Photosynthesis: Using Light to Make Food 7

Seen from space, Earth is a blue-green jewel—blue light reflected from the oceans and green light reflected from the mantle of vegetation that covers much of the land. From orbit, astronauts can see the deep green that cloaks the equator and watch the advance and retreat of green as the seasons unfold in the temperate regions. Green is the color of chlorophyll, the most important chemical on Earth. In the process of photosynthesis, chlorophyll captures the energy of the sun. It enables plants and other producers to store solar energy in the food used by all living things. This chapter is about photosynthesis, the food-making process that starts with sunlight shining on green chlorophyll.

Organizing Your Knowledge

Exercise 1 (Module 7.1)

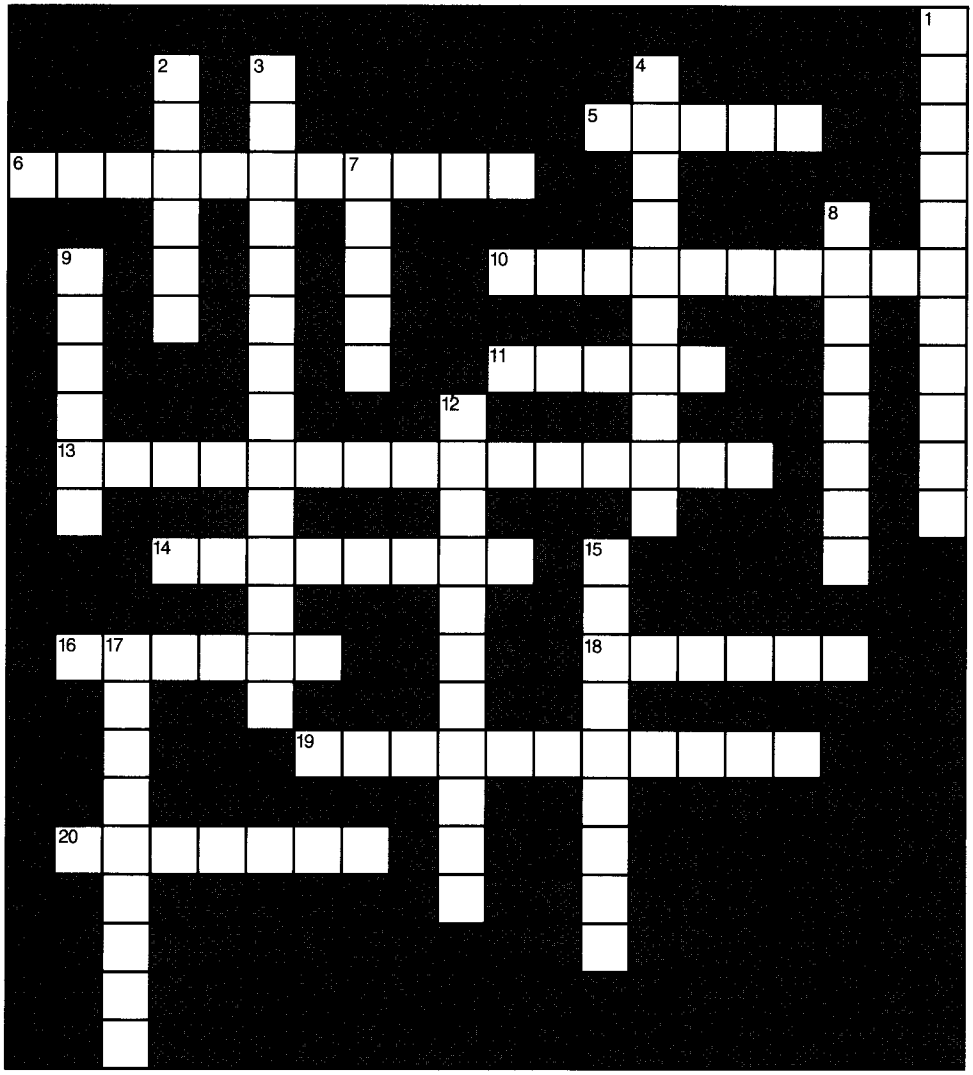
Autotrophs are able to produce their own organic molecules. All organisms that use light energy to make food are called photosynthetic autotrophs. Circle the organisms below that are photosynthetic autotrophs.

