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TEACHER'S RESOURCE BOOK
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INTRODUCTION

What is the most abundant protein on Earth? The answer may surprise you.

Most people would think first of meat, trying to recall the name of the major protein in animal muscle. After all, it's not unreasonable to assume the most abundant protein is a structural molecule. They might guess proteins such as the myoglobin of animal muscle or the collagen that forms so much of the connective tissue in animal bodies, or perhaps the well-known hemoglobin that carries oxygen in our red blood cells.

These guesses, however, are incorrect.

In reality, the most abundant protein on Earth comes from plants. Even more surprising is the fact that the most abundant protein is actually an enzyme. The most abundant protein on Earth is RUBISCO or RuBP carboxylase. This enzyme makes up as much as 30 percent of the total protein of a typical plant leaf. Obviously, it has a very significant role in the life of plants, and, indirectly, it is important to most of the life on our planet.

RUBISCO carries out one of the important steps in photosynthesis. The abundance of the protein should help us to remember the crucial significance of photosynthesis in sustaining life. As people turn their attention to biology, they often put the study of plants second (or third or fourth...) to the study of animals, despite the dependency of animal life on plants. Ultimately, that dependency comes back to the essential role of photosynthesis—the ability of plants to use the sun's energy to feed almost all forms of life, either directly or indirectly.

Exploring Photosynthesis offers a lively way for your students to understand the interesting and essential aspects of photosynthesis, from the reactions themselves to the far-reaching implications of harnessing of the energy of the sun.

LEARNING OBJECTIVES

After watching the video ***Exploring Photosynthesis*** and participating in the activities in this Teacher's Resource Book, your students will be able to:

- state the overall function of photosynthesis
- explain how living systems—including humans—depend on photosynthesis
- describe where photosynthesis takes place
- describe the structure of a chloroplast in terms of its function
- relate the green color they see in plant leaves to the actual reactions of photosynthesis

The video ***Exploring Photosynthesis*** opens with a striking look at a human-devised way to harness solar energy: an array of solar collectors in the Arizona desert. This interesting example serves as an introduction to the idea of our dependency on energy from the sun. Plants have their own solar collectors to harness energy, and these biological systems are much more efficient than any built by humans.

Next the video takes us deep below the sunlit surface of the ocean to the black depths where scientists discovered deep sea vents in the ocean floor. These vents spew hot gases. The unusual animals and chemosynthetic bacteria living here provide a stark contrast to almost all other living systems on Earth: the life at the vents is unique, because it is not dependent on photosynthesis as the basis of the food web, unlike almost all other life.

The introductory segment of the video shows students how humans depend on energy stored through photosynthesis, either directly by eating plants, by eating the animals that eat plants, or even through the fossil fuels we burn.

The next portion of the video demonstrates the importance of the products of photosynthesis. Students learn that the chemical equation for photosynthesis is a kind of shorthand that represents the use of energy from sunlight to drive the manufacture of carbohydrates, using carbon from carbon dioxide. Water molecules supply the oxygen.

The program describes the importance of glucose in the formation of cellulose, starches and sugars. Using the image of a runner, students see how glucose is converted into energy in a process called *respiration*. Respiration is described as the opposite of photosynthesis. The program next looks into the importance of oxygen as a product of photosynthesis, and the fact that the oxygen comes from water.

The investigation of another key question is demonstrated on the video by middle school students doing a laboratory investigation. They show that the green portion of the leaf is the part carrying out photosynthesis. The green color results from chlorophyll pigments contained within subcellular structures called *chloroplasts*. The program presents the detailed structure of the chloroplast. It goes on to explain the spectrum of sunlight and its significance in the absorption of light energy by the chlorophyll pigments.

The program concludes with a brief summary of the key points.

STUDENT ACTIVITIES

The following activities, complete with student worksheets, provide a way to stimulate thinking. Doing the activities helps students synthesize the information and concepts presented in the video, thus improving retention and usefulness of what is being learned. In several cases, the activities require that students connect ideas from the video with outside content.

For some activities, you may want to have students work individually; other activities lend themselves well to group, or cooperative learning, work.

Consider setting up learning goals for students before they watch the video. One way to do this is to have them read and think about several activities you select ahead of time, to give students a sense of specific needs while they watch the video. Students would then complete the activities after viewing.

