

# **PLANTS, LIGHT AND WATER**

# PLANTS, LIGHT AND WATER

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### **Teacher's Resource Book**

Ellen Friedman, Ph.D.

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# PLANTS, LIGHT AND WATER

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How do you interest your students in one of the most fundamental processes for life on Earth—photosynthesis? Many students ignore or feel intimidated by this topic, mainly because they do not understand it. Students may have had some prior exposure only in the form of memorizing a formula, and this prior experience has left them with reluctance for the topic. Yet photosynthesis—a starting point for the processes of life—is an active and exciting event. Through this process organisms capture the energy of the sun and trap carbon into living systems. Many elaborate processes and exchanges transfer matter and energy among organisms in a food web, but the source of the material and energy involved in these events depends originally on photosynthesis.

The video program, *Plants, Light and Water* examines the way chloroplasts in plants can harvest energy and carbon and use them to build basic resources in the form of simple sugars and storage starches. The content of the video program is very accessible, using straightforward language and clearly presented explanations. Although the process itself is somewhat complex, the fundamental ideas are simple and powerful: plants use sunlight as the energy source to fuel the making of their own food. Pigment molecules are excited by light, and this energy is transferred to energy transfer molecules and used to build simple sugars. Carbon for this process is drawn from the non-living world as carbon dioxide from the atmosphere, thus making a flow of carbon into living systems.

*Plants, Light and Water* is a program that combines the enticement of video images and sound with interactive student exercises from the print teachers' resource guide to bring the topic of photosynthesis in plants to life. This program follows the recommendations of the National Science Education Standards for Life Science not only with regard to specific content but also in approach. The program builds understanding and critical thinking by focusing on the big ideas related to photosynthesis: students think first about what is happening and why it matters—and then fill in the details. In addition, the student exercises from the teachers' resource guide not only review the material presented in the video, they also expand it. Through responding to the questions and doing the exercises, students reinforce what they have learned about this fundamental process of life.

**LEARNING OBJECTIVES**

After watching the video *Plants, Light and Water* and participating in the class activities included in this Teacher's Resource Book, your students will be able to:

- Understand the significance of the fact that plants make their own food through photosynthesis
- Be aware of the role of light as an energy source for plants to live and grow
- Know the way water is transported and used in plants
- Be aware of the reactants and products of photosynthesis
- Recognize the role of starch for energy storage
- Be able to write and understand a quantitative summary of photosynthesis
- Understand that plant cells release the energy from sugars and starch products through cellular respiration using oxygen
- Understand the function of roots, stems and leaves

The program *Plants, Light and Water* shows students how energy from sunlight plus water can be used by photosynthetic organisms to meet their fuel needs. Using a combination of visually appealing images and concise and clear graphics, the program helps students understand how water is transported and used by plants and see its important connection to the process of photosynthesis.

The program opens with a presentation of the concepts of autotrophy, heterotrophy and photosynthesis. Students begin to think about fuel needs in organisms and how energy is converted to chemical forms and stored. They learn that the green pigments called chlorophylls, which are found in subcellular chloroplasts, can trap energy from sunlight as a starting point in building new sugars. Excess sugars are converted to starch, which is found at sites of photosynthesis (such as green leaves) and also in storage tissue (such as tuberous roots).

In order to provide students with concrete images and examples for these concepts, *Plants, Light and Water* shows plant material under different conditions being tested for starch content. The simple iodine test provides a visually clear demonstration of starch production and encourages students to rely on evidence for the ideas presented. Using the water plant elodea, the video also demonstrates that photosynthesis produces a gas which, on testing with a glowing ember, shows itself to be oxygen. The rate of oxygen release is related to the amount of sunlight, which helps students make the connection between photosynthesis and oxygen production.

Plants do produce their own “food” but, like heterotrophic organisms, they still need to use the reactions of cellular respiration to make the energy and carbon stored in that food available for immediate use. This concept is too often overlooked by students, so the video emphasizes the dual occurrence of photosynthesis and cellular respiration in plants. Students learn the importance of ATP as an energy carrier and that ATP is produced during cellular respiration. They also learn that oxygen is required for this reaction. Thus the video builds a picture of the relationship between different cellular processes. As photosynthesis uses energy from sunlight to power the production of new sugar, cellular respiration can make the energy stored in sugar available for immediate use by a variety of cell processes by producing ATP. Oxygen is a waste product of photosynthesis, and oxygen is required for oxidative cellular respiration.

To make this material easier to understand and retain, the video first introduces the basic concepts of what is happening in these two important processes: Photosynthesis requires energy in order to produce “food” in the form of sugars, and cellular respiration uses sugar (glucose) to release energy (as heat and stored in ATP). Next the program adds an additional layer of knowledge: the reactants and products of each process are described *in words rather than symbols*. For example, students learn that photosynthesis requires water, carbon dioxide and light to carry out the reactions that produce glucose and the by-product oxygen.

Chlorophyll pigments are a key feature in the process in gathering energy that is supplied to the reaction. Students learn that the products of one reaction—sugars and oxygen—are actually the reactants for the other process.

Once the program has given students the opportunity to grasp these details through several examples and demonstrations, it then presents a simplified version of the chemical equations for the reactions. Photosynthesis is described by the formula  $6\text{CO}_2 + 6\text{H}_2\text{O} + \text{sunlight}$  (in presence of chlorophyll)  $\implies \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

Students now can see the formula without fear, because they can recognize that these are just symbols that stand for a process they already understand. This layering approach to the presentation helps students actually appreciate and remember what happens in these important processes rather than to simply memorize the equations. Students are reminded of the concepts of autotroph and heterotroph, and they see the role of photosynthesis in making plants autotrophic.

An important recommendation of the National Science Education Standards is to teach concepts and understanding rather than simply supplying facts and to help students to make meaningful connections between ideas. These connections not only help students better understand the significance of what they learn but also help students to retain and use the information they work so hard to acquire. With these goals as targets, *Plants, Light and Water* goes beyond an isolated description of the reactions of photosynthesis to put the process into context in a living plant. The program introduces the topic of transport of photosynthesis products throughout the plant, and it emphasizes the importance of delivering water and minerals to photosynthetic and other tissues.

The topic of transport is covered in considerable detail. The energy considerations of transport are emphasized. Visuals that demonstrate diffusion and osmosis provide concrete examples of these fundamental concepts. Students see that diffusion drives the movement of water into a wilted plant stem, and they also watch a demonstration of water moving across a semi-permeable membrane to into a compartment of lower concentration of water (higher concentration of the solute, in this case the protein called albumin).

These fundamental processes underlie the transport of material in plants. Students learn that passive capillary action and diffusion help move water from plant roots up through the stem, into leaves and out of the plant via transpiration. They see that plants deprived of water wilt and lose turgidity, but that movement of water into these tissues (and thus into the vacuoles inside the affected cells) can restore plant turgor. The demonstration is striking: this is not a subtle difference.

Students also learn that movement of sugars, which occurs via the vascular material known as phloem, occurs faster than could be explained simply by diffusion alone. Movement of dissolved sugars through the phloem is an energy-requiring or “active” process.

