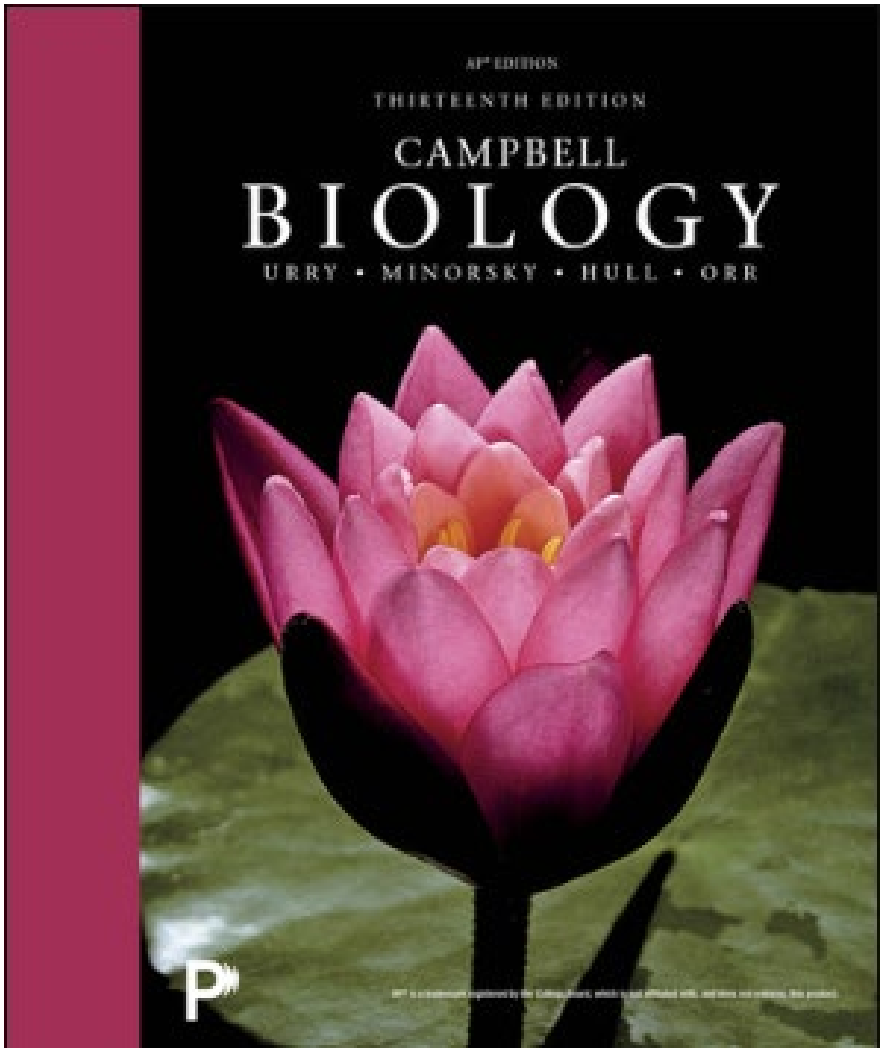

Campbell Biology 13e, AP® Edition

Correlation to the 2025 AP® Course & Exam Description

Topic	Big Idea	Learning Objective	Essential Knowledge	Concept No.	Details
1.1 Structure of Water and Hydrogen Bonding	Big Idea 4: Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	1.1.A Explain how the properties of water that result from its polarity and hydrogen bonding affect its biological function.	1.1.A.1 Living systems depend on the properties of water to sustain life. i. Water has polarity, because of the formation of polar covalent bonds between hydrogen and oxygen within water molecules. This polarity contributes to hydrogen bonding between and within biological molecules. ii. Water has a high specific heat capacity, which allows for the maintenance of homeostatic body temperature within living organisms. iii. Water has a high heat of vaporization, which allows for the evaporative cooling of the surrounding environment. In living organisms, this property allows for body temperature to be maintained.	3.1, 3.2	Polar covalent bonds in water molecules result in hydrogen bonding. Moderation of Temperature by Water
			1.1.A.2 The hydrogen bonds between adjacent polar water molecules result in cohesion, adhesion, and surface tension.	3.2	Cohesion of Water Molecules

1.2 Elements of Life	Big Idea 2: Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	1.2.A Describe the composition of macromolecules required by living organisms.	1.2.A.1 Atoms and molecules from the environment are necessary to build new molecules. Carbon, hydrogen, and oxygen are the most prevalent elements used to build biological molecules such as carbohydrates, proteins, lipids, and nucleic acids. Additionally: i. Sulfur is used in the building of proteins. ii. Phosphorus is used in the building of phospholipids (a type of lipid) and nucleic acids. iii. Nitrogen is used in the building of nucleic acids.	4.2, 4.3,	The Chemical Groups Most Important in the Processes of Life ATP: An Important Source of Energy for Cellular Processes The Chemical Elements of Life: A Review
1.3 Introduction to Macromolecules	Big Idea 4: Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	1.3.A Describe the chemical reactions that build and break biological macromolecules.	1.3.A.1 Hydrolysis is a chemical reaction involving the cleaving of covalent bonds. This type of reaction breaks down molecules into smaller molecules. When water is added to the bond between monomers in a polymer, the bond is broken. The hydrogen ion from a water molecule is added to one monomer and the hydroxyl group of the water molecule is added to the other monomer, completing the reaction.	5.1	The Synthesis and Breakdown of Polymers
			1.3.A.2 Dehydration synthesis occurs when two smaller molecules are joined together through covalent bonding. A hydrogen ion is removed from one monomer and a hydroxyl group is removed from the other. This causes the loss of the equivalent of a water molecule from the reactants and the connection of the two remaining	5.1	The Synthesis and Breakdown of Polymers

			monomers. The connection of many monomers is known as polymerization.		
1.4 Carbohydrates	Big Idea 4: Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	1.4.A Describe the structure and function of carbohydrates.	1.4.A.1 Monosaccharides (simple sugars) are the monomers for polysaccharides (complex carbohydrates). These monomers are connected by covalent bonds to form polymers such as complex carbohydrates, which may be linear or branched. **X EXCLUSION STATEMENT—***The molecular structure of specific carbohydrate polymers is beyond the scope of the AP Exam.*	5.2	Sugars Polysaccharides
Lipids	BIG IDEA 4 Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	1.5.A Describe the structure and function of lipids.	1.5.A.1 Lipids are typically nonpolar, hydrophobic molecules whose structure and function are derived from the way their subcomponents are assembled. Fatty acids can be described as either saturated or unsaturated. i. Saturated fatty acids contain only single bonds between carbon atoms. ii. Unsaturated fatty acids contain at least one double bond between carbon atoms, which causes the carbon chain to kink. iii. The more double bonds in a fatty acid tail, the more unsaturated the lipid becomes. iv. The more unsaturated a lipid is, the more liquid it is at room temperature.	5.3	Lipids are a diverse group of hydrophobic molecules

			1.5.A.2 Lipids provide a variety of functions for living organisms. Some examples of lipids are fats, steroids including cholesterol, and phospholipids. i. Fats provide energy storage and support cell function. In some cases, they can also provide insulation to help keep mammals warm. ii. Steroids are hormones that support physiological functions including growth and development, energy metabolism, and homeostasis. iii. Cholesterol provides essential structural stability to animal cell membranes. iv. Phospholipids group together to form the lipid bilayers found in plasma and cell membranes. **EXCLUSION STATEMENT**—The molecular structure of specific lipids is beyond the scope of the AP Exam.	5.3	Steroids Phospholipids Fats
Nucleic Acids	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and	1.6.A Describe the structure and function of DNA and RNA.	1.6.A.1 In nucleic acids (DNA and RNA), biological information is encoded in sequences of nucleotide monomers. Each nucleotide has the following structural components: a five-carbon sugar (deoxyribose or ribose), a phosphate, and a nitrogenous base (adenine, thymine, guanine, cytosine, or uracil).	5.5	The Roles of Nucleic Acids

	respond to information essential to life processes.		1.6.A.2 Nucleic acids have a linear sequence of nucleotides that have ends, defined by the 3’ (three prime) hydroxyl and 5’ (five prime) phosphates of the sugar in the nucleotide. During nucleic acid synthesis, nucleotides are added to the 3’ end of the growing strand, resulting in the formation of covalent bonds between nucleotides. **EXCLUSION STATEMENT**—The molecular structure of specific nucleotides is beyond the scope of the AP Exam.	5.5	The Components of Nucleic Acids
			1.6.A.3 DNA is structured as an antiparallel double helix, with two strands of nucleotides running in opposite 5’ to 3’ orientation. In DNA, adenine nucleotides pair with thymine nucleotides via hydrogen bonds (A-T), and cytosine nucleotides pair with guanine nucleotides via hydrogen bonds (C-G). In RNA, adenine pairs with uracil (A-U).	5.5	The Structures of DNA and RNA Molecules
			1.6.A.4 Structural differences between DNA and RNA include: i. DNA contains the sugar deoxyribose, and RNA contains the sugar ribose. ii. DNA contains the nitrogenous base thymine, and RNA contains the nitrogenous base uracil. iii. DNA is typically double stranded, while RNA is typically single stranded.	5.5	The Structures of DNA and RNA Molecules

Proteins	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	1.7.A Describe the structure and function of proteins.	1.7.A.1 Proteins comprise linear chains of amino acids connected by the formation of covalent (peptide) bonds that form between a carboxyl group (−COOH) of one amino acid and an amine group (−NH2) of the next amino acid, resulting in a growing peptide chain.	5.4	Concept 5.4: Proteins include a diversity of structures, resulting in a wide range of functions
			1.7.A.2 Amino acids are composed of a central carbon atom with a hydrogen atom, a carboxyl group, an amine group, and a variable R group covalently bound to it. The R group of an amino acid can be categorized by three possible chemical properties: hydrophobic/nonpolar, hydrophilic/polar, or ionic. The interactions of these R groups determine the structure and function of that region of the protein.	5.4	Amino Acids (Monomers)
			1.7.A.3 The specific sequence of amino acids in proteins determines the primary structure of a polypeptide as well as the overall shape of the protein. **EXCLUSION STATEMENT**—The molecular structure of amino acids is beyond the scope of the AP Exam.	5.4	Protein Structure and Function Exploring Levels of Protein Structure
			1.7.A.4 Secondary structures of proteins are made through the local folding that forms from interactions between atoms of the polypeptide backbone of the amino acid chain. Hydrogen bonding forms shapes such as alpha-helices and beta-pleated sheets.	5.4	Polypeptides (Amino Acid Polymers) Exploring Levels of Protein Structure

