4.2 Overview of Photosynthesis

**KEY CONCEPT** The overall process of photosynthesis produces sugars that store chemical energy.

**MAIN IDEAS**
- Photosynthetic organisms are producers.
- Photosynthesis in plants occurs in chloroplasts.

**VOCABULARY**
- photosynthesis, p. 103
- chlorophyll, p. 103
- thylakoid, p. 104
- light-dependent reactions, p. 105
- light-independent reactions, p. 105

**Connect** Solar-powered calculators, homes, and cars are just a few things that use energy from sunlight. In a way, you are also solar-powered. Of course, sunlight does not directly give you the energy you need to play a sport or read this page. That energy comes from ATP. Molecules of ATP are often made from the breakdown of sugars, but how are sugars made? Plants capture some of the energy in sunlight and change it into chemical energy stored in sugars.

**Photosynthetic organisms are producers.**

Some organisms are called producers because they produce the source of chemical energy for themselves and for other organisms. Plants, as well as some bacteria and protists, are the producers that are the main sources of chemical energy for most organisms on Earth. Certainly, animals that eat only plants obtain their chemical energy directly from plants. Animals that eat other animals, and bacteria and fungi that decompose other organisms, get their chemical energy indirectly from plants. When a wolf eats a rabbit, the tissues of the rabbit provide the wolf with a source of chemical energy. The rabbit’s tissues are built from its food source—the sugars and other carbon-based molecules in plants. These sugars are made through photosynthesis.

**Photosynthesis** is a process that captures energy from sunlight to make sugars that store chemical energy. Therefore, directly or indirectly, the energy for almost all organisms begins as sunlight. Sunlight has several types of radiant energy, such as ultraviolet radiation, microwaves, and the visible light that lets you see. Plants absorb visible light for photosynthesis. Visible light appears white, but it is made up of several colors, or wavelengths, of light.

**Chlorophyll** (KLAWR-uh-fihl) is a molecule in chloroplasts, shown in **FIGURE 4.4**, that absorbs some of the energy in visible light. Plants have two main types of chlorophyll, called chlorophyll \( a \) and chlorophyll \( b \). Together, these two types of chlorophyll absorb mostly red and blue wavelengths of visible light. Neither type absorbs much green light. Plants have other light-absorbing molecules that absorb green light, but there are fewer of these molecules. As a result, the green color of plants comes from the reflection of light’s green wavelengths by chlorophyll.

**Apply** Describe the importance of producers and photosynthesis.
Photosynthesis in plants occurs in chloroplasts.

Chloroplasts are the membrane-bound organelles where photosynthesis takes place in plants. Most of the chloroplasts are in leaf cells that are specialized for photosynthesis, which has two main stages as shown in Figure 4.5. The two main parts of chloroplasts needed for photosynthesis are the grana and the stroma. Grana (singular, granum) are stacks of coin-shaped, membrane-enclosed compartments called thylakoids. The membranes of the thylakoids contain chlorophyll, other light-absorbing molecules, and proteins. The stroma is the fluid that surrounds the grana inside a chloroplast.

**MAIN IDEA**

**Figure 4.5 Photosynthesis Overview**

Chloroplasts absorb energy from sunlight and produce sugars through the process of photosynthesis.

**Stage 1: Light-Dependent Reactions**

1. Energy from sunlight is absorbed. Water molecules are broken down and oxygen is released.

2. Energy is transferred from thylakoids to chloroplasts.

3. Carbon dioxide molecules are used to build sugars.

4. Six-carbon simple sugars are produced. The sugars are often used to build starches and cellulose.

**Identify** What are the reactants and the products in photosynthesis?

- **Reactants**: 6H₂O, 6CO₂
- **Products**: 6O₂, 1 six-carbon sugar
The light-dependent reactions capture energy from sunlight. These reactions take place within and across the membrane of the thylakoids. Water \((H_2O)\) and sunlight are needed for this stage of photosynthesis.

1. Chlorophyll absorbs energy from sunlight. The energy is transferred along the thylakoid membrane. \(H_2O\) molecules are broken down. Oxygen molecules \((O_2)\) are released.

2. Energy carried along the thylakoid membrane is transferred to molecules that carry energy, such as ATP.

The light-independent reactions use energy from the light-dependent reactions to make sugars. These reactions occur in the stroma of chloroplasts. Carbon dioxide molecules \((CO_2)\) are needed during this stage of photosynthesis.

3. \(CO_2\) is added to a cycle of chemical reactions to build larger molecules. Energy from the light-dependent reactions is used in the reactions.

4. A molecule of a simple sugar is formed. The sugar, usually glucose \((C_6H_{12}O_6)\), stores some of the energy that was captured from sunlight.

