The Ultimate AP® Biology Unit 4 Cheat Sheet

4.1 Cell Communication

Why Cells Signal

Signals coordinate cells → growth, metabolism, development, immune response, homeostasis.
Ligand = signaling molecule (protein, steroid, gas, ion). Binds a specific **receptor** on or inside the target cell only.
Target cell: only cells w/ the matching receptor respond. Same signal can cause diff. responses in diff. cells.

Signal Distance

Type	Range	Example
Direct contact	Touching	Gap junctions
Cell-cell recog.	Touching	MHC, T cells
Paracrine	Local	Growth factors
Synaptic	Local	Neurotransmitter
Endocrine	Long	Hormones (blood)
Autocrine	Self	Some immune cells

Gap junctions (animals) / **plasmodesmata** (plants): channels → ions, small molecules pass directly.
Cell-cell recognition: surface molecules (glycoproteins, MHC) touch receptors → e.g., an antigen-presenting cell activates a T cell (the adaptive immune response).
Hormones: endocrine glands → blood → distant targets (insulin, epinephrine, human growth hormone).

Single Cells Signal Too

Quorum sensing: bacteria release a signal; high pop. → high conc. → genes switch on together (biofilms, bioluminescence, toxin release in V. fischeri, cholera).
Yeast mating factors: a & α cells signal each other → fuse. Shows that cell signaling evolved very early.

⚠ A cell responds only if it has the receptor. No receptor → no response, even if the signal is there.

✓ Classify by distance: touching → contact; nearby → paracrine/synaptic; via blood → endocrine.

4.2 Intro to Signal Transduction

Three Stages

1) Reception: ligand binds the receptor → the receptor changes shape (a conformational change).
2) Transduction: relay molecules pass the signal on, often as a multistep cascade inside the target cell.
3) Response: gene expression, enzyme activity, cell division, apoptosis, or movement of the whole cell.

Receptor Types

Receptor	Where	Ligand
GPCR	Membrane	Epinephrine
Receptor TK	Membrane	Insulin, GFs
Ligand-gated	Membrane	Acetylcholine
Intracellular	Cytoplasm/nuc.	Steroids

Polar/large ligands (proteins, peptides) can't cross the memb. → they bind **membrane receptors** on the surface.
Nonpolar/small ligands (steroids like testosterone, estrogen; NO) cross the memb. → bind **intracellular receptors** → often act as transcription factors in the nucleus.
GPCR: 7-pass receptor; ligand → activates G protein (GDP → GTP) → activates enzyme (e.g., adenylyl cyclase).
Receptor tyrosine kinase: 2 subunits pair up → phosphorylate each other → relay proteins bind → many pathways start at once (insulin, growth factors).
Ligand-gated ion channel: ligand opens gate → ions flow (Na^+, Ca^{2+}) → fast response (nerves, muscle).
Specificity: receptor shape matches ligand shape → the same logic as an enzyme + its substrate.
Signal strength: more ligand → more receptors bound → bigger response, until receptors saturate.

⚠ Ligands usually don't enter the cell. The RECEPTOR changes shape and passes the message.

✓ Predict receptor location from ligand: hydrophobic → inside cell; hydrophilic → on membrane.

4.3 Signal Transduction Pathways

Phosphorylation Cascades

Protein kinase: adds phosphate (from ATP) to a protein → activates it. Next kinase in line → domino effect.
Protein phosphatase: removes the phosphate → switches the protein off → resets the pathway for reuse.
Amplification: each enzyme activates many more → 1 ligand → millions of product molecules in seconds.

Second Messengers

Second messenger: small, nonprotein molecule; spreads fast through cytoplasm. e.g., **cAMP**, **Ca^{2+}**, IP_3.

cAMP: adenylyl cyclase turns ATP → cAMP → activates protein kinase A. Phosphodiesterase breaks cAMP → off.
Ca^{2+}: IP_3 opens ER channels → Ca^{2+} floods the cytosol → muscle contraction, secretion, fertilization.

Example: Epinephrine → Glucose

Step	What happens
Reception	Epinephrine binds GPCR
Relay	G protein → adenylyl cyclase
2nd messenger	ATP → cAMP
Cascade	PKA → kinases phosph.
Response	Glycogen → glucose

Responses: in cytoplasm (enzyme on/off, fast) or nucleus (transcription factor → new proteins, slower).
Scaffolding proteins hold relay proteins together → faster, more specific & efficient signaling w/ less crosstalk.
Turning off: ligand leaves receptor, GTP → GDP (G protein off), phosphatases, PDE → cell ready for next signal.