*Plants, Light and Water* also makes the connection between structure and function in vascular tissue. Students learn that xylem, the vascular tissue that transports water and dissolved substances, form a continuous set of tubes throughout the plant. They show up as veins in leaves. Xylem includes rigid fiber cells that provide support for tissue. Part of the cells of mature xylem die, but the remaining dead tissue continues to provide essential support for the plant. Unlike the xylem, the mature phloem contains living cells. Students learn about sieve tube cells and companion cells in phloem and see that structure is directly related to the function the tissue carries out for the plant.

Now the video ties together the big ideas already presented in the program. The reactions of photosynthesis, which require carbon dioxide, light and water, take place in green tissue that has contact with sunlight. This tissue also has a way to exchange gases (oxygen, carbon dioxide, water vapor) with the air through the openings known as stomata. The photosynthetic tissue is also tied to the delivery tissue of a plant: xylem that brings needed water from the roots, and phloem that carries away the photosynthetic products. The production and delivery of sugars supplies the energy needs of tissues throughout the plant. And like the vascular tissue, the roots also provide advantages other than transport for the plant: they provide a physical anchorage to hold the plant in place in the soil.

Photosynthesis is a fundamental process that not only is essential for a green plant's survival but also for the food web as a whole. *Plants, Light and Water* brings this topic to students in a manner that makes it meaningful and accessible.

Please note that students will learn the basic reactions of photosynthesis *based on a fundamental understanding of the overall process*. In that way they can avoid meaningless memorization of formulae. Students will need to learn some terms specific to photosynthesis, and the glossary can be helpful.

The combination of video, classroom discussion and student activities provides a powerful way to build layers of meaningful knowledge about photosynthesis. One useful approach is to address a few quick preview questions to students before they view the video, in order to draw attention to key concepts and so that you can get a more accurate sense of students' starting knowledge. At this stage it is not necessary to press for specific, detailed answers. These same questions can be used and expanded *after* students have seen the video in order to review the material while it is fresh in their minds. Then the use of student exercises offers students the opportunity for additional review and the chance to apply what they have learned to new material.

It is important for students to grasp the basic idea of large concepts before they try to fill in the details. Sometimes this requires learning in layers or cycles through a given topic.

These preview questions are intended to tantalize the students; if you use several of them as preview questions, it is best not to press for detailed or complete answers. Let students express ideas freely and then have the students amend or expand their own responses after they learn more from the program. Obviously time will limit how many you select, but it is also important to limit the number of preview questions to not overwork a topic prior to the students viewing the video.

You may want to follow the viewing of the video immediately with revisiting one or more of these questions for discussion as a quick way to set the material firmly in students' memory and understanding before they begin the activities. If so, you may want to press for greater depth in the answers than you did in the preview.

Sample responses are given in italics. For preview questions, expect a simplified version of these answers or expect that some students will not know the answers.

1. **Why are plants green?**

*Plants that do photosynthesis contain a green pigment (although they may contain other pigments that mask the color). Students may know that the pigment is called chlorophyll. The purpose of the question is to get students to make the connection between the pigment and its role, not necessarily to already know these terms.*

2. **What is photosynthesis?**

*It is the process through which an organism (such as a plant) makes its own food from nonliving material, using energy from sunlight.*

3. **Where does the carbon in plants come from?**

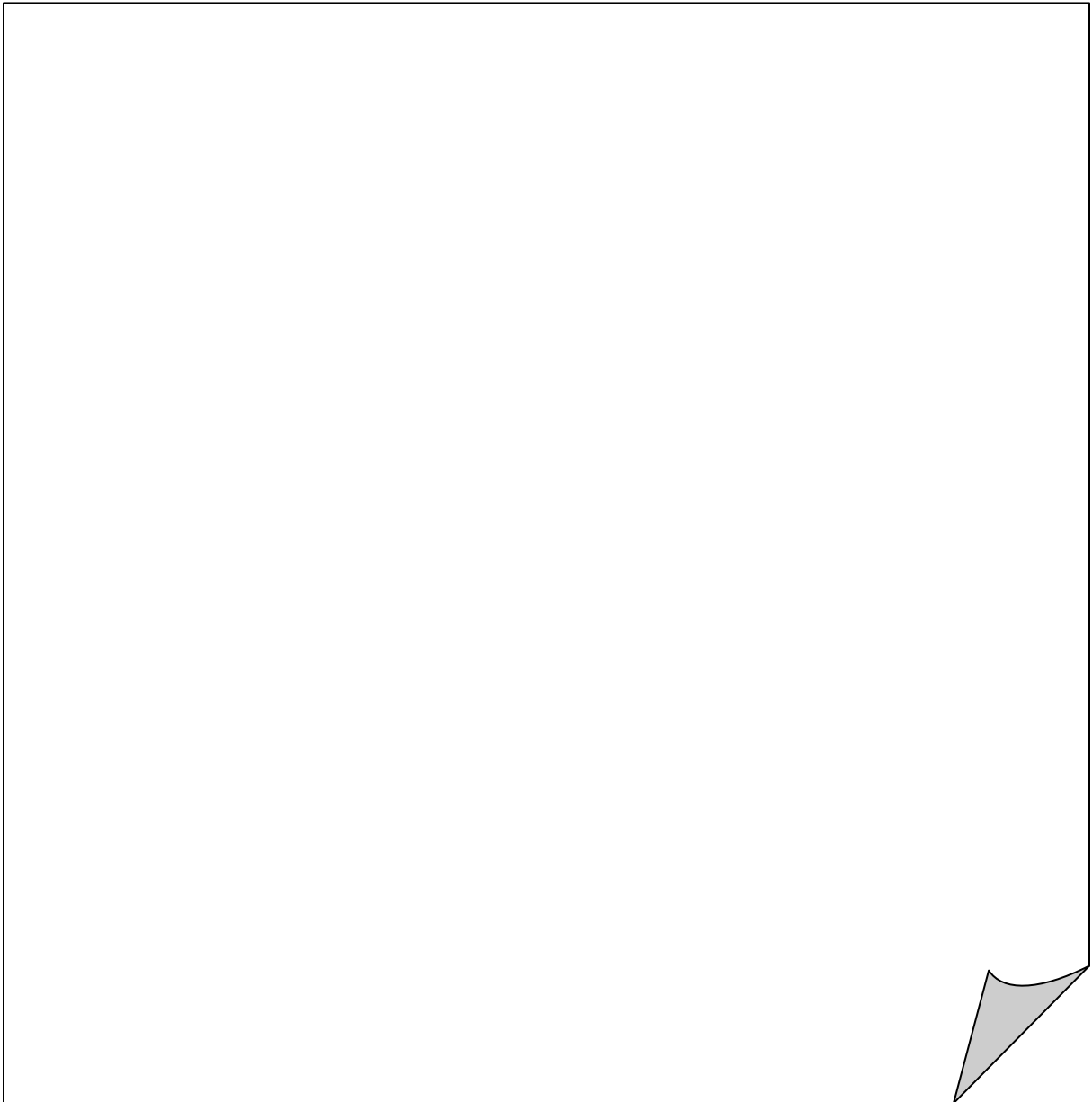
*The purpose of this question is just to place the question in their minds before they watch the video; if students do not already know the answer, let them wonder. Carbon comes ultimately from an inorganic source, the carbon dioxide of the atmosphere.*

