Section 8–2

1 FOCUS

Objectives

8.2.1 ***Explain*** what the experiments of van Helmont, Priestley, and Ingenhousz reveal about how plants grow.

8.2.2 ***State*** the overall equation for photosynthesis.

8.2.3 ***Describe*** the role of light and chlorophyll in photosynthesis.

Guide for Reading

Vocabulary Preview

Have students write the Vocabulary words, dividing each into its separate syllables as best they can. Remind students that each syllable usually has only one vowel sound. The correct syllabications are pho•to•syn•the•sis, pig•ment, chlo•ro•phyll.

Reading Strategy

Students' summaries should describe the findings of van Helmont, Priestley, and Ingenhousz and explain that plants use the energy of sunlight to convert water and carbon dioxide into oxygen and high-energy sugars. They should also describe the role of light and chlorophyll in photosynthesis.

2 INSTRUCT

Investigating Photosynthesis

Build Science Skills

Applying Concepts To help students grasp the basic problem faced by researchers centuries ago, on the board draw a large tree with leaves and roots. Point to the roots and ask: **What could trees obtain from underground that could help them grow?** *(Minerals, water)* Point to the leaves and ask: **What could trees obtain from the air that could help them grow?** *(Students might suggest oxygen or other gases. Some may mention light.)* Ask for their opinions about answers to the questions in the text about where a tall tree gets its mass. L1 L2

8–2 Photosynthesis: An Overview

Guide for Reading

Key Concepts

- What did the experiments of van Helmont, Priestley, and Ingenhousz reveal about how plants grow?
- What is the overall equation for photosynthesis?
- What is the role of light and chlorophyll in photosynthesis?

Vocabulary

photosynthesis
pigment
chlorophyll

Reading Strategy: Summarizing As you read, find the key ideas under each blue head. Write down a few key words from each key idea. Then, use the key words in your summary.

The key cellular process identified with energy production is photosynthesis. In the process of **photosynthesis,** plants use the energy of sunlight to convert water and carbon dioxide into high-energy carbohydrates—sugars and starches—and oxygen, a waste product. The investigations of many scientists have contributed to the current understanding of the process of photosynthesis.

Investigating Photosynthesis

Research into photosynthesis began centuries ago with a simple question: When a tiny seedling grows into a tall tree with a mass of several tons, where does the tree's increase in mass come from? From the soil? From the water? From the air?

Van Helmont's Experiment In the 1600s, the Belgian physician Jan van Helmont devised an experiment to find out if plants grew by taking material out of the soil. Van Helmont determined the mass of a pot of dry soil and a small seedling. Then, he planted the seedling in the pot of soil. He watered it regularly. At the end of five years, the seedling, which by then had grown into a small tree, had gained about 75 kg.

Biology and History

Understanding Photosynthesis

Many scientists have contributed to understanding how plants carry out photosynthesis. Early research focused on the overall process. Later researchers investigated the detailed chemical pathways.

1643
Jan van Helmont
After careful measurements of a plant's water intake and mass increase, van Helmont concludes that trees gain most of their mass from water.

1771
Joseph Priestley
Using a bell jar, a candle, and a plant, Priestley finds that the plant releases oxygen.

1779
Jan Ingenhousz
Ingenhousz finds that aquatic plants produce oxygen bubbles in the light but not in the dark. He concludes that plants need sunlight to produce oxygen.

1600 1700 1800

TIME SAVER

SECTION RESOURCES

Print:

- ***Laboratory Manual A,*** Chapter 8 Lab
- ***Laboratory Manual B,*** Chapter 8 Lab
- ***Teaching Resources,*** Lesson Plan 8–2, Adapted Section Summary 8–2, Section Summary 8–2, Worksheets 8–2, Section Review 8–2, Enrichment
- ***Reading and Study Workbook A,*** Section 8–2

Technology:

- ***iText,*** Section 8–2
- ***Animated Biological Concepts DVD,*** 9 Photosynthesis
- ***Transparencies Plus,*** Section 8–2
- ***Lab Simulations CD-ROM,*** Photosynthesis
- ***Virtual Labs,*** Lab 6, Lab 7

The mass of the soil, however, was almost unchanged. He concluded that most of the gain in mass had come from water, because that was the only thing that he had added.

Van Helmont's experiment accounts for the "hydrate," or water, portion of the carbohydrate produced by photosynthesis. But where does the carbon of the "carbo-" portion come from? Although van Helmont did not realize it, carbon dioxide in the air made a major contribution to the mass of his tree. The carbon in carbon dioxide is used to make sugars and other carbohydrates in photosynthesis. Van Helmont had only part of the story, but he had made a major contribution to science.

