AP BIOLOGY | UNIT 4 | TOPICS 4.1 TO 4.3

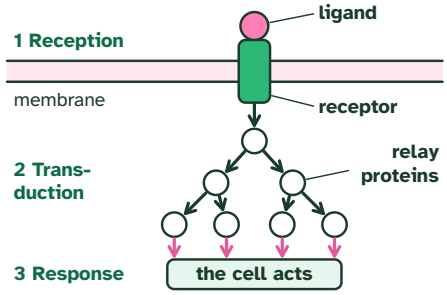
REVISION ON TWO PAGES

# How cells *signal*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

**A ligand binds the receptor that fits it. The receptor changes shape, relays inside pass the message on and amplify it, and the cell responds.**




**Read it like this.** One ligand outside, more active molecules at each step inside: the signal is amplified.

4.2.A START HERE

## Reception, transduction, *response*

- A **signal transduction pathway** links what a receptor senses to what the cell does. In **reception** the ligand binds its receptor, and the receptor **changes shape**.
- In **transduction** that change passes along a chain of relay molecules, mostly proteins, each switching on the next. In the **response** the last ones act: an enzyme starts work, a channel opens, a gene is read.
- Most relays are switched by a phosphate group. Its negative charges change how the protein folds, and so what it does. In a **phosphorylation cascade**, kinase switches on kinase, each one acting on many of the next.

THE ON AND OFF SWITCH

*a Kinase Kicks, a Phosphatase Peels*

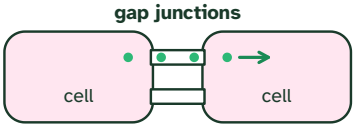
**K Kinase**
kicks a phosphate on, taken from ATP

**P Phosphatase**
peels it off, so the relay rests again

4.1.A DIRECT CONTACT

## Cells that *touch*

- **Gap junctions**: protein tunnels that join the cytoplasm of two animal cells. Ions and small molecules pass; proteins are too big. Heart muscle beats as one this way.
- **Plasmodesmata**: channels through plant cell walls, lined with plasma membrane, so cytoplasm runs on from cell to cell.
- **Surface contact:** a molecule on one cell binds a receptor on the other, as when an antigen-presenting cell switches on a helper T cell.




ions and small molecules pass

4.1.B ACROSS THE FLUID

## *Near* or far

- A **local regulator** acts on cells near the one that released it, then is broken down or taken up.
- **Paracrine:** it diffuses to neighbors, as a growth factor does. **Synaptic:** a neurotransmitter crosses the cleft between a neuron and the next cell.
- **Endocrine:** a gland releases a **hormone** into the blood. It reaches nearly every cell, but only **target cells**, those with its receptor, respond.
- Hormones to know: insulin, human growth hormone, thyroid hormones, testosterone, estrogen.

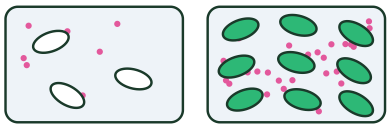
**20 nm**
a synaptic cleft: crossed in under a millisecond

**1 min**
about how long blood takes around the body

4.1.A, 4.3.A QUORUM SENSING

## Bacteria that *count heads*

- **Quorum sensing** is signaling that measures population density.
- Each cell releases a small signaling molecule, an **autoinducer**, and carries receptors for it: more cells, a higher concentration.
- Above a **threshold** it binds the receptors and switches genes on in every cell: a change in gene expression.
- *Vibrio fischeri* glows only when crowded inside a squid. Other bacteria time biofilms and toxins this way.

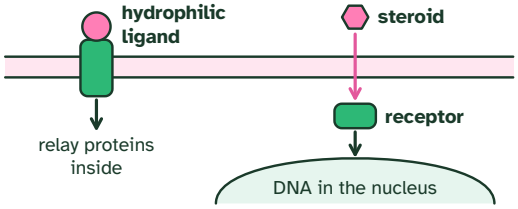


few cells | many cells

4.2.B

## A receptor fits *one ligand*

- A signaling molecule is a **ligand**, and the protein it binds is its **receptor**. The **ligand-binding domain** has a shape and a pattern of charges that fit one ligand: one to one.
- Binding is weak and reversible: the more ligand there is, the more receptors are filled at any moment.
- A cell with no receptor for a ligand cannot respond, however much is around.




The core of the membrane is hydrophobic, so where a receptor sits depends on its ligand

**In the membrane** hydrophilic or large
Proteins such as insulin, peptides, epinephrine. The ligand **never enters**: the receptor carries the message across by changing shape.

