

# Unit 4: Cell Communication and Cell Cycle

Unit 4 covers how cells communicate through signal transduction pathways and how the cell cycle is regulated from interphase through mitosis. CED topics 4.1 through 4.6.

AP Biology

Cell Communication

About 12 minutes to read

## How to use this guide

Read it in order the first time because the topics build on each other. Cell communication introduces the signals, signal transduction follows one signal from reception to response, feedback shows how systems regulate themselves, and the cell cycle applies regulation to cell division. Exam questions usually describe a scenario, such as a mutation in a pathway or a cell stuck in one phase, and ask you to predict the outcome.

After the first read, use the trap boxes and the tables to review the distinctions that exam questions test most often. Finish with the practice questions, then complete the recall check on the last page out loud and note any items you cannot explain yet.

**What this unit is worth.** Unit 4 is one of the shorter units in the course, but its ideas return constantly. Signal transduction comes back in Unit 6 when you study gene regulation, and feedback mechanisms show up again in the nervous, immune, and endocrine topics of later units. The cell cycle is also the foundation for meiosis in Unit 5, so the phases you learn here get reused.

## 4.1 Cell Communication

Cells have two basic ways to reach each other. They can touch, or they can send a chemical message across a distance. **Cell-to-cell contact** is direct communication through touching. **Chemical signaling** means a released signal travels to target cells somewhere else.

Chemical signals sort by distance. **Local regulators** act on cells near the emitting cell.

Neurotransmitters are the example you know best. The CED also lists plant immune responses, quorum sensing in bacteria, and morphogens in embryos as short-distance examples. **Hormones** travel long distances in the bloodstream. The CED examples are insulin, human growth hormone, thyroid hormones, testosterone, and estrogen.

| SIGNAL TYPE          | DISTANCE                           | CED EXAMPLES                                                                                    |
|----------------------|------------------------------------|-------------------------------------------------------------------------------------------------|
| Cell-to-cell contact | Cells must touch                   | Immune cell interaction, including antigen-presenting cells, helper T cells, and killer T cells |
| Local regulators     | Nearby cells only                  | Neurotransmitters, quorum sensing in bacteria, morphogens in embryos                            |
| Hormones             | Long distance, via the bloodstream | Insulin, human growth hormone, thyroid hormones, testosterone, estrogen                         |

One kind of contact signaling is worth knowing by name. Immune cells interact through cell-to-cell contact, including antigen-presenting cells, helper T cells, and killer T cells. The CED lists this as an illustrative example, which means you should recognize it but will not be asked for details beyond what is here.

**Trap.** Distance is the sorting rule. A chemical messenger is not automatically a hormone. Hormones travel in the blood to distant targets. If the signal acts on nearby cells, it is a local regulator no matter what released it.

## 4.2 Introduction to Signal Transduction

A **signal transduction pathway** links the reception of a signal to a cellular response. It runs in three stages, always in this order. **Reception** is when a target cell detects the signal. **Transduction** is when the signal is relayed and amplified inside the cell. **Response** is what the cell does at the end.

Reception starts with two players. The **ligand** is the chemical messenger, a peptide or small molecule. The **receptor protein** recognizes it through a ligand-binding domain. Receptors sit on the cell surface or inside the cell, in the cytoplasm or nucleus. A ligand that cannot cross the plasma membrane binds a surface receptor. A ligand that can cross the membrane may bind a receptor inside the cell instead.

Specificity comes from the match between the two. Only cells carrying the right receptor respond to a given ligand. That is why a hormone traveling everywhere in the blood still affects only its target cells. The signal is public. The ability to hear it is not.

**Trap.** The receptor decides who responds, not the signal. If a question asks why a widespread hormone affects only a few tissues, the answer is receptors.

## 4.3 Signal Transduction

Two receptor types do most of the work you need to know. A **G protein-coupled receptor** sits in the membrane of the target cell. When the ligand binds on the outside, the intracellular domain changes shape and starts transduction. A **ligand-gated channel** is also in the membrane, but binding opens or closes the channel itself.

Inside the cell, a **signaling cascade** relays the signal from the receptor to its target in a sequence of steps. Two tools carry it. **Second messengers** are small intracellular molecules, such as cyclic AMP (cAMP), that spread the signal inside the cell. A **phosphorylation cascade** adds phosphate groups to a series of proteins, and each activated protein can activate many copies of the next one. That multiplication is where most of the amplification happens.

The **cellular response to signaling** is whatever the cell does at the end of the pathway. Signal transduction can change gene expression and cell function, alter the phenotype, or trigger apoptosis, which is programmed cell death. The CED example is **epinephrine stimulating glycogen breakdown** in mammals. One hormone outside the cell leads to many glucose molecules released inside, which shows amplification in action.

