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The Chemistry of Biology: Photosynthesis

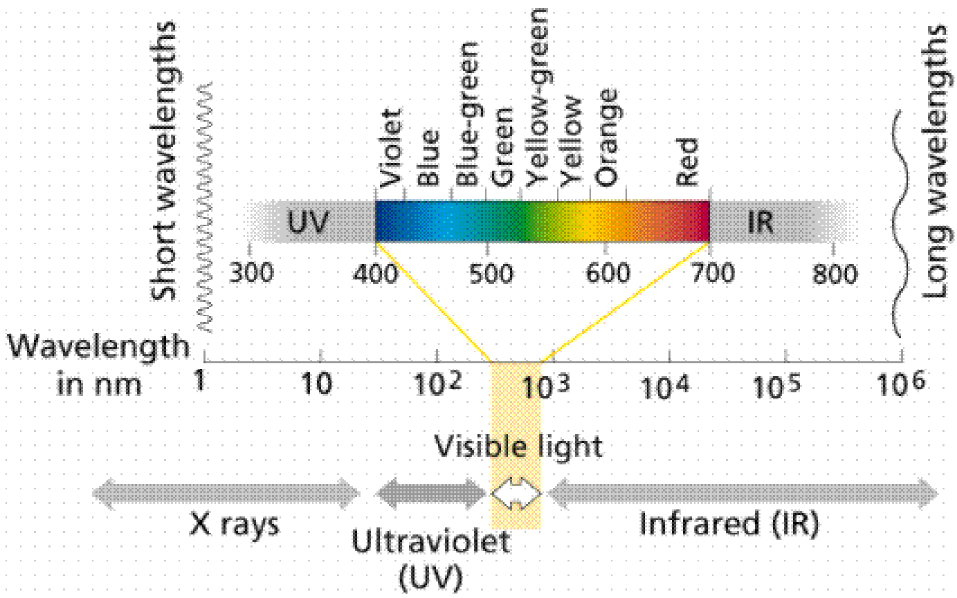
Photosynthesis is the process by which plants, some bacteria and some protists use energy from the sun to create food in the form of glucose from carbon dioxide and water. This definition is oversimplified, as the process of photosynthesis is a complex and complicated series of chemical reactions occurring at the molecular level. Many scientists break down this complicated process into two major steps, with smaller steps within each of those two steps. The reactions that take place during photosynthesis involve both oxidation reactions, where electrons are lost, and reduction reactions, where electrons are gained. Although both types of reactions occur during the process of photosynthesis, scientists tend to focus on the reduction reactions as opposed to the oxidations reactions. The electron movement throughout photosynthesis have been described as moving up and down an energy hill as they become first more and then less energetic (Krogh, 2005).

Photosynthesis and the Electromagnetic Spectrum (EMS)

Prior to discussing the inner workings of photosynthesis at the molecular level, it is important to understand where the energy needed to carry out this process originates. All energy on earth is obtained from either the sun or the core of the earth. While there are some bacteria that are producing food without sunlight, this paper will focus on photosynthesis which utilizes sunlight. Living things that can create their own food by using carbon dioxide and the sun are called photoautotrophs and include plants, some bacteria and protist.

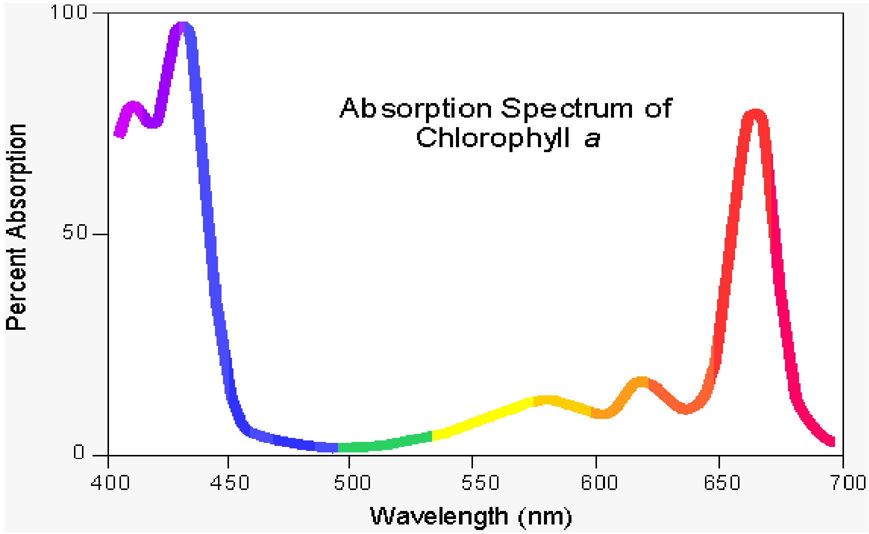
Sunlight contains various types of electromagnetic waves including the high energy ultra violet rays, visible light rays, and the lower energy infrared rays.

