4.3B Light-Independent Reactions

Photosynthesis in Detail

KEY CONCEPT Photosynthesis requires a series of chemical reactions.

MAIN IDEAS

- The second stage of photosynthesis uses energy from the first stage to make sugars.

VOCABULARY

ATP synthase, p. 110
Calvin cycle, p. 111

Review
light-independent reactions

CALIFORNIA STANDARDS

1.f ***Students know*** **usable energy is captured from sunlight by chloroplasts and is stored through the synthesis of sugar from carbon dioxide.**

1.i.* *Students know* how chemiosmotic gradients in the mitochondria and chloroplast store energy for ATP production.

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

carbon dioxide + water → a sugar + oxygen

MAIN IDEA

The second stage of photosynthesis uses energy from the first stage to make sugars.

The light-independent reactions, like the light-dependent reactions, take place inside chloroplasts. But as the name implies, the light-independent reactions do not need sunlight. These reactions can take place anytime that energy is available. The energy sources for the light-independent reactions are the molecules of ATP and NADPH formed during the light-dependent reactions. The energy is needed for a series of chemical reactions called the Calvin cycle, which is named for the scientist who discovered the process.

The Calvin Cycle

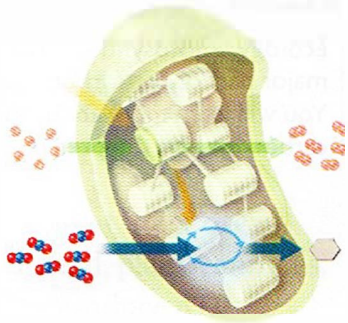
The Calvin cycle cannot take place without the ATP from the light-dependent reactions. The chemical reactions of the **Calvin cycle** use carbon dioxide (CO_2) gas from the atmosphere and the energy carried by ATP and NADPH to make simple sugars. Because the light-independent reactions build sugar molecules, they are the *synthesis* part of photosynthesis. Only one molecule of CO_2 is actually added to the Calvin cycle at a time. The simplified cycle in **FIGURE 4.9** shows three CO_2 molecules added at once.

VOCABULARY

The light-dependent reactions are the *photo-* part of photosynthesis. The light-independent reactions are the *synthesis* part of photosynthesis.

The Calvin Cycle

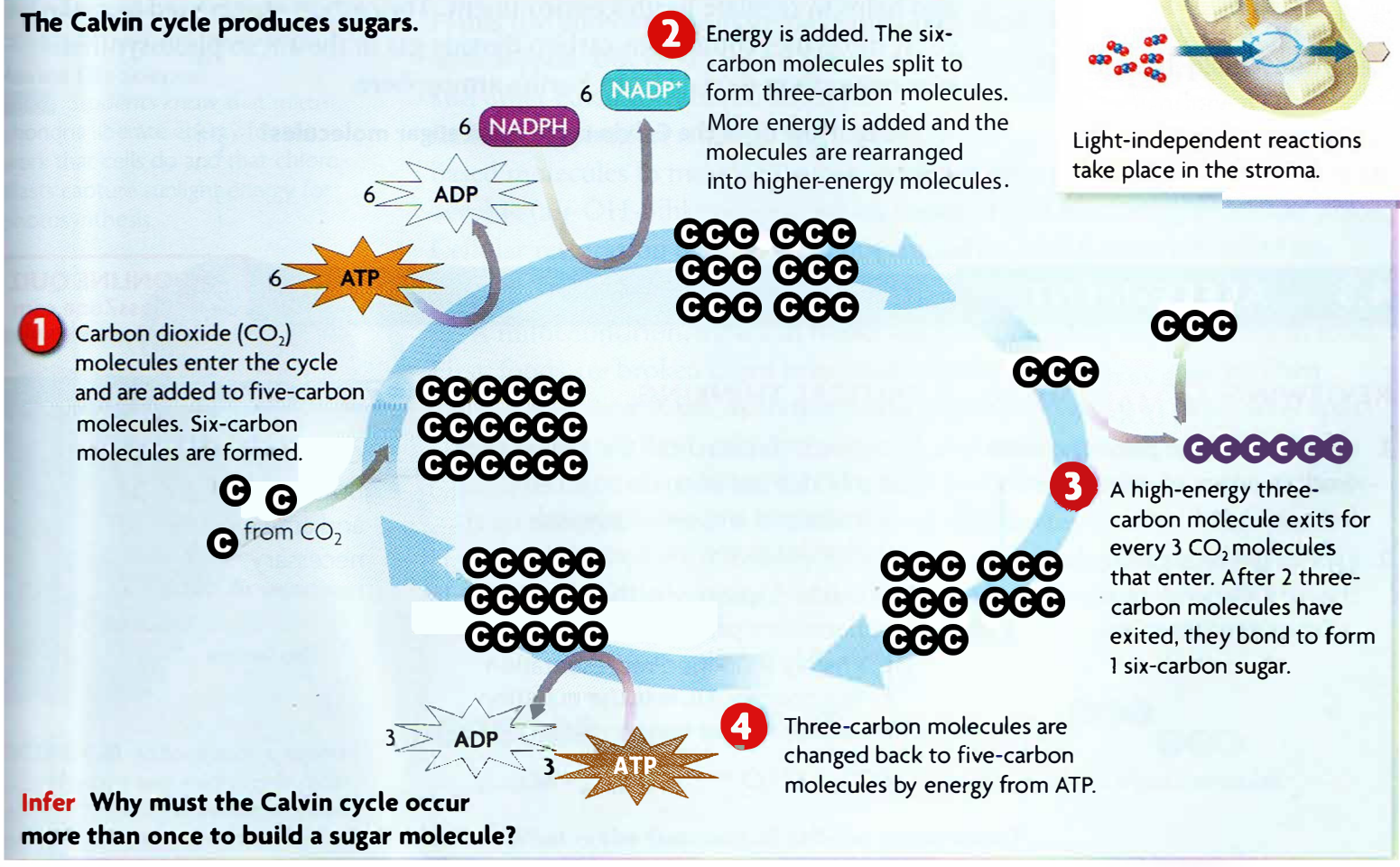
1. **Carbon dioxide added** CO_2 molecules are added to five-carbon molecules already in the Calvin cycle. Six-carbon molecules are formed.
2. **Three-carbon molecules formed** Energy—ATP and NADPH—from the light-dependent reactions is used by enzymes to split the six-carbon molecules. Three-carbon molecules are formed and rearranged.
3. **Three-carbon molecules exit** Most of the three-carbon molecules stay in the Calvin cycle, but one high-energy three-carbon molecule leaves the cycle. After two three-carbon molecules have left the cycle, they are bonded together to build a six-carbon sugar molecule such as glucose.
4. **Three-carbon molecules recycled** Energy from ATP molecules is used to change the three-carbon molecules back into five-carbon molecules. The five-carbon molecules stay in the Calvin cycle. These molecules are added to new CO_2 molecules that enter the cycle.



