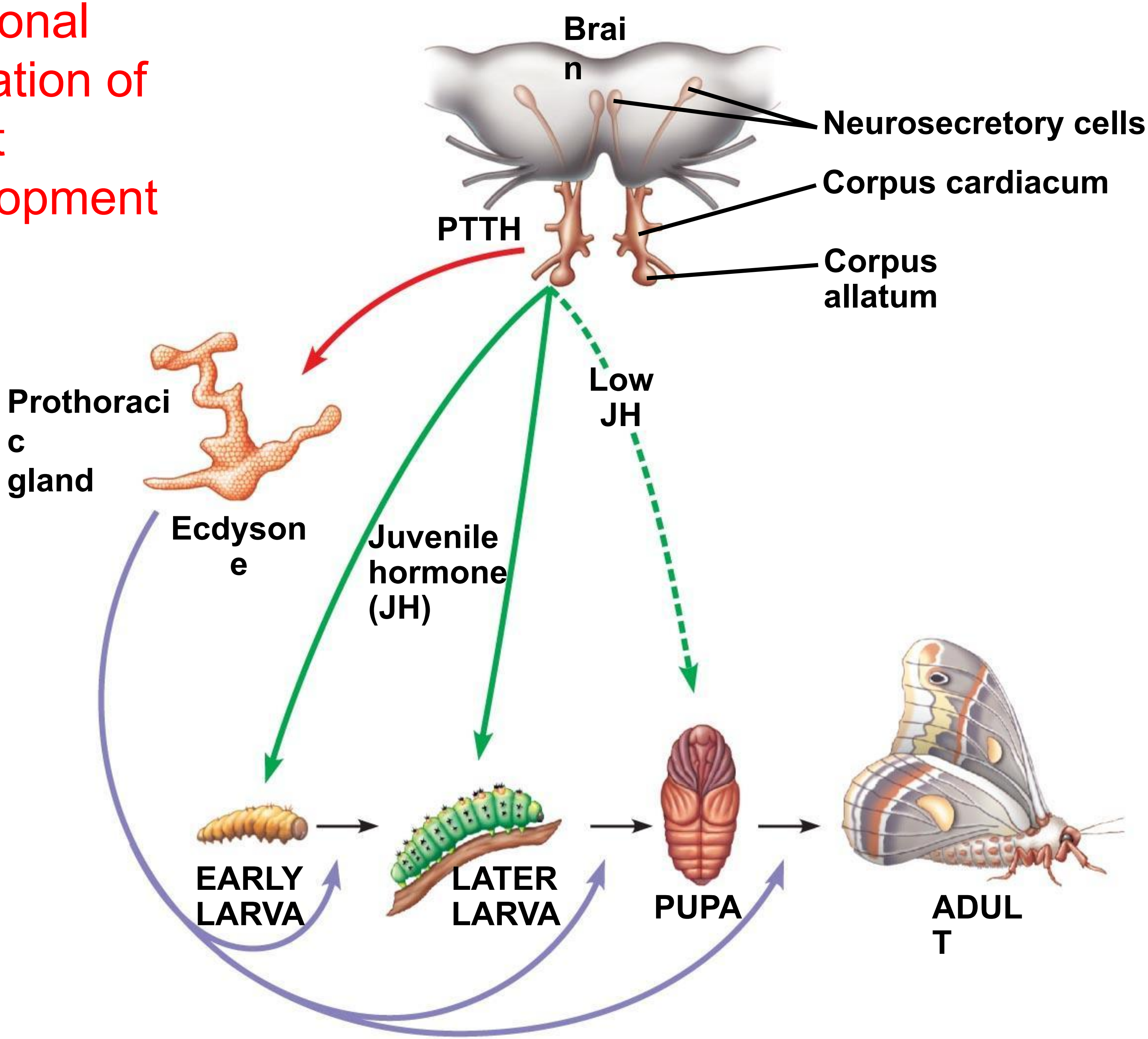
Hormonal regulation of insect development



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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.

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- 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

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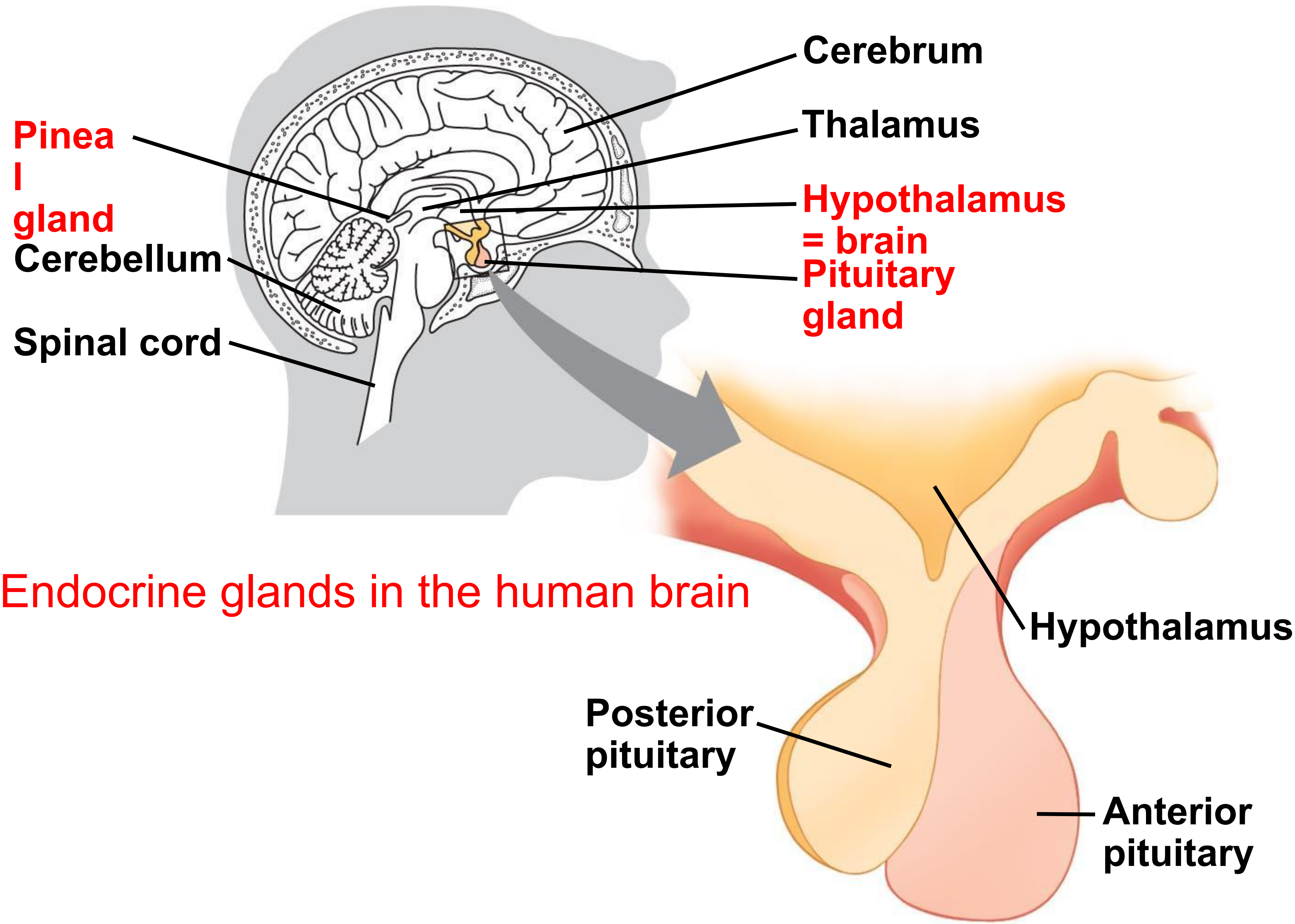