**Trap.** Amplification happens during transduction, not at reception. One ligand binding one receptor is a small event. The cascade is what turns it into a large response.

## 4.4 Changes in Signal Transduction Pathways

Pathways can change, and the response changes with them. A mutation in any domain of a receptor protein, or in any component of a signaling pathway, can alter signal transduction downstream. Chemicals that interact with any component of the pathway can activate it or inhibit it.

Work through the logic in both directions. If a mutation prevents the ligand from binding, the pathway stays silent and the response never happens. If a mutation locks a component in its active shape, the pathway can fire without any signal at all. Exam questions often give you one of these two cases and ask for the outcome, so check which part of the pathway the change hits before you answer.

**Trap.** The location of the change determines the direction of the effect. A broken binding domain silences the pathway. A component stuck in its active form turns the pathway on. Do not assume every mutation breaks the pathway.

## 4.5 Feedback

**Feedback** is how biological systems regulate themselves. In **negative feedback**, the response reduces the initial stimulus. When a variable moves off its set point, the system pushes it back. In **positive feedback**, the response amplifies the stimulus. The variable moves further from the set point as the stimulus intensifies, and the system changes instead of stabilizing.

|                           | NEGATIVE FEEDBACK            | POSITIVE FEEDBACK                |
|---------------------------|------------------------------|----------------------------------|
| Effect on the stimulus    | Reduces it                   | Intensifies it                   |
| Direction of the variable | Returns toward the set point | Moves away from the set point    |
| Result for the system     | Stability                    | Change, often toward a new state |

**Homeostasis** is the maintenance of stable internal conditions in response to internal and external change, and feedback is the mechanism that achieves it. It operates at the molecular, cellular, and organismal levels. The CED example is **blood sugar regulation**. When blood glucose rises, insulin is released and cells take up glucose, bringing the level back down. Glucagon acts in the other direction when glucose falls. The stimulus is reduced either way, which is what makes it negative feedback.

**Trap.** Homeostasis is the outcome. Feedback is the mechanism. If a question asks what maintains stability, the answer is negative feedback, not homeostasis itself.

## 4.6 Cell Cycle Regulation

The **cell cycle** is the regulated series of events by which eukaryotic cells grow and reproduce. It alternates between **interphase**, when the cell grows and copies its DNA, and mitosis, when the copied genome is divided between two daughter cells.

Interphase has three stages, always in this order. In **G1 phase** the cell is metabolically active, duplicating organelles and cytosolic components. In **S phase** DNA replicates, and each chromosome becomes two **sister chromatids** joined at the **centromere**. In **G2 phase** the cell synthesizes proteins, produces ATP in large quantities, and replicates its **centrosomes**. Some cells leave the cycle for **G0 phase**, a stage where they no longer divide but can reenter the cell cycle if the right cues arrive.

**Mitosis** moves a complete genome into two genetically identical daughter cells. It also drives growth, tissue repair, and asexual reproduction. The stages are defined by what you would see under a microscope.

| STAGE     | WHAT YOU WOULD SEE                                                                                                                            |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Prophase  | Sister chromatids condense and become visible. The <b>mitotic spindle</b> begins to form, and centrosomes move to opposite poles of the cell. |
| Metaphase | Spindle fibers align the chromosomes along the equator of the cell.                                                                           |
| Anaphase  | Paired sister chromatids separate as spindle fibers pull them toward opposite poles.                                                          |
| Telophase | The mitotic spindle breaks down and a new nuclear envelope develops around each set of chromosomes.                                           |

After the nucleus divides, **cytokinesis** divides the cytoplasm. In animal cells a cleavage furrow pinches the cell inward. In plant cells a cell plate forms across the middle. Either way the result is two new daughter cells.

**Cell cycle checkpoints** are the internal controls that regulate progress through the cycle. They are operated by two partners. **Cyclins** are proteins whose levels rise and fall through the cycle. **Cyclin-dependent kinases** (CDKs) are enzymes that, together with cyclins, drive events forward. Learn the partnership, not a list. The CED states that knowledge of specific cyclin-CDK pairs is beyond AP scope.

When these controls fail, division can run unchecked. **Cancer** is uncontrolled cell division resulting from disruptions to the cell cycle. A broken checkpoint lets a damaged cell keep dividing instead of pausing for repair or undergoing apoptosis.

**Trap.** Mitosis divides the nucleus. Cytokinesis divides the cytoplasm. Questions that ask what happens right after telophase are usually testing whether you keep those two separate.

