Photosynthesis

Science Background

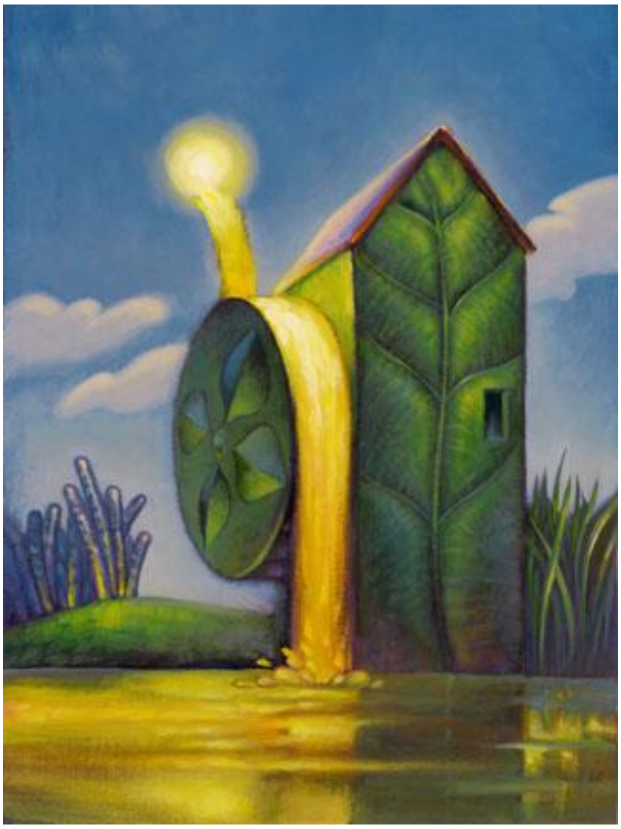
BIOLOGY
Plant
Physiology

Introduction to photosynthesis

In the process of photosynthesis plants, some bacteria, and some protistans use light energy to produce sugar molecules from carbon dioxide and water. Organisms able to photosynthesis are called autotrophs. The oxygen is released during this process. The following chemical equation shows the net input and output of photosynthesis.

$$6CO_2 + 6H_2O + \textbf{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Photosynthesis takes place in green parts of a plant, in chloroplast where the solar energy is absorbed by the green pigment chlorophyll. Chlorophyll also serves as a catalyst for reactions of hydrocarbonates synthesis. *Chloroplasts* have a complicated structure. Chlorophyll is contained in *thylakoid membranes* forming chloroplast *grana*.



drawing by Michael Hagelberg, Arizona State University's Center for the Study of Early Events in Photosynthesis

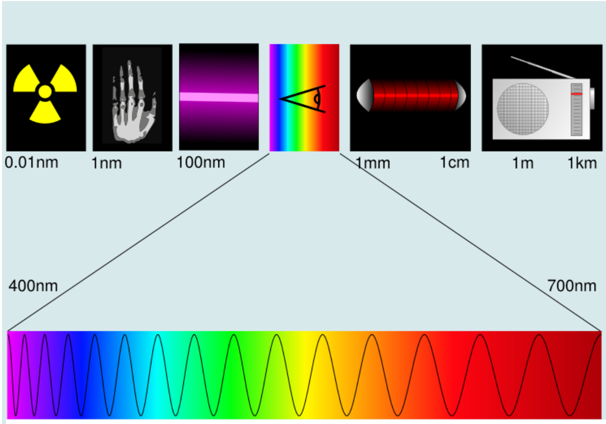
http://photoscience.la.asu.edu/photosyn/default.html

Most plants make more sugar than they need and store it. These stored sugars are a major source of food for many animals. On a global scale, photosynthesis by plant chloroplasts creates billions of tons of organic matter each year. This makes photosynthesis the most important chemical process to life on Earth. This process provides the food supply for other organisms and the oxygen for those organisms that require oxygen for respiration.

Visible radiation drives the light reactions

Our Sun emits most of it's electro-magnetic radiation in the range of visible light which is only a small fraction of the whole electromagnetic spectrum. Visible light consists of different wavelengths that our eyes see as different colours.

The light reactions of photosynthesis use only certain wavelengths of visible light.



