

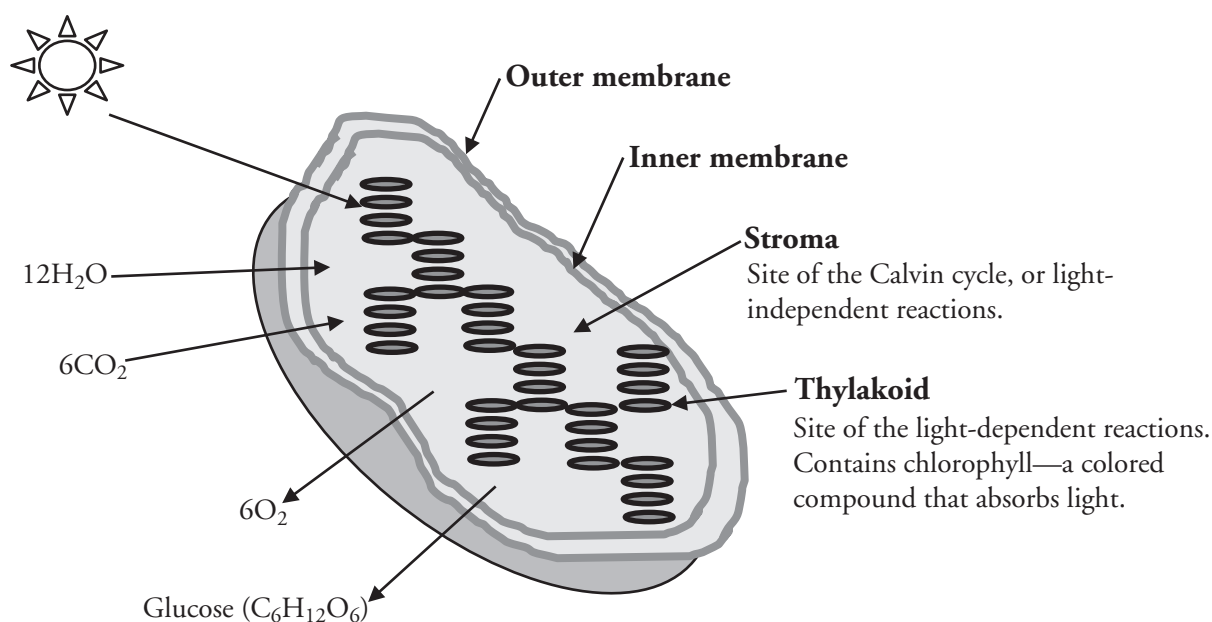
Photosynthesis

How do light-dependent and light-independent reactions provide food for a plant?

Why?

Plants are the original solar panels. Through photosynthesis a plant is able to convert electromagnetic (light) energy into chemical energy. This energy is used not only to keep the plant alive, but also to sustain all creatures that rely on the plant for food and shelter. Plants and photosynthetic algae are also the source of all oxygen on Earth, allowing the inhabitants of Earth to benefit from our most plentiful renewable energy resource.

