Chapter 10: Photosynthesis

10.1 Describe the roles of autotrophs and heterotrophs in the biosphere.

10.2 Specify where photosynthesis occurs and describe, in general, how it converts light energy into chemical energy.

10.3 Trace the sequence of events during the light reactions that convert solar energy to chemical energy.

10.4 Explain how the Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO_2 to sugar.

10.5 Identify alternative mechanisms of carbon fixation that have evolved in hot, arid climates.

10.6 Describe photosynthesis and explain why all life on Earth depends on this process.

This chapter is as challenging as the one you just finished on cellular respiration. However, conceptually it will be a little easier because the concepts learned in Chapter 9—namely, chemiosmosis and an electron transport system—will play a central role in photosynthesis. During your study of Chapters 9 and 10, consider how they are related in their transfer of energy and matter.

Study Tip: First, get a big picture view of photosynthesis by working through Figures 10.1 and 10.3. Notice from Figure 10.1 that some plant cells have chloroplasts but almost all plant cells have mitochondria. Use Figure 10.3 to consider the amazing details of photosynthesis inside chloroplasts in the context of the entire plant. Finally, turn back to p. 164, Figure 9.1, to reinforce how the processes of photosynthesis and cellular respiration are related.

Keep in mind that plants have *both* mitochondria and chloroplasts and do both cellular respiration and photosynthesis!

Concept 10.1 Photosynthesis feeds the biosphere

LO 10.1: Describe the roles of autotrophs and heterotrophs in the biosphere.

1. Define *autotrophs* and *heterotrophs*. Which are the *producers* of the ecosystem? Which are the *consumers*? Give an example of each group.

Concept 10.2 Photosynthesis converts light energy to the chemical energy of food

LO 10.2: Specify where photosynthesis occurs and describe, in general, how it converts light energy into chemical energy.

2. Expand on your initial, general look at chloroplasts in Figure 10.3 by drawing a picture of a chloroplast. Label the *stroma, thylakoid, thylakoid space, inner membrane*, and *outer membrane*.

3. Use both chemical symbols and words to write out the formula for photosynthesis. (Use the one that indicates only the net consumption of water.) Notice that the formula is essentially the opposite of cellular respiration.

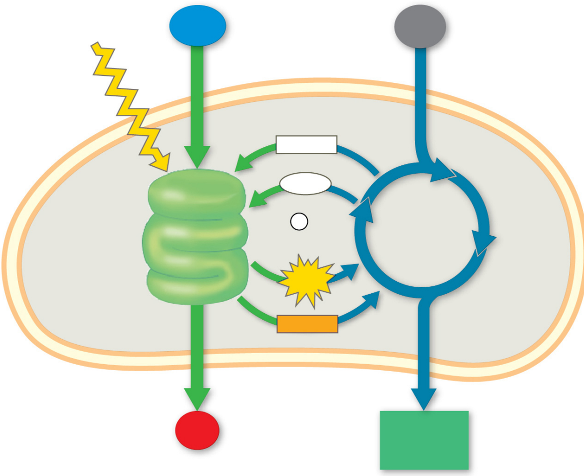
4. Using ^{18}O as the basis of your discussion, explain how we know that the oxygen released in photosynthesis comes from water.

5. Photosynthesis is not a single process, but two processes, each with multiple steps.

   a. Explain what occurs in the *light reactions* stage of photosynthesis. Be sure to use *NADP*$^+$ and *photophosphorylation* in your discussion.

   b. Explain the *Calvin cycle*, using the term *carbon fixation* in your discussion.

6. The details of photosynthesis will be easier to organize if you can visualize the overall process. Label the following figure. As you work on this, underline or highlight the items that are cycled between the light reactions and the Calvin cycle.



Concept 10.3 The light reactions convert solar energy to the chemical energy of ATP and NADPH

LO 10.3: Trace the sequence of events during the light reactions that convert solar energy to chemical energy.

This is a long and challenging concept. Take your time, work through the questions, and realize that this is the key concept for photosynthesis.

7. Some of the types of energy in the electromagnetic spectrum will be familiar, such as X-rays, microwaves, and radio waves. The most important part of the spectrum in photosynthesis is visible light. In order, what are the colors of the *visible spectrum*?

