Unit 04: Cellular Energetics

Content Area: **Science**
Course(s): **AP Biology**
Time Period: **November**
Length: **4 weeks**
Status: **Published**

Transfer Skills

In this unit, 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 will provide students with the knowledge necessary to master the concepts of energy capture and use. Students gain a deeper understanding of the processes of photosynthesis and cellular respiration, knowledge they will use in Unit 6 while studying how cells use energy to fuel life processes.

Students often lack an understanding of metabolic pathways, confusing them with other processes. Students should know inputs and outputs of metabolic pathways, predict how changes in reactants affect them, and explain how organisms and ecosystems are affected by changes. Common misconceptions include: 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 to predict and justify the effect of environmental changes on those processes. 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.

Enduring Understandings

The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

Naturally occurring diversity among and between components within biological systems affects interactions with the environment.

Essential Questions

How does the acquisition of energy relate to the health of a biological system?

How is energy captured and then used by a living system?

How do organisms use energy or conserve energy to respond to environmental stimuli?

Content

Pigments and photosynthesis

Photosynthesis: light reactions and Calvin Cycle

Cellular respiration (aerobic): glycolysis, Krebs (citric acid cycle), and ETC

Fermentation (aerobic respiration)

Respiration rates in endotherms vs. ecototherms and large vs. small mammals

Learning Objectives

ENE-1.H Describe the role of energy in living organisms.
ENE-1.I Describe the photosynthetic processes that allow organisms to capture and store energy.
ENE-1.J Explain how cells capture energy from light and transfer it to biological molecules for storage and use.
ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.
ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions
ENE-1.M Describe the strategies organisms use to acquire and use energy.
SYI-3.A Explain the connection between variation in the number and types of molecules within cells to the ability of the organism to survive and/or reproduce in different environments.

Standards

ENE-1.H.1 All living systems require constant input of energy
ENE-1.H.2 Life requires a highly ordered system and does not violate the second law of thermodynamics—
a. Energy input must exceed energy loss to maintain order and to power cellular processes.
b. Cellular processes that release energy may be coupled with cellular processes that require energy.
c. Loss of order or energy flow results in death.
X *Students will need to understand the concept of energy, but the equation for Gibbs free energy is beyond the scope of the course and the AP exam.*
ENE-1.H.3 Energy-related pathways in biological systems are sequential to allow for a more controlled and efficient transfer of energy. A product of a reaction in a metabolic pathway is generally the reactant for the subsequent step in the pathway
ENE-1.I.1 Organisms capture and store energy for use in biological processes—
a. Photosynthesis captures energy from the sun and produces sugars.
i. Photosynthesis first evolved in prokaryotic organisms

ii. Scientific evidence supports the claim that prokaryotic (cyanobacteria) photosynthesis was responsible for the production of an oxygenated atmosphere.

iii. Prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis.

ENE-1.I.2 The light-dependent 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.

ENE-1.J.1 During photosynthesis, chlorophylls absorb energy from light, boosting electrons to a higher energy level in photosystems I and II.

ENE-1.J.2 Photosystems I and II are embedded in the internal membranes of chloroplasts and are connected by the transfer of higher energy electrons through an electron transport chain (ETC).

ENE-1.J.3 When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) is established across the internal membrane.

ENE-1.J.4 The formation of the proton gradient is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase.

ENE-1.J.5 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, which occurs in the stroma of the chloroplast.

X *Memorization of the steps of the Calvin Cycle, the structure of the molecules, and the names of the enzymes (with the exception of ATP synthase) is beyond the scope of the course and the AP exam.*

ENE-1.K.1 Fermentation and cellular respiration use energy from biological macromolecules to produce ATP. Respiration and fermentation are characteristic of all forms of life.

ENE-1.K.2 Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that capture energy from biological macromolecules.

ENE-1.K.3 The electron transport chain transfers energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes—

a. Electron transport chain reactions occur in chloroplasts, mitochondria, and prokaryotic plasma membranes.

b. In cellular respiration, electrons delivered by NADH and FADH are passed to a series of electron acceptors as they move toward the terminal electron acceptor, oxygen. In photosynthesis, the terminal electron acceptor is NADP+. Aerobic prokaryotes use oxygen as a terminal electron acceptor, while anaerobic prokaryotes use other molecules.

c. The transfer of electrons is accompanied by the formation of a proton gradient across the inner mitochondrial membrane or the internal membrane of chloroplasts, with the membrane(s) separating a region of high proton concentration from a region of low proton concentration. In prokaryotes, the passage of electrons is accompanied by the movement of protons across the plasma membrane.

d. 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 cellular respiration, and photophosphorylation in photosynthesis.

e. In cellular respiration, decoupling oxidative phosphorylation from electron transport generates heat. This heat can be used by endothermic organisms to regulate body temperature.

X *The names of specific electron carriers in the electron transport chain are beyond the scope of the course and the AP exam.*

ENE-1.L.1 Glycolysis is a biochemical pathway that releases energy in glucose to form ATP from ADP and inorganic phosphate, NADH from NAD+, and pyruvate.

ENE-1.L.2 Pyruvate is transported from the cytosol to the mitochondrion, where further oxidation occurs.

ENE-1.L.3 In the Krebs cycle, carbon dioxide is released from organic intermediates, ATP is synthesized from ADP and inorganic phosphate, and electrons are transferred to the coenzymes NADH and FADH2.

ENE-1.L.4 Electrons extracted in glycolysis and Krebs cycle reactions are transferred by NADH and FADH2 to the electron transport chain in the inner mitochondrial membrane.

ENE-1.L.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.

ENE-1.L.6 Fermentation allows glycolysis to proceed in the absence of oxygen and produces organic molecules, including alcohol and lactic acid, as waste products.
ENE-1.L.7 The conversion of ATP to ADP releases energy, which is used to power many metabolic processes.

X *Specific steps, names of enzymes, and intermediates of the pathways for these processes are beyond the scope of the course and the AP exam.*

X *Memorization of the steps of glycolysis and the Krebs cycle, and of the structures and molecules and names of the enzymes involved, is beyond the scope of the course and the AP exam.*

ENE-1.M.1 Organisms use energy to maintain organization, grow, and reproduce—

a. Organisms use different strategies to regulate body temperature and metabolism.
   i. Endotherms use thermal energy generated by metabolism to maintain homeostatic body temperatures.
   ii. Ectotherms lack efficient internal mechanisms for maintaining body temperature, though they may regulate their temperature behaviorally by moving into the sun or shade or by aggregating with other individuals.

b. Different organisms use various reproductive strategies in response to energy availability.

c. There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms—generally, the smaller the organism, the higher the metabolic rate.

SYI-3.A.1 Variation at the molecular level provides organisms with the ability to respond to a variety of environmental stimuli.
SYI-3.A.2 Variation in the number and types of molecules within cells provides organisms a greater ability to survive and/or reproduce in different environments.

Resources

College Board AP Central: https://apcentral.collegeboard.org/courses/ap-biology/course

College Board AP Biology course and exam description manual: https://apcentral.collegeboard.org/pdf/ap-biology-course-and-exam-description-0.pdf

AP Biology Lab Manual:

https://apcentral.collegeboard.org/pdf/ap-biology-teacher-lab-manual-fall-2019.pdf?course=ap-biology

AP Biology Classroom Resources: https://apcentral.collegeboard.org/courses/ap-biology/classroom-resources?course=ap-biology

Khan Academy AP Biology: https://www.khanacademy.org/science/ap-biology

Bozeman Science AP Biology videos: http://www.bozemanscience.com/ap-biology

HHMI Biointeractive: https://www.biointeractive.org/