Section 8–3

1 FOCUS

Objectives

8.3.1 ***Describe*** the structure and function of a chloroplast.
8.3.2 ***Describe*** what happens in the light-dependent reactions.
8.3.3 ***Explain*** what the Calvin cycle is.
8.3.4 ***Identify*** factors that affect the rate at which photosynthesis occurs.

Guide for Reading

Preview Vocabulary

Before reading, have students find each Vocabulary word in the section and preview its meaning.

Reading Strategy

Suggest that students write a summary of the information in Figures 8–7, 8–10, and 8–11. Have them revise their summaries after reading the section.

2 INSTRUCT

Inside a Chloroplast

Use Visuals

Figure 8–6 Have student volunteers read the annotations for the parts of a chloroplast. Then, with students' help, make a Venn diagram on the board that shows the relationships among a granum, thylakoids, and photosystems. The diagram should show a thylakoid within a granum and photosystems within the thylakoid. Then, ask: **Within the chloroplast, where do the light-dependent reactions occur, and where does the Calvin cycle occur?** *(The light-dependent reactions occur within the thylakoid membranes, and the Calvin cycle occurs in the stroma.)* Have students locate these places on the figure. L1 L2

8–3 The Reactions of Photosynthesis

Guide for Reading

Key Concepts
- What happens in the light-dependent reactions?
- What is the Calvin cycle?

Vocabulary
thylakoid
photosystem
stroma
NADP+
light-dependent reactions
ATP synthase
Calvin cycle

Reading Strategy: Using Visuals Before you read, preview **Figures 8–7, 8–10,** and **8–11.** As you read, notice where in the chloroplast each stage of photosynthesis takes place.

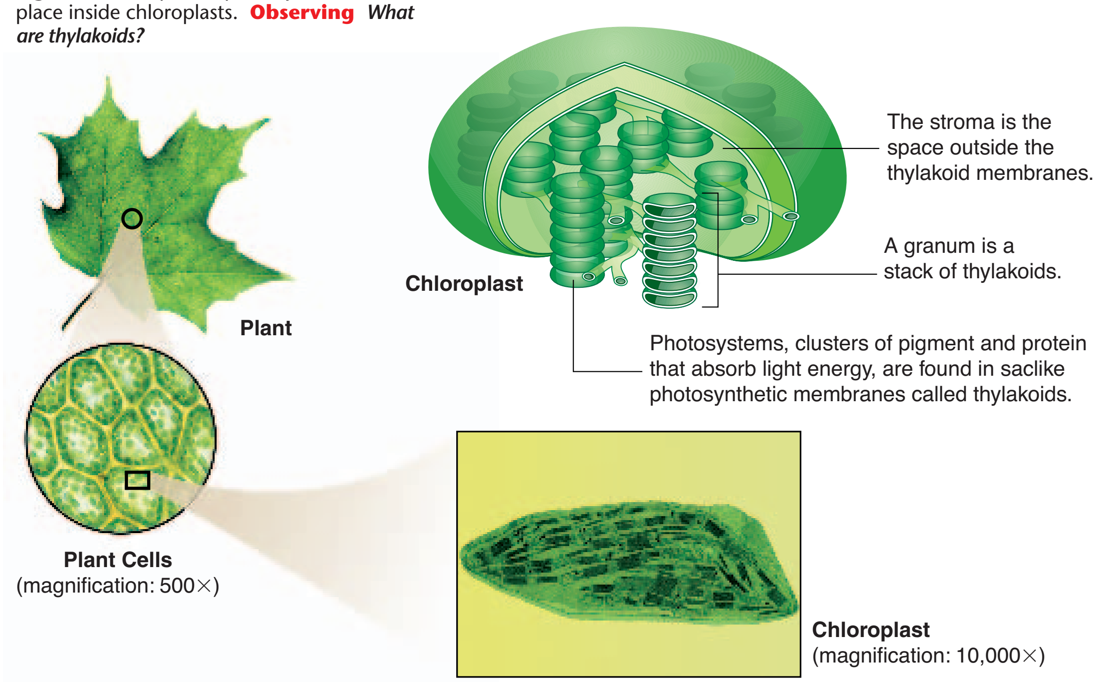
The requirements of photosynthesis were discovered in the 1800s. It was not until the second half of the 1900s, however, that biologists understood the complex reactions that make this important cellular process possible.

Inside a Chloroplast

In plants and other photosynthetic eukaryotes, photosynthesis takes place inside chloroplasts. The chloroplasts, shown in **Figure 8–6,** contain saclike photosynthetic membranes called **thylakoids** (THY-luh-koydz). Thylakoids are arranged in stacks known as grana (singular: granum). Proteins in the thylakoid membrane organize chlorophyll and other pigments into clusters known as **photosystems.** These photosystems are the light-collecting units of the chloroplast.