			1.7.A.5 The three-dimensional shape of the tertiary structure of a protein results from the formation of hydrogen bonds, hydrophobic interactions, ionic interactions, or disulfide bridges.	5.4	Exploring Levels of Protein Structure
			1.7.A.6 The quaternary structure arises from interactions between multiple polypeptides. All four levels of a protein structure determine the function of a protein.	5.4	Exploring Levels of Protein Structure
Cell Structure and Function	BIG IDEA 4 Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	2.1.A Explain how the structure and function of subcellular components and organelles contribute to the function of cells.	2.1.A.1 Ribosomes are comprised of ribosomal RNA (rRNA) and protein. These non-membrane, subcellular structures are found in cells in all forms of life and reflect the common ancestry in all known life. Ribosomes synthesize proteins according to messenger RNA (mRNA) sequences.	6.3	Ribosomes: Protein Factories
			2.1.A.2 The endomembrane system consists of a group of membrane-bound organelles and subcellular components (endoplasmic reticulum (ER), Golgi complex, lysosomes, vacuoles and transport vesicles, the nuclear envelope, and the plasma membrane) that work together to modify, package, and transport polysaccharides, lipids, and proteins intercellularly.	6.4	The endomembrane system regulates protein traffic and performs metabolic functions

			2.1.A.3 Endoplasmic reticulum provides mechanical support by helping cells maintain shape and plays a role in intracellular transport. i. Rough ER is associated with membrane bound ribosomes, allows for the compartmentalization of cells, and helps carry out protein synthesis. ii. Smooth ER functions include the detoxification of cells and lipid synthesis. **EXCLUSION STATEMENT**—Knowledge of the specific functions of smooth ER in specialized cells is beyond the scope of the AP Exam.	6.4	The Endoplasmic Reticulum: Biosynthetic Factory
			2.1.A.4 The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs. Functions of the Golgi include: i. Correctly folding and chemically modifying newly synthesized cellular products ii. Packaging proteins for trafficking **EXCLUSION STATEMENT**—Knowledge of the role of Golgi in the synthesis of specific phospholipids and packaging of specific enzymes for lysosomes, peroxisomes, and secretory vesicles is beyond the scope of the AP Exam.	6.4	The Golgi Apparatus: Shipping and Receiving Center
			2.1.A.5 Mitochondria have a double membrane that provides compartments for different metabolic reactions involved in aerobic cellular respiration. The outer membrane is smooth, while the inner membrane is highly	6.5	Mitochondria: Chemical Energy Conversion

			convoluted, forming folds that enable ATP to be synthesized more efficiently.		
			2.1.A.6 Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes that digest material. Lysosomes also play a role in programmed cell death (apoptosis).	6.4	Lysosomes: Digestive Compartments
			2.1.A.7 Vacuoles are membrane-bound sacs that play many different roles. i. In plant cells, a specialized large vacuole maintains turgor pressure through nutrient and water storage. ii. In animal cells, vacuoles are smaller in size, are more plentiful than in plant cells, and store cellular materials.	6.4	Vacuoles: Diverse Maintenance Compartments
			2.1.A.8 Chloroplasts are specialized organelles that are found in plants and photosynthetic algae. Chloroplasts contain a double membrane and serve as the location for photosynthesis.	6.5	Chloroplasts: Capture of Light Energy

Cell Size	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	2.2.A Explain the effect of surface area-to-volume ratios on the exchange of materials between cells or organisms and the environment.	2.2.A.1 Surface area-to-volume ratios affect the ability of a biological system to obtain necessary nutrients, eliminate waste products, acquire or dissipate thermal energy, and otherwise exchange chemicals and energy with the environment. **RELEVANT EQUATIONS** Volume of a Sphere: $V = \frac{4}{3}\pi r^3$ Volume of a Cube: $V = s^3$ Volume of a Rectangular Solid: $V = lwh$ Volume of a Cylinder: $V = \pi r^2 h$ Surface Area of a Sphere: $SA = 4\ \pi r^2$ Surface Area of a Cube: $SA = 6s^2$ Surface Area of a Rectangular Solid: $SA = 2lh + 2lw + 2wh$ Surface Area of a Cylinder: $SA = 2\pi rh + 2\pi r^2$ r = radius l = length h = height w = width s = length of one side of a cube	6.2	Comparing Prokaryotic and Eukaryotic Cells Geometric relationships between surface area and volume.

			2.2.A.2 The surface area of the plasma membrane must be large enough to adequately exchange materials. i. The surface area-to-volume ratio can restrict cell size and shape. Smaller cells typically have a higher surface area-to-volume ratio as well as a more efficient exchange of materials with the environment than do larger cells. ii. As cells increase in volume, the surface area-to-volume ratio decreases and the demand for internal resources increases. iii. More complex cellular structures (e.g., membrane folds) are necessary to adequately exchange materials with the environment. iv. As organisms increase in size, their surface area-to-volume ratio decreases, affecting properties like rate of heat exchange with the environment. Smaller amounts of mass exchange proportionally more heat with the ambient environment than do larger masses. As mass increases, both the surface area-to-volume ratio and the rate of heat exchange decrease. v. There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms; typically, the smaller the organism, the higher the metabolic rate per unit body mass.	6.2 40.4	Comparing Prokaryotic and Eukaryotic Cells Geometric relationships between surface area and volume. Influences on Metabolic Rate

Plasma Membrane	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	2.3.A Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell.	2.3.A.1 Phospholipids have both hydrophilic and hydrophobic regions. The polar hydrophilic phosphate regions of the phospholipids are oriented toward the aqueous external or internal environment, while the nonpolar hydrophobic fatty acid regions face each other within the interior of the membrane.	5.3	The structure of a phospholipid.
			2.3.A.2 Embedded proteins can be hydrophilic (with charged and polar side groups), hydrophobic (with nonpolar side groups), or both. i. Hydrophilic regions of the proteins are either inside the interior of the protein or exposed to the cytosol (cytoplasm). ii. Hydrophobic regions of proteins make up the protein surface that interacts with the fatty acids in the interior membrane.	5.3	Phospholipids
		2.3.B Describe the fluid mosaic model of cell membranes.	2.3.B.1 Plasma membranes consist of a structural framework of phospholipid molecules embedded with proteins, steroids (such as cholesterol in vertebrate animals), glycoproteins, and glycolipids. All of these can move around the surface of the cell within the membrane, as illustrated by the fluid mosaic model.	7.1	Cellular membranes are fluid mosaics of lipids and proteins

Membrane Permeability	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	2.4.A Explain how the structure of biological membranes influences selective permeability.	2.4.A.1 Plasma membranes separate the internal environment of the cell from the external environment. Selective permeability is the result of the plasma membrane having a hydrophobic interior.	7.2	Concept 7.2: Membrane structure results in selective permeability
			2.4.A.2 Small nonpolar molecules, including N2, O2, and CO2 , freely pass across the membrane. Hydrophilic substances, such as large polar molecules and ions, move across the membrane through embedded channels and transport proteins.	7.2	Concept 7.2: Membrane structure results in selective permeability
			2.4.A.3 The nonpolar hydrocarbon tails of phospholipids prevent the movement of ions and polar molecules across the membrane. Small polar, uncharged molecules, like H2O or NH3 (ammonia), pass through the membrane in small amounts.	7.2	Concept 7.2: Membrane structure results in selective permeability
		2.4.B Describe the role of the cell wall in maintaining cell structure and function.	2.4.B.1 Cell walls of Bacteria, Archaea, Fungi, and plants provide a structural boundary as well as a permeability barrier for some substances to the internal or external cellular environments and protection from osmotic lysis.	27.1	Cell-Surface Structures
Membrane Transport	BIG IDEA 2 Energetics: Biological systems use energy and	2.5.A Describe the mechanisms that organisms use to maintain solute and	2.5.A.1 The selective permeability of membranes allows for the formation of concentration gradients of solutes across the membrane.	7.3	Passive transport is diffusion of a substance across a membrane with no energy investment

	molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	water balance.	2.5.A.2 Passive transport is the net movement of molecules from regions of high concentration to regions of low concentration without the direct input of metabolic energy.	7.3	Passive transport is diffusion of a substance across a membrane with no energy investment
			2.5.A.3 Active transport requires the direct input of energy to move molecules. In some cases, active transport is utilized to move molecules from regions of low concentration to regions of high concentration.	7.4	The Need for Energy in Active Transport
		2.5.B Describe the mechanisms that organisms use to transport large molecules across the plasma membrane.	2.5.B.1 The processes of endocytosis and exocytosis require energy to move large substances or large amounts of substances into and out of cells. i. In endocytosis, the cell takes in large molecules and particulate matter by folding the plasma membrane in on itself and forming new (small) vesicles that engulf material from the external environment. ii. In exocytosis, internal vesicles release material from cells by fusing with the plasma membrane and secreting large molecules from the cell.	7.5	Bulk transport across the plasma membrane occurs by exocytosis and endocytosis
Facilitated Diffusion	BIG IDEA 2 Energetics: Biological systems use energy and molecular building	2.6.A Explain how the structure of a molecule affects its ability to pass through the	2.6.A.1 Facilitated diffusion requires transport or channel proteins to enable the movement of charged ions across the membrane. i. Membranes may become polarized by the movement of ions across the membrane. ii. Charged ions, including Na+ (sodium) and	7.3	Facilitated Diffusion: Passive Transport Aided by Proteins

	blocks to grow, reproduce, and maintain dynamic homeostasis.	plasma membrane.	K+ (potassium), require channel proteins to move through the membrane.		
			2.6.A.2 Facilitated diffusion enables the movement of large polar molecules through membranes with no energy input. In this type of diffusion, substances move down the concentration gradient.	7.3	Facilitated Diffusion: Passive Transport Aided by Proteins
			2.6.A.3 Aquaporins transport large quantities of water across membranes.	7.2 36.2	Transport proteins Aquaporins: Facilitating Diffusion of Water

Tonicity and Osmoregulation	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	2.7.A Explain how concentration gradients affect the movement of molecules across membranes.	2.7.A.1 External environments can be hypotonic, hypertonic, or isotonic to internal environments of cells. Movement of water can also be described as moving from hypotonic to hypertonic regions. Water moves by osmosis from regions of high water potential to regions of low water potential. **RELEVANT EQUATION** Water Potential: $\Psi = \Psi_p + \Psi_s$ where: Ψ_p = pressure potential Ψ_s = solute potential	7.3	Effects of Osmosis on Water Balance Water Balance of Cells Without Cell Walls
		2.7.B Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.	2.7.B.1 Growth and homeostasis are maintained by the constant movement of molecules across membranes.	36.2 44.1	Short-Distance Transport of Water Across Plasma Membranes osmoregulation