Model 1 – Chloroplast

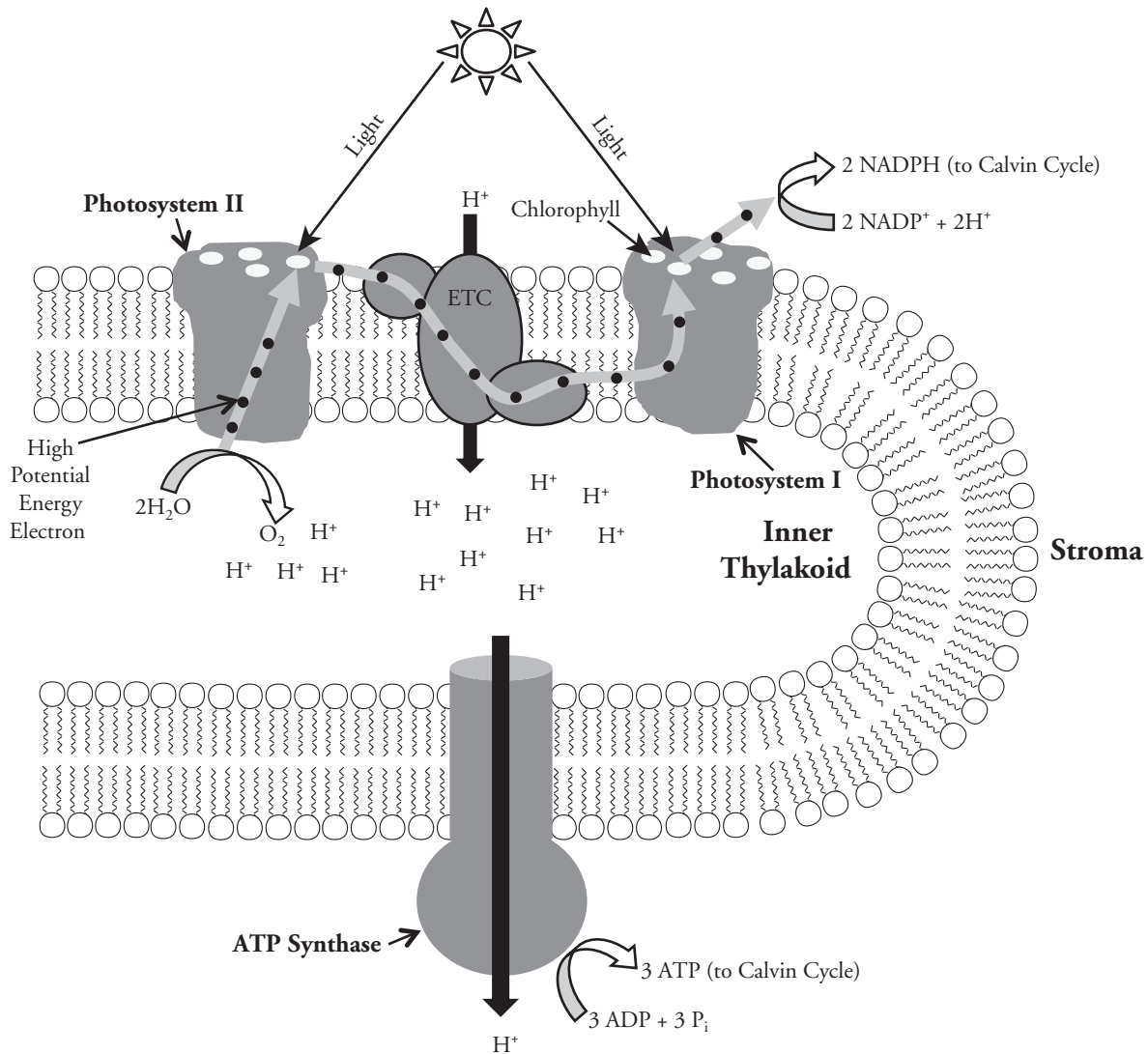


1. Consider the organelle illustrated in Model 1.
 - a. What is the name of this organelle?
 - b. Is this organelle more likely to be found in animal cells or plant cells?
2. The structures inside the organelle in Model 1 are called thylakoids. What compound necessary for photosynthesis is contained in the thylakoids?

3. Consider the chemical reaction in Model 1. This represents photosynthesis.
 - a. What substances are the reactants in photosynthesis? Include the name and chemical formula of each substance in your answer.
 - b. Where in the organelle are these molecules stored before they are used in photosynthesis?
 - c. Is photosynthesis an endergonic or exergonic reaction? Support your answer with evidence from Model 1.
 - d. What is the energy source for photosynthesis?
4. Photosynthesis occurs in two parts—the **light-dependent reactions** and the **light-independent reactions**.
 - a. What is another name for the light-independent reactions?
 - b. In what part of the chloroplast do the light-dependent reactions occur?
 - c. In what part of the chloroplast do the light-independent reactions occur?
5. Considering your answers to Question 4, what compound is best able to absorb the light energy from the Sun and convert it into chemical energy?
6. What substances are produced during photosynthesis? Include the name and chemical formula of each substance in your answer.
7. Why is it necessary to have six CO₂ entering the chloroplast?



Model 2 – The Light-Dependent Reactions



8. In Model 2, what shape or symbol represents a single electron?
9. In the light-dependent reactions electrons are released from molecules in two ways.
 - a. Find two places in Model 2 where electrons are released from chlorophyll by a photon of light coming from the Sun.
 - b. Find one place in Model 2 where electrons are released from water molecules.
 - c. When the electrons are released from water molecules, what other products are formed?

