Transforming Light Energy into Chemical Energy

So far you have seen that plants transform energy from sunlight into chemical energy stored in the chemical bonds of sugar molecules. But, how does this transformation of energy happen? Chloroplasts in cells are like solar-powered chemical factories. They transfer light energy to energy-carrying molecules called ATP and NADPH. Cells use these molecules as energy currency for cell processes. In plant cells, they are used to convert carbon dioxide into sugars.

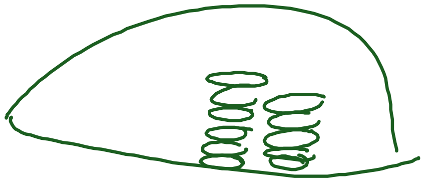
FIGURE 8: Two energy-carrying molecules are used in photosynthesis. ATP stores energy in a phosphate-phosphate bond, and NADPH carries high-energy electrons.

$$\text{ADP} + \text{P} \rightarrow \text{ATP}$$

$$\text{NADP}^+ + \text{H}^+ + 2\,\text{e}^- \rightarrow \text{NADPH}$$

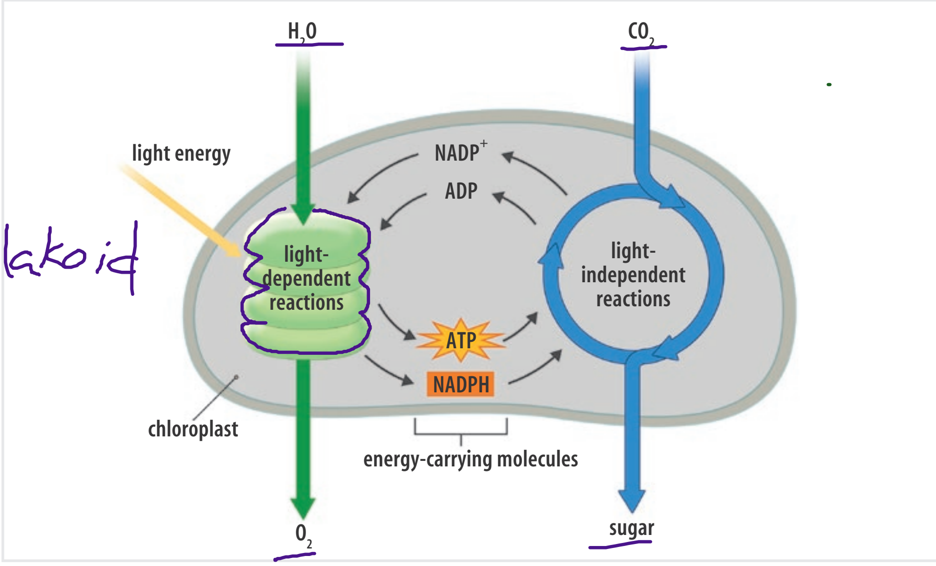
Predict How do you think plant cells transfer energy from sunlight to the energy-carrying molecules ATP and NADPH?

Stages of Photosynthesis



Photosynthesis can be broken into two stages – the light-dependent reactions and the light-independent reactions. The light-dependent reactions take place within and across the membrane of the thylakoids, which are stacked inside the chloroplast. The light-independent reactions take place in the stroma, the area outside the thylakoids.

FIGURE 9: The two stages of photosynthesis, light-dependent reactions and light-independent reactions, occur in the chloroplast.



Thylakoid

Gather Evidence Examine the diagram of the chloroplast. How does alternating between light-dependent and light-independent reactions help the cell conserve energy and matter? Cite evidence from the diagram to support your answer.

Analyze Identify the inputs and outputs for both stages of photosynthesis. Specify for both energy and matter.

The Light-Dependent Reactions

The light-dependent reactions are the *photo* part of photosynthesis. The main functions of the light-dependent reactions are to capture and transfer energy. Light energy is captured and transferred in the thylakoid membrane by two groups of molecules called photosystem II and photosystem I. They are named for the order in which they were discovered, not the order in which they occur.