Scientists describe the reactions of photosystems in two parts: the light-dependent reactions and the light-independent reactions, or Calvin cycle. The relationship between these two sets of reactions is shown in **Figure 8–7.** The light-dependent reactions take place within the thylakoid membranes. The Calvin cycle takes place in the **stroma,** the region outside the thylakoid membranes.

Figure 8–6 In plants, photosynthesis takes place inside chloroplasts. **Observing** *What are thylakoids?*



TIME SAVER

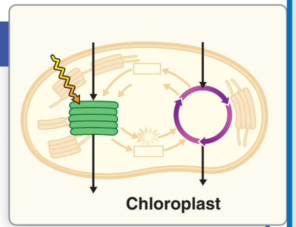
SECTION RESOURCES

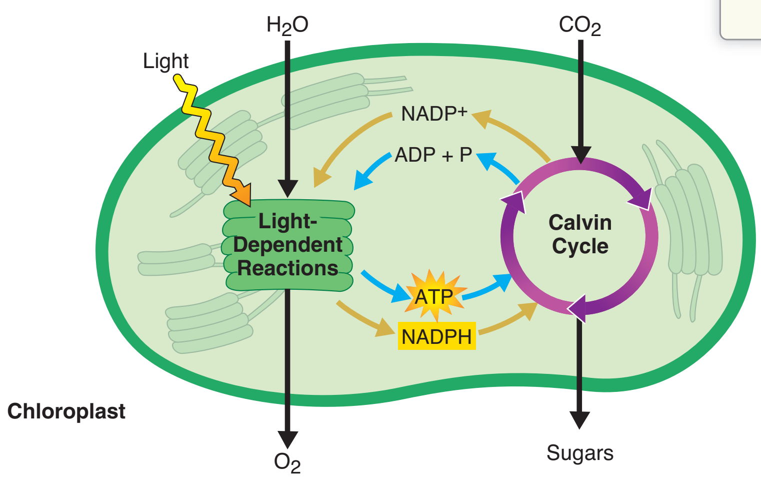
Print:
- ***Teaching Resources,*** Lesson Plan 8–3, Adapted Section Summary 8–3, Adapted Worksheets 8–3, Section Summary 8–3, Worksheets 8–3, Section Review 8–3
- ***Reading and Study Workbook A,*** Section 8–3
- ***Adapted Reading and Study Workbook B,*** Section 8–3
- ***Biotechnology Manual,*** Lab 17, Issue 4
- ***Lab Worksheets,*** Chapter 8 Design an Experiment

Technology:
- ***iText,*** Section 8–3
- ***Animated Biological Concepts DVD,*** 10 Light-Dependent Reactions, 11 Calvin Cycle
- ***Transparencies Plus,*** Section 8–3
- ***Lab Simulations CD-ROM,*** Photosynthesis
- ***Virtual Labs,*** Lab 7

FIGURE 8–7 PHOTOSYNTHESIS: AN OVERVIEW

The process of photosynthesis includes the light-dependent reactions as well as the Calvin cycle. **Interpreting Graphics** *What are the products of the light-dependent reactions?*



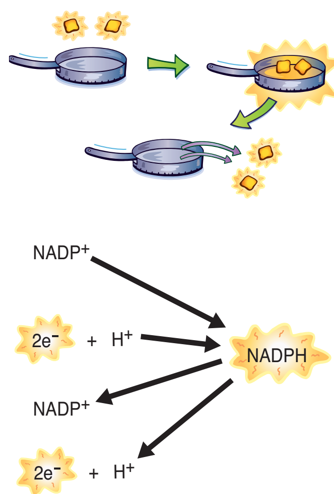


Electron Carriers

When sunlight excites electrons in chlorophyll, the electrons gain a great deal of energy. These high-energy electrons require a special carrier. Think of a high-energy electron as being similar to a red-hot coal from a fireplace or campfire. If you wanted to move the coal from one place to another, you wouldn't pick it up in your hands. You would use a pan or bucket—a carrier—to transport it. Cells treat high-energy electrons in the same way. Instead of a pan or bucket, they use electron carriers to transport high-energy electrons from chlorophyll to other molecules, as shown in **Figure 8–8.** A carrier molecule is a compound that can accept a pair of high-energy electrons and transfer them along with most of their energy to another molecule. This process is called electron transport, and the electron carriers themselves are known as the electron transport chain.

One of these carrier molecules is a compound known as **$NADP^+$** (nicotinamide adenine dinucleotide phosphate). The name is complicated, but the job that $NADP^+$ has is simple. $NADP^+$ accepts and holds 2 high-energy electrons along with a hydrogen ion (H^+). This converts the $NADP^+$ into NADPH. The conversion of $NADP^+$ into NADPH is one way in which some of the energy of sunlight can be trapped in chemical form.

