

AP BIOLOGY STUDY GUIDE

180 High-Yield Concepts

Advanced Placement Course | College Board CED-aligned

- All 8 CED units: Chemistry of Life to Ecology
- Every concept: explanation + high-yield exam tip + example
- Hardy-Weinberg, cellular energetics, gene regulation & more
- Perfect for the AP Biology exam in May

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How to Use This Guide

This guide condenses the AP Biology course and exam description into 176 high-yield concepts. It is not a textbook replacement -- it is the fastest way to review everything the exam covers and to target your weak units.

The AP Biology exam is 60 minutes of 60 multiple-choice questions, then 90 minutes of 6 free-response questions. About 25% of the exam involves quantitative skills: the four big ideas are evolution, energetics, information storage/transmission, and systems interactions.

How to use the concepts

- Each concept = term + concise explanation + high-yield exam tip (+ example where useful).
- First pass: read every concept in order. Underline anything unfamiliar.
- Second pass: focus only on the concepts you underlined.
- Two weeks before the exam: rapid-review every tip line (they are the highest-yield).
- Use the Table of Contents to jump straight to your weakest units.

Table of Contents

1	Chemistry of Life	25 concepts
2	Cell Structure & Function	22 concepts
3	Cellular Energetics	22 concepts
4	Cell Communication & Cell Cycle	22 concepts
5	Heredity	22 concepts
6	Gene Expression & Regulation	23 concepts
7	Natural Selection	23 concepts
8	Ecology	21 concepts

Total: 180 high-yield concepts

How to use the TOC: work through the units in order on your first pass, then jump back to your weakest units for review. Each concept includes an Explanation, a high-yield exam tip, and where useful an Example. Mark the concepts you miss with a small dot in the margin and revisit them 48 hours later.

Unit 1: Chemistry of Life

8-11% of the AP Bio exam. Water, macromolecules, and the chemical foundations of living systems.

1 Matter & Elements

Explanation: Living things are made of matter composed of elements. CHNOPS (carbon, hydrogen, nitrogen, oxygen, phosphorus, sulfur) make up about 96% of living matter. Trace elements are required in tiny amounts but are essential (e.g., iron in hemoglobin).

AP Bio Tip: *AP Bio loves 'which elements make up most of living matter?' -- answer CHNOPS, carbon first. Trace elements like zinc and iodine still matter for specific functions.*

Example: Carbon, hydrogen, oxygen, and nitrogen make up roughly 96% of the mass of the human body. Iodine (trace) is needed to make thyroid hormones.

2 Atomic Structure & Isotopes

Explanation: Atoms have protons (+) and neutrons in the nucleus, electrons (-) in shells. Atomic number = protons; mass number = protons + neutrons. Isotopes are same element, different neutron count; some are radioactive (used in dating and medicine).

AP Bio Tip: *The atomic number defines the element -- it never changes for that element. Radioactive isotopes decay at characteristic half-lives; carbon-14 dating works this way.*

Example: Carbon-12 (6p+6n) and carbon-14 (6p+8n) are both carbon; C-14 is radioactive and used to date fossils.

3 Chemical Bonds Overview

Explanation: Covalent bonds share electrons (strong); ionic bonds transfer electrons (attraction between charged ions); hydrogen bonds are weak attractions between a hydrogen already bonded to N/O/F and another electronegative atom.

AP Bio Tip: *Rank bond strength: covalent > ionic > hydrogen > van der Waals. Covalent bonds hold atoms in molecules; hydrogen bonds hold molecules together (e.g., between water molecules).*

Example: Water molecules are held to each other by hydrogen bonds; the H-O bonds within a water molecule are covalent.

4 Water's Properties

Explanation: Water is polar, forms hydrogen bonds, and is an excellent solvent. It has high specific heat (resists temperature change), high heat of vaporization, high cohesion/adhesion, and its solid form (ice) is less dense than liquid water.

AP Bio Tip: *Connect water's properties to life: high specific heat stabilizes body temperature; cohesion enables water transport in plants; ice floating insulates lakes in winter; being a solvent allows chemistry in cells.*

Example: A lake freezes from the top down because ice is less dense -- aquatic life survives under the ice.

5 pH & Buffers

Explanation: $\text{pH} = -\log[\text{H}^+]$. $\text{pH} < 7$ acidic, $\text{pH} > 7$ basic, 7 neutral. Each pH unit = 10x change in H^+ concentration. Buffers resist pH change by accepting or donating H^+ ; biological buffers maintain internal pH.

AP Bio Tip: *The pH scale is logarithmic -- a solution at pH 4 has 100x more H^+ than pH 6. Blood is buffered near 7.4; small shifts are dangerous.*

Example: Carbonic acid/bicarbonate ($\text{H}_2\text{CO}_3/\text{HCO}_3^-$) buffer human blood. If blood pH falls below ~7.35, acidosis results.

6 Carbon & Organic Molecules

Explanation: Carbon forms 4 covalent bonds, enabling chains, branches, and rings. This versatility makes carbon the backbone of biological molecules. Functional groups (hydroxyl, carboxyl, amino, phosphate, etc.) give molecules specific properties.

AP Bio Tip: *Carbon's 4 bonds explain the diversity of organic molecules. Know the functional groups: -OH (hydroxyl, polar), -COOH (carboxyl, acidic), -NH₂ (amino, basic), -PO₄ (phosphate, energy transfer).*

Example: Amino acids have both an amino group and a carboxyl group -- that is what makes them amino acids.

7 Monomers & Polymers

Explanation: Most macromolecules are polymers built from monomers via dehydration synthesis (removes water, requires energy) and broken down via hydrolysis (adds water, releases energy).

AP Bio Tip: *Dehydration synthesis = building (losing water); hydrolysis = breaking (gaining water). Every time you digest food, hydrolysis breaks polymers into monomers.*

Example: Starch (polymer of glucose) is digested by hydrolysis into glucose monomers. Protein is built by dehydration synthesis linking amino acids.

8 Carbohydrates

Explanation: Monosaccharides (glucose, fructose) are the simplest sugars; disaccharides (sucrose, lactose) are two monosaccharides; polysaccharides (starch, glycogen, cellulose) are long chains. Function: energy storage and structure.

AP Bio Tip: *Know the polysaccharides: starch (plant energy storage, alpha glucose), glycogen (animal energy storage, alpha glucose, more branched), cellulose (plant cell wall, beta glucose -- humans can't digest it).*

Example: Chitin is a structural polysaccharide in arthropod exoskeletons. Cellulose gives plants their rigidity.

9 Lipids

Explanation: Lipids are hydrophobic (mostly C-H bonds): fats (triglycerides = glycerol + 3 fatty acids), phospholipids (2 fatty acids + phosphate group, form membranes), steroids (4 fused rings, e.g., cholesterol, hormones). Saturated vs unsaturated fatty acids affect state at room temperature.

AP Bio Tip: *Saturated fats (no double bonds) are solid at room temp (butter); unsaturated (double bonds = kinks) are liquid (oils). Phospholipids are amphipathic -- hydrophilic head, hydrophobic tails -- which drives membrane formation.*

Example: Phospholipids in water spontaneously form a bilayer with heads facing water and tails hidden -- the basis of every cell membrane.

10 Proteins

Explanation: Polymers of amino acids linked by peptide bonds. Four levels of structure: primary (sequence), secondary (alpha helix/beta sheet via H-bonds), tertiary (3D folding, R-group interactions), quaternary (multiple polypeptides). Function: enzymes, structure, transport, signaling.

AP Bio Tip: *Denaturation (heat, pH) disrupts secondary/tertiary structure and destroys function -- but NOT the primary sequence. Know the four levels and what holds each together.*

Example: Enzymes are proteins; high fever denatures them, which is why very high fever is dangerous. Insulin is a protein hormone.

11 Nucleic Acids

Explanation: DNA and RNA are polymers of nucleotides (sugar + phosphate + nitrogenous base). DNA: double helix, A-T / G-C, deoxyribose, stores genetic info. RNA: single-stranded, A-U / G-C, ribose, involved in protein synthesis. ATP is a nucleotide used for energy.

AP Bio Tip: *DNA base pairing: A=T (2 H-bonds), G=C (3 H-bonds -- harder to break, so G-C rich regions are more stable). RNA uses uracil instead of thymine. ATP = adenine + ribose + 3 phosphates.*

Example: If one DNA strand is ATCG, the complement is TAGC. The mRNA transcribed would be UAGC.

12 Enzymes Overview

Explanation: Enzymes are biological catalysts that speed reactions by lowering activation energy without being consumed. They are specific to their substrate (active site). Most are proteins.

AP Bio Tip: *Enzymes DO NOT change the equilibrium or the products -- they only make the reaction reach equilibrium faster by lowering E_a . They are reusable.*

Example: Catalase speeds the breakdown of hydrogen peroxide into water and oxygen. One catalase molecule can process millions of substrate molecules.

13 Enzyme Kinetics & Inhibition

Explanation: Reaction rate increases with substrate concentration until saturation (all active sites busy = V_{max}). Competitive inhibitors bind the active site (blocked by more substrate); noncompetitive inhibitors bind elsewhere (allosteric site) and change shape.

AP Bio Tip: *Competitive inhibition is overcome by adding more substrate; noncompetitive is not. Know this distinction -- it is a classic AP Bio multiple-choice question.*

Example: Methotrexate competitively inhibits an enzyme needed for DNA synthesis. Cyanide binds noncompetitively to cytochrome oxidase (ETC).

14 Feedback Regulation

Explanation: Metabolic pathways are often controlled by feedback inhibition: the end product inhibits an enzyme earlier in the pathway, preventing waste. This keeps resources efficient.

AP Bio Tip: *Feedback inhibition is negative feedback at the molecular level. In AP Bio, isoleucine inhibiting the first enzyme of its own synthesis pathway is the classic example.*

Example: In bacteria, isoleucine (end product) binds the first enzyme of its synthesis pathway, shutting it down when enough isoleucine exists.

15 Metabolic Pathways

Explanation: Metabolism = all chemical reactions in a cell. Catabolic pathways break down molecules (release energy, e.g., cellular respiration). Anabolic pathways build molecules (require energy, e.g., protein synthesis).

AP Bio Tip: *Catabolic = breaking (cat = destroy) releases energy. Anabolic = building (anabolic steroids build muscle) requires energy. Coupled reactions transfer energy (ATP).*

Example: Cellular respiration is catabolic; photosynthesis and protein synthesis are anabolic. ATP links the two types.

16 ATP & Energy Coupling

Explanation: ATP (adenosine triphosphate) is the cell's energy currency. Hydrolysis of ATP to ADP + Pi releases energy (exergonic). Cells couple exergonic ATP hydrolysis to endergonic reactions (energy coupling).

AP Bio Tip: *ATP is regenerated by phosphorylation (adding Pi to ADP) during respiration/photosynthesis. ATP is not long-term energy storage -- it is immediate use.*

Example: Muscle contraction uses the energy released when ATP is hydrolyzed to ADP + Pi. The cell rephosphorylates ADP using energy from glucose breakdown.

17 Cell Theory & Common Features

Explanation: All organisms are made of cells; the cell is the basic unit of life; all cells come from pre-existing cells. All cells share: plasma membrane, cytoplasm, ribosomes, genetic material (DNA).

AP Bio Tip: *Prokaryotes vs eukaryotes is a defining AP Bio distinction: prokaryotes lack a nucleus and membrane-bound organelles (but DO have ribosomes).*

Example: Bacteria are prokaryotic -- no nucleus, no mitochondria, but they have ribosomes and a plasma membrane.

18 Prokaryotic vs Eukaryotic Cells

Explanation: Prokaryotes: no nucleus, no membrane-bound organelles, circular DNA, small, binary fission. Eukaryotes: nucleus, membrane-bound organelles, linear DNA, larger, mitosis. Plants and animals are eukaryotic.

AP Bio Tip: *A classic AP Bio question: 'which feature do all cells share?' -- plasma membrane, ribosomes, cytoplasm, DNA. 'Which is absent in prokaryotes?' -- nucleus and membrane-bound organelles.*

Example: E. coli (prokaryote) vs a human liver cell (eukaryote): the liver cell has mitochondria, ER, and a nucleus; E. coli does not.