mushroom	pine tree	squirrel	green bacteria
rosebush	seaweed	moss	bread mold
parasitic bacterium	alga	sponge	grass

Exercise 2 (Modules 7.1 – 7.7)

Web/CD Activity 7A *The Sites of Photosynthesis*
Web/CD Activity 7B *Overview of Photosynthesis*
Web/CD Activity 7C *Light Energy and Pigments*

Review some of the basic terminology of photosynthesis by completing this crossword puzzle.



Across

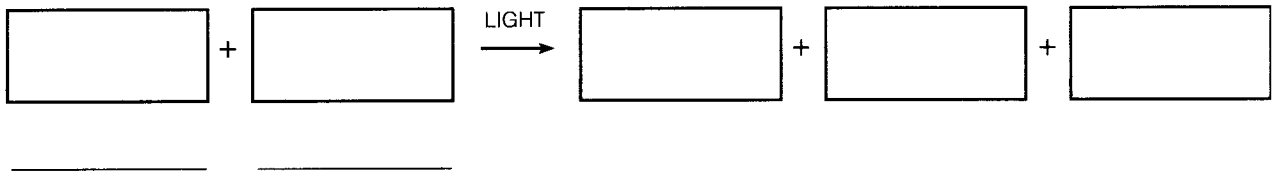
5. ____ is oxidized in the process of photosynthesis.
6. The ____ is the cell organelle where photosynthesis takes place.
10. ____ are the light-catching membranes in a chloroplast.
11. Stacks of thylakoids in a chloroplast are called ____.
13. ____ energy travels through space as rhythmic waves.
14. When chlorophyll absorbs a photon, an ____ is excited.
16. Sugar is actually made in the ___ cycle.
18. The Calvin cycle occurs in the ____—the fluid of the chloroplast.
19. ____ is the green pigment in a leaf.
20. ____ are pores in a leaf.

Down

1. A ____ is an antennalike energy-harvesting unit in a thylakoid.
2. A ____ is a fixed quantity of light energy.
3. ____ is the process by which plants make food from carbon dioxide and water.
4. The color of light is related to its ____.
7. ____ is the source of energy for photosynthesis.
8. Carbon ____ is the incorporation of carbon dioxide into or ganic compounds.
9. The reaction ____ is the chlorophyll molecule that donates excited electrons.
12. ____ are yellow-orange pigments in a chloroplast.
15. ____ is the green tissue in the interior of a leaf.
17. A photosynthetic ____ is an organism that uses light to make food.

Exercise 3 (Modules 7.3 - 7.4)

Write the overall equation for photosynthesis in the boxes below. Show the substances used on the left, and those produced on the right. Use different colors for carbon, hydrogen, oxygen in carbon dioxide, and oxygen in water, and then use your color code to show where atoms of C, H, and O on the left end up in the products on the right. On the lines under the substances used, state which is oxidized and which is reduced.