			2.7.B.2 Osmoregulation maintains water balance and allows organisms to control their internal solute composition and water potential. Water moves from regions of low osmolarity or solute concentration to regions of high osmolarity or solute concentration. **RELEVANT EQUATION** Solute Potential of a Solution: $\psi_s = -iCRT$ where: i = ionization constant C = molar concentration R = pressure constant $\left(R = 0.0831 \frac{L \cdot bars}{mol \cdot K} \right)$ T = temperature in Kelvin (°C + 273)	44.1	Osmoregulation balances the uptake and loss of water and solutes Osmosis and Osmolarity
Mechanisms of Transport	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	2.8.A Describe the processes that allow ions and other molecules to move across membranes.	2.8.A.1 Metabolic energy (such as that from ATP) is required for active transport of molecules and ions across the membrane and to establish and maintain electrochemical gradients. i. Membrane proteins are necessary for active transport. ii. The Na+/K+ pump and ATPase contribute to the maintenance of the membrane potential.	7.4	7.4: Active transport uses energy to move solutes against their gradients How Ion Pumps Maintain Membrane Potential
Cell Compartmentalization	BIG IDEA 2 Energetics: Biological systems use energy and	2.9.A Describe the membrane bound structures of the eukaryotic cell.	2.9.A.1 Membranes and membrane-bound organelles in eukaryotic cells compartmentalize intracellular metabolic processes and specific enzymatic reactions.	6.2	Eukaryotic cells have internal membranes that compartmentalize their functions

	molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	2.9.B Explain how internal membranes and membranebound organelles contribute to compartmentalization of eukaryotic cell functions.	2.9.B.1 Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing the surface area where reactions can occur.	6.2	Eukaryotic cells have internal membranes that compartmentalize their functions
Origins of Cell Compartmentalization	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life.	2.10.A Describe similarities and/or differences in compartmentalization between prokaryotic and eukaryotic cells.	2.10.A.1 Membrane-bound organelles such as mitochondria and chloroplasts evolved from once free-living prokaryotic cells via endosymbiosis.	6.5	The Evolutionary Origins of Mitochondria and Chloroplasts
			2.10.A.2 Prokaryotes typically lack internal membrane bound organelles but have internal regions with specialized structures and functions.	6.2	Figure 6.5 A prokaryotic cell
			2.10.A.3 Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.	6.2	A Panoramic View of the Eukaryotic Cell
Enzymes	BIG IDEA 2 Energetics: Biological systems use energy and molecular building	3.1.A Explain how enzymes affect the rate of biological reactions.	3.1.A.1 The structure and function of enzymes contribute to the regulation of biological processes. Enzymes are proteins that are biological catalysts that facilitate chemical reactions in cells by lowering the activation energy.	8.4	Enzymes speed up metabolic reactions by lowering energy barriers

	blocks to grow, reproduce, and maintain dynamic homeostasis.		3.1.A.2 For an enzyme-mediated chemical reaction to occur, the shape and charge of the substrate must be compatible with the active site of the enzyme. This is illustrated by the enzyme substrate complex model.	8.4	Substrate Specificity of Enzymes
Environmental Impacts on Enzyme Function	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	3.2.A Explain how changes to the structure of an enzyme may affect its function.	3.2.A.1 Change to the molecular structure of a component in an enzymatic system may result in a change to its function or efficiency. i. Denaturation of proteins, such as enzymes, occurs when the protein structure is disrupted by a change in temperature, pH, or chemical environment, eliminating the ability to catalyze reactions. ii. Environmental temperatures and pH outside the optimal range for a given enzyme will cause changes to its structure (by disrupting the hydrogen bonds), altering the efficiency with which it catalyzes reactions.	8.4	Catalysis in the Enzyme's Active Site
			3.2.A.2 In some cases, enzyme denaturation is reversible, allowing the enzyme to regain activity.	8.4	Catalysis in the Enzyme's Active Site
		3.2.B Explain how the cellular environment affects enzyme activity.	3.2.B.1 The relative concentrations of substrates and products determine how efficiently an enzymatic reaction proceeds.	8.4	Catalysis in the Enzyme's Active Site

			3.2.B.2 Higher environmental temperatures increase the average speed of movement of molecules in a solution, increasing the frequency of collisions between enzymes and substrates and therefore increasing the rate of reaction until the optimal temperature is achieved.	8.4	Effects of Local Conditions on Enzyme Activity
			3.2.B.3 Competitive inhibitor molecules can bind reversibly to the active site of the enzyme. Noncompetitive inhibitors can bind to allosteric sites, changing the activity of the enzyme.	8.4	Enzyme Inhibitors
Cellular Energy	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	3.3.A Describe the role of energy in living organisms.	3.3.A.1 All living systems require an input of energy.	8.1	How do the laws of thermodynamics relate to biological processes?
			3.3.A.2 Life requires a highly ordered system and does not violate the first and second laws of thermodynamics. i. Energy input must exceed energy loss to maintain order and to power cellular processes. ii. Cellular processes that release energy may be coupled with cellular processes that require energy. iii. Significant loss of order or energy flow results in death. **EXCLUSION STATEMENT** —Students will need to understand the concept of energy, but the equation for Gibbs free energy is beyond the scope of the AP Exam.	8.1 8.3	An organism's metabolism transforms matter and energy Concept 8.3 ATP powers cellular work by coupling exergonic reactions to endergonic reactions

			3.3.A.3 Energy-related pathways in biological systems are sequential to allow for a more controlled transfer of energy. A product of a reaction in a metabolic pathway is typically the reactant for the subsequent step in the pathway.	8.2	Free Energy and Metoabolism
		3.3.B Explain how shared, conserved, and fundamental processes and features support the concept of common ancestry for all organisms.	3.3.B.1 Core metabolic pathways (e.g., glycolysis, oxidative phosphorylation) are conserved across all currently recognized domains (Archaea, Bacteria, and Eukarya).	8.1 9.6	Metabolic Pathways The Evolutionary Significance of Glycolysis
Photosynthesis	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	3.4.A Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy.	3.4.A.1 Photosynthesis is the series of reactions that use carbon dioxide (CO_2), water (H_2O), and light energy to make carbohydrates and oxygen (O_2). i. Photosynthetic organisms capture energy from the sun and produce sugars that can be used in biological processes or stored. ii. Photosynthesis first evolved in prokaryotic organisms. iii. Scientific evidence supports the claim that prokaryotic (cyanobacterial) photosynthesis was responsible for the production of an oxygenated atmosphere. iv. Prokaryotic photosynthetic pathways	10.1, 10.2	Concept 10.1: Photosynthesis feeds the biosphere

			were the foundation of eukaryotic photosynthesis.		
			3.4.A.2 Stroma and thylakoids are found within the chloroplast. i. The stroma is the fluid within the inner chloroplast membrane and outside the thylakoid. The carbon fixation (Calvin cycle) reactions of photosynthesis occur in the stroma. ii. The thylakoid membranes contain chlorophyll pigments organized into two photosystems, as well as electron transport proteins. iii. Thylakoids are organized in stacks called grana. The light reactions of photosynthesis occur in the grana.	10.2	Chloroplasts: The Sites of Photosynthesis in Plants
			3.4.A.3 The light reactions of photosynthesis in eukaryotes involve a series of coordinated reaction pathways that capture energy present in light to yield ATP and NADPH, which power the production of organic molecules in the Calvin cycle. This provides energy for metabolic processes.	10.2, 10.3	The Two Stages of Photosynthesis: *A Preview*

		3.4.B Explain how cells capture energy from light and transfer it to biological molecules for storage and use.	3.4.B.1 Electron transport chain (ETC) reactions occur in chloroplasts, in mitochondria, and across prokaryotic plasma membranes. In photosynthesis, electrons that pass through the thylakoid membrane are picked up and ultimately transferred to NADP+ reducing it to NADPH in photosystem I. **EXCLUSION STATEMENT** —The full names of the specific electron carriers in the electron transport chain are beyond the scope of the AP Exam. **EXCLUSION STATEMENT** —Specific steps, names of enzymes, and intermediates of the pathways for these processes are beyond the scope of this course and the AP Exam.	10.3 10.3	Linear Electron Flow Cyclic Electron Flow Comparison of chemiosmosis in mitochondria and chloroplasts.
			3.4.B.2 During photosynthesis, I. chlorophylls absorb energy from light, boosting electrons to a higher energy level in photosystems I and II. Water then splits, supplying electrons to replace those lost from photosystem II.	10.3	Linear Electron Flow
			3.4.B.3 Photosystems I and II are embedded in the thylakoid membranes of chloroplasts and are connected by the transfer of electrons through an ETC.	10.3	Linear Electron Flow

			3.4.B.4 When electrons are transferred between molecules in a series of oxidation/reduction reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) is established across the thylakoid membrane. The membrane separates a region of low proton concentration outside the thylakoid membrane from a region of high proton concentration inside the thylakoid membrane.	10.3	A Comparison of Chemiosmosis in Chloroplasts and Mitochondria
			3.4.B.5 The formation of the proton gradient is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase. The flow of protons back through membrane-bound ATP synthase by chemiosmosis drives the formation of ATP from ADP and inorganic phosphate; this is known as photophosphorylation.	10.3	A Comparison of Chemiosmosis in Chloroplasts and Mitochondria
			3.4.B.6 The energy captured in the light reactions and transferred to ATP and NADPH powers the production of carbohydrates from carbon dioxide in the Calvin cycle. This occurs in the stroma of the chloroplast.	10.4	Concept 10.4: The Calvin cycle uses the chemical energy of AP and NADPH to reduce CO_2 to sugar
Cellular Respiration	BIG IDEA 2 Energetics: Biological systems use energy and molecular	3.5.A Describe the processes and structural features of mitochondria that	3.5.A.1 Cellular respiration uses energy from biological macromolecules to synthesize ATP. Respiration and fermentation are characteristic of all forms of life.	9.1	Figure 9.1: How is the chemical energy stored in food used to generate ATP, the molecule that drives most cellular work?