Endocrine glands in the human brain

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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 (PRL)	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)	Amine	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

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Table 45.1 Major Human Endocrine Glands and Some of Their Hormones

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	Steroid	Raise blood glucose level	ACTH
		Mineralocorticoids	Steroid	Promote reabsorption of Na^+ and excretion of K^+ in kidneys	K^+ in blood; angiotensin II
Gonads					
Testes		Androgens	Steroid	Support sperm formation; promote development and maintenance of male secondary sex characteristics	FSH and LH
Ovaries		Estrogens	Steroid	Stimulate uterine lining growth; promote development and maintenance of female secondary sex characteristics	FSH and LH
		Progestins	Steroid	Promote uterine lining growth	FSH and LH
Pineal gland		Melatonin	Amine	Involved in biological rhythms	Light/dark cycles

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Posterior Pituitary Hormones

- **Oxytocin** induces uterine contractions and the release of milk
- Suckling sends a message to the hypothalamus via the nervous system to release oxytocin, which further stimulates the milk glands
- This is an example of **positive feedback**, where the stimulus leads to an even greater response
- **Antidiuretic hormone (ADH)** enhances water reabsorption in the kidneys

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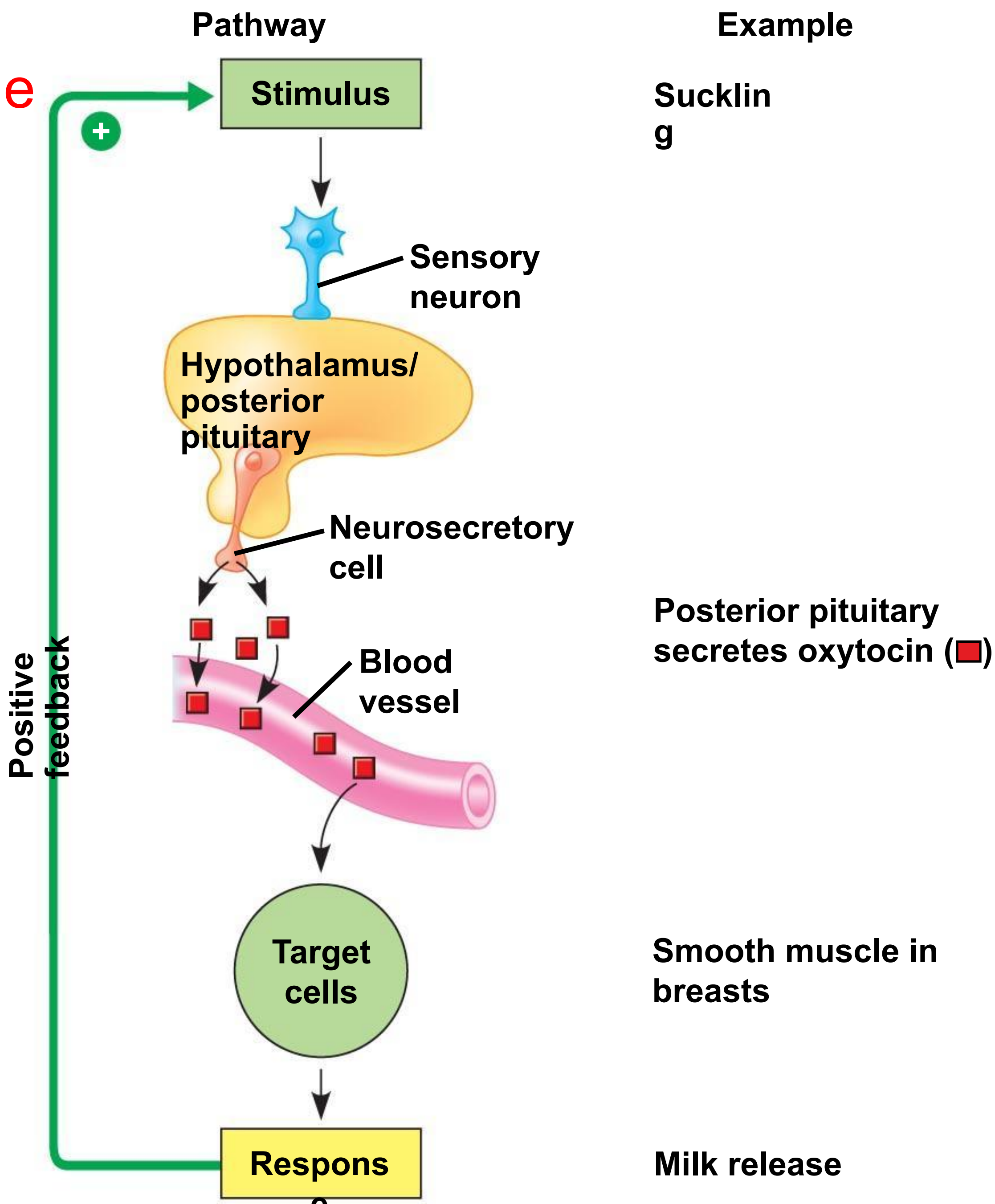
A simple neurohormone pathway



