Unit 3: Cellular Energetics

Topic	Learning Objective(s)
3.1 Enzyme Structure	**ENE-1.D** Describe the properties of enzymes.
3.2 Enzyme Catalysis	**ENE-1.E** Explain how enzymes affect the rate of biological reactions.
3.3 Environmental Impacts on Enzyme Function	**ENE-1.F** Explain how changes to the structure of an enzyme may affect its function.
	ENE-1.G Explain how the cellular environment affects enzyme activity
3.4 Cellular Energy	**ENE-1.H** Describe the role of energy in living organisms.
3.5 Photosynthesis	**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
3.6 Cellular Respiration	**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.
3.7 Fitness	**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.

Free Response Practice

2022 #3

Fireflies emit light when the enzyme luciferase catalyzes a reaction in which its substrate, D-luciferin, reacts to form oxyluciferin and other products (Figure 1). In order to determine the optimal temperature for this enzyme, scientists added ATP to a solution containing D-luciferin, luciferase, and other substances needed for the reaction. They then measured the amount of light emitted during the first three seconds of the reaction when it was carried out at different temperatures.

$$\text{D-Luciferin} + O_2 + \text{ATP} \xrightarrow{\text{Luciferase}} \text{Oxyluciferin} + CO_2 + \text{AMP} + PP_i + \text{Light}$$

Figure 1. Light is emitted as a result of the reaction catalyzed by luciferase.

(a) **Describe** a characteristic of the luciferase enzyme that allows it to catalyze the reaction.

(b) **Identify** the dependent variable in the experiment.

(c) **State** the null hypothesis for the experiment.

(d) A student claims that, as temperature increases, there will be an increase in the amount of light given off by the reaction in the first three seconds. **Support** the student's claim.

2021 #3

Researchers hypothesize that the plant compound resveratrol improves mitochondrial function. To test this hypothesis, researchers dissolve resveratrol in dimethyl sulfoxide (DMSO). The solution readily passes through cell membranes. They add resveratrol solution to mammalian muscle cells growing in a nutrient-rich solution (culture medium) that contains glucose. They measure ATP production at several time points after the addition of the resveratrol solution and find an increase in ATP production by the muscle cells.

(a) **Describe** the primary advantage for a mammalian muscle cell in using aerobic respiration over fermentation.

(b) **Identify** an appropriate negative control for this experiment that would allow the researchers to conclude that ATP is produced in response to the resveratrol treatment.

(c) **Predict** the effect on short-term ATP production when resveratrol-treated mammalian muscle cells are grown in a culture medium that lacks glucose or other sugars.

(d) The researchers find that resveratrol stimulates the production of components of the electron transport chain. The researchers claim that treatment with resveratrol will also increase oxygen consumption by the cells if glucose is not limiting. **Justify** this claim.

2017 #5

Microcystis aeruginosis is a freshwater photosynthetic cyanobacterium. When temperatures increase and nutrients are readily available in its pond habitat, M. aeruginosis undergoes rapid cell division and forms an extremely large, visible mass of cells called an algal bloom. M. aeruginosis has a short life span and is decomposed by aerobic bacteria and fungi. Identify the metabolic pathway and the organism that is primarily responsible for the change in oxygen level in the pond between time I and II AND between times III and IV.