	building blocks to grow, reproduce, and maintain dynamic homeostasis.	allow organisms to use energy stored in biological macromolecules.	3.5.A.2 Aerobic cellular respiration in eukaryotes involves a series of coordinated enzyme catalyzed reactions that capture energy from biological macromolecules.	9.1	The Stages of Cellular Respiration: A Preview
			3.5.A.3 The ETC transfers electrons in a series of oxidation-reduction reactions that establish an electrochemical gradient across membranes. i. In cellular respiration, electrons delivered by NADH and FADH2 are passed to a series of electron acceptors as they move toward the terminal electron acceptor, oxygen. Aerobic prokaryotes use oxygen as a terminal electron acceptor, while anaerobic prokaryotes use other molecules.	9.1 9.4	Redox Reactions: Oxidation and Reduction The Pathway of Electron Transport
			ii. The transfer of electrons, through the ETC, is accompanied by the formation of a proton gradient across the inner mitochondrial membrane, with the membrane(s) separating a region of high proton concentration outside the membrane from a region of low proton concentration inside the membrane. The folding of the inner membrane increases the surface area, which allows for more ATP to be synthesized. In prokaryotes, the passage of electrons is accompanied by the movement of protons across the plasma membrane.	9.1 9.4	Oxidation of Organic Fuel Molecules During Cellular Respiration Chemiosmosis: The Energy-Coupling Mechanism

			iii. The flow of protons back through membrane-bound ATP synthase by chemiosmosis drives the formation of ATP from ADP and inorganic phosphate. This is known as oxidative phosphorylation in aerobic cellular respiration.	9.1	In eukaryotic cells, the inner membrane of the mitochondrion is the site of electron transport and another process called chemiosmosis, together making up oxidative phosphorylation.
			iv. In aerobic cellular respiration, decoupling oxidative phosphorylation from electron transport generates heat. This heat can be used by endothermic organisms to regulate body temperature. **EXCLUSION STATEMENT** —The full names of the specific electron carriers in the electron transport chain are beyond the scope of the AP Exam. **EXCLUSION STATEMENT** —Specific steps, names of enzymes, and intermediates of the pathways for these processes are beyond the scope of this course and the AP Exam.	9.4	An Accounting of ATP Production by Cellular Respiration
		3.5.B Explain how cells obtain energy from biological macromolecules in	3.5.B.1 Glycolysis is a biochemical pathway that releases the energy in glucose molecules to form ATP (from ADP and inorganic phosphate), NADH (from NAD+), and pyruvate.	9.2, 9.3	Concept 9.2: Glycolysis harvests chemical energy by oxidizing glucose to pyruvate

		order to power cellular functions. **EXCLUSION STATEMENT** — Memorization of the steps in glycolysis and the Krebs cycle, and of the structures of the molecules and the names of the enzymes involved, is beyond the scope of this course and the AP Exam.	3.5.B.2 Pyruvate is transported from the cytosol to the mitochondrion where oxidation occurs. This process releases electrons during the Krebs (citric acid) cycle, reducing NAD+ to NADH and FAD to FADH2, and releasing CO2 .	9.3	Figure 9.8: The steps of glycolysis.
			3.5.B.3 The Krebs cycle takes place in the mitochondrial matrix. During the Krebs cycle, carbon dioxide is released from organic intermediates, ATP is synthesized from ADP and inorganic phosphate, and electrons are transferred by the coenzymes NAD+ and FAD.	9.3	Concept 9.3: After pyruvate is oxidized, the citric acid cycle completes the energy-yielding oxidation of organic molecules
			3.5.B.4 Electrons extracted in glycolysis and Krebs cycle reactions are transferred by NADH and FADH2 to the ETC in the inner mitochondrial membrane.	9.4	Concept 9.4: During oxidative phosphorylation, chemiosmosis couples electron transport to ATP synthesis
			3.5.B.5 When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) across the inner mitochondrial membrane is established. The pH inside the mitochondrial matrix is higher than in the intermembrane space.	9.4	Figure 9.14 Chemiosmosis couples the electron transport chain to ATP synthesis.
			3.5.B.6 Fermentation allows glycolysis to proceed in	9.5	Concept 9.5: Fermentation and anaerobic respiration

			the absence of oxygen and produces organic molecules such as alcohol and lactic acid.		enable cells to produce ATP without the use of oxygen
Cell Communication	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	4.1.A Describe the ways that cells can communicate with one another.	4.1.A.1 Cells communicate with one another through direct contact with other cells or from a distance via chemical signaling.	11.1	Local and Long-Distance Signaling
		4.1.B Explain how cells communicate with one another over short and long distances.	4.1.B.1 Cells communicate over short distances by using local regulators that target cells in the vicinity of the signal-emitting cell.	11.1	Local and Long-Distance Signaling
			4.1.B.2 Signals released by one cell type can travel long distances to target cells of another type.	11.1	Local and Long-Distance Signaling
Introduction to Signal Transduction	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	4.2.A Describe the components of a signal transduction pathway.	4.2.A.1 Signal transduction pathways link signal receptions with cellular responses.	11.1	Local and Long-Distance Signaling

			4.2.A.2 Many signal transduction pathways include protein modifications and involve phosphorylation cascades.	11.3	Concept 11.3: Signal transduction: Cascades of molecular interactions transmit signals form receptors to relay molecules in the cell
		4.2.B Describe the role of components of a signal transduction pathway in producing a cellular response.	4.2.B.1 Signaling begins with the recognition of a chemical messenger—a ligand—by a receptor protein in a target cell. The ligand-binding domain of a receptor recognizes a specific chemical messenger, which can be a peptide (protein) or a small molecule. ii. G protein-coupled receptors are an example of a receptor protein in eukaryotes. iii. Receptors may be located on the surface of a target cell or in the cytoplasm or nucleus of the target cell.	11.2	Concept 11.2: Signal reception: A signaling molecule binds to a receptor, causing it to change shape

			4.2.B.2 Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, resulting in the appropriate responses by the cell. Responses could include cell growth, secretion of molecules, or gene expression. i. After the ligand binds, the intracellular domain of a receptor protein changes shape, initiating transduction of the signal. ii. Enzymes and second messengers such as cyclic AMP (cAMP) relay and amplify the intracellular signal. iii. Hormones are an example of a signaling messenger that can travel long distances in the bloodstream. iv. The binding of ligands to ligand-gated channels can cause the channel to open or close.	11.3	Concept 11.3: Signal transduction: Cascades of molecular interactions transmit signals from receptors to relay molecules in the cell
Signal Transduction Pathways	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	4.3.A Describe the different types of cellular responses elicited by a signal transduction pathway.	4.3.A.1 Signal transduction may result in changes in gene expressions and cell function, which may alter phenotype or result in programmed cell death (apoptosis).	11.4, 11.5	Apoptosis requires integration of multiple cell-signaling pathways
		4.3.B Explain how a change in the structure of any signaling molecule affects the	4.3.B.1 Changes in signal transduction pathways can alter cellular responses. Mutations in any domain of the receptor protein or in any component of the signaling pathway may affect the downstream components by	11.4, 11.5	Apoptosis requires integration of multiple cell-signaling pathways

		activity of the signaling pathway.	altering the subsequent transduction of the signal.		
			4.3.B.2 Chemicals that interact with any component of the signaling pathway may activate or inhibit the pathway.	11.4, 11.5	Apoptosis requires integration of multiple cell-signaling pathways
Feedback	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	4.4.A Explain how positive and negative feedback helps maintain homeostasis.	4.4.A.1 Organisms use feedback mechanisms to maintain their internal environments in response to internal and external changes. i. Negative feedback mechanisms maintain homeostasis by reducing the initial stimulus to regulate physiological processes. If a system is perturbed or disrupted, negative feedback mechanisms return the system back to its target set point. These processes operate at the molecular, cellular, and organismal levels. ii. Positive feedback mechanisms amplify responses and processes in biological organisms. The variable initiating the response is moved further away from the initial set point. Amplification occurs when the stimulus is further intensified, which, in turn, initiates an additional response that produces system change.	40.2	Homeostasis

Cell Cycle	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	4.5.A Describe the events that occur in the cell cycle.	4.5.A.1 The cell cycle is a highly regulated series of events that controls the growth and reproduction of eukaryotic cells. i. The cell cycle consists of sequential stages of interphase (G1, S, G2), mitosis, and cytokinesis. ii. G1 phase: The cell is metabolically active, duplicating organelles and cytosolic components. iii. S phase: DNA is in the form of chromatin and replicates to form two sister chromatids connected at a centromere. iv. G2 phase: Protein synthesis occurs, ATP is produced in large quantities, and centrosomes replicate. v. A cell can enter a stage (G0) in which it no longer divides, but it can reenter the cell cycle in response to appropriate cues. vi. Nondividing cells may exit the cell cycle or be held at a particular stage in the cell cycle.	12.2	Phases of the Cell Cycle

		4.5.B Explain how mitosis results in the transmission of chromosomes from one generation of cells to the next.	4.5.B.1 Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells in eukaryotes. i. Mitosis plays a role in growth, tissue repair, and asexual reproduction. ii. Mitosis occurs in sequential steps (prophase, metaphase, anaphase, telophase) and alternates with interphase in the cell cycle. iii. Prophase: Sister chromatids condense, mitotic spindle begins to form, and centrosomes move to opposite poles of the cell. iv. Metaphase: Spindle fibers align chromosomes along the equator of the cell. v. Anaphase: Paired sister chromatids separate as spindle fibers pull chromatids toward poles. vi. Telophase: Mitotic spindle breaks down, a new nuclear envelope develops, and then the cytoplasm divides. vii. Cytokinesis: A cleavage furrow forms in animal cells or a cell plate forms in plant cells, resulting in two new daughter cells.	12.2	Exploring Mitosis in an Animal Cell
Regulation of Cell Cycle	BIG IDEA 3 Information Storage and Transmission:	4.6.A Describe the role of checkpoints in	4.6.A.1 A number of internal controls or checkpoints regulate progression through the cell cycle.	12.3	The Cell Cycle Control System

	Living systems store, retrieve, transmit, and respond to information essential to life processes.	regulating the cell cycle.	4.6.A.2 Interactions between cyclins and cyclin dependent kinases control the cell cycle. **EXCLUSION STATEMENT**—Knowledge of pecific cyclin-CdK pairs or growth factors is beyond the scope of the AP Exam.	12.3	The Cell Cycle Clock: Cyclins and Cyclin-Dependent Kinases
		4.6.B Describe the effects of disruptions to the cell cycle on the cell or organism.	4.6.B.1 Disruptions to the cell cycle may result in cancer or apoptosis (programmed cell death).	12.3	Loss of Cell Cycle Controls in Cancer Cells
Meiosis	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information	5.1.A Explain how meiosis results in the transmission of chromosomes from one generation to the next.	5.1.A.1 Meiosis is a process that ensures the formation of haploid gamete cells, sometimes referred to as daughter cells, in sexually reproducing diploid organisms.	13.1 13.2	Meiosis: Figure 13.1: What biological mechanisms account for the resemblance between offspring and their parents? Concept 13.2: Fertilization and meiosis alternate in sexual life cycles

	essential to life processes.		5.1.A.2 Meiosis I involves the following steps: i. Prophase I: Homologous chromosomes pair up and condense, synapsis occurs and then chiasmata may form, meiotic spindle begins to form, centrosomes move to opposite poles of the cell, and the nuclear envelope breaks down. ii. Metaphase I: Meiotic spindle fibers align homologous pairs of chromosomes along the equator of the cell at the metaphase plate. iii. Anaphase I: Homologous chromosomes separate, while sister chromatids remain attached, as meiotic spindle fibers pull chromosomes toward poles. iv. Telophase I: Meiotic spindle breaks down, a new nuclear envelope develops, a cleavage furrow (animal cell) or cell plate (plant cell) forms, and cytokinesis occurs. Two haploid daughter cells are formed (at the end of meiosis I).	13.3	The Stages of Meiosis