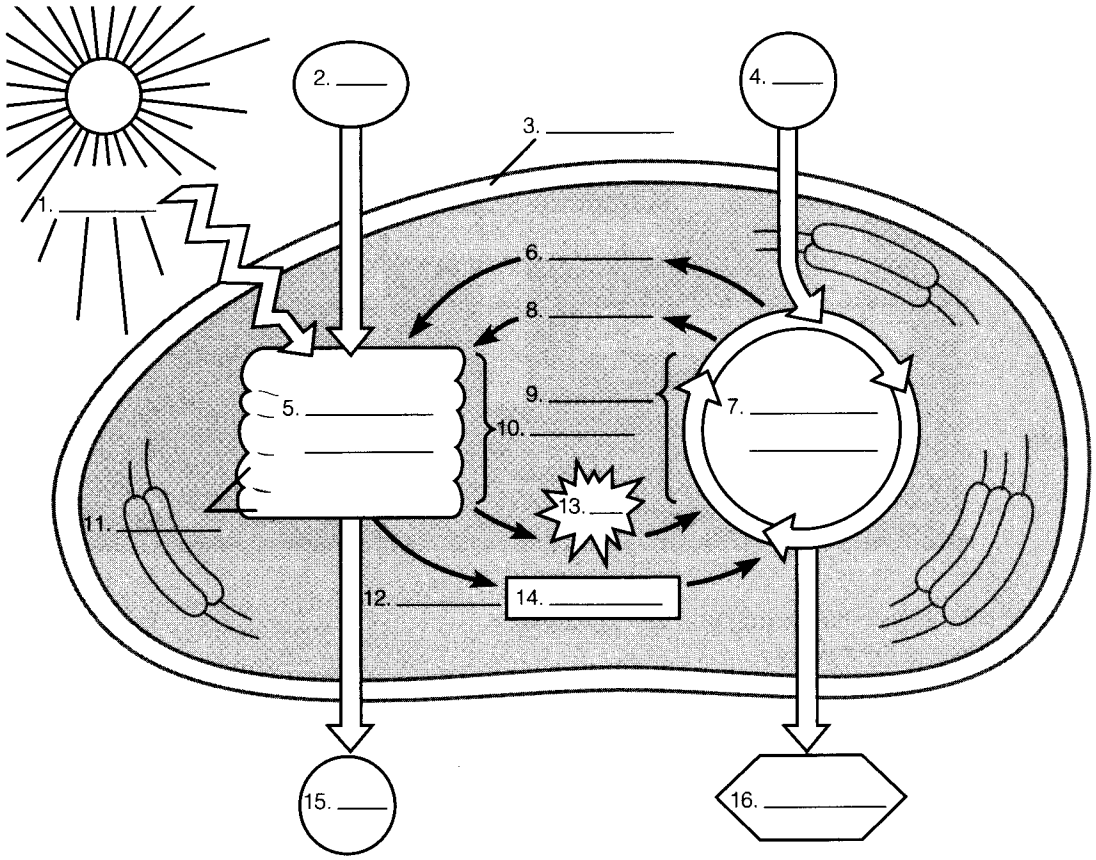


_____ _____

Exercise 4 (Modules 7.3 - 7.5)

Web/CD Activity 7B *Overview of Photosynthesis*

Label this diagram summarizing the two stages of photosynthesis. Include **outer membrane of chloroplast, thylakoids, granum, stroma, light reactions, Calvin cycle, light, H_2O, O_2, electrons, NADPH, ATP, CO_2, sugar, ADP + P,** and **$NADP^+$.** (Note: 5 and 7 are processes, 3, 9, 10, and 11 are places or structures, and the rest are inputs and outputs.)



Exercise 5 (Modules 7.3 – 7.5)

Web/CD Activity 7B *Overview of Photosynthesis*

Refer to the equations and diagrams in the modules to match each of the phrases on the left with one of the ingredients or products of photosynthesis listed on the right.

_____ 1. Oxidized in light reactions
_____ 2. Reduced in Calvin cycle
_____ 3. Carries H and electrons from light reactions to Calvin cycle
_____ 4. Food produced by photosynthesis
_____ 5. Source of H and electrons in glucose
_____ 6. Source of O atoms in glucose
_____ 7. Where O atoms from water end up
_____ 8. Oxidized in Calvin cycle
_____ 9. Reduced in light reactions
_____10. Supplies energy to Calvin cycle
_____11. Where C and O atoms in carbon dioxide end up
_____12. Recycled from Calvin cycle to make ATP
_____13. Supplies energy to light reactions
_____14. Gas produced by reactions in the thylakoids
_____15. Gas consumed by reactions in the stroma
_____16. Source of carbon for carbon fixation
_____17. Source of H for the Calvin cycle
_____18. Picks up energized electrons from reactions in the thylakoids

A. Carbon dioxide, CO_2
B. Water, H_2O
C. Glucose, $C_6H_{12}O_6$
D. Oxygen, O_2
E. ADP + P
F. ATP
G. $NADP^+$
H. NADPH
I. Light

Exercise 6 (Modules 7.6 – 7.7)

Web/CD Activity 7C *Light Energy and Pigments*

Order the following forms of electromagnetic energy from the shortest wavelength (1) to the longest (9). At which wavelength do photons have the most energy? Which are used by plants in photosynthesis?