8. Notice the colors and their corresponding wavelengths. Explain the relationship between wavelength and energy.

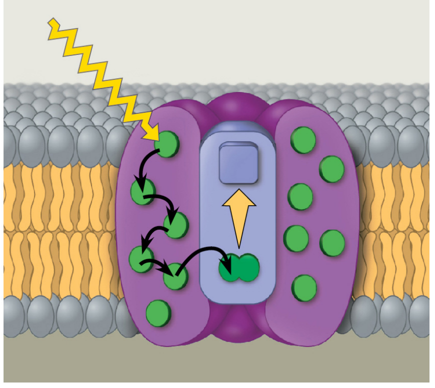
9. Study Inquiry Figure 10.9 on p. 194 which describes the classic experiment of Theodor W. Englemann. Describe how he determined an action spectrum long before the invention of a spectrophotometer.

10. Use this same figure to explain the correlation between an *absorption spectrum* and an *action spectrum.*

11. The absorption spectrum of chlorophyll *a* alone underestimates the effectiveness of certain wavelengths in driving photosynthesis. Explain why this is so.

12. A *photosystem* is composed of a protein complex called a _________ -________ complex surrounded by several ___________-__________ complexes.

13. Within the photosystems, the critical conversion of solar energy to chemical energy occurs. This process is the essence of being a producer! Using Figure 10.12 from the main text as a guide, label the following diagram and then explain the role of the components of the photosystem listed below.



a. Reaction-center complex

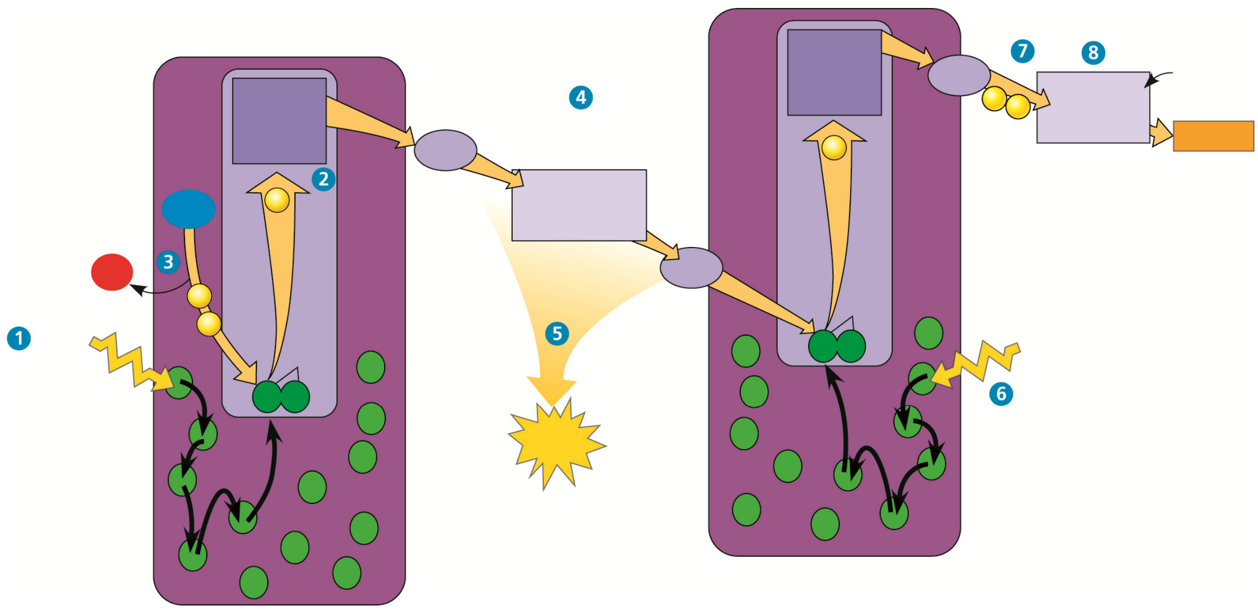
b. Light-harvesting complex

c. Primary electron acceptor

14. *Photosystem II* (*PSII*) has at its reaction center a special pair of chlorophyll *a* molecules called P680. What is the explanation for this name?

