Chapter 11

Cell Communication

PowerPoint Lectures for

Biology, Seventh Edition

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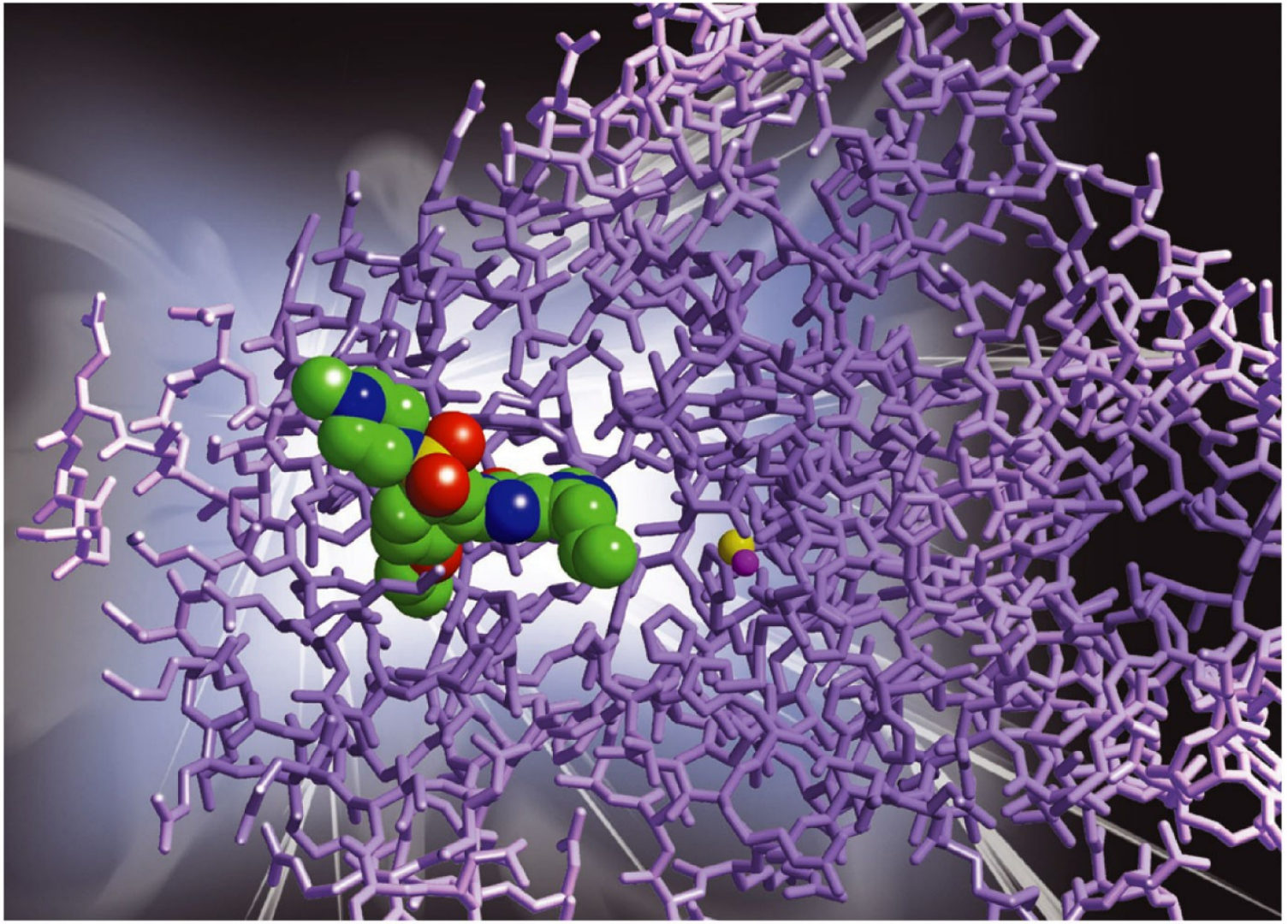
Lectures by Chris Romero

Overview: The Cellular Internet

- Cell-to-cell communication is essential for multicellular organisms
- Biologists have discovered some universal mechanisms of cellular regulation



Concept 11.1: External signals are converted into responses within the cell

- Microbes are a window on the role of cell signaling in the evolution of life

Evolution of Cell Signaling

- A signal-transduction pathway is a series of steps by which a signal on a cell's surface is converted into a specific cellular response
- Signal transduction pathways convert signals on a cell's surface into cellular responses
- Pathway similarities suggest that ancestral signaling molecules evolved in prokaryotes and have since been adopted by eukaryotes

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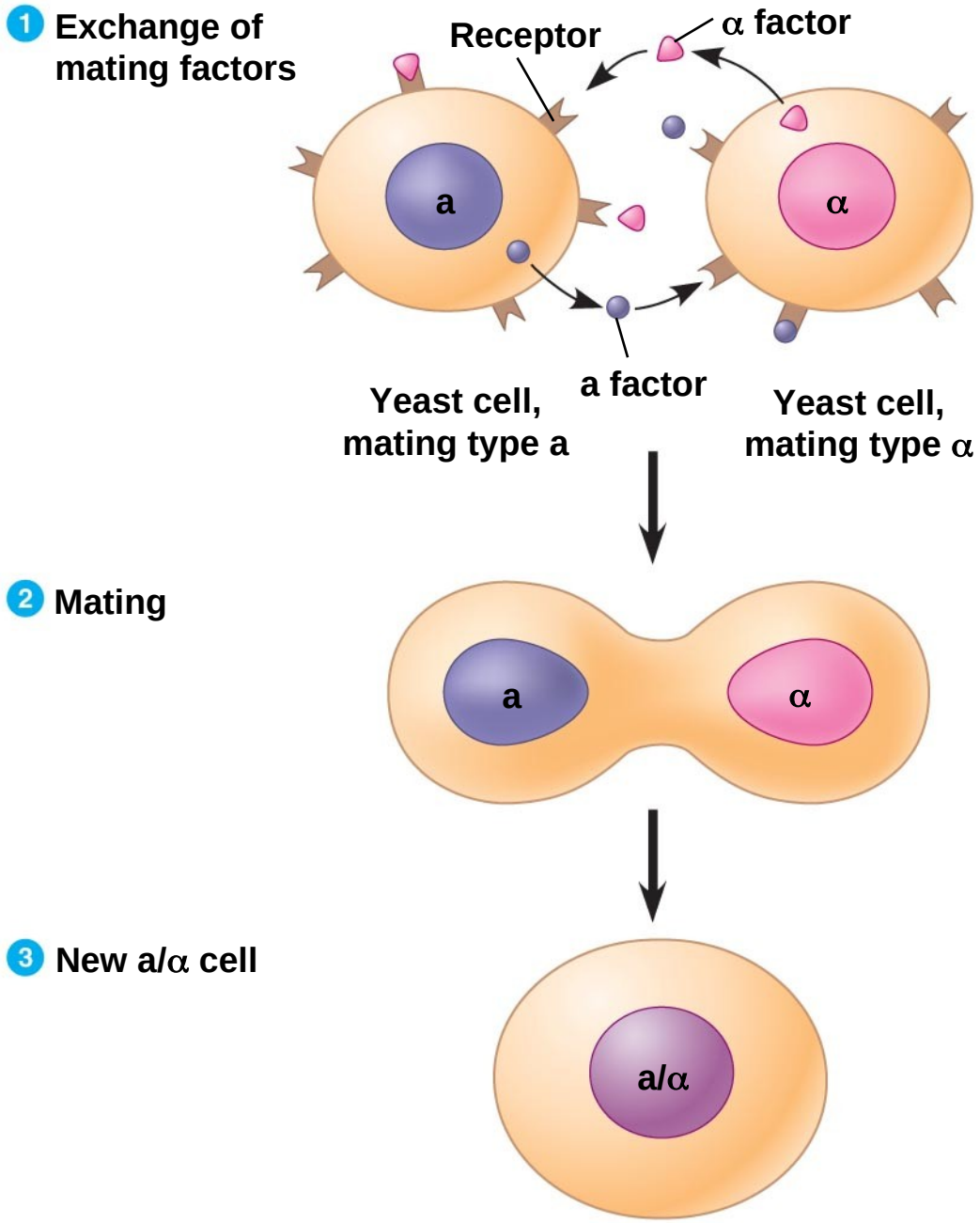

Local and Long-Distance Signaling

- Cells in a multicellular organisms communicate by chemical messengers
- Animal and plant cells have cell junctions that directly connect the cytoplasm of adjacent cells
- In local signaling, animal cells may communicate by direct contact

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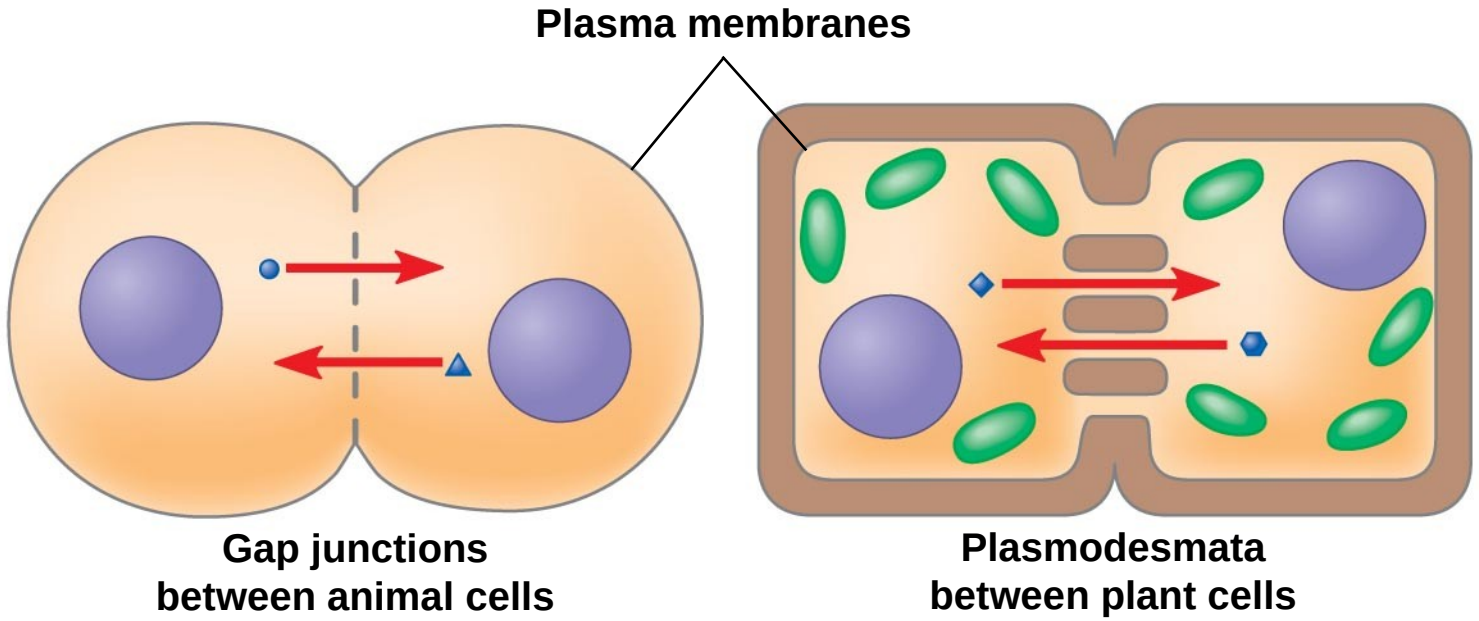
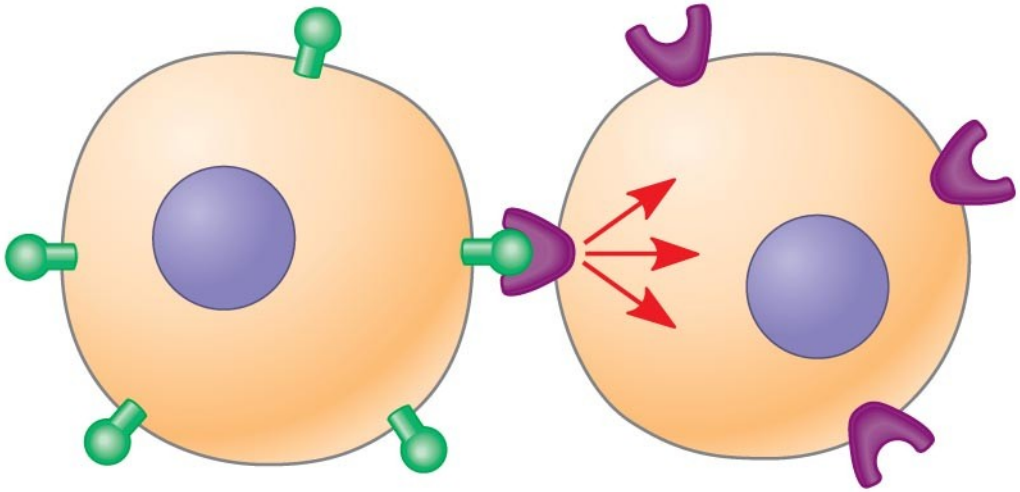