The NADPH can then carry high-energy electrons produced by light absorption in chlorophyll to chemical reactions elsewhere in the cell. These high-energy electrons are used to help build a variety of molecules the cell needs, including carbohydrates like glucose.



▲ **Figure 8–8** Like a pan being used to carry hot coals, electron carriers such as $NADP^+$ transport electrons. **Interpreting Graphics** *What eventually happens to those electrons?*

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Less Proficient Readers

To reinforce understanding of the Calvin cycle and the electron transport chain, divide the class into pairs, matching less proficient readers with students who have shown a grasp of the details of photosynthesis. Ask the paired students to quiz each other on the details of both the light-dependent reactions and the Calvin cycle, using Figure 8–10 and Figure 8–11 as their primary resources. L1 L2

Advanced Learners

The investigation of the light-independent reactions by Melvin Calvin in the late 1940s is a fascinating example of biochemical discovery. Encourage advanced learners to find out about Calvin's work through library research and to prepare a presentation to the class. Ask students to make drawings or provide other visual aids to help show how Calvin used carbon-14 to identify the sequence of reactions involved in the process. L3

Electron Carriers

Use Visuals

Figure 8–7 After students have studied the figure and read the caption, have them answer the following questions on a sheet of paper: **What materials come into the chloroplast that are used in the light-dependent reactions?** *(Light and H_2O)* **What material comes into the chloroplast that is used in the Calvin cycle?** *(CO_2)* **What material moves out of the chloroplast from the light-dependent reactions?** *(O_2)* **What materials move out of the chloroplast from the Calvin cycle?** *(Sugars)* **What materials move from the light-dependent reactions to the Calvin cycle?** *(ATP and NADPH)* **What materials move from the Calvin cycle back to the light-dependent reactions?** *($NADP^+$ and ADP + P)* L1 L2

Make Connections

Chemistry Remind students that an ion is an atom, or group of atoms, that has a positive or negative charge because it has lost or gained electrons. Ask: **If an ion has more protons than electrons, is its charge positive or negative?** *(Positive)* Point out that $NADP^+$ is a positive ion, which explains why it can accept a negative electron. Then, ask: **What does a hydrogen atom consist of?** *(One proton and one electron)* **If a hydrogen atom loses its electron, what is the result?** *(A hydrogen ion, or H^+)* L2

Answers to . . .

Figure 8–6 *Thylakoids are saclike photosynthetic membranes contained in chloroplasts.*

Figure 8–7 *The products of the light-dependent reaction are O_2, ATP, and NADPH.*

Figure 8–8 *The electrons are carried to chemical reactions elsewhere in the cell, where they are used to help build a variety of molecules that the cell needs, including carbohydrates.*

8–3 (continued)

Light-Dependent Reactions

Make Connections

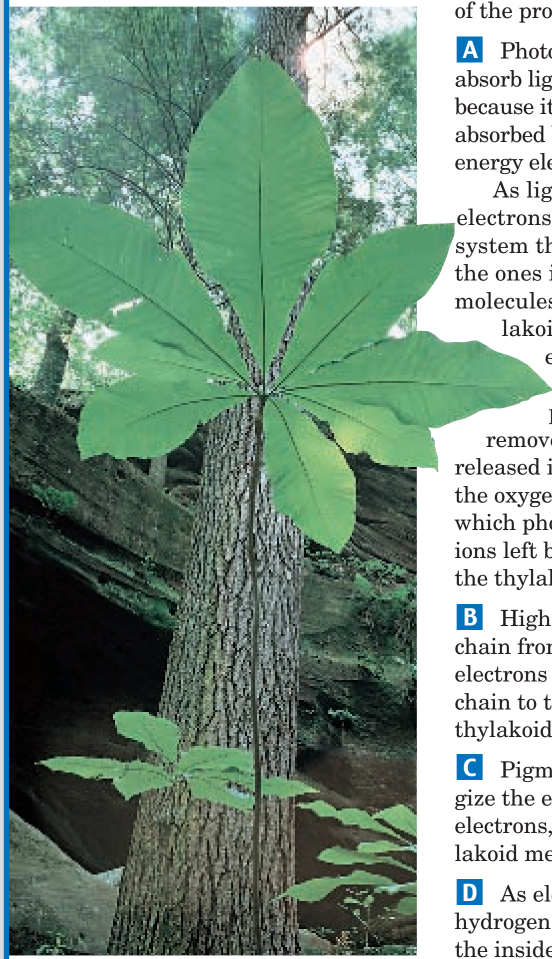
Physics Ask: **Does light radiate in waves or particles?** *(Some students may say waves, others particles.)* Explain that light has both the properties of waves and the properties of a stream of particles. A particle of light is called a photon, and some photons have more energy than others. The amount of energy in a photon depends on the wavelength; the shorter the wavelength, the more energy a photon has. Explain that when a photon of a certain amount of energy strikes a molecule of chlorophyll, the energy of that photon is transferred to an electron in that chlorophyll molecule. L2 L3