_____ a. Green light
_____ b. Radio waves
_____ c. X-rays
_____ d. Red light
_____ e. Ultraviolet light
_____ f. Infrared
_____ g. Microwaves
_____ h. Blue light
_____ i. Gamma rays

Exercise 7 (Modules 7.7 - 7.11)

Web/CD Activity 7D *The Light Reactions*
Web/CD Activity 7E *The Calvin Cycle*

To review photosynthesis, fill in the blanks in the following story.

The next time you eat an apple, reflect on the apple tree's ability to make the sugars it contains, using sunlight to assemble simple substances from air and soil. This process is called [1]_____, and it takes place in structures called [2]_____ in cells of tissues called the [3]_____ inside the leaves of the apple tree. Photosynthesis actually consists of two processes: In the [4]_____ reactions, [5]_____ molecules in membranes called [6]_____ in the chloroplast capture light energy. In the [7]_____ cycle, which takes place in the [8]_____ surrounding the thylakoids, this energy is used to make sugar, a process called [9]_____ fixation.

Chlorophyll molecules absorb [10]_____, packets of light energy. Chlorophyll absorbs only certain wavelengths, or colors, of light, mainly in the [11]_____ and [12]_____ parts of the spectrum. It reflects [13]_____ light. Other pigments, such as [14]_____, can absorb colors that chlorophyll cannot use directly, and transfer this energy to chlorophyll. Chlorophyll and other pigments are clustered on the thylakoid membranes in groups called photosystems. All the pigment molecules in a photosystem pass their energy along to a single chlorophyll molecule, called the [15]_____, in the middle of the photosystem. There are two kinds of photosystems, photosystem I and photosystem II, which absorb slightly different colors of light.

Most bacteria and all [16]_____ and algae power the production of [17]_____ through a process that starts when photons energize a chlorophyll molecule in photosystem I. This raises the chlorophyll's [18]_____ to an excited state. The excited electrons are passed to the chlorophyll at the reaction center, which passes them to a protein called the [19]_____. From here, the electrons travel along an [20]_____ chain and end up as high-energy electrons in a molecule called [21]_____.

In the cells in the leaves of an apple tree, photosystem II replaces the electrons lost by photosystem I. A chlorophyll molecule of photosystem II absorbs [22]_____ and ejects [23]_____. These pass to a primary electron acceptor and on to an electron transport chain. The electrons pass down the chain and eventually end up replacing the electrons lost by the chlorophyll of [24]_____. On their way down the electron transport chain, the electrons perform important work. One of the electron carriers in the chain uses the energy released by the electrons to transport [25]_____ ions from the [26]_____ into the space inside the [27]_____. This creates a buildup of H^+ ions, a concentration [28]_____ of H^+ across the membrane. The H^+ ions then diffuse through the membrane via a protein complex called [29]_____, which captures their energy to make [30]_____. In photosynthesis, this chemiosmotic production of ATP is called [31]_____. How does photosystem II replace its lost electrons? It gets them by splitting [32]_____. When the electrons of

photosystem II are jarred loose, the reaction center develops a strong attraction for electrons. It obtains them by breaking apart a molecule of [33]_____. This leaves two H^+ ions (which pass into the thylakoid space) and an [34]_____ atom. This atom combines with another from another water molecule to form a molecule of [35]_____ gas, which diffuses out of the leaf—a product of photosynthesis important to us and other animals.