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# **STUDENT ACTIVITIES**

Name: \_\_\_\_\_

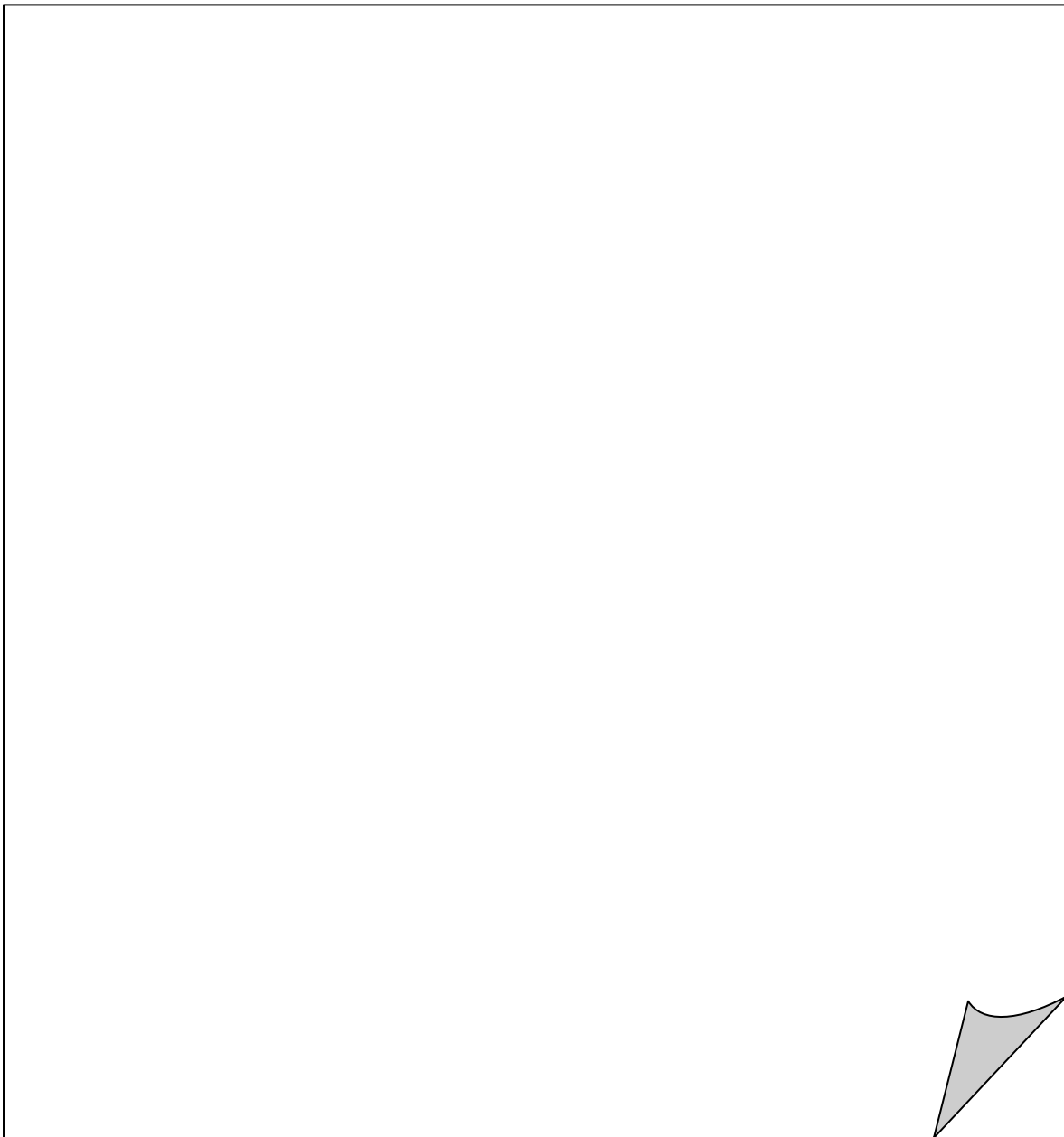
One of the most significant steps in photosynthesis is that carbon is brought into living systems, a process generally known as “carbon fixation”. Assume you can detect a molecule of carbon you breathe out from your lungs. (Scientists detect specific atoms by using a radioactive version such as  $^{14}\text{C}$ ). Write at least a paragraph and draw a diagram to show how might this molecule end up in a potato on your dinner plate? Label or enlarge specific structures to make your explanation clear.



Name: \_\_\_\_\_

Research scientists can use a radioactive version of particular elements as tags to be able to trace the events in biochemical reactions. Suppose you had access to radioactive carbon,  $^{14}\text{C}$ , and could use it to label the carbon in some inorganic source such as the carbon dioxide of air.

*Draw a diagram with labels and descriptions to clearly show how that  $^{14}\text{C}$  could end up in the starch inside of a potato.*



Name: \_\_\_\_\_

1. What is the role of light in photosynthesis?

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2. Why is this an advantage to almost all living systems?

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3. How is the energy of light captured and used?

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4. Scientists talk about “light dependent reactions” and “light independent reactions” in photosynthesis. What does this mean?

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5. What does light dependent reactions produce? What does light independent reactions produce?

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6. Can either of these types of reactions take place in the dark?

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Name: \_\_\_\_\_

## Answer Key

1. What is the role of light in photosynthesis?  
*Light supplies the energy for the fixation of carbon and production of high-energy compounds.*
2. Why is this an advantage to almost all living systems?  
*Plants are bringing energy (and carbon) into living systems and storing energy in chemical compounds. Other organisms use plants as food. Organisms also benefit from the release of oxygen to the atmosphere during photosynthesis. Without light, these reactions eventually stop.*
3. How is the energy of light captured and used?  
*Pigments such as chlorophylls become energized by light and transfer this energy (as excited electrons) to reactions that produce high-energy molecules such as ATP.*
4. Scientists talk about “light dependent reactions” and “light independent reactions” in photosynthesis. What does this mean?  
*Some reactions require light in order to proceed while others can take place without a source of light.*
5. What does light dependent reactions produce? What does light independent reactions produce?  
*Light dependent reactions transfer energy from sunlight to high-energy compounds such as ATP (and NADPH). Light independent reactions fix carbon and produce sugars.*
6. Can either of these types of reactions take place in the dark?  
*Yes, light independent reactions will take place in the dark as long as there is a supply of energy rich compounds such as ATP.*



Name: \_\_\_\_\_

**PHOTOSYNTHESIS AND  
CELLULAR RESPIRATION**

## Part Two: Keeping Score

Look at the chemical equations you have written. Check to see that they “add up” or balance with regard to the total atoms in reactants and products. Then answer these questions.

1. How many carbon atoms are in the reactants for cellular respiration (not including the generation of ATP)?

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2. Given the number you recorded, how many should be present in the products of cellular respiration? Explain.

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3. How many oxygen atoms are in the products of photosynthesis, and what form do they take?

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4. How does the fate of the oxygen atoms in the products of photosynthesis affect animal life on Earth?

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Name: \_\_\_\_\_

## Answer Key

### Part Two: Keeping Score

Look at the chemical equations you have written. Check to see that they “add up” or balance with regard to the total atoms in reactants and products. Then answer these questions.