Demonstration

To reinforce the concept that light-dependent reactions require the presence of light, show students two healthy potted green-leafed plants of the same species and about the same size. Ask: **If one of these plants did not get any light for a week, what do you predict would happen?** *(Most students will predict that the plant will suffer from lack of light.)* Then, place one plant in a sunny spot in the room and the other in a dark place. Water each plant the same amount every other day. After a week, students should observe that the plant that received sunlight remained healthy, while the plant that spent the week in the dark became pale and straggly. L1 L2

Light-Dependent Reactions

As you might expect from their name, the **light-dependent reactions** require light. That is why plants like the one in **Figure 8–9** need light to grow. The light-dependent reactions use energy from light to produce ATP and NADPH. **The light-dependent reactions produce oxygen gas and convert ADP and $NADP^+$ into the energy carriers ATP and NADPH.** Look at **Figure 8–10** to see what happens at each step of the process.



▲ **Figure 8–9** Like all plants, this seedling needs light to grow. **Applying Concepts** *What stage of photosynthesis requires light?*

A Photosynthesis begins when pigments in photosystem II absorb light. That first photosystem is called photosystem II because it was discovered after photosystem I. The light energy is absorbed by electrons, increasing their energy level. These high-energy electrons are passed on to the electron transport chain.

As light continues to shine, does the chlorophyll run out of electrons? No, it does not. The thylakoid membrane contains a system that provides new electrons to chlorophyll to replace the ones it has lost. These new electrons come from water molecules (H_2O). Enzymes on the inner surface of the thylakoid membrane break up each water molecule into 2 electrons, 2 H^+ ions, and 1 oxygen atom. The 2 electrons replace the high-energy electrons that chlorophyll has lost to the electron transport chain. As plants remove electrons from water, oxygen is left behind and is released into the air. This reaction is the source of nearly all of the oxygen in Earth's atmosphere, and it is another way in which photosynthesis makes our lives possible. The hydrogen ions left behind when water is broken apart are released inside the thylakoid membrane.

B High-energy electrons move through the electron transport chain from photosystem II to photosystem I. Energy from the electrons is used by the molecules in the electron transport chain to transport H^+ ions from the stroma into the inner thylakoid space.

C Pigments in photosystem I use energy from light to reenergize the electrons. $NADP^+$ then picks up these high-energy electrons, along with H^+ ions, at the outer surface of the thylakoid membrane, plus an H^+ ion, and becomes NADPH.

D As electrons are passed from chlorophyll to $NADP^+$, more hydrogen ions are pumped across the membrane. After a while, the inside of the membrane fills up with positively charged hydrogen ions. This makes the outside of the thylakoid membrane negatively charged and the inside positively charged. The difference in charges across the membrane provides the energy to make ATP. This is why the H^+ ions are so important.

E H^+ ions cannot cross the membrane directly. However, the cell membrane contains a protein called **ATP synthase** (SIN-thays) that spans the membrane and allows H^+ ions to pass through it. As H^+ ions pass through ATP synthase, the protein rotates like a turbine being spun by water in a hydroelectric power plant.

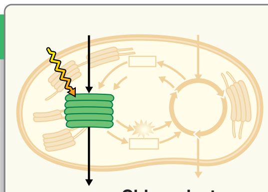
TEACHER TO TEACHER

When I introduce photosynthesis to students, I first present information about the physical properties of light, especially how light can be thought of as either waves or photons. This information both sparks the interest of students and helps them understand how the light-dependent reactions work. Then, I move on to the biochemistry of photosynthesis. Students often get bored with the specifics of the chemical reactions. Turning their attention to an illustration of chloroplast structure can help renew interest in the biochemistry. Using paper chromatography to identify the different pigments in plants also helps students understand photosynthesis.