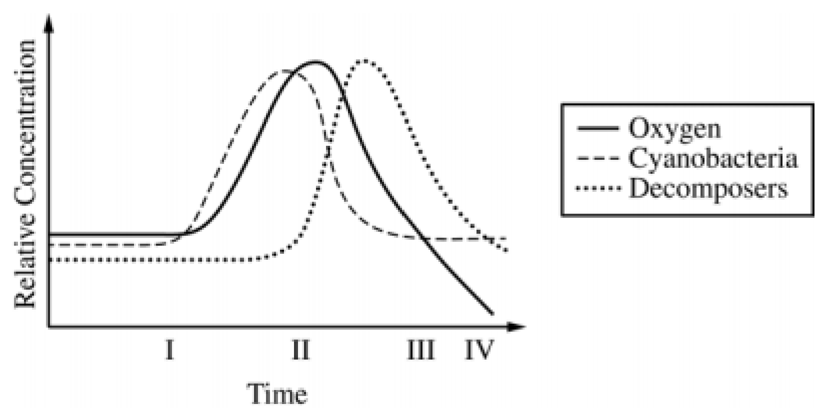


Figure 1. Characteristics of a pond community over time

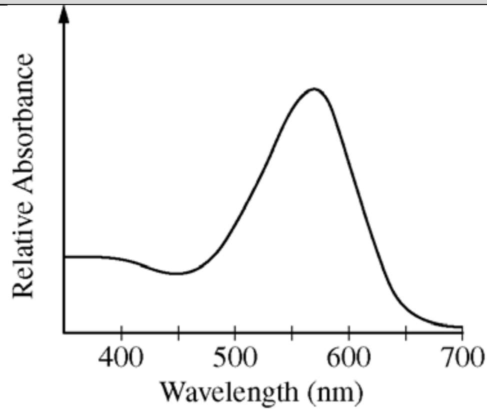
2017 #7

Many species of bacteria grow in the mouths of animals and can form biofilms on teeth (plaque). Within plaque, the outer layers contain high levels of oxygen and the layers closest to the tooth contain low levels of oxygen. The surface of the tooth is covered in a hard layer of enamel, which can be dissolved under acidic conditions. When the enamel breaks down, the bacteria in plaque can extract nutrients from the tooth and cause cavities.
Certain types of bacteria (e.g. *Streptococcus mutans*) thrive in the innermost anaerobic layers of the plaque and are associated with cavities. Other types of bacteria (*Streptococcus sanguinis*) compete with *S. mutans* but are unable to thrive in acidic environments.

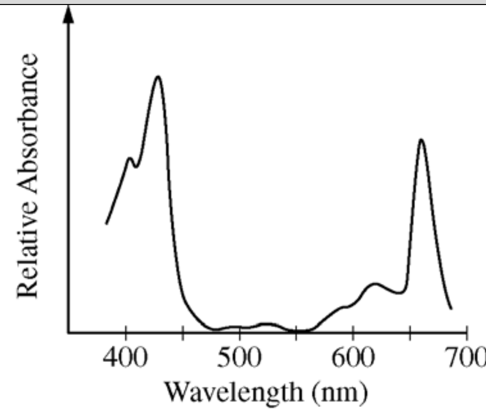
(a) **Identify** the biochemical pathway *S. mutans* uses for metabolizing sugar and **describe** how the pathway contributes to the low pH in the inner layers of plaque.

(b) Normal tooth brushing effectively removes much of the plaque from the flat surfaces of teeth, but cannot reach the surfaces between teeth. Many commercial toothpastes contain alkaline components, which raise the pH of the mouth. **Predict** how the population sizes of *S. mutans* AND *S. sanguinis* in the bacterial community in the plaque between the teeth are likely to change when these toothpastes are used.

2013 #2



Graph I



Graph II

Color	Wavelength (nm)
Violet	380 – 450
Blue	450 – 475
Cyan	475 – 495
Green	495 – 570
Yellow	570 – 590
Orange	590 – 620
Red	620 - 750

An absorption spectrum indicates the relative amount of light absorbed across a range of wavelengths. The graphs above represent the absorption spectra of individual pigments isolated from two different organisms. One of the pigments is chlorophyll a, commonly found in green plants. The other pigment is bacteriorhodopsin, commonly found in purple photosynthetic bacteria. The table above shows the approximate ranges of wavelengths of different colors in the visible light spectrum.

(a) **Identify** the pigment (chlorophyll a or bacteriorhodopsin) used to generate the absorption spectrum in each of the graphs above. **Explain** and **justify** your answer.

(b) In an experiment, identical organisms containing the pigment from Graph II as the predominant light-capturing pigment are separated into three groups. The organisms in each group are illuminated with light of a single wavelength (650 nm for the first group, 550 nm for the second group, and 430 nm for the third group). The three light sources are of equal intensity, and all organisms are illuminated for equal lengths of time. **Predict** the relative rate of photosynthesis in each of the three groups. **Justify** your predictions.

(c) Bacteriorhodopsin has been found in aquatic organisms whose ancestors existed before the ancestors of plants evolved in the same environment. **Propose** a possible evolutionary history of plants that could have resulted in a predominant photosynthetic system that uses only some of the colors of the visible light spectrum.

Free Response Scoring Guidelines

2022 #3		
Part	Scoring Guidelines	Topic
(a)	**Describe** a characteristic of the luciferase enzyme that allows it to catalyze the reaction. Accept one of the following: • It has an active site/a shape that can bind with the substrate(s)/brings reactants together. • It has a charge that is compatible with the substrate(s).	3.1
(b)	**Identify** the dependent variable in the experiment. • The amount of light emitted	
(c)	**State** the null hypothesis for the experiment. • Temperature has no effect on the amount of light emitted.	
(d)	A student claims that, as temperature increases, there will be an increase in the amount of light given off by the reaction in the first three seconds. **Support** the student's claim. Accept one of the following: • Higher temperature increases the frequency of collisions/interactions between molecules, resulting in an increase in reaction rate. • The higher temperature results in a change to the active site that enhances substrate binding.	3.3