- 1. How many carbon atoms are in the reactants for cellular respiration (not including the generation of ATP)?**  
*Six carbon atoms, in the form of glucose.*
- 2. Given the number you recorded, how many should be present in the products of cellular respiration? Explain.**  
*Six carbon atoms, because the equations should balance.*
- 3. How many oxygen atoms are in the products of photosynthesis, and what form do they take?**  
*Eighteen, six of which are in sugar and twelve in oxygen gas.*
- 4. How does the fate of the oxygen atoms in the products of photosynthesis affect animal life on Earth?**  
*Plants add oxygen to the air, which provides a source of oxygen for cellular respiration. Students may connect the question to outside information and realize that the oxygen added to the air also contributes to the ozone layer that protects organisms from dangerous ultraviolet radiation.*

Name: \_\_\_\_\_

**PHOTOSYNTHESIS  
AND THE OCEAN**

Green land plants are not the only organisms to carry out photosynthesis. Many microorganisms in the ocean, collectively called phytoplankton, also are photosynthetic. NASA has devised a way for instruments on board satellites to observe and measure the amount of certain pigments near the ocean surface.

1. Why would measurement of pigments near the surface of ocean tell scientists anything about the amount of ocean life in those areas?

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2. In what part of the ocean would you predict you would find photosynthetic phytoplankton?

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3. Scientists are studying the life processes and pigments found in various marine photosynthetic bacteria and green algae. Do an Internet search or read in *Science News* or other reliable sources of research news for recent developments. Make a concise report to the class on this topic.

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4. Photosynthetic organisms are producers who synthesize their own food using sunlight to supply the energy. Almost all life on Earth depends on these producers, but there is an exception found at deep vents in the ocean floor known as smokers. Organisms living at these vents house special bacteria in their bodies, bacteria that are producers but are not photosynthetic. How can this happen? (Hint: read or do an Internet search to find out more about autotrophic bacteria at deep-sea vents. NASA website often has updates on research at these fascinating locations).

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Name: \_\_\_\_\_

## Answer Key

Green land plants are not the only organisms to carry out photosynthesis. Many microorganisms in the ocean, collectively called phytoplankton, also are photosynthetic. NASA has devised a way for instruments on board satellites to observe and measure the amount of certain pigments near the ocean surface.

1. **Why would measurement of pigments near the surface of ocean tell scientists anything about the amount of ocean life in those areas?**

*Photosynthetic organisms rely on pigments to collect the energy of sunlight. These producers are the basis for food webs, so they also are indicators of the amount of other ocean life in the area.*

2. **In what part of the ocean would you predict you would find photosynthetic phytoplankton?**

*Because they need sunlight, they are restricted to the upper few meters of the huge depth of ocean.*

3. **Scientists are studying the life processes and pigments found in various marine photosynthetic bacteria and green algae. Do an Internet search or read in Science News or other reliable sources of research news for recent developments. Make a concise report to the class on this topic.**

*Answers will vary.*

4. **Photosynthetic organisms are producers who synthesize their own food using sunlight to supply the energy. Almost all life on Earth depends on these producers, but there is an exception found at deep vents in the ocean floor known as smokers. Organisms living at these vents house special bacteria in their bodies, bacteria that are producers but are not photosynthetic. How can this happen? (Hint: read or do an Internet search to find out more about autotrophic bacteria at deep-sea vents. NASA website often has updates on research at these fascinating locations).**

*Students should be able to find their own information about sulfur oxidizing bacteria at ocean vents that rely on oxidation of hydrogen sulfide at these hot vents for energy to drive chemosynthetic reactions. Useful Internet keywords for search include "thermal ocean vents". NASA for example published an online update on this research in March of 2004. The vents were discovered by scientists in 1977 diving in the ocean vessel known as Alvin.*

Name: \_\_\_\_\_

**PLANT STRUCTURE  
AND PHOTOSYNTHESIS**

Trees are among the largest photosynthetic plants and are found in many different environments. To consider how plants function on this large size scale, read the following description of trees based on information from the book Trees: Their Natural History, written by Peter Thomas and published by Cambridge University Press.

*Trees are food producers on a grand scale. By definition, trees are plants with a self-supporting woody stem (trunk) of a height at least 6 m (20 ft) tall. Banana “trees” for instance are not truly trees because the trunk is just bundled leaves and it is not woody. The woody material of the trunk or stem contains a lot of cellulose fiber. It is secondary growth of the cambium layer beneath the bark. The oldest wood is in the center of the tree. The trunk contains vascular material (xylem and phloem) that extends all the way from roots to leaves. In the leaves, it can be seen as veins. The trunk of a tree supports and raises toward the sun its collection of leaves. How many leaves does a tree have? This varies with species, but examples are listed in this table:*

<i>Species of tree</i>	<i>Approximate number of leaves in a mature tree</i>
Apple	75,000
Birch	200,000
Oak	700,000
American Elm	5,000,000

*A large, flat leafed deciduous tree loses 40-300 l/day of water in contrast to a woody cactus in the desert that loses only 25 l/day of water. Water loss occurs mainly through pores in leaves called the stomata. This is also the entrance point for carbon dioxide. Stomata are usually found on the underside of leaves. They can close to reduce water loss. Leaves vary in the number of stomata they have, but generally these pores are not more than 1 percent of the leaf surface. Leaves on a mature deciduous tree have different shapes and different amount of greenness. They fall roughly into two groups: sun and shade leaves. Shade leaves are thinner, broader and darker green than the sun type of leaf for the same tree. Shade leaves also tend to be less lobed in shape and to have thinner waxy coating (cuticle). When shaded from the sun, sun leaves become thinner and darker green. At different points in development, the number of shade or sun leaves on a particular tree may change.*

*This activity is continued on the following page.*

Name: \_\_\_\_\_

**PLANT STRUCTURE  
AND PHOTOSYNTHESIS**

1. Are trees vascular plants? Explain.

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2. Describe the role of the vascular system for vascular plants.

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3. Why are leaves often green and roots are not?

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4. Stomata are the openings through which carbon dioxide enters the plant. How much of the leaf surface is generally covered with stomata? Given that carbon dioxide is useful for photosynthesis, why don't leaves have a larger percentage of their surface covered with stomata?

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5. Describe the average amount of leaves on mature deciduous trees and explain why that number is useful for photosynthesis.

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## Answer Key

- 1. Are trees vascular plants? Explain.**  
*Yes, trees have vascular tissue to move water and minerals up from roots and into other tissue and to distribute fuel (sugars) from sites of photosynthesis to tissues that need energy or building material.*
- 2. Describe the role of the vascular system for vascular plants.**  
*Like non-woody plants, vascular material in trees is used to transport water, minerals and biomolecules such as sugars. However, the dead cells of xylem in woody trunks and branches also provides physical support for the tree and helps it reach a size sufficient to support photosynthesis. By definition, a tree is a self-supporting plant.*
- 3. Why are leaves often green and roots are not?**  
*Leaves use a green pigment to carry out photosynthesis, which requires sunlight. Roots are buried in soil and thus not able to carry out photosynthesis, so it is not surprising that they lack this green pigment.*
- 4. Stomata are the openings through which carbon dioxide enters the plant. How much of the leaf surface is generally covered with stomata? Given that carbon dioxide is useful for photosynthesis, why don't leaves have a larger percentage of their surface covered with stomata?**  
*Stomata are also the site of water loss through transpiration. There needs to be a balance between the benefit of more carbon dioxide and too much loss of water. Stomata may close at midday in a hot sunny place.*
- 5. Describe the average amount of leaves on mature deciduous trees and explain why that number is useful for photosynthesis.**  
*Trees have tens to hundreds of thousands of leaves. This huge number results in a large surface area to expose to sunlight for photosynthesis.*

Name: \_\_\_\_\_

**SUNLIGHT AND PLANT  
DEVELOPMENT: TREES**

Use the information from the video, the description of trees from Activity 5 plus data from the field to answer these questions.

