Minnesota Academic Standards - Science K-12 (2009 version)

7	4. Life Science	2. Interdependence Among Living Systems	2. The flow of energy and the recycling of matter are essential to a stable ecosystem.	7.4.2.2.1	Recognize that producers use the **energy from sunlight to make sugars from carbon dioxide and water through a process called photosynthesis**. This food can be used immediately, stored for later use, or used by other organisms.
7	4. Life Science	2. Interdependence Among Living Systems	2. The flow of energy and the recycling of matter are essential to a stable ecosystem.	7.4.2.2.2	Describe the roles and relationships among producers, consumers, and decomposers in changing energy from one form to another in a food web within an ecosystem.
7	4. Life Science	2. Interdependence Among Living Systems	2. The flow of energy and the recycling of matter are essential to a stable ecosystem.	7.4.2.2.3	Explain that the total amount of matter in an ecosystem remains the same as it is transferred between organisms and their physical environment, even though its form and location change. *For example:* Construct a food web to trace the flow of matter in an ecosystem.
9-12	4. Life Science	1. Structure and Function of Living Systems	2. Cells and cell structures have specific functions that allow an organism to grow, survive and reproduce.	9.4.1.2.4	Explain the function and importance of cell organelles for prokaryotic and/or eukaryotic cells as related to the basic cell processes of respiration, photosynthesis, protein synthesis and cell reproduction.
9-12	4. Life Science	2. Interdependence Among Living Systems	2. Matter cycles and energy flows through different levels of organization of living systems and the physical environment, as chemical elements are combined in different ways.	9.4.2.2.1	Use words and equations to differentiate between the processes of photosynthesis and respiration in terms of energy flow, **beginning reactants and end products**.
9-12	4. Life Science	2. Interdependence Among Living Systems	2. Matter cycles and energy flows through different levels of organization of living systems and the physical environment, as chemical elements are combined in different ways.	9.4.2.2.2	**Explain how** matter and **energy is transformed** and transferred among organisms in an ecosystem, and how energy is dissipated as heat into the environment.

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MS-LS1 From Molecules to Organisms: Structures and Processes

Students who demonstrate understanding can:

MS-LS1-6. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms. [Clarification Statement: Emphasis is on tracing movement of matter and flow of energy.] [Assessment Boundary: Assessment does not include the biochemical mechanisms of photosynthesis.]

MS-LS1-7. Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism. [Clarification Statement: Emphasis is on describing that molecules are broken apart and put back together and that in this process, energy is released.] [Assessment Boundary: Assessment does not include details of the chemical reactions for photosynthesis or respiration.]

Disciplinary Core Ideas

LS1.C: Organization for Matter and Energy Flow in Organisms

- Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. (MS-LS1-6)

PS3.D: Energy in Chemical Processes and Everyday Life

- The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen. (secondary to MS-LS1-6)
- Cellular respiration in plants and animals involve chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials. (secondary to MS-LS1-7)

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HS-LS1 From Molecules to Organisms: Structures and Processes

Students who demonstrate understanding can:

HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy. [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [Assessment Boundary: Assessment does not include specific biochemical steps.]

HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules. [Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.]

HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy. [Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.]

LS1.C: Organization for Matter and Energy Flow in Organisms

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (HS-LS1-5)
- The sugar molecules thus formed contain carbon, hydrogen, and oxygen: their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (HS-LS1-6)
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6),(HS-LS1-7)
- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. (HS-LS1-7)

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics

Students who demonstrate understanding can:

HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions. [Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.] [Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.]

HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. [Clarification Statement: Examples of models could include simulations and mathematical models.] [Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.]

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. (HS-LS2-3)
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. (HS-LS2-4)
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. (HS-LS2-5)

PS3.D: Energy in Chemical Processes

- The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. (secondary to HS-LS2-5)

Learning objective 2.41 The student is able to evaluate data to show the relationship between photosynthesis and respiration in the flow of free energy through a system. [See **SP 5.3, 7.1; Essential knowledge 2.A.2**]

Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce and to maintain dynamic homeostasis.

Autotrophic cells capture free energy through photosynthesis and chemosynthesis. Photosynthesis traps free energy present in sunlight that, in turn, is used to produce carbohydrates from carbon dioxide. Chemosynthesis captures energy present in inorganic chemicals. Cellular respiration and fermentation harvest free energy from sugars to produce free energy carriers, including ATP. The free energy available in sugars drives metabolic pathways in cells. Photosynthesis and respiration are interdependent processes.

Enduring understanding 2.A: Growth, reproduction and maintenance of the organization of living systems require free energy and matter.