Priestley's Experiment More than 100 years after van Helmont's experiment, the English minister Joseph Priestley performed an experiment that would give another insight into the process of photosynthesis. Priestley took a candle, placed a glass jar over it, and watched as the flame gradually died out. Something in the air, Priestley reasoned, was necessary to keep a candle flame burning. When that substance was used up, the candle went out. That substance was oxygen.

Priestley then found that if he placed a live sprig of mint under the jar and allowed a few days to pass, the candle could be relighted and would remain lighted for a while. The mint plant had produced the substance required for burning. In other words, it released oxygen.

CHECKPOINT *What did Priestley discover about photosynthesis?*

Word Origins

Photosynthesis comes from the Greek words *photo,* meaning "light," and *synthesis,* meaning "putting together." Therefore, *photosynthesis* means "using light to put something together," specifically, carbohydrates. *Chemo* means "having to do with chemicals or chemical reactions." **What do you think *chemosynthesis* means?**

Writing in Science

Use the Internet or library resources to research the experiments conducted by one of these scientists. Then, write a summary describing how the scientist contributed to the modern understanding of photosynthesis.

1845
Julius Robert Mayer
Mayer proposes that plants convert light energy into chemical energy.

1948
Melvin Calvin
Calvin traces the chemical path that carbon follows to form glucose. These reactions are also known as the Calvin cycle.

1992
Rudolph Marcus
Marcus wins the Nobel Prize in chemistry for describing the process by which electrons are transferred from one molecule to another in the electron transport chain.

1800 1900 2000

UNIVERSAL ACCESS

Less Proficient Readers
Focus students' attention on pages 204–206. Help them analyze the discoveries of the three scientists and develop a table to show what each one learned. Direct them to the word equation on page 206, and ask which part of the process each scientist discovered. L1 L2

English Language Learners
Have students compare the two equations on page 206. Relate each formula to its written name. Students who have studied the periodic table can use element symbols (such as C for carbon) to recognize each name. Help students restate the photosynthesis equation as a sentence. L1

Advanced Learners
With students, review the Writing Activity on this page. Have each student research a scientist and write a feature story on him or her. Stress that students must find more information than is given in the textbook. Emphasize that their stories should be written for the average citizen. L3

Word Origins

Chemosynthesis means "using chemical reactions to put something together." L2

Biology and History

Invite student volunteers to read aloud to the class the annotations on the timeline. Encourage students to add to the timeline by suggesting historical events that took place near in time to one of the discoveries mentioned. For each contribution to the understanding of photosynthesis mentioned in the timeline, challenge students to suggest how that discovery might have provided the basis for the next.

Writing in Science

Encourage students to look for descriptions of these experiments in books about photosynthesis, books about the history of biology, and college-level textbooks, as well as at Internet sites that specialize in biology. Provide several examples of news articles about medical and other scientific breakthroughs from a large daily newspaper. L2 L3

Build Science Skills

Designing an Experiment Divide the class into small groups and challenge them to design an experiment similar to the experiment that Joseph Priestley did in the 1700s. They should keep this concept in mind: Plant photosynthesis produces oxygen that animals need to breathe, while animal and plant respiration produces carbon dioxide that plants need in photosynthesis. Ask students to list the materials they would need and to write a step-by-step procedure. L2

Answer to . . .

CHECKPOINT *Priestley discovered that a plant releases a substance that keeps a candle burning. This substance, oxygen, is released during photosynthesis.*

The Photosynthesis Equation

Quick Lab

Objective Students will be able to conclude that oxygen is produced by plants during photosynthesis.

L2 L3

Skills Focus Observing, Inferring

Materials large clear plastic cup, sodium bicarbonate solution, elodea plant, large test tube

Time 10 minutes for setup, 5 minutes for observations

Advance Prep Prepare the sodium bicarbonate solution by mixing 5 g of sodium bicarbonate into each liter of water. Obtain the elodea plants. If they are not available, any small water plants will do.

Safety If students break a test tube, warn them not to handle the glass.

Strategies

• It will take up to 30 minutes for oxygen to appear, so you may want to set up this lab at the beginning of the class and return to it at the end.

• To show that the gas is oxygen, you may want to demonstrate the glowing splint test. CAUTION: *Wear goggles and heat-resistant gloves during this demonstration.* Remove one of the test tubes, keeping it upside down. Remove the elodea and let the water drain out. Light a splint, blow it out, and then turn the tube sideways next to the splint. The splint will glow brighter and possibly reignite.

• Students may need to repeat step 3 several times to make sure no air is trapped.

