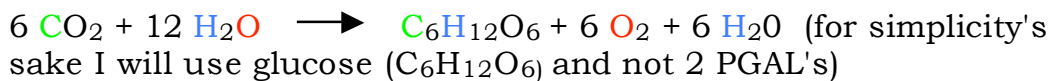


Chapter 4 notes: The following is a great link, view and use!

<http://photoscience.la.asu.edu/photosyn/education/learn.html>

Use your book for pictures and explanations as you read this, don't try to do either one without the other. **IT WON'T WORK.** This sheet is marvelous (if I do say so myself) but is not sufficient alone, you must take great notes, read the book and ask questions about all three of these information sources. This is very tough stuff, don't give up, by carefully listening during lecture, carefully reading and highlighting your book and using this sheet, you will have increased your chances to understand this difficult material.

Keep in mind why photosynthesis occurs. It supplies a stationary organism i.e. a plant, with a carbohydrate **molecule** that it can use for energy during cellular respiration or can instead, be modified into all the other organic compounds (other carbohydrates, proteins, lipids and nucleic acids). This **molecule** is **phosphoglyceraldehyde (PGAL)**, see pg. 111. We often, somewhat incorrectly, represent the carbohydrate product of photosynthesis as glucose (C₆H₁₂O₆) but it is more accurately 2 PGAL's. The balanced formula, meaning the total number and types of atoms on the left/reactant side equals the total number and kinds of atoms on the right/product side, for photosynthesis is :



Photosynthesis occurs in the plant cell organelle called a **chloroplast**. All plants have at least some cells with these organelles, autotrophic protists also have chloroplasts. Those plant cells that have chloroplasts, are found mainly in the plant "organs" called leaves. Within the leaves, chloroplast containing cells are mostly in the upper surface in an area called the palisade layer. Locate the palisade layer on page **728** showing a cross section of a leaf. Why do you think it is this way? Every palisade layer cell can have hundreds of chloroplasts. Look at page **104** at the structure of **one** chloroplast from a corn leaf. Read the caption of figure 4.3, because of its own DNA, RNA and enzymes, it makes sense that many scientists feel that the chloroplast used to be a free living

organism approximately 2 billion years ago.

The entire photosynthesis formula requires two sets of reactions, or **pathways**; called the **Light reaction (LR)** and the **Calvin Cycle (CC)**. Pathways occur in certain cellular locations because that is where that pathway's enzymes and other necessary cellular machinery are located. Read page **113 FOCUS ON**. In the case of the LR, those pigments and enzymes are found in the **thylakoid discs**.

The Light Reaction **requires water** and **sunlight** and **produces** some **ATP, NADPH** (some books call it NADPH₂) and **O₂** or molecular oxygen.

There are **two** photosystems involved in the LR, photosystem **I** and photosystem **II**. In order to understand the Light Reaction, I want you to look at page **108** and picture in your mind's eye, two slightly different chlorophyll molecules (p. **108** "A") and on page **105**, figure 4.4. Both of these chlorophyll's absorb slightly different wavelengths of light, the chlorophyll molecules are part of systems called **reaction centers**. There are thousands of chlorophyll molecules in each reaction center and thousands of reaction centers in each chloroplast and hundreds of chloroplasts in each leaf cell and thousands of leaf cells in each leaf andyou get the picture!

Back to page **108**, I will refer to the picture and their letters A-E. **Photosystem II** starts when light energy (photons), especially blue and red photons of visible light strike a reaction center's chlorophyll pigments (A). This causes a pair of outer (or valence) electrons from chlorophyll to become so energized that they are ejected. It is at this exact moment that solar energy has been **transformed** into chemical energy. **Energy** that can do cellular work.

In **Photosystem II** these energized electrons do chemical work. Their energy is used to pump protons (H⁺), into the thylakoid disc (D), this creates a high concentration gradient of H⁺ **inside** the thylakoid disc. The protons now diffuse back out, through an enzyme

called **ATP synthetase**. This enzyme, **ATP synthetase** when protons flow through it, combine ADP and a P, forming ATP (E). The ejected electrons, after doing the work of "pumping" the protons inside the thylakoid disc are now less excited, they are energy poor and attach to the other chlorophyll molecule from **photosystem I** that had electron "vacancies" as a result of its own earlier electron ejections.

