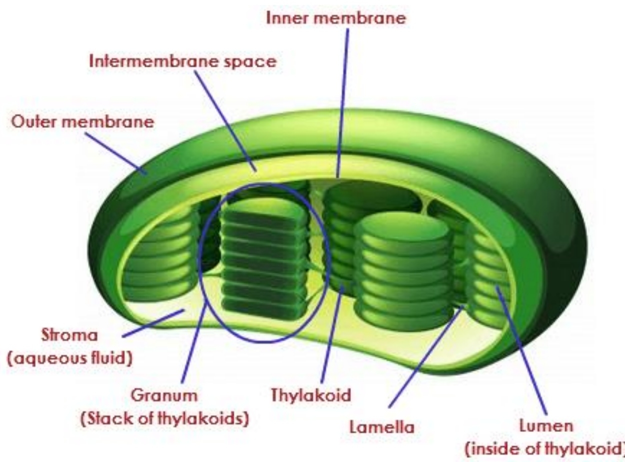
AP Biology **Photosynthesis**

Chapter 8 Reading Guide – ANSWER KEY

1. As a review, define the terms ***autotroph*** and ***heterotroph***. Keep in mind that plants have mitochondria and chloroplasts and do both cellular respiration and photosynthesis! Autotrophs are able to sustain themselves without eating other living organisms or material derived from living organisms. Autotrophs make their own "food" through either photosynthesis (solar energy → glucose) or chemosynthesis (inorganic materials such as methane and hydrogen sulfide → organic molecules). Autotrophs are also known as producers. Heterotrophs must consume other organisms for energy. Decomposers (some bacteria and fungi) are considered heterotrophs.

2. Draw a picture of a chloroplast and label the ***stroma, thylakoid, thylakoid space, inner membrane***, and ***outer membrane***.



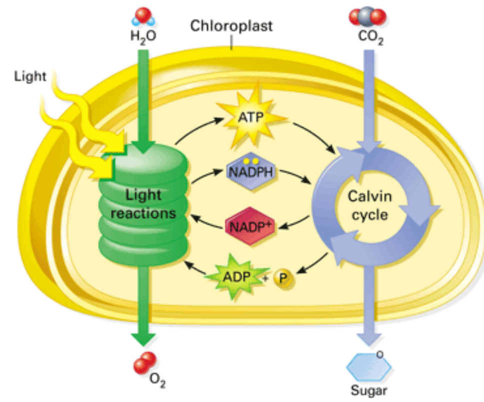
3. Use both chemical symbols and words to write out the formula for photosynthesis. $6CO_2 + 6H_2O$ + Light Energy → $C_6H_{12}O_6 + 6O_2$. Carbon dioxide reacts with water and energy from the sun to produce glucose and oxygen. Photosynthesis is another example of a redox reaction where carbon dioxide is reduced to glucose and water is oxidized to oxygen. The electrons increase in potential energy as they move from water to sugar (endergonic). The energy is provided by the sun.

4. 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. The light reactions occur in the thylakoid membranes of the chloroplasts. During the light reactions, water is split which provides a source of electrons and H^+ ions (protons). When water is split, oxygen gas is released as a byproduct. Light absorption by chlorophyll transfer electrons and H^+ to an electron carrier called NADP+. The light reactions also generate ATP, using chemiosmosis to power the addition of a phosphate to ADP. This is called photophosphorylation. At the end of the light reactions, light energy is converted into chemical energy store in ATP and NADPH. (No sugar yet!)

   b. Explain the ***Calvin cycle***, utilizing the term ***carbon fixation*** in your discussion. The Calvin cycle occurs in the stroma of the chloroplasts. The Calvin cycle begins with the incorporation of carbon dioxide from the air into organic molecules already present in the chloroplast. This is known as carbon fixation. The Calvin cycle then reduces the fixed carbon into carbohydrates by adding electrons provided NADPH. Chemical energy is supplied by ATP. The end result of the Calvin cycle is carbohydrate molecules called G3P which consist of 3 carbons each. G3P molecules are used to produce glucose.

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



6. 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. What are the colors of the ***visible spectrum***? The visible spectrum ranges from 380 nm to 750 nm with colors ranging from violet, indigo, blue, green, yellow, orange and red.