19 Organelles & Functions

Explanation: Nucleus (DNA, gene expression control); ribosomes (protein synthesis); rough ER (protein processing); smooth ER (lipid synthesis, detox); Golgi (packaging/shipping); mitochondria (ATP); lysosomes (digestion); vacuoles (storage); chloroplasts (photosynthesis, plants); cytoskeleton (shape, movement).

AP Bio Tip: *Match organelle to function quickly: mitochondria = ATP, ribosomes = protein, lysosomes = digestion, Golgi = ship, chloroplast = photosynthesis. Structure-function correlation is a central AP Bio theme.*

Example: A cell with high protein secretion (e.g., pancreatic cell) has a large rough ER and Golgi. A muscle cell is packed with mitochondria.

20 Endomembrane System

Explanation: The nuclear envelope, ER, Golgi, lysosomes, and plasma membrane form a connected system. Proteins made on rough ER are modified in the Golgi and shipped in vesicles to the membrane or out of the cell.

AP Bio Tip: *Follow the protein path: ribosome -> rough ER -> vesicle -> Golgi -> vesicle -> plasma membrane (or lysosome). AP Bio asks this pathway repeatedly.*

Example: A digestive enzyme is synthesized on the rough ER, glycosylated in the ER and Golgi, packaged into a vesicle, and secreted by exocytosis.

21 Mitochondria & Chloroplasts

Explanation: Mitochondria: site of cellular respiration (Krebs cycle, ETC), double membrane, own DNA. Chloroplasts: site of photosynthesis, thylakoids/grana + stroma, own DNA. Both are evidence for the endosymbiont theory.

AP Bio Tip: *Endosymbiont evidence: double membranes, own circular DNA, own ribosomes, divide independently. Both organelles have an inner membrane with high surface area (cristae / thylakoids).*

Example: Mitochondria and chloroplasts resemble free-living bacteria -- the endosymbiont theory explains their double membranes and own DNA.

22 Cell Size & Surface Area

Explanation: As a cell grows, volume increases faster than surface area. A low SA:V ratio limits exchange of nutrients/waste, so cells must divide or stay small. Small cells are efficient.

AP Bio Tip: *The SA:V ratio explanation for why cells are small is a guaranteed AP Bio topic. Surface area increases by square, volume by cube.*

Example: A cube 1 cm per side has SA:V = 6; a cube 2 cm per side has SA:V = 3. Smaller cells exchange materials more efficiently.

23 The Cell Membrane

Explanation: The plasma membrane is a fluid mosaic: phospholipid bilayer with embedded proteins, cholesterol (animal cells, fluidity), and carbohydrates (cell recognition). It is selectively permeable.

AP Bio Tip: *The membrane is 'fluid' because phospholipids and proteins move laterally; 'mosaic' because of the patchwork of components. Fluidity depends on temperature and fatty acid saturation.*

Example: Cell membranes self-seal when punctured because of the hydrophobic effect driving phospholipids together.

24 Membrane Transport: Passive

Explanation: Passive transport needs no energy: diffusion (high to low concentration), osmosis (water movement across a selectively permeable membrane), facilitated diffusion (through transport proteins). All move down the concentration gradient.

AP Bio Tip: *Osmosis = water moves TOWARD higher solute concentration. Isotonic (no net movement), hypotonic (water enters cell, swells), hypertonic (water leaves cell, shrinks). Plant cells prefer hypotonic (turgor).*

Example: A red blood cell in pure water (hypotonic) swells and may burst; in salt water (hypertonic) it shrinks.

25 Membrane Transport: Active

Explanation: Active transport moves substances against the gradient using energy (ATP): pumps (e.g., Na⁺/K⁺ pump), cotransport, endocytosis (phagocytosis, pinocytosis), exocytosis. Bulk transport uses vesicles.

AP Bio Tip: *The Na⁺/K⁺ pump moves 3 Na⁺ out and 2 K⁺ in per ATP -- against gradients, maintaining the resting membrane potential. Endocytosis brings material in; exocytosis releases it.*

Example: White blood cells engulf bacteria by phagocytosis (endocytosis). Neurons use the Na⁺/K⁺ pump to maintain their resting potential.

Unit 2: Cell Structure & Function

10-13% of the exam. Subcellular components, the endomembrane system, and how structure enables function.

26 Nucleus & Nuclear Envelope

Explanation: The nucleus stores DNA and is the site of transcription. The nuclear envelope is a double membrane with nuclear pores that regulate passage of mRNA and proteins. The nucleolus makes ribosomal RNA (rRNA) and assembles ribosome subunits.

AP Bio Tip: *mRNA exits through nuclear pores; ribosomes are assembled in the nucleolus. Transcription happens in the nucleus; translation happens in the cytoplasm (or on rough ER).*

Example: A ribosome is assembled in the nucleolus, exported through a nuclear pore, and translates mRNA in the cytoplasm.

27 Ribosomes

Explanation: Ribosomes (free or bound to rough ER) are the site of translation (protein synthesis). Free ribosomes make proteins for the cytosol; bound ribosomes make proteins destined for membranes, secretion, or lysosomes.

AP Bio Tip: *Free ribosome = cytosolic protein. Bound ribosome = secreted/membrane/lysosomal protein. This distinction is frequently tested.*

Example: Insulin (secreted) is made on bound ribosomes; a cytosolic enzyme like hexokinase is made on free ribosomes.

28 Endoplasmic Reticulum

Explanation: Rough ER has ribosomes and modifies/transport proteins (folding, glycosylation). Smooth ER synthesizes lipids, detoxifies drugs, and stores calcium (muscle cells have extensive smooth ER).

AP Bio Tip: *Rough ER = protein; smooth ER = lipid + detox. Liver cells (detox) and muscle cells (Ca²⁺ storage) have lots of smooth ER.*

Example: Liver cells detoxify alcohol using enzymes of the smooth ER -- chronic drinking enlarges smooth ER.

29 Golgi Apparatus

Explanation: The Golgi modifies, sorts, and packages proteins and lipids into vesicles for secretion or delivery to other organelles. It adds sugar groups (glycosylation) and can synthesize polysaccharides.

AP Bio Tip: *Golgi = the cell's 'post office' -- modify, tag, ship. Cis face receives from ER; trans face ships out.*

Example: A protein destined for secretion gets its final carbohydrate modifications in the Golgi and leaves in a vesicle from the trans face.

30 Lysosomes & Vacuoles

Explanation: Lysosomes contain hydrolytic enzymes for digestion (intracellular digestion, autophagy, apoptosis). Vacuoles store water, ions, and waste; plant central vacuoles maintain turgor pressure.

AP Bio Tip: *Lysosomal enzymes work best at acidic pH (maintained by proton pumps). Plant cells: large central vacuole = turgor. Animal cells: small vacuoles.*

Example: Macrophages fuse lysosomes with phagosomes to digest engulfed bacteria. Plant wilting = loss of turgor from vacuole water loss.

31 Mitochondria Structure

Explanation: Mitochondria have a double membrane. The inner membrane is folded into cristae (increased surface area for the electron transport chain). The matrix contains enzymes of the Krebs cycle, DNA, and ribosomes.

AP Bio Tip: *Cristae = surface area for ETC = more ATP. The matrix = Krebs cycle location. Mitochondria are semi-autonomous (own DNA).*

Example: Cardiac muscle cells are mitochondria-dense with extensive cristae because they need constant ATP.

32 Chloroplast Structure

Explanation: Chloroplasts (plants/algae) have a double membrane. Thylakoids (stacked into grana) are the site of the light reactions; the stroma (fluid) is the site of the Calvin cycle. Contains chlorophyll.

AP Bio Tip: *Light reactions happen in the thylakoid membrane; Calvin cycle in the stroma. This 'where' knowledge is a top AP Bio question.*

Example: During photosynthesis, ATP and NADPH are produced in the thylakoids and consumed in the stroma to make glucose.

33 Cytoskeleton

Explanation: A network of protein fibers: microtubules (tubulin, cell shape, chromosome separation, flagella/cilia), microfilaments (actin, muscle contraction, cell movement), intermediate filaments (structural support).

AP Bio Tip: *Microtubules = tracks + spindle; microfilaments = muscle + crawling; intermediate = cables. Colchicine (prevents microtubule assembly) blocks mitosis.*

Example: Cilia and flagella are microtubule-based (9+2 arrangement). Amoebas crawl using actin microfilaments.

34 Cell Junctions

Explanation: Plant cells connect via plasmodesmata (cytoplasmic channels). Animal cells: tight junctions (seal, prevent leakage), desmosomes (anchoring), gap junctions (communication -- allow small molecules through).

AP Bio Tip: *Gap junctions = communication (heart muscle cells). Tight junctions = no leakage (intestinal lining). Plasmodesmata = plant version of gap junctions.*

Example: Cardiac muscle cells are connected by gap junctions so the signal to contract spreads quickly through the heart.

35 Extracellular Matrix (ECM)

Explanation: Animal cells secrete an ECM (collagen, proteoglycans) that provides support and influences cell behavior through integrins (links ECM to cytoskeleton). Plant cell walls are cellulose + pectin.

AP Bio Tip: *The ECM affects gene expression and cell signaling through integrins. Plant cell walls provide rigidity -- turgor presses against them.*

Example: Collagen in skin ECM gives it strength; integrins transmit mechanical signals into cells.

36 Structure-Function Correlation

Explanation: A central AP Bio theme: cellular and subcellular structures are correlated with their functions. Form follows function at every level.

AP Bio Tip: *When AP Bio asks 'why does X have this structure?', answer with the function it enables: cristae = ATP, microvilli = absorption, many mitochondria = high energy demand.*

Example: Intestinal epithelial cells have microvilli (increased surface area for absorption). Sperm have many mitochondria (energy for flagellum).

37 Selective Permeability

Explanation: The membrane lets some substances through and blocks others. Small nonpolar molecules (O₂, CO₂) pass freely; ions and large polar molecules need transport proteins; water uses aquaporins (facilitated).

AP Bio Tip: *O₂ and CO₂ diffuse freely through the lipid bilayer (nonpolar). Ions and glucose cannot -- they need channels/carriers. Size + polarity determine permeability.*

Example: CO₂ diffuses out of cells without a channel; Na⁺ requires a channel or pump; glucose uses a carrier protein.

38 Osmosis & Water Potential

Explanation: Water moves across membranes from higher water potential to lower water potential. Water potential = solute potential + pressure potential. Solutions with more solute have lower (more negative) water potential.

AP Bio Tip: *Water flows toward the more negative water potential (more solute). In AP Bio: cell in pure water (0 solute) -- water enters. This drives turgor and transpiration.*

Example: A plant cell placed in pure water gains water and builds turgor pressure until water potential inside equals outside.

39 Facilitated Diffusion

Explanation: Transport proteins (channels and carriers) allow specific polar molecules and ions to cross the membrane down their gradient without ATP. Saturation occurs when all carriers are busy.

AP Bio Tip: *Facilitated diffusion is still passive -- down the gradient, no ATP. Carriers are specific and saturable; channels are often gated.*

Example: Glucose enters red blood cells via the GLUT1 carrier down its concentration gradient -- no ATP used.

40 Tonicity & Cells

Explanation: Isotonic: no net water movement. Hypotonic: solute lower outside -> water enters -> cell swells (animal cells may lyse; plant cells become turgid). Hypertonic: solute higher outside -> water leaves -> cell shrinks (animal) or plasmolyzes (plant).

AP Bio Tip: *Animal cells: prefer isotonic (no wall to resist swelling). Plant cells: prefer hypotonic (wall resists, turgor is good). Plasmolysis = plant cell membrane pulls away from wall in hypertonic solution.*

Example: Putting a plant in salt water plasmolyzes it; putting a red blood cell in pure water lyses it.

41 Active Transport Pumps

Explanation: Pumps (e.g., Na⁺/K⁺ ATPase, proton pumps) use ATP to move ions against their gradients. This maintains concentration gradients that power secondary transport and electrical potentials.

AP Bio Tip: *The Na⁺/K⁺ pump creates the Na⁺ gradient; glucose-sodium cotransport then uses that gradient to pull glucose in (secondary active transport).*

Example: Intestinal cells use the Na⁺ gradient (created by the pump) to cotransport glucose against its own gradient.

