AP BIOLOGY

UNIT 3

Cellular Energetics

12–16%
AP EXAM WEIGHTING

~12–14
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Progress Checks** for this unit.

Whether assigned as homework or completed in class, the **Progress Checks** provide each student with immediate feedback related to this unit's topic and skills.

Progress Check 3

Multiple-choice: ~19 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing (partial)
- Scientific Investigation (partial)

UNIT 3

12–16% AP EXAM WEIGHTING | **~12–14** CLASS PERIODS

Cellular Energetics

BIG IDEA 2
Energetics
- How is energy captured and then used by a living system?

Developing Understanding

In Unit 3, students build on knowledge gained in Unit 2 about the structure and function of cells, focusing on cellular energetics. Living systems are complex in their organization and require constant energy input. This unit provides students with the knowledge necessary to master the concepts of energy capture and usage. Students work through enzyme structure and function, learning the ways in which the environment plays a role in how enzymes perform their function(s). Students gain a deeper understanding of the processes of photosynthesis and cellular respiration, which is knowledge they will use in Unit 6 while studying how cells use energy to fuel life processes.

Building Science Practices

1.B 3.C 4.A 6.B 6.C 6.E

Since students learned how to make scientific claims in the previous unit, the instructional focus of this unit should be on gaining proficiency in argumentation through supporting claims with evidence. The evidence can be from biological principles, concepts, processes, and/or data. Students should provide reasoning to justify a claim by connecting evidence to biological theories.

A key concept in this unit is structure–function relationships. This concept should be reinforced in context as students proceed through the course. It is important that students understand rates of enzyme reactions and how they are affected by environmental factors, such as enzyme or substrate concentration, pH, temperature, and the presence of inhibitors.

As students learn about cellular respiration and photosynthesis, be sure to emphasize the differences between the two processes, how they function together within an ecosystem, and the consequences of a disruption in either process on a cellular, organismal, and ecosystem level.

Preparing for the AP Exam

Students often lack an understanding of metabolic pathways, confusing them with other processes. Students should know inputs and outputs of metabolic pathways, be able to predict how changes in reactants affect them, and be able to explain how organisms and ecosystems are affected by changes.

Common misconceptions include the following: only animals conduct cellular respiration, oxygen is created during photosynthesis, and only plants conduct photosynthesis. Be sure to make clear the distinction between memorizing molecules and demonstrating an understanding of how molecular events connect to overall function of organisms and to carbon transfer within ecosystems. Students should have an understanding of cellular respiration and photosynthesis in order to predict and justify the effect of environmental changes on those processes.

On the exam, students may be required to graph data from an experiment—using the skills learned in Unit 2—and calculate reaction rates. Students are advised to show their calculations, ensuring that units are included in their final answer.

UNIT AT A GLANCE

Topic	Suggested Skills	Class Periods **~12–14** CLASS PERIODS
3.1 Enzymes	**1.B** Explain biological concepts and processes. **3.C** Identify experimental procedures that align with the question, including: i. identifying dependent and independent variables ii. identifying appropriate controls iii. justifying appropriate controls	
3.2 Environmental Impacts on Enzyme Function	**6.E** Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
3.3 Cellular Energy	**6.C** Provide reasoning to justify a claim by connecting evidence to biological theories.	
3.4 Photosynthesis	**6.B** Support a claim with evidence from biological principles, concepts, processes, and data.	
3.5 Cellular Respiration	**4.A** Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components: i. the type of graph appropriate for the data ii. axis labeling, including appropriate units and legend iii. scaling iv. accurately plotted data (including error bars when appropriate) v. trend line (when appropriate)	

Go to **AP Classroom** to assign the **Progress Check** for Unit 3.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are encouraged to adapt the activities to best support students in your classroom. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	3.2	**Error Analysis** Perform the "toothpickase" activity with students by placing 100 toothpicks onto a paper towel and asking them to use their fingers to break as many toothpicks as they can in 10-second intervals (without looking). Students should keep both the broken and unbroken toothpicks mixed together on the paper towel. Each toothpick can only be broken once. Have them continue breaking toothpicks for time intervals of 60, 120, and 180 seconds. Students then graph the number of toothpicks broken at each time interval. Once they have graphed their own data, allow students to pair up and compare graphs to determine whether errors have occurred based on expected outcomes in enzyme catalysis.
2	3.4	**Construct an Argument** Provide students with a visual representation of photosystems I and II and have them work in pairs to construct an argument about whether (or why) plants need both photosystems for photosynthesis to occur.
3	3.5	**Graph and Switch** Have students perform a yeast fermentation lab using the sucrose solutions from the Diffusion and Osmosis lab found in the AP Biology lab manual. Students should measure the amount of carbon dioxide produced as the dependent variable. At the conclusion of the lab, collect class data. Have students graph the class data, including error bars on their graphs.

