Photosynthesis

What is photosynthesis?

Plants take mineral carbon, in the form of CO_2, from the atmosphere. They turn this mineral carbon into organic matter through photosynthesis.
This process is not spontaneous: an energy input is needed, in the form of light.
O_2 is produced during photosynthesis. The oxygen atoms come from the water absorbed by the plant.

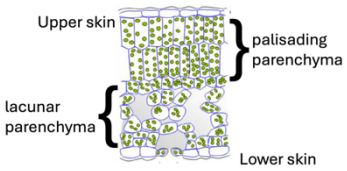
Photosynthesis is a mechanism driven by light energy and catalyzed by enzymes, that can be summarized as an oxidation of water and the reduction of carbon dioxide:

$$CO_2 + H_2O \xrightarrow{light} organic\ matter + O_2$$

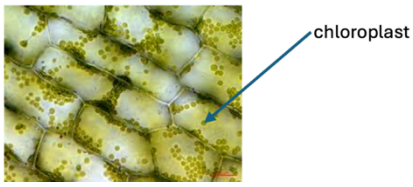
Note: Organic matter is often simplified as glucose: $6CO_2 + 6H_2O \xrightarrow{light} C_6H_{12}O_6 + 6O_2$
However, hexoses (6C carbohydrates) are only one out of several other organic molecules produced (carbohydrates, aminoacids, organic acids, ...), depending of the needs of the plant.

Where does photosynthesis take place?

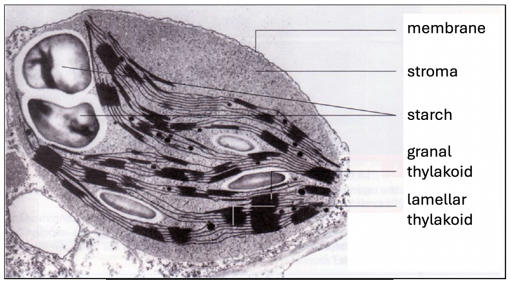
Chlorophyll cells are mainly found on the upper face of a leaf, shined upon by light., just under the upper skin, in the parenchyma. This is where photosynthesis takes place.
The lower skin of the leaf is perforated with pores that allow carbon dioxide to enter and oxygen gas to leave: the stomata.



1. The chloroplast, key organelle of a chlorophyll cell

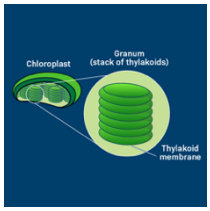


Photosynthesis takes place in small cytoplasmic organelles called chloroplasts. They measure an average of 10 µm and are surrounded by two membranes (an inner membrane and an outer membrane) that delimit an internal compartment containing the stroma, where the numerous enzymes essential for the synthesis of organic matter are located. Thylakoids are immersed in the stroma. These are flattened, elongated membrane sacs that contain chlorophyll within complexes called photosystems. Thylakoids are stacked in places and form structures called grana (granum in the singular).



2. Absorption of light energy by the chloroplasts

Observation of the absorption spectrum of chlorophyll pigments shows that they are capable of absorbing red and blue-violet light radiation (but not green radiation, which explains the green color of most chlorophyll-containing plants). Comparing this with the radiation effective for photosynthesis (action spectrum) reveals a match between the two spectra for chlorophylls a and b: these are photosynthetic pigments capable of capturing the light energy needed for photosynthesis. Chlorophylls that absorb light are contained in the thylakoid membranes.



A 2-phase mechanism

Photosynthesis takes place in the chloroplasts of chlorophyll cells in two complementary and simultaneous stages that occur in the thylakoids and in the stroma:

- The first stage is entirely dependent on light and is therefore called the **photochemical phase**. It allows the capture of light energy from the photons that make up light radiation and its conversion into chemical energy that can be used by the cell in metabolic reactions. This occurs in the thylakoids.
- The second stage occurs in the stroma. It is dependent on the presence of CO_2 but does not directly require light: it is a **non-photochemical phase**. It allows the fixation of mineral carbon and its reduction in the cell's organic molecules to form carbohydrates. The energy provided by the products of the photochemical phase is essential to this phase.

1. The photochemical phase

a. Synthesis of reduced carriers

The photons absorbed by the pigments in the photosystems of the thylakoids trigger two remarkable redox events:

- The photolysis of water, or oxidation of water, which leads to the decomposition of the water molecule and thus to the production of oxygen and the transfer of electrons and protons.