15. What is the name of the chlorophyll *a* at the reaction center of PS I? ________________

16. *Linear electron flow* is, fortunately, easier to understand than it looks. It is an electron transport chain, somewhat like the one we worked through in cellular respiration. While reading the section "Linear Electron Flow" and studying Figure 10.13 in your text, label this diagram number by number as you read.



17. The following set of questions deals with linear electron flow:

a. What is the source of energy that excites the electron in photosystem II? ____________

b. What compound is the source of electrons for linear electron flow? ____________

c. What is the source of O_2 in the atmosphere? ______________________

d. As electrons fall from photosystem II to photosystem I, the cytochrome complex uses the energy to pump ______________ ions. This builds a proton gradient that is used in chemiosmosis to produce what molecule? _____________

e. In photosystem I, $NADP^+$ reductase catalyzes the transfer of the excited electron and H^+ to $NADP^+$ to form ______________.

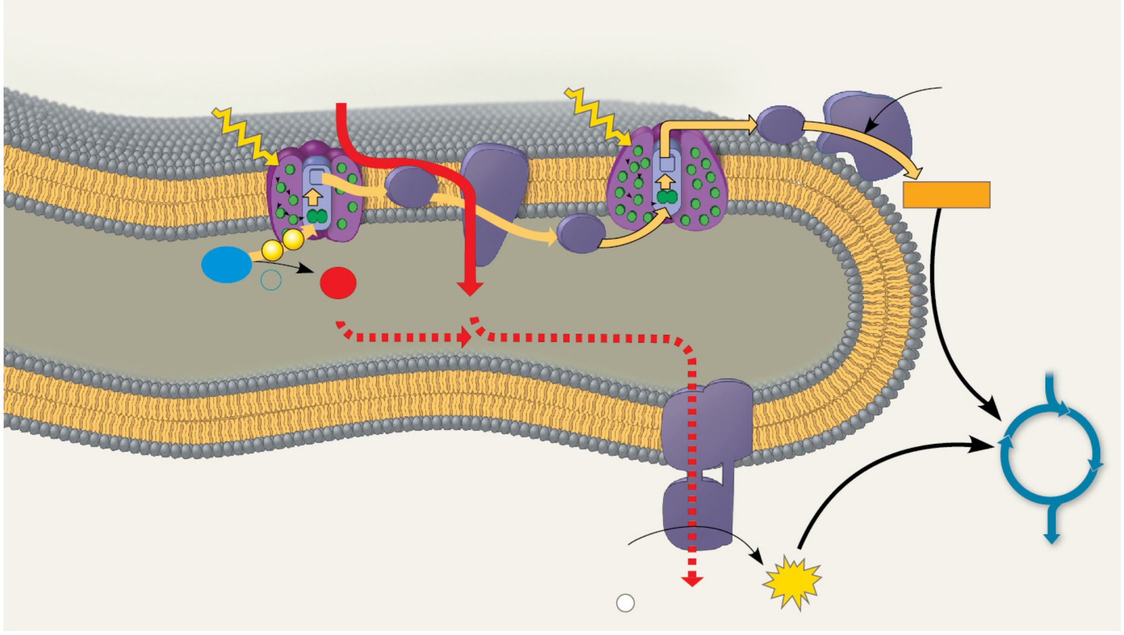
**Notice that two high-energy compounds have been produced by the light reactions: ATP and NADPH. Both compounds will be used in the Calvin cycle.*

18. *Cyclic electron flow* can be visualized in Figure 10.15 in your text. Cyclic electron flow is thought to be similar to the first forms of photosynthesis to evolve. In cyclic electron flow no water is split, there is no production of ________________, and there is no release of _____________. (The Big Picture: Why did oxygen not accumulate in the atmosphere until cyclic electron flow evolved?)

19. The last idea in this challenging concept is how chemiosmosis works in photosynthesis. Describe four ways that chemiosmosis is *similar* in photosynthesis and cellular respiration.