Photosystem II center's chlorophyll molecule is still missing electrons, it will get them by splitting 2 water molecules (2 H₂O) into two oxygen atoms and four hydrogen atoms, a hydrogen atom can be further split into one proton and one electron (B). It is these electrons that will fill the electron holes of **Photosystem II** chlorophyll molecules.

The two oxygen atoms combine forming molecular oxygen (O₂). This O₂ can either be used by the plant during cellular respiration or if there is a surplus it will **diffuse** out of the chloroplast, out of the cell, out of the leaf through the open stomata and into the atmosphere.

It is the extra O₂ that plants aren't using for their own cellular respiratory needs, that has diffused out to the atmosphere, accumulating over billions of years and is now 18% of our current atmosphere. All aerobic organisms and even the non-photosynthetic tissues (stems, roots, fruit, flower etc.) of plants use this atmospheric O₂, during cellular respiration. Some of the hydrogen's protons (H⁺), from the split water, will be used along with the **photosystem I** Chlorophyll's electrons to remake complete hydrogen atoms. These hydrogens will then be picked up an empty hydrogen carrier molecule called NADP⁺, when it has its cargo (H⁺ or proton and e⁻ or electrons) it is called **NADPH** (F). We are still looking at page **108**.



We have now explained what is happening on the left hand side (reactant) 12 H₂O and the right hand side (product) 6 O₂.

To summarize; **photosystem II**; splits **water** molecules, forming molecular **oxygen (O₂)** which is released into the atmosphere, protons and synthesizes **ATP**. **Photosystem I** forms **NADPH** from **photosystem II's** protons and electrons. Go back and see if you can make sense of page **108's** diagram!

Together photosystem I and II are the light reaction pathway.

The other major pathway of photosynthesis is called the **Calvin cycle (CC)**. The Calvin cycle occurs in the stroma of the chloroplast, go back to page **104** figure 4.3 and locate the stroma, the stroma is the goo inside of the chloroplast but outside of the thylakoids. The Calvin cycle uses the **ATP** and **NADPH** from the Light reaction as well as atmospheric **carbon dioxide** that has diffused from the atmosphere into the leaf cells and into their chloroplasts.

In order for six carbon dioxide molecules (6 CO₂ -which have a total of 6 carbon atoms and 12 oxygen atoms) to have the same number and types of atoms as a glucose (C₆H₁₂O₆) molecule, then there needs to be an additional twelve hydrogens added and six oxygen atoms removed. Look at the two molecules and confirm this.

If the plant does the above paragraph then it will have a glucose molecule plus those six extra oxygen atoms, these six extra oxygen atoms are combined with additional NADPH's hydrogens forming six water molecules (H₂O).



Now we have accounted for the reactant 6 CO₂ and the products C₆H₁₂O₆ and 6 H₂O. In fact when we combine the results of the light reaction and Calvin cycle we have accounted for all the reactants and products .

Look at page **111** figure 4.13. Remember that the **ATP's** and **NADPH's** (shown at the lower right of diagram) are all coming from the same chloroplast, formed during the light reaction! Remember

that millions of these molecules are being produced and used every second in every chloroplast when all the photosynthetic reactants are available and conditions are correct.

Carbon dioxide is "shuttled" or carried into the Calvin Cycle (**CC**) by an enzyme called **rubisco**, this enzyme only works when activated by light. **Rubisco** combines carbon dioxide with a five carbon molecule called ribulose biphosphate, this results in a very unstable six carbon molecule that breaks into **two** three carbon molecules called **PGA**. After ATP and NADPH do their itty bitty magic stuff of adding on hydrogens and raising the energy level of these molecules, two **PGAL**'s are the result, one remains in the cycle and the other is combined with more **PGA**'s until another ribulose biphosphate is formed and the **CC** can occur again.