(a) Cell junctions



(b) Cell-cell recognition

- In many other cases, animal cells communicate using local regulators, messenger molecules that travel only short distances
- In long-distance signaling, plants and animals use chemicals called hormones

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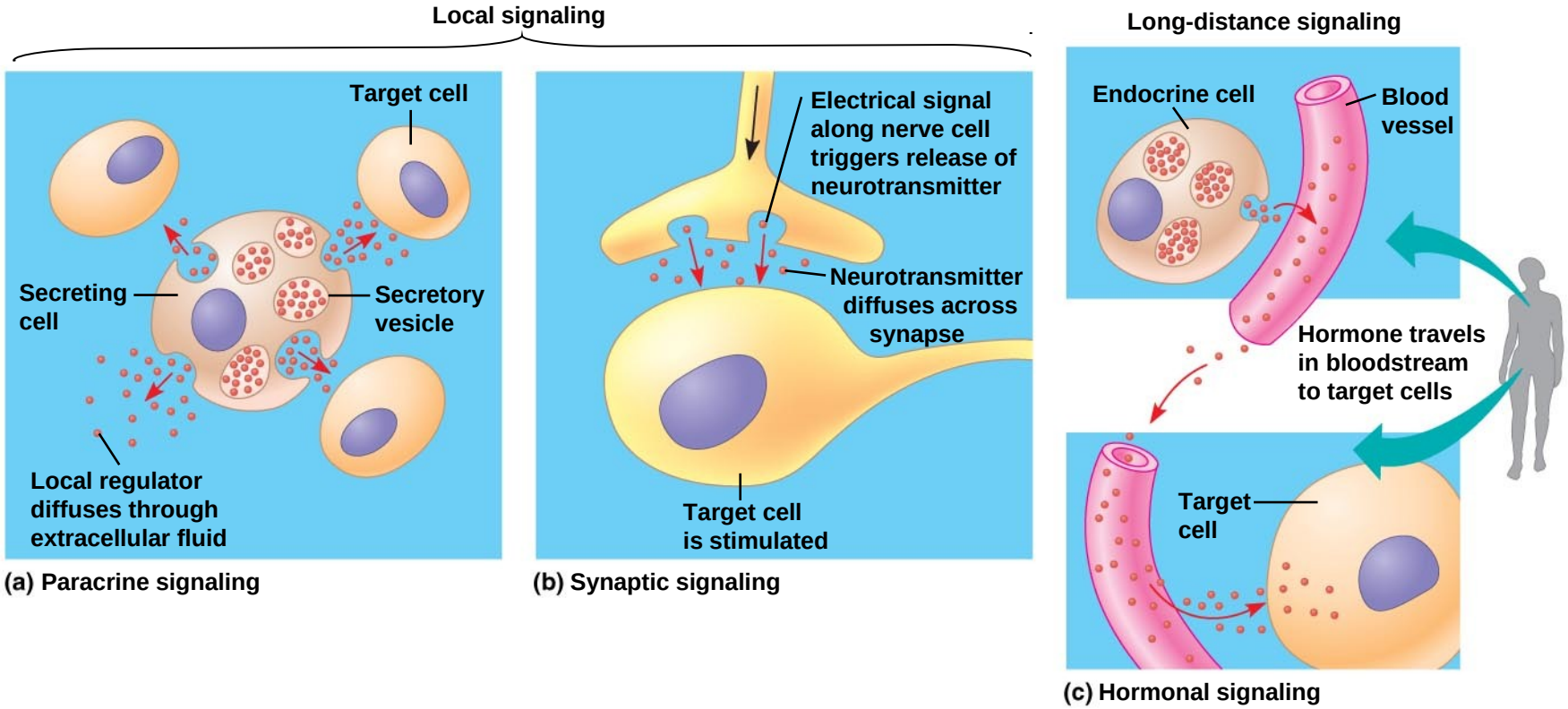

The Three Stages of Cell Signaling: *A Preview*

- Earl W. Sutherland discovered how the hormone epinephrine acts on cells
- Sutherland suggested that cells receiving signals went through three processes:
  - Reception
  - Transduction
  - Response

Animation: Overview of Cell Signaling

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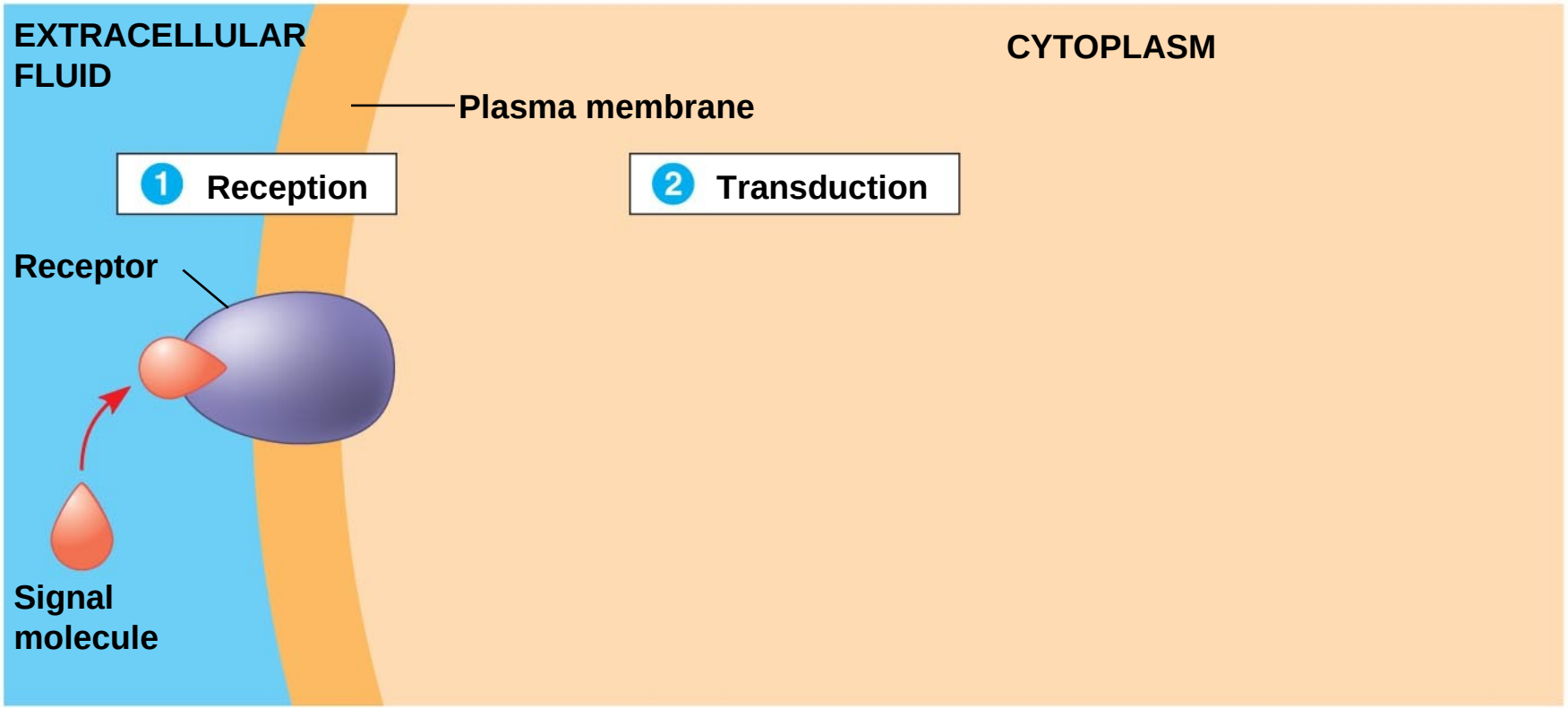