FIGURE 10: The Light-Dependent Reactions

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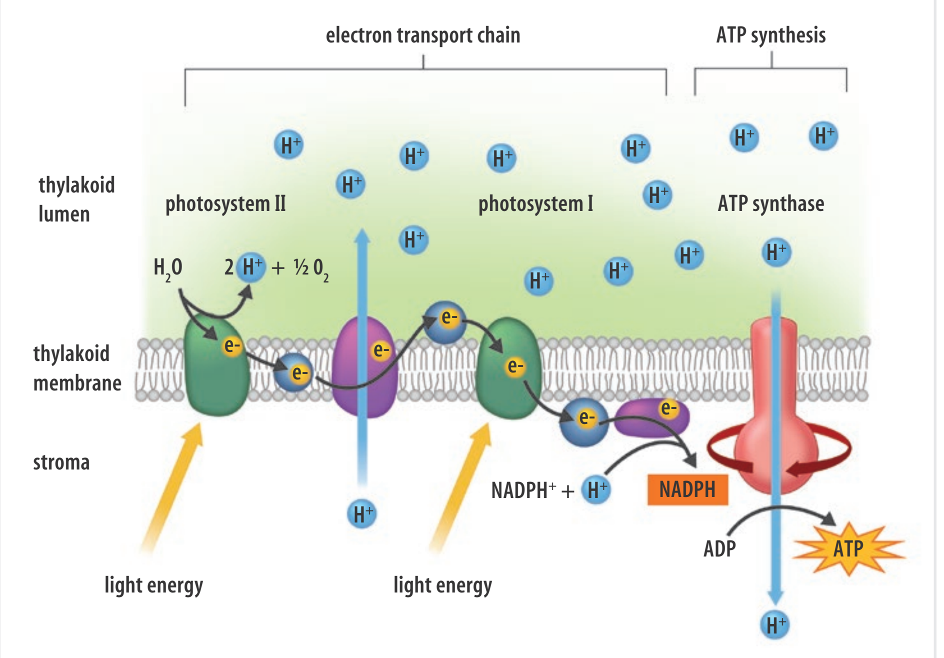


The light-dependent reactions are summarized in the steps below.