Read This!

The light-dependent reactions of photosynthesis include three major processes:

- A. Excited electrons leave chlorophyll and reduce NADP⁺ into NADPH.
 - B. Excited electrons moving through the electron transport chain provide the free energy needed to pump hydrogen ions into the inner thylakoid.
 - C. Hydrogen ions flowing out of the thylakoid via a protein channel provide the free energy needed to convert ADP to ATP.
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10. In Model 2, label the diagram with “A,” “B,” and “C” to indicate where the three steps in the *Read This!* box are occurring.
11. The light-dependent reactions include an electron transport chain system that works in a very similar fashion to the electron transport chain in respiration. Briefly describe how this system works and what job it performs in the light-dependent reactions. (Your answer should include a discussion about concentration gradient.)

12. Refer to Model 2.
 - a. Name the embedded protein complex found in the thylakoid membrane that uses excited electrons to reduce NADP⁺ into NADPH.

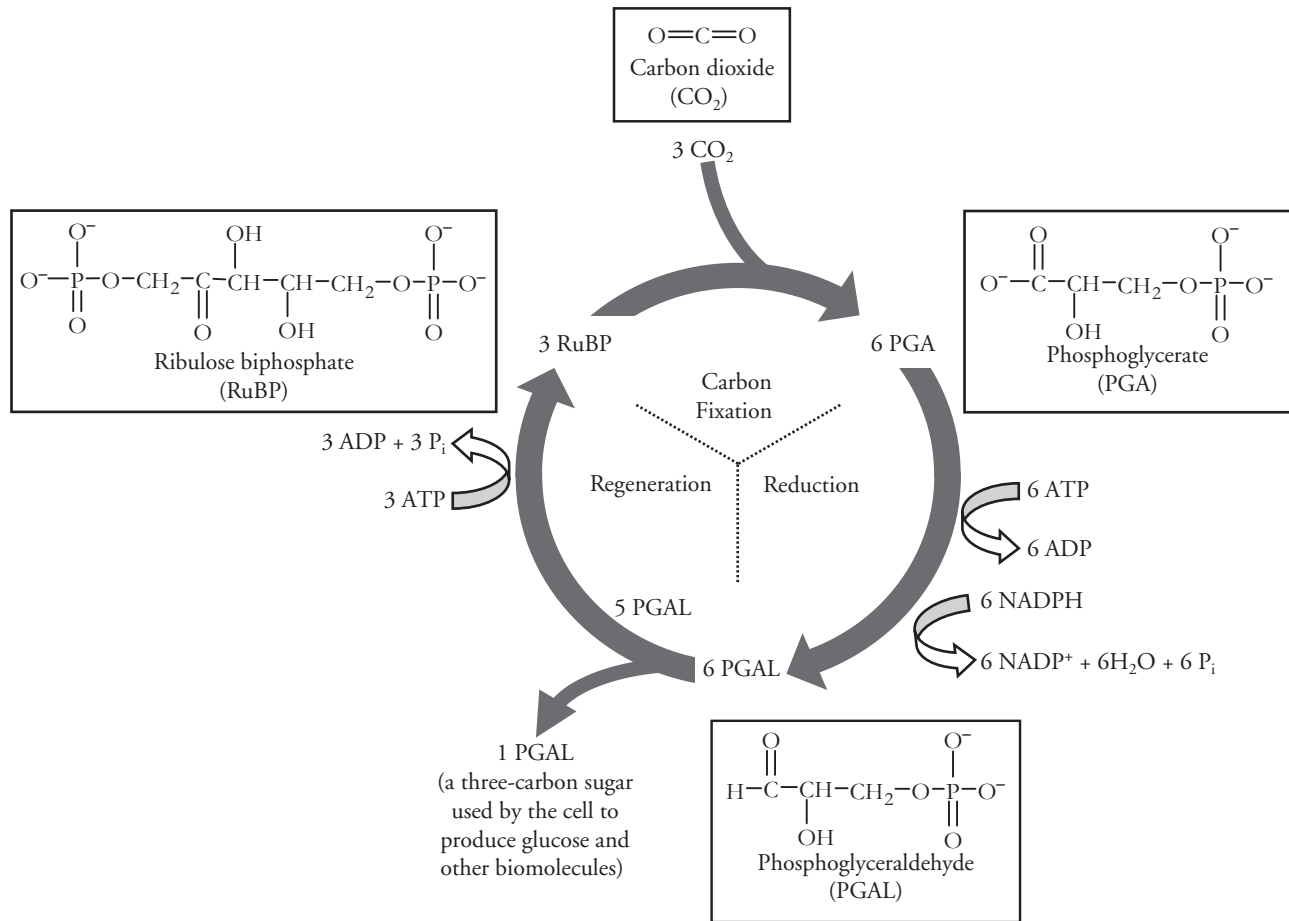
 - b. Name the embedded protein complex found in the thylakoid membrane that provides excited electrons to the electron transport chain.