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Anterior Pituitary Hormones

- Hormone production in the anterior pituitary is controlled by releasing and inhibiting hormones from the hypothalamus
- For example, the production of *thyrotropin releasing hormone* (*TRH*) in the hypothalamus stimulates secretion of the *thyroid stimulating hormone* (*TSH*) from the anterior pituitary

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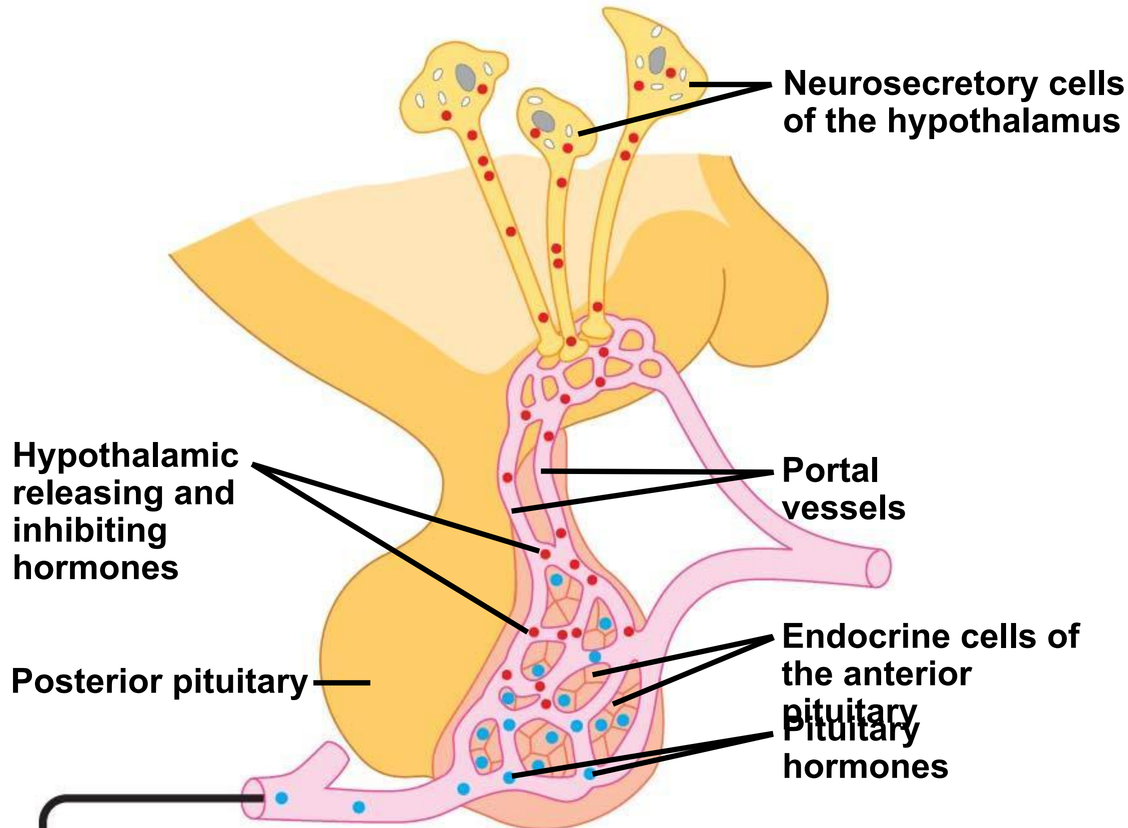
Production and release of anterior pituitary hormones

Tropic effects only:
FSH
LH
TSH
ACTH

Nontropic effects only:
Prolactin
MSH

Nontropic and tropic effects:
GH



HORMONE	FSH and LH	TSH	ACTH	Prolactin	MSH	GH
TARGET	Testes or ovaries	Thyroid	Adrenal cortex	Mammary glands	Melanocytes	Liver, bones, other tissues

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Hormone Cascade Pathways

- 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 are usually regulated by negative feedback*.

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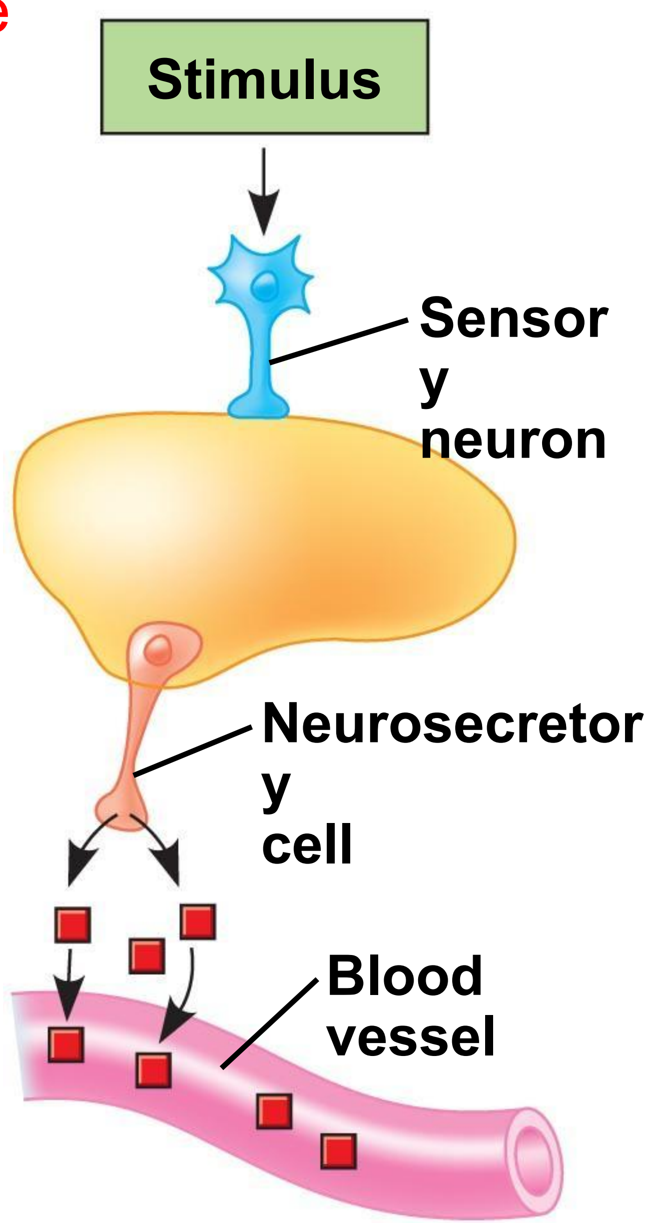
A hormone casade pathway