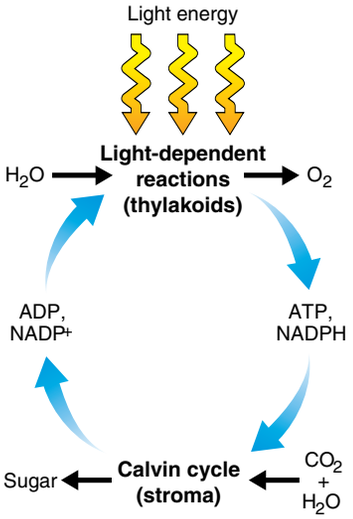
Expected Outcome Students should observe a gas forming on the elodea leaves and conclude that it is oxygen.

Analyze and Conclude

1. Students should see bubbles of gas. An answer of "oxygen" is an inference, not an observation.

2. Photosynthesis produces sugars and oxygen. Because sugars are not gases, the gas must be oxygen. Oxygen is a waste product because it is released into the environment.

3. The chloroplast



▲ **Figure 8–4** Photosynthesis is a series of reactions that uses light energy from the sun to convert water and carbon dioxide into sugars and oxygen.

Jan Ingenhousz Later, the Dutch scientist Jan Ingenhousz showed that the effect observed by Priestley occurred only when the plant was exposed to light. The results of both Priestley's and Ingenhousz's experiments showed that light is necessary for plants to produce oxygen. **The experiments performed by van Helmont, Priestley, and Ingenhousz led to work by other scientists who finally discovered that in the presence of light, plants transform carbon dioxide and water into carbohydrates, and they also release oxygen.**

The Photosynthesis Equation

Because photosynthesis usually produces 6-carbon sugars ($C_6H_{12}O_6$) as the final product, the overall equation for photosynthesis can be shown as follows:

$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$$

carbon dioxide + water $\xrightarrow{\text{light}}$ sugars + oxygen

Photosynthesis uses the energy of sunlight to convert water and carbon dioxide into high-energy sugars and oxygen. Plants then use the sugars to produce complex carbohydrates such as starches. Plants obtain carbon dioxide from the air or water in which they grow. The process of photosynthesis is shown in **Figure 8–4.**

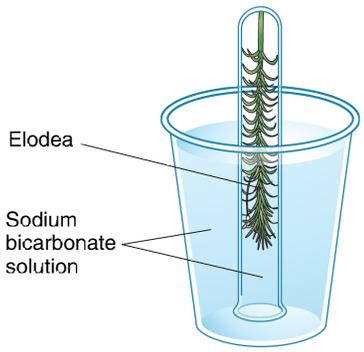
Quick Lab

What waste material is produced during photosynthesis?

Materials large clear plastic cup, sodium bicarbonate solution, elodea plant, large test tube

Procedure

1. Fill a large clear plastic cup about half full with sodium bicarbonate solution. The sodium bicarbonate solution is a source of carbon dioxide.
2. Place an elodea plant in a large test tube with the cut stem at the bottom. Fill the tube with sodium bicarbonate solution. **CAUTION:** *Handle the test tube carefully.*
3. Hold your thumb over the mouth of the tube. Turn the tube over, and lower it to the bottom of the cup. Make sure there is no air trapped in the tube.
4. Place the cup in bright light.
5. After at least 20 minutes, look closely at the elodea leaves. Record your observations.



Analyze and Conclude

1. **Observing** What did you observe on the elodea leaves?
2. **Inferring** What substance accumulated in the leaves? Should that substance be considered a waste product? Explain.
3. **Applying Concepts** What plant organelle carries out photosynthesis and produces the gas?

BIO INSIGHTS

HISTORY OF SCIENCE

Priestley's experiment "purifies" air

Joseph Priestley (1733–1804), a British Unitarian minister, never formally studied science. His interest in science began when he met Benjamin Franklin in London in 1766. For one of his many experiments, Priestley devised an apparatus that consisted of enclosed containers of air sealed at the bottom by a trough of water. He discovered that a burning candle in one of the closed containers caused the air to become "impure," eventually putting out the flame. He also found that a mouse placed inside the container of "impure" air died. He expected the same to happen to a sprig of spearmint. Much to his surprise, instead of dying, the plant flourished. Furthermore, he discovered that the plant "purified" the air, since after leaving the plant in the space for several weeks, a candle would burn or a mouse could live in the same enclosed space.