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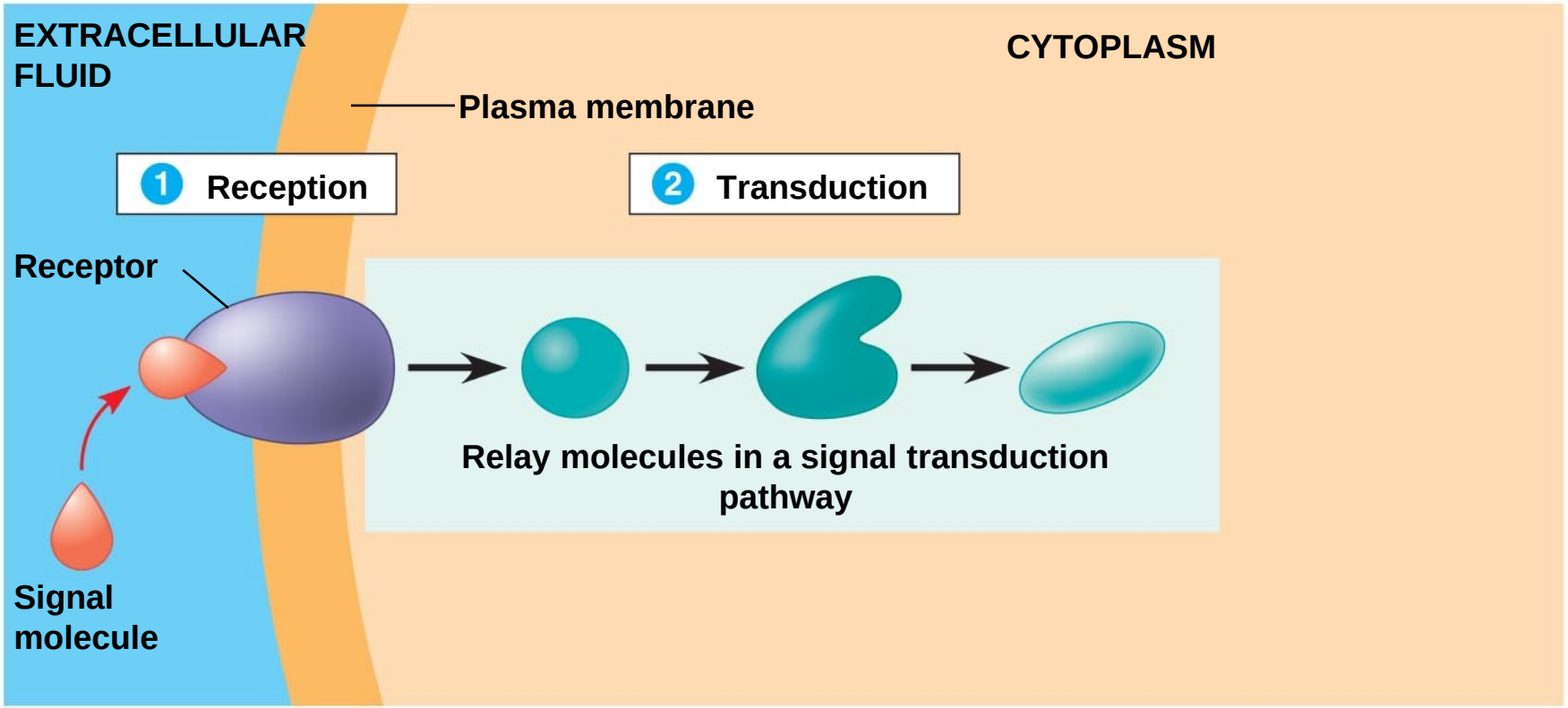

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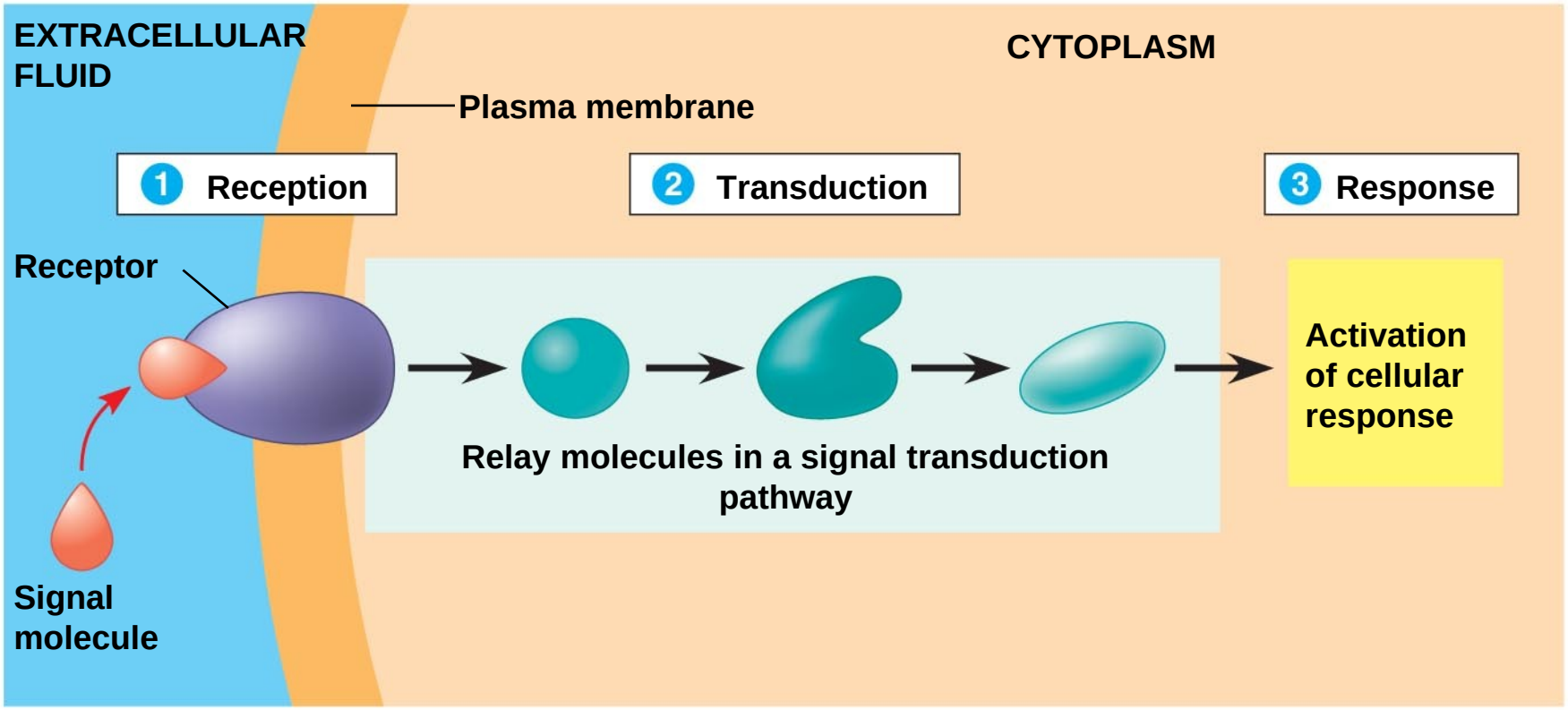

Concept 11.2: Reception: A signal molecule binds to a receptor protein, causing it to change shape

- The binding between a signal molecule (ligand) and receptor is highly specific
- A conformational change in a receptor is often the initial transduction of the signal
- Most signal receptors are plasma membrane proteins

Intracellular Receptors

- Some receptor proteins are intracellular, found in the cytosol or nucleus of target cells
- Small or hydrophobic chemical messengers can readily cross the membrane and activate receptors
- Examples of hydrophobic messengers are the steroid and thyroid hormones of animals
- An activated hormone-receptor complex can act as a transcription factor, turning on specific genes

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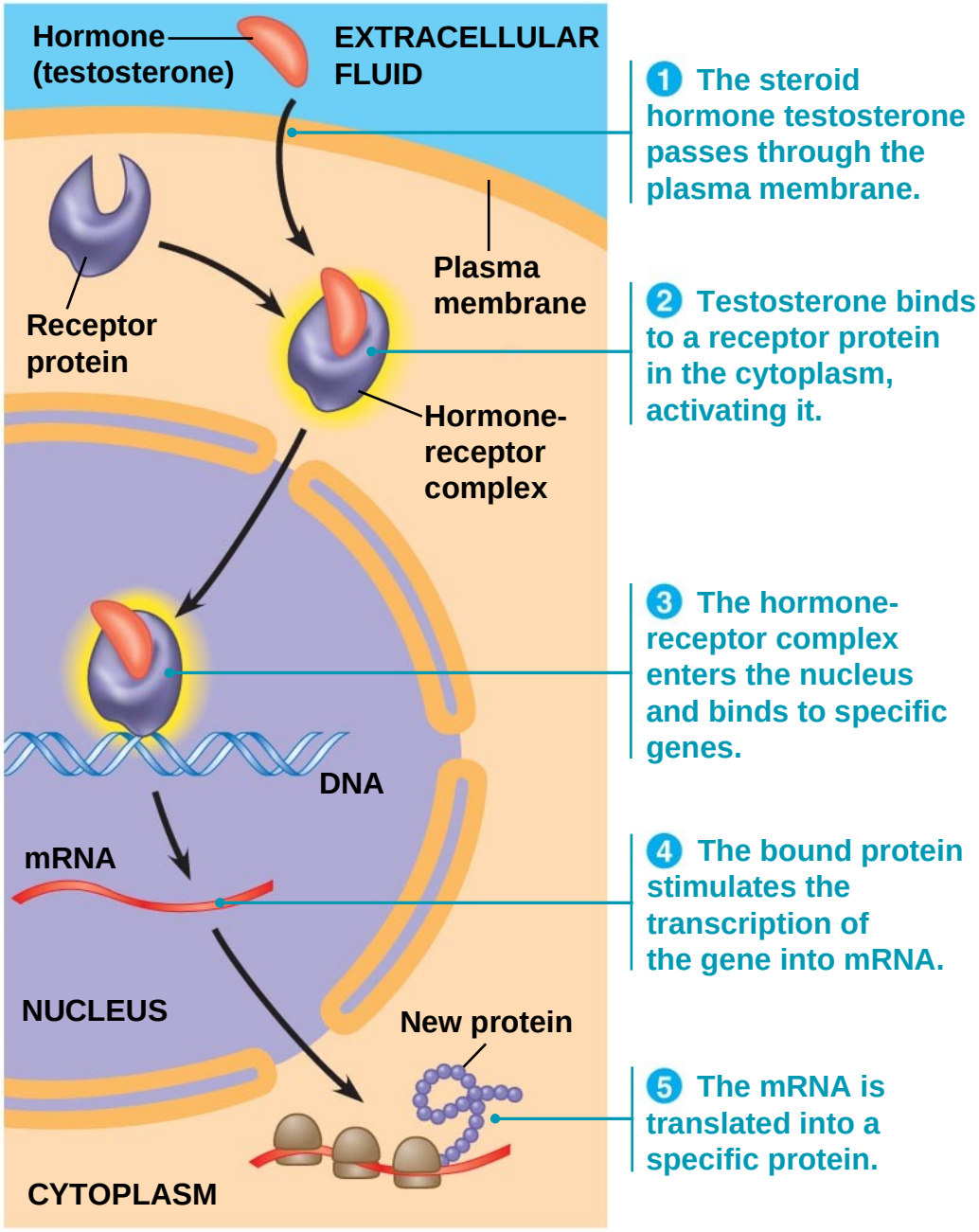

Receptors in the Plasma Membrane

- Most water-soluble signal molecules bind to specific sites on receptor proteins in the plasma membrane
- There are three main types of membrane receptors:
  - G-protein-linked receptors
  - Receptor tyrosine kinases
  - Ion channel receptors

- A G-protein-linked receptor is a plasma membrane receptor that works with the help of a G protein
- The G-protein acts as an on/off switch: If GDP is bound to the G protein, the G protein is inactive