—Greg McCurdy
Biology Teacher
Salem High School
Salem, IN

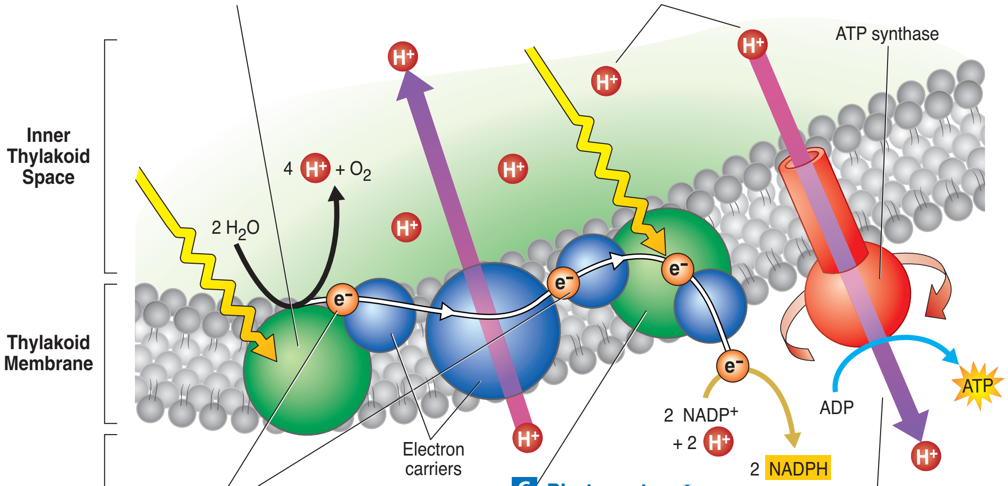
Light-Dependent Reactions

Figure 8–10 **The light-dependent reactions use energy from sunlight to produce ATP, NADPH, and oxygen.** The light-dependent reactions take place within the thylakoid membranes of chloroplasts.



A Photosystem II
Light absorbed by photosystem II is used to break up water molecules into energized electrons, hydrogen ions (H^+), and oxygen.

D Hydrogen Ion Movement
The inside of the thylakoid membrane fills up with positively charged hydrogen ions. This action makes the outside of the thylakoid membrane negatively charged and the inside positively charged.



B Electron Transport Chain
High-energy electrons from photosystem II move through the electron transport chain to photosystem I.

C Photosystem I
Electrons released by photosystem II are energized again in photosystem I. Enzymes in the membrane use the electrons to form NADPH. NADPH is used to make sugar in the Calvin cycle.

E ATP Formation
As hydrogen ions pass through ATP synthase, their energy is used to convert ADP into ATP.

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Web Code: cbp-3083

As it rotates, ATP synthase binds ADP and a phosphate group together to produce ATP. Because of this system, light-dependent electron transport produces not only high-energy electrons but ATP as well.

As we have seen, the light-dependent reactions use water, ADP, and $NADP^+$, and they produce oxygen and two high-energy compounds: ATP and NADPH. What good are these compounds? As we will see, they have an important role to play in the cell: They provide the energy to build energy-containing sugars from low-energy compounds.

CHECKPOINT *What is the role of photosystem II? How does that role compare with the role of photosystem I?*

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Visit: PHSchool.com
Web Code: cbe-3083
Students identify the products and reactants of photosynthesis.

Make Connections

Earth Science Explain that Earth's atmosphere is about 21 percent oxygen. Point out that the atmosphere that surrounded Earth billions of years ago contained little oxygen. Then, about 3.3 billion years ago, photosynthetic organisms appeared on Earth. The atmosphere changed in composition over time, until it reached its present composition about 500 million years ago. Ask: **What process do you think increased the percentage of oxygen in the atmosphere over time?** *(Earth's photosynthetic organisms, including plants, added oxygen to the air as they carried out photosynthesis.)* **What is the source of the oxygen released into the atmosphere by photosynthetic organisms?** *(Oxygen released into the atmosphere is produced during the light-dependent reactions as water molecules are broken up.)* L2

Teacher to Teacher

To illustrate the importance of light to the process of photosynthesis, describe what happens to sun-loving lawn plants such as grasses when a board, cloth, or some other object is left on the lawn for a number of days. Tell students that the lack of light causes photosynthesis to slow down. After a longer period of sun deprivation, the plants begin to die, the chlorophyll begins to break down, and a yellow color can be observed.

You also can describe what happens to a farm crop such as corn when it is planted in a field that borders a forest. Explain how the rows of corn next to the woodland will become pale green and stunted because the forest will block some of the corn's sunlight.

—*Dale Faughn*
Biology Teacher
Caldwell County High School
Princeton, KY

Answers to . . .

CHECKPOINT *In photosystem II, the energy from light is absorbed by chlorophyll and transferred to electrons, and then these high-energy electrons are passed on to the electron transport chain. In photosystem I, pigments use energy from light to reenergize the electrons.*

Figure 8–9 *The light-dependent reactions of photosynthesis require light.*

8–3 (continued)

