**Unit 4: Cells & Metabolism Unit Guide HSPVA AP Biology**

**EK 2.A.1: All living systems require constant input of free energy. (4.1)**

a. Life requires a highly ordered system.

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

1. Order is maintained by constant free energy input into the system.

2. Loss of order or free energy flow results in death.

3. Increased disorder and entropy are offset by biological processes that maintain or increase order.

b. Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.

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

1. Order is maintained by coupling cellular processes that increase entropy (and so have negative changes in free energy) with those that decrease entropy (and so have positive changes in free energy).

2. Energy input must exceed free energy lost to entropy to maintain order and power cellular processes.

3. Energetically favorable exergonic reactions, such as ATP→ADP, that have a negative change in free energy can be used to maintain or increase order in a system by being coupled with reactions that have a positive free energy change.

c. Energy-related pathways in biological systems are sequential and may be entered at multiple points in the pathway. [See also **2.A.2**]

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Krebs cycle
* Glycolysis
* Calvin cycle
* Fermentation

d. Organisms use free energy to maintain organization, grow and reproduce.

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

1. Organisms use various strategies to regulate body temperature and metabolism.

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Endothermy (the use of thermal energy generated by metabolism to maintain homeostatic body temperatures)
* Ectothermy (the use of external thermal energy to help regulate and maintain body temperature)
* Elevated floral temperatures in some plant species

2. Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Seasonal reproduction in animals and plants
* Life-history strategy (biennial plants, reproductive diapause)

3. 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.

4. Excess acquired free energy versus required free energy expenditure results in energy storage or growth.

5. Insufficient acquired free energy versus required free energy expenditure results in loss of mass and, ultimately, the death of an organism.

e. Changes in free energy availability can result in changes in population size.

f. Changes in free energy availability can result in disruptions to an ecosystem.

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Change in the producer level can affect the number and size of other trophic levels.
* Change in energy resources levels such as sunlight can affect the number and size of the trophic levels.

**LO 2.1** The student is able to explain how biological systems use free energy based on empirical data that all organisms require constant energy input to maintain organization, to grow and to reproduce. [See **SP 6.2**]

**LO 2.2** The student is able to justify a scientific claim that free energy is required for living systems to maintain organization, to grow or to reproduce, but that multiple strategies exist in different living systems. [See **SP 6.1**]

**LO 2.3** The student is able to predict how changes in free energy availability affect organisms, populations and ecosystems. [See **SP 6.4**]

**EK 2.A.2: Organisms capture and store free energy for use in biological processes. (4.1)**

a. Autotrophs capture free energy from physical sources in the environment.

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

1. Photosynthetic organisms capture free energy present in sunlight.

2. Chemosynthetic organisms capture free energy from small inorganic molecules present in their environment, and this process can occur in the absence of oxygen.

b. Heterotrophs capture free energy present in carbon compounds produced by other organisms.

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

1. Heterotrophs may metabolize carbohydrates, lipids and proteins by hydrolysis as sources of free energy.

2. Fermentation produces organic molecules, including alcohol and lactic acid, and it occurs in the absence of oxygen.

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

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

**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**]

**EK 4.B.1: Interactions between molecules affect their structure and function. (4.2)**

a. Change in the structure of a molecular system may result in a change of the function of the system. [See also **3.D.3**]

b. The shape of enzymes, active sites and interaction with specific molecules are essential for basic functioning of the enzyme.

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

1. For an enzyme-mediated chemical reaction to occur, the substrate must be complementary to the surface properties (shape and charge) of the active site. In other words, the substrate must fit into the enzyme’s active site.

2. Cofactors and coenzymes affect enzyme function; this interaction relates to a structural change that alters the activity rate of the enzyme. The enzyme may only become active when all the appropriate cofactors or coenzymes are present and bind to the appropriate sites on the enzyme.

c. Other molecules and the environment in which the enzyme acts can enhance or inhibit enzyme activity. Molecules can bind reversibly or irreversibly to the active or allosteric sites, changing the activity of the enzyme.

d. The change in function of an enzyme can be interpreted from data regarding the concentrations of product or substrate as a function of time. These representations demonstrate the relationship between an enzyme’s activity, the disappearance of substrate, and/or presence of a competitive inhibitor.