42 Bulk Transport

Explanation: Endocytosis (phagocytosis = cell eating, pinocytosis = cell drinking, receptor-mediated = specific uptake) and exocytosis move large items via vesicles. Requires energy.

AP Bio Tip: *Receptor-mediated endocytosis is specific (e.g., LDL uptake). Defects in LDL receptors cause familial hypercholesterolemia -- a classic AP Bio example.*

Example: Cells take up LDL cholesterol via receptor-mediated endocytosis; when receptors are defective, cholesterol accumulates in blood.

43 Compartmentalization

Explanation: Eukaryotic cells compartmentalize functions in organelles: separate environments (e.g., lysosomal acidity), increased efficiency, and regulation of reactions.

AP Bio Tip: *Why do eukaryotic cells have organelles? Compartmentalization allows incompatible reactions to occur simultaneously and concentrates enzymes/substrates. Prokaryotes lack this -- a key evolutionary difference.*

Example: Digestive enzymes would destroy the cell, but lysosomes isolate them at low pH.

44 Cellular Response to Environment

Explanation: Cells respond to environmental changes: osmotic regulation (contractile vacuoles in protists), temperature adaptation (membrane fluidity changes, more unsaturated fatty acids in cold), and signal transduction.

AP Bio Tip: *Membrane fluidity is maintained: cold -> more unsaturated fatty acids + cholesterol adjustments. Contractile vacuoles pump out excess water in freshwater protists.*

Example: A freshwater Paramecium continuously pumps out water with contractile vacuoles because water keeps entering by osmosis.

45 Cell Wall (Plants & Prokaryotes)

Explanation: Plant cell walls (cellulose) provide support and prevent bursting. Prokaryotic cell walls contain peptidoglycan. Fungi have chitin walls. Walls are porous (plasmodesmata in plants).

AP Bio Tip: *The cell wall is the reason plant cells tolerate hypotonic environments. Antibiotics like penicillin target bacterial peptidoglycan walls.*

Example: Penicillin kills bacteria by inhibiting peptidoglycan synthesis -- it has no effect on human cells (no peptidoglycan).

46 Endosymbiosis Evidence

Explanation: Mitochondria and chloroplasts originated from engulfed prokaryotes. Evidence: double membranes, own circular DNA, own ribosomes, divide by binary fission, similar size to bacteria.

AP Bio Tip: *List the four lines of evidence quickly: double membrane, own DNA, own ribosomes, self-replication. This is a frequent AP Bio free-response topic.*

Example: Mitochondrial DNA is circular like bacterial DNA and is inherited maternally.

Explanation: Cells communicate via direct contact (gap junctions, plasmodesmata), local signaling (paracrine, synaptic), and long-distance signaling (hormones). Signal transduction converts an external signal into a cellular response.

AP Bio Tip: *Three steps of cell signaling: reception, transduction, response. Local vs long-distance: paracrine (nearby) vs hormones (bloodstream).*

Example: Insulin travels in the blood (long-distance) to trigger glucose uptake; a growth factor acts on neighboring cells (paracrine).

Unit 3: Cellular Energetics

12-16% of the exam. Enzymes, energy, and how cells harvest energy -- respiration and photosynthesis.

48 Energy & Enzymes

Explanation: Enzymes lower activation energy (E_a), speeding reactions. They are specific, reusable, and regulated. Reaction coupling: exergonic reactions power endergonic ones via ATP.

AP Bio Tip: *Enzymes don't change delta G (free energy change) or equilibrium -- they only lower E_a . Delta G negative = spontaneous (exergonic); positive = requires energy.*

Example: Hydrolysis of ATP (exergonic) is coupled to muscle contraction (endergonic). Catalase lowers E_a for H_2O_2 breakdown.

49 Free Energy & Spontaneity

Explanation: Delta G = change in free energy. Negative delta G = exergonic (spontaneous, releases energy, e.g., respiration). Positive = endergonic (requires input, e.g., photosynthesis). $\Delta G = \Delta H - T\Delta S$.

AP Bio Tip: *Spontaneous does not mean fast -- a reaction can have negative delta G and still need an enzyme (activation energy). AP Bio tests this distinction.*

Example: Glucose oxidation has negative delta G but glucose is stable at room temperature -- because E_a is high without enzymes.

50 Enthalpy & Entropy

Explanation: Enthalpy (H) = total energy; entropy (S) = disorder. Reactions tend toward lower enthalpy and higher entropy. Spontaneous reactions can increase entropy even if enthalpy stays similar.

AP Bio Tip: *Entropy increases are a driving force: molecules spreading out, heat released. Biological reactions often couple unfavorable enthalpy with favorable entropy increases.*

Example: ATP hydrolysis releases energy (favorable enthalpy) and increases entropy (more particles in solution).

51 ATP Structure & Function

Explanation: ATP = adenine + ribose + 3 phosphate groups. Energy is stored in the bonds between phosphates; hydrolysis releases it. ATP is constantly regenerated from ADP + P_i .

AP Bio Tip: *The 'energy' in ATP is from the instability of three closely packed negative phosphate groups -- not a special bond. ATP is recycled, not stored in bulk.*

Example: Cells regenerate ATP during respiration; a human turns over ~50 kg of ATP per day.

52 Enzyme-Substrate Specificity

Explanation: The active site has a specific shape complementary to the substrate. Induced fit: the enzyme changes shape slightly upon substrate binding, tightening the fit and catalyzing the reaction.

AP Bio Tip: *Induced fit is the modern model (vs rigid lock-and-key). The active site is specific -- one enzyme, one type of substrate (or closely related).*

Example: Sucrase binds sucrose specifically, not maltose. Upon binding, sucrase changes shape slightly (induced fit).

53 Enzyme Regulation: Inhibitors

Explanation: Competitive inhibitors occupy the active site (substrate can outcompete them). Noncompetitive (allosteric) inhibitors bind elsewhere and change enzyme shape. Reversible vs irreversible.

AP Bio Tip: *More substrate relieves competitive inhibition but not noncompetitive. Allosteric regulation can be inhibition OR activation.*

Example: At high substrate concentrations, competitive inhibition is overcome; noncompetitive inhibition is not.

54 Allosteric Regulation

Explanation: Allosteric regulators bind a site other than the active site, changing enzyme shape and activity. Many enzymes are regulated by feedback inhibition via allosteric sites.

AP Bio Tip: *Feedback inhibition: end product binds the first enzyme's allosteric site, shutting the pathway down. This is efficient and common.*

Example: ATP is an allosteric inhibitor of phosphofructokinase in glycolysis -- high ATP slows glycolysis.

55 Cellular Respiration Overview

- Explanation:** $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \sim 36-38 \text{ ATP}$. Stages: glycolysis (cytosol), pyruvate oxidation + Krebs cycle (mitochondrial matrix), oxidative phosphorylation (inner membrane). Redox reactions move electrons to oxygen.
- AP Bio Tip:** *Respiration is a series of redox reactions: glucose is oxidized (loses electrons/H), O_2 is reduced. NADH and FADH₂ carry electrons to the ETC.*
- Example:** Oxygen is the final electron acceptor -- without it, the ETC stops and ATP production collapses.

56 Redox Reactions

- Explanation:** Oxidation = loss of electrons (often with H). Reduction = gain of electrons (often with H). Redox = oxidation-reduction pairs. In respiration, electrons from glucose are transferred to NAD⁺ (making NADH) and finally to O₂.
- AP Bio Tip:** *OIL RIG: Oxidation Is Loss, Reduction Is Gain (of electrons). NAD⁺ is reduced to NADH; FAD is reduced to FADH₂. The electron carriers feed the ETC.*
- Example:** In glycolysis, two NAD⁺ are reduced to 2 NADH as glucose is oxidized to pyruvate.

57 Glycolysis

- Explanation:** Occurs in the cytosol. Glucose (6C) $\rightarrow$ 2 pyruvate (3C). Net yield: 2 ATP (4 made, 2 used) + 2 NADH. No oxygen required. Two phases: energy investment (2 ATP) and payoff (4 ATP).
- AP Bio Tip:** *Glycolysis net = 2 ATP + 2 NADH + 2 pyruvate. It happens in the CYTOPLASM and works with or without oxygen (anaerobic first step).*
- Example:** During sprinting, glycolysis still runs -- producing pyruvate and 2 ATP per glucose even before oxygen arrives.

58 Pyruvate Oxidation

- Explanation:** Pyruvate enters the mitochondrial matrix, loses CO₂, and becomes acetyl-CoA (2C). Produces 1 NADH per pyruvate. Acetyl-CoA feeds the Krebs cycle.
- AP Bio Tip:** *Per glucose: 2 pyruvate $\rightarrow$ 2 acetyl-CoA $\rightarrow$ 2 CO₂ released + 2 NADH. The CO₂ you exhale comes from these decarboxylation steps (and Krebs).*
- Example:** Each glucose yields 2 acetyl-CoA, each entering the Krebs cycle. The carbon lost as CO₂ here leaves the body when you exhale.

59 Krebs (Citric Acid) Cycle

- Explanation:** In the mitochondrial matrix. Acetyl-CoA (2C) + oxaloacetate (4C) $\rightarrow$ citrate (6C), then a series of steps regenerate oxaloacetate. Per acetyl-CoA: 3 NADH, 1 FADH₂, 1 ATP (GTP), 2 CO₂.
- AP Bio Tip:** *Per GLUCOSE (2 turns): 6 NADH, 2 FADH₂, 2 ATP, 4 CO₂. The cycle produces most of the NADH/FADH₂ that feed the ETC.*
- Example:** Krebs cycle intermediates can leave to make amino acids or fats (amphibolic pathway) -- connects metabolism.

60 Oxidative Phosphorylation

- Explanation:** Electrons from NADH/FADH₂ pass down the electron transport chain (inner membrane) through protein complexes, pumping H⁺ into the intermembrane space. The H⁺ gradient drives ATP synthase (chemiosmosis). $\sim 26-28$ ATP per glucose.
- AP Bio Tip:** *The ETC is a series of redox reactions; O_2 is the final electron acceptor (forms water). ATP synthase is a molecular motor powered by the proton-motive force.*
- Example:** Rotenone blocks complex I of the ETC, halting ATP production. Cyanide blocks complex IV, preventing O₂ reduction.

61 Chemiosmosis & Proton Motive Force

- Explanation:** The ETC pumps H⁺ to create a proton gradient (electrochemical gradient). H⁺ flows back through ATP synthase, driving ATP production. This coupling of redox to ATP synthesis is chemiosmosis.
- AP Bio Tip:** *Chemiosmosis is the mechanism: proton gradient $\rightarrow$ ATP synthase $\rightarrow$ ATP. Uncouplers (e.g., DNP) let H⁺ leak back, producing heat instead of ATP.*
- Example:** Brown fat mitochondria use uncoupling proteins to generate heat -- H⁺ bypasses ATP synthase.

62 Anaerobic Respiration & Fermentation

Explanation: Without O₂, the ETC stops. Fermentation regenerates NAD⁺ so glycolysis can continue: lactic acid fermentation (animals, bacteria) and alcohol fermentation (yeast). Net 2 ATP per glucose.

AP Bio Tip: *Fermentation's ONLY job is to regenerate NAD⁺ from NADH -- no additional ATP. Alcohol fermentation: pyruvate -> acetaldehyde -> ethanol + CO₂.*

Example: Yeast produce ethanol and CO₂ in beer/bread; muscle cells produce lactate during intense exercise.

63 Oxygen Debt & Lactate

Explanation: During intense exercise, muscle cells use fermentation producing lactate. The 'oxygen debt' is repaid by converting lactate back to pyruvate when oxygen is available (Cori cycle in the liver).

AP Bio Tip: *Lactate is NOT a waste product dumped to make you sore -- it is a fuel that can be reconverted. The soreness (DOMS) is from microdamage, not lactate per se.*

Example: After sprinting, you breathe heavily (repaying oxygen debt) while the liver processes lactate back to glucose.

64 Photosynthesis Overview

Explanation: 6CO₂ + 6H₂O + light -> C₆H₁₂O₆ + 6O₂. Occurs in chloroplasts: light reactions (thylakoid membrane) make ATP + NADPH + O₂; Calvin cycle (stroma) uses ATP + NADPH to fix CO₂ into sugar.