Several means to capture, use and store free energy have evolved in organisms. Cells can capture free energy through photosynthesis and chemosynthesis. Autotrophs capture free energy from the environment, including energy present in sunlight and chemical sources, whereas heterotrophs harvest free energy from carbon compounds produced by other organisms. Through a series of coordinated reaction pathways, photosynthesis traps free energy in sunlight that, in turn, is used to produce carbohydrates from carbon dioxide and water. Cellular respiration and fermentation use free energy available from sugars and from interconnected, multistep pathways (i.e. glycolysis, the Krebs cycle, and the electron transport chain) to phosphorylate ADP, producing the most common energy carrier, ATP. The free energy available in sugars can be used to drive metabolic pathways vital to cell processes. The processes of photosynthesis and cellular respiration are interdependent in their reactants and products.

Essential knowledge 2.A.2: Organisms capture and store free energy for use in biological processes.

c. Different energy-capturing processes use different types of electron acceptors.
To foster student understanding of this concept, instructors can choose an illustrative example such as:

- NADP+ in photosynthesis
- Oxygen in cellular respiration

d. The light-dependent reactions of photosynthesis in eukaryotes involve a series of coordinated reaction pathways that capture free energy present in light to yield ATP and NADPH, which power the production of organic molecules.

Evidence of student learning is a demonstrated understanding of each of the following:

1. During photosynthesis, chlorophylls absorb free energy from light, boosting electrons to a higher energy level in Photosystems I and II.
2. Photosystems I and II are embedded in the internal membranes of chloroplasts (thylakoids) and are connected by the transfer of higher free energy electrons through an electron transport chain (ETC). [See also **4.A.2**]
3. When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of hydrogen ions (protons) across the thylakoid membrane is established.
4. The formation of the proton gradient is a separate process, but it is linked to the synthesis of ATP and ADP and inorganic phosphate via ATP synthase.
5. The energy captured in the light reactions as ATP and NADPH powers the production of carbohydrates from carbon dioxide in the Calvin cycle, which occurs in the stroma of the chloroplast.

Memorization of the steps in the Calvin cycle, the structure of the molecules and the names of enzymes (with the exception of ATP synthase) are beyond the scope of the course and the AP Exam.

e. Photosynthesis first evolved in prokaryotic organisms; scientific evidence supports that projaryotic (bacterial) photosynthesis was responsible for the production of an oxygenated atmosphere; prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis.

f. Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzes reactions that harvest free energy from simple carbohydrates.
Evidence of student learning is a demonstrated understanind of each of the following:

1. Glycolysis rearranges the bonds of glucose molecules, releasing free energy to form ATP from ADP and inorganic phosphate, and resulting in the production of pyruvate.
2. Pyruvate is transported from the cytoplasm to the mitochondrion, where further oxidation occurs. [See also **4.A.2**]
3. In the Krebs cycle, carbon dioxide is released from organic intermediates ATP is synthesized from ADP and inorganic phosphate via substrate level phosphorylation and electrons are captured by coenzymes.
4. Electrons that are extracted in the series of Krebs cycle reactions are carried by NADH and FADH2 to the electron transport chain.

Memorization of the steps on glycolysis and the Krebs cycle, or of the structures of the molecules and the names of the enzymes involved, are beyond the scope of the course and the AP Exam.

g. The electron transport chain captures free energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes.
Evidence of student learning is demonstrated understanding of each of the following:

1. Electron transport chain reactions occur in chloroplasts (photosynthesis), mitochondria (cellular respiration) and prokaryotic plasma membranes.
2. In cellular respiration, electrons are delivered by NADH and FADH2 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+.
3. The passage of electrons is accompanied by the formation of a proton gradient across the inner mitochondrial membrane or the thylakoid 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 outward movement of protons across the plasma membrane.
4. The flow of protons back through membrane-bound ATP synthase by chemiosmosis generates ATO from ADP and inorganic phosphate.
5. In cellular respiration, decoupling oxidative phosphorylation from electron transport is involved in thermoregulation.

The names of the specific electron carrier in the ETC are beyond the scope of the course and the AP Exam.

h. Free energy becomes available for metabolism by the conversion of ATP to ADP, which is coupled by many steps in metabolic pathways.

<u>Learning Objectives:</u>

LO 2.4 The student is able to use representations to pose scientific questions about what mechanisms and structural features allow organisms to capture, store and use free energy. [See **SP 1.4, 3.1**]

LO 2.5 The student is able to construct explanations of the mechanisms and structural features of cells that allow organisms to capture, store or use free energy. [See **SP 6.2**]

LO 2.41 The student is able to evaluate data to show the relationship between photosynthesis and respiration in the flow of free energy through a system. [See **SP 5.3, 7.1**]