7. Explain the relationship between wavelength and energy. The shorter the wavelength of light, the higher the energy. The longer the wavelength of light, the lower the energy. Therefore, red light has less energy than violet light because it has a longer wavelength.

8. What colors of the visible spectrum are used for photosynthesis? Pigments are light absorbing protein molecules. The primary pigments in chloroplasts are chlorophyll *a* and chlorophyll *b* and accessory pigments called carotenoids. Chlorophyll *a* absorbs violet-blue and red light best. Green light is the least effective light for photosynthesis.

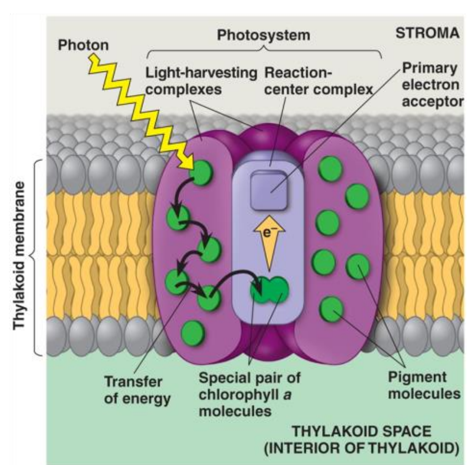
9. What is a ***photosystem***? A photosystem is an organized association of proteins holding a pair of chlorophyll *a* molecules surrounded by various other pigment molecules (cholorophyll *a*, *b* and carotenoids) bound to proteins. It acts as a reaction center and a light harvesting complex.

10. Within the photosystems, the critical conversion of solar energy to chemical energy occurs. This process is the essence of being a producer! Label the diagram and then explain the role of the terms in the photosystem.

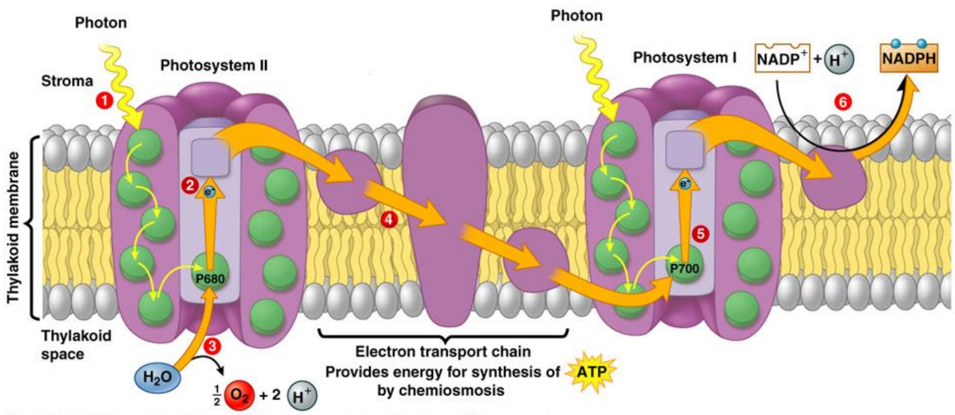
Reaction center complex – an excited electron from the special pair of chlorophyll molecules is transferred to a primary electron acceptor

Light-harvesting complex – a pigment molecule absorbs a Photon from light energy and passes the energy from pigment molecule to pigment molecule until it reaches the reaction center complex

Primary electron acceptor – accepts electrons and becomes reduced, prevents the potential energy from being lost as light and heat



11. ***Linear* electron *flow*** is, fortunately, easier than it looks. While reading the section "Linear Electron Flow," label the diagram number by number as you read.



12. The following set of questions deal with linear electron flow:

   a. What is the source of energy that requires the electron in photosystem II? Chlorophyll pigments