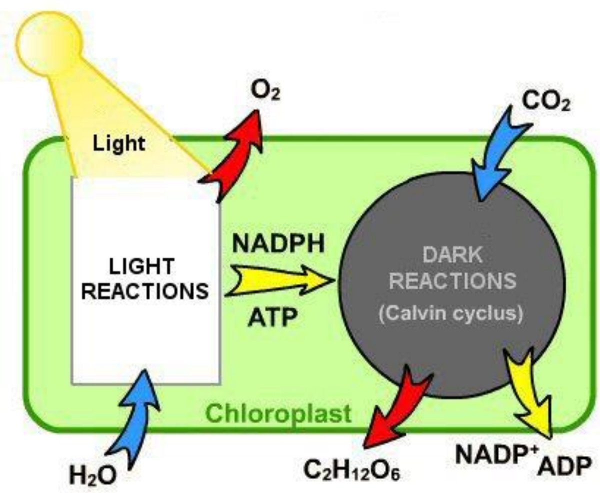
The electromagnetic spectrum; visible light consists of wavelengths from 400 to 700 nm.

Light absorbing molecules called pigments in the membranes of a granum absorb mainly blue-violet and red-orange wavelengths (for instance *chlorophyll a* absorbs mainly blue-violet and red light, *chlorophyll b* absorbs mainly blue and orange light and reflects yellow-green).

We do not see these absorbed wavelengths. What we see when we look at a leaf are the green wavelengths that the pigments transmit and reflect.

Photosynthesis in detail

Photosynthesis is not a simple process, but it occurs in two stages, each consisting of multiple steps. The steps of the first stage are known as light reactions and the steps of the second stage as dark reactions.



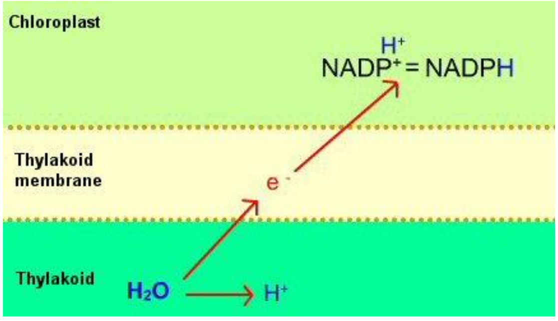
The light reactions are the reactions that absorb light energy and convert it to chemical energy stored in ATP and NADPH. As a by-product O_2 gas is produced. This process takes place in the thylakoids.

The dark reactions are known as the Calvin cycle. This is a cyclic series of reactions that assemble sugar molecules using CO_2 and the energy-containing products (ATP and NADPH) of the light reactions. This process takes place outside the thylakoids.

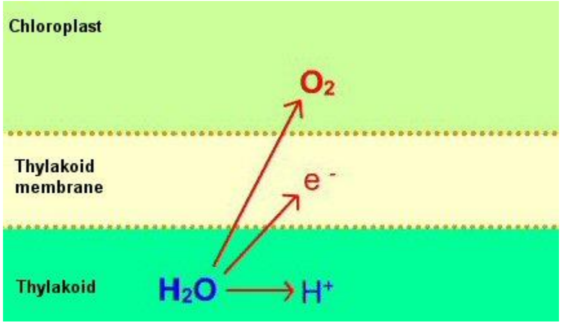
The two-stage mechanism of photosynthesis makes fixation of carbon dioxide possible independently of time. It may be important in hot and dry conditions when plants close their stomata to prevent loss of water. CO_2 is admitted only at night, and then glucose production occurs in a light-independent process. (However, in most plants, the Calvin cycle runs during daytime, when the light reactions power the cycle's sugar assembly line by supplying it with NADPH and ATP.)

The light reactions

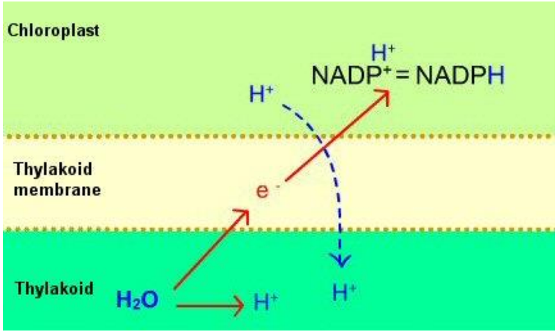
The light reactions occur in thylakoid membranes of the chloroplast's grana. In this first stage of photosynthesis light energy is converted into chemical energy in the form of ATP and NADPH.