## Confusions That Cost Points

Most missed questions in this unit come from a short list of pairs that look alike under time pressure. Review each pair carefully so you can tell them apart when you see them in a question.

| PAIR                                        | HOW TO SEPARATE THEM                                                                                                                                                                                                                   |
|---------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ligand vs receptor                          | The ligand is the message. The receptor is the receiver, and it determines which cells can respond.                                                                                                                                    |
| GPCR vs ligand-gated channel                | A G protein-coupled receptor changes shape inside the cell to start transduction. A ligand-gated channel opens or closes to let substances through. Both sit in the membrane. What happens after binding is what differs.              |
| Second messenger vs phosphorylation cascade | Second messengers are small molecules such as cAMP that spread the signal inside the cell. A phosphorylation cascade is a series of protein modifications. They often work together, but one is a molecule and the other is a process. |
| Negative vs positive feedback               | Negative feedback reduces the stimulus and restores the set point. Positive feedback amplifies the response and moves the system away from the set point.                                                                              |
| Mitosis vs cytokinesis                      | Mitosis divides the nucleus into two identical sets of chromosomes. Cytokinesis divides the cytoplasm. One can finish without the other starting.                                                                                      |
| Sister chromatids vs separated chromosomes  | After S phase, a chromosome consists of two sister chromatids joined at the centromere. They separate during anaphase, and each chromatid then counts as its own chromosome.                                                           |
| Cyclin vs cyclin-dependent kinase           | Cyclins are regulatory proteins whose levels rise and fall. CDKs are the enzymes that do the work. The pair together drives the cycle forward.                                                                                         |
| Prophase vs metaphase                       | Prophase condenses chromosomes and builds the spindle. Metaphase lines chromosomes up at the equator. Build, then line up.                                                                                                             |
| Cell-to-cell contact vs chemical signaling  | Contact requires cells to touch. Chemical signaling sends molecules across a distance, nearby for local regulators and far for hormones.                                                                                               |

## Practice Questions

Original questions written for this guide in the style of the AP exam. Answers and explanations are on the next page, so complete the questions before checking them.

**1.** A pancreatic cell releases insulin into the bloodstream, and muscle cells far away take up glucose in response. A nearby neuron releases a neurotransmitter that affects only the adjacent muscle fiber.

Which statement correctly compares the two signals?

- A. Both are local regulators because both involve chemical messengers
- B. Insulin is a long-distance hormone, while the neurotransmitter is a local regulator
- C. Both require direct cell-to-cell contact
- D. The neurotransmitter is a hormone because it is released by a neuron

**2.** A peptide ligand cannot cross the plasma membrane of its target cell. Where does this ligand bind, and why?

- A. In the cytoplasm, because all ligands bind intracellular receptors
- B. On a receptor at the cell surface, because the ligand cannot enter the cell
- C. Directly to a second messenger, skipping the receptor
- D. In the nucleus, where it alters gene expression immediately

**3.** In a phosphorylation cascade, one activated kinase activates many copies of the next kinase in the series. What is the main advantage of this arrangement?

- A. The signal is amplified, so a small input produces a large cellular response
- B. The response becomes permanent and cannot be reversed
- C. The cell no longer needs a receptor to detect the signal
- D. The ligand is carried into the nucleus by the kinases

**4.** A mutation alters the ligand-binding domain of a receptor protein so that its normal ligand can no longer bind. What is the most direct consequence?

- A. The signaling pathway is activated continuously without the ligand
- B. The receptor cannot initiate transduction, so the downstream response does not occur
- C. The cell begins producing large amounts of the ligand to compensate
- D. Second messengers are destroyed before they can act

- 5.** After a meal, rising blood glucose triggers insulin release. Insulin causes cells to take up glucose, and blood glucose falls back toward its set point. This sequence is an example of
- A. positive feedback, because insulin amplifies the rise in glucose
  - B. negative feedback, because the response reduces the initial stimulus
  - C. a phosphorylation cascade, because insulin is a kinase
  - D. quorum sensing, because many cells respond at once
- 6.** A cell is in the phase of interphase during which each chromosome is replicated into two sister chromatids joined at the centromere. Which phase is it?
- A. G1 phase
  - B. S phase
  - C. G2 phase
  - D. M phase
- 7.** During mitosis, spindle fibers shorten and sister chromatids are pulled toward opposite poles of the cell. This describes
- A. prophase
  - B. metaphase
  - C. anaphase
  - D. telophase
- 8.** A cell with damaged DNA fails to pause before dividing, and the damage is passed to both daughter cells. The control that most likely failed is
- A. a cell cycle checkpoint
  - B. the cleavage furrow
  - C. a ligand-gated ion channel
  - D. the centrosome