1. Would you expect a young tree growing in a forest beneath the branches of mature trees to have a 50-50 mix of sun and shade leaves or would you expect more of one kind? Explain your answer.

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2. Would it help a tree for leaves in the shade to be darker green than those in full sun? Explain.

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3. A large tree is cut down, and suddenly a small tree that had grown in its shade is completely exposed to direct sunlight. What would you expect to happen? Explain your answer and justify your conclusions.

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4. Do trees in your area display sun and shade leaves? Make a field trip to observe tree leaves. Write the question you would like to address, design a good way to collect data, make your observations and draw conclusions, giving data (evidence) to support what you say. There are many ways you can address this general question about shade and sun leaves; the one you pick should be based in part on what trees you have available and how long you can observe them (and under what conditions). Here are some examples of specific questions you could ask:

- Does a single tree contain both types of leaves? (Be sure to examine more than one example; record its location and type of tree; record how much and where the sunlight falls on the trees you observe.)
- Do young trees in the shade of another tree have more shade leaves or sun leaves?
- How quickly does a sun leaf begin to change into a shade type of leaf if removed from direct sun exposure?

Name: \_\_\_\_\_

## Answer Key

Use the information from the video, the description of trees from Activity 5 plus data from the field to answer these questions.

- 1. Would you expect a young tree growing in a forest beneath the branches of mature trees to have a 50-50 mix of sun and shade leaves or would you expect more of one kind? Explain your answer.**

*Generally a young tree growing in the shade would have almost entirely shade leaves.*
- 2. Would it help a tree for leaves in the shade to be darker green than those in full sun? Explain.**

*Darker green indicates more chlorophyll. With less light available, more pigment to collect light is helpful.*
- 3. A large tree is cut down, and suddenly a small tree that had grown in its shade is completely exposed to direct sunlight. What would you expect to happen? Explain your answer and justify your conclusions.**

*If the change is abrupt, the tree may die because the leaf structure is not suited to the new conditions. For example, a thin broad shade leaf might lose too much water and wilt in the sun. A tree is likely to be able to adapt to gradual change.*
- 4. Do trees in your area display sun and shade leaves? Make a field trip to observe tree leaves. Write the question you would like to address, design a good way to collect data, make your observations and draw conclusions, giving data (evidence) to support what you say. There are many ways you can address this general question about shade and sun leaves; the one you pick should be based in part on what trees you have available and how long you can observe them (and under what conditions). Here are some examples of specific questions you could ask:**

  - **Does a single tree contain both types of leaves? (Be sure to examine more than one example; record its location and type of tree; record how much and where the sunlight falls on the trees you observe.)**
  - **Do young trees in the shade of another tree have more shade leaves or sun leaves?**
  - **How quickly does a sun leaf begin to change into a shade type of leaf if removed from direct sun exposure?**

*Student responses will depend on the question and observation they select. Students can be assessed on how well they understand the exercise, on whether their question is specific enough to answer and whether observations and data recording are careful and sufficient. Students will need to devise a system for measuring leaf size and shape and relative degree of green color.*

Name: \_\_\_\_\_

**INTERACTIONS: SUGARS AND POLLINATORS**

Sugars are produced by photosynthesis, using carbon from carbon dioxide and energy from sunlight. Chemical reactions can further can one sugar into another. For example, the 6-carbon first product of photosynthesis is converted into two 3-carbon molecules, some of which is used to produce glucose that is needed for cellular respiration. Some sugars are converted to a double-sugar known as sucrose (table sugar). It is a combination of two other sugars, glucose and fructose. Often sucrose is the form transported from one tissue to another.

Many flowering plants produce a sweet liquid known as nectar that attracts pollinators, animals which eat the nectar and accidentally carry pollen from one flower to another. Flowers differ with the amounts of different sugars found in their nectar. Scientists observed which pollinators went most often to which flowers based on the relative amounts of sugar in the nectar. This table shows the data from their observations.

Pollinators	Ratio of sucrose to glucose + fructose			
	<0.1	0.1-0.5	0.5-1.0	>1.0
hummingbirds	0	13	32	55
sunbirds	74	23	3	0
short-tongued bees	44	39	11	6
long-tongued bees	6	37	24	33
butterflies	7	23	32	38
bats	29	62	6	3
flies	40	38	10	12
hawk moth	3	13	31	53

These data are from *The Natural History of Pollination* by Michael Proctor, Peter Yeo and Andrew Lack, published by HarperCollins Publishers (London) in 1996.

*This activity is continued on the following page.*

Name: \_\_\_\_\_

**INTERACTIONS: SUGARS AND POLLINATORS**

1. Do flowers associated with the left-most column (ratio  $<0.1$ ) have more or less sucrose than flowers associated with the right-most column (ratio  $>1.0$ )? Explain your response.

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2. Do hummingbirds prefer nectar rich in sucrose or low in sucrose? Explain.

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3. Do flies prefer nectar rich in sucrose or low in sucrose? What data supports your conclusion?

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4. How would you describe the nectar preferred by bats?

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5. Do these data support a general pattern of insects feeding on low nectar flowers and vertebrate animals (birds and bats) feeding on high nectar flowers? Give specific data to support your answer.

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6. Consider this observation: "Sucrose-rich flowers generally have long, deep flower tubes." Do the data reported here support or refute this statement? Explain.

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Name: \_\_\_\_\_

## Answer Key

Sugars are produced by photosynthesis, using carbon from carbon dioxide and energy from sunlight. Chemical reactions can further can one sugar into another. For example, the 6-carbon first product of photosynthesis is converted into two 3-carbon molecules, some of which is used to produce glucose that is needed for cellular respiration. Some sugars are converted to a double-sugar known as sucrose (table sugar). It is a combination of two other sugars, glucose and fructose. Often sucrose is the form transported from one tissue to another.

Many flowering plants produce a sweet liquid known as nectar that attracts pollinators, animals which eat the nectar and accidentally carry pollen from one flower to another. Flowers differ with the amounts of different sugars found in their nectar. Scientists observed which pollinators went most often to which flowers based on the relative amounts of sugar in the nectar. This table shows the data from their observations.

