UNIT 2: PLANT BIOLOGY
CHAPTER 8: PHOTOSYNTHESIS

LEARNING OUTCOMES

8.1 Overview of Photosynthesis

1. Compare and contrast autotrophs and heterotrophs.
2. Explain the role of photosynthesis for all organisms on Earth.
3. Explain the overall chemical equation for photosynthesis.
4. Describe the process of photosynthesis in terms of two sets of reactions that take place in a chloroplast.

8.2 Plants as Solar Energy Converters

1. Identify the photosynthetic pigments required to absorb the various wavelengths of light necessary for photosynthesis.
2. Explain the role of the noncyclic electron pathway and the cyclic electron pathway.
3. Describe the organization of the thylakoid and how this organization is critical to the production of ATP during photosynthesis.

8.3 Plants as Carbon Dioxide Fixers

1. Describe the three phases of the Calvin cycle.
2. Explain how the products of the Calvin cycle are used to form the other molecules found in plants.

8.4 Alternative Pathways for Photosynthesis

1. Contrast C_3, C_4, and CAM photosynthesis.
2. Explain how different photosynthetic modes allow plants to adapt to a particular environment.

8.5 Photosynthesis Versus Cellular Respiration

1. Compare the overall chemical equation for photosynthesis and cellular respiration.
2. Describe the similarities and differences between cellular respiration and photosynthesis.

LECTURE OUTLINE

8.1 Overview of Photosynthesis

Photosynthesis converts solar energy into the chemical energy of a carbohydrate. Photosynthetic organisms are called **autotrophs** because they produce their own food. Consumers are called **heterotrophs**. Pigments are the means by which autotrophs capture solar energy.

Flowering Plants as Photosynthesizers

The leaves and roots of a plant are specialized to provide raw materials for photosynthesis. Chloroplasts are the organelles in leaves that carry on photosynthesis.

Photosynthetic Reaction

The overall equation for photosynthesis is carbon dioxide plus water plus solar energy produce glucose and oxygen.

Two Sets of Reactions

Two sets of reactions are involved in photosynthesis: the **light reactions** and the **Calvin cycle reactions**.

8.2 Plants as Solar Energy Converters

The pigments within the thylakoid membranes in the chloroplasts absorb solar energy.

Visible Light

Visible light contains various wavelengths of light. The pigments found within most types of photosynthesizing cells (chlorophyll *a* and *b* and the carotenoids) absorb violet, indigo, blue, and red light better than the other parts of the visible light spectrum.

Light Reactions

The light reactions consist of two electron pathways called the noncyclic electron pathway and the cyclic electron pathway.

Noncyclic Electron Pathway

In the **noncyclic electron pathway** the electron flow can be traced from water to a molecule of $NADP^+$. The pathway uses **photosystem** I and photosystem II. Water is oxidized releasing oxygen. ATP and NADPH are produced.

Cyclic Electron Pathway

In the **cyclic electron pathway** the electrons are recycled back to photosystem I. This produces ATP but not NADPH.

The Organization of the Thylakoid Membrane

Photosystem I, photosystem II, the electron transport chain, and the ATP synthase complex are all present in the thylakoid membrane.

ATP Production

A reservoir of hydrogen ions (H^+) creates an electrochemical gradient in the thylakoid space. As H^+ flows across the concentration gradient enough energy is provided to enzymatically produce ATP, a process called chemiosmosis.

8.3 Plants as Carbon Dioxide Fixers

The Calvin cycle is a series of reactions that take place after the light reactions and produce carbohydrate before returning to the starting point.

Fixation of Carbon Dioxide

The first step of the Calvin cycle is **carbon dioxide fixation**. The enzyme that speeds this reaction is called **RuBP carboxylase**.

Reduction of Carbon Dioxide

Each of two 3PG molecule undergoes reduction to G3P in two steps in a reaction that uses some of the ATP and NADPH from the light reactions.

Regeneration of RuBP

It takes three turns of the Calvin cycle to re-form the RuBP required for the cycle to continue.

The Importance of the Calvin Cycle

G3P is the product of the Calvin cycle that can be converted to other molecules a plant needs.

8.4 Alternative Pathways for Photosynthesis

Various modes of photosynthesis have evolved to allow plants to live under varying environmental conditions.