## Answer Key

- 1. B.** Insulin travels in the bloodstream to distant targets, which makes it a hormone. The neurotransmitter acts only on a nearby cell, which makes it a local regulator. A conflates chemical with local. Distance is the sorting rule, not chemistry. C describes direct contact, which neither signal uses. D misapplies the hormone label. Neurons release many signal types, and this one acts locally.
- 2. B.** A ligand that cannot cross the membrane must bind on the outside, at a cell-surface receptor. A reverses the rule. Intracellular receptors are for ligands that can cross the membrane. C skips reception entirely, which breaks the pathway order. D confuses the eventual response with the binding site. Gene expression changes happen downstream, after transduction.
- 3. A.** Each step activating many copies of the next is how the pathway amplifies a small input into a large response. B is the trap. Phosphorylation is a reversible modification, and nothing here makes the response permanent. C is wrong because the cascade sits downstream of reception. The receptor is still required. D invents a transport job for kinases. The ligand stays outside the cell.
- 4. B.** If the ligand cannot bind, the receptor never initiates transduction and the response never happens. A describes a different mutation, one that locks a component in its active shape and causes constant firing. That is the direction trap for this topic. C invents a compensatory mechanism the pathway does not include. D targets the wrong component. The defect is at reception, not in the second messengers.
- 5. B.** The response reduces the initial stimulus. Rising glucose triggers a response that lowers glucose back toward the set point, which is negative feedback. A reverses the direction. Positive feedback would push glucose even higher. C mislabels insulin, which is a hormone, not a kinase, and names the wrong mechanism. D borrows a bacterial term for a mammalian process.
- 6. B.** DNA replication happens in S phase, producing two sister chromatids joined at the centromere. A is the trap for students who remember G1 involves duplication. G1 duplicates organelles and cytosolic components, not DNA. C comes after replication. G2 handles protein synthesis and centrosome replication. D is mitosis, when chromatids separate. Replication is already finished by then.
- 7. C.** Sister chromatids separating toward opposite poles defines anaphase. A is condensation and spindle formation. B is alignment at the equator. D is the trap. Telophase reforms the nuclear envelope, which happens after separation is complete.
- 8. A.** Checkpoints are the internal controls that pause the cycle, and a damaged cell that divides anyway points to checkpoint failure. B divides the cytoplasm during cytokinesis. It does not inspect DNA. C belongs to signal transduction, a different process entirely. D organizes the spindle. It carries out separation but makes no go or no-go decisions.

# One-Page Recall Check

Say each answer out loud before you look back, and mark the ones you cannot finish. Anything you cannot say out loud yet belongs in your flashcard deck. In Rycal, add those items to the Cell Communication and Cell Cycle deck and let spaced review bring them back over the next few days.

- Sort these by signaling distance, shortest to longest: cell-to-cell contact, local regulator, hormone. State what sets each apart.
- Explain why only some cells respond to a hormone that travels everywhere in the blood.
- Define ligand and receptor, then explain which one determines the specificity of the response.
- Walk through reception, transduction, and response using epinephrine and glycogen breakdown.
- Explain how a phosphorylation cascade amplifies a signal, and name one second messenger.
- Distinguish a G protein-coupled receptor from a ligand-gated channel by what happens right after the ligand binds.
- Explain how a mutation in a pathway component can silence a response in one case and activate it without a signal in another.
- Contrast negative and positive feedback by what happens to the initial stimulus in each.
- Explain homeostasis and the role of feedback in maintaining it.
- List G1, S, and G2 in order and state what the cell accomplishes in each.
- Explain what G0 is and how a cell in G0 differs from one in G1.
- For prophase, metaphase, anaphase, and telophase, state the one visible event that defines each stage.
- Distinguish mitosis from cytokinesis, and state how cytokinesis differs in plant and animal cells.
- Explain the jobs of cyclin and cyclin-dependent kinases, and why their interaction matters more than either protein alone.
- Explain how a disruption to cell cycle checkpoints can lead to cancer.

**Where to go next.** Turn every missed item above into flashcards and drill them spaced out over several days rather than in one sitting. In Rycal, open the Cell Communication and Cell Cycle deck under AP Biology. The deck covers the terms in this guide, and its practice questions target the same traps named here. If you have a test date, add it in the Test Planner. You can also start your next review with a Brain Dump, then check what you missed against this guide.

## Key terms for this unit

Cell-to-cell contact, chemical signaling, local regulators, immune cell interaction, long-distance hormones, local signaling examples, signal transduction pathway, ligand, receptor protein, G protein-coupled receptor, signaling cascade, second messenger, phosphorylation cascade, ligand-gated channel, hormone, cellular response to signaling, signaling pathway disruption, quorum sensing, epinephrine and glycogen breakdown, negative feedback, positive feedback, homeostasis, blood sugar regulation, cell cycle, interphase, G1 phase, S phase, G2 phase, G0 phase, mitosis, prophase, metaphase, anaphase, telophase, cytokinesis, sister chromatid, centromere, mitotic spindle, centrosome, cell cycle checkpoint, cyclin, cyclin-dependent kinase, cancer, apoptosis.