*Note to teachers:*

*You may first want to explain that the symbol “<” means “less than” and the symbol “>” means “greater than”. Also verify that students understand how to read these data, as tested in the first question. In other words, before students make conclusions about the association between sugar content in a plant and its pollinators, they should clearly understand that plants with >0.1 ratio of sucrose to glucose+ fructose have very little sucrose compared with plants in the far right column whose ration is >1.0.*

*This activity affords an excellent opportunity for students to think critically, read and use quantitative data and make connections to other biology content*

1. **Do flowers associated with the left-most column (ratio <0.1) have more or less sucrose than flowers associated with the right-most column (ratio >1.0)?**

**Explain your response.**

*They have less sucrose because the ratio is between sucrose (numerator) and the separate sugars glucose and fructose (denominator). Thus the flowers associated with the left hand column have a very small amount of sucrose.*

2. **Do hummingbirds prefer nectar rich in sucrose or low in sucrose? Explain.**

*Hummingbirds visit flowers reported in the right hand column (sucrose rich) much more often than those in the far left hand column (sucrose poor). This difference is shown by a larger number of visits (55) as compared to 0.*

Name: \_\_\_\_\_

## Answer Key continued

3. **Do flies prefer nectar rich in sucrose or low in sucrose? What data support your conclusion?**

*Using the same reasoning, students should conclude that flies prefer flowers low in sucrose but rich in glucose and fructose. This conclusion is based on data showing 40 visits to sucrose-poor flowers as opposed to 12 visits to sucrose-rich flowers, and with a consistent pattern for intermediate values. It is excellent if students also notice that flies do not completely avoid flowers richer in sucrose.*

4. **How would you describe the nectar preferred by bats?**

*Like flies, bats prefer flowers low in sucrose but rich in glucose and fructose.*

5. **Do these data support a general pattern of insects feeding on low nectar flowers and vertebrate animals (birds and bats) feeding on high nectar flowers? Give specific data to support your answer.**

*No, there are examples of insects feeding on both types of flowers and examples of vertebrates feeding on both types of flowers.*

6. **Consider this observation: “Sucrose-rich flowers generally have long, deep flower tubes.” Do the data reported here support or refute this statement? Explain.**

*Yes, the data partially support the statement. They do not refute it. Pollinators with long mouths or collection parts, such as hummingbirds and long-tongued bees, prefer flowers that are richer in sucrose, as shown by higher numbers of visits for flowers in the far right column of data for each of these animals. However, these observations do not rule out the possibility that shallow flowers also are sucrose-rich.*

Name: \_\_\_\_\_

**LIGHT AND DEVELOPMENT OF  
PLANT TISSUE**

Green plants carry out photosynthesis. Why are the plants green?

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Research Question:

Is light required for plants to produce chlorophyll? In order to test this question, design an experiment in which you observe the effect of light on plants' ability to produce green tissue.

Suggested Protocol:

Plant fast-sprouting seeds, such as bean seeds, in controlled light conditions and carefully record what you observe about plant growth and color. Be certain to provide enough samples for accurate observation and provide specific controls.

For example, you could plant about 24 beans, with half or two thirds kept in the dark and the rest exposed to light for at least several hours a day. Dark samples could be placed under a box or bag with occasional opening for observation and air circulation, or they could be kept in a dark cabinet. Check on the beans in the dark carefully, with minimal exposure to light. Record the day each sample sprouts, when true leaves (not the initial dicotyledon leaves) grow, and the color of each plant every several days. Water and fertilize as needed.

After plants have had a chance to grow, bring some of the dark seedlings out to the light, recording their appearance, color, and the day they are exposed. Carefully record any changes you observe each day, especially in their color. Continue to observe all the seedlings. If time permits, you might want to remove some of the light-only seedlings to the dark to observe the parallel change. Once your data collection is complete, answer the research question about the relationship between light and chlorophyll based on your observations. It may help to organize your observations around some simpler issues as you build up to your conclusion. For example:

- Is light required for germination?
- Do plants grow faster in the presence or absence of light over the time period you observed?
- Do you observe a difference in the color of plant tissue grown in light or dark?
- Does light appear to act as a “switch” for the genes that control chlorophyll production?

Explain your reasoning and support your ideas with evidence.



Name: \_\_\_\_\_

## Answer Key

**autotroph:** *Organism that can manufacture its own food (fuel) from inorganic sources.*

**heterotroph:** *Organism that depends on organic sources to supply its energy and carbon.*

**Which term applies to green plants? Explain your response.**

*Green plants manufacture their own food and thus are autotrophs.*

**Which term applies to humans? Explain your response.**

*Humans are heterotrophs because they rely on eating food that was originally produced by other organisms (plants, fungi or animals generally).*

Name: \_\_\_\_\_

**TALKING ABOUT  
CHEMICAL REACTIONS**

1. In a chemical reaction, what is meant by the term “reactants”?

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2. In a chemical reaction, what is meant by the term “products”?

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3. In a chemical reaction, what is meant by the term “catalyst”?

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4. In a chemical reaction, what is meant by the term “enzyme”?

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5. Define these terms:

ergonomics:

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undergone:

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6. What is the difference in the terms “inorganic” and “non-living”?

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Name: \_\_\_\_\_

## Answer Key

- 1. In a chemical reaction, what is meant by the term “reactants”?**  
*Reactants are the substances that provide the starting material in a reaction; they are changed in some way in the reaction.*
- 2. In a chemical reaction, what is meant by the term “products”?**  
*Products are the materials that result from a chemical reaction. An arrow in a chemical formula indicates that the reaction proceeds from reactants to products.*
- 3. In a chemical reaction, what is meant by the term “catalyst”?**  
*A catalyst is a component that helps a chemical reaction to occur but which is not directly a reactant or product and is not used up or modified in the reaction.*
- 4. In a chemical reaction, what is meant by the term “enzyme”?**  
*An enzyme is a chemical catalyst in a reaction in a living system. Most enzymes are proteins.*
- 5. Define these terms:**

**ergonomics:** *An ergonomics reaction releases energy. Students might be helped in remembering the term by associating the word with “exit”—going out—in that energy goes out to the environment in an ergonomics reaction.*

**undergone:** *An undergone reaction requires an input of energy in order to take place.*
- 6. What is the difference in the terms “inorganic” and “non-living”?**  
*“Inorganic” means a source that is not associated with an organism, live or dead. “Non-living” is sometimes used for that idea, but that use can be confusing, because non-living could mean material produced by an organism that has died. Our food is generally nonliving when we eat it, but it is an organic source of fuel, not an inorganic source.*

Name: \_\_\_\_\_

1. What important function does photosynthesis provide for plants?

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2. What are the reactants in photosynthesis?

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3. What is the ultimate source of energy in photosynthesis?

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4. “Carbon fixation” is a term that refers to trapping carbon from an inorganic source into a living system. What connection is there between carbon fixation and photosynthesis?

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Name: \_\_\_\_\_

## Answer Key

- 1. What important function does photosynthesis provide for plants?**  
*Photosynthesis is a set of reactions that let plants produce their own food.*
- 2. What are the reactants in photosynthesis?**  
*The reactants are carbon dioxide and water.*
- 3. What is the ultimate source of energy in photosynthesis?**  
*The energy comes into living systems from sunlight.*
- 4. “Carbon fixation” is a term that refers to trapping carbon from an inorganic source into a living system. What connection is there between carbon fixation and photosynthesis?**  
*Carbon is “fixed” or trapped into living systems from a nonorganic source—carbon dioxide in the air—when the carbon is incorporated into sugars during photosynthesis.*

Name: \_\_\_\_\_

**PHOTOSYNTHESIS  
AND SUGAR**

1. The video described some of the roles that sugar plays for plants. What are they?

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2. How is sugar moved from one part of the plant to another?

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3. What is meant by the term “carbohydrates”?

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4. What is the connection between sugar and starch?

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5. What is the connection between photosynthesis and sugar?