Pathway | **Example**



Cold

Hypothalamus secretes thyrotropin-releasing hormone (TRH ■)

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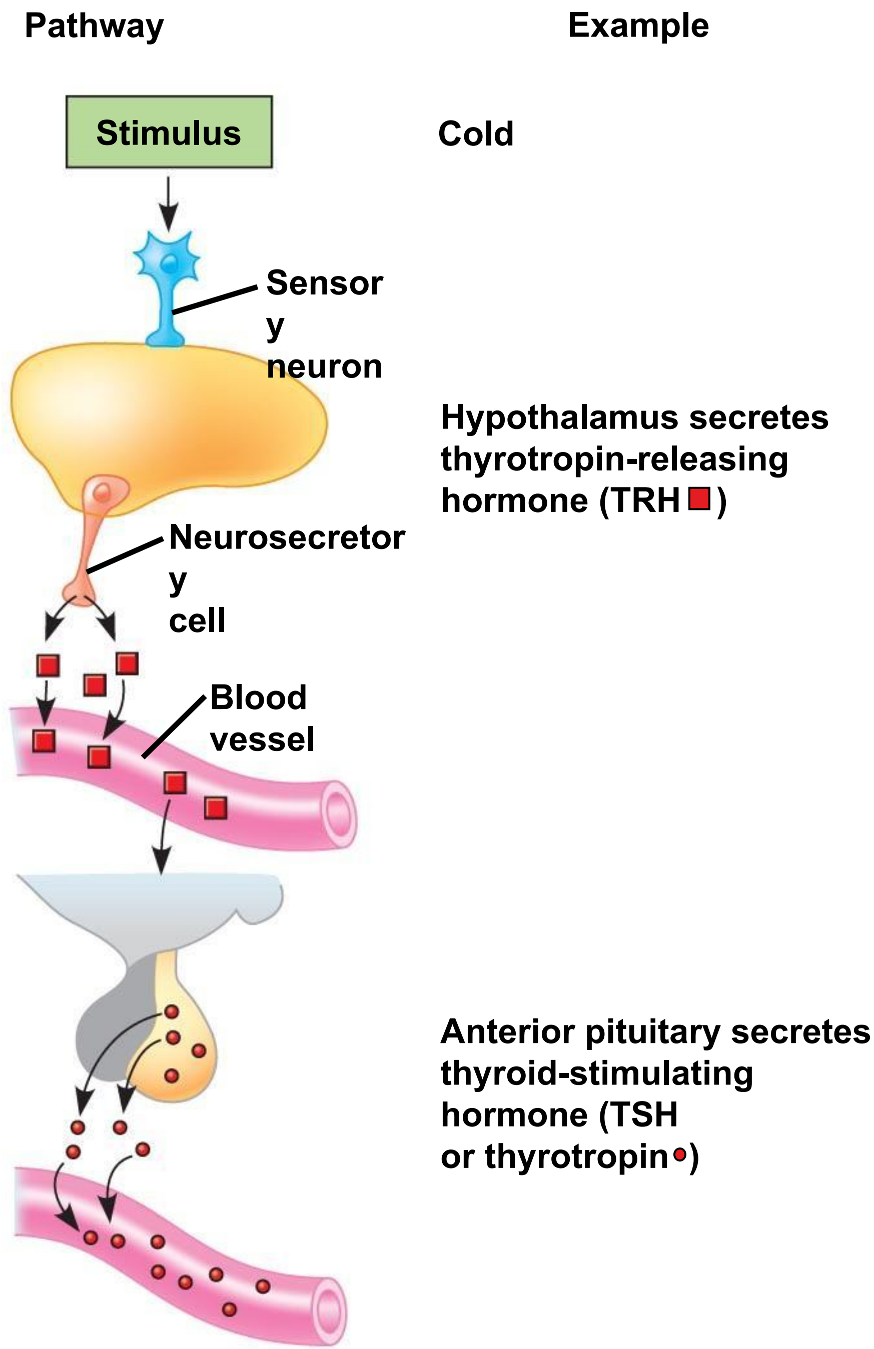
A hormone casade pathway



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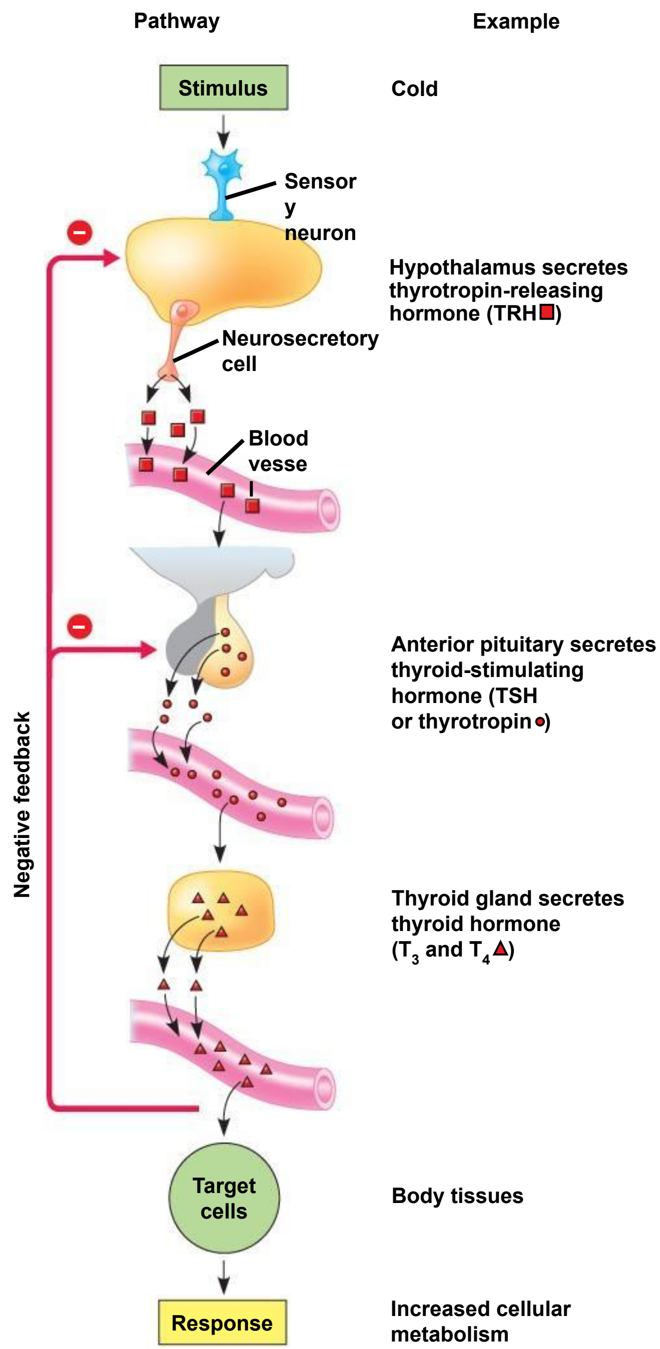
A hormone casade pathway