20. Use two key differences to explain how chemiosmosis is *different* in photosynthesis and cellular respiration.

21. Label all the locations in this diagram. Then, follow the steps in linear electron flow to label the components of the light reactions in chemiosmosis that are seen in this figure.



22. List the three places in the light reactions where a proton-motive force is generated.

23. To summarize, note that the light reactions store chemical energy in ______________ and ________________, which shuttle the energy to the carbohydrate-producing ____________ cycle.

Concept 10.4 The Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO_2 to sugar

LO 10.4: Explain how the Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO_2 to sugar.

The Calvin cycle is a metabolic pathway in which each step is governed by an enzyme, much like the citric acid cycle in cellular respiration. However, keep in mind that the Calvin cycle uses energy (in the form of ATP and NADPH) and is therefore anabolic. In contrast, cellular respiration is catabolic and releases energy that is used to generate ATP and NADH.

24. The carbohydrate produced directly from the Calvin cycle is not glucose, but the three-carbon compound ________________________________. Each turn of the Calvin cycle fixes one molecule of CO_2; therefore, it will take ______ turns of the Calvin cycle to net one G3P.

25. Explain the important events that occur in the *carbon fixation* stage of the Calvin cycle.

26. The enzyme responsible for carbon fixation in the Calvin cycle, and possibly the most abundant protein on Earth, is ____________________.

27. In phase two, the *reduction stage*, what molecule will donate electrons, and therefore is the source of the reducing power?

28. In this *reduction stage,* the low-energy acid 1,3-bisphosphoglycerate is reduced by electrons from NADPH to form the three-carbon sugar ___________________.

29. Examine Figure 10.18 in your text while we tally carbons. This figure is designed to show the production of one net G3P. That means the Calvin cycle must be turned three times. Each turn will require a starting molecule of *ribulose bisphosphate (RuBP)*, a five-carbon compound. This means we start with ______ carbons distributed in three RuBPs. After fixing three molecules of CO_2 using the enzyme __________, the Calvin cycle forms six G3Ps with a total of _______ carbons. At this point the net gain of carbons is _____, or one net G3P molecule.

30. Three turns of the Calvin cycle nets one G3P because the other five G3Ps must be recycled to three RuBPs. Explain how the *regeneration* of RuBP is accomplished.

31. The net production of one G3P requires ______ molecules of ATP and ______ molecules of NADPH.

Concept 10.5 Alternative mechanisms of carbon fixation have evolved in hot, arid climates

LO 10.5: Identify alternative mechanisms of carbon fixation that have evolved in hot, arid climates.

This concept deals with the important topic of evolution—notice that different solutions to the problems of a hot, dry climate have evolved.

32. Explain what is meant by a *C_3 plant*.

33. What happens when a plant undergoes *photorespiration*?

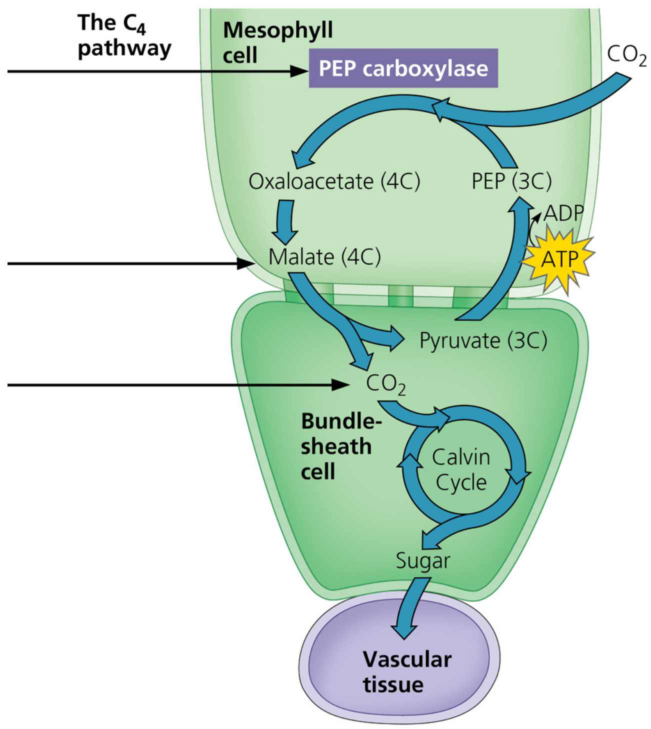
34. Explain how photorespiration can be a problem in agriculture.