⚠ Kinases ADD phosphates; phosphatases REMOVE them. Both are needed to turn signals on AND off.

✓ FRQ: describe each step in order and say exactly which molecule activates the next one in the chain.

4.4 Changes in Signal Transduction

What Can Go Wrong

Any step can fail: the ligand, receptor, a relay protein, 2nd messenger, or the final response protein.
Mutation in receptor → can't bind ligand (no response) OR stuck "on" w/o ligand (constant response).
Mutation in a relay protein → signal blocked OR always on, no matter what the receptor upstream does.

Classic Examples

Change	Effect
Ras stuck on (GTP)	Constant growth → cancer
Cholera toxin	G protein stuck on → diarrhea
Pertussis toxin	G protein stuck off
Insulin resistance	Type 2 diabetes
Beta-blockers	Block epinephrine recep.
Viagra (sildenafil)	Blocks PDE → more cGMP

Cholera: toxin keeps G_s active → cAMP stays high → Cl^- & H_2O are pumped into the gut → diarrhea.
Drugs: many mimic ligands (agonists) or block receptors (antagonists); others block enzymes (e.g., PDE).

Reasoning Pattern

Upstream vs downstream: a block AFTER the receptor stops the response even if ligand binds. A protein stuck ON downstream → a response w/o any ligand.
Fix: adding more ligand only helps if the problem is too little ligand, not a broken receptor or relay protein.
Evolution link: shared pathways (e.g., kinase cascades) across eukaryotes → common ancestry.

⚠ A stuck-ON protein causes response with NO signal. Don't say "no response" for every mutation.

✓ Predict Qs: find the broken step → is it stuck on or off → what happens to every step downstream.

4.5 Feedback

Negative Feedback

Negative feedback: response opposes the change → returns to set point → **homeostasis**. Most common.
Parts: stimulus → sensor/receptor → control center → effector → response that reverses stimulus.
Blood glucose ↑ → pancreas β cells release **insulin** → cells take up glucose, liver stores glycogen → glucose ↓.
Blood glucose ↓ → α cells release **glucagon** → liver breaks down glycogen → blood glucose ↑ again.
Body temp ↑ → sweat, vasodilation → temp ↓. **Temp ↓** → shiver, vasoconstriction → temp ↑ to set point.

Positive Feedback

Positive feedback: response amplifies the change → pushes further from set point → ends w/ a big event.

Example	Loop
Childbirth	Oxytocin → contractions ↑
Lactation	Suckling → oxytocin → milk
Blood clotting	Platelets recruit more
Fruit ripening	Ethylene → more ethylene

When Feedback Fails

Diabetes: type 1 = no insulin made; type 2 = cells don't respond to insulin → glucose stays high.
Graves' disease: thyroid hormone keeps rising (normal feedback is bypassed) → metabolism stays high.
Thermoregulation is run by the hypothalamus (the control center), which compares temp to its set point.
Plants: guard cells close stomata when H_2O is low (ABA hormone signal) → limits further water loss by transpiration.

⚠ "Positive" ≠ good. It means the loop amplifies. "Negative" means it reverses the change.

✓ Graph Q: values swing around a set point → negative. Values climb until an endpoint → positive.

4.6 Cell Cycle

Interphase (~90% of Time)

Phase	What happens
G_1	Grow, make organelles
S	DNA replicated
G_2	Grow, prep for mitosis
G_0	Non-dividing (neurons)
M	Mitosis + cytokinesis

After S: each chromosome = 2 identical **sister chromatids** joined at the **centromere** (the classic X shape).
DNA content: 2n → 4n DNA in S; back to 2n per cell after division. Chromosome # stays the same.

Mitosis: PMAT

Prophase: chromatin condenses; spindle forms; nuclear envelope breaks (prometaphase); kinetochores attach.
Metaphase: chromosomes line up single file at the **metaphase plate**; spindle fibers attach at kinetochores.
Anaphase: sister chromatids split → pulled to opposite poles (each one now counts as a chromosome).
Telophase: nuclear envelopes re-form; chromosomes uncoil.
Cytokinesis: animals → cleavage furrow (actin ring pinches); plants → **cell plate** (vesicles → new wall).

