Lesson Review

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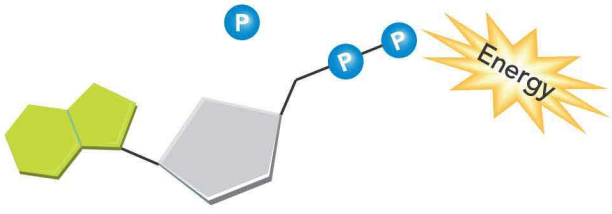
9.1 Energy and Life

All living things need energy to stay alive and carry out their life processes. Cells can store energy in the bonds of chemical compounds. One of the most important of these compounds is ATP (adenosine triphosphate). A cell can store a small amount of energy by adding a phosphate group to ADP to make ATP. When a cell needs energy, it can release it by breaking the chemical bond between the second and third phosphate groups of ATP.

Most life on Earth depends on the ability of autotrophs (plants and algae) to capture the energy from sunlight and convert it into the chemical energy stored in carbohydrates. This process is known as photosynthesis.

- ATP
- photosynthesis



Use An Analogy Describe how ADP and ATP act like a rechargeable battery to store and release energy.

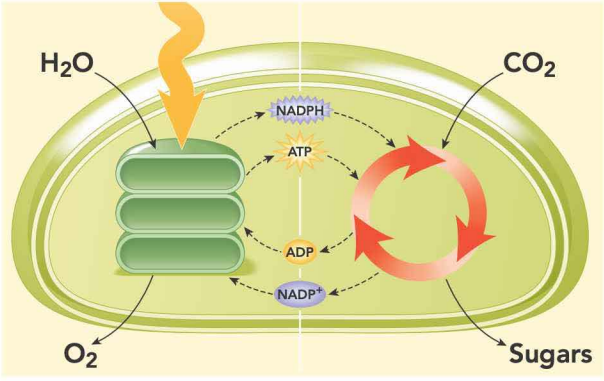
9.2 Photosynthesis: An Overview

Nearly every living thing on Earth depends on photosynthesis. Photosynthetic organisms capture energy from sunlight with pigments.

Plant cells use compounds called electron carriers to accept and transfer pairs of high-energy electrons from the chlorophyll to other molecules. One of these carrier compounds is $NADP^+$ (nicotinamide adenine dinucleotide phosphate).

Photosynthesis uses light energy to convert water and carbon dioxide into high-energy sugars and oxygen. Photosynthesis involves two sets of reactions: light-dependent and light-independent. The light-dependent reactions take place in the thylakoid membranes. The light-independent reactions take place in the stroma.

- pigment
- chlorophyll
- thylakoid
- stroma
- $NADP^+$
- light-dependent reactions
- light-independent reactions



Interpret Diagrams Label each side of the diagram. Then, write a caption to describe each process.

9.3 The Process of Photosynthesis

The light-dependent reactions of photosynthesis use light energy to produce oxygen and convert ADP and $NADP^+$ into ATP and NADPH.

The light-independent reactions of photosynthesis are also known as the Calvin cycle. The Calvin cycle uses the ATP and NADPH synthesized during the light-dependent reactions and carbon dioxide to make high-energy sugars.

Although many factors affect the rate of photosynthesis, the most important are temperature, light intensity, and the availability of water.

- photosystem
- electron transport chain
- ATP synthase
- Calvin cycle

Apply Concepts Explain why temperature, light intensity, and water availability affect the rate of photosynthesis.

Organize Information

Complete the table to summarize the processes described in this chapter.

Process	Occurs in	Inputs	Outputs
1.	2.	CO_2, H_2O, sunlight	O_2, high-energy sugars
Calvin cycle	3.	NADPH, ATP, CO_2	6-carbon sugar, ADP, $NADP^+$
4.	thylakoids	5.	NADPH, ATP, O_2
Electron transport chain	6.	7.	low-energy electrons, energy to pump H^+ ions from the stroma inside the thylakoid sac
	Photosystem II	8.	9.
	Photosystem I	10.	11.
	ATP synthase	12.	13.