The Calvin Cycle

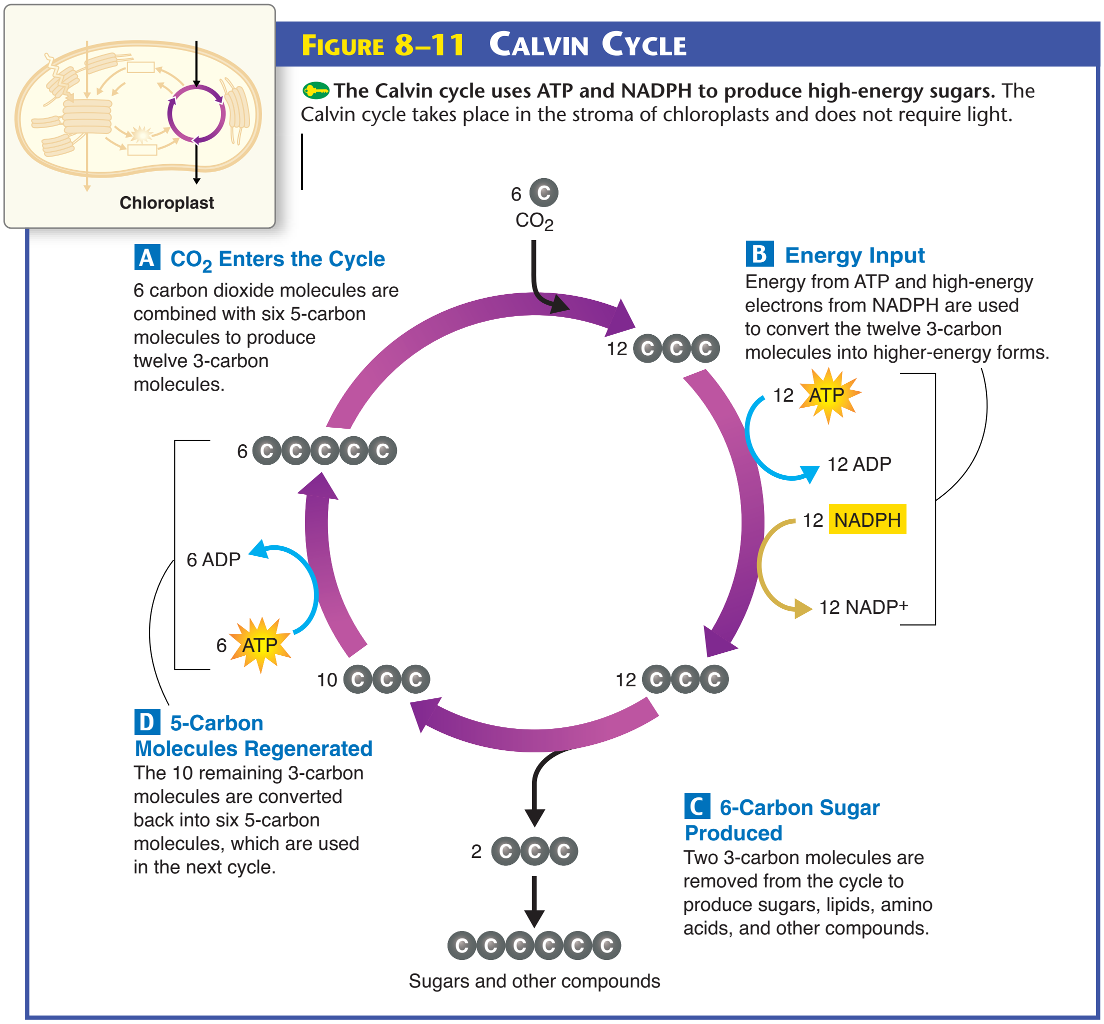
Use Visuals

Figure 8–11 Have students study the figure and read the caption. Then, ask: **Where does the Calvin cycle take place?** *(It takes place in the stroma, outside the grana.)* **What enters the Calvin cycle from the atmosphere?** *(Six CO_2 molecules)* Ask a volunteer to describe where on the figure those molecules enter the cycle. Then, ask another volunteer to point out where in the cycle ATP and NADPH become involved. Ask: **Where do the ATP and NADPH come from?** *(Both ATP and NADPH come from the light-dependent reactions.)* Emphasize that the Calvin cycle uses the energy of those high-energy molecules from the light-dependent reactions to keep the cycle going. Ask: **What is the product of this cycle?** *(Two 3-carbon molecules)* Have a volunteer describe where in the cycle the two 3-carbon molecules are yielded. Ask: **What happens next to the 3-carbon molecules?** *(They are used to form one 6-carbon sugar.)* Ask: **How is the cycle completed?** *(The cycle is complete when the remaining 3-carbon molecules are converted back into 5-carbon molecules, which are ready to combine with new carbon dioxide molecules to begin the cycle again.)* L2

Go Online NSTA SCILINKS
Download a worksheet on the Calvin cycle for students to complete, and find additional teacher support from NSTA SciLinks.

FIGURE 8–11 CALVIN CYCLE

The Calvin cycle uses ATP and NADPH to produce high-energy sugars. The Calvin cycle takes place in the stroma of chloroplasts and does not require light.



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For: Links on Calvin cycle
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The Calvin Cycle

The ATP and NADPH formed by the light-dependent reactions contain an abundance of chemical energy, but they are not stable enough to store that energy for more than a few minutes. During the **Calvin cycle,** plants use the energy that ATP and NADPH contain to build high-energy compounds that can be stored for a long time. **The Calvin cycle uses ATP and NADPH from the light-dependent reactions to produce high-energy sugars.** The Calvin cycle is named after the American scientist Melvin Calvin, who worked out the details of this remarkable cycle. Because the Calvin cycle does not require light, these reactions are also called the light-independent reactions. Follow **Figure 8–11** to see how the Calvin cycle works.