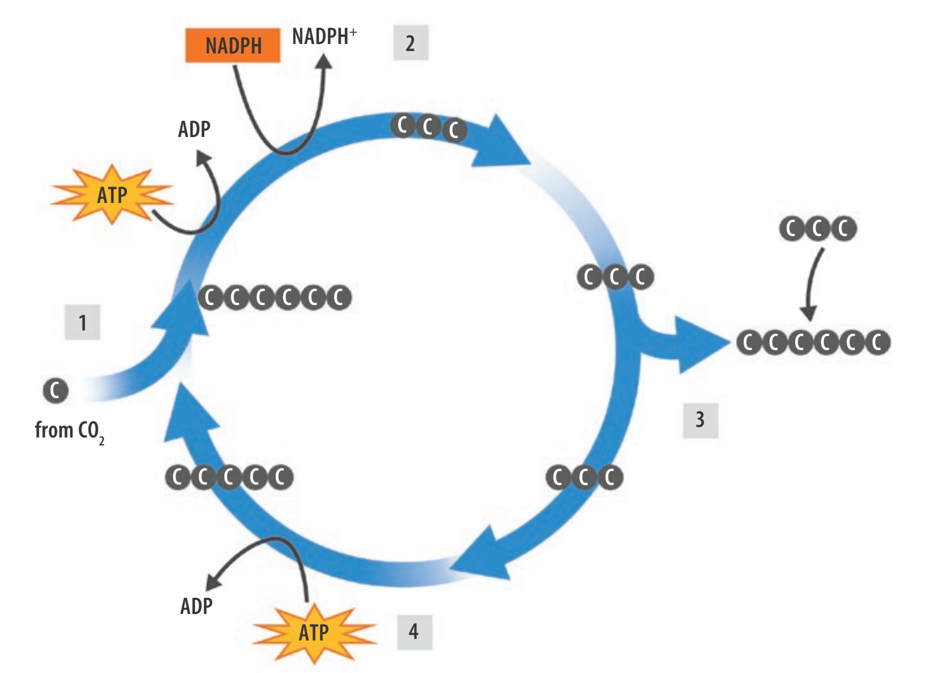
1. **Energy absorbed from sunlight**—In photosystem II, chlorophyll and other pigment molecules in the thylakoid membrane absorb energy from sunlight. The energy is transferred to electrons (e^-). These high-energy electrons leave the chlorophyll and enter the electron transport chain, a series of proteins in the thylakoid membrane.
2. **Water molecules split**—Enzymes break down water molecules. Electrons from water molecules replace the electrons that left the chlorophyll. Hydrogen ions (H^+) remain inside the thylakoid, and oxygen is released as a waste product.
3. **Hydrogen ions transported**—Energized electrons move from protein to protein in the electron transport chain. Their energy is used to pump hydrogen ions across the thylakoid membrane. The result is a buildup of hydrogen ions inside the thylakoid, establishing a concentration gradient, which is a form of stored energy. The electrons move on to photosystem I.
4. **Energy absorbed from sunlight**—In photosystem I, chlorophyll and other pigment molecules in the thylakoid membrane absorb energy from sunlight. Energized electrons leave the pigment molecules.
5. **NADPH produced**—The energized electrons from photosystem I are added to $NADP^+$ to form NADPH, an energy-carrying molecule, by an enzyme.
6. **Hydrogen ion diffusion**—Hydrogen ions diffuse out of the thylakoid through the ATP synthase protein channel. Diffusion of the hydrogen ions is powered by the concentration gradient. ATP synthase uses energy from the concentration gradient to make ATP by adding a phosphate group to ADP.

Model Make a simple flow chart to show how energy is transferred from light to ATP in the light-dependent stage of photosynthesis.

The Light-Independent Reactions

The second stage of photosynthesis uses energy from the light-dependent reactions to make sugars. As the name for this stage implies, the light-independent reactions do not need sunlight. These reactions can take place any time energy is available. The energy sources for the light-independent reactions are the molecules ATP and NADPH formed during the light-dependent reactions. This energy is needed for a series of chemical reactions called the Calvin cycle, named for the scientist Melvin Calvin, who discovered the process. The Calvin cycle is the *synthesis* part of photosynthesis. Its chemical reactions use the energy carried by the ATP and NADPH produced by the light-dependent reactions to make simple sugars.

FIGURE 11: The Light-Independent Reactions



The light-independent reactions are summarized in the steps below.

1. **Carbon dioxide added**—A CO_2 molecule is added to a 5-carbon molecule already in the cycle, yielding a 6-carbon molecule.
2. **Three-carbon molecules formed**—The 6-carbon molecule splits, forming two 3-carbon molecules. ATP and NADPH provide the energy to rearrange these 3-carbon molecules into higher-energy molecules that also have 3 carbons each.
3. **Three-carbon molecules exit**—One high-energy 3-carbon molecule leaves the cycle while the rest remain. One 6-carbon sugar molecule is formed from every two 3-carbon molecules that exit the cycle.
4. **Three-carbon molecules recycled**—Energy from ATP is used to change five 3-carbon molecules into three 5-carbon molecules, which stay in the Calvin cycle to accept new CO_2 molecules that enter the cycle.

Collaborate A common misconception is that the bulk of a plant's material comes from soil or water. Explain where the carbon in sugars actually comes from, citing evidence from the Calvin cycle to support your answer.

Explain How does the Calvin cycle act as a bridge between carbon in the atmosphere and carbon-based molecules in the food you eat?

Model Develop a model to illustrate how photosynthesis transforms light energy into chemical energy. In your model, show how energy from sunlight is transformed to energy stored in sugars, and identify the inputs and outputs for each stage of the process.