AP Bio Tip: *The oxygen released comes from splitting WATER, not CO₂ -- proven with isotope experiments. Light reactions need light; Calvin cycle can run in the dark briefly.*

Example: Isotopic labeling showed O₂ from photosynthesis originates from H₂O, not CO₂.

65 Light Reactions

Explanation: Photosystems II and I capture light energy; electrons are excited and passed along. Water is split (releases O₂, electrons, H⁺). Electron transport pumps H⁺ into the thylakoid lumen; ATP synthase makes ATP (photophosphorylation). NADPH is made at photosystem I.

AP Bio Tip: *Light reactions produce ATP, NADPH, and O₂ -- all in the thylakoid. Noncyclic electron flow makes both ATP and NADPH; cyclic flow makes only ATP (extra ATP need).*

Example: In the thylakoid, H⁺ builds up in the lumen; H⁺ flows out through ATP synthase into the stroma, making ATP.

66 Calvin Cycle

Explanation: In the stroma. Three phases: carbon fixation (RuBP + CO₂ -> 3-PGA, catalyzed by rubisco), reduction (3-PGA -> G3P using ATP + NADPH), regeneration (RuBP rebuilt). 3 turns fix 3 CO₂ -> net one G3P sugar.

AP Bio Tip: *Calvin cycle inputs: CO₂ + ATP + NADPH. Outputs: G3P (sugar) + ADP + NADP⁺. Rubisco is the most abundant enzyme on Earth -- it fixes CO₂.*

Example: For one G3P to exit, 9 ATP and 6 NADPH are consumed. C₃ plants use rubisco directly.

67 C₄ & CAM Photosynthesis

Explanation: C₄ plants (corn, sugarcane) fix CO₂ in mesophyll cells into a 4-carbon compound, then release CO₂ in bundle-sheath cells for the Calvin cycle -- minimizing photorespiration. CAM plants (cacti, pineapple) fix CO₂ at night, storing it as malate for daytime use.

AP Bio Tip: *Photorespiration happens when rubisco fixes O₂ instead of CO₂ (hot, dry, high O₂). C₄ and CAM are adaptations to reduce it. C₄ = spatial separation; CAM = temporal separation.*

Example: Cacti open stomata at night (CAM) to take in CO₂ while avoiding daytime water loss.

68 Energy Yield Comparison

Explanation: Aerobic respiration: ~36-38 ATP per glucose. Anaerobic: 2 ATP. Photosynthesis stores light energy as chemical energy in glucose (endergonic). Respiration releases it (exergonic).

AP Bio Tip: *Photosynthesis is endergonic (needs light energy); respiration is exergonic (releases energy). They are reverse processes in net equation form.*

Example: The net equations are reverses: 6CO₂ + 6H₂O + light <-> C₆H₁₂O₆ + 6O₂ + energy.

Explanation: Metabolism is highly integrated: glycolysis, Krebs, and the pentose phosphate pathway provide intermediates for biosynthesis; excess glucose becomes glycogen or fat; amino acids can enter the Krebs cycle.

AP Bio Tip: *Know that pathways are amphibolic -- catabolism and anabolism share intermediates. Insulin promotes storage; glucagon promotes release.*

Example: Acetyl-CoA is a metabolic hub: it feeds the Krebs cycle for energy or becomes fatty acids when energy is abundant.

Unit 4: Cell Communication & Cell Cycle

10-15% of the exam. Signal transduction, feedback, and the cell cycle including mitosis and cancer.

70 Cell Signaling Overview

Explanation: Cells communicate via: direct contact (gap junctions, plasmodesmata, immune cell-antigen), local signaling (paracrine = nearby cells; synaptic = neurotransmitters), and long-distance (hormones in blood).

AP Bio Tip: *Three signal types: direct contact, local, long-distance. Endocrine = hormone through blood; paracrine = local; synaptic = across a synapse.*

Example: Epinephrine travels through blood to many organs (long-distance); growth factors act on nearby cells (paracrine).

71 Signal Transduction Steps

Explanation: Three stages: (1) Reception -- ligand binds receptor. (2) Transduction -- cascade of protein modifications (often phosphorylation). (3) Response -- cellular activity changes (gene expression, enzyme activity).

AP Bio Tip: *Signal transduction amplifies the signal: one ligand can trigger thousands of products via cascades. Phosphorylation cascades are the most common transduction mechanism.*

Example: One epinephrine molecule binding a receptor can ultimately activate glycogen phosphorylase in thousands of enzyme molecules.

72 Ligand-Receptor Specificity

Explanation: Ligands (signaling molecules) bind specific receptors based on shape/complementarity. Receptors can be membrane-bound (hydrophilic ligands like insulin) or intracellular (hydrophobic ligands like steroids that cross the membrane).

AP Bio Tip: *Steroid hormones (hydrophobic) cross the membrane and bind intracellular receptors -- slower response, longer lasting. Peptide hormones bind membrane receptors -- fast response.*

Example: Cortisol (steroid) binds an intracellular receptor and alters transcription. Insulin (peptide) binds a membrane receptor.

73 G-Protein Coupled Receptors (GPCRs)

Explanation: A receptor that activates a G protein when a ligand binds. The G protein exchanges GDP for GTP and activates an effector (e.g., adenylyl cyclase → cAMP). cAMP activates protein kinase A.

AP Bio Tip: *GPCR pathway: ligand → receptor → G protein (GTP) → adenylyl cyclase → cAMP → PKA → response. GTP hydrolysis turns the G protein off. Many drugs target GPCRs.*

Example: Epinephrine acts through a GPCR in liver cells, raising cAMP and activating glycogen breakdown.

74 Receptor Tyrosine Kinases (RTKs)

Explanation: Membrane receptors that dimerize and autophosphorylate on tyrosine when ligand binds. They activate multiple downstream pathways (e.g., Ras-MAP kinase cascade) -- important in growth signaling.

AP Bio Tip: *RTKs phosphorylate tyrosines on themselves (autophosphorylation) and recruit signaling proteins. They often link to cell division -- overactive RTK signaling is linked to cancer.*

Example: Epidermal growth factor (EGF) binds its RTK, triggering a cascade that promotes cell division; mutations can cause cancer.

75 Second Messengers

Explanation: Small molecules that relay signals inside the cell: cAMP, Ca²⁺, IP₃, DAG. They amplify the signal and spread it within the cytoplasm.

AP Bio Tip: *cAMP and Ca²⁺ are the two most-tested second messengers. Ca²⁺ is released from the ER into the cytosol by IP₃.*

Example: IP₃ triggers Ca²⁺ release from the ER; Ca²⁺ then activates calmodulin and other targets.

76 Phosphorylation Cascades

Explanation: A series of kinases phosphorylate and activate each other in sequence, amplifying the signal. Protein phosphatases remove phosphates, turning the cascade off.

AP Bio Tip: *Kinases ADD phosphate; phosphatases REMOVE phosphate. The balance controls signal duration. Cascades amplify (one kinase activates many of the next).*

Example: MAP kinase cascade: Raf → MEK → ERK, each phosphorylating and activating the next, with amplification at each step.

77 Feedback in Signaling

Explanation: Signal transduction is regulated by positive and negative feedback. Negative feedback damps the response (e.g., the product inhibits the pathway). Positive feedback amplifies (e.g., blood clotting, oxytocin during childbirth).

AP Bio Tip: *Negative feedback = stabilizing; positive = amplifying. Most biological systems use negative feedback; positive feedback is rarer and used for rapid completion.*

Example: Platelet activation releases chemicals that attract more platelets (positive feedback). Blood glucose regulation is negative feedback.

78 Apoptosis

Explanation: Programmed cell death: cells shrink, DNA fragments, cell is dismantled without inflammation. Triggered by internal signals (mitochondrial cytochrome c) or external signals (death receptors). Important in development and immune function.

AP Bio Tip: *Apoptosis is tidy and quiet (no inflammation); necrosis is messy (cell bursts, inflammation). During development, apoptosis sculpts structures (e.g., webbing between fingers).*

Example: Frog tadpole tail cells die by apoptosis during metamorphosis. Defective apoptosis can lead to cancer (cells won't die).

79 Cell Cycle Overview

Explanation: Interphase (G1, S, G2) + mitotic phase (M). G1: growth; S: DNA synthesis (chromosomes duplicate); G2: prep for division; M: mitosis + cytokinesis. G0 = non-dividing state.

AP Bio Tip: *DNA is replicated in S phase only. Before S: each chromosome is 1 chromatid; after S: 2 sister chromatids. Interphase is most of the cycle.*

Example: A cell with 46 chromosomes in G1 has 46 chromosomes in G2, but now each is a duplicated chromosome with 2 sister chromatids.

80 Checkpoints

Explanation: Cell cycle checkpoints monitor conditions: G1 (size, nutrients, DNA damage, growth signals -- the most important), G2 (DNA replication complete, damage), M (chromosome attachment to spindle).

AP Bio Tip: *The G1 checkpoint is the main gate -- if conditions are bad, cells enter G0. p53 is a key G1 checkpoint protein that halts the cycle if DNA is damaged.*

Example: If p53 detects DNA damage, it halts the cycle (or triggers apoptosis). Mutated p53 = damaged cells keep dividing = cancer.

81 Cyclins & Cdks

Explanation: The cell cycle is driven by cyclin-dependent kinases (Cdks) activated by cyclins. Cyclin concentrations rise and fall, activating different Cdks at different stages. MPF (M-phase promoting factor) triggers mitosis.

AP Bio Tip: *Cyclins fluctuate; Cdks are constant. Cyclin-Cdk complexes phosphorylate target proteins to advance the cycle. MPF = cyclin B + Cdk1, triggers entry into mitosis.*

Example: MPF levels rise in G2, peak at metaphase, and drop as cyclin is degraded after anaphase.

82 Mitosis Stages

Explanation: PMAT: Prophase (chromosomes condense, spindle forms), Metaphase (chromosomes align at equator), Anaphase (sister chromatids separate to poles), Telophase (nuclei reform, chromosomes decondense). Cytokinesis follows.

AP Bio Tip: *Anaphase separates SISTER CHROMATIDS (now called chromosomes). Know PMAT order and what happens in each. Mitosis produces 2 identical diploid cells.*

Example: In anaphase, sister chromatids are pulled apart by spindle fibers shortening; each pole gets one copy of every chromosome.

83 Cytokinesis

Explanation: Animal cells: cleavage furrow pinches using actin microfilaments (contractile ring). Plant cells: cell plate forms from Golgi vesicles, becoming the new cell wall.

AP Bio Tip: *Animal = cleavage furrow (actin); plant = cell plate (vesicles). This is a classic AP Bio distinction.*

Example: A plant cell divides by building a cell plate outward from the center; animal cells pinch inward.

84 Mitosis vs Meiosis

Explanation: Mitosis: 1 division, 2 identical diploid daughter cells, for growth/repair. Meiosis: 2 divisions, 4 genetically different haploid cells, for gamete production. Meiosis includes crossing over and independent assortment.

AP Bio Tip: *Mitosis = somatic (body) cells, identical, diploid. Meiosis = gametes, varied, haploid. 'Reduction division' = meiosis halves chromosome number.*

Example: Skin cells divide by mitosis. Sperm and eggs are produced by meiosis (23 chromosomes each in humans).

85 Karyotype & Ploidy

Explanation: Ploidy = number of chromosome sets. Diploid (2n) = two sets (human 46). Haploid (n) = one set (human 23). Polyploid = more than 2 sets (common in plants). Karyotype = ordered display of chromosomes.

AP Bio Tip: *Human somatic cells are 2n=46; gametes are n=23. Fertilization restores diploidy. Polyploidy can create new plant species instantly.*

Example: A triploid (3n) plant has three sets of chromosomes -- common in cultivated bananas.

86 Cancer & the Cell Cycle

Explanation: Cancer = uncontrolled cell division from accumulated mutations in genes regulating the cell cycle: proto-oncogenes (promote division; mutations -> oncogenes), tumor suppressor genes (inhibit division; e.g., p53, Rb).