The equation for the whole photosynthesis process is shown below. As you can see, there are many arrows between the reactants—\(CO_2\) and \(H_2O\)—and the products—a six-carbon sugar and \(O_2\). Those arrows tell you that photosynthesis has many steps. For example, the light-independent reactions need only one molecule of \(CO_2\) at a time, and the six-carbon sugar comes from a reaction that combines two three-carbon sugars. Also, enzymes and other chemicals are needed, not just light, carbon dioxide, and water.

\[
6CO_2 + 6H_2O \rightarrow \text{light, enzymes} \rightarrow C_6H_{12}O_6 + 6O_2
\]

carbon dioxide water light, enzymes a sugar oxygen

Glucose and other simple sugars, such as fructose, are not the only carbohydrates that come from photosynthesis. Plants need the simple sugars to build starch and cellulose molecules. In effect, plants need photosynthesis for their growth and development. You will learn more about the importance of another product of photosynthesis—oxygen—in Sections 4.4 and 4.5.

**Summarize** How is energy from sunlight used to make sugar molecules?

**4.2 ASSESSMENT**

**REVIEWING MAIN IDEAS**

1. What are the roles of chloroplasts and chlorophyll in photosynthesis?
2. Describe the stages of photosynthesis. Use the terms thylakoid, light-dependent reactions, and light-independent reactions in your answer.

**CRITICAL THINKING**

3. Apply Suppose you wanted to develop a light to help increase plant growth. What characteristics should the light have? Why?

4. Analyze Explain why photosynthesis is important for building the structure of plant cells.

5. Chemical Reactions Overall, do you think photosynthesis is endothermic or exothermic? Explain your answer.

**Calvin Cycle** The light-independent reactions include a series of chemical reactions called the Calvin cycle. You can read more about the Calvin cycle in Section 4.3.
Rates of Photosynthesis

Photosynthesis converts some of the energy absorbed from sunlight into the chemical energy of sugars. The process is also the major source of oxygen in Earth's atmosphere. In this lab you will design an experiment to determine the effect of different light sources on the rate of photosynthesis in leaves.

PROBLEM How does a light source affect the rate of photosynthesis?

PROCEDURE

1. Use the hole punch to make five disks from an ivy leaf.
2. Fill one beaker halfway with the sodium bicarbonate/detergent solution. Fill a second beaker with water.
3. Remove the plunger from the syringe and place the ivy leaf disks into the syringe. Insert the plunger and draw 5 cc (5 mL) of the sodium bicarbonate/detergent solution into the syringe as shown in the photograph below (left).
4. Hold the syringe so that the tip is pointing upwards. Push on the plunger to squirt out any air in the syringe.
5. Place your finger on the tip of the syringe, as shown in the photograph below (right). Withdraw the plunger to form a vacuum, but be careful to not pull the plunger all the way out of the syringe. When the vacuum is formed, the gases in the air spaces in the leaf disks move into the syringe and the solution diffuses into the air spaces. Shake the syringe several times while your finger is on the tip.
6. Take your finger off of the tip of the syringe. This causes the leaf disks to sink to the bottom of the syringe because they become more dense from the diffusion of solution into the air spaces.
7. Open the syringe by pulling the plunger almost all the way out. Place your finger over the tip of the syringe and turn it so the tip is pointing down. Carefully remove the plunger and pour the contents of the syringe into the beaker of water. Use the forceps to remove the leaf disks if they stick to the walls of the syringe.
8. Place the beaker with the leaf disks under the light source and immediately start the stopwatch. Record the time it takes for each leaf disk to float to the top of the water. Use the rate at which the disks float as an indirect measurement of the rate of photosynthesis.
DESIGN
1. Decide how to test different light sources on the rate of photosynthesis. Identify your independent variable. Have your teacher approve your choice.
2. Identify your control condition and the constants in the experiment. Examples of constants are the distance between the light and the beaker, and the temperature of the water.
3. Write the procedure for your experiment.
4. Design a data table, such as the one shown below, to record and organize your results.

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Type of light ( # of disks)</th>
<th>Type of light ( # of disks)</th>
<th>Type of light ( # of disks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

5. Gather the additional materials you need for your experiment.
6. Test the rate of photosynthesis using the procedure on page 106. Be sure not to get any water on the light sources. Record your results. Continue collecting data until all five disks float in each experimental condition. (Note: If you test more than one condition at once, record a time and disk count for all of the beakers every time a disk floats in any of the beakers.)
7. If time allows, conduct three trials of your experiment.

ANALYZE AND CONCLUDE
1. Identify What are the independent and dependent variables in your experiment?
2. Calculate Determine the mean rate of photosynthesis in each condition of your experiment. To calculate the rate of photosynthesis, use the formula below:

\[
\frac{5 \text{ (# disks floating)}}{\text{total time (sec)}} = \text{disks/sec}
\]
3. Analyze Determine the best type of graph to use to represent your data. Explain your choice and construct the graph. Be sure to carefully label the axes of the graph.
4. Conclude Based on your data, what can you conclude about how your independent variable affects the rate of photosynthesis?
5. Infer Why do you think sodium bicarbonate was used in this investigation? (Hint: Think about the equation for the overall process of photosynthesis.)
6. Experimental Design What are possible sources of unavoidable error in your design? Explain why they were present.
7. Experimental Design Identify possible reasons for inconsistent results.