			5.1.A.3 Meiosis II involves the following steps: i. Prophase II: Meiotic spindle forms; sister chromatids connected at the centromere attach to meiotic spindle. ii. Metaphase II: Chromosomes align along the metaphase plate; the kinetochore of each chromatid is attached to a microtubule extending from the poles. iii. Anaphase II: Proteins at the centromeres break down, and sister chromatids are pulled apart and toward opposite poles in the cell. iv. Telophase II: Meiotic spindle breaks down, a new nuclear envelope develops, a cleavage furrow (animal cell) or a cell plate (plant cell) forms, chromatids begin to decondense, and cytokinesis occurs. Four haploid daughter cells are formed, each with an unduplicated chromatid.	13.3	The Stages of Meiosis
		5.1.B Describe similarities and differences between the phases and outcomes of mitosis and meiosis.	5.1.B.1 Mitosis and meiosis are similar in the use of a spindle apparatus to move chromosomes but differ in the number of cells produced and the genetic content of the daughter cells.	13.3	A Comparison of Mitosis and Meiosis
Meiosis and Genetic Diversity	BIG IDEA 3 Information Storage and Transmission: Living systems	5.2.A Explain how the process of meiosis generates genetic diversity.	5.2.A.1 Correct separation of the homologous chromosomes in meiosis I and sister chromatids in meiosis II ensures that each gamete receives a haploid (1n) set of chromosomes that comprises an assortment of both maternal and paternal	13.4	Origins of Genetic Variation Among Offspring

	store, retrieve, transmit, and respond to information essential to life processes.		chromosomes. When incorrect separation occurs (nondisjunction), gametes are no longer haploid.		
			5.2.A.2 During prophase I of meiosis, non-sister chromatids exchange genetic material via a process called crossing over (recombination), which increases genetic diversity among the resultant gametes.	13.4	Crossing Over
			5.2.A.3 Sexual reproduction in eukaryotes increases genetic variation, including crossing over, random assortment of chromosomes during meiosis, and subsequent fertilization of gametes. **EXCLUSION STATEMENT**—Knowledge of the details of sexual reproduction cycles in various plants and animals is beyond the scope of the AP Exam.	13.4	Origins of Genetic Variation Among Offspring
Mendelian Genetics	BIG IDEA 1 Evolution: The process of evolution drives the	5.3.A Explain the inheritance of genes and traits as	5.3.A.1 Mendel's laws of segregation and independent assortment can be applied to genes that are on different chromosomes.	14.1	Concept 14.1: Mendel used the scientific approach to identify two laws of inheritance

	diversity and unity of life. BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	described by Mendel's laws.	5.3.A.2 In most cases, fertilization involves the fusion of two haploid gametes, restoring the diploid number of chromosomes and increasing genetic variation in populations by creating new combinations of alleles in the zygote. i. Rules of probability can be applied to analyze the passing of single-gene traits from parent to offspring. ii. Monohybrid, dihybrid, and test crosses can be used to determine whether alleles are dominant or recessive. iii. An organism's genotype is the set of alleles inherited for one or more genes by an individual organism. An organism's genotype can be homozygous or heterozygous for each gene. iv. An organism's phenotype is the observable expression of the inherited traits. v. Patterns of inheritance (autosomal, genetically linked, sex-linked) and whether an allele is dominant or recessive can often be predicted from data, including pedigrees. Punnett squares can be used to predict the genotypes and phenotypes of parents and offspring. **RELEVANT EQUATIONS** Laws of Probability: If *A* and *B* are mutually exclusive, then: $P(A \text{ or } B) = P(A) + P(B)$ If *A* and *B* are independent, then: $P(A \text{ and } B) = P(A) \times P(B)$	14.2	Concept 14.2: Probability laws govern Mendelian inheritance

Non-Mendelian Genetics	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	5.4.A Explain deviations from Mendel's model of the inheritance of traits.	5.4.A.1 Patterns of inheritance of many traits do not follow the ratios predicted by Mendel's laws and can be identified by quantitative analysis, when the observed phenotypic ratios statistically differ from the predicted ratios. i. Genes located on the same chromosome are referred to as being genetically linked. The probability that these linked genes segregate together during meiosis can be used to calculate the map distance (or map units) between them on a chromosome. This calculation is called gene or genetic mapping.	15.3	Concept 15.3: Linked genes tend to be inherited together because they are located near each other on the same chromosome
			ii. Codominance occurs when the phenotype from both alleles is expressed such that the heterozygote would have a different phenotype than either homozygote.	14.3	Degrees of Dominance
			iii. Incomplete dominance occurs when neither allele of a gene can mask the other, so the phenotype of the heterozygote is a blended version of the dominant and recessive phenotypes.	14.3	Degrees of Dominance
			5.4.A.2 Some traits, known as sex-linked traits (X- or Y-linked), are determined by genes on sex chromosomes. The pattern of inheritance of sex-linked traits can often be predicted from data, including pedigrees, indicating the genotypes and phenotypes of both parents and offspring.	15.2	Concept 15.2: Sex-linked genes exhibit unique patterns of inheritance

			5.4.A.3 Pleiotropy is a phenomenon in which the expression of a single gene results in multiple traits or effects; these traits therefore do not segregate independently.	14.3	Pleiotropy
			5.4.A.4 Some traits result from non-nuclear inheritance. i. Chloroplasts and mitochondria are randomly assorted to gametes and daughter cells; thus, traits determined by chloroplast and mitochondrial DNA do not follow simple Mendelian rules.	15.5	Concept 15.5: Some inheritance patterns are exceptions to standard Mendelian inheritance
			ii. In animals, mitochondria are usually transmitted by the egg and not by sperm; thus, traits determined by the mitochondrial DNA are typically maternally inherited.	15.5	Inheritance of Organelle Genes
			iii. In plants, mitochondria and chloroplasts are transmitted in the ovule and not in the pollen; as such, mitochondria-determined and chloroplast-determined traits are typically maternally inherited.	15.5	Inheritance of Organelle Genes
Environmental Effects on Phenotype	BIG IDEA 4 Systems Interactions: Biological systems interact, and these systems and their interactions	5.5.A Explain how the same genotype can result in multiple phenotypes under different environmental conditions.	5.5.A.1 Environmental conditions influence gene expression and can lead to phenotypic plasticity (e.g., the ability of individual genotypes to produce different phenotypes).	14.3 35.1	Nature and Nuture: The Environmental Impact on Phenotype Data from D. L. Royer et al., Phenotypic plasticity of leaf shape along a temperature

	exhibit complex properties.				gradient in Acer rubrum, PLoS ONE 4(10):e7653 (2009).
DNA and RNA Structure	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	6.1.A Describe the structures involved in passing hereditary information from one generation to the next.	6.1.A.1 Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules.	16.1	Concept 16.1: DNA is the genetic material
			i. Prokaryotic organisms typically have circular chromosomes.	27.1 16.2	Internal Organization and DNA Figure 16.13 Origins of replication in E. coli and eukaryotes.
			ii. Eukaryotic organisms typically have multiple linear chromosomes that are comprised of DNA. These chromosomes are condensed using histones and associated proteins.	16.3	Concept 16.3: A chromosome consists of a DNA molecule packed together with proteins
			6.1.A.2 Prokaryotes and eukaryotes can contain plasmids, which are extra-chromosomal circular molecules of DNA.	27.1	Internal Organization and DNA

		6.1.B Describe the characteristics of DNA that allow it to be used as hereditary material.	6.1.B.1 Nucleic acids exhibit specific nucleotide base pairing that is conserved through evolution. i. Purines (guanine and adenine) have a double ring structure. ii. Pyrimidines (cytosine, thymine, and uracil) have a single ring structure. iii. Purines pair with pyrimidines: adenine with thymine (or uracil in RNA) and guanine with cytosine.	16.1	Figure 16.5: The structure of a DNA strand. Animation: DNA and RNA Structure

DNA Replication	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	6.2.A Describe the mechanisms by which genetic information is copied for transmission between generations.	6.2.A.1 DNA replication ensures continuity of hereditary information. i. DNA is synthesized in the 5' to 3' direction. ii. Replication is a semiconservative process, meaning one strand of DNA serves as the template for a new strand of complementary DNA. iii. Helicase unwinds the DNA strands. iv. Topoisomerase relaxes supercoiling in front of the replication fork. v. DNA polymerase requires RNA primers to initiate DNA synthesis. vi. DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand. vii. Ligase joins the fragments on the lagging strand. **EXCLUSION STATEMENT**—The names of the steps and particular enzymes involved, excluding DNA polymerase, ligase, RNA polymerase, helicase, and topoisomerase, are beyond the scope of the AP Exam.	16.2	Concept 16.2: Many proteins work together in DNA replication and repair
Transcription and RNA Processing continued	BIG IDEA 3 Information Storage and Transmission: Living systems store,	6.3.A Describe the mechanisms by which genetic information flows from DNA to	6.3.A.1 The sequence of the RNA bases, together with the structure of the RNA molecule, determines RNA function.	17.1	Concept 17.1: Gene specify proteins via transcription and translation Figure 17.1: How can one change in DNA

	retrieve, transmit, and respond to information essential to life processes.	RNA to protein.			result in such a dramatic change in appearance?
			i. Messenger RNA (mRNA) molecules carry information from DNA in the nucleus to the ribosome in the cytoplasm.	17.1	Basic Principles of Transcription and Translation.
			ii. Distinct transfer RNA (tRNA) molecules bind specific amino acids and have anticodon sequences that base pair with the codons of mRNA. tRNA is recruited to the ribosome during translation to generate the primary peptide sequence based on the mRNA sequence.	17.4	The Structure and Function of Transfer RNA
			iii. Ribosomal RNA (rRNA) molecules are functional building blocks of ribosomes."	17.4	The Structure and Function of Ribosomes
			6.3.A.2 RNA polymerases use a single template strand of DNA to direct the inclusion of bases in the newly formed RNA molecule. This process is known as transcription.	17.2	Molecular Components of Transcription
			6.3.A.3 The enzyme RNA polymerase synthesizes mRNA molecules in the 5’ to 3’ direction by reading the template DNA strand in the 3’ to 5’ direction.	17.2	Molecular Components of Transcription