See *Notes to Teacher* on pages 5 and 6 for supporting information related to each student activity.

1. Human Dependence *pages 7 - 8*

This activity gives students a way to collect their own data. Their response can be based on information presented in the video, particularly that photosynthesis provides the link between the major source of energy for life (sunlight) and organisms higher in the food web (such as humans).

2. Light and Life *pages 9 - 10*

Activity 2 offers a combination of direct questions and other questions that require students to seek additional information from outside sources. This approach helps students learn to research a topic and to link learning between different topics.

Student responses will depend on the particular sources of information they access. Generally, students need to see that life at deep sea vents was surprising because most life on Earth is part of food webs that ultimately depend on photosynthetic organisms. At the vents there is no light.

Light penetration in the open ocean varies. According to Sea Life: A Complete Guide to the Marine Environment (G. Waller, ed., 1996), the area of abundant light and therefore photosynthesis is in the uppermost 100 meters; below 1000 meters there is no sunlight at all. For this reason, life is most abundant in the upper, lighted region. Keep in mind that some organisms move from depths to upper regions or rely on material from dead phytoplankton that filters down to lower levels.

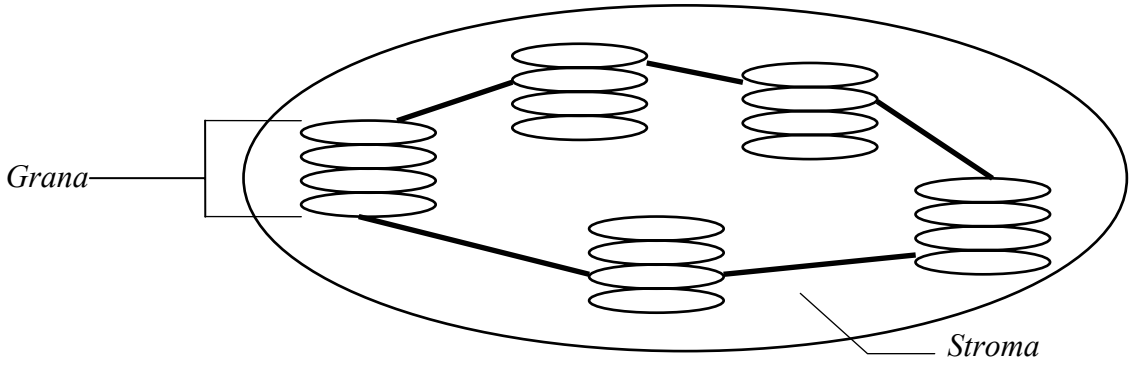
3. Photosynthesis *page 11*

(a) Photosynthesis produces PGAL (or students may say glucose). Energy from sunlight drives the reactions. Carbon dioxide contributes carbon. Water is the source of the oxygen given off by photosynthesis.

(b) $6\ CO_2 + 6\ H_20 \xrightarrow{\text{energy from sunlight}} C_6H_{12}0_6 + 6\ 0_2$

4. Chloroplasts *page 12*

Diagram of Chloroplast



Legend might read:

Chlorophyll is contained in the membranes that make up grana. Chloroplasts are found inside the cells in the green parts of plants, such as the leaves.

5. Life Processes *page 13*

Student diagrams and posters will vary. The main idea expressed by each team should be the role of photosynthesis (and subsequent reactions) to produce glucose and the role of cellular respiration to make available the energy stored in glucose.

6. Cellular Respiration *page 14*

This activity is another version of the ideas expressed in Activity 5, *Life Processes*.

STUDENT ACTIVITIES

HUMAN DEPENDENCE

"Humans depend on the photosynthesis that is carried out by plants."

After you answer the following questions, you will be asked to give evidence to support the statement above.

In the space below, list examples of ways that you or your family have used fossil fuels in the last month. Remember that fossil fuels include coal and petroleum products such as gasoline, oil, or kerosene. Petroleum products are also used to make plastics.

Write an explanation of how fossil fuels are formed:

_____

_____

_____

What foods do you eat? List 10 foods you eat often, and circle which ones contain food that comes directly from plants.

Activity 1-b continues on the next page.