 - c. Name the embedded protein complex found in the thylakoid membrane that converts ADP to ATP using free energy from a flow of hydrogen ions.

13. Once a chlorophyll molecule has released electrons it is no longer useful until those electrons are replaced.
- According to Model 2, what is the source of replacement electrons for those released from photosystem I?
 - According to Model 2, what is the source of replacement electrons for those released from photosystem II?
14. Is carbon dioxide involved in the light-dependent reaction?
15. Refer to Model 2.
- Write a chemical reaction that summarizes all of the chemical reactions in the light-dependent reactions of photosynthesis starting with two water molecules.
 - In the photosynthesis reaction in Model 1, twelve water molecules are shown as reactants, but six water molecules are shown as products. Are any of the twelve water molecules products of the light-dependent reactions?
 - Calculate the total number of oxygen, NADPH, and ATP molecules that are produced when twelve water molecules complete the light-dependent reactions.
16. Where do the ATP and NADPH produced during the light-dependent reactions go when the process is complete?



Model 3 – The Light-Independent Reactions (Calvin Cycle)



17. According to Model 3, what are the three phases of the Calvin cycle?

18. Find the compound ribulose biphosphate (RuBP) in Model 3.
 - a. How many RuBP molecules are used in one turn of the Calvin cycle?

 - b. How many carbon atoms are in each RuBP molecule?

 - c. Calculate the total number of carbon atoms represented in all of the RuBP molecules used in one turn of the Calvin cycle.

19. Ribulose biphosphate (RuBP) combines with carbon dioxide (CO_2) to form phosphoglycerate (PGA) during the carbon fixation phase of the Calvin cycle.
- How many CO_2 molecules are used in one turn of the Calvin cycle?
 - How many PGA molecules are made in one turn of the Calvin cycle?
 - How many carbon atoms are in each PGA molecule?
 - Calculate the total number of carbon atoms represented in all of the PGA molecules used in one turn of the Calvin cycle.
20. Explain what happened to the carbon atoms from the carbon dioxide molecules that entered the Calvin cycle.
21. Consider the term “carbon fixation.” Think individually for a moment what this term might mean, then share ideas among the group. Record the group’s consensus definition for carbon fixation here.

Read This!

Model 3 is a simplified version of the Calvin cycle. Each of the three phases in the cycle consist of multiple reactions that are catalyzed by enzymes specific to that reaction. These enzymes have names like RuBisCo, phosphoglycerate kinase, and PGAL hydrogenase.

22. Refer to the reduction phase of the Calvin cycle in Model 3.
- What molecule does the PGA molecule turn into during this phase of the Calvin cycle?
 - Describe specifically how the structures of the two molecules in part *a* are different.
 - Identify the types and numbers of molecules that provide the free energy necessary for the reduction of the PGA molecules.
 - Is the total number of carbon atoms present in the Calvin cycle changed during the reduction phase? Support your answer with evidence from Model 3.

23. Water is a product of the reduction phase of the Calvin cycle.
- How many water molecules are produced?

 - Explain where the hydrogen and oxygen atoms in these water molecules originated.
24. Refer to the regeneration phase of the Calvin cycle in Model 3.
- How many PGAL molecules continue on to the regeneration phase of the Calvin cycle?

 - Identify the types and numbers of molecules that provide the free energy necessary for the regeneration of these molecules.

 - How many total carbon atoms remain in the Calvin cycle at this point?

 - What molecule(s) are “regenerated” in this phase of the cycle?

 - How many total carbon atoms leave the Calvin cycle before the regeneration phase?