Light and Pigments

Although the equation tells you that water and carbon dioxide are required for photosynthesis, it does not tell you how plants use these low-energy raw materials to produce high-energy sugars. To answer that question, you have to know how plants capture the energy of sunlight. **In addition to water and carbon dioxide, photosynthesis requires light and chlorophyll, a molecule in chloroplasts.**

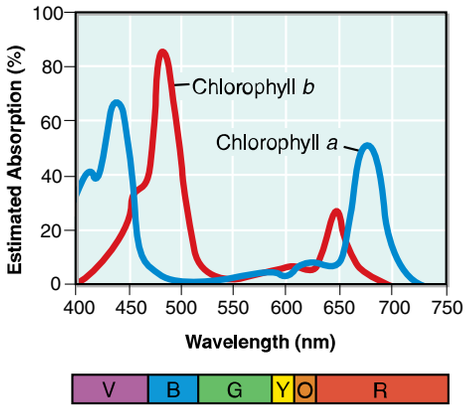
Energy from the sun travels to Earth in the form of light. Sunlight, which your eyes perceive as "white" light, is actually a mixture of different wavelengths of light. Many of these wavelengths are visible to your eyes and make up what is known as the visible spectrum. Your eyes see the different wavelengths of the visible spectrum as different colors.

Plants gather the sun's energy with light-absorbing molecules called **pigments.** The plants' principal pigment is **chlorophyll** (KLAWR-uh-fil). There are two main types of chlorophyll: chlorophyll *a* and chlorophyll *b*.

As **Figure 8–5** shows, chlorophyll absorbs light very well in the blue-violet and red regions of the visible spectrum. However, chlorophyll does not absorb light well in the green region of the spectrum. Green light is reflected by leaves, which is why plants look green. Plants also contain red and orange pigments such as carotene that absorb light in other regions of the spectrum.

Because light is a form of energy, any compound that absorbs light also absorbs the energy from that light. When chlorophyll absorbs light, much of the energy is transferred directly to electrons in the chlorophyll molecule, raising the energy levels of these electrons. These high-energy electrons make photosynthesis work.

Absorption of Light by Chlorophyll *a* and Chlorophyll *b*



▲ **Figure 8–5** **Photosynthesis requires light and chlorophyll.** In the graph above, notice how chlorophyll *a* absorbs light mostly in the blue-violet and red regions of the visible spectrum, whereas chlorophyll *b* absorbs light in the blue and red regions of the visible spectrum.

8–2 Section Assessment

1. **Key Concept** What did van Helmont, Priestley, and Ingenhousz discover about plants?
2. **Key Concept** Describe the process of photosynthesis, including the reactants and products.
3. **Key Concept** Why are light and chlorophyll needed for photosynthesis?
4. Describe the relationship between chlorophyll and the color of plants.
5. **Critical Thinking** **Predicting** How well would a plant grow under pure yellow light? Explain your answer.

Writing in Science

Descriptive Writing
Write a summary paragraph describing either van Helmont's, Priestley's, or Ingenhousz's experiments with plants and light. *Hint:* Use the first boldface key sentence on page 206 to give you an idea for the topic sentence.

8–2 Section Assessment

1. Van Helmont discovered that water was involved in increasing the mass of a plant. Priestley discovered that a plant produces the substance in air required for burning. Ingenhousz discovered that light is necessary for plants to produce oxygen.
2. Photosynthesis uses the energy of sunlight to convert water and carbon dioxide into oxygen and high-energy sugars.
3. Light provides the energy needed to produce high-energy sugars. Chlorophyll absorbs light, and the energy of that absorbed light makes photosynthesis work.
4. Plants are green because green light is reflected by the chlorophyll in leaves.
5. The plant would not grow well because chlorophyll does not absorb much light in the yellow region of visible light.

Light and Pigments

Build Science Skills

Using Tables and Graphs After students have examined the graph in Figure 8–5, ask: **How does the color spectrum at the bottom relate to the graph itself?** *(Each of the colors of the visible spectrum has a characteristic range of wavelengths, as designated on the horizontal axis of the graph.)* **In what region of the spectrum does chlorophyll *b* absorb light best?** *(In the blue region)* Challenge students to convert the data in the graph into a data table that shows, for example, the estimated absorption of chlorophyll *a* and chlorophyll *b* at 550 nm. L2

3 ASSESS

Evaluate Understanding

Have students write a paragraph, using their own words, that explains how plants produce high-energy sugars through the process of photosynthesis. Call on students at random to read their paragraphs.

Reteach

Ask students to make a labeled drawing based on Figure 8–4 but with more realistic objects, including a leafy tree, the sun, and clouds in the sky (visually representing the atmosphere). Ask that they use arrows and symbols in their drawing to show the same equation for photosynthesis that Figure 8–4 does.

Writing in Science

Students should write a paragraph summarizing the experiments of one of the three scientists discussed in the section. A good paragraph should have a topic sentence derived from the first boldface sentence on page 206, details about the experiments performed, and a concluding sentence that explains the significance of the scientist's work.

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 8–2.