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Name: \_\_\_\_\_

## Answer Key

- 1. The video described some of the roles that sugar plays for plants. What are they?**  
*Sugars have many specific functions in a cell, but the video especially focused on their role as short term energy sources. They are products of photosynthesis and serve as a source of energy (in cellular respiration) for plants.*
- 2. How is sugar moved from one part of the plant to another?**  
*Sugar is moved through conductive tissue (such as veins in leaves) from the sites of photosynthesis to other cells in need of sugar. (Please note: One of the most common forms of sugar being transported is sucrose, although it is converted to glucose before being used for energy needs of cells.)*
- 3. What is meant by the term “carbohydrates”?**  
*Carbohydrates are a class of biochemical compounds that consist of carbon, oxygen and hydrogen. They include sugars and starch.*
- 4. What is the connection between sugar and starch?**  
*Sugar is a short-term energy storage form and is produced by photosynthesis. If it is not needed immediately, excess sugar is used as a building block for the carbohydrates known as starch for longer-term energy storage.*
- 5. What is the connection between photosynthesis and sugar?**  
*Photosynthesis ultimately produces sugars (Additional detail not discussed in the video: the immediate product, a 6-carbon sugar, is rapidly converted to two 3-carbon compounds. Some of these products are used to regenerate a 5-carbon sugar that is the receptor for carbon in photosynthesis. In this way, a net addition of carbon is accomplished gradually rather than 6 new molecules of carbon being added with each round of photosynthesis.)*

Name: \_\_\_\_\_

1. What is the role of starch in plant's ability to produce fuel?

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2. In the video, leaves were tested with iodine. What would that show?

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3. If photosynthesis requires light, why test a leaf exposed to light and one removed from light?

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4. In the video, what results did this test show?

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Name: \_\_\_\_\_

## Answer Key

- 1. What is the role of starch in plant's ability to produce fuel?**  
*Starch is used for long-term energy storage.*
- 2. In the video, leaves were tested with iodine. What would that show?**  
*Testing with iodine reveals the presence of starch.*
- 3. If photosynthesis requires light, why test a leaf exposed to light and one removed from light?**  
*The comparison provides a control. If the question is to understand the effect of light (and by inference, photosynthesis) on starch production, it is necessary to test a leaf exposed and one protected from light.*
- 4. In the video, what results did this test show?**  
*A leaf exposed to light has more starch than a leaf kept in the dark. By inference based on outside knowledge, the test supports the idea that photosynthesis leads to more starch production (though not necessarily directly).*



Name: \_\_\_\_\_

## Answer Key

1. **In the video, an aquatic plant called elodea was trapped under a glass container, allowing us to see bubbles given off. When the amount of light on the plant was increased, more bubbles occurred. What is the explanation?**

*The reactions that release a gas are dependent on light.*

2. **Why was the gas from the bubbles tested with a glowing splint? What was the result?**

*This test was done to show that the gas being released is oxygen.*

3. **What does this demonstration show about photosynthesis?**

*Through additional knowledge, students realize that plants carry out the reactions known as photosynthesis and that at least a part of these reactions requires light. This demonstration lets students infer that photosynthesis results in a production of oxygen gas.*



Name: \_\_\_\_\_

## Answer Key

- 1. What are chloroplasts and where are they found?**  
*Chloroplasts are substructures in green plant cells. Green parts of plants generally are the stems and mainly the leaves. From outside sources, students may know that chloroplasts are membrane bound organelles found only in eukaryotic photosynthetic cells. Based on the video alone, it is sufficient to know that chloroplasts are the site where photosynthesis occurs.*
- 2. Why are chloroplasts green?**  
*Chloroplasts contain the green pigments known as chlorophyll.*
- 3. What role do chloroplast play in photosynthesis?**  
*Chlorophyll found in chloroplasts gather energy from sunlight to power the first steps in photosynthesis.*

Name: \_\_\_\_\_

1. What is meant by the term “cellular respiration”?

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2. Explain why human cells need to carry out cellular respiration.

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3. Do green plant cells carry out cellular respiration? Explain.

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4. What is ATP and what role does it play in cells?

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5. Is oxygen a product or reactant in cellular respiration? Explain.

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## Answer Key

- 1. What is meant by the term “cellular respiration”?**  
*Cellular respiration refers to the reactions through which a cell releases energy stored in a starting product such as glucose and makes it available for use by the cell.*
- 2. Explain why human cells need to carry out cellular respiration.**  
*The housekeeping reactions of human cells need energy, and cellular respiration is a very efficient way to release the energy stored in glucose.*
- 3. Do green plant cells carry out cellular respiration? Explain.**  
*Although green plants carry out photosynthesis, they also need cellular respiration to make the energy of sugars such as glucose available for use, just as cells of animals and other organisms need to do. The difference is not the requirement for cellular respiration but the source of the fuel. In the case of humans, for instance, we must get the fuel from other organisms while plants can make their own from inorganic sources.*
- 4. What is ATP and what role does it play in cells?**  
*ATP is a molecule that stores a large amount of energy that can be easily made available for chemical reactions in a cell. Students may recall from the video that one advantage of cellular respiration is the production of ATP. Students may independently know that ATP is an abbreviation for adenosine triphosphate.*
- 5. Is oxygen a product or reactant in cellular respiration? Explain.**  
*Oxygen is used as a reactant to help break down glucose in a process that produces ATP.*



Name: \_\_\_\_\_

## Answer Key

1. **The video described the role of the following parts of plants. What are the main function of each of these?**

**roots:** *Roots provide anchorage for a plant, they bring in water and minerals from the soil and in some plants (such as potatoes) they store starch.*

**stems:** *Stems hold the transport tissue and provide support for the upper parts of the plant*

**leaves:** *Leaves provide a large surface area exposed to sunlight for photosynthesis and they contain pores (stomata) for gas exchange.*

2. **How do these parts of plants function together to help to move water throughout a plant?**

*Roots take in water that moves (by osmosis and capillary action) through transport (vascular) tissue to other parts of the plant. At the leaf surface, openings call stomata provide a route for water to evaporate into the air, providing a pull for transport through the process of transpiration.*

3. **How does each part help to supply sugars to the tissues that need them?**

*Leaves are the site of photosynthesis and sugar production; vascular tissue (phloem) in stems provides a route to move sugars to other parts of the plant. Excess sugars can be made into starch and stored in root tissue.*

Name: \_\_\_\_\_

1. What is the name of the vascular structure that moves water and minerals up from roots to other parts of a plant?

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2. What role does this tissue play other than transport?

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3. What is the name of the vascular structure that delivers sugars from one part of a plant to another?

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4. Is transport through phloem an active or passive process? Explain.

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5. What are stomata?

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6. Explain the process of transpiration and how stomata play a role in transpiration.