**Inside the cell** hydrophobic
Steroids such as testosterone and estrogen slip through the bilayer to a receptor in the cytoplasm or nucleus.

4.2.B LEARN THE PATTERN

## Four *receptors*, four speeds

| RECEPTOR | ITS LIGAND | WHAT BINDING DOES | THE RESPONSE | HOW FAST |
|---|---|---|---|---|
| **G protein-coupled** GPCR: crosses the membrane 7 times | Epinephrine | A **G protein** swaps its GDP for GTP, then switches on an enzyme. | A second messenger, then a kinase cascade. | **Seconds** |
| **Ligand-gated ion channel** receptor and channel in one | Acetylcholine | The channel opens. In a muscle fiber, **$Na^+$** rushes in down its gradient. | The membrane depolarizes: no second messenger. | **A millisecond** |
| **Receptor tyrosine kinase** its inner domain is a kinase | Insulin | It adds phosphates to its own tyrosines; relay proteins bind them. | Glucose transporters move to the membrane. | **Seconds to minutes** |
| **Intracellular receptor** in the cytoplasm or nucleus | Testosterone, estrogen | Hormone and receptor together bind DNA beside their target genes. | Transcription changes: new proteins are made. | **Hours, but it lasts** |

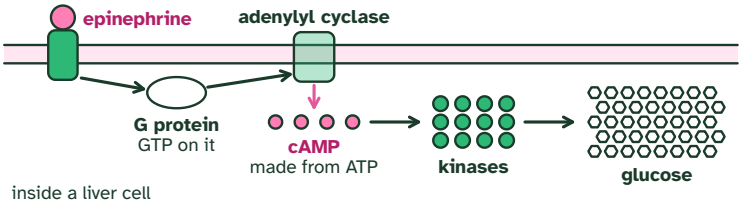
One signal can do different things in cells with different receptors and pathways.

A G protein is **off with GDP, on with GTP**

4.2.A, 4.2.B

## Epinephrine: one hormone, *millions of glucose*

- **Cyclic AMP (cAMP)** is a **second messenger**: the cell makes it once the receptor is active. Epinephrine, the first messenger, stays outside.
- Each enzyme acts on many molecules, so the signal is **amplified** at every step, down to glycogen phosphorylase, which breaks glycogen down.
- **Off:** the G protein breaks down its GTP, **phosphodiesterase** turns cAMP into AMP, and phosphatases take the phosphates off.




In order: *Real Gamers Always Collect Keys* (receptor, G protein, adenylyl cyclase, cAMP, kinases)

4.3.A RESPONSES

## What a signal makes a cell *do*

SLOW, LASTING
**Gene expression**
Ethylene ripens a fruit.

FAST, BRIEF
**Cell function**
An enzyme switches on.

MANY CELLS
**Phenotype**
An embryo grows testes.

THE END
**Apoptosis**
Programmed cell death.

4.3.B STUCK ON OR STUCK OFF

## When a pathway *breaks*

STUCK OFF
**Mutated receptor**
The ligand cannot bind.

STUCK OFF
**Beta blocker**
Binds; switches nothing on.

STUCK ON
**Cholera toxin**
GTP is never broken down.

OFF SWITCH LOST
**Caffeine, high dose**
cAMP is not broken down.

WATCH OUT

## Five mistakes that *cost points*

- ✕ **The ligand of a membrane receptor never enters the cell.** The receptor changes shape and relays carry the message.
- ✕ **GDP does not become GTP.** The G protein lets go of a GDP and picks up a new GTP.
- ✕ **cAMP is not the hormone, nor a piece of it.** The cell makes it from its own ATP.
- ✕ **A kinase's phosphate is a switch, not fuel.** It changes a protein's shape; no energy is stored there.
- ✕ **A target cell is set by its receptor, not its place.** Blood takes a hormone to nearly every cell.

COVER THE SHEET

## Can you *answer these?*

1. Describe three ways cells signal by direct contact.
2. Explain why a hormone changes only its target cells.
3. Predict the glow of *V. fischeri* after a tenfold dilution.
4. Identify where a peptide's receptor sits, and justify it.
5. Describe what a protein kinase does to its target.
6. Explain how a cascade amplifies a signal.
7. Explain why a steroid acts more slowly than epinephrine.
8. Predict the response if a phosphatase is lost.

IN THE EXAM

**One part changed?** Find it, decide whether it is stuck on or stuck off, then follow every arrow after it to the response. Parts above the change carry on as normal.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.