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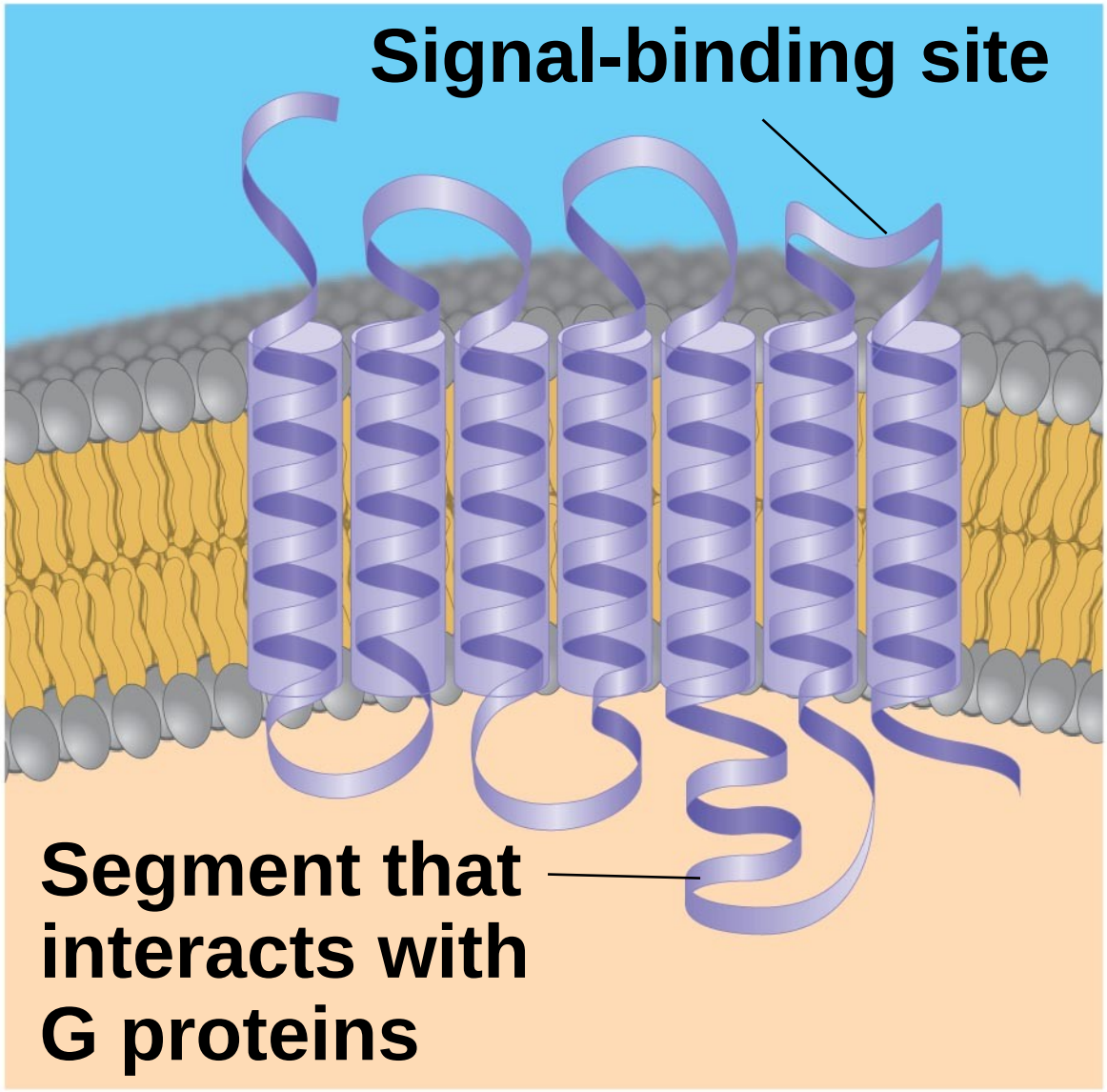

G-protein-linked receptor

- Receptor tyrosine kinases are membrane receptors that attach phosphates to tyrosines
- A receptor tyrosine kinase can trigger multiple signal transduction pathways at once

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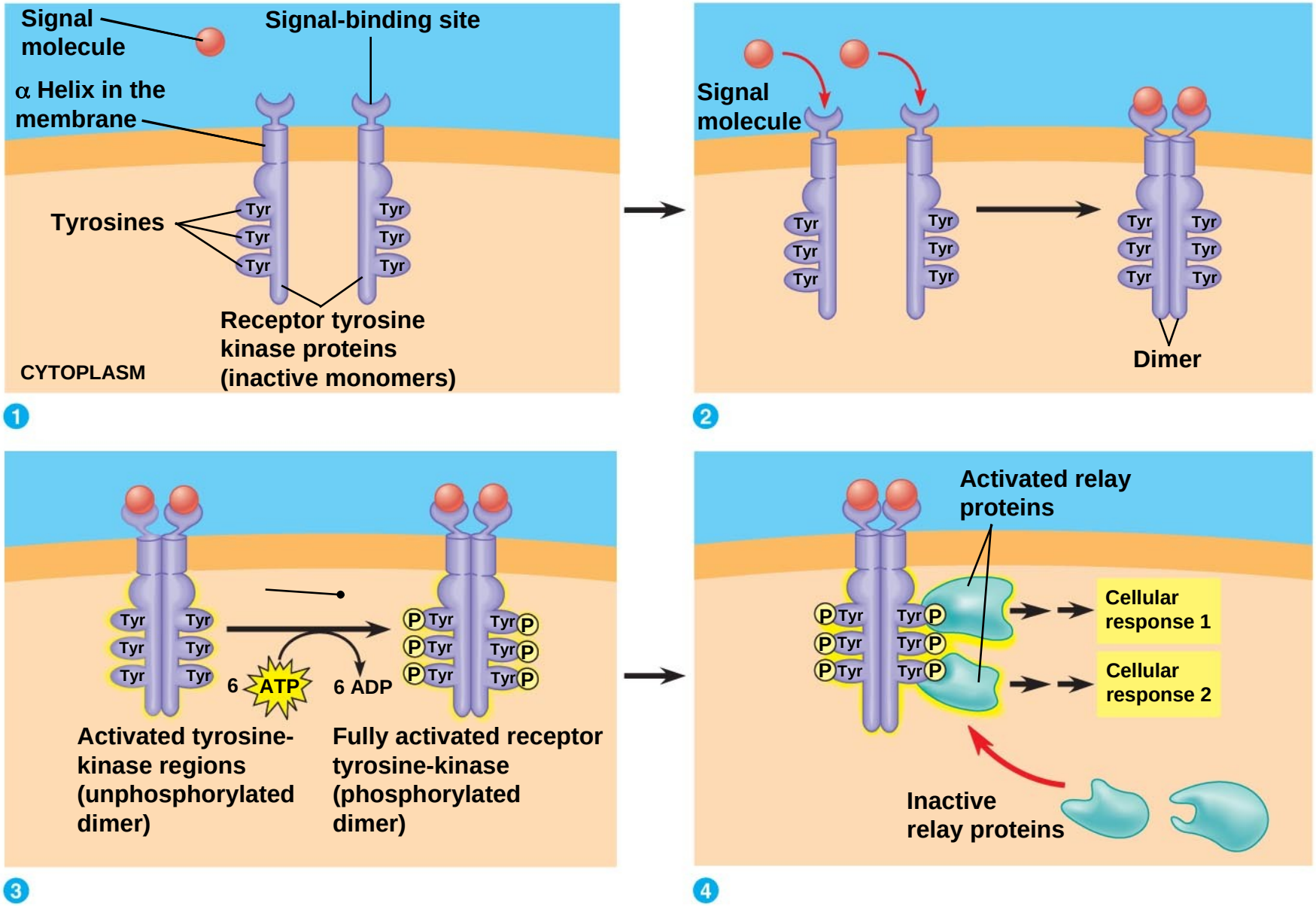

- An ion channel receptor acts as a gate when the receptor changes shape
- When a signal molecule binds as a ligand to the receptor, the gate allows specific ions, such as Na^+ or Ca^{2+}, through a channel in the receptor

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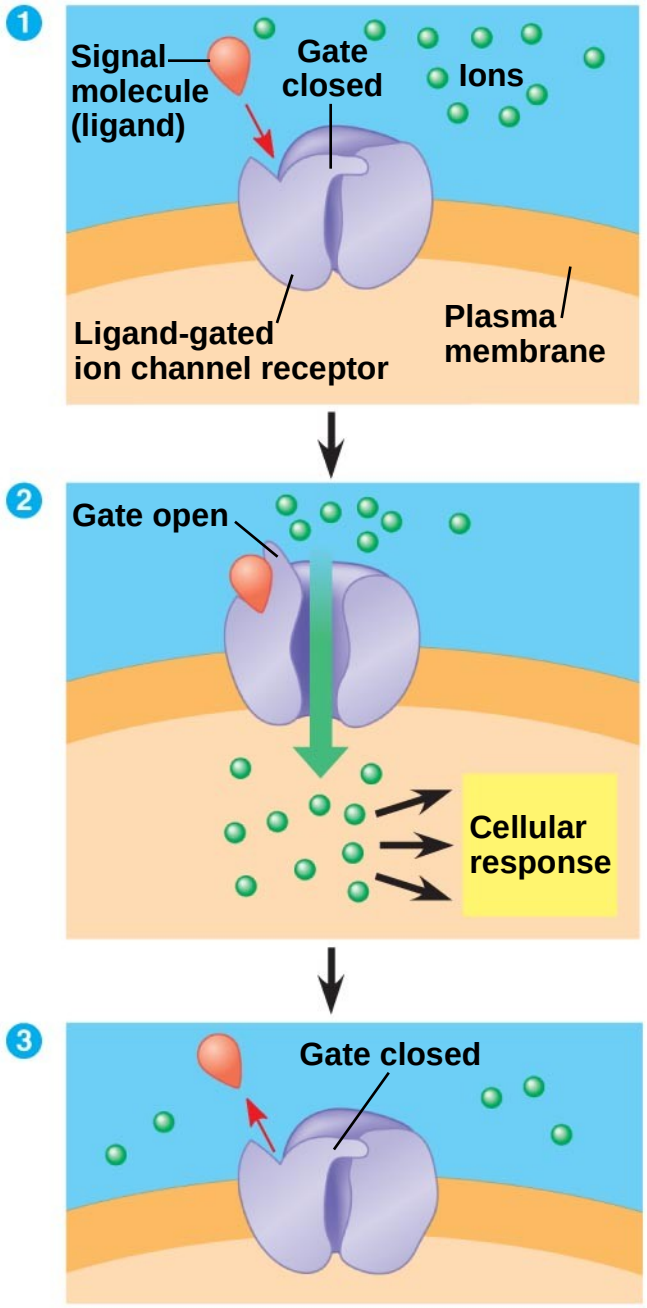

Concept 11.3: Transduction: Cascades of molecular interactions relay signals from receptors to target molecules in the cell