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Tropic Hormones

- A **tropic hormone** regulates the function of endocrine cells or glands.
- The four strictly tropic hormones are:
  - **Thyroid-stimulating hormone (TSH)**
  - **Follicle-stimulating hormone (FSH)**
  - **Luteinizing hormone (LH)**
  - **Adrenocorticotropic hormone (ACTH)**

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Nontropic Hormones - target nonendocrine tissues.

- Nontropic hormones produced by the anterior pituitary are:
  - **Prolactin (PRL)**
  - **Melanocyte-stimulating hormone (MSH)**
- Prolactin stimulates lactation in mammals but has diverse effects in different vertebrates.
- MSH influences skin pigmentation in some vertebrates and fat metabolism in mammals.

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Growth Hormone

- **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.

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Endocrine glands respond to diverse stimuli in regulating metabolism, homeostasis, development, and behavior

- Endocrine signaling regulates metabolism, homeostasis, development, and behavior.

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Thyroid Hormone: Control of Metabolism and Development

- The **thyroid gland** consists of two lobes on the ventral surface of the trachea.
- It produces two iodine-containing hormones: **triiodothyronine (T_3)** and **thyroxine (T_4).**
- Proper thyroid function requires dietary iodine for thyroid hormone production.

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- ***Thyroid hormones stimulate metabolism*** and influence development and maturation.
- Hyperthyroidism, excessive secretion of thyroid hormones, causes high body temperature, weight loss, irritability, and high blood pressure.
- *Graves' disease is a form of hyperthyroidism in humans.*
- Hypothyroidism, low secretion of thyroid hormones, causes weight gain, lethargy, and intolerance to cold.

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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

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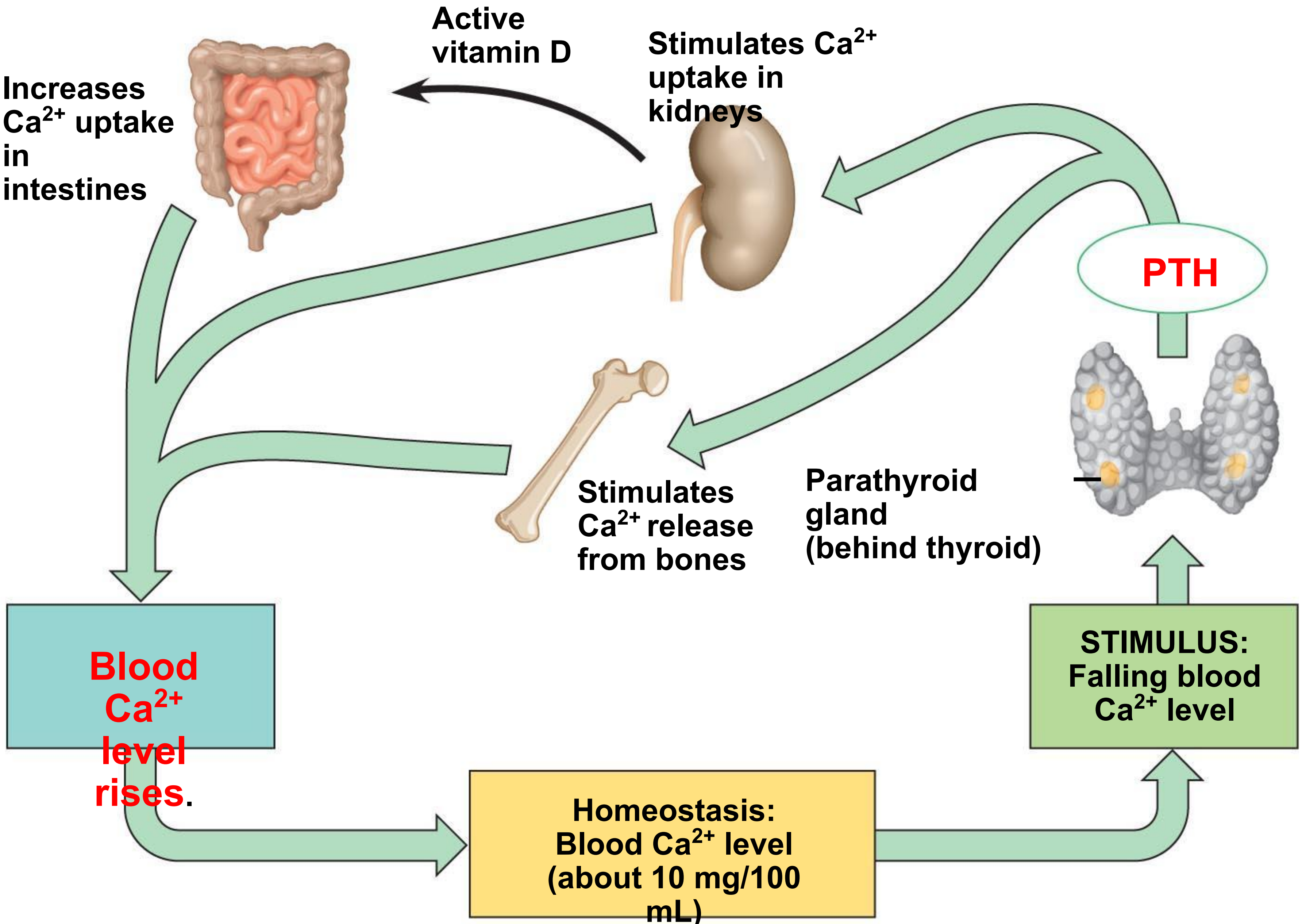
Antagonistic Hormone Pairs control blood calcium levels



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- **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

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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).