Light-independent reactions take place in the stroma.

FIGURE 4.9 Light-Independent Reactions (Calvin Cycle)

The Calvin cycle produces sugars.



Infer **Why must the Calvin cycle occur more than once to build a sugar molecule?**

Summary of the Light-Independent Reactions

- Carbon dioxide enters the Calvin cycle.
- ATP and NADPH from the light-dependent reactions transfer energy to the Calvin cycle and keep the cycle going.
- One high-energy three-carbon molecule is made for every three molecules of carbon dioxide that enter the cycle.
- Two high-energy three-carbon molecules are bonded together to make a sugar. Therefore, six molecules of carbon dioxide must be added to the Calvin cycle to make one six-carbon sugar.
- The products are a six-carbon sugar such as glucose, $NADP^+$, and ADP. The $NADP^+$ and ADP molecules return to the light-dependent reactions.

Functions of Photosynthesis

Photosynthesis is much more than just a biochemical process. Photosynthesis is important to most organisms on Earth, as well as to Earth's environment. Recall that plants produce food for themselves and for other organisms through photosynthesis. Both plant cells and animal cells release the energy stored in sugars through cellular respiration. Cellular respiration, which uses the oxygen that is a waste product of photosynthesis, is the process that makes most of the ATP used by plant and animal cells.

Connecting CONCEPTS

Ecology Photosynthesis is a major part of the carbon cycle. You will learn more about the carbon cycle in **Chapter 13.**

Photosynthesis does more than make sugars. It also provides materials for plant growth and development. The simple sugars from photosynthesis are bonded together to form complex carbohydrates such as starch and cellulose. Starches store sugars until they are needed for energy. Cellulose is a major part of plant structure—it is the building block of plant cell walls. Photosynthesis also helps to regulate Earth's environment. The carbon atoms used to make sugar molecules come from carbon dioxide gas in the air, so photosynthesis removes carbon dioxide from Earth's atmosphere.

Summarize **How does the Calvin cycle build sugar molecules?**

4.3 ASSESSMENT

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REVIEWING MAIN IDEAS

1. How do the two **photosystems** work together to capture energy from sunlight? 1.f
2. Explain the relationship between the light-dependent and the light-independent reactions. 1.i*

CRITICAL THINKING

3. **Connect** Explain how the **Calvin cycle** is a bridge between carbon in the atmosphere and carbon-based molecules in the food you eat.
4. **Evaluate** Explain why the chemical equation for photosynthesis (below) is a highly simplified representation of the process. How is the equation accurate? How is it inaccurate?

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

Connecting CONCEPTS

5. **Cell Functions** Explain how both passive transport and active transport are necessary for photosynthesis to occur. 1.i*