HUMAN DEPENDENCE

When you eat meat, you are eating the muscle of an animal. Explain how the growth of that muscle could depend on plants.

What plant products do you use for clothing?

Now use your responses to the questions above to write a paragraph that justifies this statement:

Humans depend on the photosynthesis that is carried out by plants.

LIGHT AND LIFE

In 1977, scientists were surprised to discover life at the bottom of the ocean, near deep sea vents from which hot gases were escaping. Why were scientists surprised to find life here? *(Hint: Sunlight only penetrates the upper layers of the ocean.)*

In the box below, draw a cross-sectional diagram that shows the different levels of the ocean. You should indicate some of the differences in life forms found at each level. Use the information provided in the video and consult reference books, the Internet or biology textbooks to find out what you need to know.

Activity 2-b continues on the next page.

Which level of the ocean (near the surface, midway down, or near the bottom) has the most abundance of living organisms? Explain your response.

PHOTOSYNTHESIS

For this assignment, you must indicate what happens during photosynthesis in two separate ways:

1.

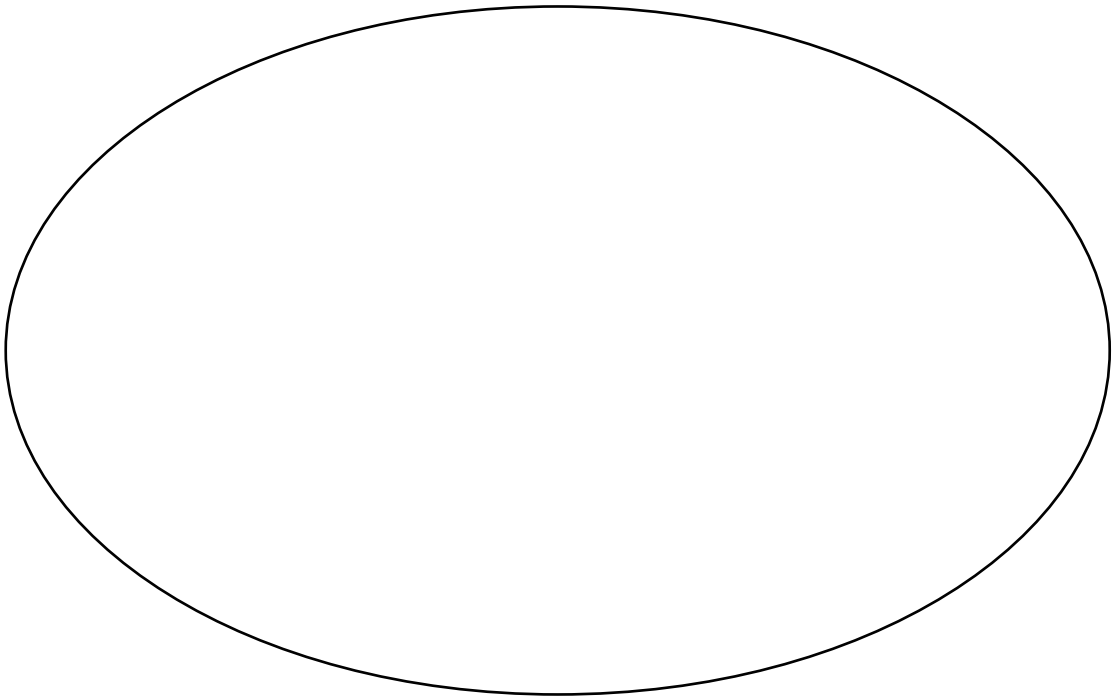
Use words to make a diagram or sentence to explain the events in photosynthesis. For example, what substances are used? What products are produced?

2.

In the space below, write all the events of photosynthesis as a chemical equation:

CHLOROPLASTS

Draw a diagram of a chloroplast showing the ***stroma*** and ***grana***. Show the location of the green pigment, ***chlorophyll***. Below your diagram, write several sentences that explain where chloroplasts are located and describe their role in photosynthesis.



For this activity, you will work in a team of four students. Half of your team is assigned to ***photosynthesis*** and half is assigned to ***cellular respiration***.

Step 1

Each half-team will draw a diagram that shows the function of the reactions assigned to your part of the team. You can use words, chemical symbols or drawings.

Draw your diagram on a separate sheet of paper.