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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***.

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- 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 nerve signals from the hypothalamus*.

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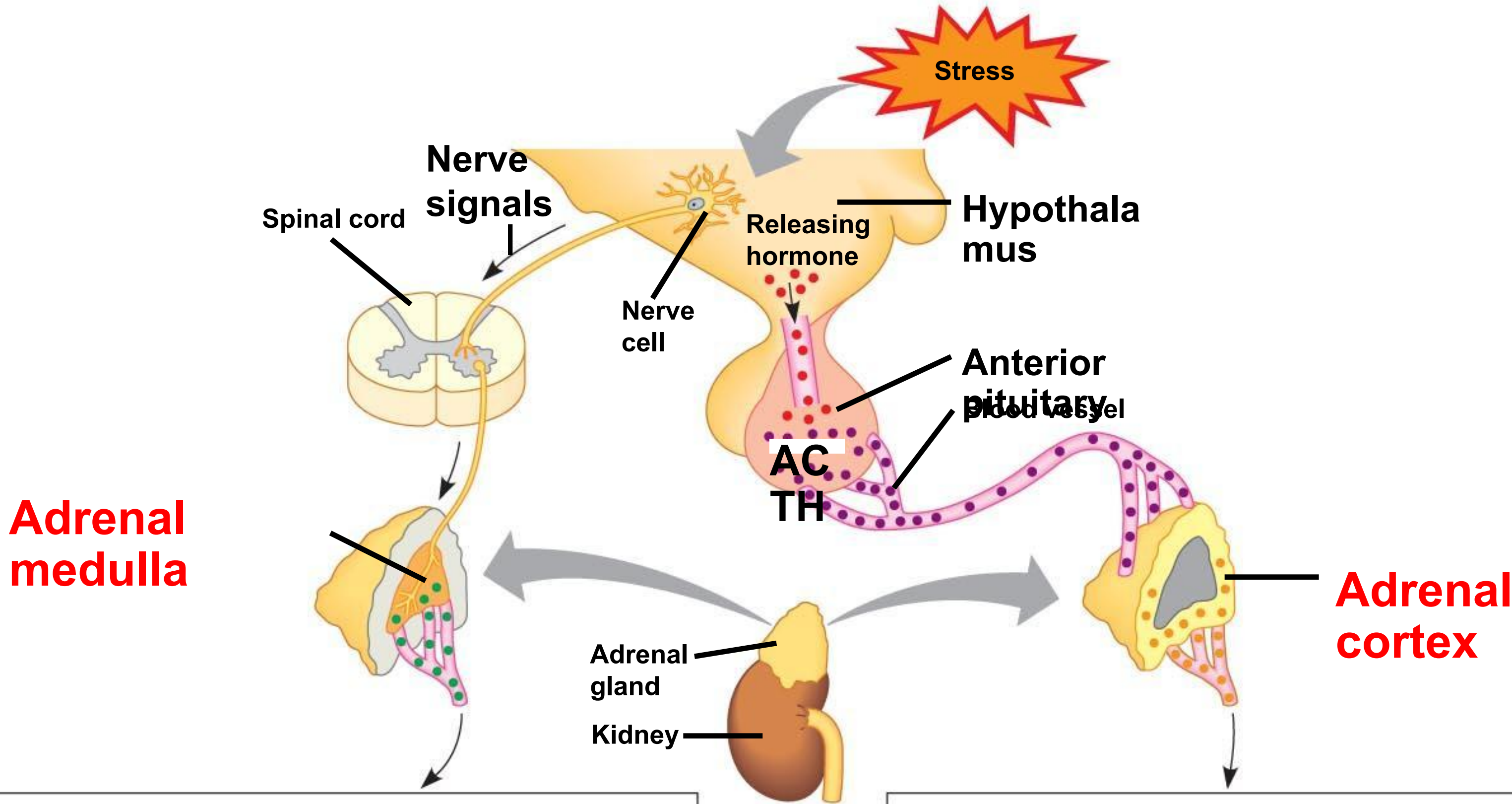
Summary: Stress and the Adrenal Gland



(a) Short-term stress response

Effects of epinephrine and norepinephrine:

1. Glycogen broken down to glucose; increased blood glucose
2. Increased blood pressure
3. Increased breathing rate
4. Increased metabolic rate
5. Change in blood flow patterns, leading to increased alertness and decreased digestive, excretory, and reproductive system activity

(b) Long-term stress response

Effects of mineralocorticoids:

1. Retention of sodium ions and water by kidneys
2. Increased blood volume and blood pressure

Effects of glucocorticoids:

1. Proteins and fats broken down and converted to glucose, leading to increased blood glucose
2. Possible suppression of immune system