Photosynthesis is driven by the visible portion of the electromagnetic spectrum (EMS) which is a combination of colors ranging in wavelengths from 380nm (violet) through 750nm (red). The shorter the length of the wave, the higher the energy involved.



http://www.emc.maricopa.edu/faculty/farabee/BIOBK/spectrum.gif

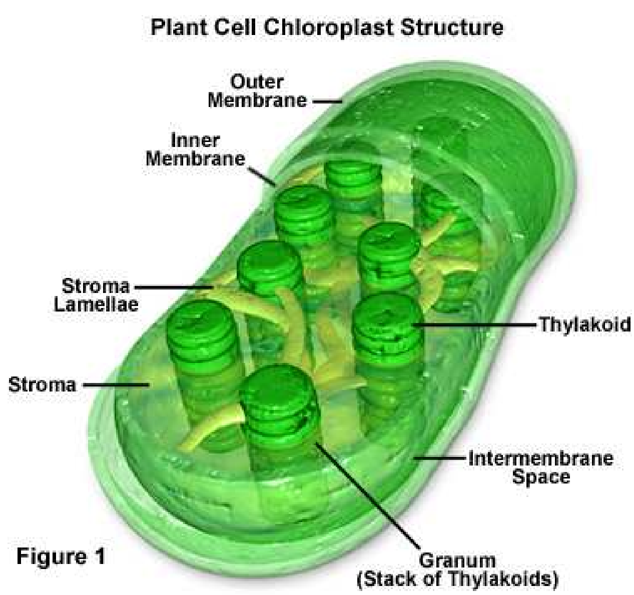
There are various pigments within a leaf and those pigments absorb and reflect different wavelengths of light. For example, the carotenoid pigments are responsible for the orange, yellow and some red leaves, visible when leaves change color in the fall, while the anthocyanins are responsible for the red or blue colors in many flowers (Lear 1986). The color of the plant and its parts are determined by which colors are reflected back to the eye. A green leaf will absorb all colors but green due to the presence of the pigment chlorophyll. Chlorophyll is directly involved and necessary for photosynthesis to occur. Chlorophyll is made of two types of compounds which include *chlorophyll a* and *chlorophyll b* and are present in a ratio of 3:1 respectively (Steer).



www.ch.ic.ac.uk/local/projects/steer/chloro.htm

Where does photosynthesis take place?

On the macro level, photosynthesis occurs in both the blades (leaf) and the stem of the leaf (petiole) of a plant. At the cellular level, photosynthesis occurs in mesophyll cells, specifically in the organelle within those cells called chloroplasts. Within the chloroplasts are membrane immersed in stroma (liquid) called thylakoids. A stack of thylakoids together are called granum. Photosynthesis takes place in the thylakoids membranes and the stoma within the chloroplast.



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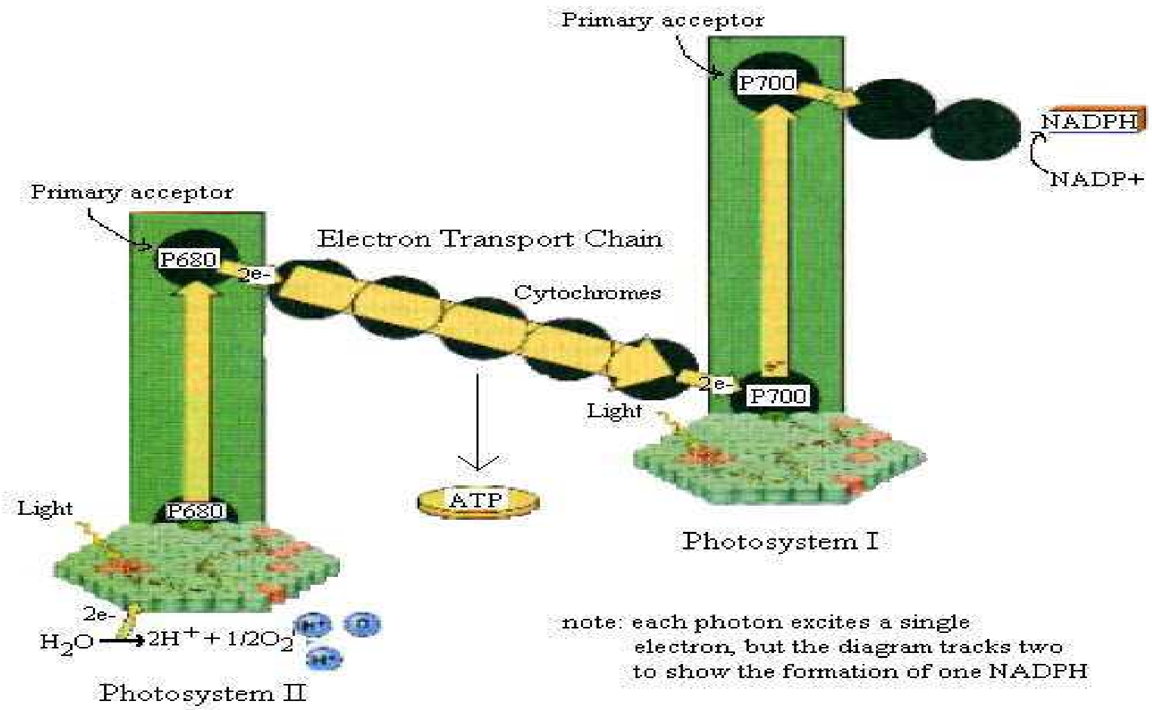
Within each of the thylakoids membranes are the photosystems. Each photosystem consists of pigment molecules such as *chlorophyll a*, a reaction center and a primary electron receptor.