AP Bio Tip: *Proto-oncogene mutation = gas pedal stuck on. Tumor suppressor mutation = brakes broken. Cancer requires MULTIPLE mutations (usually). Oncogenes are dominant; tumor suppressors often recessive.*

Example: Ras (proto-oncogene) mutation locks it 'on' -> uncontrolled growth. Loss of p53 (tumor suppressor) removes the DNA-damage brake.

87 Quorum Sensing

Explanation: Bacteria communicate via chemical signals (autoinducers) to coordinate group behavior based on population density -- e.g., biofilm formation, bioluminescence. A classic example of cell-to-cell communication in prokaryotes.

AP Bio Tip: *Quorum sensing = bacteria counting themselves. When autoinducer concentration crosses a threshold, genes for group behavior switch on. Biofilm formation is a common consequence.*

Example: *Vibrio fischeri* bacteria in a squid light organ only produce light when enough bacteria are present (quorum sensing).

88 Synaptic Signaling

Explanation: Neurons communicate via synapses: an action potential triggers neurotransmitter release; the neurotransmitter binds receptors on the postsynaptic cell. This is fast, local, and specific.

AP Bio Tip: *Synaptic signaling is a specialized form of paracrine (local) signaling -- neurotransmitters act across the tiny synaptic cleft.*

Example: Acetylcholine released at a neuromuscular junction triggers muscle contraction within milliseconds.

89 Immune Cell Signaling

Explanation: Immune cells communicate via direct contact (MHC-antigen presentation, B-T cell interaction) and cytokines (local signaling molecules). This coordination underlies the adaptive immune response.

AP Bio Tip: *Direct cell-to-cell contact is key in immunity: antigen-presenting cells show antigen to T cells via MHC. Cytokines coordinate the response.*

Example: A helper T cell recognizes antigen presented on an MHC molecule by a macrophage -- direct contact signaling.

90 Hormonal (Endocrine) Signaling

Explanation: Hormones travel in blood to distant target cells. Peptide hormones (hydrophilic) bind membrane receptors (fast, second messengers). Steroid hormones (hydrophobic) enter cells and bind intracellular receptors (slower, alter gene expression).

AP Bio Tip: *Peptide = membrane receptor, fast, second messenger. Steroid = intracellular receptor, slower, transcription change. Know one example of each: insulin (peptide), testosterone (steroid).*

Example: Testosterone enters a cell, binds its receptor, and the complex acts as a transcription factor -- response takes hours.

Explanation: Amplification: a single signal molecule activates many downstream molecules via cascades. Termination: phosphatases remove phosphates, GTPases hydrolyze GTP, ligand is removed, so the response stops.

AP Bio Tip: *Amplification requires termination -- otherwise signaling runs forever. GTP hydrolysis turns off G proteins; phosphatases turn off kinases.*

Example: One epinephrine $\rightarrow$ $\sim 10^8$ glucose molecules released (amplification). Phosphatases then reset the pathway.

Unit 5: Heredity

8-11% of the exam. Meiosis, Mendelian genetics, non-Mendelian patterns, and chromosomal inheritance.

92 Meiosis Overview

Explanation: Meiosis produces 4 genetically unique haploid cells from 1 diploid cell. Meiosis I separates homologous chromosomes (reduction); Meiosis II separates sister chromatids. Includes crossing over and independent assortment.

AP Bio Tip: *Meiosis I = homologs separate (halving). Meiosis II = sister chromatids separate (like mitosis). Know what separates in each division.*

Example: Human spermatogenesis: one diploid cell → 4 haploid sperm. Oogenesis: one diploid → 1 egg + polar bodies.

93 Crossing Over

Explanation: During prophase I, homologous chromosomes pair (synapsis) and exchange segments at chiasmata. This creates new combinations of alleles (recombination).

AP Bio Tip: *Crossing over happens in PROPHASE I between NON-SISTER chromatids of homologous chromosomes. It increases genetic variation.*

Example: Homologs exchange a segment: a chromosome ends up with one allele from each parent -- a recombinant chromosome.

94 Independent Assortment

Explanation: Homologous chromosomes line up randomly at metaphase I; each pair orients independently. This produces 2^n possible gamete combinations (n = haploid number).

AP Bio Tip: *Independent assortment occurs in METAPHASE I (homolog orientation). For humans: 2^{23} possible gametes from this alone.*

Example: For 2 pairs ($n=2$), independent assortment gives $2^2 = 4$ gamete types. For humans ($n=23$): over 8 million combinations.

95 Mendelian Genetics: Law of Segregation

Explanation: Each individual has two alleles for each gene; they separate (segregate) during gamete formation, so each gamete gets one allele. Explains 3:1 ratios in monohybrid crosses.

AP Bio Tip: *The law of segregation is about ONE gene's alleles separating into gametes. A heterozygous (Aa) individual makes 50% A and 50% a gametes.*

Example: In a Bb x Bb cross, each parent makes B and b gametes in equal proportion -- offspring are 1 BB : 2 Bb : 1 bb.

96 Punnett Squares & Probability

Explanation: Punnett squares predict offspring genotype/phenotype ratios. Probability rules: product rule (and = multiply), sum rule (or = add). Monohybrid cross Aa x Aa: 1:2:1 genotype, 3:1 phenotype.

AP Bio Tip: *Use the product rule for independent events: probability of being Aa AND Bb = $P(Aa) \times P(Bb)$. For a dihybrid AaBb x AaBb, the phenotype ratio is 9:3:3:1.*

Example: AaBb x AaBb: probability of aabb = $1/4 \times 1/4 = 1/16$. The classic dihybrid ratio is 9:3:3:1.

97 Test Cross

Explanation: To determine an unknown genotype (AA or Aa) that shows the dominant phenotype, cross it with a homozygous recessive (aa). Any recessive offspring reveal the parent was heterozygous.

AP Bio Tip: *Test cross = cross with a homozygous recessive. If any offspring show the recessive phenotype, the unknown parent must be heterozygous.*

Example: A tall pea plant (T?) crossed with tt: if any offspring are short (tt), the tall parent was Tt, not TT.

98 Dihybrid Crosses

Explanation: A cross tracking two genes. AaBb x AaBb gives 9:3:3:1 phenotypic ratio (if genes are on different chromosomes and dominant/recessive). Demonstrates independent assortment.

AP Bio Tip: *9:3:3:1 requires independent assortment (unlinked genes) and complete dominance. Deviations suggest linkage or other patterns.*

Example: Seed color (Y/y) and shape (R/r): YyRr x YyRr → 9 yellow-round : 3 yellow-wrinkled : 3 green-round : 1 green-wrinkled.

99 Incomplete Dominance

Explanation: Heterozygote shows an intermediate phenotype (e.g., red x white → pink snapdragons). Neither allele is fully dominant. Phenotype ratio in F₂ = 1:2:1 (same as genotype).

AP Bio Tip: *Incomplete dominance = blending in the heterozygote (pink). Codominance = BOTH phenotypes fully expressed (AB blood). Distinguish them.*

Example: Snapdragon flower color: CRCR = red, CRCW = pink, CWCW = white. A pink x pink cross gives 1 red : 2 pink : 1 white.

100 Codominance & Multiple Alleles

Explanation: Codominance: both alleles expressed in heterozygote (ABO blood type: I^A and I^B both expressed → AB). Multiple alleles: more than two alleles exist in the population (ABO has I^A, I^B, i).

AP Bio Tip: *ABO blood type is both codominant (I^A/I^B) and multiple-allele. i is recessive to both. Type O = ii; type AB = I^AI^B.*

Example: A person with I^AI^B has both A and B antigens (codominance). There are 3 alleles (I^A, I^B, i) but each person has 2.

101 Lethal Alleles & Pleiotropy

Explanation: Lethal alleles cause death (e.g., 2:1 ratios from lethal homozygotes). Pleiotropy: one gene affects multiple phenotypes (sickle cell affects blood, joints, immunity).

AP Bio Tip: *A 2:1 ratio hints at a lethal homozygous genotype. Pleiotropy = one gene, many effects -- sickle cell is the classic example.*

Example: Sickle-cell allele homozygotes often die young; heterozygotes have resistance to malaria (heterozygote advantage).

102 Epistasis

Explanation: One gene masks/affects the expression of another gene. Classic example: coat color in Labrador retrievers -- the E gene controls pigment deposition; ee = yellow regardless of B gene.

AP Bio Tip: *Epistasis = gene interaction where one gene's alleles hide another's phenotype. 9:3:4 ratios often result (vs 9:3:3:1).*

Example: Labrador color: B/b controls pigment type, E/e controls deposition. ee dogs are always yellow, masking B/b.

103 Polygenic Inheritance

Explanation: Multiple genes contribute to one trait (quantitative traits): height, skin color, weight. Produces a bell-shaped distribution of phenotypes. NOT simple dominant/recessive.

AP Bio Tip: *Polygenic traits show continuous variation (bell curve) -- many genes + environment. Skin color is a classic example (3+ genes).*

Example: Human height is influenced by hundreds of genes and nutrition -- phenotypes form a bell-shaped distribution.

104 Sex-Linked Inheritance

Explanation: Genes on the X chromosome are X-linked. Males (XY) have one X, so recessive X-linked traits appear more often in males (hemizygous). Examples: red-green color blindness, hemophilia. Mothers pass X to sons.

AP Bio Tip: *X-linked recessive: males affected more; no father-to-son transmission (sons get Y from father). Carrier mothers pass it to ~50% of sons.*

Example: A color-blind man (X^cY) cannot pass the trait to sons (sons get his Y), but daughters become carriers (X^cX).

105 Pedigree Analysis

Explanation: Pedigrees track traits through families. Patterns: autosomal dominant (every generation, both sexes), autosomal recessive (skips generations, consanguinity), X-linked recessive (mostly males, no father-son).

AP Bio Tip: *To determine mode: check if it skips generations (recessive), if males >> females affected (X-linked), if every generation (dominant). X-linked recessive never passes father to son.*

Example: In a pedigree where affected males appear in each generation but no affected females and no father-son transmission -- X-linked dominant or recessive pattern analysis required.

106 Chromosomal Abnormalities

- Explanation:** Nondisjunction (failure of chromosomes to separate) causes aneuploidy: monosomy ($2n-1$) or trisomy ($2n+1$). Down syndrome = trisomy 21. Abnormal chromosome structure: deletion, duplication, inversion, translocation.
- AP Bio Tip:** *Nondisjunction can occur in meiosis I (homologs don't separate) or meiosis II (sister chromatids don't). Down syndrome risk increases with maternal age.*
- Example:** Trisomy 21 (Down syndrome) results from nondisjunction: an egg with 2 copies of chromosome 21 is fertilized by a normal sperm.

107 Non-Mendelian: Linked Genes

- Explanation:** Genes on the same chromosome tend to be inherited together (linkage). Crossing over can separate them; recombination frequency reflects distance (linked genes show fewer recombinant offspring).
- AP Bio Tip:** *Linked genes do NOT show 9:3:3:1 -- parental combinations are overrepresented. Recombination frequency = map distance (1% = 1 map unit).*
- Example:** Genes A and B 10 map units apart produce 10% recombinant offspring; genes 50 units apart assort independently (unlinked).

108 Chromosomal Basis of Sex

- Explanation:** Sex is determined by sex chromosomes: XX female, XY male in humans. The Y chromosome carries the SRY gene (testis-determining). X inactivation (Barr bodies) equalizes gene dosage in females.
- AP Bio Tip:** *One X is inactivated at random in each female cell (Barr body) -- explains calico cat patches. SRY on the Y triggers male development.*
- Example:** Calico cats are female because coat color is X-linked and X inactivation creates patchwork expression.

109 Linked Genes & Recombination

- Explanation:** Recombination frequency between linked genes is proportional to their distance. Recombinant phenotypes (new combinations) appear less often than parental. Used to build genetic maps.
- AP Bio Tip:** *Higher recombination frequency = farther apart on the chromosome. Max frequency = 50% (unlinked/independent). 1% recombination = 1 centimorgan.*
- Example:** If 15% of offspring are recombinant for genes C and D, they are 15 map units apart.