 - What happens to the PGAL molecule that does not continue on in the Calvin cycle?



Read This!

As you have learned from your careful study of the Calvin cycle illustrated in Model 3, three atoms of carbon enter the cycle as carbon dioxide and three carbon atoms leave the cycle as PGAL. It is easy to assume that the three atoms that leave are one and the same with the three that entered, but that is incorrect. It may be that none of the carbon atoms from the carbon dioxide become incorporated into a molecule of PGAL that leaves the cycle. Alternatively, it is also possible that one of the carbon atoms from the carbon dioxide will become part of a PGAL molecule that leaves the cycle. Eventually all of the carbon atoms that enter the cycle will leave as part of a PGAL molecule, but they must wait their turn.



25. The reaction in Model 1 shows glucose ($C_6H_{12}O_6$) as a product of photosynthesis.
- How many PGAL molecules will it take to make one molecule of glucose? Justify your answer with a discussion of numbers of carbon atoms.
 - How many turns of the Calvin cycle will it take to make one molecule of glucose?
 - Calculate the total number of ATP and NADPH molecules used in the production of one molecule of glucose.
26. Where do the ADP and $NADP^+$ go after they are used in the Calvin cycle?



27. Explain in detail, using complete sentences, how the two reactions (light-dependent and light-independent) depend on each other.



28. Under each molecule in the equation below, indicate whether it is involved (either used or produced) in the light-dependent reactions or the Calvin cycle.



29. Throughout photosynthesis, energy is transferred from light to several molecules with increasingly higher potential energy. Use the words below to summarize the order in which the energy flow occurs.

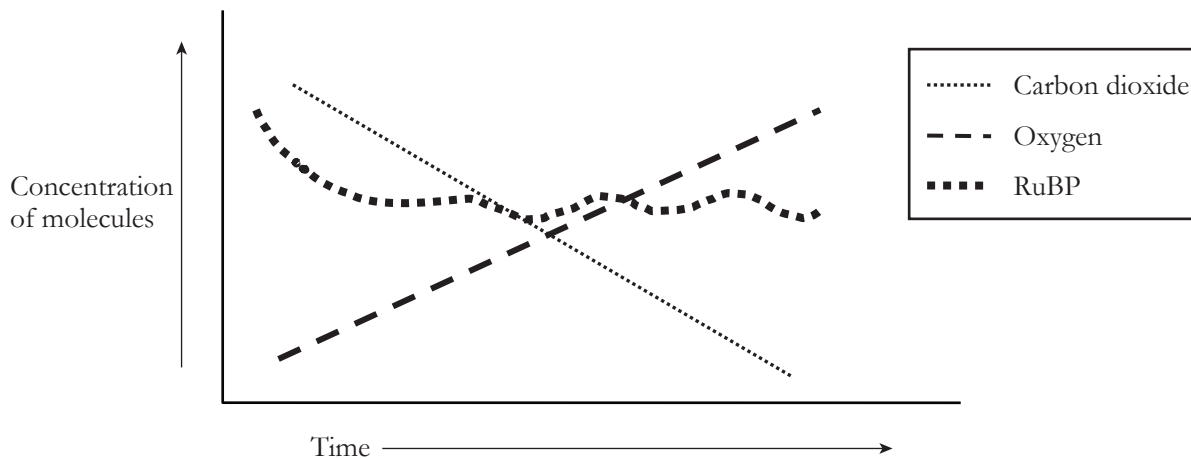
electrons ATP glucose sunlight

30. Although photosynthesis does produce some ATP, these molecules are not used to do the work of the plant cells. What other process occurs in the cells that provides the ATP necessary to do cellular work such as make proteins, divide cells, and move substances across membranes?



Extension Questions

Model 4 – The Study of Photosynthesis



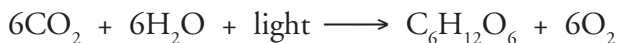
31. When algae are undergoing photosynthesis, the concentrations of various molecules change within the cells. These concentrations can be monitored and graphed. In complete sentences, explain the shape of each line on the graph in Model 4.

carbon dioxide—

oxygen—

RuBP—

32. Photosynthesis is typically represented by a simple equation.



- a. Compare and contrast this simplified equation with the one presented in Model 1.
- b. Using the information from this activity explain why the equation above is a vastly oversimplified representation of the actual process.