kvhs.nbed.nb.ca/gallant/biology/ps1_2.jpg

Part One: Light Reactions

In the first part of photosynthesis, light energy from the sun hits the plant and that energy is absorbed by the chlorophyll in photosystem II. It must be noted that the first photosystem encountered during photosynthesis is actually called photosystem II. The photosystems were named for the order in which they were discovered, not in the order in which they are encountered during photosynthesis. That energy then energizes an electron from the chlorophyll located in the reaction center. The electron then relocates to the primary electron acceptor. Because the electron is leaving the reaction center, the reaction is considered to be an oxidizing one. Water within the plant is also being oxidized (losing electrons) when it is split by a specific enzyme. When the water is split, oxygen essential for life as we know it is formed (O_2). The remaining hydrogen is used for photosynthesis. The electrons lost from the splitting of the water then move to the electron acceptor. In terms of the energy hill (Krogh 2005), the electrons are moving up the hill. Because they are now considered to be at the top of the energy hill, the electrons are now in a position to fall back down the hill through an electron transport chain (see above diagram). This process results in the production of ATP, which will be used during the second stage of photosynthesis. It is at the bottom of this chain that the electrons arrive at photosystem I. This photosystem also has a reaction center receiving energy from the sun and the electrons are once again boosted up the energy hill and again are transported back down that hill via an electron transport chain. At the bottom of the hill, the electrons are taken on board by the $NADPH^+$ which becomes reduced to NADPH by gaining the electrons. The NADPH takes the electrons to the second step of photosynthesis called the Calvin cycle, or light independent reactions.

<u>Part Two: The Calvin Cycle (Light Independent Reactions)</u>

The second part of photosynthesis involves utilizing the energy captured during the light reactions in conjunction with carbon dioxide to ultimately produce food in the form of an energy rich carbohydrate for the plant. This process is called the Calvin cycle. Recall that the light reactions produced NADPH and ATP in the stroma. The Calvin cycle is broken down into a series of three steps.

Step One: *Carbon Fixation*

In this first step, three molecules of carbon dioxide are incorporated into a specific sugar called ribulose biphosphate, commonly called RuBP. The carbon dioxide is provided from the air surrounding the plant and the RuBP is present in plants from the time they are embryos. The process is made possible by the protein rubisco. Rubisco is a specific type of protein called an enzyme. Like many enzymes, it has an active site where the carbon may be added to the RuBP. RuBP contains a total of five carbon atoms. One carbon from each of the three starting carbon dioxide molecules is added to each RuBP. Although it may seem logical that there would be three six-carbon molecules formed, there are actually six three-carbon molecules formed (3-phosphogyleric acid). This is due to the instability of the of the six-carbon molecule which only allows the six-carbon molecules to form temporarily. At the end of this step, there are six molecules of 3-PGA.