110 Meiosis Errors & Human Conditions

- Explanation:** Chromosomal conditions from nondisjunction: Down (trisomy 21), Turner (XO), Klinefelter (XXY), and others. Most aneuploidies are lethal (autosomal).
- AP Bio Tip:** *Turner = XO (female, sterile, short). Klinefelter = XXY (male, tall, sterile). Sex chromosome aneuploidies are more survivable than autosomal ones.*
- Example:** A child with XXY (Klinefelter) usually arises from nondisjunction in either parent's gamete formation.

111 Sexual vs Asexual Reproduction

- Explanation:** Asexual: one parent, mitosis, genetically identical offspring (budding, fragmentation, vegetative propagation). Sexual: two parents, meiosis, genetically varied offspring. Sexual reproduction increases variation for natural selection.
- AP Bio Tip:** *Asexual = clones, fast, no variation (except mutations). Sexual = variation via crossing over, independent assortment, fertilization -- but slower and costlier.*
- Example:** Bacteria reproduce asexually (binary fission); humans reproduce sexually. Aphids do both depending on season.

112 Fertilization & Genetic Variation

- Explanation:** Fertilization fuses two haploid gametes, restoring diploidy and creating a unique genotype. Together with crossing over and independent assortment, it generates enormous genetic variation.
- AP Bio Tip:** *Three sources of variation in sexual reproduction: crossing over, independent assortment, random fertilization. All three are tested.*
- Example:** Two humans can produce $2^{23} \times 2^{23} \times$ crossing over = billions of possible offspring genotypes.

Explanation: The Hardy-Weinberg equilibrium describes allele frequencies that stay constant across generations when no evolution occurs: $p + q = 1$ and $p^2 + 2pq + q^2 = 1$.

AP Bio Tip: *Hardy-Weinberg requires: no mutation, random mating, no natural selection, large population, no gene flow. AP Bio asks which condition is being violated.*

Example: If $p = 0.7$, then $q = 0.3$; homozygous dominant = $p^2 = 0.49$, heterozygotes = $2pq = 0.42$, recessive = $q^2 = 0.09$.

Unit 6: Gene Expression & Regulation

12-17% of the exam. DNA structure, transcription/translation, mutations, and regulation of gene expression.

114 DNA Structure

Explanation: DNA is a double helix of two antiparallel strands. Sugar-phosphate backbone; bases pair A-T (2 H-bonds) and G-C (3 H-bonds). Antiparallel: 5' to 3' on one strand, 3' to 5' on the other.

AP Bio Tip: *Antiparallel means one strand runs 5'→3' and the other 3'→5'. New DNA and RNA are always synthesized 5' to 3'.*

Example: Replication reads the template 3'→5' and builds new strands 5'→3'.

115 DNA Replication: Overview

Explanation: Semi-conservative: each new DNA molecule has one old and one new strand (Meselson-Stahl proved this). Origins of replication: replication forks proceed bidirectionally. Helicase unwinds; DNA polymerase synthesizes.

AP Bio Tip: *Meselson-Stahl used heavy/light nitrogen isotopes to show semi-conservative replication. Know the key enzymes: helicase (unwind), polymerase (synthesize), ligase (seal), primase (RNA primer).*

Example: After one round of replication in ¹⁵N-then-¹⁴N medium, all DNA is hybrid (one heavy, one light strand) -- proving semi-conservative replication.

116 Leading & Lagging Strands

Explanation: DNA polymerase adds nucleotides 5'→3' only. Leading strand: synthesized continuously toward the fork. Lagging strand: synthesized in Okazaki fragments away from the fork, joined by ligase. Each fragment starts with an RNA primer.

AP Bio Tip: *Leading = continuous; lagging = Okazaki fragments. This asymmetry is entirely due to the 5'→3' rule.*

Example: The lagging strand is made in short pieces (Okazaki fragments) that DNA ligase stitches together.

117 DNA vs RNA

Explanation: DNA: deoxyribose, double-stranded, thymine, stays in nucleus. RNA: ribose, single-stranded, uracil, made in nucleus and travels to cytoplasm. Three RNA types: mRNA, tRNA, rRNA.

AP Bio Tip: *DNA = T, double, deoxyribose. RNA = U, single, ribose. mRNA carries the code; tRNA carries amino acids; rRNA is in ribosomes.*

Example: During transcription, an A in DNA produces U in RNA (not T).

118 Central Dogma

Explanation: DNA → RNA → protein. Transcription (DNA to mRNA, in nucleus) and translation (mRNA to protein, in cytoplasm at ribosomes). Flow is one-way for most organisms; retroviruses reverse-transcribe RNA to DNA.

AP Bio Tip: *Central dogma: DNA → RNA → protein. Reverse transcription (RNA → DNA) occurs in retroviruses like HIV using reverse transcriptase.*

Example: HIV converts its RNA genome into DNA using reverse transcriptase, inserting it into the host genome.

119 Transcription

Explanation: RNA polymerase synthesizes mRNA from a DNA template in the 5'→3' direction. Initiation: RNA polymerase binds the promoter. Elongation: adds RNA nucleotides. Termination: stops at terminator sequence.

AP Bio Tip: *Transcription produces mRNA in the NUCLEUS (eukaryotes). The promoter tells RNA polymerase where to start. No primer needed (unlike DNA polymerase).*

Example: The lac operon promoter is where RNA polymerase binds to transcribe the lac genes.

120 RNA Processing (Eukaryotes)

Explanation: Pre-mRNA is modified: 5' cap added, 3' poly-A tail added, introns removed and exons joined (splicing). Alternative splicing produces different mRNAs from one gene.

AP Bio Tip: *Introns = removed (intervening); exons = expressed. Alternative splicing = one gene, many proteins. 5' cap and poly-A tail protect mRNA and aid export.*

Example: The same gene can produce different proteins in different tissues via alternative splicing -- no change in DNA sequence.

121 Translation

Explanation: mRNA is decoded at ribosomes. Codons (3 nucleotides) specify amino acids. tRNA carries amino acids and has anticodons that pair with codons. AUG (start) codes for methionine; UAA/UAG/UGA are stop codons.

AP Bio Tip: *tRNA anticodon pairs with mRNA codon (anticipate wobble). Ribosome: P site (growing chain), A site (incoming tRNA), E site (exit). Translation occurs 5'→3' on mRNA.*

Example: The codon AUG on mRNA pairs with the anticodon UAC on the initiator tRNA carrying methionine.

122 Genetic Code & Wobble

Explanation: The genetic code is universal (nearly), redundant (multiple codons per amino acid), and unambiguous. Wobble: the third base of a codon can pair loosely, allowing one tRNA to read multiple codons.

AP Bio Tip: *Redundancy protects against some mutations (silent mutations). Universality supports common ancestry -- a strong AP Bio argument.*

Example: Both UUU and UUC code for phenylalanine -- a change in the third base may be silent.

123 Mutations: Types

Explanation: Point mutations: substitution (silent = no change, missense = different amino acid, nonsense = premature stop). Frameshift mutations: insertion/deletion shifting the reading frame -- usually severe.

AP Bio Tip: *Frameshifts are worse than substitutions because they scramble everything downstream. Nonsense mutations create early stop codons -- truncated proteins.*

Example: Deleting one nucleotide in a coding sequence shifts the reading frame, changing nearly all downstream amino acids.

124 Mutations: Causes & Effects

Explanation: Mutations arise from replication errors and mutagens (UV, radiation, chemicals). Most are neutral; some harmful, few beneficial. Mutations in gametes are heritable; in somatic cells they are not.

AP Bio Tip: *Only germ-line (gamete) mutations are inherited. UV causes thymine dimers -- repaired by nucleotide excision repair. Cancer arises from somatic mutations.*

Example: UV light causes thymine dimers in skin cell DNA; if repair fails, mutations accumulate and can lead to skin cancer.

125 Gene Regulation: Prokaryotes

Explanation: Prokaryotes regulate genes mainly at transcription via operons. The lac operon: repressible/inducible system with promoter, operator, structural genes. Lac operon is induced by lactose; trp operon is repressed by tryptophan.

AP Bio Tip: *Lac operon: lactose present → repressor released → genes ON (inducible). Trp operon: tryptophan present → repressor binds → genes OFF (repressible).*

Example: When lactose is absent, the lac repressor binds the operator, blocking RNA polymerase. When lactose (inducer) is present, it inactivates the repressor.

126 Operons & CAP/cAMP

Explanation: The lac operon is also regulated by catabolite activation: when glucose is low, cAMP is high, CAP binds and enhances transcription. When glucose is high, cAMP is low, transcription is low even with lactose.

AP Bio Tip: *Lac operon is maximally on only when: lactose present AND glucose absent. CAP-cAMP is positive control; repressor is negative control.*

Example: E. coli prefers glucose: with glucose available, CAP-cAMP doesn't bind and the lac operon stays low even if lactose is present.

127 Gene Regulation: Eukaryotes

Explanation: Eukaryotes regulate at multiple levels: chromatin structure, transcription factors, RNA processing, mRNA stability, translation, and protein modification. Transcription regulation is the most common control point.

AP Bio Tip: *Eukaryotic regulation is complex and multi-level; most control at transcription initiation via transcription factors. DNA methylation and histone modification affect chromatin accessibility.*

Example: Histone acetylation loosens chromatin, increasing transcription. DNA methylation usually silences genes.

128 Epigenetics

Explanation: Heritable changes in gene expression that do NOT alter the DNA sequence: DNA methylation, histone modification. Can be influenced by environment (diet, stress).

AP Bio Tip: *Epigenetics = phenotype changes without genotype changes. Methylation typically silences; acetylation typically activates. Some epigenetic marks are inherited.*

Example: Identical twins have the same DNA but different methylation patterns as they age, producing different gene expression.

129 Transcription Factors & Enhancers

Explanation: Eukaryotic transcription requires general transcription factors + RNA polymerase at the promoter. Enhancers (DNA sequences) bind specific activators that loop DNA to boost transcription. Silencers repress.

AP Bio Tip: *Enhancers work over long distances by DNA looping. Cell-specific transcription factors are why different cell types express different genes.*

Example: A muscle-specific enhancer plus activators makes muscle genes transcribed only in muscle cells.

130 Differential Gene Expression

Explanation: All cells in an organism have the same DNA, but different cells express different genes -- producing specialized cells. Cell type identity comes from which genes are on/off.

AP Bio Tip: *Same genome, different proteome. This is why a liver cell and neuron look different despite identical DNA. Differential expression is driven by transcription factors.*

Example: Hemoglobin genes are expressed in red blood cell precursors but silenced in most other cells.

131 Viruses & Gene Expression

Explanation: Viruses use host machinery to express their genes. Lytic cycle: virus replicates and lyses the cell. Lysogenic cycle: viral DNA integrates (prophage) and replicates with host until triggered. Retroviruses reverse-transcribe.

AP Bio Tip: *Lytic = immediate destruction. Lysogenic = silent integration, later activation. HIV is a retrovirus (RNA → DNA via reverse transcriptase).*

Example: Bacteriophage lambda can enter the lytic or lysogenic cycle depending on conditions.

132 Regulation of Cell Cycle Genes

Explanation: Proto-oncogenes promote cell division; tumor suppressor genes inhibit it. Mutations that overactivate proto-oncogenes (→ oncogenes) or inactivate tumor suppressors cause uncontrolled division (cancer).

AP Bio Tip: *Oncogene = gas stuck on (dominant). Tumor suppressor loss = brakes broken (often recessive, two hits). Ras and p53 are the classic examples.*

Example: Mutations in Ras (proto-oncogene) or p53 (tumor suppressor) are found in many human cancers.

133 Operon vs Eukaryotic Control

Explanation: Prokaryotic operons control gene expression by regulatory proteins binding the operator, blocking or allowing transcription. Eukaryotes use chromatin remodeling, transcription factors, enhancers, RNA processing, and post-translational control.

AP Bio Tip: *Prokaryotes = mostly transcription-level, operon-based, coupled transcription/translation (no nucleus). Eukaryotes = multi-level regulation with spatial separation.*

Example: Bacteria can begin translating mRNA while it is still being transcribed (no nuclear membrane); eukaryotes cannot.

134 Noncoding RNA & Regulation

Explanation: Many noncoding RNAs regulate genes: microRNAs (miRNAs) and small interfering RNAs (siRNAs) bind mRNA, causing degradation or blocking translation. Regulatory RNA controls ~30% of human genes.