			6.3.A.4 In eukaryotic cells the mRNA transcript undergoes a series of enzyme-mediated modifications. i. The addition of a poly-A tail makes mRNA more stable. ii. The addition of a GTP cap helps with ribosomal recognition. iii. The excision of introns, along with the splicing and retention of exons, generates different versions of the resulting mature mRNA molecule. This process is known as alternative splicing.	17.3	Alteration of mRNA Ends
Translation	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	6.4.A Explain how the phenotype of an organism is determined by its genotype.	6.4.A.1 Translation of the mRNA to generate a polypeptide occurs on ribosomes that are present in the cytoplasm of both prokaryotic and eukaryotic cells, as well as the cytoplasmic surface of the rough ER of eukaryotic cells.	17.4	Concept 17.4: Translation is the RNA-directed synthesis of a polypeptide: A Closer Look Figure 17.18: The anatomy of a functioning ribosome.
			6.4.A.2 In prokaryotic organisms, translation of the mRNA molecule occurs while it is being transcribed.	17.4	Figure 17.24: Coupled transcription and translation in bacteria.
			6.4.A.3 Translation involves many sequential steps, including initiation, elongation, and termination. The salient features of translation include:	17.4	Building a Polypeptide

			i. Translation is initiated when the rRNA in the ribosome interacts with the mRNA at the start codon (AUG, coding for the amino acid methionine). ii. The sequence of nucleotides on the mRNA is read in triplets, called codons. iii. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids are encoded by more than one codon. iv. Nearly all living organisms use the same genetic code, which is evidence for the common ancestry of all living organisms. v. tRNA brings the correct amino acid to the place specified by the codon on the mRNA. vi. The amino acid is transferred to the growing polypeptide chain. vii. The process continues along the mRNA until a stop codon is reached. viii. Translation terminates with the release of the newly synthesized protein. **EXCLUSION STATEMENT**—The details and names of the enzymes and factors involved in each of these steps are beyond the scope of the AP Exam. **EXCLUSION STATEMENT**—Memorization of the genetic code, with the exception of the start codon AUG, is beyond the scope of the AP Exam.		

			6.4.A.4 Genetic information in retroviruses is a special case and has an alternate flow of information: from RNA to DNA, made possible by reverse transcriptase, an enzyme that copies the viral RNA genome into DNA. This DNA integrates into the host genome and is transcribed and translated for the assembly of new viral progeny.	19.2	Viral Genetic Material
Regulation of Gene Expression	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information	6.5.A Describe the types of interactions that regulate gene expression.	6.5.A.1 Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription. Some genes are constitutively expressed, and others are inducible.	18.1	Concept 18.1: Bacteria often respond to environmental change by regulating transcription.
			6.5.A.2 Epigenetic changes can affect gene expression through reversible modifications of DNA or histones.	18.2	Epigenetic Inheritance

	essential to life processes.		6.5.A.3 The phenotype of a cell or an organism is determined by the combination of genes that are expressed and the levels at which they are expressed. i. Observable cell differentiation results from the expression of genes for tissue-specific proteins. ii. Induction of transcription factors during development results in sequential gene expression. iii. The function and amount of gene products determine the phenotype of organisms.	18.4	Concept 18.4: A program of differential gene expression leads to the different cell type in a multicellular organism.
		6.5.B Explain how the location of regulatory sequences relates to their function.	6.5.B.1 Both prokaryotes and eukaryotes have groups of genes that are coordinately regulated. i. Prokaryotes regulate operons in an inducible or repressible system.	18.1	Operons: The Basic Concept
			ii. In eukaryotes, groups of genes may be influenced by the same transcription factors to coordinately regulate expression.	18.2	Concept 18.2: Eukaryotic gene expression is regulated at many stages
Gene Expression and Cell Specialization	BIG IDEA 3 Information Storage and Transmission: Living systems	6.6.A Explain how the binding of transcription factors to promoter regions	6.6.A.1 RNA polymerase and transcription factors bind to promoter or enhancer DNA sequences to initiate transcription. These sequences can be upstream or downstream of the	18.2	Organization of a Typical Eukaryotic Gene and Its Transcript

	store, retrieve, transmit, and respond to information essential to life processes.	affects gene expression and the phenotype of the organism.	transcription start site.		
			6.6.A.2 Negative regulatory molecules inhibit gene expression by binding to DNA and blocking transcription.	18.2	Regulation of Transcription Initiation
		6.6.B Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.	6.6.B.1 Gene regulation results in differential gene expression and influences cell products and functions.	18.2	Differential Gene Expression
			6.6.B.2 Certain small RNA molecules have roles in regulating gene expression.	18.3	Effects on mRNAs by MicroRNAs and Small Interfering RNAs

Mutations	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	6.7.A Describe the various types of mutation.	6.7.A.1 Alterations in a DNA sequence are mutations that can cause changes in the type or amount of the protein produced and the consequent phenotype. DNA mutations can be beneficial, detrimental, or neutral based on the effect or the lack of effect they have on the resulting nucleic acid or protein and the phenotypes that are conferred by the protein. i. Point mutations occur when one nucleotide has been substituted for a different nucleotide. ii. Frameshift mutations occur when one or more nucleotides are inserted or deleted, causing the reading frame to be shifted. iii. Nonsense mutations occur when there is a point mutation that causes a premature stop. iv. Silent mutations occur when the change in the nucleotide sequence has no effect on the amino acid sequence. **EXCLUSION STATEMENT**—Knowledge of specific mutations and their effects is beyond the scope of the AP Exam.	17.5	Concept 17.5: Mutations of one or a few nucleotides can affect protein structure and function

		6.7.B Explain how changes in genotype may result in changes in phenotype.	6.7.B.1 Errors in DNA replication or DNA repair mechanisms as well as external factors, including radiation and reactive chemicals, can cause random mutations in the DNA. i. Whether a mutation is beneficial, detrimental, or neutral depends on the environmental context. ii. Mutations are a source of genetic variation.	17.5	New Mutations and Mutagens
			6.7.B.2 Errors in mitosis or meiosis can result in changes in phenotype. i. Changes in chromosome number resulting from nondisjunction often result in new phenotypes caused by triploidy (aneuploidy). ii. Changes in chromosome number often result in disorders with developmental limitations. iii. Alterations in chromosome structure lead to genetic disorders. **EXCLUSION STATEMENT**—Knowledge of specific disorders related to changes in chromosome number is beyond the scope of the AP Exam.	15.4	Concept 15.4: Alterations of chromosome number or structure cause some genetic disorders

		6.7.C Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.	6.7.C.1 Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected for by environmental conditions. i. The horizontal acquisitions of genetic information in prokaryotes via transformation (uptake of DNA), transduction (viral transmission of genetic information), conjugation (cell-to-cell transfer of DNA), and transposition (movement of DNA segments within and between DNA molecules) increase genetic variation.	27.2	Genetic Recombination
			ii. Related viruses can recombine genetic information if they infect the same host cell.	19.3	Emerging Viral Diseases

			iii. Reproductive processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.	23.1	Concept 23.1: Genetic variation makes evolution possible
Biotechnology	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	6.8.A Explain the use of genetic engineering techniques in analyzing or manipulating DNA.	6.8.A.1 Genetic engineering techniques can be used to analyze and manipulate DNA and RNA. i. Gel electrophoresis is a process that separates DNA fragments by size and charge. ii. During polymerase chain reaction (PCR), DNA fragments are amplified by denaturing DNA, annealing primers to the original strand, and extending the new DNA molecule. iii. Bacterial transformation introduces foreign DNA into bacterial cells. iv. DNA sequencing technology determines the order of nucleotides in a DNA molecule. Typically, these techniques result in a DNA fingerprint that allows for the comparison of DNA sequences from various samples. **EXCLUSION STATEMENT**—Knowledge of the details of each of these genetic engineering techniques is beyond the scope of the AP Exam.	20.1	Concept 20.1: DNA sequencing and DAN cloning are valuable tools for genetic engineering and biological inquiry
Introduction to Natural Selection	BIG IDEA 1 Evolution: The process	7.1.A Describe the causes	7.1.A.1 Natural selection is a major mechanism of evolution.	22.2	Key Features of Natural Selection

	of evolution drives the diversity and unity of life.	of natural selection.	7.1.A.2 According to Darwin's theory of natural selection, competition for limited resources results in differential survival. Individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing on those favorable traits to subsequent generations.	22.2	Ideas from the Origin of Species
		7.1.B Explain how natural selection affects populations.	7.1.B.1 Evolutionary fitness is measured by reproductive success.	23.1	Genetic variation makes evolution possible
			7.1.B.2 Biotic and abiotic environments can fluctuate, affecting the rate and direction of evolution. Different genetic variations can be selected in each generation.	23.3 52.4	Natural selection, genetic drift, and gene flow can alter allele frequencies in a population Biotic Factors Abiotic Factors
Natural Selection	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life.	7.2.A Describe the importance of phenotypic variation in a population.	7.2.A.1 Natural selection acts on phenotypic variations in populations.	23.3	Natural Selection
			7.2.A.2 Environments change and apply selective pressures to populations.	23.3	Natural Selection
			7.2.A.3 Some phenotypic variations can increase or decrease the fitness of an organism in particular environments.	23.3	Natural Selection
		7.2.B Explain how variation in molecules within cells	7.2.B.1 Variation in the number and types of molecules within cells can provide	23.1	Concept 23.1: Genetic variation makes evolution possible

		connects to the fitness of an organism.	populations a greater ability to survive and reproduce in different environments.	23.4	Relative Fitness
Artificial Selection	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life.	7.3.A Explain how humans can affect diversity within a population.	7.3.A.1 Through artificial selection, humans affect variation in other species.	22.2	Artificial Selection, Natural Selection, and Adaptation
Population Genetics	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life. LEARNING	7.4.A Explain how random occurrences affect the genetic makeup of a population.	7.4.A.1 Evolution is also driven by random occurrences. i. Mutation is a random process that adds new genetic variation to a population.	23.1	Sources of Genetic Variation
			ii. Genetic drift is a change in allele frequencies attributable to a nonselective process occurring in small populations. iii. The bottleneck effect is a type of genetic drift that occurs when a population size is reduced to a small number of individuals for at least one generation. iv. The founder effect is a type of genetic drift that occurs when a population is separated from other members of the population. The frequency of genes and traits will shift based on the genes in this new founder population.	23.3	Concept 23.3: Natural selection, genetic drift, and gene flow can alter allele frequencies in a population
			v. Migration can result in gene flow (the addition or removal of alleles from a population).	23.3	Gene Flow