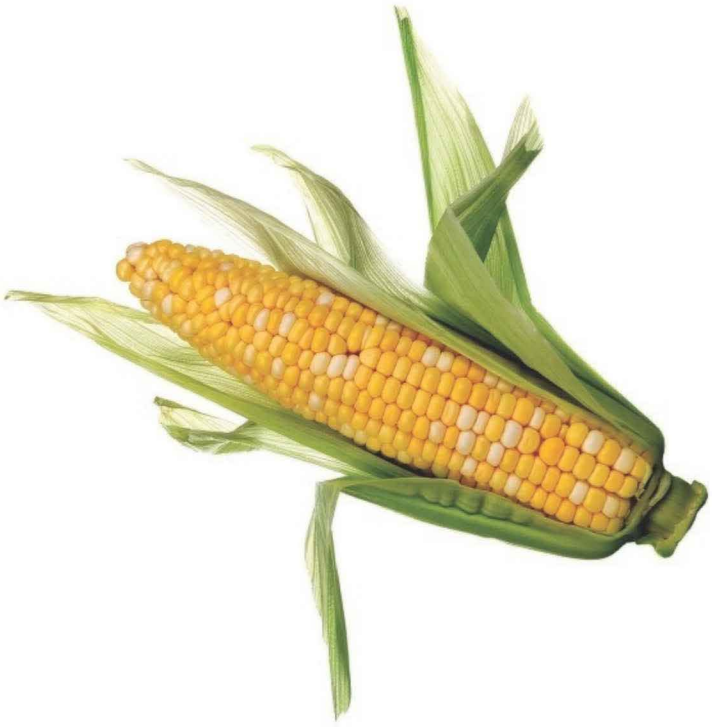
PERFORMANCE-BASED ASSESSMENT

Data From the Corn Field

Design a Solution

HS-LS1-5, HS-LS1-6, HS-LS2-4, HS-LS2-5, CCSS.ELA-LITERACY.RST.9-10.1, CCSS.ELA-LITERACY.WHST.9-10.1, CCSS.ELA-LITERACY.WHST.9-10.7, CCSS.MATH.CONTENT.HSN.Q.A.1, CCSS.MATH.CONTENT.HSS.IC.B.6

Matter is constantly moving in and out of the biosphere, which is the part of Earth in which all life exists. For example, consider the gain in mass that might be shown by a typical field of corn in the American Midwest.



On a warm morning in late spring, a farmer plants his fields with row after row of corn seeds. After a week or so, tiny seedlings begin poking out of the ground. Then the seedlings grow taller. Over the next few weeks they develop new roots and leaves, and then corn ears. After only three or four months, the fields are covered in tall, green corn plants, the ears ready to harvest. This process and these changes are repeated year after year across the United States, especially in a band of land that stretches from Ohio to Nebraska.

A typical acre can yield more than 3800 kilograms of corn. This yield includes only the corn itself. More than half the mass of the corn plant is not harvested, but is plowed under to enrich the soil for the next growing season. What is the source of the mass of these plants? It cannot be the soil. The soil remains thick and fertile year after year. Water is part of the source of the mass, but not all of it. Only about one fourth of the mass of a corn plant is water. A corn plant is about 40 percent carbon by mass. Where does all that carbon come from?

SCIENCE PROJECT

The table describes the significant inputs and outputs of a one-acre corn field. The inputs are things that are added to the field, either by the farmer or naturally. The outputs are the products that the field produces.

Typical Inputs and Outputs of a One-Acre Corn Field

Component	Role	Weight
Corn	Output	3800 kg (8400 lb)
Seeds	Input	5 kg (11 lb)
Fertilizer	Input	23 kg (50 lb)
Water (56 cm of rain)	Input	2.3 million kg (5 million lb)

1. **Construct an Explanation** What are the sources of the mass of corn plants? How does photosynthesis contribute to the mass of corn plants?
2. **Calculate** Use the data provided to calculate, as precisely as you can, the amount of carbon dioxide removed from the atmosphere by one acre of corn.
3. **Design a Solution** Is it reasonable to expect that Earth's plants can take up the extra carbon that human activities are adding to the atmosphere? Would some plants be better than others?
   - Research the productivity of different types of plants, including agricultural crops as well as forests. Include plants from different climates. You also may wish to research carbon sequestration in soil.
   - Identify other criteria that should be considered—for example, uses of the plants, water consumption, and cold hardiness.
   - Choose 2–3 plants that could be the most effective at removing carbon from the atmosphere. Write a proposal, citing evidence from your research. Include a model of how your solution depends on plants, photosynthesis, and the carbon cycle.