It takes three "turns" of the **CC** and three CO₂'s to make one surplus **PGAL**. Six "turns" of the **CC** and six CO₂'s to make two surplus **PGAL**'s. **The plant can either use the PGAL during cellular respiration to remake ATP or for biosynthesis. Biosynthesis is the production of other organic compounds.**

These PGAL's are the reason that photosynthesis exists. This is why plants can just stay in one place. They don't need to run around and find food for their energy needs or for their source of organic compounds. They make PGAL. The other organic compounds that PGAL's can be changed or modified into are amino acids (which when combined form proteins), lipids, nucleic acids (DNA and RNA) and still other carbohydrates such as fructose (which makes fruit sweet and attractive to animals, which will help spread baby plants - seeds to new areas), cellulose (strong component of cell walls), starch (large carbohydrate storage molecule).

These 2 PGAL's are the equivalent of one glucose molecule (**C₆H₁₂O₆**)

Look at page **117** figure 4.19. If there is too much molecular oxygen (**O₂**) it will compete with the carbon dioxide (**CO₂**) and instead some of the rubisco will instead combine with the O₂. Since some of the

rubisco isn't carrying carbon dioxide to the **CC**, this will result in less photosynthesis. When this happens it is called **photorespiration**. **Photorespiration** has no known function or advantage, pretty strange! Read FOCUS ON page **120**.

The plants discussed above are called **C₃** plants, because the carbon dioxide is first "fixed" or added to a two carbon molecule to make the **three** carbon molecule PGA. The majority of our food crop plants, and trees are all C₃ plants. Other plants are called **C₄** plants for a similar reason. These plants have gotten around the photorespiration problem. They usually can out compete, make more PGAL, grow faster, do more than the C₃ plants. Examples of such fast growing C₄ plants are corn, sugarcane and a variety of "weeds". **CAM** plants (**C**rassulacean **A**cid **M**etabolism) have evolved a different strategy, they are very inefficient, but can out compete all other plants in very dry and hot habitats, such as deserts, where the other plants can't survive. Read pages **117-120**, section 4.6.

Another group of autotrophs are called **chemoautotrophs**, they don't use solar energy to build PGAL. Instead, different chemoautotrophs oxidize a variety of chemicals for the energy to make ATP and NADPH for their calvin cycles. See page **123** table 4.2, heading "Electron Donor". Chemoautotrophs are also very inefficient, but are the dominant producers in those ecosystems that are too harsh for photoautotrophs to survive in. Such ecosystems are hydrothermal vents, hot springs, polar regions or thousands of meters deep in rocks. In fact because of these huge regions, **chemoautotrophs** may be the most common life form in the biosphere! Read pages **124-124**, section 4.9. The last two sentences in this chapter are pretty grim if you happen to be a heterotrophic bacteria or fungi dependent on these producers. *"They may grow so slowly in this nutrient-poor environment that they reproduce less than once per century. Eventually, they may die of starvation or be crushed as the pores [in the rocks] they occupy fill up with mineral deposits."*

What is the energy source for the LIGHT REACTIONS?

What molecule ejects its electrons when struck by red and blue photons and where do these molecules get their replacement electrons?

What molecules are made during the LIGHT REACTION?

What molecules are used during the Calvin cycle and where do they come from?

What molecules are made during the Calvin cycle?

From the lecture and book you MUST be able to explain the following. How do each: light, carbon dioxide and water reach the palisade layer cell's chloroplasts?

What will the plant be able to use the PGAL for?

"The oceans cover over 70% of the Earth's surface. Just from the sheer coverage and volume, the phytoplankton environment can be thought of as the world's most expansive jungle. Its affect on the Earth's life, climate, and geology is significant. Being at the bottom of the pelagic food-chain, it is literally the source of most oceanic life. Through photosynthesis, it may affect the Earth's climate by absorbing a significant portion of the world's carbon dioxide. When phytoplankton die, if their carbon is not consumed by other living creatures first, it settles on the ocean bottom and eventually is locked-up in sedimentary rock. This rock can reenter the Earth's crust from which it may be eventually emitted back into the atmosphere again through volcanism; part of the process known as the carbon cycle, which affects long-term global change. " From: [MODIS OPP/SCF: Overview](#), NASA scientists that are studying phytoplankton.

* "An average hectare of corn produces enough oxygen per hectare per day in mid summer to meet the respiratory needs of about 325 people. This means that the one million or so of corn grown in Ontario produce enough oxygen for the annual respiratory needs of Ontario's 10 million residents in about 11 summer days!" From: [Corn and Photosynthesis](#)