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8.3 The Process of Photosynthesis

Lesson Objectives

- Describe what happens during the light-dependent reactions.
- Describe what happens during the light-independent reactions.
- Identify factors that affect the rate at which photosynthesis occurs.

Lesson Summary

The Light-Dependent Reactions: Generating ATP and NADPH

Photosynthesis begins with these reactions, which occur in thylakoid membranes.

- **Photosystems** are clusters of proteins and chlorophyll in thylakoid membranes.
- High-energy electrons form when pigments in photosystem II absorb light. The electrons pass through **electron transport chains**, a series of electron carrier proteins.
  - The movement of electrons through an electron transport chain causes a thylakoid to fill up with hydrogen ions and generates ATP and NADPH.
  - **ATP synthase** is a membrane protein through which excess hydrogen ions escape a thylakoid in a process that makes ATP.

The Light-Independent Reactions: Producing Sugars

They occur in the stroma of thylakoids and are commonly called the **Calvin cycle**.

- Six carbon dioxide molecules from the atmosphere enter the Calvin cycle and combine with 5-carbon compounds already present. They produce twelve 3-carbon molecules.
- Two 3-carbon molecules are removed from the cycle. They are used by the plant to build sugars, lipids, amino acids, and other compounds.
- The remaining ten 3-carbon molecules are converted back to 5-carbon molecules and begin a new cycle.

Factors Affecting Photosynthesis

Many factors influence the rate of photosynthesis.

- Temperature, light intensity, and availability of water affect photosynthesis.
- C4 and CAM plants have a modified type of photosynthesis that enables the plants to conserve water in dry climates.

The Light-Dependent Reactions: Generating ATP and NADPH

For Questions 1–5, write True if the statement is true. If the statement is false, change the underlined word or words to make the statement true.

True **1.** Photosystems are clusters of chlorophyll and <u>proteins</u>.

photosystem II **2.** The light-dependent reactions begin when <u>photosystem I</u> absorbs light.

True **3.** Electrons from <u>water</u> molecules replace the ones lost by photosystem II.

NADPH **4.** <u>ATP</u> is the product of photosystem I.

energy **5.** ATP and NADPH are two types of <u>protein</u> carriers.

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6. How does ATP synthase produce ATP? *ATP synthase allows H^+ ions to pass through the thylakoid membrane. As the ions pass through, ATP synthase rotates. The rotation creates the energy needed to bind ADP and a phosphate group together to produce ATP.*

7. When sunlight excites electrons in chlorophyll, how do the electrons change? *The electrons take on a great deal of energy, which causes them to move to a higher energy level.*

8. Where do the light-dependent reactions take place? *The light-dependent reactions take place in the thylakoid membranes inside of chloroplasts.*

9. Complete the table by summarizing what happens in each phase of the light-dependent reactions of photosynthesis.

Light-Dependent Reactions	Summary
Photosystem II	*Photosystem II absorbs light and increases the electrons' energy level. The electrons are passed to the electron transport chain. Enzymes in the thylakoid break up water molecules into 2 electrons, 2 H^+ ions, and 1 oxygen atom. The 2 electrons replace the high-energy electrons that have been lost to the electron transport chain.*
Electron Transport Chain	*Energy from the electrons is used by the proteins in the chain to pump H^+ ions from the stroma into the thylakoid space. At the end of the electron transport chain, the electrons themselves pass to photosystem I.*
Photosystem I	*The electrons do not contain as much energy as they used to. Pigments use energy from light to reenergize the electrons. At the end of a short second electron transport chain, $NADP^+$ molecules in the stroma pick up the high-energy electrons, along with H^+ ions, at the outer surface of the thylakoid membrane, to become NADPH.*
Hydrogen Ion Movement and ATP Formation	*Hydrogen ions began to accumulate within the thylakoid space. The buildup of hydrogen ions makes the stroma negatively charged relative to the space within the thylakoids. This gradient, the difference in both charge and H^+ ion concentration across the membrane, provides the energy to make ATP.*

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The Light-Independent Reactions: Producing Sugars

10. What does the Calvin cycle use to produce high-energy sugars?

The Calvin cycle uses carbon dioxide molecules as well as ATP and NADPH from the light-dependent reactions to make sugars.