Why Mitosis

Result: 2 genetically identical diploid daughter cells. Used for growth, repair & asexual reproduction in eukaryotes.
Plants: no centrioles, but spindle still forms.
Nondividing cells (G_0): mature neurons, muscle cells; liver cells can re-enter the cycle if the tissue is damaged.
Counting: a human cell in G_2 = 46 chromosomes but 92 chromatids (each chromosome is doubled).

⚠ DNA doubles in S phase, NOT in mitosis. Mitosis just splits what was already copied into 2 nuclei.

✓ Micrograph Q: count the cells in each phase; the % of cells ∝ the time spent in that phase of the cycle.

4.7 Regulation of the Cell Cycle

Checkpoints

G_1 checkpoint: big enough? nutrients? growth factors? DNA OK? → if no, enter **G_0**. Main "go/no-go" point.
G_2 checkpoint: DNA fully & correctly replicated? → if no, the cell pauses to repair it before mitosis.
M (spindle) checkpoint: all chromosomes attached to the spindle? → if no, anaphase waits until they are.
Why it matters: skipping checkpoints → aneuploidy (wrong chromosome #) or damaged DNA passed on.

Cyclins & CDKs

CDK (cyclin-dependent kinase): always present in the cell, but active ONLY when it's bound to a **cyclin**.
Cyclin levels rise & fall each cycle → CDK activity rises & falls → drives the cell into the next phase on schedule.
MPF (cyclin + CDK) peaks at G_2→M → triggers mitosis; cyclin is degraded → MPF off → cell exits mitosis.
Growth factors (e.g., PDGF) bind RTKs → signal → cell passes G_1 checkpoint. **Density-dependent inhibition** & **anchorage dependence** stop crowded or loose cells.

Cancer & Apoptosis

Gene	Normal job	Cancer if...
Proto-oncogene	Gas pedal	Stuck on
Tumor suppr.	Brake (p53)	Lost/off

p53: senses DNA damage → halts cycle for repair or triggers apoptosis. Mutated in ~50% of cancers.
Apoptosis: programmed cell death; removes damaged cells; shapes development (webbing between fingers).
Cancer cells: ignore checkpoints, growth factors & density limits → divide endlessly → form tumors.

⚠ Cancer usually needs MULTIPLE mutations: an oncogene stuck ON plus tumor suppressors switched OFF.

✓ Graph Q: cyclin rises through interphase, peaks at M, then drops sharply as it's degraded after mitosis.

Unit 4 Exam Strategy & Connections

Signal Pathway FRQ Template

1) Ligand binds specific receptor → **2) shape change** → **3) relay** (G protein, kinase, 2nd messenger) → **4) response**.
Justify w/ molecule names: "cAMP activates PKA" beats a vague "the signal is passed on" every time on FRQs.
Predict a block: steps BEFORE it still work; steps AFTER don't (unless something downstream is stuck on).

Data & Graph Skills

DNA per cell graph: flat (G_1) → rises (S) → high (G_2, M) → halves at cytokinesis, then repeats each cycle.
Phase timing: % of cells in a phase × total cycle time = the time spent in that phase (e.g., 10% × 24 h = 2.4 h).
Hormone graphs: insulin peaks after glucose peaks → a negative feedback lag, then both fall back down.
Experiment design: control = no ligand / no drug; vary 1 factor; DV = response (e.g., cAMP level).

Compare	Mitosis	Binary fission
Who	Eukaryotes	Prokaryotes
Chrom.	Many, linear	1 circular
Spindle	Yes	No

Links

Unit 2: membrane receptors; the phospholipid bilayer controls which ligands can enter the cell directly.
Unit 3: kinases use ATP. **Unit 5**: meiosis vs mitosis. **Unit 6**: transcription factors, gene regulation.
Unit 7: shared signaling & cell cycle proteins across all eukaryotes → strong evidence of common ancestry.
Medicine: many cancer drugs target kinases or block growth factor receptors on tumor cells (e.g., Herceptin).

⚠ Mitosis keeps the chromosome # the same (2n → 2n). Meiosis (Unit 5) halves it (2n → n) for gametes.

✓ Every answer: name the molecule, the step, and the effect on the cell. All 3 parts, every single time.