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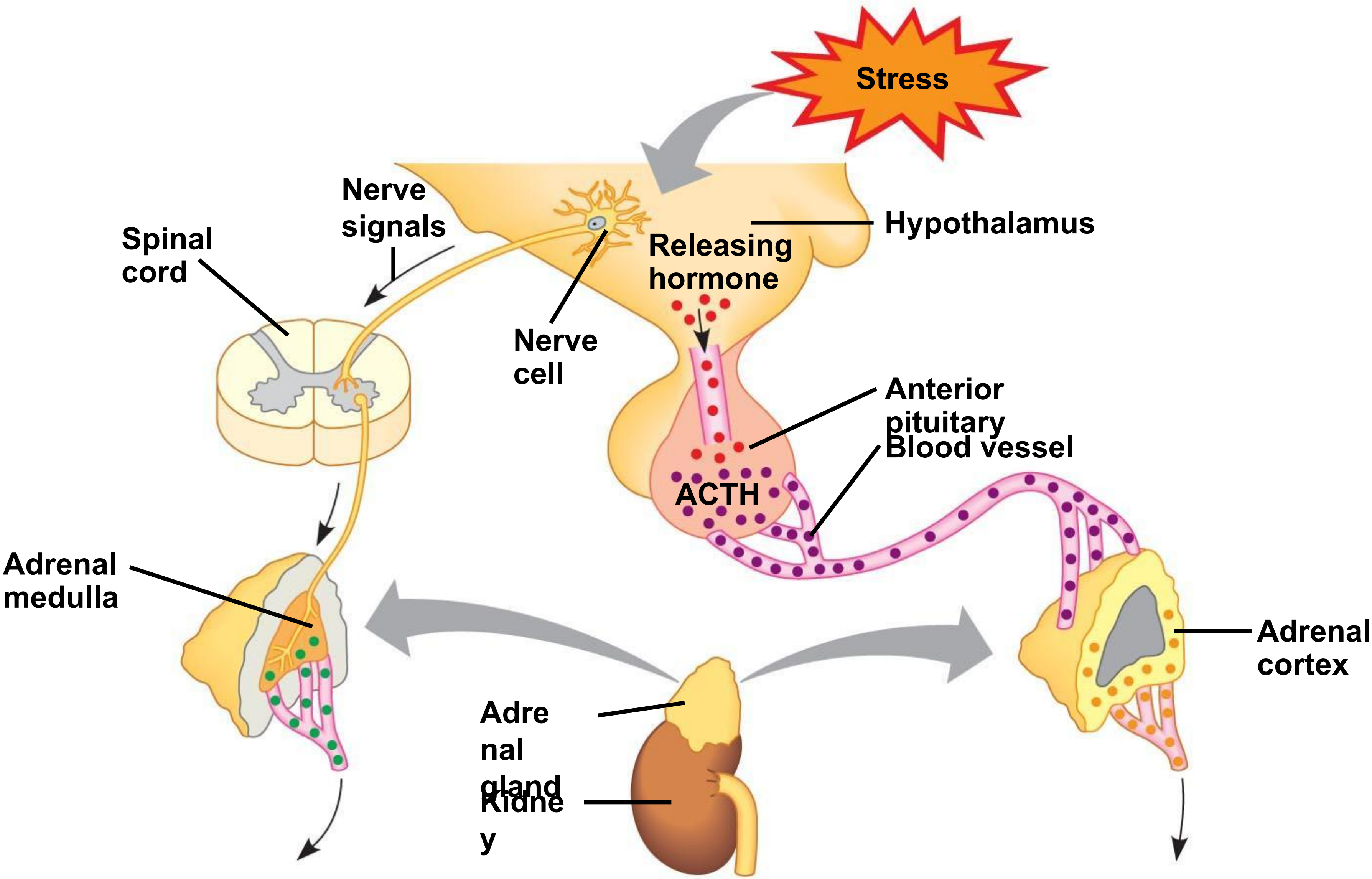
Stress and the Adrenal Gland



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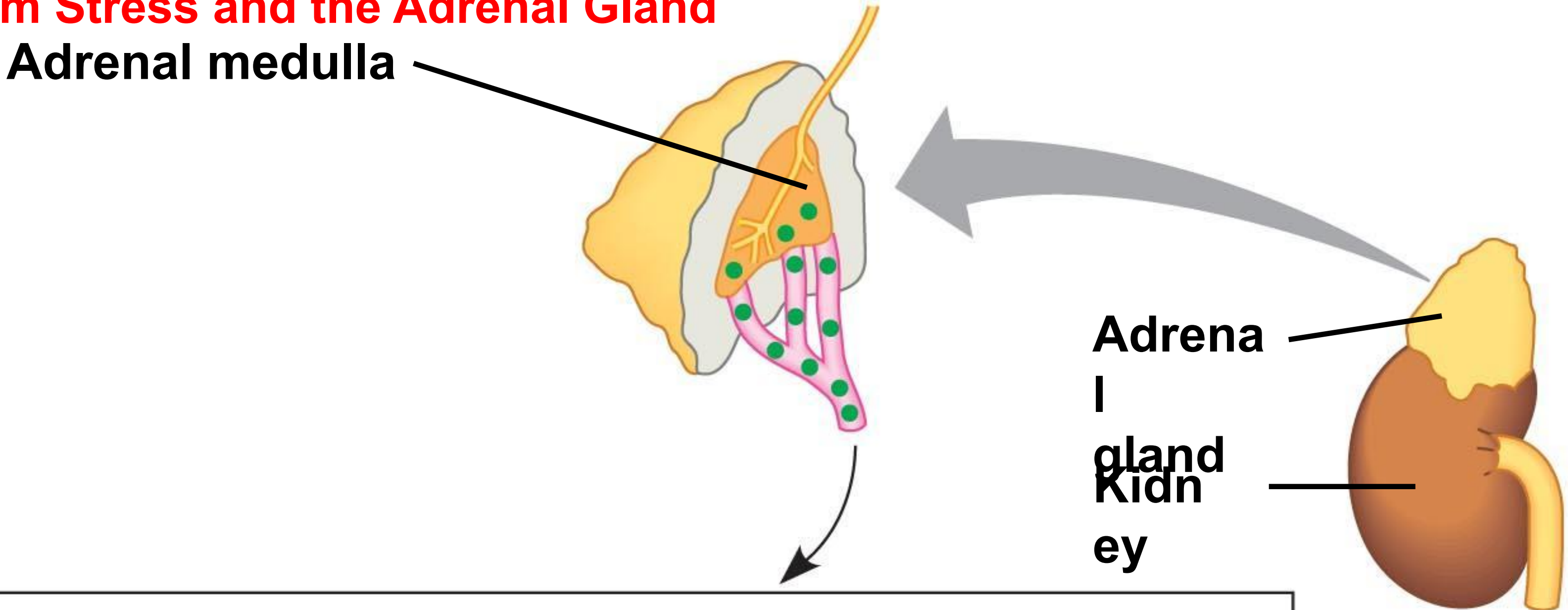
Short-term Stress and the Adrenal Gland



(a) Short-term stress response

Effects of epinephrine and norepinephrine:

1. Glycogen broken down to glucose; increased blood glucose
2. Increased blood pressure
3. Increased breathing rate
4. Increased metabolic rate
5. Change in blood flow patterns, leading to increased alertness and decreased digestive, excretory, and reproductive system activity

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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.
- Humans produce two types of corticosteroids: glucocorticoids and mineralocorticoids.