		7.4.B Describe the role of random processes in the evolution of specific populations.	7.4.B.1 Random processes can lead to changes in allele frequencies in a population. i. Mutations result in genetic variation, which provides phenotypes on which natural selection acts. ii. Genetic drift can allow a small population to diverge from other populations of the same species. iii. Gene flow between two populations prevents them from diverging into separate species.	23.3	Genetic Drift Gene Flow
		7.4.C Describe the change in the genetic makeup of a population over time.	7.4.C.1 Changes in allele frequencies provide evidence for the occurrence of evolution in a population.	23.3 23.2	Natural Selection Concept 23.2: The Hardy-Weinberg equation can be used to test whether a population is evolving
Hardy–Weinberg Equilibrium	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life.	7.5.A Describe the conditions under which allele and genotype frequencies will change in populations.	7.5.A.1 The Hardy–Weinberg Equilibrium is a model for describing and predicting allele frequencies in a non-evolving population. Conditions for a population or an allele to be in Hardy–Weinberg equilibrium are: i. A large population size ii. No migration iii. No new mutations iv. Random mating v. No natural selection	23.2	The Hardy-Weinberg Equation

			These conditions are never met, but they provide a valuable null hypothesis.		
			7.5.A.2 Allele frequencies in a nonevolving population can be calculated from genotype frequencies. **RELEVANT EQUATIONS** Hardy–Weinberg Equation— $p^2+2pq+q^2=1$ $p+q=1,$ where: p = frequency of allele 1 in the population q = frequency of allele 2 in the population	23.2	The Hardy-Weinberg Equation
Evidence of Evolution	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life.	7.6.A Describe the types of data that provide evidence for evolution.	7.6.A.1 Evolution is supported by scientific evidence from many disciplines (geographical, geological, physical, biochemical, and mathematical data).	22.3	Concept 22.3: Evolution is supported by an overwhelming amount of scientific evidence
		7.6.B Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.	7.6.B.1 Molecular, morphological, and genetic evidence from extant and extinct organisms adds to our understanding of evolution. i. Fossils can be dated by a variety of methods. These include 1) the age of the rocks where a fossil is found; 2) the rate of decay of isotopes including carbon-14; and 3) geographical data.	22.3	The Fossil Record
			ii. Morphological homologies, including vestigial structures, provide evidence of common ancestry.	22.3	Homology

			7.6.B.2 A comparison of DNA nucleotide sequences and protein amino acid sequences provides evidence for evolution and common ancestry.	22.3	Figure 22.17 Tree thinking: information provided in an evolutionary tree.
Common Ancestry	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life.	7.7.A Describe structural and functional evidence on cellular and molecular levels that provides evidence for the common ancestry of all eukaryotes.	7.7.A.1 Structural and functional evidence indicates common ancestry of all eukaryotes. This evidence includes: i. Membrane-bound organelles ii. Linear chromosomes iii. Genes that contain introns	28.1 27.1 21.3	Endosymbiosis in Eukaryotic Evolution Internal Organization and DNA Genomes vary in size, number of genes, and gene density
Continuing Evolution	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life.	7.8.A Explain how evolution is an ongoing process in all living organisms.	7.8.A.1 All species have evolved and continue to evolve. Examples include: i. Genomic changes over time	21.5	Concept 21.5: Duplication, rearrangement, and mutation of DNA contribute to genome evolution
			ii. Continuous change in the fossil record	25.4	Figure 25.1
			iii. Evolution of resistance to antibiotics, pesticides, herbicides, or chemotherapy drugs	22.3	The Evolution of Drug-Resistant Bacteria
			iv. Pathogens evolving and causing emergent diseases	19.3	Concept 19.3: Viruses and prions are formidable pathogens in animals and plants

Phylogeny	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life.	7.9.A Describe the types of evidence that can be used to infer an evolutionary relationship.	7.9.A.1 Phylogenetic trees and cladograms show hypothetical evolutionary relationships among lineages that can be tested.	26.1	Concept 26.1: Phylogenies show evolutionary relationships
			7.9.A.2 Phylogenetic trees show the amount of change over time calibrated by fossils or a molecular clock, whereas cladograms do not show time scale or the evolutionary difference between groups.	26.2 26.3	Concept 26.2: Phylogenies are inferred from morphological and molecular data Concept 26.3: Shared characteristics are used to construct phylogenetic trees
			7.9.A.3 Traits that are either gained or lost during evolution can be used to construct phylogenetic trees and cladograms. The out-group represents the lineage that is least closely related to the remainder of the organisms in the phylogenetic tree or cladogram. i. Shared derived characters can be present in more than one lineage and indicate common ancestry. These are informative for the construction of phylogenetic trees and cladograms. ii. Molecular data typically provide more accurate and reliable evidence than morphological traits in the construction of phylogenetic trees or cladograms.	26.5 26.6	Concept 26.5: Molecular clocks help track evolutionary time Concept 26.6: Our understanding of the tree of life continues to change based on new data

		7.9.B Explain how phylogenetic trees and cladograms can be used to infer evolutionary relatedness.	7.9.B.1 Phylogenetic trees and cladograms can be used to illustrate speciation that has occurred. The nodes on a tree represent the most recent common ancestor of any two groups or lineages.	26.1	Concept 26.1: Phylogenies show evolutionary relationships
			7.9.B.2 Phylogenetic trees and cladograms can be constructed from morphological similarities of living or fossil species and from DNA and protein sequence similarities.	26.3	Concept 26.3 Shared characters are used to construct phylogenetic trees
			7.9.B.3 Phylogenetic trees and cladograms represent hypotheses that are constantly being revised based on evidence.	26.3	Phylogenetic Trees as Hypotheses
Speciation	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life.	7.10.A Describe the conditions under which new species may arise.	7.10.A.1 Speciation occurs when two populations become reproductively isolated from each other.	24.1	Concept 24.1: The biological species concept emphasizes reproductive isolation
			7.10.A.2 The biological species concept provides a commonly used definition of a species for sexually reproducing organisms. It states that species can be defined as a group capable of interbreeding and exchanging genetic information to produce viable, fertile offspring.	24.1	The Biological Species Concept

		7.10.B Describe the rate of evolution and speciation under different ecological conditions.	7.10.B.1 Punctuated equilibrium is when evolution occurs rapidly after a long period of stasis. Gradualism is when evolution occurs slowly over hundreds of thousands or millions of years.	24.4	Patterns in the Fossil Record
			7.10.B.2 Divergent evolution occurs when adaptation to new habitats results in phenotypic diversification. Speciation rates can be especially rapid during times of adaptive radiation as new habitats become available.	24.2 21.5	Inquiry: Can divergence of allopatric populations lead to reproductive isolation? Reading an Amino Acid Sequence Identity Table
			7.10.B.3 Convergent evolution occurs when similar selective pressures result in similar phenotypic adaptations in different populations or species.	22.3	A Different Cause of Resemblance: Convergent Evolution
		7.10.C Explain the processes and mechanisms that drive speciation.	7.10.C.1 Sympatric speciation occurs in populations with geographic overlap. Allopatric speciation occurs in populations that are geographically isolated.	24.2	Concept 24.2: Speciation can take place with or without geographic separation

			7.10.C.2 Various pre-zygotic and post-zygotic mechanisms can maintain reproductive isolation and prevent gene flow between populations.	24.1	Figure 24.3: Exploring Reproductive Barriers
Variations in Populations	BIG IDEA 4 Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	7.11.A Explain how the genetic diversity of a species or population affects its ability to withstand environmental pressures.	7.11.A.1 The level of variation in a population affects population dynamics. i. The ability of a population to respond to changes in the environment is influenced by genetic diversity. Species and populations with little genetic diversity are at risk of decline or extinction.	21.5	How Transposable Elements Contribute to Genome Evolution Over many generations, the resulting genetic diversity provides valuable raw material for natural selection.
			ii. Genetically diverse populations are more resilient to environmental perturbation because they are more likely to contain individuals that can withstand the environmental pressure.	23.4	The Key Role of Natural Selection in Adaptive Evolution
			iii. Alleles that are adaptive in one environmental condition may be deleterious in another because of different selective pressures.	23.4	Figure 23.13: Modes of selection.

Origins of Life on Earth	BIG IDEA 4 Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	7.12.A Describe the scientific evidence that supports models of the origin of life on Earth.	7.12.A.1 The origin of life on Earth is supported by scientific evidence. i. Geological evidence reinforces models of the origin of life on Earth. ii. Earth formed approximately 4.6 billion years ago (bya). The environment was too hostile for life until about 3.9 bya, and the earliest fossil evidence for life dates to 3.5 bya. Taken together, this evidence provides a plausible range of dates for the origin of life.	25.1, 25.2, 25.3, 25.4, 25.5, 25.6	Chapter 25: The History of Life on Earth
			7.12.A.2 The RNA world hypothesis proposes that RNA could have been the earliest genetic material. There are three assumptions: i. At some point in time, genetic continuity was assured by the replication of RNA. ii. Base-pairing is necessary for replication. iii. Genetically encoded proteins were not involved as catalysts.	25.1	Thus, life as we know it may have been preceded by an "RNA world," in which small RNA molecules were able to replicate and to store genetic information about the vesicles that carried them.
Responses to the Environment	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce,	8.1.A Explain how the behavioral and physiological response of an organism is related to changes in internal or	8.1.A.1 Organisms respond to changes in their environment through behavioral and physiological mechanisms. **EXCLUSION STATEMENT**—Knowledge of specific behavioral or physiological mechanisms is beyond the scope of the AP Exam.	40.3 51.1	Homeostatic processes for thermoregulation involve form, function, and behavior Concept 51.1: Discrete sensory input can stimulate

	and maintain dynamic homeostasis.	external environment.		39.3	both simple and complex behaviors Photoperiodism and Responses to Seasons
			8.1.A.2 Organisms exchange information with one another in response to internal changes and external cues, which can change behavior.	40.3 39.5	Behavioral Responses Figure 39.27: Levels of Plant Defences Against Herbivores
	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	8.1.B Explain how the behavioral responses of organisms affect their overall fitness and may contribute to the success of a population.	8.1.B.1 Organisms communicate through various mechanisms (visual, audible, tactile, electrical, and/or chemical signals). i. Organisms have a variety of signaling behaviors that produce changes in the behavior of other organisms and can result in differential reproductive success. ii. Animals use signals to indicate dominance, find food, establish territory, and ensure reproductive success. **EXCLUSION STATEMENT**—Knowledge of specific mechanisms of communication is beyond the scope of the AP Exam.	51.1	Concept 51.1: Animal Signals and Communication
			8.1.B.2 Responses to information and	51.3	Concept 51.3: Selection for

			communication of information are vital to natural selection and evolution. i. Fitness favors innate and learned behaviors that increase survival and reproductive success. ii. Cooperative behavior tends to increase the fitness of the individual and the survival of the population. **EXCLUSION STATEMENT**—The details of the various communications and community behavioral systems are beyond the scope of the AP Exam.		individual survival and reproductive success can explain diverse behaviors
Energy Flow Through Ecosystems	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	8.2.A Describe the strategies organisms use to acquire and use energy.	8.2.A.1 Organisms use energy to organize, grow, reproduce, and maintain homeostasis. i. Organisms use different strategies to regulate body temperature and metabolism. Endotherms use thermal energy generated by metabolism to maintain homeostatic body temperatures. Ectotherms lack efficient internal mechanisms for maintaining body temperature, although they may regulate their temperature behaviorally by moving into the sun or shade or by aggregating with other individuals.	40.3 40.4	Concept 40.3: Homeostatic processes for thermoregulation involve forms, function, and behavior. Concept 40.4: Energy requirements are related to animal size activity, and environment
			ii. A net gain in energy results in energy storage, the growth of an organism, and increased reproductive output. iii. A net loss of energy results in loss of mass, a decrease in reproductive output, and, eventually, the death of an organism.	40.4	How Do Energy Budgets Differ for Three Terrestrial Vertebrates?