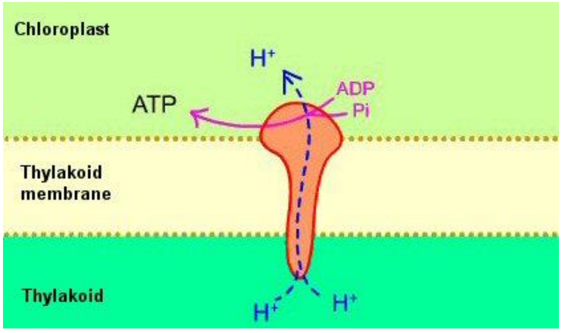
The two photosystems absorb light energy through pigments – primarily the chlorophylls. The light reactions start in photosystem II. In photosystem II a chlorophyll molecule absorbs a photon, an electron in this molecule gains a higher energy level. Through a chain of redox reactions, called an electron transport chain, this unstable electron is transferred. In photosystem I the electron gets the energy from another photon. When NADP+ gains the two high-energy electrons (the reduction) and an H+ ion, then it forms NADPH. Needed as an energy carrier in the dark reaction.



High energy NADPH and it's waste product O_2 both result directly from redox reactions. The synthesis of ATP is different, it is driven by chemiosmosis. Some of the electron carriers use energy released from the electrons to actively transport hydrogen ions H^+ from one side of the membrane to the other. This generates the concentration gradient of H^+ across the membrane.

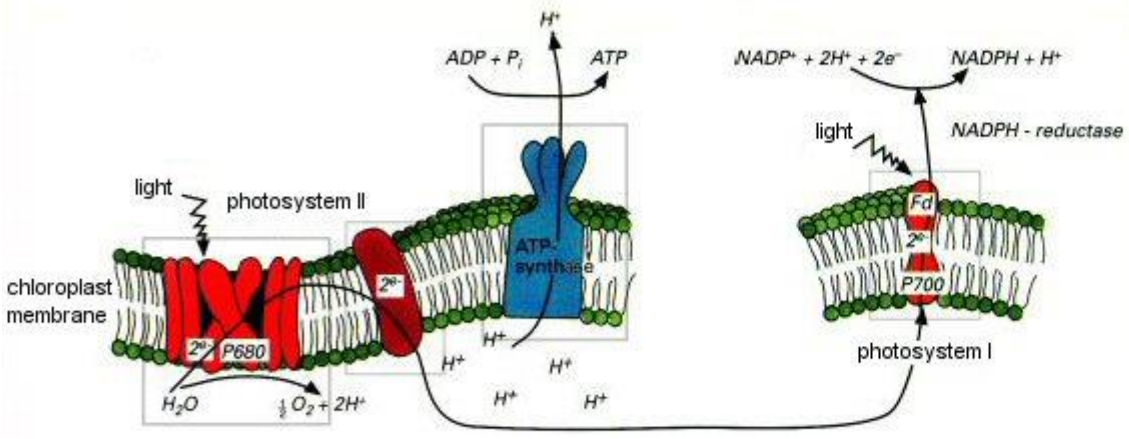


The protein complex ATP synthase provides a port through which H^+ can diffuse back into the stoma from the thylakoid compartment. The energy of the H+ gradient drives H+ back across, and energy is released in the process. ATP synthase uses some of this energy to phosphorylate ADP, making ATP.



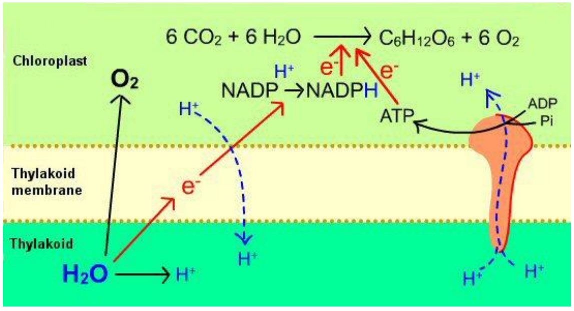
In the light reactions there is no sugar production.

The processes which take place during light reactions of the photosynthesis are shown below.



The dark reactions

The dark reactions - Calvin Cycle[1]- occur in the stroma of the chloroplast. The incorporation of carbon from CO_2 into organic compounds is called carbon fixation. After carbon fixation, enzymes of the cycle make sugars by further reducing the fixed carbon – by adding high-energy electrons to it, along with H^+.