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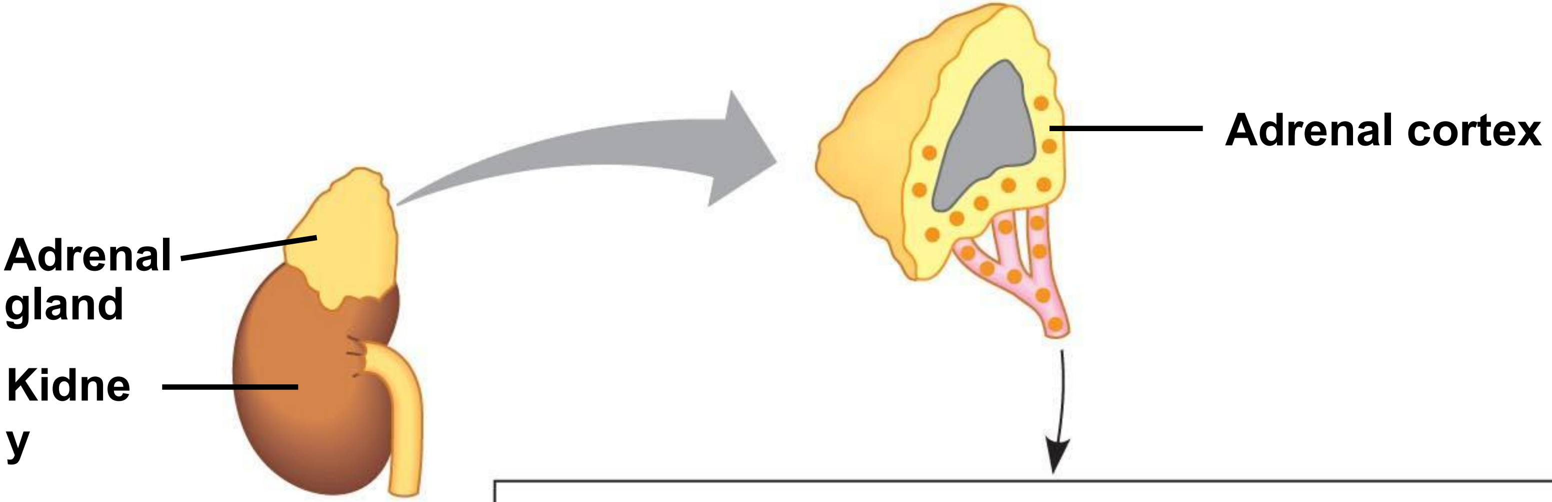
Long-term Stress and the adrenal gland



(b) **Long-term stress response**

Effects of **mineralocorticoids**:	Effects of **glucocorticoids**:
1. Retention of sodium ions and water by kidneys	1. Proteins and fats broken down and converted to glucose, leading to increased blood glucose
2. Increased blood volume and blood pressure	2. Possible suppression of immune system

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

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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 different amounts.

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

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- **Estrogens**, made in the **ovary**, 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**.

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Pineal Gland - 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*.

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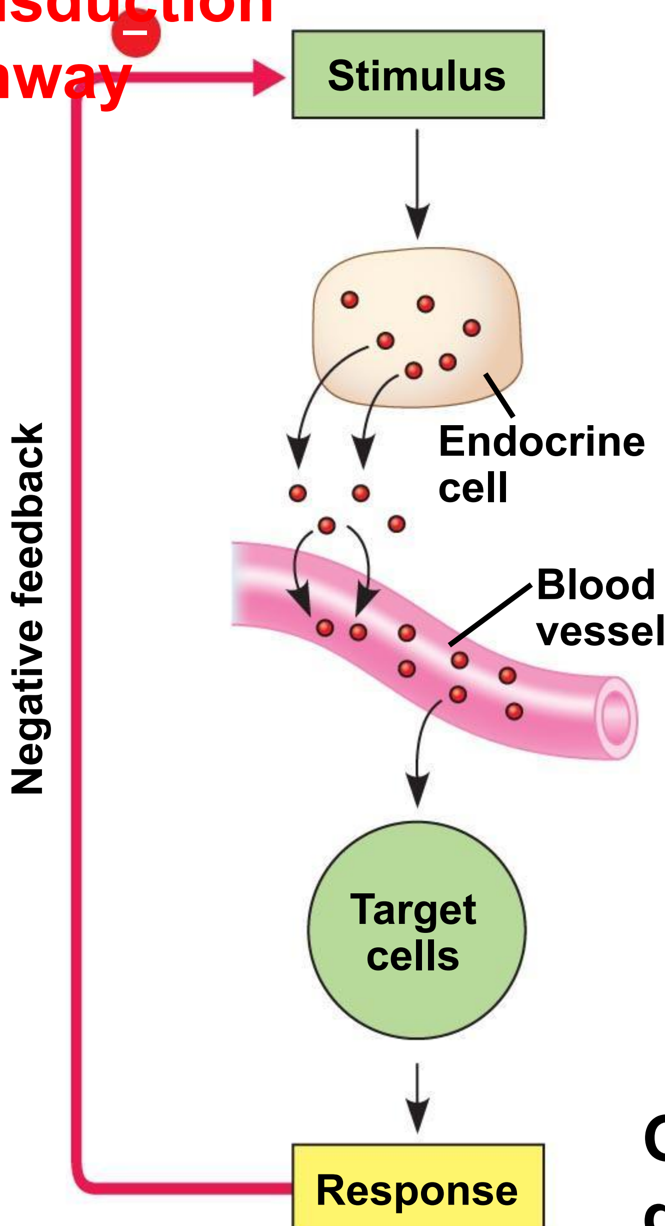
Signal Transduction Pathway



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Exampl
e

Low blood glucose

Pancreas alpha cells secretes glucagon

Live
r

Glycogen breakdown, glucose release into blood

You should now be able to:

1. Distinguish between the following pairs of terms: hormones and local regulators, paracrine and autocrine signals.
2. Describe the evidence that steroid hormones have intracellular receptors, while water-soluble hormones have cell-surface receptors.
3. Explain how the antagonistic hormones insulin and glucagon regulate carbohydrate metabolism.
4. Distinguish between type 1 and type 2 diabetes.

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5. Explain how the hypothalamus and the pituitary glands interact and how they coordinate the endocrine system.
6. Explain the role of tropic hormones in coordinating endocrine signaling throughout the body.
7. List and describe the functions of hormones released by the following: anterior and posterior pituitary lobes, thyroid glands, parathyroid glands, adrenal medulla, adrenal cortex, gonads, pineal gland.

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