KEY QUESTIONS AND TERMS

9.1 Energy and Life

HS-LS1-5, HS-LS2-3

1. Energy is defined as the ability to
   a. communicate.
   b. reproduce.
   c. grow.
   d. do work.
2. Which of the following is NOT a form of energy?
   a. light
   b. oxygen
   c. heat
   d. electricity
3. Which of the following is used by cells to store and release the energy needed to power cellular processes?
   a. ATP.
   b. RNA.
   c. DNA.
   d. $NADP^+$.
4. How do heterotrophs and autotrophs differ in the way they obtain energy?
5. Compare the amounts of energy stored by ATP and glucose. Which compound is used by a cell as an immediate source of energy?
6. Describe how ATP can release and store energy for the cell.
7. How do plants synthesize high-energy carbohydrates?

9.2 Photosynthesis: An Overview

HS-LS1-5, HS-LS2-5

8. Plants use the green pigment chlorophyll to
   a. absorb sunlight.
   b. store sunlight.
   c. reflect sunlight.
   d. change light to heat.
9. High-energy electrons are transported from chlorophyll to other molecules in the chloroplast by
   a. the thylakoid membranes.
   b. pigments such as carotene.
   c. electron carriers such as $NADP^+$.
   d. the protein ATP synthase.
10. Identify and describe the two main parts of a chloroplast where photosynthesis occurs.
11. Write the basic equation for photosynthesis using the names of the starting and final substances of the process.

9.3 The Process of Photosynthesis

HS-LS1-5, HS-LS1-6, HS-LS2-5

12. The clusters of chlorophyll and proteins that absorb sunlight and generate high-energy electrons in the chloroplasts are called
    a. carrier proteins.
    b. transport chains.
    c. photosystems.
    d. synthase proteins.
13. In photosystem II, as high-energy electrons are passed to the electron transport chain, the chlorophyll gains new electrons from
    a. oxygen atoms.
    b. water molecules.
    c. hydrogen ions.
    d. carbon dioxide.
14. The light-independent reactions of photosynthesis are also known as the
    a. Calvin cycle.
    b. sugar cycle.
    c. carbon cycle.
    d. ATP cycle.
15. What is the function of the electrons as they move along the electron transport chain?
16. What occurs as H^+ ions pass through ATP synthase in the thylakoid membrane, and what is this process called?
17. Why is it important that carbon dioxide molecules from the atmosphere enter the Calvin cycle?
18. Name three important factors that can affect the rate of photosynthesis.
19. Crabgrass is an example of a C4 plant. In addition to biochemical adaptations seen in C4 and CAM plants, what is another way that plants can protect themselves from dry, hot conditions?

20. How does a cow use the sugar molecules stored in the grass it eats?

21. Discuss three factors that affect the rate at which photosynthesis occurs.

CRITICAL THINKING

HS-LS1-5, HS-LS1-6, HS-LS2-5

22. **Use Models** Photosynthesis usually produces glucose ($C_6H_{12}O_6$) as a final product. What are the sources of the carbon atoms and hydrogen atoms in glucose? Use a symbolic equation as a model to support your explanation.

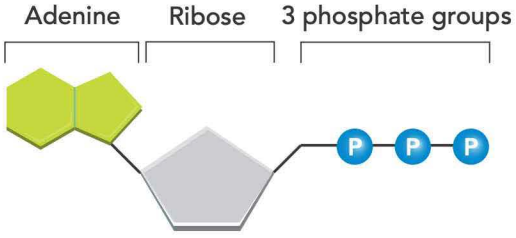
23. **Develop Models** Draw a diagram to use as a model of photosynthesis. The model should show the flow of matter and the transformation of light energy into chemical energy.

24. **Summarize** Explain the role of $NADP^+$ as an energy carrier in photosynthesis.

25. **Analyze Text Structure** Using the text from this chapter, analyze the relationships among the key terms *ATP, NADP*$^+$, and *ATP synthase*.

26. **Construct an Explanation** How does photosynthesis benefit both the organism that undergoes it and many other organisms? Include in your explanation how carbon, hydrogen, and oxygen atoms from the reactants of photosynthesis recombine to form compounds that are useful to the organisms.