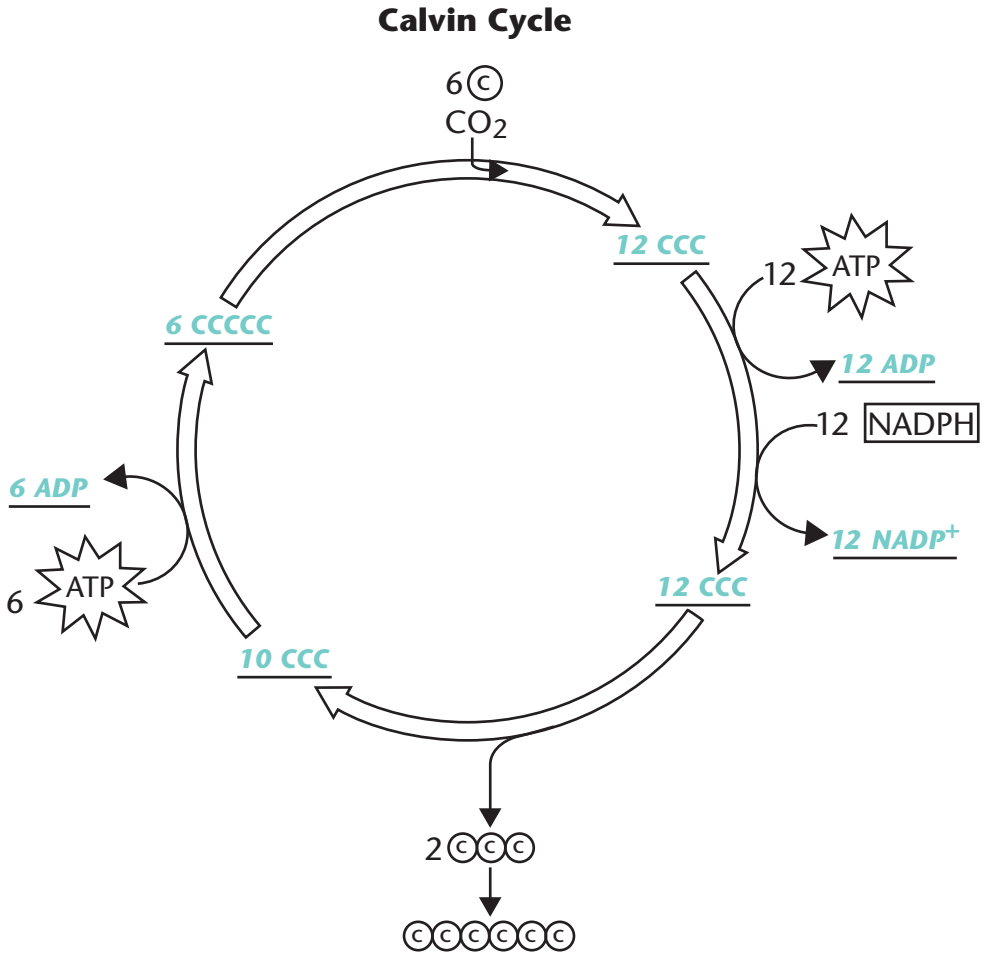
11. Why are the reactions of the Calvin cycle called light-independent reactions?

The reactions of the Calvin cycle use ATP and NADPH as energy sources. They do not directly require light.

12. What makes the Calvin cycle a cycle?

The compound with which CO_2 from the air combines is a product of the cycle, which enables the series of reactions to occur over and over.

13. Complete the diagram of the Calvin cycle by filling in the missing labels.



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Factors Affecting Photosynthesis

14. What are three factors that affect the rate at which photosynthesis occurs?

Three factors that affect the rate of photosynthesis are temperature, light intensity, and the availability of water.

15. Would a plant placed in an atmosphere of pure oxygen be able to conduct photosynthesis? Explain your answer.

SAMPLE ANSWER: No. One of the materials that plants use in photosynthesis is carbon dioxide. None of this gas would be present in an atmosphere of pure oxygen. Therefore, photosynthesis could not occur.

16. Complete the table about variations of photosynthesis.

Type	Description	Examples
C4 Photosynthesis	Occurs in plants that have a specialized chemical pathway that allows them to capture even very low levels of carbon dioxide and pass it to the Calvin cycle.	*corn, sugar cane, and sorghum*
CAM	*CAM plants only allow air into their leaves at night which minimizes water loses. Carbon dioxide is trapped in the leaves and it is released during the day, enabling carbohydrate production.*	pineapple trees, many desert cacti, and "ice plants"

Apply the Big idea

17. Photosynthesis plays an important role in supplying energy to living things. Considering what the products of photosynthesis are, what is another way in which photosynthesis is vital to life?

Photosynthesis is the way in which new organic macromolecules are added to the living portion of the biosphere. All living things that are not photosynthetic rely on photosynthesis as a source of the organic building blocks needed for growth. Photosynthesis also releases oxygen into the atmosphere. Without this oxygen we would not be able to breathe.

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Chapter Vocabulary Review

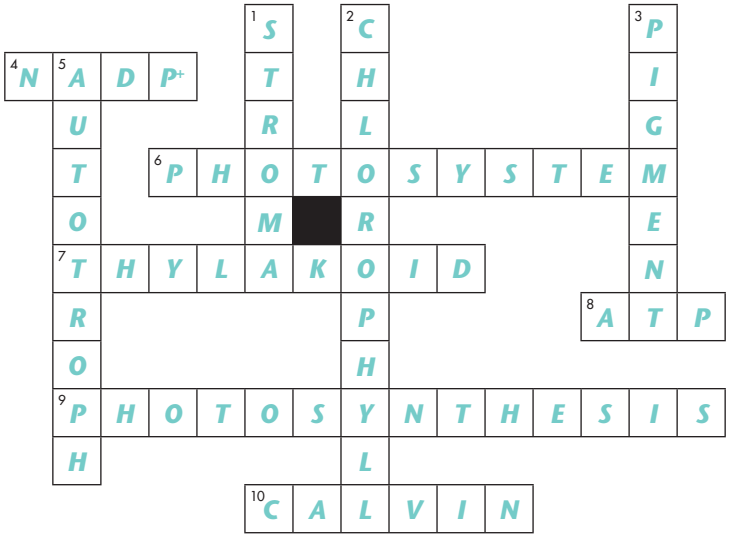
Crossword Puzzle *Complete the puzzle by entering the term that matches the description.*