**LO 4.17** The student is able to analyze data to identify how molecular interactions affect structure and function. [See **SP 5.1**]

**EK 2.B.3: Eukaryotic cells maintain internal membranes that partition the cell into specialized regions. (4.3)**

a. Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing surface area where reactions can occur.

b. Membranes and membrane-bound organelles in eukaryotic cells localize (compartmentalize) intracellular metabolic processes and specific enzymatic reactions. [See also **4.A.2**]

*To foster student understanding of this concept, instructors can choose an illustrative*  *example, such as:*

* Endoplasmic reticulum
* Mitochondria
* Chloroplasts
* Golgi
* Nuclear envelope

c. Archaea and Bacteria generally lack internal membranes and organelles and have a cell wall.

**LO 2.13** The student is able to explain how internal membranes and organelles contribute to cell functions. [See **SP 6.2**]

**LO 2.14** The student is able to use representations and models to describe differences in prokaryotic and eukaryotic cells. [See **SP 1.4**]

**EK 4.A.2: The structure and function of subcellular components, and their interactions, provide essential cellular processes. (4.3)**

a. Ribosomes are small, universal structures comprised of two interacting parts: ribosomal RNA and protein. In a sequential manner, these cellular components interact to become the site of protein synthesis where the translation of the genetic instructions yields specific polypeptides. [See also **2.B.3**]

b. Endoplasmic reticulum (ER) occurs in two forms: smooth and rough. [See also **2.B.3**]

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

1. Rough endoplasmic reticulum functions to compartmentalize the cell, serves as mechanical support, provides site-specific protein synthesis with membrane-bound ribosomes and plays a role in intracellular transport.

2. In most cases, smooth ER synthesizes lipids.

c. The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs (cisternae). [See also **2.B.3**]

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

1. Functions of the Golgi include synthesis and packaging of materials (small molecules) for transport (in vesicles), and production of lysosomes.

d. Mitochondria specialize in energy capture and transformation. [See also **2.A.2**, **2.B.3**]

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

1. Mitochondria have a double membrane that allows compartmentalization within the mitochondria and is important to its function.

2. The outer membrane is smooth, but the inner membrane is highly convoluted, forming folds called cristae.

3. Cristae contain enzymes important to ATP production; cristae also increase the surface area for ATP production.

e. Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes, which are important in intracellular digestion, the recycling of a cell’s organic materials and programmed cell death (apoptosis). Lysosomes carry out intracellular digestion in a variety of ways. [See also **2.B.3**]

f. A vacuole is a membrane-bound sac that plays roles in intracellular digestion and the release of cellular waste products. In plants, a large vacuole serves many functions, from storage of pigments or poisonous substances to a role in cell growth. In addition, a large central vacuole allows for a large surface area to volume ratio. [See also **2. A.3, 2.B.3**]

g. Chloroplasts are specialized organelles found in algae and higher plants that capture energy through photosynthesis. [See also **2.A.2, 2 B.3**]

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

1. The structure and function relationship in the chloroplast allows cells to capture the energy available in sunlight and convert it to chemical bond energy via photosynthesis.

2. Chloroplasts contain chlorophylls, which are responsible for the green color of a plant and are the key light-trapping molecules in photosynthesis. There are several types of chlorophyll, but the predominant form in plants is chlorophyll *a*.

3. Chloroplasts have a double outer membrane that creates a compartmentalized structure, which supports its function. Within the chloroplasts are membrane-bound structures called thylakoids. Energy-capturing reactions housed in the thylakoids are organized in stacks, called “grana,” to produce ATP and NADPH2, which fuel carbon-fixing reactions in the Calvin-Benson cycle. Carbon fixation occurs in the stroma, where molecules of CO2 are converted to carbohydrates.