Note: Oxygen gas is a waste product of photosynthesis. It is therefore evacuated from the cell.

- The transfer of electrons at the thylakoid level allows the reduction of small molecules in the stroma: coenzymes NADP. These molecules behave as electron and proton acceptors. Once reduced, NADPH represent a reducing power that can then be transferred to other molecules during subsequent chemical reactions. This oxidation-reduction is not spontaneous; it requires energy supplied by light.

b. Synthesis of ATP

The transfer of electrons and protons to an acceptor that changes from an oxidized state to a reduced state also enables the synthesis of ATP, adenosine triphosphate, from ADP + P_i in enzyme complexes called ATP-synthases located on the thylakoid membrane. ATP produced in the stroma of chloroplasts is a small molecule that stores energy. It is therefore described as a high-energy molecule. This energy is released during the hydrolysis of ATP and can be used by the many enzymatic reactions of metabolism that require energy and therefore cannot occur without coupling with ATP hydrolysis.

Reduced transporters NADH and ATP are the two forms of chemical energy resulting from the conversion of light energy carried by photons, which will be usable during the second phase of photosynthesis, enabling carbon assimilation.

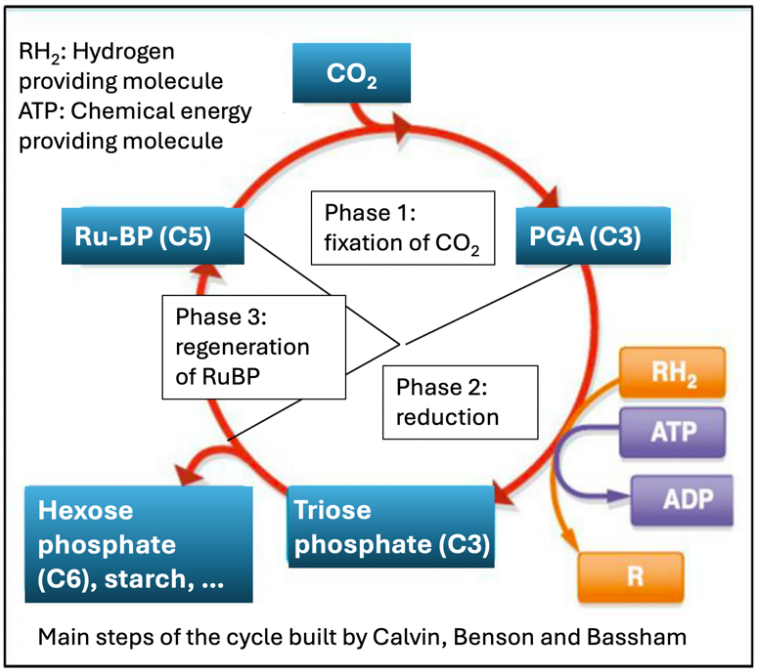
2. The chemical phase

a. Fixation and reduction of CO_2

The mineral CO_2 from the air that enters through the stomata of the leaves is incorporated into the organic matter in the stroma of the chloroplasts: CO_2 is fixed to a 5-carbon CO_2 acceptor, ribulose 1-5 bisphosphate (Ru-BP), which produces 2 molecules of PGA (phosphoglycerate), a 3-carbon intermediate. This CO_2 reduction phase is carried out by reduced NADH transporters and ATP produced during the photochemical phase of photosynthesis.

b. The future of CO_2 fixation products

From PGA molecules, triose phosphates are produced, followed by simple or complex carbohydrates such as starch, as well as amino acids. Some of the triose phosphates are also used to regenerate the CO_2 acceptor, ribulose 1-5 bisphosphate: the reactions in the non-photochemical phase therefore constitute a cycle localized in the stroma and called the Calvin cycle. This cycle requires a lot of energy, which is provided by the ATP synthesized during the photochemical phase.



Main steps of the cycle built by Calvin, Benson and Bassham

Note: RH_2 is NADPH and R is NADP

The products of photosynthesis are exported from the chloroplast to the cytoplasm of the chlorophyll cell, where they are converted into other carbohydrates and amino acids: these molecules feed the cell but also the entire plant, particularly the non-chlorophyll parts.

!!! Photosynthesis is the source of all biomass !!!

A diagram to summarize all this