Across

4. energy carrier cells use to transport high-energy electrons
6. cluster of pigments and proteins that absorbs light
7. a saclike photosynthetic membrane found in chloroplasts
8. energy carrier made as a result of photosystem II
9. process of using the sun's energy to make food
10. man who worked out the light-independent reactions

Down

1. liquid part of the inside of a chloroplast
2. chemical that absorbs light for photosynthesis
3. light-absorbing chemical
5. organism that makes its own food



For Questions 11–16, complete each statement by writing the correct word or words.

11. The light-*dependent* reactions occur in thylakoid membranes.

12. Carbon dioxide is used to make sugars in the light-*independent* reactions.

13. The light-independent reactions are also called the *Calvin cycle*.

14. *ATP synthase* spins to provide the energy for adding a phosphate group to ADP.

15. Electron *transport chains* move high-energy electrons between photosystems.

16. An animal that obtains food by eating other organisms is called a(n) *heterotroph*.

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CHAPTER MYSTERY

OUT OF THIN AIR?

In the Chapter Mystery, you read about a five-year-long experiment that Jan van Helmont performed in the middle of the seventeenth century. That experiment is a milestone in the history of science and is taught in high schools and colleges around the world.

21st Century Learning

Explore and Teach van Helmont's Experiment

But, van Helmont's experiment, as famous as it is, led him to the wrong conclusion. In the end, he did not know where the tree's mass came from. He guessed that it came from the water he'd added. It turns out he was wrong.

The problem was the way van Helmont set up his experiment. He set up his experiment to prove that the tree's extra mass came from the soil, and he did not consider other possible explanations of where the extra mass might come from. Therefore, the experiment, as carried out, could not prove where the tree's extra mass came from. In the 1600s, science and the scientific method were in their infancy. Now we know that an experiment should take all the variables into account and consider every possible outcome. An experiment should be done to find out what happens, or at least to find out if something happens, not to "prove" that the scientist's preconceived notion is correct.

Consider how you could modify van Helmont's procedures if you were to carry out the experiment today. Start with van Helmont's original hypothesis: A tree's mass comes from absorbing matter from the soil. What variable(s) would you need to control in this experiment?

SAMPLE ANSWER: I would need to control all matter that could enter the tree, including air, water, and material in the soil.

What procedure would you follow in your experiment?

SAMPLE ANSWER: I would completely enclose the tree in a container so that I could measure the mass of everything that entered and exited the container. I would start by measuring the soil's mass, the tree's mass, the air's mass, and the mass of any water I added to the system. I would allow the tree to grow for a period of time, and then measure the mass of all the materials in the container again to see how their masses had changed.

What materials and tools would you need for your experiment?

SAMPLE ANSWER: a seedling; a large, airtight container; a scale; metered gas valves; soil; tubing

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21st Century Themes Science Literacy

1. How does your experimental procedure make sure that nothing comes into contact with the tree without your being aware of it?

SAMPLE ANSWER: I would enclose the tree, soil, and all watering mechanisms inside an airtight dome.

2. How would you account for the mass of the water that comes into contact with the tree during the five-year experiment?

SAMPLE ANSWER: I would measure the mass of the water before I introduced it into the dome.

3. How would you account for the mass of the air that comes into contact with the tree over the five years?

SAMPLE ANSWER: I would have a metered valve at the air intake.

4. How would you account for the gases that would be released by the tree over the five years?

SAMPLE ANSWER: I would have a metered valve at the air outtake.

5. Are there any variables you would not be able to account for? If so, what are they?

SAMPLE ANSWER: There are no mass-related variables that are unaccounted for; the only other variable affecting the growth of the tree is sunshine. Energy from the sun is entering the system, but I don't know how to account for that.

21st Century Skills Communicating Results

The skills used in this activity include **communication skills; critical thinking and systems thinking; problem identification, formulation, and solution;** and **creativity** and **intellectual curiosity.**

How might you change your experiment to improve it? List any alterations you would make to ensure your results would be more valid. Then prepare a lesson plan that you could use to teach another student about van Helmont's experiment. The lesson plan should include an outline of what you would say, as well as any diagrams or pictures you would show to the student.

Ask your teacher to arrange for a time when you can meet with a middle-school student and teach him or her the lesson.

Students may suggest that they improve their experiment by more carefully controlling for the mass of materials entering and exiting the tree's enclosed container. Evaluate students' lesson plans based on the clarity, accuracy, and completeness of the written plan. Also make sure that the charts, diagrams, and pictures illustrate specific points made in the lesson and illuminate and expand these points.