AP Bio Tip: *miRNA/siRNA silence genes post-transcriptionally by base-pairing with mRNA. This is a major regulatory mechanism in eukaryotes.*

Example: A miRNA that matches an oncogene's mRNA can silence it, reducing cancer risk -- a current therapeutic strategy.

135

Genome Structure & Chromatin

Explanation: Eukaryotic DNA is wrapped around histones to form nucleosomes, then compacted into chromatin and chromosomes. Euchromatin = loosely packed (active transcription); heterochromatin = tightly packed (silenced).

AP Bio Tip: *Looser chromatin = more transcription. Histone acetylation opens chromatin; methylation can close it. Barr bodies (inactivated X) are heterochromatin.*

Example: The inactive X chromosome in female cells is highly condensed heterochromatin -- visible as a Barr body.

136

Stem Cells & Differentiation

Explanation: Stem cells can divide and differentiate into specialized cells. Totipotent (any cell type), pluripotent (most types), multipotent (limited). Differentiation = selective gene expression. Induced pluripotent stem cells (iPSCs) are reprogrammed adult cells.

AP Bio Tip: *Differentiation does NOT change DNA -- it changes gene expression. iPSCs (e.g., via Yamanaka factors) show expression can be reprogrammed.*

Example: Embryonic stem cells are pluripotent; adult stem cells (e.g., bone marrow) are multipotent; iPSCs are reprogrammed from adult cells.

Unit 7: Natural Selection

13-20% of the exam. Evolution, population genetics, speciation, phylogeny, and evidence for evolution.

137 Natural Selection Basics

Explanation: Individuals with heritable traits better suited to the environment survive and reproduce more (differential reproductive success). Over generations, favorable alleles increase in frequency. Requires variation, heritability, and differential fitness.

AP Bio Tip: *Natural selection acts on PHENOTYPES but changes ALLELE frequencies (populations evolve, individuals don't). It is not goal-directed -- it works with existing variation.*

Example: Peppered moths: dark moths increased during industrial revolution because they were less visible to predators on soot-darkened trees.

138 Darwin's Postulates

Explanation: Darwin's logic: (1) More offspring produced than can survive. (2) Individuals vary. (3) Variation is heritable. (4) Survival/reproduction is nonrandom -- those with favorable traits leave more offspring.

AP Bio Tip: *All four postulates must hold for natural selection. If variation is not heritable, selection can't change the population.*

Example: Antibiotic resistance in bacteria: variation exists, resistance is heritable, resistant cells survive antibiotics and reproduce -- selection in action.

139 Fitness & Adaptation

Explanation: Fitness = relative ability to survive and reproduce (contribution to next generation's gene pool). An adaptation is a heritable trait that increases fitness in a specific environment.

AP Bio Tip: *Fitness is relative and environment-specific -- 'fittest' means most reproducing, not strongest. An adaptation is only adaptive in its environment.*

Example: A peacock's tail is costly but increases mating success -- high fitness despite lower survival.

140 Evidence for Evolution

Explanation: Evidence: fossil record (transitional forms), comparative anatomy (homologous vs analogous structures), embryology, molecular biology (DNA/protein similarity), biogeography (distribution of species), and direct observation (antibiotic resistance, beak changes).

AP Bio Tip: *Homologous structures = common ancestry (same origin, different function -- mammal forelimbs). Analogous = convergent evolution (same function, different origin -- bird and insect wings).*

Example: Whale flippers, bat wings, and human arms are homologous -- modified forelimbs from a common ancestor.

141 Homology vs Analogy

Explanation: Homology: similarity due to common ancestry (e.g., forelimbs of vertebrates). Analogy: similarity due to convergent evolution, not shared ancestry (e.g., wings of birds and insects, similar body shapes of sharks and dolphins).

AP Bio Tip: *Analogous structures arise when unrelated organisms face similar selective pressures. Vestigial structures (pelvis in whales, appendix) are evidence of ancestry.*

Example: Marsupial and placental mammals evolved similar forms (flying squirrels vs sugar gliders) independently -- analogy.

142 Convergent & Divergent Evolution

Explanation: Convergent: unrelated species evolve similar traits due to similar environments (analogous). Divergent: related species become different (adaptive radiation -- Darwin's finches, Hawaiian honeycreepers).

AP Bio Tip: *Adaptive radiation = one ancestral species diversifies into many niches (finches). Convergent evolution produces analogous structures.*

Example: Darwin's finches radiated into 13+ species with different beak shapes from one ancestor.

143 Population Genetics & Allele Frequencies

Explanation: A population is the smallest unit of evolution. Evolution = change in allele frequencies over generations. The gene pool is all alleles in a population.

AP Bio Tip: *Evolution happens to POPULATIONS, not individuals. Allele frequency change is the definition of evolution (microevolution).*

Example: If the frequency of allele A changes from 0.7 to 0.6 over generations, the population has evolved.

144 Hardy-Weinberg Equilibrium

Explanation: The null model: allele frequencies stay constant if no evolution occurs. Conditions: no mutations, random mating, no selection, no gene flow, infinite population. Equations: $p + q = 1$; $p^2 + 2pq + q^2 = 1$.

AP Bio Tip: Use HW to detect evolution: if observed frequencies deviate from expected, evolution is occurring (one condition violated). p^2 = homozygous dominant, $2pq$ = heterozygous, q^2 = recessive.

Example: If q^2 (recessive phenotype) = 0.09, then $q = 0.3$, $p = 0.7$, heterozygotes = $2pq = 0.42$ (42%).

145 Mechanisms of Evolution

Explanation: Five mechanisms change allele frequencies: natural selection (adaptive), genetic drift (random, small populations), gene flow (migration), mutation (new alleles), nonrandom mating (changes genotype frequencies).

AP Bio Tip: Only natural selection consistently ADAPTS organisms. Genetic drift is random -- founder effect and bottleneck effect are its forms.

Example: A small population that recolonizes an island carries only a subset of alleles (founder effect) -- drift, not selection.

146 Genetic Drift

Explanation: Random changes in allele frequencies due to chance, strongest in small populations. Bottleneck effect: population crashes, reducing diversity. Founder effect: small group colonizes new area. Drift can fix or lose alleles randomly.

AP Bio Tip: Drift = random, most impactful in small populations. Bottlenecks lose alleles even if survivors are 'fittest'. Drift can reduce fitness (nonadaptive).

Example: Cheetahs went through a bottleneck ~10,000 years ago -- they have extremely low genetic diversity today.

147 Gene Flow

Explanation: Movement of alleles between populations via migration. Gene flow increases genetic diversity within populations and reduces differences between populations -- it can oppose local adaptation.

AP Bio Tip: Gene flow homogenizes populations. If it stops (barrier), populations diverge -- an early step toward speciation.

Example: Pollen carried between plant populations mixes alleles; a dam blocking fish migration stops gene flow and populations diverge.

148 Mutations & Variation

Explanation: Mutations are the ultimate source of all new alleles. Most are neutral or harmful; a few beneficial. Sexual reproduction shuffles existing variation (crossing over, independent assortment, fertilization).

AP Bio Tip: Mutations create variation; sexual reproduction recombines it. Selection then sorts it. Mutations are random with respect to need.

Example: A mutation creating a new allele in one bacterium can spread if it aids survival -- e.g., new antibiotic resistance gene.

149 Natural Selection Types

Explanation: Directional: favors one extreme (larger beaks). Stabilizing: favors the middle (birth weight). Disruptive: favors both extremes, selects against middle (can lead to speciation).

AP Bio Tip: Directional = shift; stabilizing = narrow; disruptive = split. Disruptive selection can drive sympatric speciation.

Example: Human birth weight is stabilizing selection -- very small and very large babies have higher mortality.

150 Sexual Selection

Explanation: Selection for traits that increase mating success, even if they reduce survival: intrasexual (competition within a sex, e.g., male-male combat) and intersexual (mate choice, e.g., female choice of elaborate displays).

AP Bio Tip: Sexual selection explains exaggerated traits (peacock tail, antlers) that seem maladaptive. It is a form of natural selection acting on mating success.

Example: Female choice selects for the peacock's elaborate tail; male-male competition selects for large antlers.

151 Speciation Overview

- Explanation:** Speciation = formation of new species. Biological species concept: populations that can interbreed and produce fertile offspring. Speciation requires reproductive isolation (barriers to gene flow).
- AP Bio Tip:** *Reproductive isolation is the key to speciation. Prezygotic barriers prevent fertilization; postzygotic barriers produce inviable/sterile hybrids.*
- Example:** Two frog species in the same pond that breed at different times are isolated by temporal isolation (prezygotic).
-

152 Reproductive Isolation

- Explanation:** Prezygotic: habitat, temporal, behavioral, mechanical, gametic isolation. Postzygotic: reduced hybrid viability, reduced hybrid fertility (mule), hybrid breakdown.
- AP Bio Tip:** *Mules (horse x donkey) are sterile -- postzygotic barrier (reduced hybrid fertility). Different mating calls = behavioral isolation (prezygotic).*
- Example:** Fireflies that flash different patterns don't mate (behavioral isolation). Mules can't reproduce (postzygotic).
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153 Allopatric vs Sympatric Speciation

- Explanation:** Allopatric: geographic separation (river, mountain) divides a population, which then diverges. Sympatric: speciation within the same area via polyploidy, habitat differentiation, or disruptive selection (common in plants).
- AP Bio Tip:** *Allopatric = physical barrier (most common). Sympatric = no barrier; polyploidy is the main mechanism in plants; can happen quickly.*
- Example:** A canyon splitting a squirrel population leads to allopatric speciation. Polyploid plant species arise sympatrically in one generation.
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154 Phylogeny & Cladistics

- Explanation:** Phylogenetic trees/cladograms show evolutionary relationships. Clades = ancestor + all descendants (monophyletic). Shared derived characters define clades. Branch points = common ancestors.
- AP Bio Tip:** *Monophyletic = valid clade (one ancestor, all descendants). Paraphyletic = ancestor + SOME descendants. Polyphyletic = no common ancestor. Cladograms are built on shared derived traits.*
- Example:** Mammals form a monophyletic clade: a common ancestor and all its descendants (monotremes, marsupials, placentals).
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155 Molecular Clocks

- Explanation:** DNA/protein differences accumulate at roughly constant rates, allowing estimates of divergence times. Calibrated with fossils. Different genes tick at different rates.
- AP Bio Tip:** *Molecular clocks assume relatively constant mutation rates. They date divergences where fossils are missing. Mitochondrial DNA ticks fast -- good for recent events.*
- Example:** Comparing hemoglobin sequences estimates when humans and chimpanzees diverged (~6-7 million years ago).
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156 Fossil Record & Transitional Forms

- Explanation:** Fossils document the history of life: transitional forms (e.g., Tiktaalik, Archaeopteryx) show intermediate features. Fossil ages use radiometric dating (half-lives) and relative position (strata).
- AP Bio Tip:** *Transitional fossils link major groups: Tiktaalik (fish -> tetrapod), Archaeopteryx (dinosaur -> bird). Older = deeper strata; radiometric dating gives absolute ages.*
- Example:** Tiktaalik has both fish features (scales, fins) and tetrapod features (limbs, neck) -- a fish-tetrapod transition.
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157 Evolution of Populations & Microevolution

- Explanation:** Microevolution = small-scale allele frequency change within a population (selection, drift, gene flow, mutation). Observed directly: antibiotic resistance, beak size changes in Darwin's finches after drought.
- AP Bio Tip:** *Direct observation of microevolution: Grants' finch studies (beak size shifted with drought -- directional selection), bacteria resistance, pesticide resistance.*
- Example:** After a drought, finches with larger beaks survived better and beak size increased in the next generation -- measurable evolution.
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158 **Adaptive Radiation & Extinction**

- Explanation:** Adaptive radiation: rapid diversification from one ancestor into many niches (finches, mammals after dinosaurs). Mass extinctions remove many species and open niches, triggering radiation.
- AP Bio Tip:** *Mass extinction events (Permian, K-T) reset ecosystems; survivors radiate. Adaptive radiation is divergent evolution on a grand scale.*
- Example:** After the K-T extinction (dinosaurs), mammals radiated into the niches left behind.
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159 **Natural Selection vs Artificial Selection**

- Explanation:** Artificial selection: humans select traits (dog breeds, crop varieties, antibiotic development). Natural selection: environment selects. Both change allele frequencies over generations.
- AP Bio Tip:** *Artificial selection demonstrates the power of selective breeding and was Darwin's starting point. Both require heritable variation.*
- Example:** All dog breeds derive from wolves via artificial selection; brassica vegetables (cabbage, broccoli, kale) were bred from one species.
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Unit 8: Ecology

10-15% of the exam. Energy flow, population dynamics, community ecology, ecosystems, and human impacts.