C_3 Photosynthesis

In **C_3 plants** cells containing the Calvin cycle are exposed to the incoming CO_2. When RuBP carboxylase binds to carbon dioxide, it produces a 3-carbon molecule. However, the enzyme can also bind to oxygen and undergo a nonproductive, wasteful reaction called photorespiration.

C_4 Photosynthesis

An alternative pathway in **C4 plants**, called C_4 photosynthesis, evolved to bypass the photorespiration problem. Carbon dioxide is initially fixed into a 4-carbon molecule. The pathway separates the components of photosynthesis by location. C_4 plants tend to grow where the weather is hot and dry and stomata close in order to conserve water.

CAM Photosynthesis

The **CAM** (**crassulacean-acid metabolism**) **pathway** separates the components of photosynthesis by time. CAM plants fix carbon dioxide into a 4-carbon molecule at night, when they can keep their stomata open without losing much water.

8.5 Photosynthesis Versus Cellular Respiration

Both plant and animal cells carry on cellular respiration, but animal cells cannot photosynthesize. The overall equation for photosynthesis is the opposite of that for cellular respiration, but both are metabolic pathways within cells, and therefore consist of a series of reactions that the overall equation does not indicate.

CONNECTIONS

Center for Bioenergy & Photosynthesis at Arizona State University provides extensive information and links to photosynthesis research at **http://bioenergy.asu.edu/**

Photosynthesis Online from Arizona State University provides a review of relevant photosynthesis web sites at **http://www.life.uiuc.edu/govindjee/photoweb/**

DVD RESOURCES

***C3 and C4 Plants*, ISBN #978-1-4213-7296-9, Films for the Humanities and Sciences, http://ffh.films.com**

Photosynthesis, Item # **BVL3677, Films for the Humanities and Sciences, http://ffh.films.com**

***Photosynthesis*, ISBN # 978-1-4213-7291-4**, Films for the Humanities and Sciences, **http://ffh.films.com**

The Botany of Desire, Item # TBOD601, PBS special, **http://www.pbs.org**

LECTURE ENRICHMENT IDEAS

1. Have students read the Science in Your Life-Ecology "The New Rice" and discuss the answers to the questions at the end of the reading. Have students search the popular press for articles on genetically modified food crops.
2. Since carbon is neither created nor destroyed, is there any requirement that the amount of photosynthesis and cellular respiration be exactly equal over the short term of hours, days, years, or geological ages? Be sure students consider the carbon tied up in fossil fuels.
3. Discuss the alternative pathways for photosynthesis. How are the structures of these plants tied to their function? How is this function tied to the environment? If there are differences in efficiencies of C_3 and C_4 plants, why doesn't one or the other come to totally dominate a continent? This does require some knowledge of variation in climate.
4. Have students read the Science in Your Life -Ecology "Diesel Power from Algae" and discuss the answers to the questions at the end of the reading. Discuss the energy crisis and whether or not algae-based fuel is a viable solution to our energy demands. Students may want to search the popular press for articles on this topic.
5. Have students compare and contrast photosynthesis with cellular respiration. Include the structure of chloroplasts and mitochondria as well as the ATP synthase and chemiosmosis. Students are often confused by the equations for these reactions. Some students may think that if you run photosynthesis backwards you get cellular respiration. Explain the concept of metabolic pathways.

ESSAY QUESTIONS WITH ANSWERS

1. As days get shorter as winter approaches, what happens to the levels of oxygen and carbon dioxide produced by a plant such as a pine tree during both day and night?
Answer: Cellular respiration and CO_2 production continues during the night, while oxygen production dwindles as the daylight period shortens.
2. We can label molecules with radioisotopes and trace where they travel. Where would we find carbon dioxide labeled with radioactive carbon?
Answer: Carbon dioxide taken into a leaf is converted by photosynthesis into sugars and then other structural compounds. A percentage of this is then used in respiration by the plant, and the carbon would be released as carbon dioxide. Some of the carbon would remain in the body of the plant to be eaten by a consumer such as humans, where it would end up in our body.
3. Why aren't all photosynthetic organisms green?
Answer: Some photosynthetic organisms contain pigments other than chlorophyll, which allow them to capture other wavelengths of the sun's light. Carotenoids are red, orange, and yellow. Phycobilins are red, and phycocyanin is blue.