- Transduction usually involves multiple steps
- Multistep pathways can amplify a signal: A few molecules can produce a large cellular response
- Multistep pathways provide more opportunities for coordination and regulation

Signal Transduction Pathways

- The molecules that relay a signal from receptor to response are mostly proteins
- Like falling dominoes, the receptor activates another protein, which activates another, and so on, until the protein producing the response is activated
- At each step, the signal is transduced into a different form, usually a conformational change

Protein Phosphorylation and Dephosphorylation

- In many pathways, the signal is transmitted by a cascade of protein phosphorylations
- Phosphatase enzymes remove the phosphates
- This phosphorylation and dephosphorylation system acts as a molecular switch, turning activities on and off

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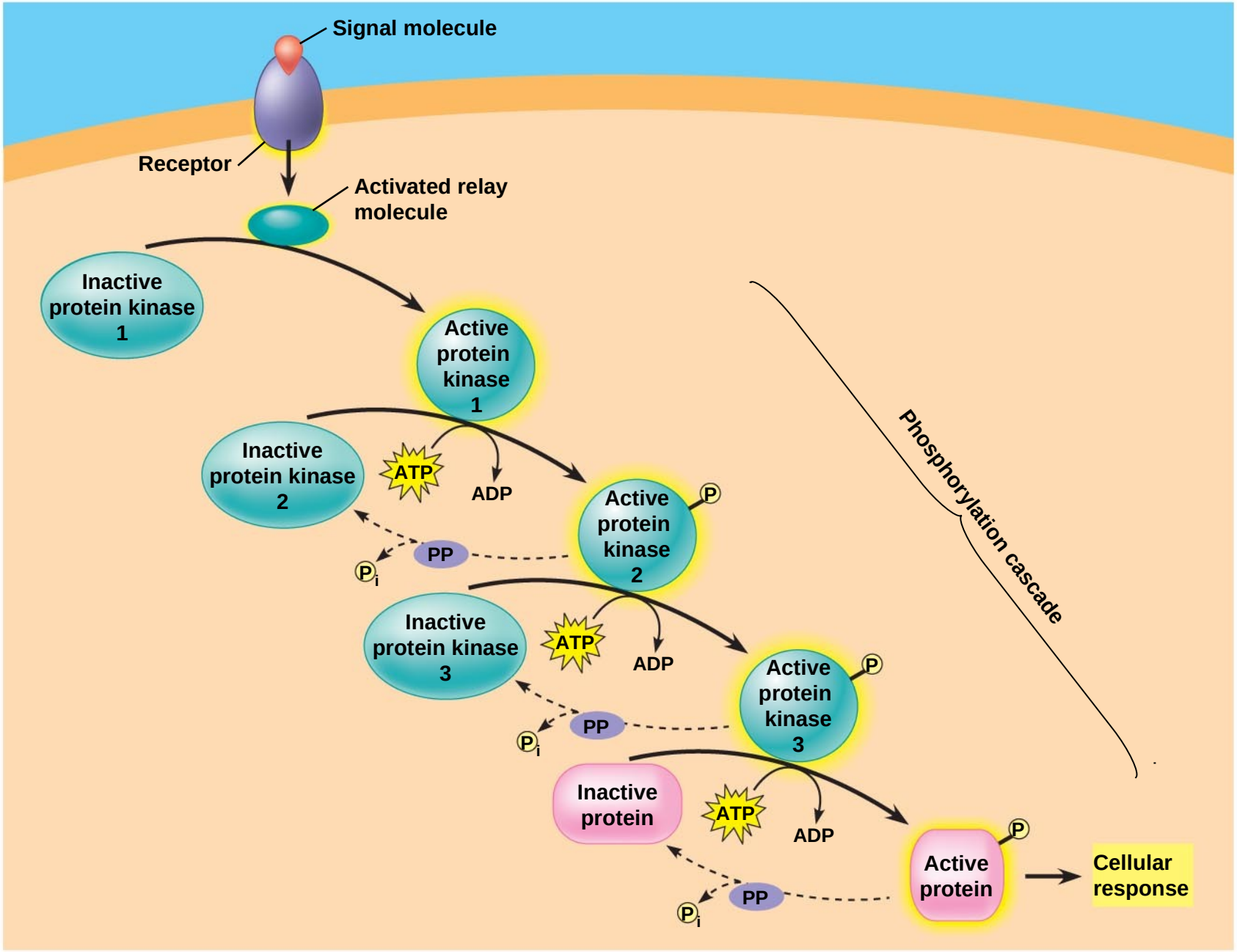

Small Molecules and Ions as Second Messengers

- Second messengers are small, nonprotein, water-soluble molecules or ions
- The extracellular signal molecule that binds to the membrane is a pathway's "first messenger"
- Second messengers can readily spread throughout cells by diffusion
- Second messengers participate in pathways initiated by G-protein-linked receptors and receptor tyrosine kinases

Cyclic AMP

- Cyclic AMP (cAMP) is one of the most widely used second messengers
- Adenylyl cyclase, an enzyme in the plasma membrane, converts ATP to cAMP in response to an extracellular signal

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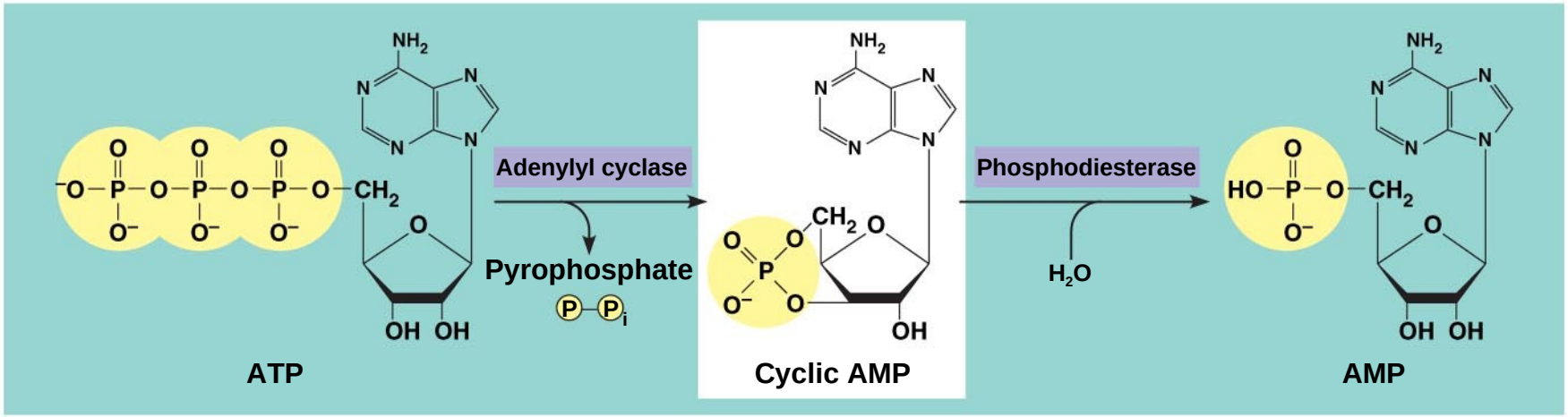

- Many signal molecules trigger formation of cAMP
- Other components of cAMP pathways are G proteins, G-protein-linked receptors, and protein kinases
- cAMP usually activates protein kinase A, which phosphorylates various other proteins
- Further regulation of cell metabolism is provided by G-protein systems that *inhibit* adenylyl cyclase

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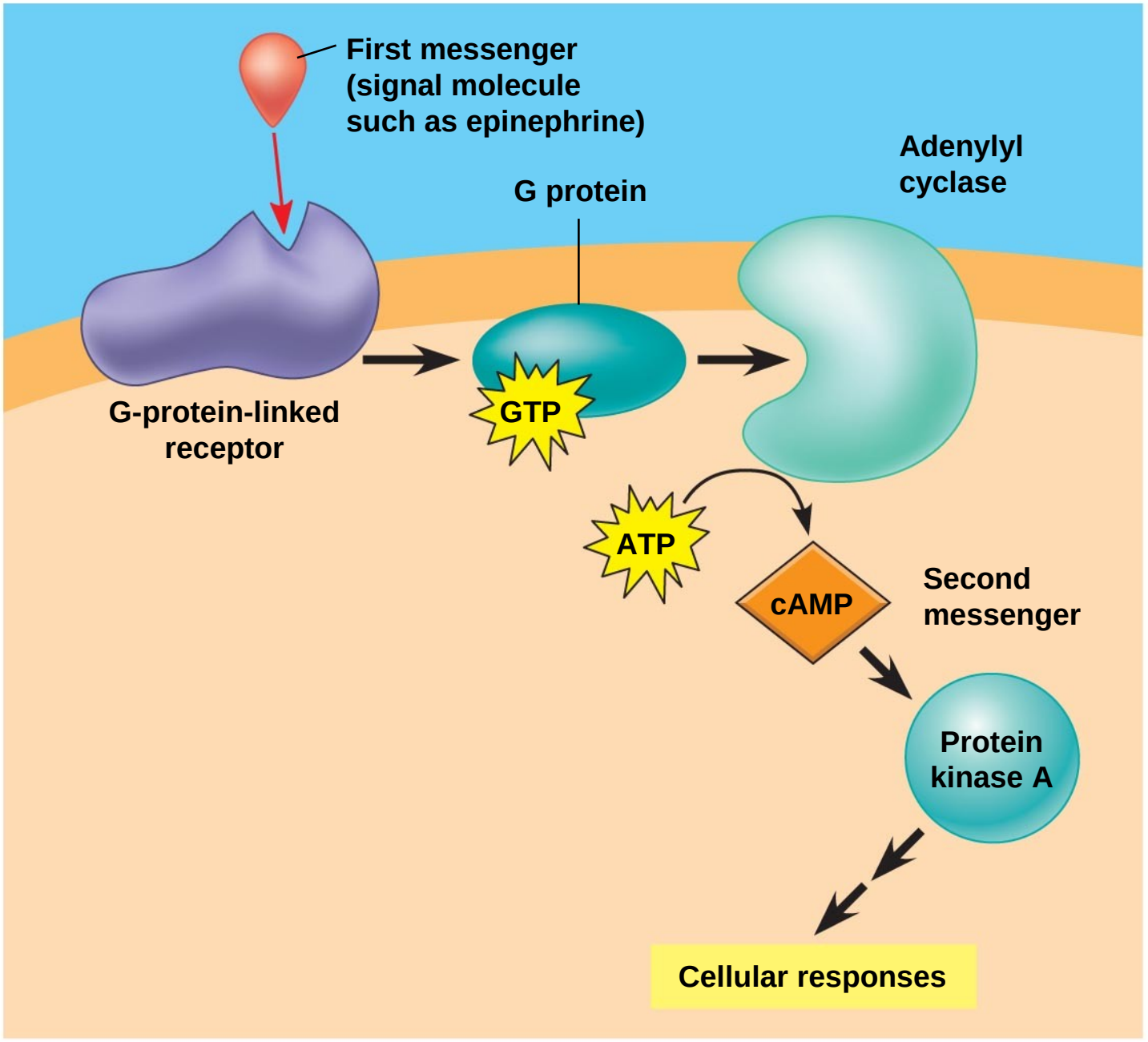