Step Two: *Reduction*

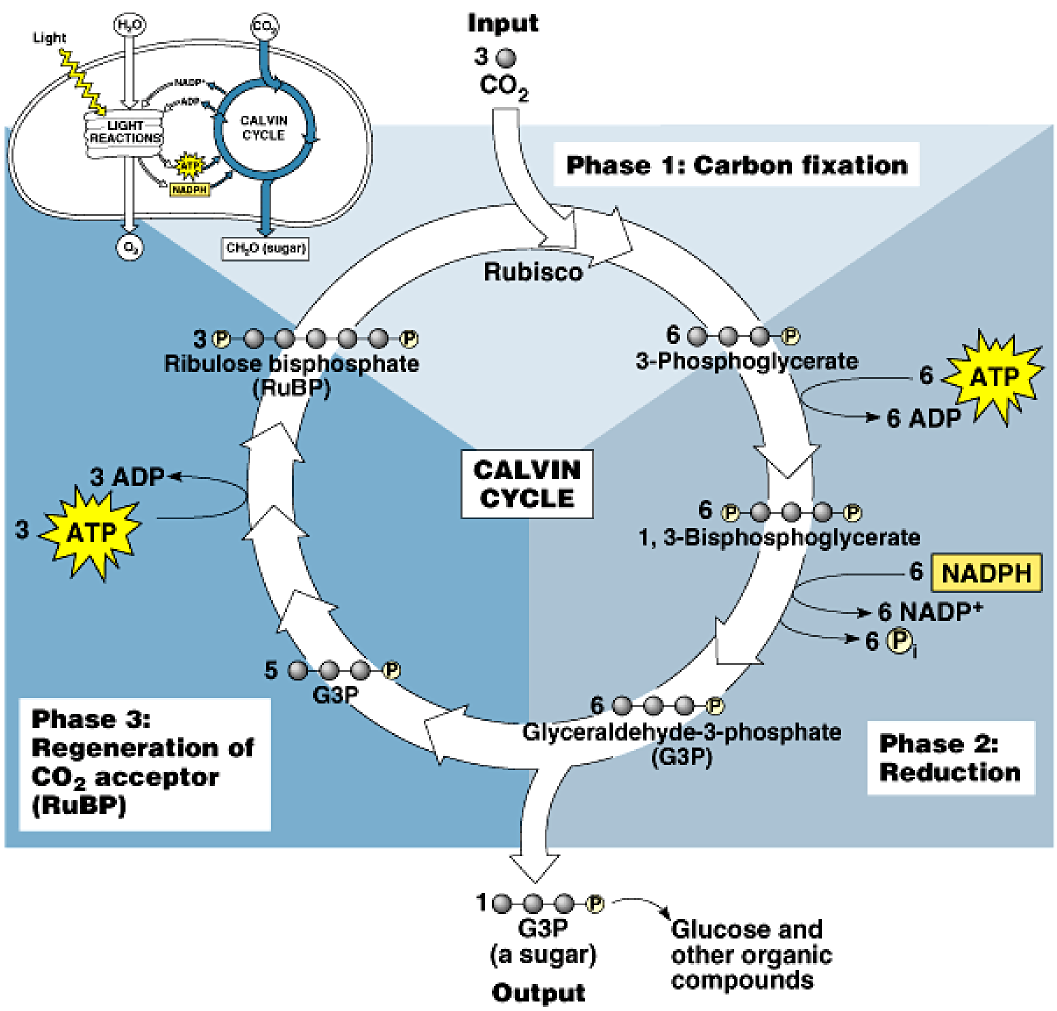
After the six molecules of 3-PGA have been produced, they now need to be energized. The molecules become energized when ATP that was formed during the light reactions places a phosphate group on each of the molecules. By donating the phosphate, the ATP becomes ADP. After the phosphate group has been attached to the 3-PGA, NADPH donates an electron pair (indeed the same electron pair that were discussed during the light reactions) to the molecule resulting in the production of glyceraldehyde-3-phosphate (G3P). When the NADPH molecule gives up its electron pair, $NADP^+$ is formed. The G3P is an energy rich sugar, that when combined with another G3P forms a six-carbon molecule commonly known as glucose.

Step Three: *Regeneration*

After the production of six molecules of G3P, five will be recycled through the Calvin cycle while one molecule is released to the plant. The plant may use this molecule for energy, it may store it as starch or it may be used in materials that make up the plant (Krogh 2005). The remaining five molecules will be used to regenerate the RuBP.

Summary of the Calvin Cycle

Step #	**What happens?**	**What is needed?**	**What is produced?**
One: *Carbon Fixation*	Sugar and CO_2 combine	CO_2, RuBP, rubisco	3-phosphoglyceric acid (3-PGA)
Two: *Reduction*	The sugar is energized, food is produced	ATP, 3-PGA, NADPH (electrons),	Glyceraldehyde-3-phosphate (G3P), $NADPH^+$ and ADP
Three: *Regeneration*	One molecule G3P is released to the plant, five are used to regenerate RuBP	G3P, ATP	RuBP



http://www.ualr.edu/botany/calvincycle.gif

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