> ***Important:*** *Be certain to show what materials are required for the process you are presenting, and show the outcome of the process. State why the reactions are useful to an organism.*

Step 2

Now rejoin your team and share your diagrams. As a whole team, make a poster that shows how these two processes (photosynthesis and cellular respiration) work together to support life.

You can brainstorm some ideas in the space below.

In the space below, answer the following question:

Do plants carry out cellular respiration? Explain why they do or do not need this process.

FACT SHEETS

GLOSSARY

Carbon dioxide: CO_2; carbon dioxide is found in the atmosphere. It also is a waste product of cellular metabolism, found in the air we exhale. Carbon dioxide is one of the starting materials for photosynthesis, providing the carbon source for the net production of sugar and other important cellular components from the photosynthetic product 3-phosphoglyceraldehyde (PGAL).

Cellular respiration: The reactions through which a living cell releases the stored chemical energy of the cellular fuel, breaking down glucose. The electron transport system of mitochondria generates short term energy storage forms (such as ATP) for use in cell functions. Respiration requires oxygen.

Chlorophyll: A pigment that provides the key link between light energy and chemical energy in photosynthesis. There are two types of chlorophyll: *chlorophyll a* absorbs blue and red light and is the primary pigment of photosynthesis. *Chlorophyll b* is an accessory pigment that absorbs light at slightly different wavelengths, extending the useable range. Chlorophyll is found in plants, algae, and cyanobacteria.

Chloroplast: A subcellular structure (organelle) within a plant cell in which photosynthesis takes place. Chloroplasts appear green because of their high content of the pigment chlorophyll.

Epidermis: The outermost layer of cells of a plant; the skin of animals also is referred to as epidermis.

Fossil fuels: Carbon-containing fuels such as coal, petroleum, and natural gas that are derived from ancient organic matter, chiefly from decayed plant material. Fossil fuels are ultimately derived from the products of photosynthesis that took place in ancient plants such as the giant tree ferns and horse-tails of the Carboniferous period of the Paleozoic era.

Glucose: A six-carbon sugar that is one of the most common forms of cellular fuel. It is synthesized in plants from the direct products of the dark reactions of photosynthesis, two molecules of phosphosgyceraldehyde (PGAL). In cellular respiration, glucose is a starting material. Glucose is a component of longer-term storage molecules such as starch in plants or glycogen in animals.

Granum (grana, plural): The site of light reactions in photosynthesis; grana are bodies found inside the chloroplast made of stacked thylakoid membranes.

Lumen: A general term that means the inner space of a hollow structure. In the case of photosynthesis, the inner space of the granum is referred to as the lumen.

GLOSSARY

NADPH: Abbreviation for nicotinamide adenine dinucleotide phosphate. NADPH is a short-term energy storage form, produced during the light reactions of photosynthesis.

Oxygen: O_2; gaseous oxygen is found in the atmosphere. It is a waste product of photosynthesis and a necessary starting material in cellular respiration.

Phytoplankton: A subgroup of the plankton which are microscopic organisms found in the world's oceans. These organisms have the ability to carry out photosynthesis.

Photosynthesis: Cellular reactions in which energy from sunlight is captured and stored in chemical form. In plants, photosynthesis takes place in chloroplasts. The light-dependent reactions occur in the grana (using enzymes bound to the thylakoid membranes of the grana) and result in production of high-energy compounds, ATP and NADPH. Energy from these compounds is used in the light-independent reactions (dark reactions) of the Calvin cycle that take place in the stroma and that produce two molecules of PGAL. PGAL that is transported out of the chloroplast can be used to produce glucose.

Stroma: The fluid within the chloroplast in which the grana bodies are located. The stroma contains the enzymes of the Calvin (Calvin/Benson) cycle, the so-called dark reactions.

Starch: A macromolecule that consists of many glucose molecules bonded together. Starch is a major storage form of cellular food in plants. The direct products of photosynthesis, molecules of PGAL, can be converted into glucose and subsequently starch.

Thylakoid: A membrane located within chloroplasts that contains the pigments and enzymes for the light reactions in photosynthesis. Stacks of thylakoid membranes form the grana.

Water: H_2O; water is a waste product of cellular respiration and it donates the oxygen that is a waste product of photosynthesis.

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