160 Ecology Levels of Organization

Explanation: Organism -> population (same species, same area) -> community (all populations) -> ecosystem (community + abiotic factors) -> biome -> biosphere. Ecology studies interactions at each level.

AP Bio Tip: AP Bio asks you to identify levels: population = one species; community = multiple species; ecosystem adds abiotic factors.

Example: All the fish in a pond = population. All species in the pond = community. Pond + water chemistry + sunlight = ecosystem.

161 Energy Flow & Trophic Levels

Explanation: Energy flows through ecosystems: producers (autotrophs) -> primary consumers -> secondary -> tertiary. Each transfer loses ~90% of energy (heat, metabolism) -- about 10% transfers (ecological efficiency).

AP Bio Tip: The 10% rule: only ~10% of energy passes between trophic levels. That limits the number of trophic levels (~4-5). Energy pyramids are always upright.

Example: A 10,000 kcal of algae supports ~1,000 kcal of zooplankton, ~100 kcal of small fish, ~10 kcal of large fish.

162 Food Chains & Webs

Explanation: Food chains are linear energy paths; food webs are interconnected chains showing complex feeding relationships. Keystone species have disproportionate effects on community structure.

AP Bio Tip: Keystone species removal collapses the community (sea otters -> urchins -> kelp). Food webs show that most species eat and are eaten by multiple species.

Example: Removing sea otters lets sea urchins overgraze kelp forests, destroying the ecosystem -- otters are a keystone species.

163 Primary Productivity

Explanation: Primary productivity = rate at which producers convert light energy to chemical energy. Gross primary productivity (GPP) = total fixed; net primary productivity (NPP) = GPP - respiration. Limits: light, water, nutrients.

AP Bio Tip: $NPP = GPP - \text{plant respiration}$. Highest NPP: tropical rainforests, estuaries. Lowest: deserts, open ocean (per area). AP Bio uses productivity to compare ecosystems.

Example: A tropical rainforest has high NPP; the open ocean has low NPP per area but covers most of the Earth.

164 Biomass & Energy Pyramids

Explanation: Pyramids of energy are always upright (energy lost at each level). Pyramids of biomass are usually upright but can invert in some aquatic systems (phytoplankton turn over fast). Pyramids of numbers can invert.

AP Bio Tip: Energy pyramids NEVER invert. Biomass pyramids can invert in the ocean (small standing phytoplankton biomass supports large zooplankton).

Example: In the open ocean, phytoplankton biomass (standing crop) can be less than zooplankton biomass -- an inverted biomass pyramid.

165 Biogeochemical Cycles: Carbon

Explanation: Carbon cycles through photosynthesis ($\text{CO}_2 \rightarrow \text{organic}$), respiration ($\text{organic} \rightarrow \text{CO}_2$), decomposition, combustion, and fossil fuel formation. Humans add CO_2 via fossil fuel burning and deforestation.

AP Bio Tip: Carbon reservoirs: atmosphere (CO_2), biomass, oceans, fossil fuels. Burning fossil fuels moves buried carbon into the atmosphere -- the driver of climate change.

Example: Carbon in a fossil fuel deposit returns to the atmosphere as CO_2 when burned -- a fast release of geologically stored carbon.

166 Nitrogen Cycle

Explanation: Nitrogen fixation ($\text{N}_2 \rightarrow \text{NH}_3/\text{NH}_4$) by bacteria (Rhizobium, cyanobacteria) and lightning. Nitrification ($\text{NH}_4 \rightarrow \text{NO}_2 \rightarrow \text{NO}_3$ by bacteria). Assimilation (plants take up). Ammonification (decomposers -> NH_4). Denitrification ($\text{NO}_3 \rightarrow \text{N}_2$).

AP Bio Tip: Nitrogen fixation and denitrification are done by BACTERIA. Plants cannot use N_2 directly. Know the five steps and who does them.

Example: Legumes host Rhizobium in root nodules, fixing nitrogen in exchange for sugars. Denitrifying bacteria return N_2 to the air.

167 Phosphorus Cycle

- Explanation:** Phosphorus cycles through rock → soil → organisms → sediment. No atmospheric phase (no gas form). Key in ATP, DNA, phospholipids. Phosphate runoff causes eutrophication.
- AP Bio Tip:** *Phosphorus has NO gas phase -- it is the slowest cycle. AP Bio contrasts it with carbon and nitrogen (which have atmospheric phases).*
- Example:** Mining phosphate for fertilizer → runoff → algal blooms → eutrophication of lakes.
-

168 Water Cycle

- Explanation:** Water moves via evaporation, transpiration, condensation, precipitation, runoff, and groundwater flow. Solar energy drives the cycle. Human impacts: deforestation reduces transpiration, paving increases runoff.
- AP Bio Tip:** *Transpiration = water loss from plants; it drives the water cycle on land. Deforestation reduces local rainfall.*
- Example:** Forests pump water from soil to atmosphere (transpiration), seeding clouds and rainfall -- clearing them dries the region.
-

169 Population Growth Models

- Explanation:** Exponential growth (J-curve): $dN/dt = rN$, no limits. Logistic growth (S-curve): $dN/dt = rN((K-N)/K)$ with carrying capacity K . Populations overshoot K then settle, or crash.
- AP Bio Tip:** *Exponential = no limits (J). Logistic = carrying capacity (S). K = max sustainable population. Real populations overshoot and fluctuate around K .*
- Example:** Bacteria in fresh broth grow exponentially until resources run out; yeast in a vat show logistic growth as alcohol accumulates.
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170 Carrying Capacity & Limiting Factors

- Explanation:** Carrying capacity (K) = max population size an environment can sustain. Density-dependent factors (competition, predation, disease) strengthen with population size. Density-independent factors (weather, fire, disasters) affect regardless.
- AP Bio Tip:** *Density-dependent = food, disease, competition (intensify as N rises). Density-independent = hurricanes, floods, temperature. Know which is which.*
- Example:** A drought (density-independent) kills birds regardless of population size; food shortage (density-dependent) hits harder at high density.
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171 Life History Strategies

- Explanation:** r -selected: many small offspring, little parental care, fast growth, colonize disturbed areas (insects, weeds). K -selected: few large offspring, heavy care, stable environments (elephants, humans).
- AP Bio Tip:** *r = rapid (many cheap offspring); K = keeping capacity (few quality offspring). Not a strict dichotomy -- a spectrum.*
- Example:** Dandelions are r -selected (thousands of seeds); elephants are K -selected (few calves, long care).
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172 Community Interactions: Predation

- Explanation:** Predation (+/-): predator benefits, prey harmed. Predator-prey cycles (lynx-hare) oscillate. Predators can maintain diversity by preventing one prey from dominating (keystone effect).
- AP Bio Tip:** *Predator-prey oscillations are classic. Predators often increase PREY diversity by suppressing dominants (starfish-mussels).*
- Example:** Sea stars prey on mussels, preventing mussels from crowding out other species -- removing stars collapses diversity.
-

173 Competition & Niche

- Explanation:** Interspecific competition (-/-) occurs when species compete for the same resources. Competitive exclusion principle: two species cannot occupy the same niche indefinitely. Resource partitioning allows coexistence (niche differentiation).
- AP Bio Tip:** *Competitive exclusion: one species wins. Resource partitioning: species specialize on different parts of the resource (different beak sizes, different times).*
- Example:** Darwin's finches coexist by eating different-sized seeds (resource partitioning). Warblers feed in different tree zones.
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174 Symbiosis: Mutualism, Commensalism, Parasitism

- Explanation:** Mutualism (+/+): both benefit (mycorrhizae, pollinators). Commensalism (+/0): one benefits, other unaffected (barnacles on whales). Parasitism (+/-): parasite benefits, host harmed (tapeworm, ticks).
- AP Bio Tip:** *Label the +/- signs: mutualism +/+, commensalism +/0, parasitism +/-.* Mycorrhizal fungi + plant roots = mutualism.
- Example:** Nitrogen-fixing bacteria in legume roots: mutualism. Cattle egrets following grazing cattle: commensalism. Heartworm in dogs: parasitism.
-

175 Succession

- Explanation:** Primary succession: colonization of lifeless area (bare rock -> lichens -> mosses -> plants). Secondary succession: recovery after disturbance (fire, farm abandonment) -- soil remains, faster. Climax community: stable endpoint.
- AP Bio Tip:** *Primary starts on rock (no soil); secondary starts with soil (after fire). Secondary is faster. Pioneer species (lichens) pave the way.*
- Example:** After a forest fire, grasses and herbs return quickly (secondary succession). After a lava flow, lichens colonize bare rock first (primary).
-

176 Ecosystem Disturbances & Resilience

- Explanation:** Disturbances (fire, storms, logging) can reset succession. Resilience = ability to recover. Moderate disturbance can increase diversity (intermediate disturbance hypothesis).
- AP Bio Tip:** *Intermediate disturbance hypothesis: moderate frequency/intensity maximizes diversity. Ecosystems with frequent fire (prairies, chaparral) are adapted to it.*
- Example:** Prairie grasses are fire-adapted; periodic fires maintain grassland diversity by preventing tree invasion.
-

177 Human Impacts: Habitat Loss & Invasive Species

- Explanation:** Habitat destruction is the leading cause of biodiversity loss. Invasive species (non-native, no predators) outcompete natives and reduce diversity (kudzu, zebra mussels, cane toads).
- AP Bio Tip:** *Invasive species succeed because they lack natural enemies in the new range. They disrupt food webs and can cause extinctions.*
- Example:** Zebra mussels (introduced via ship ballast) outcompete native mussels and clog infrastructure across the Great Lakes.
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178 Climate Change & the Carbon Cycle

- Explanation:** Burning fossil fuels and deforestation increase atmospheric CO₂, a greenhouse gas that traps heat. Consequences: warming, sea-level rise, shifting biomes, ocean acidification (CO₂ + H₂O -> carbonic acid).
- AP Bio Tip:** *CO₂ is both a greenhouse gas and the driver of ocean acidification. Rising CO₂ lowers ocean pH, harming coral (calcification).*
- Example:** As atmospheric CO₂ rises, oceans absorb more CO₂, forming carbonic acid -- coral skeletons dissolve.
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179 Biodiversity & Its Value

- Explanation:** Biodiversity (genetic, species, ecosystem) provides ecosystem services: pollination, nutrient cycling, medicine, resilience. Loss of biodiversity reduces ecosystem stability and services.
- AP Bio Tip:** *Biodiversity increases ecosystem stability and productivity. Genetic diversity within species is the raw material for adaptation.*
- Example:** Diverse grasslands resist drought better than monocultures; diverse crop genetics underpin food security.
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180 Conservation Biology

- Explanation:** Conservation biology applies ecology to protect biodiversity: protected areas, habitat corridors, captive breeding, sustainable resource use. Endangered species = small populations vulnerable to drift and inbreeding.
- AP Bio Tip:** *Small populations face genetic drift, inbreeding depression, and Allee effects. Corridors connect fragmented habitats, allowing gene flow.*
- Example:** Connecting fragmented forests with wildlife corridors restores gene flow between isolated populations of endangered species.
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What's Next?

You have now reviewed every unit of the AP Biology course. The concepts that matter most are the ones you almost knew -- go back to the Table of Contents, find the units you marked, and reread just those tip lines. Two weeks out, do a rapid pass over the entire guide; the day before, review only the tip lines. On exam day, read each question twice, eliminate the two clearly wrong answers first, and watch your time on the free response -- answer every part, even if briefly.

Pair it with the Study Mastery Cheat Sheet (\$19) -- how to actually retain all of it

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