Calcium ions and Inositol Triphosphate (IP_3)

- Calcium ions (Ca^{2+}) act as a second messenger in many pathways
- Calcium is an important second messenger because cells can regulate its concentration

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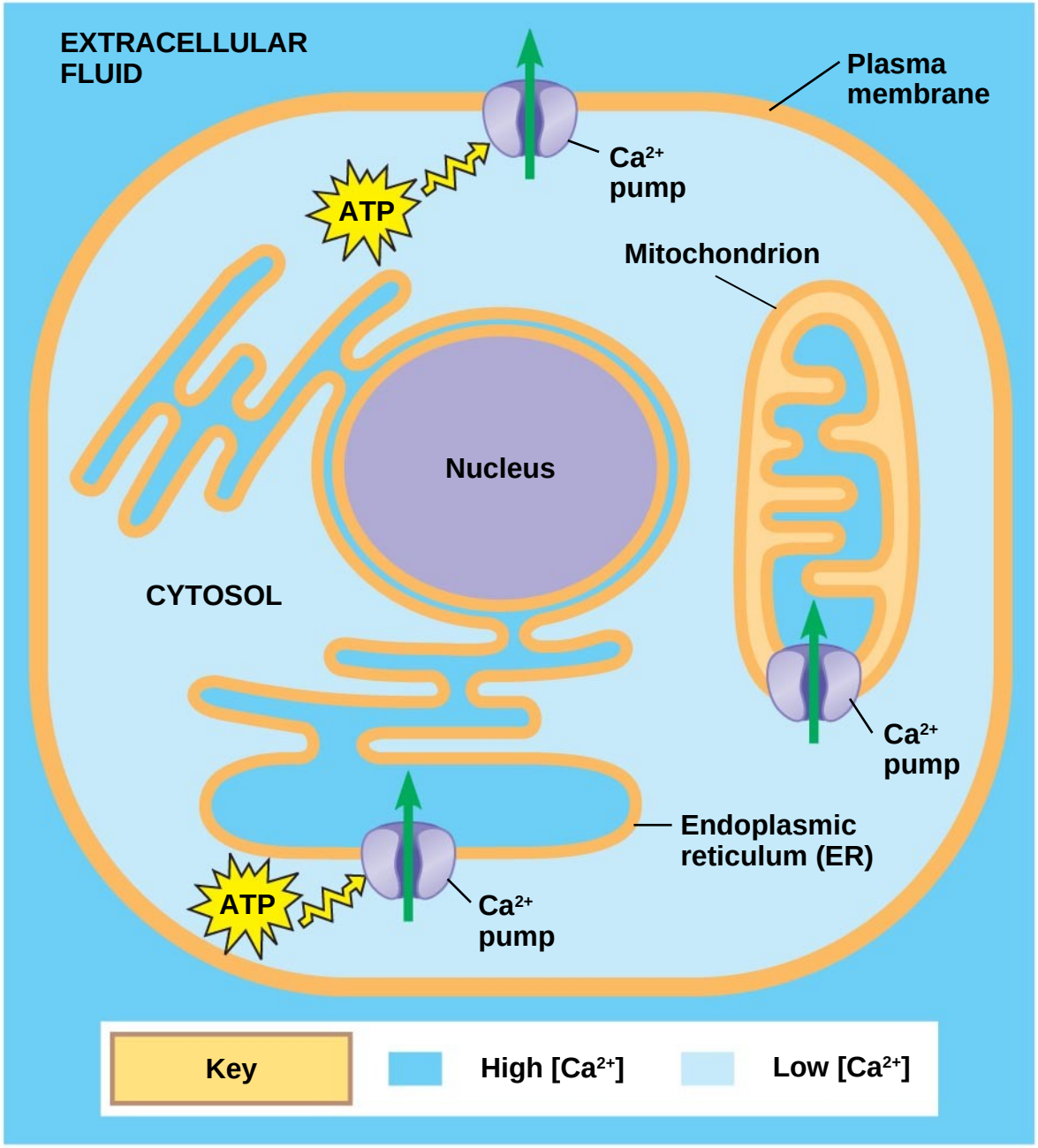

- A signal relayed by a signal transduction pathway may trigger an increase in calcium in the cytosol
- Pathways leading to the release of calcium involve inositol triphosphate (IP_3) and diacylglycerol (DAG) as second messengers

Animation: Signal Transduction Pathways

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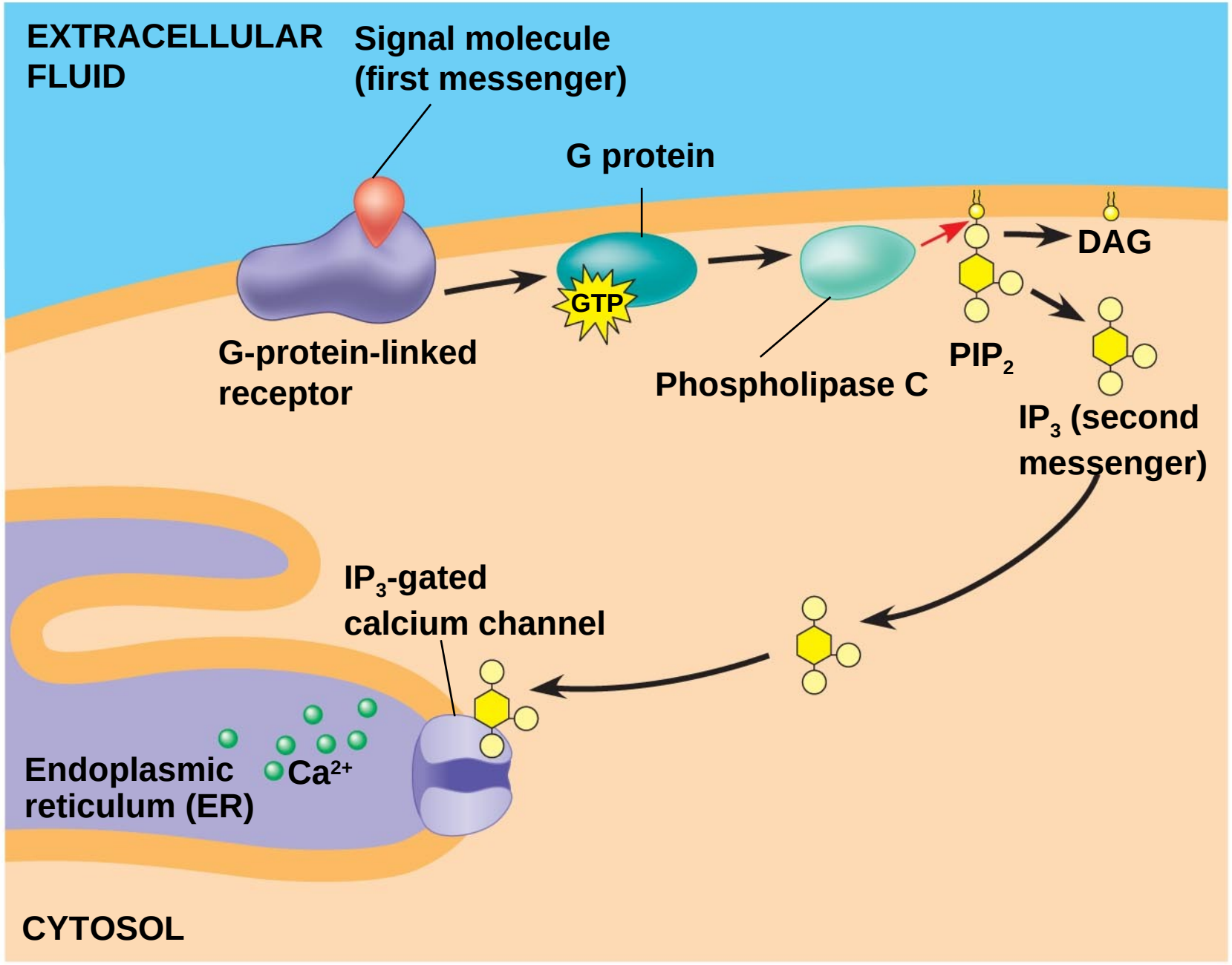

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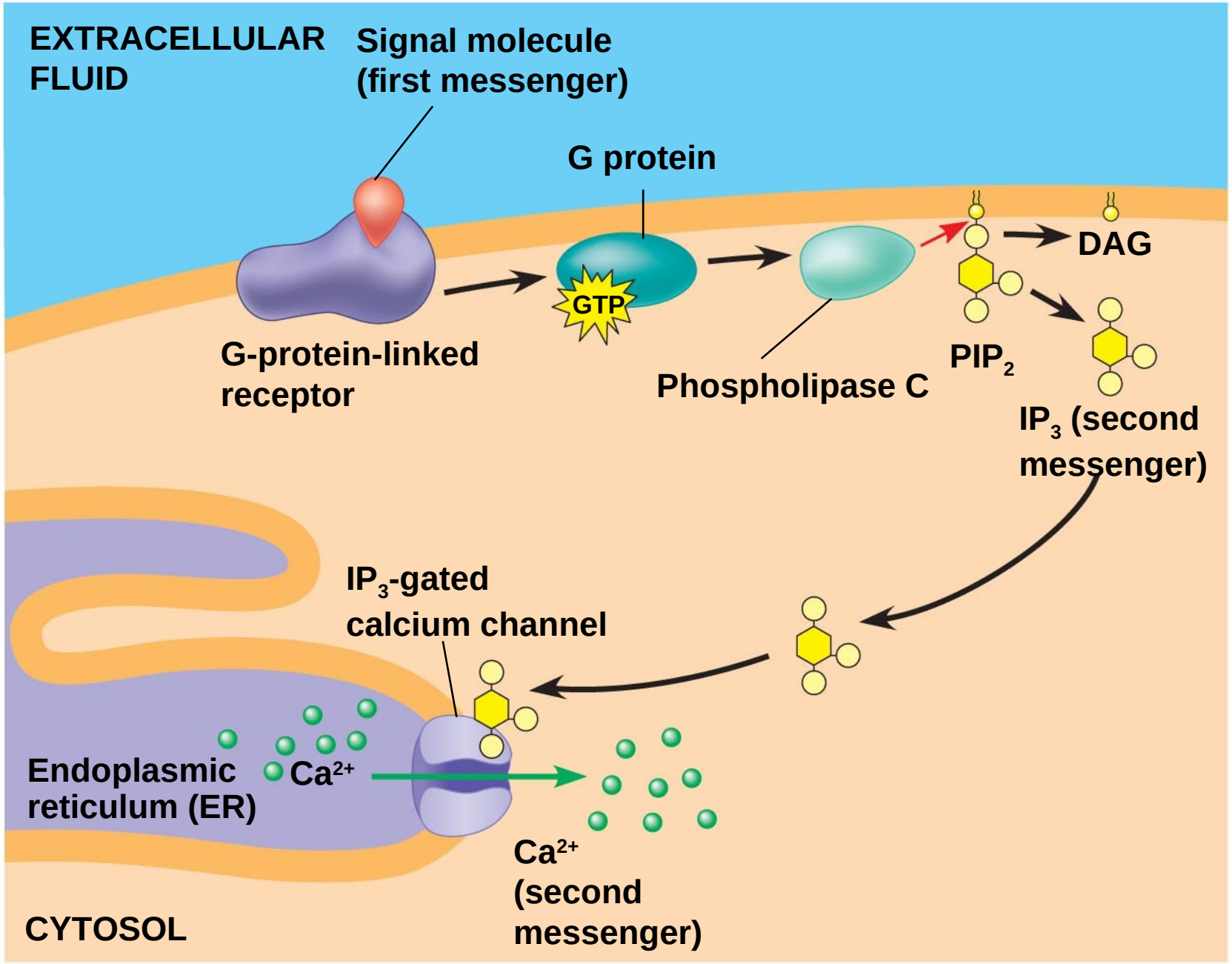