At this point, the cells of the apple leaf have captured the energy of the sun in molecules of NADPH and ATP, but so far they have made no sugar. The NADPH and ATP are used, and sugar is made, in the [36]_____ cycle, the second portion of [37]_____ that takes place in the [38]_____ of the chloroplast, around the thylakoids. Using carbon from [39]_____ obtained from the air, energy from [40]_____, and hydrogen and high-energy electrons carried by [41]_____, the enzymes of the Calvin cycle construct [42]_____, a high-energy sugar molecule. In a series of steps, these molecules are combined to form the important six-carbon sugar [43]_____ and other organic compounds, in the leaves and in other parts of the plant.

The cellulose that gives an apple its crunch and the sugar that gives it its sweet taste are made from the glucose made in photosynthesis. In your intestine, the sugars enter your blood and are transported to your body cells. There the chemical pathways of cellular [44]_____ release the energy in the sugar molecules and use it to build [45]_____, which is in turn used to power cellular work. Energy from the sun, captured by the apple and passed on to you, enables you to see, to move, and to contemplate this amazing story.

Exercise 8 (Module 7.12)

Web/CD Activity 7F *Photosynthesis in Dry Climates*

Plants employ a variety of ways of fixing CO_2 and saving water. State whether each of the following statements relates to **C_3** plants, **C_4** plants, or **CAM** plants.

_____ 1. May waste energy on photorespiration on a hot day
_____ 2. Trap carbon in four-carbon compound, which donates it to Calvin cycle
_____ 3. Corn and sugarcane
_____ 4. Open stomata and trap CO_2 at night
_____ 5. Most plants
_____ 6. Soybeans, oats, wheat, rice
_____ 7. Can grow in hot, dry climates
_____ 8. Also can grow in hot, dry climates
_____ 9. Pineapple and many cacti
_____ 10. Calvin cycle uses CO_2 directly from the air

Exercise 9 (Module 7.13)

Test your understanding of this module by stating whether you think each of the following would be likely to **warm** or **cool** the Earth through alteration of the greenhouse effect.

_____ 1. Increased burning of coal to produce electricity
_____ 2. Increased rate of growth of algae in the oceans
_____ 3. Increased cloud cover, which would reflect more sunlight
_____ 4. Better gas mileage, so cars would go farther on a tank of gasoline
_____ 5. Increased cutting of tropical rain forests
_____ 6. Using nuclear power instead of coal and oil to make electricity
_____ 7. Reforesting deforested and overgrazed land
_____ 8. Increased rate of decomposition of organic matter
_____ 9. Slowing the population growth rate

Exercise 10 (Module 7.14)

Summarize this module by describing the relationship between CFCs and the Earth's protective ozone layer *in exactly 25 words.*

Testing Your Knowledge

Multiple Choice

1. The ultimate source of energy in the sugar molecules produced by photosynthesis is
   a. sugar.
   b. the sun.
   c. oxygen.
   d. ATP.
   e. chlorophyll.

2. Which of the following is produced by the light reactions of photosynthesis and consumed by the Calvin cycle?
   a. NADPH
   b. O_2
   c. H_2O
   d. sugar
   e. ADP + P

3. Which of these wavelengths is least useful for photosynthesis?
   a. green
   b. yellow
   c. blue
   d. orange
   e. red

4. When chloroplast pigments absorb light,
   a. they become reduced.
   b. they lose potential energy.
   c. their electrons become excited.
   d. the Calvin cycle is triggered.
   e. their photons become excited.

5. The light reactions of photosynthesis generate high-energy electrons, which end up in ____. They also produce ____ and ____.
   a. ATP . . . NADPH . . . O_2
   b. O_2 . . . sugar . . . ATP
   c. chlorophyll . . . ATP . . . NADPH
   d. water . . . sugar . . . O_2
   e. NADPH . . . ATP . . . O_2

6. The overall function of the Calvin cycle is
   a. capturing sunlight.
   b. making sugar.
   c. producing CO_2.
   d. splitting water.
   e. oxidizing glucose.