2021 #3		
Part	Scoring Guidelines	Topic
(a)	**Describe** the primary advantage for a mammalian muscle cell in using aerobic respiration over fermentation. • More ATP (per glucose molecule) is produced by aerobic respiration.	3.6
(b)	**Identify** an appropriate negative control for this experiment that would allow the researchers to conclude that ATP is produced in response to the resveratrol treatment. Accept one of the following: • The researchers must run the experiment without adding resveratrol. • The researchers must treat the cells with DMSO alone.	3.6
(c)	**Predict** the effect on short-term ATP production when resveratrol-treated mammalian muscle cells are grown in a culture medium that lacks glucose or other sugars. Accept one of the following: • No ATP production • Reduced ATP production	3.6
(d)	The researchers find that resveratrol stimulates the production of components of the electron transport chain. The researchers claim that treatment with resveratrol will also increase oxygen consumption by the cells if glucose is not limiting. **Justify** the claim. • More electrons can be transferred so that more oxygen is required as the final electron acceptor.	3.6

2017 #5

Part	Scoring Guidelines	Topic
	Identification (2 points per row; 4 points maximum)	3.5 3.6

Time Period	Metabolic pathway **(1 point per box)**	Organism **(1 point per box)**
I – II	Photosynthesis	Cyanobacteria (*M. aeruginosis*)
III – IV	Cellular respiration	Decomposers/fungi/bacteria

2017 #7

Part	Scoring Guidelines	Topic
(a)	**Identify** the biochemical pathway *S. mutans* uses for metabolizing sugar and **describe** how the pathway contributes to the low pH in the inner layers of plaque. **(2 points; both points must be earned from the same row.)**	3.6

Identification	Description
fermentation	(lactic) acid/lactate
anaerobic respiration	acid
glycolysis	(pyruvic) acid/pyruvate

Part	Scoring Guidelines	Topic
(b)	Normal tooth brushing effectively removes much of the plaque from the flat surfaces of teeth but cannot reach the surfaces between teeth. Many commercial toothpastes contain alkaline components, which raise the pH of the mouth. **Predict** how the population sizes of *S. mutans* AND *S. sanguinis* in the bacterial community in the plaque between the teeth are likely to change when these toothpastes are used. **(1 point)** **Prediction (1 point)** • *S. mutans* decreases AND *S. sanguinis* increases	3.6

2013 #2

Part	Scoring Guidelines	Topic
(a)	**Identify** the pigment (chlorophyll *a* or bacteriorhodopsin) used to generate the absorption spectrum in each of the graphs above. **Explain** and **justify** your answer. (**3 points maximum**)	3.5

1 point per box
Identify BOTH pigments: Graph 1 = bacteriorhodopsin AND graph 2 = chlorophyll *a*
Explain that an organism containing bacteriorhodopsin appears purple because the pigment absorbs light in the green range of the light spectrum and/or reflects violet or red and blue light. The reflected red and blue light appears purple.
Explain that an organism containing chlorophyll *a* appears green because the pigment absorbs light in the red and blue ranges of the light spectrum and/or reflects green light.

Part	Scoring Guidelines	Topic
(b)	) In an experiment, identical organisms containing the pigment from Graph II as the predominant light-capturing pigment are separated into three groups. The organisms in each group are illuminated with light of a single wavelength (650 nm for the first group, 550 nm for the second group, and 430 nm for the third group). The three light sources are of equal intensity, and all organisms are illuminated for equal lengths of time. **Predict** the relative rate of photosynthesis in each of the three groups. **Justify** your predictions. (**5 points maximum**)	3.5

Wavelength (Group)	Prediction (**1 point each box**)	Justification (**1 point each box**)
650 nm (1st Group)	Intermediate rate	An intermediate level of absorption occurs at 650 nm (compared to 430 nm and 550 nm); *therefore*, an intermediate amount of energy is available to drive photosynthesis.
550 nm (2nd Group)	Lowest rate	The lowest level of absorption occurs at 550 nm; *therefore*, the least amount of energy is available to drive photosynthesis.
430 nm (3rd Group)	Highest rate	The highest level of absorption occurs at 430 nm; *therefore*, the greatest amount of energy is available to drive photosynthesis.

Part	Scoring Guidelines	Topic
(c)	) Bacteriorhodopsin has been found in aquatic organisms whose ancestors existed before the ancestors of plants evolved in the same environment. **Propose** a possible evolutionary history of plants that could have resulted in a predominant photosynthetic system that uses only some of the colors of the visible light spectrum. (**1 point per box; 2 points maximum**)	3.7

Proposal that includes an environmental selective pressure: • Green light was being absorbed by aquatic organisms using bacteriorhodopsin. • Unabsorbed wavelengths of light were available resources that organisms could exploit. • Absorbing visible light at all wavelengths may provide too much energy to the organism. • Absorbing light from ultraviolet wavelengths (shorter wavelengths = higher energy) could cause damage to the organism. • Absorbing light with longer wavelengths may not provide sufficient energy for the organism.
Appropriate reasoning to support the proposal: • Natural selection favored organisms that rely on pigments that absorb available wavelengths of light. • Endosymbiosis: chloroplasts evolved from cyanobacteria with pigments that used only certain wavelengths. • Genetic drift eliminated pigments that absorbed certain wavelengths of light. • Mutation(s) altered the pigment(s) used by organism.