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Name: \_\_\_\_\_

## Answer Key

- 1. What is the name of the vascular structure that moves water and minerals up from roots to other parts of a plant?**  
*This structure is called xylem.*
- 2. What role does this tissue play other than transport?**  
*The dead cells in xylem of woody stems provides support.*
- 3. What is the name of the vascular structure that delivers sugars from one part of a plant to another?**  
*This structure is called phloem.*
- 4. Is transport through phloem an active or passive process? Explain.**  
*Transport through phloem is an active process that requires energy.*
- 5. What are stomata?**  
*Stomata are openings in leaf surface, especially the underside of the leaf, that allow gases to move in and out of the plant.*
- 6. Explain the process of transpiration and how stomata play a role in transpiration.**  
*Transpiration is the process through which water is lost from leaves and stem. It mostly occurs through stomata. Water evaporates into the air, creating a lower water pressure in the parts of the plant undergoing transpiration.*

Name: \_\_\_\_\_

1. **ATP: (adenosine triphosphate):** This molecule is produced during oxidative cellular respiration and is useful because it provides an efficient way to transfer energy in the short term. Removal of a phosphate from ATP via hydrolysis provides usable energy for cell reactions.
2. **autotroph:** organism able to synthesize its own food from inorganic substance.
3. **carbon dioxide:** CO<sub>2</sub>, a waste product of cellular respiration and a reactant in photosynthesis that is the source of carbon for carbon fixation.
4. **carbohydrate:** biomolecule consisting of carbon chain and twice as much hydrogen as oxygen. Sugars and starch are carbohydrates.
5. **cell wall:** outer structure surrounding plant cells that provides structural support for the cell.
6. **cellular respiration:** release of energy from sugars such as glucose. In the presence of oxygen, this is an efficient process that produces a lot of ATP for immediate source of energy in other reactions.
7. **chlorophyll:** green pigment that absorbs and transfers energy from light during photosynthetic reactions.
8. **chloroplast:** substructure (organelle) in plant cells that contains chlorophyll and that carries out light harvesting in photosynthesis.
9. **companion cell:** cells next to sieve tube cells in vascular tissue that help keep the phloem alive.
10. **cuticle:** protective waxy layer on plant leaves formed of cutin and wax. It protects the plant from toxins and pathogens and also retards loss of water.
11. **diffusion:** movement of substance from lower to higher concentration. This is a passive form of transport in plants.
12. **epidermis:** a layer of cells at the surface of an organism structure, like skin. Leaves are covered by a layer of epidermal cells.
13. **glucose:** six carbon (6-C) sugar that is a common source of fuel for cellular respiration.
14. **guard cell:** specialized epidermal cell surrounding an opening such as a stoma. Turgor of guard cells determines the opening or closing of the stoma.
15. **heterotroph:** an organism that takes its food (for energy and carbon source) from material produced by another organism. Compare this to autotroph that makes its own food from inorganic sources.

*The glossary is continued on the next page.*

Name: \_\_\_\_\_

16. **osmosis:** a form of diffusion that involves movement across a permeable membrane.
17. **phloem:** vascular tissue that transports food (often the sugar known as sucrose) throughout the tissues of a vascular plant.
18. **photosynthesis:** processes in green plants, green algae and some bacteria that use energy of sunlight to produce sugars.
19. **plasmolysis:** water loss from vacuole of a plant cell that results in cytoplasm pulling away from the cell wall and membrane and makes the cell limp.
20. **root hairs:** outgrowths of epidermal cells in root found in zone of maturation. Root hairs greatly increase the surface area of a root making it much more effective.
21. **sieve tube:** special type of cells in phloem through which translocated material moves.
22. **starch:** storage form for cellular “food” that is formed from excess sugars. Starch is a complex carbohydrate.
23. **stomata (plural of stoma):** tiny openings most often found on lower surface (epidermis) of plant leaf. It is controlled by guard cells whose turgor determines whether or not the stoma is open or closed. Gases enter and leave the plant through stomata.
24. **sucrose:** a double sugar or disaccharide consisting of glucose plus fructose. Sucrose is common in plants and is the most common form of sugar that is transported.
25. **sugar:** simple carbohydrates. Glucose, fructose and sucrose are examples of sugars.
26. **translocation:** movement of water, minerals and other material from one part of a plant to another.
27. **transpiration:** loss of water from leaves and stem of a plant.
28. **turgor:** stiffness of structure in plant cells that relies on pressure produced in part by water in plant vacuoles. A loss of turgor results in wilting.
29. **vascular tissue:** plant tissue associated with conducting of material (water, sugar, minerals). Xylem and phloem are vascular tissue.
30. **xylem:** complex vascular tissue carrying water and minerals.

Name: \_\_\_\_\_

## Books

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Alberts, Bruce; Bray, Dennis; Lewis, Julian; Raff, Martin; Roberts, Keith and Watson, James. *Molecular Biology of the Cell 3rd ed.* Garland Publisher, Taylor and Francis Group: New York, 1994

Margulis, Lynn and Schwartz, Karlene V. *Five Kingdoms 3<sup>rd</sup> ed.* W.H. Freeman & Co.: New York, 1998.

Proctor, Michael, Yeo, Peter and Lack, Andrea. *The Natural History of Pollination.* HarperCollins Publisher: London, 1996.

Raven, Peter H. Evert, Ray F. and Eichhorn, Susan E. *Biology of Plants 6<sup>th</sup> ed.* W.H. Freeman & Co.: New York, 1999.

Stearns, Stephen C. and Hoekstra, Rolf F. *Evolution: An Introduction.* Oxford University Press: Oxford, 2000.

Thomas, Peter. *Trees: Their Natural History.* Cambridge University Press: Cambridge, England, 2000.

Name: \_\_\_\_\_

## Articles

**Please note:** Current articles on related topics may be found in the following reliable scientific publications: *Discover*, *Natural History Magazine*, *Science News*, *Scientific American*. Selected articles and current issue of some, such as *Natural History Magazine*, generally are available online. Please search with these names for up-to-date URLs. For example:

<http://www.naturalhistorymag.com/> is the home page for *Natural History Magazine*. Selecting “web site archive” provides access to many useful articles.

In addition, there are many excellent online resources from universities, botanic gardens and nature organizations. To locate current addresses, these are most easily found through a keyword search with search engine such as Google. Note that URLs listed here are current at time of publication but may change. Recommendation for keyword searches include:

**keyword: photosynthesis**

**keyword: photosynthetic pigments**

Look especially for links that are associated with reliable resources, such as Universities, botanic gardens, or academic publications.

**keyword: Cal Photos Plants**

current URL is <http://elib.cs.berkeley.edu/photos/flora>

This digital library has an excellent collection of images of wildflowers, many with associated information about location or other details. The database can be easily searched with common name for plant, scientific name or the name of the photographer.

**keyword: Nature Conservancy**

current URL is <http://nature.org/>

This organization does extensive conservation work and includes information about natural refuge sites in your area.

**keyword: Native Plant Society**

This search will provide links to native plant groups in your area. Example is the Native Plant Society for Maryland <http://www.mdflora.org/>

**keyword: Cambridge Botanic Garden**

Current URL is <http://www.botanic.cam.ac.uk/>

This site is run by the excellent academic botanic garden of Cambridge University in Cambridge, England. Search for keywords of botanic gardens in your area as well. Another excellent garden is the Missouri Botanic Garden with URL <http://www.mobot.org/>

Other Biology Education Products  
from Human Relations Media

<i>Introduction to Plants</i>	<i>video/print or DVD/print</i>
<i>Scientific Inquiry: Steps, Skills and Action</i>	<i>video/print or DVD/print</i>
<i>Ethical Issues in Biology</i>	<i>video/print or DVD/print</i>
<i>Biodiversity: The Web of Life</i>	<i>video/print or DVD/print</i>
<i>The Classification of Living Things</i>	<i>video/print or DVD/print</i>
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