27. **Use Models** The diagram shows a model of ATP. How would you revise the diagram to illustrate how ATP provides energy for the cell?



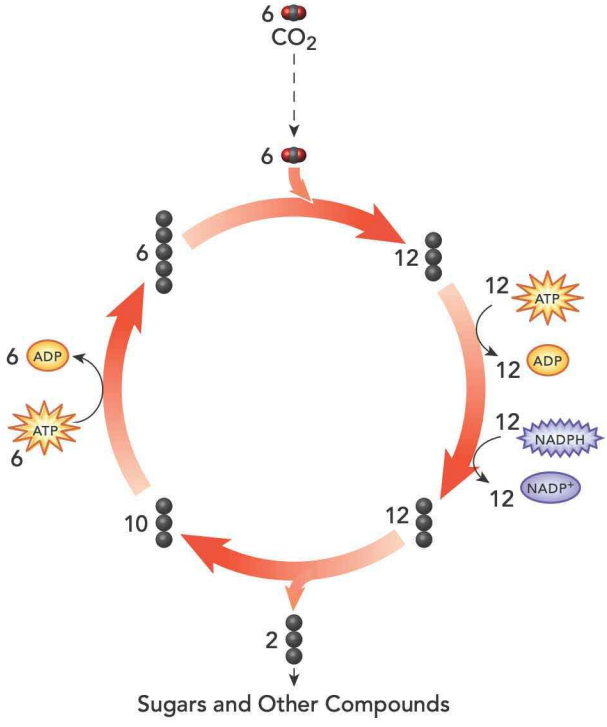
28. **Defend Your Claim** Could heterotrophs survive without autotrophs? Could autotrophs survive without heterotrophs? Make a claim, and then cite evidence from the text and use logical reasoning to defend it.

29. **Ask Questions** You are observing a species of single-celled algae in a well-lit aquarium. What questions could you ask, and then investigate, to help explain the role of photosynthesis in the algae?

30. **Evaluate** A student plans to isolate chlorophyll, mix it in a solution of carbon dioxide and water, and then shine light on the mixture. Do you predict glucose will be produced inside the mixture? Evaluate this investigation and explain your reasoning.

31. **Construct an Explanation** During photosynthesis, water molecules (H_2O) split to produce H^+ ions. Use this information, and what you know about the reactions involved in photosynthesis, to explain why water is necessary for photosynthesis to occur.

32. **Energy and Matter** Review the diagram that summarizes the light-independent reactions (Calvin cycle) shown.
    - **a.** Why are the light-independent reactions shown as a cycle? What are the inputs and outputs of the cycle?
    - **b.** How many carbon atoms enter the Calvin cycle to produce one molecule of glucose? What is the source of these carbon atoms?
    - **c.** Why do the light-independent reactions depend on the light-dependent reactions?



CROSSCUTTING CONCEPTS

33. Systems and System Models A student uses a marble track, like the one shown below, as a model to demonstrate part of the process of photosynthesis. The marbles represent electrons. What process of photosynthesis does the model demonstrate? Describe a way that the model could be improved.

34. Energy and Matter Explain how the process of photosynthesis can be used as evidence that energy flows through an ecosystem while matter cycles through an ecosystem.

MATH CONNECTIONS

Analyze and Interpret Data

CCSS.MATH.CONTENT.MP2, CCSS.MATH.CONTENT.HSF.BF.A.1, CCSS.MATH.CONTENT.HSS.ID.A.1

Consider the chemical equation that describes the flow of matter in the process of photosynthesis. Use the equation to answer questions 35–37.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

35. Draw Conclusions What is the source of the hydrogen atoms in glucose ($C_6H_{12}O_6$), one of the products of the reaction?

36. Infer When a carbon dioxide molecule (CO_2) enters the reaction, do all three of its atoms become part of a glucose molecule ($C_6H_{12}O_6$)? Explain your reasoning.

37. Reason Quantitatively Over time, a leaf converts 264 grams of carbon dioxide into 180 grams of glucose. How do you account for the difference in mass of 84 grams?

An aquatic plant emits bubbles of oxygen when placed under a bright light. The table shows the results of an experiment to show the effect of light intensity on bubble production. Use the data in the table to answer questions 38–40.