35. Explain what is meant by a *C_4 plant*.

36. Explain the role of *PEP carboxylase* in C_4 plants, including key differences between it and *rubisco*.

37. Conceptually, it is important to know that the C_4 pathway does not replace the Calvin cycle but works as a CO_2 pump that prefaces the Calvin cycle. Explain how changes in leaf architecture (Figure 10.19) help isolate rubisco in regions of the leaf that are high in CO_2 but low in O_2.

38. Using Figure 10.19 in your text as a guide, explain the three key events—indicated by the arrows below—in the C_4 pathway.



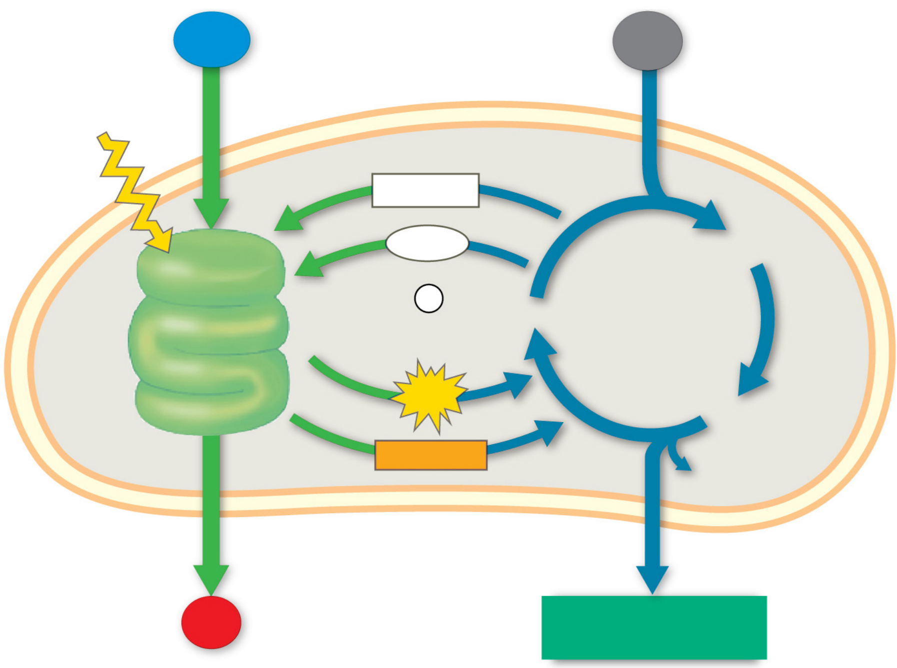
39. Compare and contrast C_4 plants with CAM plants. In your explanation, give two key similarities and two key differences.

Concept 10.6 Photosynthesis is essential for life on Earth: a review

LO 10.6: Describe photosynthesis and explain why all life on Earth depends on this process.

40. Explain this statement: "Only the green cells of a plant are the autotroph while the rest of the plant is a heterotroph."

41. Now that you have worked through the entire chapter, study Figure 10.21 in your text. On the figure below, add the title Light Reactions and list the key events. Next, add the title Calvin Cycle and summarize additional information for the Calvin cycle reactions. Finally, label this entire figure without looking back in your book! If you can do this, you understand the "big picture."



Make Connections: The Working Cell, Figure 10.22

"A picture is worth a thousand words!" That is the case with this one, as it reviews many of the key points in Chapters 5 through 10. Follow carefully the points reviewed until you are ready to answer the Making Connections question found at the bottom right of the figure. Think about where each process occurs and how it progresses. Get a partner and explain each process illustrated by this figure.

Test Your Understanding, p. 211.

Now you should be ready to test your knowledge. Place your answers here:

1. _____ 2. _____ 3. _____ 4. _____ 5. _____ 6. _____ 7. _____