

Chapter 7

Topic: Photosynthesis

Main concepts:

- Overall equation for photosynthesis: $6 \text{ CO}_2 + 6 \text{ H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{ O}_2$
- Photosynthetic organisms are autotrophs (also called producers), and include plants, some protists, and photosynthetic bacteria. (Fungi are NOT photosynthetic, so are not autotrophs.)
- Photosynthetic cells of a plant's leaf contain chloroplasts.
- Within the chloroplast are multiple stacks of membranes (thylakoids) within a semi-fluid medium (stroma). The thylakoids are the location of the light-dependent (energy-gathering) reactions of photosynthesis. The stroma is where the light-independent (molecular synthesis) reactions of photosynthesis occur.
- The light-dependent reactions gather light energy and use it to manufacture ATP and NADPH, which are used to power the light-independent reactions.
- Light-dependent (energy-gathering) reactions produce ATP that the chloroplast needs for making molecules:
 - The light-dependent reactions in green plants use mostly red and blue light. This is why plants are green: they're reflecting, rather than using, green light.
 - The first part of the light-dependent reactions is Photosystem II (unfortunately named, because it was discovered after Photosystem I). Energy is collected by an array of chlorophyll molecules and other light-sensitive molecules. The energy is used to split water, release H^+ ions and electrons, and to energize the electrons (oxygen, the waste product from splitting water, is released at this time). The electrons are sent down an electron transport chain and the energy released runs a proton pump which powers ATP synthesis.
 - The second part of the light-dependent reactions is Photosystem I. The spent electron from Photosystem I is re-energized in another array of chlorophyll. It moves down another electron transport chain, and the energy released is used directly to power NADPH production.
 - ATP and NADPH from the light-dependent reactions are used to power the light-independent reactions of photosynthesis.
- Light-independent (molecular synthesis) reactions use ATP and carbon dioxide to make sugar and other biomolecules:
 - ATP and NADPH enter the stroma, the semi-liquid material in the chloroplast. These will be used in the C_3 , or Calvin-Benson cycle.
 - The C_3 cycle has three parts:
 - Carbon fixation: Carbon dioxide from the atmosphere enters the stroma. RuBP, a 5-carbon compound, picks up carbon dioxide, forming an unstable 6-carbon compound. This breaks apart into two 3-carbon compounds, PGA, from which the C_3 cycle gets its name.
 - Synthesis: ATP and NADPH are used to convert PGA into another 3-carbon compound, G3P. Some of this compound leaves the cycle and is used to make organic compounds.
 - Regeneration of RuBP: More ATP is used to take the remaining PGA molecules and convert them to RuBP.
 - The 3-carbon G3P is used to make glucose or fructose (6 carbons) or fatty acid chains. By adding nitrogen, the G3P can be used to manufacture amino acids and nucleotide bases. From these simple monomers, the plant can synthesize larger polymers, such as cellulose, fats, proteins, etc.
- The C_3 cycle can only run if there is plenty of carbon dioxide dissolved in the cytoplasm of photosynthetic cells. If plants are water-stressed, such as during hot, dry weather, the stomata in their leaves close. Air cannot get into the leaves, and the plant may use up available carbon dioxide. If this happens, excess RuBP and oxygen accumulate. The free oxygen may oxidize RuBP in a process called photorespiration, a wasteful process that produces little or no energy.
- C_4 plants are adapted to hot, dry conditions. These plants add another chemical cycle to the light-independent reactions. This cycle captures a plentiful supply of carbon dioxide by bonding it to a 3-carbon molecule, PEP, to make a 4-carbon molecule. If the plant is water-stressed and must close its stomata, the 4-carbon molecule releases one carbon that can be used in the C_3 cycle. C_4 plants can continue to photosynthesize even with their stomata closed on hot days.

Common misconceptions:

- The most common misconception about photosynthesis is that plants get all the energy they need from the sun, and so they only make sugars and other molecules for other organisms. But the sun's energy is only used to power Photosystem II of photosynthesis, and the ATP that is made never leaves the chloroplast. To get energy for its cell's needs, plants must break down the sugars produced using glycolysis and cellular respiration. Plants also use the compounds they make to build their own cell parts.
- Students often believe that photosynthesis and respiration are inverse reactions of one another. This may be because the overall equations appear to be inverse reactions. Both processes, however, involve a different set of reactions.
- Many students believe that the light-dependent reactions occur in the daytime and the light-independent reactions (sometimes called the "dark" reactions) occur at night when the plant can't get sunlight, so it needs sugar. In fact, the light independent reactions occur at the same time as the light dependent reactions, because they are driven by the ATP made by the light-dependent reactions. Both systems shut down in the dark. The light-independent reactions can last a little longer if there is ATP remaining in the chloroplast.
- Students often believe that photosynthesis is a plant's way of doing cellular respiration. But all eukaryotes, including plants, carry out cellular respiration. Overall, photosynthesis is an endergonic process that stores energy in molecules, while respiration is an exergonic reaction that releases energy for the cell to use.
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- When they hear the word "photorespiration," many students immediately assume it is the plant's way of doing cellular respiration. However, photorespiration is a wasteful process in which RuBP is oxidized, and is not of benefit to the plant.

Chapter study guide:

- State several ways in which leaves are adapted for photosynthesis.
 - Observe the cross-section of a leaf and note which cells contain chloroplasts (hint: the green ones).
 - Name the two types of reactions in photosynthesis and summarize what happens in each (see page 118, first section).
 - Note which wavelengths of light are used in photosynthesis, and which pigments are commonly used by green plants. The Figure 7.5 shows which wavelengths of light each pigment absorbs. Consider why it might be an advantage for a plant to use more than one kind of pigment.
 - Use Figure 7.7 to summarize the important steps of Photosystem II and Photosystem I. Notice what important energy related molecules are produced.
 - State why it is important for water to be split in these processes (see page 120). Notice where oxygen gas is given off and where it comes from.
 - Read the Closer look section to see how the proton pump works in photosynthesis. Notice that the electron transport chain and proton pump are similar to those used at the end of cellular respiration, and are used for the same purpose.
 - List and summarize the three parts of the C3 cycle. Figure 7.10 will help.
 - State what energy-carrying molecules go into the C3 cycle, and what molecules are made.
 - C3 plants can suffer from photorespiration (this is NOT cellular respiration, nor is it what plants do "instead of" cellular respiration). State what photorespiration is and why it is a problem.
 - Describe the C4 pathway employed by C4 plants. State why this is an advantage in hot, dry conditions.
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Useful websites:

- “Harvesting Light” <http://www.sumanasinc.com/webcontent/anisamples/majorsbiology/harvestinglight.swf> is a narrated tutorial of the light-dependent reactions of photosynthesis.
 - “Photosynthesis animation” http://www.web.virginia.edu/gg_demo/movies/figure18_12b.html is a fairly detailed animation of the processes involved in Photosystem II and Photosystem I.
 - “Photosynthesis” <http://www.stolaf.edu/people/giannini/flashanimat/metabolism/photosynthesis.swf> is an unnarrated animation of the main events in the light-dependent reactions.
 - “Calvin Cycle” http://faculty.nl.edu/jste/calvin_cycle.htm is a series of simple animations that illustrate the steps of the C3 cycle.
 - “Calvin” <http://www.science.smith.edu/departments/Biology/Bio231/calvin.html> is an interactive animations of the C3 cycle.
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