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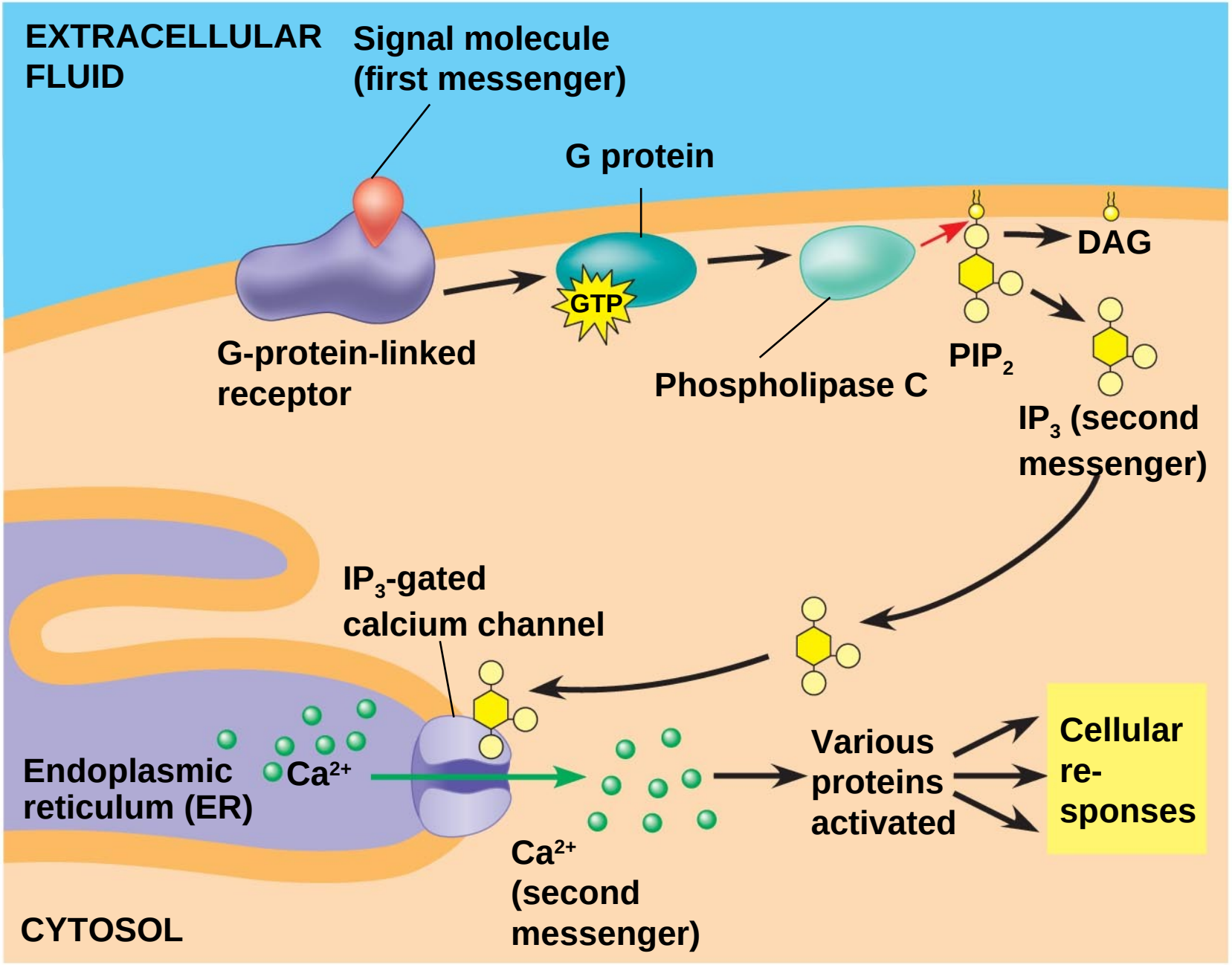

Concept 11.4: Response: Cell signaling leads to regulation of cytoplasmic activities or transcription

- The cell's response to an extracellular signal is sometimes called the "output response"

Cytoplasmic and Nuclear Responses

- Ultimately, a signal transduction pathway leads to regulation of one or more cellular activities
- The response may occur in the cytoplasm or may involve action in the nucleus
- Many pathways regulate the activity of enzymes

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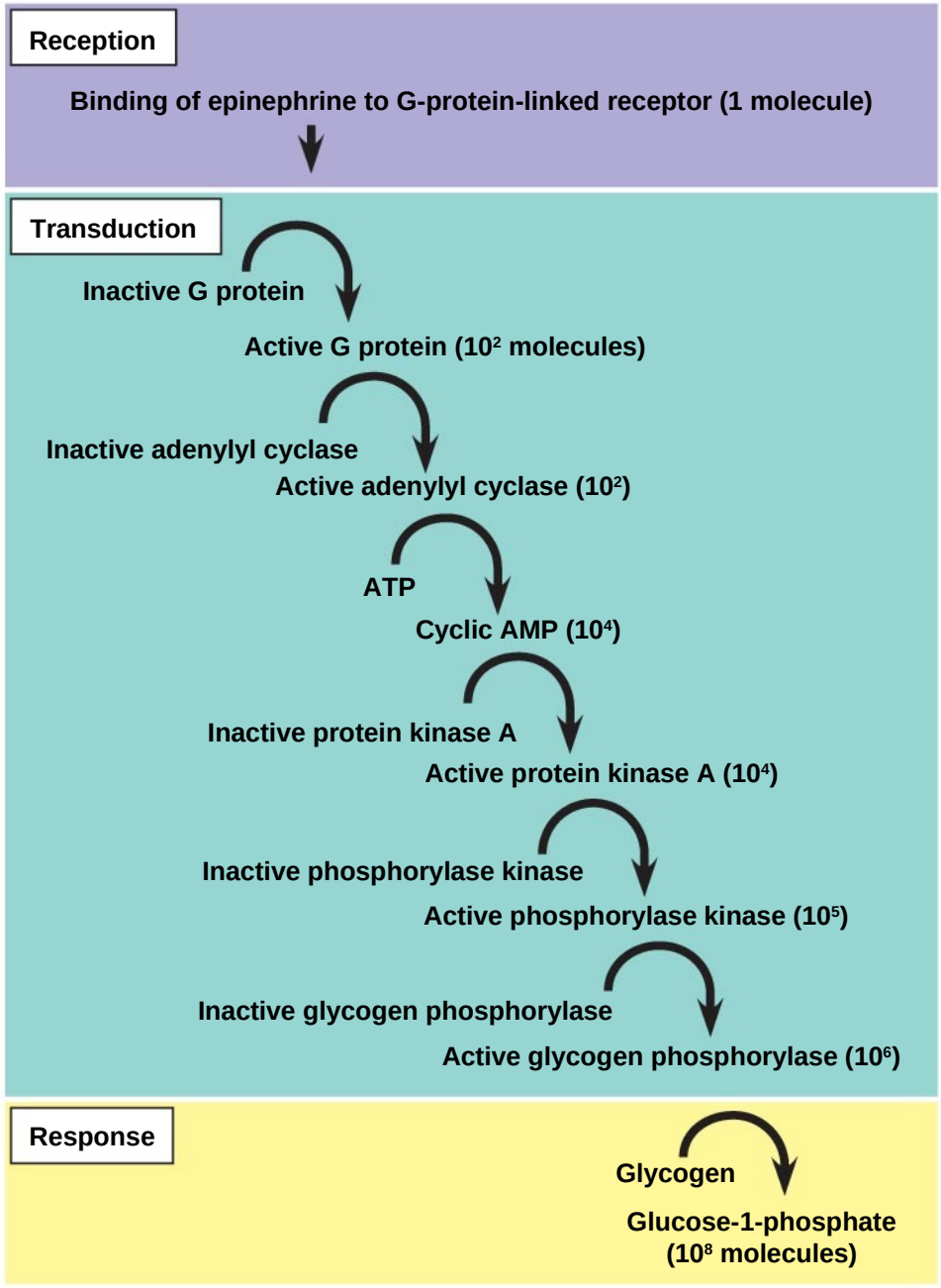

- Many other signaling pathways regulate the *synthesis* of enzymes or other proteins, usually by turning genes on or off in the nucleus
- The final activated molecule may function as a transcription factor