SUGGESTED SKILLS

Concept Explanation

1.B

Explain biological concepts and processes.

Questions and Methods

3.C

Identify experimental procedures that align with the question, including:

i. identifying dependent and independent variables

ii. identifying appropriate controls

iii. justifying appropriate controls

TOPIC 3.1
Enzymes

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

3.1.A

Explain how enzymes affect the rate of biological reactions.

ESSENTIAL KNOWLEDGE

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.

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.

TOPIC 3.2

Environmental Impacts on Enzyme Function

SUGGESTED SKILL

Argumentation

6.E

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

AVAILABLE RESOURCES

- AP Central > AP Biology Lab Manual > Enzyme Lab
- AP Central > Classroom Resources > Visualizing Information

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
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. **3.2.A.2** In some cases, enzyme denaturation is reversible, allowing the enzyme to regain activity.
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.

LEARNING OBJECTIVE

3.2.B
Explain how the cellular environment affects enzyme activity.

ESSENTIAL KNOWLEDGE

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.

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.

TOPIC 3.3
Cellular Energy

SUGGESTED SKILL

Argumentation

6.C

Provide reasoning to justify a claim by connecting evidence to biological theories.

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

3.3.A

Describe the role of energy in living organisms.

ESSENTIAL KNOWLEDGE

3.3.A.1

All living systems require an input of energy.

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.*

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.

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LEARNING OBJECTIVE

3.3.B

Explain how shared, conserved, and fundamental processes and features support the concept of common ancestry for all organisms.

ESSENTIAL KNOWLEDGE

3.3.B.1

Core metabolic pathways (e.g., glycolysis, oxidative phosphorylation) are conserved across all currently recognized domains (Archaea, Bacteria, and Eukarya).

TOPIC 3.4
Photosynthesis

SUGGESTED SKILL

Argumentation

6.B

Support a claim with evidence from biological principles, concepts, processes, and data.

AVAILABLE RESOURCES

- AP Central > AP Biology Lab Manual > Photosynthesis Lab
- AP Central > Classroom Resources > Visualizing Information

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

3.4.A

Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy.

EXCLUSION STATEMENT— *Memorization of the steps in the Calvin cycle, the structure of the molecules, and the names of the enzymes involved, with the exception of ATP synthase, is beyond the scope of the AP Exam.*

ESSENTIAL KNOWLEDGE

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 were the foundation of eukaryotic photosynthesis.

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LEARNING OBJECTIVE

3.4.A

Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy.

EXCLUSION STATEMENT— *Memorization of the steps in the Calvin cycle, the structure of the molecules, and the names of the enzymes involved, with the exception of ATP synthase, is beyond the scope of the AP Exam.*

ESSENTIAL KNOWLEDGE

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.

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.

LEARNING OBJECTIVE

3.4.B

Explain how cells capture energy from light and transfer it to biological molecules for storage and use.

ESSENTIAL KNOWLEDGE

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.*

3.4.B.2

During photosynthesis, 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.

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LEARNING OBJECTIVE

3.4.B

Explain how cells capture energy from light and transfer it to biological molecules for storage and use.

ESSENTIAL KNOWLEDGE

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.

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.

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.

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.

SUGGESTED SKILL

Representing and Describing Data

4.A

Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components:

i. the type of graph appropriate for the data

ii. axis labeling, including appropriate units and legend

iii. scaling

iv. accurately plotted data (including error bars when appropriate)

v. trend line (when appropriate)

AVAILABLE RESOURCES

- AP Central > AP Biology Lab Manual > Cellular Respiration Lab
- AP Central > Classroom Resources > Visualizing Information

TOPIC 3.5

Cellular Respiration

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

3.5.A

Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules.

ESSENTIAL KNOWLEDGE

3.5.A.1

Cellular respiration uses energy from biological macromolecules to synthesize ATP. Respiration and fermentation are characteristic of all forms of life.

3.5.A.2

Aerobic cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that capture energy from biological macromolecules.

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 $FADH_2$ 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.

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LEARNING OBJECTIVE

3.5.A

Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules.

ENDURING UNDERSTANDING

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.

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.

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.*

3.5.B

Explain how cells obtain energy from biological macromolecules in 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.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.

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 $FADH_2$, and releasing CO_2.

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LEARNING OBJECTIVE

3.5.B

Explain how cells obtain energy from biological macromolecules in 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.*

ESSENTIAL KNOWLEDGE

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.

3.5.B.4

Electrons extracted in glycolysis and Krebs cycle reactions are transferred by NADH and $FADH_2$ to the ETC in the inner mitochondrial membrane.

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.

3.5.B.6

Fermentation allows glycolysis to proceed in the absence of oxygen and produces organic molecules such as alcohol and lactic acid.