7. Which of the following correctly matches each of the inputs of the Calvin cycle with its role in the cycle?
   a. CO_2: high-energy electrons; ATP: energy; NADPH: oxidation
   b. CO_2: carbon; ATP: energy; NADPH: high-energy electrons
   c. CO_2: high-energy electrons; ATP: carbon; NADPH: energy
   d. CO_2: energy; ATP: carbon; NADPH: high-energy electrons
   e. CO_2: hydrogen; ATP: carbon; NADPH: energy

8. The main photosynthetic autotrophs in aquatic environments are
   a. plants and animals.
   b. plants and fungi.
   c. animals and algae.
   d. algae and bacteria.
   e. plants and bacteria.

9. Which of the following is *not* a product of the light reactions of photosynthesis?
   a. O_2
   b. sugar
   c. high-energy electrons
   d. ATP
   e. NADPH

10. Which of the following is oxidized in photosynthesis?
    a. O_2
    b. CO_2
    c. $C_6H_{12}O_6$
    d. ATP
    e. H_2O

11. In photosynthesis, plants use carbon from ____ to make sugar and other organic molecules.
    a. water
    b. the air
    c. chlorophyll
    d. the sun
    e. soil

Essay

1. Photosynthesis uses water and carbon dioxide to produce sugar and oxygen gas. Scientists long wondered whether the oxygen atoms in the oxygen gas produced in photosynthesis were obtained from carbon dioxide or water. Describe the experiments that enabled them to find out, and the results of these experiments.

2. Draw two squares, one labeled to represent the **light reactions** and the other to represent the **Calvin cycle**. Using arrows, show the inputs and outputs of each process. Include the following: **NADPH, ADP + P, O_2, light, CO_2, sugar, H_2O, ATP, $NADP^+$, electrons.**

3. Photosynthesis has been called "the most important chemical process on Earth." Explain why.

4. State two activities of humans that tend to intensify the greenhouse effect. Why are people concerned about this? State two actions we could take that would reduce our contribution to the greenhouse effect.

Applying Your Knowledge

Multiple Choice

1. A photon of which of these colors would carry the most energy?
   a. green
   b. yellow
   c. blue
   d. orange
   e. red

2. A plant is placed in a sealed greenhouse with a fixed supply of water, soil, and air. After a year, the plant weighs 5 kg more than at the start of the experiment, and the ____ weighs almost 5 kg less.
   a. soil in the pot
   b. water left in the room
   c. organic matter in the soil
   d. air in the room
   e. soil in the pot together with the water in the soil

3. In a rosebush, chlorophyll is located in
   a. chloroplasts, which are in mesophyll cells in the thylakoids of a leaf.
   b. mesophyll cells, which are in the thylakoids in chloroplasts in a leaf.
   c. thylakoids, which are in mesophyll cells in the chloroplasts in a leaf.
   d. chloroplasts, which are in thylakoids in the mesophyll cells of a leaf.
   e. thylakoids, which are in chloroplasts in the mesophyll cells of a leaf.

4. In an experiment, a plant was given ____ containing radioactive ^{18}O, and the radioactive oxygen atoms were used to make sugar.
   a. water
   b. chlorophyll
   c. oxygen gas
   d. ATP
   e. carbon dioxide

5. The *photo* part of the word *photosynthesis* refers to _____, whereas *synthesis* refers to _____.
   a. the reactions that occur in the thylakoids . . . carbon fixation
   b. the reactions in the stroma . . . the reactions in the thylakoids
   c. the Calvin cycle . . . carbon fixation
   d. the Calvin cycle . . . the reactions in the stroma
   e. the light reactions . . . reactions in the thylakoids

6. The energy used to produce ATP in the light reactions of photosynthesis comes from
   a. the "burning" of sugar molecules.
   b. splitting water.
   c. movement of H^+ through a membrane.
   d. carbon fixation.
   e. fluorescence.

7. The following (*P* through *U*) are the main steps of chemiosmotic ATP synthesis in the light-dependent reactions of photosynthesis. Which answer places them in the correct order?