**LO 4.4** The student is able to make a prediction about the interactions of subcellular organelles. [See **SP 6.4**]

**LO 4.5** The student is able to construct explanations based on scientific evidence as to how interactions of subcellular structures provide essential functions. [See **SP 6.2**]

**LO 4.6** The student is able to use representations and models to analyze situations qualitatively to describe how interactions of subcellular structures, which possess specialized functions, provide essential functions. [See **SP 1.4**]

**EK 2.B.1: Cell membranes are selectively permeable due to their structure. (4.4)**

a. Cell membranes separate the internal environment of the cell from the external environment.

b. Selective permeability is a direct consequence of membrane structure, as described by the fluid mosaic model. [See also **4.A.1**]

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

1. Cell membranes consist of a structural framework of phospholipid molecules, embedded proteins, cholesterol, glycoproteins and glycolipids.

2. Phospholipids give the membrane both hydrophilic and hydrophobic properties.

3. The hydrophilic phosphate portions of the phospholipids are oriented toward the aqueous external or internal environments, while the hydrophobic fatty acid portions face each other within the interior of the membrane itself.

4. Embedded proteins can be hydrophilic, with charged and polar side groups, or hydrophobic, with nonpolar side groups.

5. Small, uncharged polar molecules and small nonpolar molecules, such as N2, freely pass across the membrane. Hydrophilic substances such as large polar molecules and ions move across the membrane through embedded channel and transport proteins. Water moves across membranes and through channel proteins called aquaporins.

c. Cell walls provide a structural boundary, as well as a permeability barrier for some substances to the internal environments.

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

1. Plant cell walls are made of cellulose and are external to the cell membrane.

2. Other examples are cells walls of prokaryotes and fungi.

**LO 2.10** The student is able to use representations and models to pose scientific questions about the properties of cell membranes and selective permeability based on molecular structure. [See **SP 1.4, 3.1**]

**LO 2.11** The student is able to construct models that connect the movement of molecules across membranes with membrane structure and function. [See **SP 1.1, 7.1, 7.2**]

**EK 2.B.2: Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. (4.4)**

a. Passive transport does not require the input of metabolic energy; the net movement of molecules is from high concentration to low concentration.

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

1. Passive transport plays a primary role in the import of resources and the export of wastes.

2. Membrane proteins play a role in facilitated diffusion of charged and polar molecules through a membrane.

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Glucose transport
* Na+/K+ transport

3. External environments can be hypotonic, hypertonic or isotonic to internal environments of cells.

b. Active transport requires free energy to move molecules from regions of low concentration to regions of high concentration.

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

1. Active transport is a process where free energy (often provided by ATP) is used by proteins embedded in the membrane to “move” molecules and/or ions across the membrane and to establish and maintain concentration gradients.

2. Membrane proteins are necessary for active transport.

c. The processes of endocytosis and exocytosis move large molecules from the external environment to the internal environment and vice versa, respectively.

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

1. In exocytosis, internal vesicles fuse with the plasma membrane to secrete large macromolecules out of the cell.

2. In endocytosis, the cell takes in macromolecules and particulate matter by forming new vesicles derived from the plasma membrane.

**LO 2.12** The student is able to use representations and models to analyze situations or solve problems qualitatively and quantitatively to investigate whether dynamic homeostasis is maintained by the active movement of molecules across membranes. [See **SP 1.4**]

**EK 2.A.2: Organisms capture and store free energy for use in biological processes-Cellular respiration. (4.5)**

f. Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that harvest free energy from simple carbohydrates.

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

1. Glycolysis rearranges the bonds in 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.

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 a 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 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 ATP from ADP and inorganic phosphate.

5. In cellular respiration, decoupling oxidative phosphorylation from electron transport is involved in thermoregulation.

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

**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**]

Untested:

✘ *No specific cofactors or coenzymes are within the scope of the course and the AP Exam.*

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

✘ *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.*

✘ *Memorization of the steps in 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.*

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

Untested:

✘ *There is no particular membrane protein that is required for teaching facilitated diffusion and active transport.*

✘ *Specific functions of smooth ER in specialized cells are beyond the scope of the course and the AP Exam*

✘ *The role of this organelle in specific phospholipid synthesis and the packaging of enzymatic contents of lysosomes, peroxisomes and secretory vesicles are beyond the scope of the course and the AP Exam.*

✘ *Specific examples of how lysosomes carry out intracellular digestion are beyond the scope of the course and the AP Exam.*

✘ *The molecular structure of chlorophyll* a *is beyond the scope of the course and the AP Exam.*