BIO INSIGHTS

HISTORY OF SCIENCE

Same stages, different names

In the early 1900s, British plant physiologist F. F. Blackman concluded that photosynthesis occurs in two stages, a stage that depends on light followed by a stage that can take place in darkness. The terms *light reactions* and *dark reactions* have been commonly used for the two stages since that time. Yet, the term *dark reactions* implies that those reactions can occur only in darkness, which is not the case. It's just that the dark reactions don't depend on sunlight to occur. To avoid this ambiguity, the authors of many modern textbooks have labeled the two stages the *light-dependent reactions* and the *light-independent reactions.* The authors of this textbook have gone a step further toward clarity by labeling the light-independent reactions the *Calvin cycle,* the name of the series of reactions that make up the light-independent reactions in most photosynthetic organisms.

A Six carbon dioxide molecules enter the cycle from the atmosphere. The carbon dioxide molecules combine with six 5-carbon molecules. The result is twelve 3-carbon molecules.

B The twelve 3-carbon molecules are then converted into higher-energy forms. The energy for this conversion comes from ATP and high-energy electrons from NADPH.

C Two of the twelve 3-carbon molecules are removed from the cycle. The plant cell uses these molecules to produce sugars, lipids, amino acids, and other compounds needed for plant metabolism and growth.

D The remaining ten 3-carbon molecules are converted back into six 5-carbon molecules. These molecules combine with six new carbon dioxide molecules to begin the next cycle.

The Calvin cycle uses six molecules of carbon dioxide to produce a single 6-carbon sugar molecule. As photosynthesis proceeds, the Calvin cycle works steadily removing carbon dioxide from the atmosphere and turning out energy-rich sugars. The plant uses the sugars to meet its energy needs and to build more complex macromolecules such as cellulose that it needs for growth and development. When other organisms eat plants, they can also use the energy stored in carbohydrates.

CHECKPOINT *What are the main products of the Calvin cycle?*

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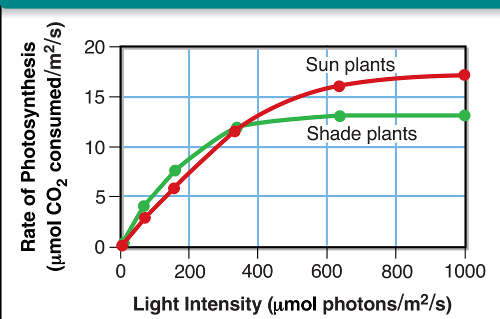
Analyzing Data

Rates of Photosynthesis

The rate at which a plant carries out photosynthesis depends in part on its environment. Plants that grow in the shade, for example, carry out photosynthesis at low levels of light. Plants that grow in the sun, such as desert plants, typically carry out photosynthesis at much higher levels of light.

The graph compares the rates of photosynthesis between plants that grow in the shade and plants that grow in the sun. It shows how the rate of photosynthesis changes with the number of micromoles of photons per square meter per second (μmol photons/m²/s), a standard unit of light intensity.

Rates of Photosynthesis



1. **Using Tables and Graphs** When light intensity is below 200 μmol photons/m²/s, do sun plants or shade plants have a higher rate of photosynthesis?
2. **Drawing Conclusions** Does the relationship in question 1 change when light intensity increases above 400 μmol photons/m²/s? Explain your answer.
3. **Inferring** The average light intensity in the Sonoran Desert is about 400 μmol photons/m²/s. According to the graph, what would be the approximate rate of photosynthesis for sun plants that grow in this environment?
4. **Going Further** Suppose you transplant a sun plant to a shaded forest floor that receives about 100 μmol photons/m²/s. Do you think this plant will grow and thrive? Why or why not? How does the graph help you answer this question?

Go Online NSTA SCILINKS
Download a worksheet on photosynthesis for students to complete, and find additional teacher support from NSTA SciLinks.

Build Science Skills

Comparing and Contrasting Have students compare what happens in the light-dependent reactions of photosynthesis with what happens in the Calvin cycle. This could be done by each student in written form or orally in class discussion. Students should particularly compare the reactants and products of each series of reactions. L2

Analyzing Data

Have student volunteers explain what is measured on the vertical axis and the horizontal axis of this graph. Tell students that understanding the unit of measure for the rate of photosynthesis is not as important as recognizing that the rate increases in units of 5 along the vertical axis. L2

Answers

1. Shade plants
2. Yes; above 400 μmol photons/m²/s, sun plants have a higher rate of photosynthesis than shade plants.
3. 13 μmol CO_2 consumed/m²/s
4. The graph shows that a sun plant's rate of photosynthesis would decrease dramatically from its normal rate if transplanted to a shaded forest, from 13 μmol CO_2 consumed/m²/s at 400 μmol photons/m²/s to only about 4 μmol CO_2 consumed/m²/s at 100 μmol photons/m²/s.