NADPH produced by light reactions provides the high energy electrons for reduction in the Calvin cycle, and ATP from the light reactions provides the chemical energy that powers several of the steps of the Calvin cycle. The Calvin cycle does not require the light directly. However, in most plants, the Calvin cycle runs during daytime, when the light reactions power the cycle's sugar assembly line by supplying it with NADPH and ATP.

Photosynthesis variations

Plants in which the Calvin cycle uses CO_2 directly from the air are called C3 plants (about 95% of the total plant biomass), because the first organic compound produced is three carbon compound 3-fosfoglyceraat(3-PGA). One of the problems of C3 plants is that in hot and dry conditions C3 plants close their stomata to prevent loss of water. Under these conditions, oxygen gas, produced by the light reactions of photosynthesis, will concentrate in the leaves causing photorespiration.

In contrast to C3 plants, so-called C4 plants have special adaptations. When the weather is hot and dry, a C4 plant keeps its stomata closed most of the time, thus conserving water. At the same time it continues making sugars by photosynthesis. A C4 plant has an enzyme that fixes carbon into a four-carbon (4-C) compound instead of into 3-PGA. The four-carbon compound acts as a carbon shuttle; it donates the CO_2 to the Calvin cycle in a nearby cell, which therefore keeps on making sugars even though the plant's stomata are closed most of the time. Many important crop plants are C4 plants including maize, sorghum, sugarcane, and millet.

Cacti and most succulents (CAM plants) have developed a third mode of carbon fixation. A CAM plant conserves water by opening its stomata and admitting CO_2 only at night. The CO_2 is released to the Calvin cycle during the day. This keeps photosynthesis operating during the day even though the leaf admits no more CO_2.

History

Knowledge about photosynthesis has accumulated rapidly in recent years, although the process was not well defined until the twentieth century.

Some important historical facts are:

- The ancient Greeks believed that the soil satisfied all plants' needs, and this idea was generally accepted.
- In the mid-seventeenth century Belgian physician Jan Baptista van Helmont (1577 - 1644) performed an experiment with a small willow tree in a pot, adding nothing to the soil except water as the tree grew. He concluded correctly that a plant does not gain most of it's substance from the soil and incorrectly that his willow tree gained most of its substance from the water he gave it.
- In the 1700s Joseph Priestley (1733 - 1804) discovered that, although a candle burned out in a closed container, when he added a living sprig of mint to the container, the candle would continue to burn. At that time, Priestley did not know of O2, but he correctly concluded that the mint sprig "restored" the air that the burning candle had depleted.
- Dutch doctor and plant physiologist Jan Ingenhousz (1730 - 1799), inspired by Priestley's research, later learned that only the green parts of plants can revitalize stale air - that is, take in carbondioxide and release oxygen - and that they do so only in the presence of sunlight. This was the first indication of light's role in the photosynthetic process. Ingenhousz also discovered that only the light of the Sun - and not the heat it generates - is necessary for photosynthesis.
- In the late 1800s, German botanist Julius von Sachs (1832 - 1897) suggested that starch is a product of carbondioxide. He also argued in 1865 that, in the presence of light, chlorophyll catalyses photosynthetic reactions, and he discovered the chlorophyll-containing chloroplasts.
- In the 1880s, German physiologist Theodor Wilhelm Engelmann (1843 - 1909) showed that the light reactions, which capture solar energy and convert it into chemical energy, occur within the chloroplasts and respond only to the red and blue hues of natural light.

It was not until the twentieth century that scientists began to understand the complex biochemistry of photosynthesis. In 1940, the discovery of carbon-14, a radioactive isotope of carbon isolated by Kamen, allowed more detailed studies of photosynthesis. Using carbon-14, Melvin Calvin was able to trace carbon's path through the entire photosynthetic process. During the 1950s and 1960s, he confirmed that the light reactions involving chlorophyll instantly capture the Sun's energy. Then he studied the subsequent dark reactions. Working with green algal cells, Calvin interrupted the photosynthetic process at different stages and plunged the cells into an alcohol solution. Then, using the laboratory technique called paper chromatography; he analysed the cells and the chemicals that had been produced, identifying at least ten intermediate products that had been created within a few seconds. This series of reactions is now called the Calvin Benson Cycle.

In 1998, scientists at Arizona State University announced that they had created an artificial photosynthetic energy system. The cell-like machine used light to power the synthesis of ATP, a carrier of chemical energy in all organisms. The new technology could eventually lead to biological computers and new drugs. (McGrath, 1999, p. 600). *(Source: http://www.geocities.com/barefeetchild/history.html)*