				40.4	Figure 40.18: Bioenergetics of an animal: an overview
			8.2.A.2 Different organisms use various reproductive strategies in response to energy availability. Some organisms alternate between asexual and sexual reproduction in response to energy availability.	38.2	Advantages and Disadvantages of Asexual and Sexual Reproduction
		8.2.B Explain how energy flows and matter cycles through trophic levels.	8.2.B.1 Ecological levels of organization include populations, communities, ecosystems, and biomes.	1.1	Theme: New Properties Emerge at Successive Levels of Biological Organization
			8.2.B.2 Energy flows through ecosystems, while matter and nutrients cycle between the environment and organisms via biogeochemical cycles. The cycles are essential for life, and each cycle demonstrates the conservation of matter. The cycles are interdependent.	55.4	Concept 55.4: Biological and geochemical processes cycle nutrients and water in ecosystems
			8.2.B.3 Biogeochemical cycles include abiotic and biotic reservoirs, as well as processes that cycle matter between reservoirs.	55.4	Biogeochemical Cycles

			8.2.B.4 The hydrologic (water) cycle involves water movement and storage within the hydrosphere. Reservoirs include oceans, surface water, the atmosphere, and living organisms. Processes include evaporation, condensation, precipitation, and transpiration.	55.4	Figure 55.14 Exploring Water and Nutrient Cycling
			8.2.B.5 The carbon cycle involves recycling carbon atoms through Earth's biosphere into organisms as carbohydrates and back into the atmosphere as carbon dioxide (CO_2). At the highest levels of organization, the carbon cycle can be simplified into four parts: photosynthesis, cellular respiration, decomposition, and combustion.	55.4	Figure 55.14 Exploring Water and Nutrient Cycling
			8.2.B.6 The nitrogen cycle involves several steps, including nitrogen fixation, assimilation, ammonification, nitrification, and denitrification. These steps are performed by microorganisms in the soil. The largest reservoir of nitrogen is the atmosphere. In nitrogen fixation, nitrogen gas (N_2) is fixed into ammonia (NH_3), which ionizes to ammonium (NH_+)	55.4	Figure 55.14 Exploring Water and Nutrient Cycling

			4 by acquiring hydrogen ions from the soil solution.		
			8.2.B.7 The phosphorus cycle involves weathering rocks releasing phosphate (PO_4^{3-}) into soil and groundwater. Producers take in phosphate, which is incorporated into biological molecules; consumers eat producers, transferring phosphate to animals. Phosphorus returns to the soil via decomposition of biomass, or excretion. Phosphate can also be incorporated back into the environment via decomposition of decaying organic matter.	55.4	Figure 55.14 Exploring Water and Nutrient Cycling
		8.2.C Explain how changes in energy availability affect populations,	8.2.C.1 Changes in energy availability can result in changes in population size.	54.2	Concept 54.2: Diversity and trophic structure characterize biological communities

		communities, and ecosystems.	8.2.C.2 Changes in energy availability can result in disruptions to an ecosystem. i. A change in energy resources such as sunlight can affect the number and size of the trophic levels. Trophic levels include producers; primary, secondary, tertiary, and quaternary consumers; and decomposers. ii. A change in the biomass or number of producers in a given geographic area can affect the number and size of other trophic levels.	54.2	Trophic Structure
		8.2.D Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.	8.2.D.1 Autotrophs capture energy from physical or chemical sources in the environment. i. Photosynthetic organisms capture energy present in sunlight contributing to primary productivity. ii. Chemosynthetic organisms capture energy from small inorganic molecules present in their environment, which can occur in the absence of oxygen.	55.1	Energy, Mass, and Trophic Levels
			8.2.D.2 Heterotrophs, which include carnivores, herbivores, omnivores, decomposers, and scavengers, metabolize carbohydrates, lipids, and proteins as sources of energy. Heterotrophs capture the energy present in carbon compounds by consuming organic matter derived from autotrophs incorporating matter into their tissues.	55.1	Energy, Mass, and Trophic Levels

Population Ecology	BIG IDEA 3 Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	8.3.A Describe factors that influence growth dynamics of populations.	8.3.A.1 Populations comprise individual organisms of the same species that interact with one another and with the environment in complex ways.	53.1	A population is a group of individuals of a single species living in the same general area.
			8.3.A.2 Many adaptations in organisms are related to obtaining and using energy and matter in a particular environment. i. Population growth dynamics depend on birth rate, death rate, and population size. **RELEVANT EQUATION** Population Growth— $\frac{dN}{dt} = B - D$ where dt = chage in time B = birth rate D = death rate N = population size dN = change in population size ii. Reproduction without constraints results in the exponential growth of a population. **RELEVANT EQUATION** Exponential Growth— $\frac{dN}{dt} = r_{max}N$ where dt = change in time N = population size dN = change in population size r_{max} = maximum per capita growth rate of population	53.2	Concept 53.2: The exponential model describes population growth in an idealized, unlimited environment

Effect of Density on Populations	BIG IDEA 4 Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	8.4.A Explain how the density of a population affects and is determined by resource availability in the environment.	8.4.A.1 Carrying capacity is the sustainable abundance of a species that can be supported by the ecosystem's total available resources.	53.3	Concept 53.3: The logistic model describes how a population grows more slowly as it nears its carrying capacity
			8.4.A.2 As limits to growth attributable to density dependent and density-independent factors are imposed, a logistic growth model t **RELEVANT EQUATION** Logistical Growth— $\frac{dN}{dt} = r_{max} N \left(\frac{K - N}{K} \right)$ where dt = change in time N = population size dN = change in population size r_{max} = maximum per capita growth rate of population K = carrying capacity	53.3	The Logistic Growth Model
Community Ecology	BIG IDEA 2 Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain	8.5.A Describe the structure of a community according to its species composition and diversity.	8.5.A.1 The structure of a community is measured and described in terms of species composition and species diversity. **RELEVANT EQUATION** Simpson's Diversity Index— $\text{Diversity Index} = 1 - \Sigma \left(\frac{n}{N} \right)^2$ where n = total number of organisms of a particular species N = total number of organisms of all species	54.2	Concept 54.2: Diversity and trophic structure characterize biological communities

	dynamic homeostasis.	8.5.B Explain how interactions within and among populations influence community structure.	8.5.B.1 Communities are groups of interacting populations of different species that change over time based on the interactions between those populations.	54.1	Concept 54.1: Interactions between species can help, harm, or have no effect on the individuals involved
			8.5.B.2 Interactions among populations determine how they access energy and matter within a community.	54.1	Concept 54.1: Interactions between species can help, harm, or have no effect on the individuals involved
			8.5.B.3 Relationships among interacting populations can be characterized by positive and negative effects and can be modeled. Examples include predator/prey interactions, cooperation, trophic cascades, and niche partitioning.	54.1	Concept 54.1: Interactions between species can help, harm, or have no effect on the individuals involved
			8.5.B.4 Competition, predation, and symbioses, including parasitism, mutualism, and commensalism, can drive population dynamics.	54.1	Interactions between species can help, harm, or have no effect on the individuals involved
Biodiversity	Systems Interactions: Biological systems interact, and these systems and their interactions exhibit	8.6.A Describe the relationship between ecosystem diversity and its resilience to changes in the environment.	8.6.A.1 Natural and artificial ecosystems with fewer component parts, and with little diversity among the parts, are often less resilient to changes in the environment.	54.3	Concept 54.3: Disturbance influences species diversity and composition
			8.6.A.2 Keystone species, producers, and essential abiotic and biotic factors contribute to maintaining the diversity of an ecosystem.	54.2	Species with a Large Impact

	complex properties.	8.6.B Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and longterm structure.	8.6.B.1 The effects of keystone species on the ecosystem are disproportionate relative to their abundance in the ecosystem. When they are removed from the ecosystem, it often collapses.	54.2	Species with a Large Impact.
Disruptions in Ecosystems	BIG IDEA 1 Evolution: The process of evolution drives the diversity and unity of life.	8.7.A Explain the interaction between the environment and random or preexisting variations in populations.	8.7.A.1 An adaptation is a genetic variation that is favored by selection and manifests as a trait that provides an advantage to an organism in a particular environment.	22.2	Descent with Modification Artificial Selection, Natural Selection, and Adaptation
			8.7.A.2 Heterozygote advantage is when the heterozygous genotype has a higher relative fitness than either the homozygous dominant or homozygous recessive genotype.	23.4	Heterozygote Advantage
			8.7.A.3 Mutations are not directed by specific environmental pressures.	23.1	Sources of Genetic Variation
	BIG IDEA 4 Systems Interactions: Biological systems interact, and these	8.7.B Explain how invasive species affect ecosystem dynamics.	8.7.B.1 The intentional or unintentional introduction of an invasive species can allow the species to exploit a new niche free of predators or competitors or to outcompete native species for resources.	56.1	Introduced Species

	systems and their interactions exhibit complex properties.	8.7.C Describe human activities that lead to changes in ecosystem structure and dynamics.	8.7.C.1 Human impact accelerates changes at local and global levels. These activities can drive changes in ecosystems, such as the following, that cause extinctions to occur: i. Biomagnification ii. Eutrophication	56.1 52.2 56.4	Concept 56.1: Human activities threaten earth's biodiversity Concept 52.2: The distribution of terrestrial biomes is controlled by climate and disturbance Toxins in the Environment
		8.7.D Explain how geological and meteorological activity leads to changes in ecosystem structure and dynamics.	8.7.D.1 Geological and meteorological events affect habitat change and ecosystem distribution. Biogeographical studies illustrate these changes.	52.1, 52.2 52.2 52.5	Global Climate Change Figure 52.13 Exploring Terrestrial Biomes Ecological change and evolution affect one another over long and short periods of time