BIO INSIGHTS **HISTORY OF SCIENCE**

Calvin's investigation
In the late 1940s, University of California biochemist Melvin Calvin worked out the details of the sequence of reactions that now bears his name. For this investigation, Calvin exposed cells of *Chlorella,* a unicellular green alga, to carbon dioxide that contained the radioactive isotope carbon-14. After a short time, he dropped the algae into boiling alcohol, killing the cells and stopping the reactions at that point. He then identified the compounds in the dead cells that contained carbon-14, reasoning that these compounds were involved in the process of photosynthesis. By varying the time between exposure and killing the cells, Calvin was able to work out the steps in the light-independent reactions, or the Calvin cycle. For this work, Calvin received the 1961 Nobel Prize in Chemistry.

Answer to . . .

CHECKPOINT *The main products of the Calvin cycle are high-energy sugars.*

8–3 (continued)

Factors Affecting Photosynthesis

Use Community Resources

Have students brainstorm a list of questions to ask a staff member at a local arboretum or conservatory about factors that limit or enhance plant growth. Ask a student volunteer to contact the person to set up an appointment for an interview. Have that student and one or two others use the list of questions as a basis for the interview. Then, have the interviewers make an oral report to the class. L2 L3

3 ASSESS

Evaluate Understanding

Call on students at random to define or explain each of the section's Vocabulary words. Encourage other students to add to any definition or explanation given by one of their classmates.

Reteach

Ask student volunteers to orally describe parts of Figures 8–10 and 8–11, in the sequence in which the light-dependent reactions and the Calvin cycle occur.

Thinking Visually

In their flowcharts, students should illustrate as many steps as they can find in the section, including events in both stages of photosynthesis. Some students may have 20 or more steps. After students have completed the task, post the flowcharts around the room and invite volunteers to present their work to the class.

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 8–3.

Answer to . . .

Figure 8–12 *They both have a waxy coating on their leaves that reduces water loss.*

The two sets of photosynthetic reactions work together—the light-dependent reactions trap the energy of sunlight in chemical form, and the light-independent reactions use that chemical energy to produce stable, high-energy sugars from carbon dioxide and water. And, in the process, we animals get an atmosphere filled with oxygen. Not a bad deal at all.

Factors Affecting Photosynthesis

Many factors affect the rate at which photosynthesis occurs. Because water is one of the raw materials of photosynthesis, a shortage of water can slow or even stop photosynthesis. Plants that live in dry conditions, such as desert plants and conifers, have a waxy coating on their leaves that reduces water loss.

Temperature is also a factor. Photosynthesis depends on enzymes that function best between 0°C and 35°C. Temperatures above or below this range may damage the enzymes, slowing down the rate of photosynthesis. At very low temperatures, photosynthesis may stop entirely.

The intensity of light also affects the rate at which photosynthesis occurs. As you might expect, increasing light intensity increases the rate of photosynthesis. After the light intensity reaches a certain level, however, the plant reaches its maximum rate of photosynthesis. The level at which light intensity no longer affects photosynthesis varies from plant type to plant type. The conifers shown in **Figure 8–12** can carry out photosynthesis only on warm, sunny days.

Figure 8–12 Both temperature and the availability of water can affect rates of photosynthesis. Desert plants such as this Joshua tree (above) are adapted to survive with little water. During the cold winter months these conifers (below) may only occasionally carry out photosynthesis. **Comparing and Contrasting** ***What do both plants shown have that helps them conserve water?***

8–3 Section Assessment

1. **Key Concept** Summarize the light-dependent reactions.
2. **Key Concept** What reactions make up the Calvin cycle?
3. How is light energy converted into chemical energy during photosynthesis?
4. What is the function of NADPH?
5. **Critical Thinking Applying Concepts** Why are the light-dependent reactions important to the Calvin cycle?

Thinking Visually

Making a Flowchart
Construct a flowchart that illustrates the steps of photosynthesis. Begin with the energy of sunlight and end with the production of sugars. Include as much detail as possible in the numerous steps.

8–3 Section Assessment

1. The light-dependent reactions produce oxygen gas and convert ADP and $NADP^+$ into the energy carriers ATP and NADPH.
2. The Calvin cycle uses ATP and NADPH from the light-dependent reactions to produce high-energy sugars.
3. Light energy is converted into chemical energy by the pigments in the chloroplast.
4. The main function of NADPH is to carry high-energy electrons produced by light absorption in chlorophyll to chemical reactions elsewhere in the cell.
5. The light-dependent reactions provide the Calvin cycle with ATP and NADPH. The Calvin cycle uses the energy in ATP and NADPH to produce high-energy sugars.