Oxygen Production

Distance From Light (cm)	Bubbles Produced per Minute
10	39
20	22
30	8
40	5

38. Create an Equation Write a linear equation that fits the data approximately. To determine the equation, plot the points and draw a line that passes near the points.

39. Interpret Graphs Describe the trend in the data. Use the linear equation you constructed to predict the number of bubbles that would appear when the light source is 5, 25, and 50 cm away.

40. Draw Conclusions What conclusion about photosynthesis is supported by the evidence from this experiment? Explain your reasoning.

LANGUAGE ARTS CONNECTIONS

Write About Science

HS-LS1-5, CCSS.ELA-LITERACY.WHST.9-10.2

41. Write Informative Texts Write a paragraph that describes how the light-dependent and light-independent reactions work together to perform photosynthesis.

42. Write Explanatory Texts Write a paragraph that explains how the flow of matter and energy into a cell results in the transfer from light energy to stored chemical energy in photosynthesis.

Read About Science

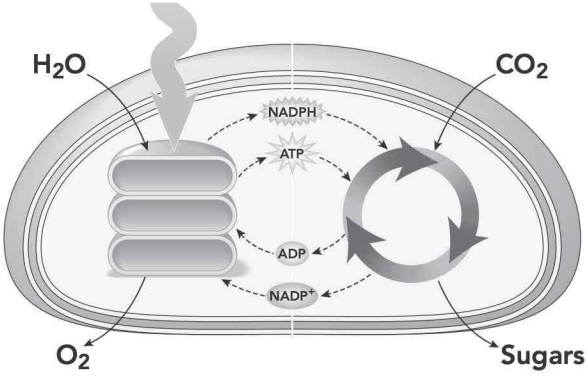
CCSS.ELA-LITERACY.RST.9-10.5

43. Analyze Text Structure Explain the relationship among these parts or systems of photosynthesis: photosystem I, photosystem II, ATP, $NADP^+$, light-dependent reactions, and light-independent reactions. Use the organization and headings of Lesson 9.2 to help you construct your response.

END-OF-COURSE TEST PRACTICE

1. A student is making a model to illustrate the functions of ADP and ATP in photosynthesis. Which model best illustrates the role of ATP in photosynthesis?
   A. A power plant that generates energy
   B. A rechargeable battery that stores and releases energy
   C. A pigment that receives the energy of sunlight
   D. A pan that carries coal
   E. A hammer that helps break apart water molecules

Questions 2 and 3.
The diagram is a model of the process of photosynthesis.



2. During photosynthesis, how is the light energy that strikes the cell transformed into the chemical energy stored in sugars?
   A. Energy is transferred directly to sugars, with no intermediates.
   B. Energy is transferred to sugars through intermediates such as H_2O, O_2, and CO_2.
   C. Energy is transferred to sugars through intermediates, such as ATP and NADPH.
   D. Energy is transferred to sugars through intermediates, such as chloroplasts.
   E. Energy is transferred to sugars through light-dependent reactions.

3. Which statement accurately describes the role of the light-independent reactions?
   A. Transforming light energy into chemical energy
   B. Transferring chemical energy to high-energy sugars
   C. Returning chemical energy to light energy
   D. Transferring light energy among different compounds
   E. Performing chemical reactions without an energy source

4. Which of the following describe the role of photosynthesis in the carbon cycle?
   A. Storage of carbon in the atmosphere
   B. Storage of carbon in the geosphere
   C. Transfer of carbon from the hydrosphere to the atmosphere
   D. Transfer of carbon from the atmosphere to the hydrosphere
   E. Transfer of carbon from the atmosphere to the biosphere

5. Plants use the sugars produced by photosynthesis to synthesize which of the following types of macromolecules?
   I. complex carbohydrates
   II. amino acids
   III. lipids
   A. I only
   B. II only
   C. III only
   D. I and II only
   E. I, II, and III

ASSESSMENT

For additional assessment practice, go online to access your digital course.

If You Have Trouble With…					
Question	1	2	3	4	5
See Lesson	9.1	9.2	9.3	9.2	9.3
Performance Expectation	HS-LS1-5	HS-LS1-5	HS-LS1-5	HS-LS2-5	HS-LS1-6