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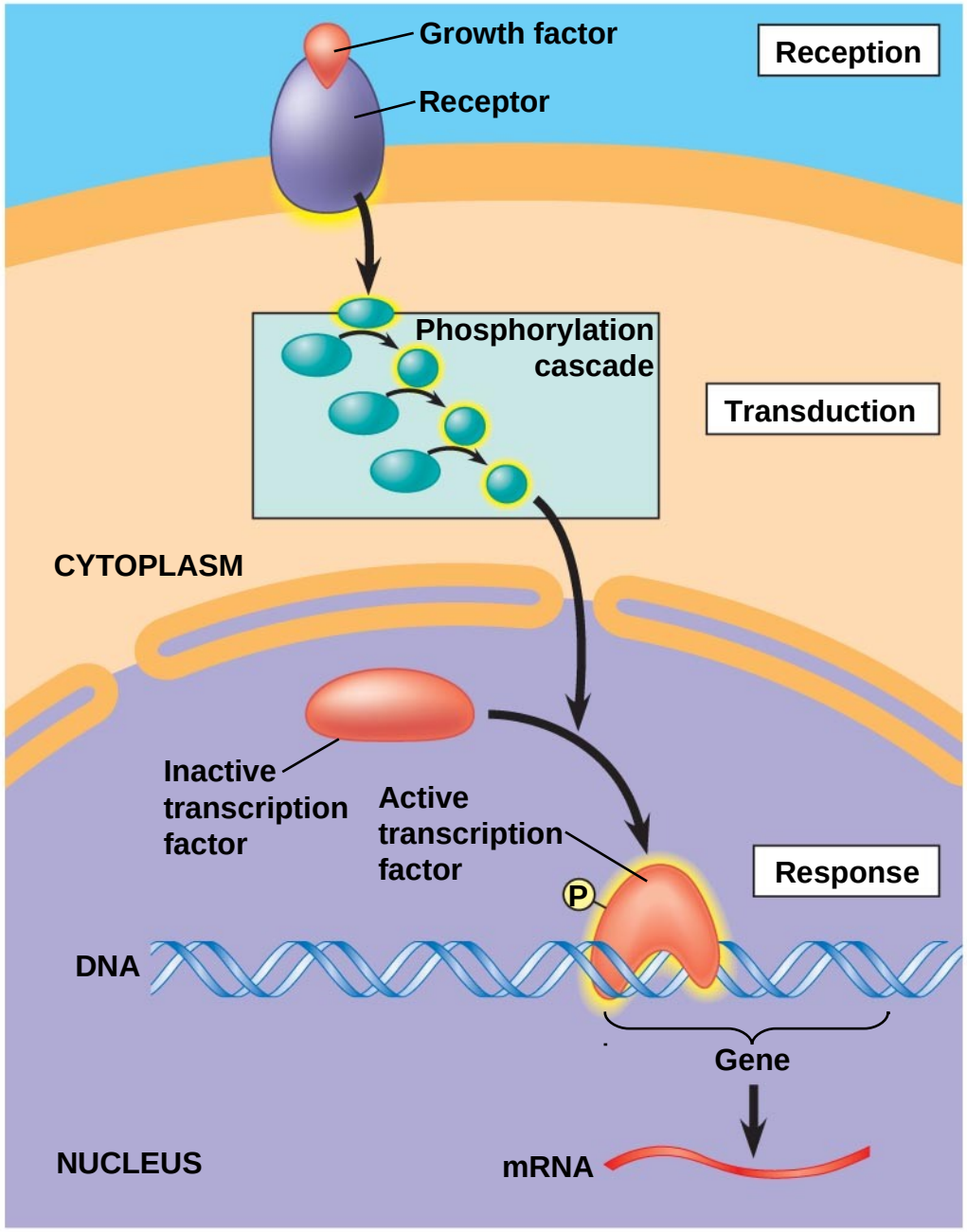

Fine-Tuning of the Response

- Multistep pathways have two important benefits:
  - Amplifying the signal (and thus the response)
  - Contributing to the specificity of the response

Signal Amplification

- Enzyme cascades amplify the cell's response
- At each step, the number of activated products is much greater than in the preceding step

The Specificity of Cell Signaling

- Different kinds of cells have different collections of proteins
- These differences in proteins give each kind of cell specificity in detecting and responding to signals
- The response of a cell to a signal depends on the cell's particular collection of proteins
- Pathway branching and "cross-talk" further help the cell coordinate incoming signals

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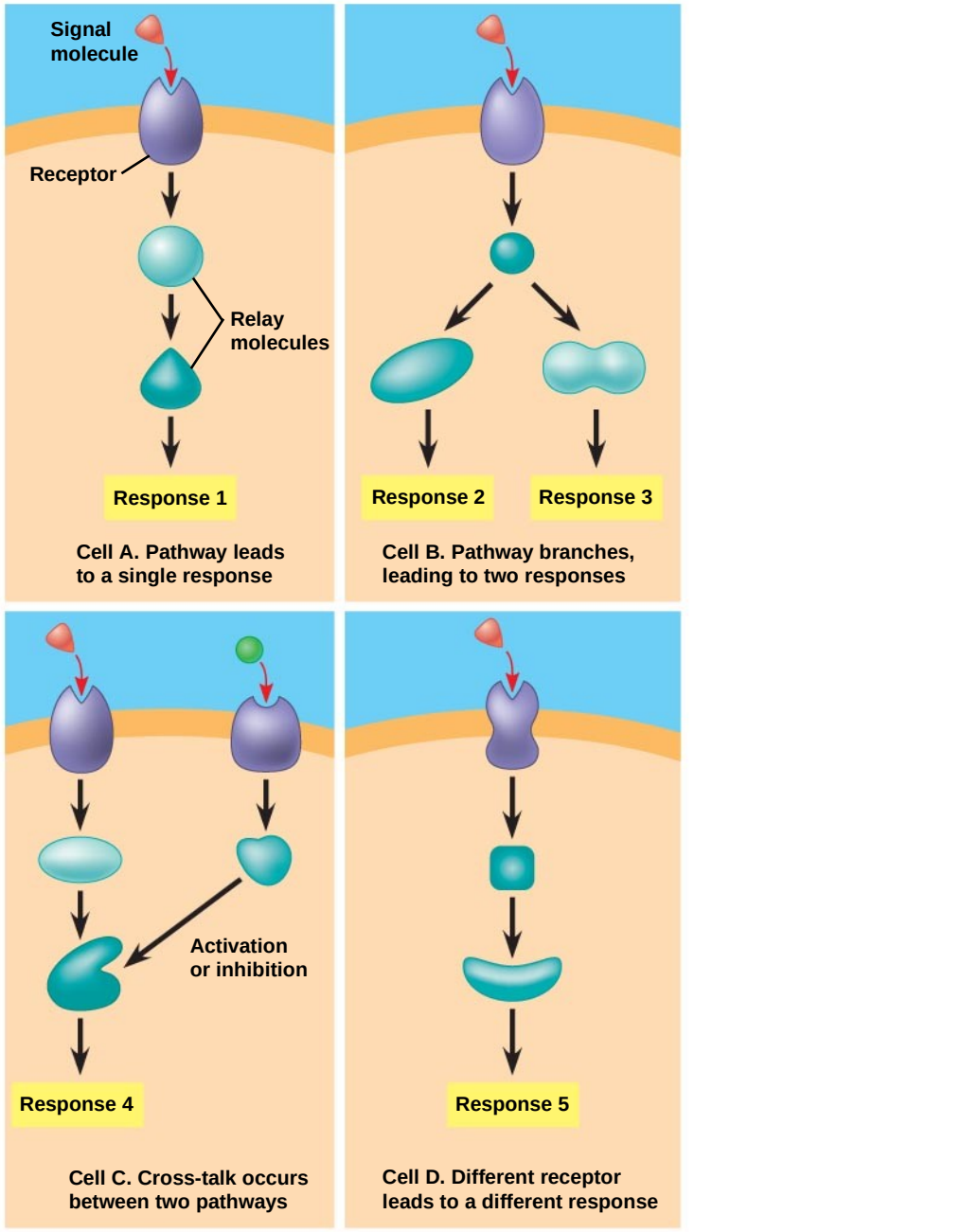

Signaling Efficiency: Scaffolding Proteins and Signaling Complexes

- Scaffolding proteins are large relay proteins to which other relay proteins are attached
- Scaffolding proteins can increase the signal transduction efficiency

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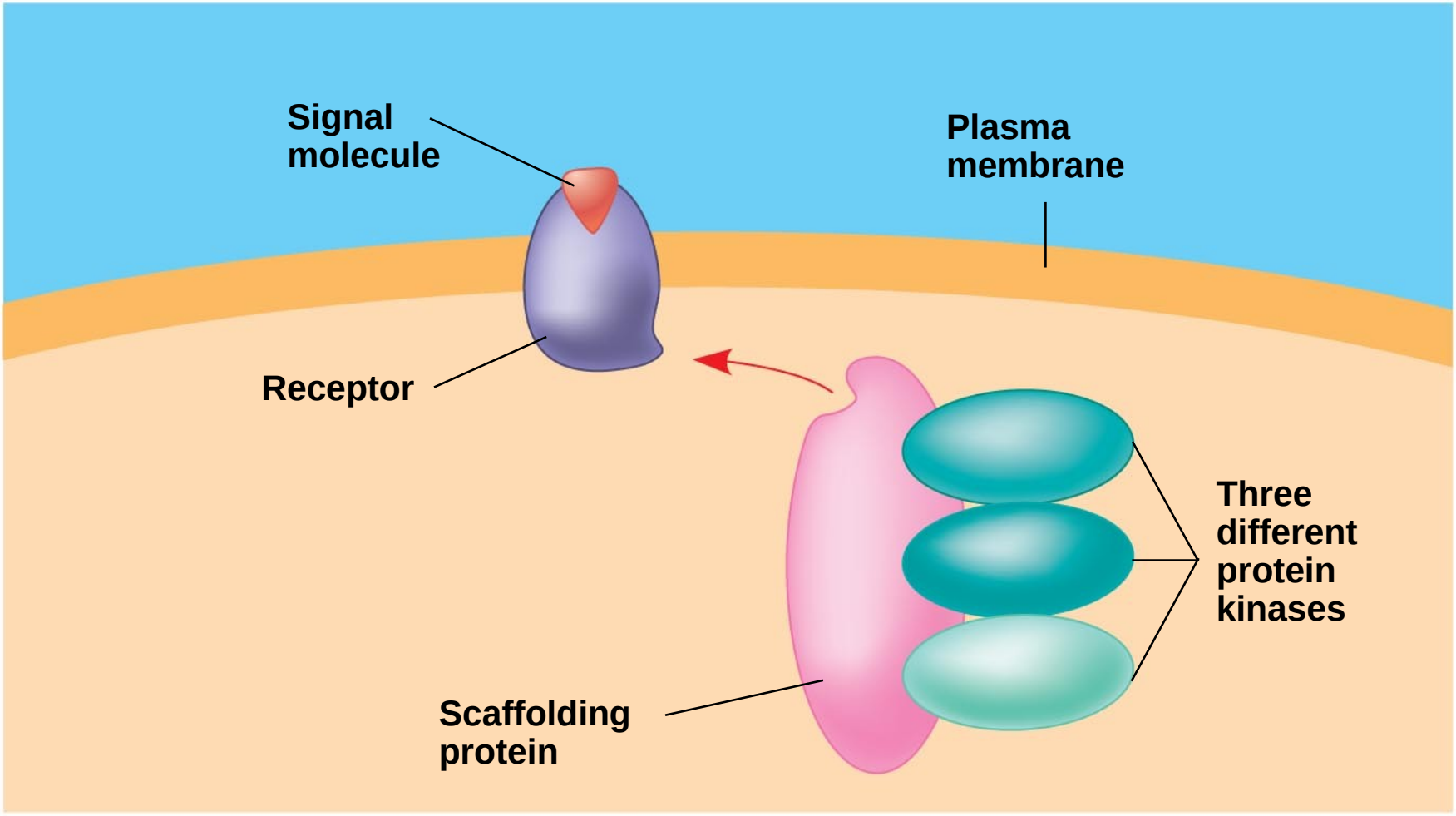

Termination of the Signal

- Inactivation mechanisms are an essential aspect of cell signaling
- When signal molecules leave the receptor, the receptor reverts to its inactive state