   P. H^+ concentration gradient established.

   Q. H^+ diffuses through ATP synthase.

   R. Carriers use energy from electrons to move H^+ across membrane.

   S. Electrons from photosystem II pass along electron transport chain.

   T. Light excites electrons in photosystem II.

   U. Energy of H^+ flow used by ATP synthase to make ATP.
   a. PQTSRU
   b. STPQRU
   c. TSRPQU
   d. TSRUQP
   e. PQUSTR

8. The way ATP synthase captures the energy of H^+ ions in the light reactions appears to be similar to the way
   a. a turbine in a dam harnesses running water.
   b. an automobile engine uses hydrocarbons for fuel.
   c. heating of water forms steam in a nuclear reactor.
   d. electricity makes a lightbulb glow.
   e. a rotating wheel stores mechanical energy.

9. An oceanographer has suggested slowing the rate of greenhouse warming by fertilizing the ocean to increase the growth of algae. How would this reduce the greenhouse effect?
   a. It would produce oxygen, which reflects sunlight from the atmosphere.
   b. It would "repair" the Earth's ozone layer.
   c. It would use up CO_2, which traps heat in the atmosphere.
   d. It would change the color of the ocean, reflecting the sun's heat.
   e. It would trap sunlight that would otherwise warm the Earth.

10. Which of the following would not be capable of performing photosynthesis?
    a. bacterium
    b. pine tree
    c. mushroom
    d. seaweed
    e. algae

11. In the 1980s scientists grew concerned that the "ozone hole" over Antarctica would expand over Australia. This might lead to
    a. warming of the climate.
    b. storms.
    c. cooling of the climate.
    d. increases in skin cancer.
    e. depletion of atmospheric CO_2.

Essay

1. In an experiment, plants were grown under colored filters that allowed equal amounts of light of different colors to strike different plants. Under which filter do you think plants grew the slowest? Why?
2. Carotenoids are yellow and orange pigments involved in photosynthesis. What colors of light must carotenoids absorb? Reflect? How is this useful to the plant?
3. Remember that the greater the concentration of hydrogen ions (H^+), the lower the pH of a solution. How do you suppose the pH of the solution in the thylakoid space compares with the pH of the solution in the stroma? What is responsible for the difference?
4. Compare chemiosmotic ATP production in photosynthesis (photophosphorylation) with ATP production in cellular respiration (oxidative phosphorylation): What is the source of high-energy electrons for each? What harnesses the energy of the electrons, and what is the energy used for? Where does each process take place? Where do the electrons end up? What actually manufactures the ATP? What is the immediate source of energy for ATP synthesis?
5. ATP is used to power the movement of your muscles as you turn the pages of this book. Where did the energy in the ATP come from? Trace the energy in the ATP molecules back to the sun.
6. In the mid-1600s, Belgian physician and chemist Jan Baptista van Helmont grew a small willow tree in a pot, adding only water to the soil. After five years, he found that the soil in the pot had lost only 60 grams, while the tree had grown by nearly 75 kilograms—more than 1000 times the material lost from the soil. Van Helmont concluded that the tree had gained most if its substance not from soil, but rather from the water he supplied. Was van Helmont right? Explain.

Extending Your Knowledge

1. What are some products you use or activities in which you participate that contribute to global warming? How might you modify your lifestyle to reduce your contribution to global warming?
2. Because photosynthesis uses carbon dioxide, deforestation increases global warming and planting trees reduces it. You can do your part to slow global warming by planting trees and encouraging others in your community to do so. Some groups that offer advice and information about planting trees:

   American Forests, P.O. Box 2000, Washington, DC 20013; www.americanforests.org

   Friends of Trees, 3117 NE Martin Luther King, Jr. Blvd., Portland, OR 97212; www.friendsoftrees.org

   National Arbor Day Foundation, 100 Arbor Ave., Nebraska City, NE 68410; www.arborday.org

   Plant-It 2000, PMB 9457 310 S. University Blvd., Highlands Ranch, CO 80126; www.plantit2000.com

   Trees for the Future, P.O. Box 7027, Silver Spring, MD 20907; www.treesftf.org

   Trees, Water, & People, 633 S. College Ave., Fort Collins, CO 80524; www.treeswaterpeople.org