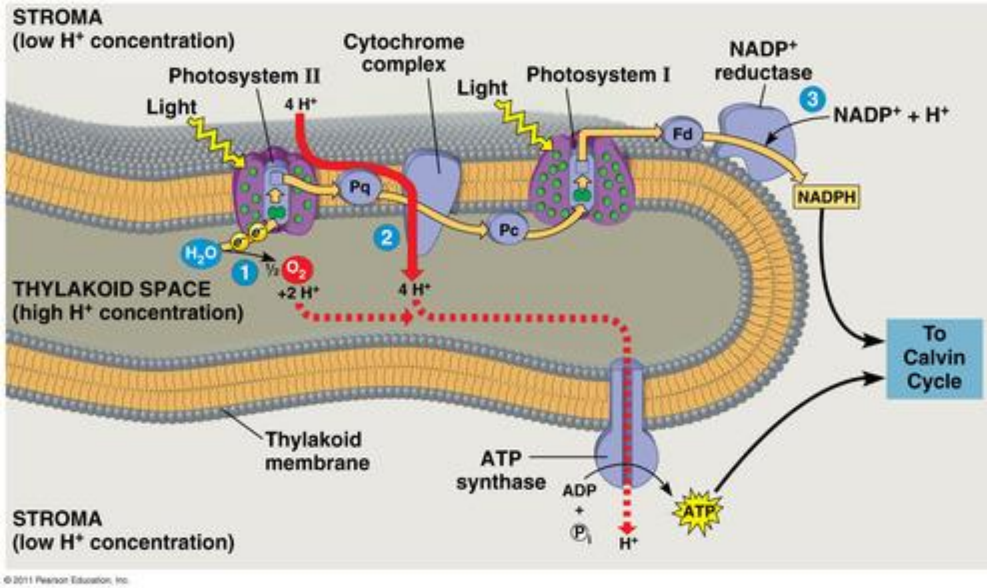
   b. What compound is the source of electrons for linear electron flow? Water This compound is also the source of oxygen in the atmosphere.

   c. As electrons fall between photosystem II and II, the cytochrome complex uses the energy to pump hydrogen ions. This builds a proton gradient that is used in chemiosmosis to produce what? ATP

   d. In photosystem II, the excited electron is eventually used by $NADP^+$ reductase to join NADP+ and a H^+ to form NADPH.

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

13. Label all the locations in the diagram first. Next, follow the steps in linear electron flow to label the components of the light reactions in **chemiosmosis**.



14. As a review, note that the light reactions store chemical energy in ATP and NADPH, which shuttle the energy to the carbohydrate-producing Calvin cycle.

The Calvin cycle is a metabolic pathway in which each step is governed by an enzyme. 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.

15. The carbohydrate produced directly from the Calvin cycle is not glucose, but the three-carbon compound G3P. Each turn of the Calvin cycle fixes one molecule of CO2; therefore, it will take three turns of the Calvin cycle to net one G3P.

16. Explain the important events that occur in the ***carbon fixation*** stage of the Calvin cycle. Each carbon dioxide molecule is joined to a 5-carbon molecule called RuBP with the assistance of an enzyme called Rubisco. The resulting 6-carbon molecule immediately splits into two 3-carbon molecules.

17. The enzyme responsible for carbon fixation in the Calvin cycle, and possibly the most abundant protein on Earth, is Rubisco (ribulose bisphosphate carboxylase).

18. In phase two, the *reduction stage*, the reducing power of NADPH will donate electrons to the low-energy acid 1,3-bisphosphoglycerate to form the three-carbon sugar G3P.

19. Examine **Figure 8.17** in your textbook 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 15 carbons distributed in three RuBPs. After fixing three carbon dioxides using the enzyme Rubisco, the Calvin cycle forms six G3Ps with a total of 18 carbons. At this point the net gain of carbons is 3, or one net G3P molecule.

20. Three turns of the Calvin cycle nets one G3P because the other five must be recycled to RuBP. Explain how the *regeneration of RuBP* is accomplished. The carbon skeletons of 5 molecules of G3P are rearranged into 3 molecules of RuBP. This reconfiguration requires the energy of 3 ATP molecules.

21. The net production of one G3P requires 9 molecules of ATP and 6 molecules of NADPH.

22. Now that you have worked through the entire chapter, study **Figure 8.19**. Use the T chart below to compare the light reactions and the Calvin cycle reactions of photosynthesis. If you can do this, you understand the "big picture".

Light Reactions	Calvin Cycle
Occurs in the thylakoid membranes	Occurs in the stroma
Water is split into oxygen (atmosphere) and H+ ions	CO_2 is fixed into organic molecules with the help of an enzyme known as Rubisco
Solar energy is captured and used to produce ATP and transfer electrons to NADPH	ATP provides energy and NADPH provides electrons
ATP is produced through chemiosmosis (ETC generates a proton gradient across the thylakoid membrane which powers ATP synthase)	G3P exits the Calvin cycle and is eventually converted into glucose