Photosynthesis

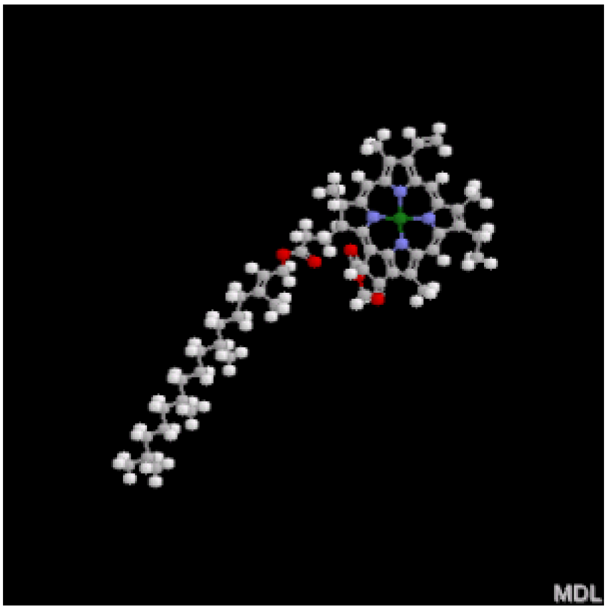
Photosynthesis is the process by which plants, some bacteria and some protistans use the energy from sunlight to produce glucose from carbon dioxide and water. This glucose can be converted into pyruvate which releases adenosine triphosphate (ATP) by cellular respiration. Oxygen is also formed.

Photosynthesis may be summarised by the word equation:

$$\text{carbon dioxide + water} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{glucose + oxygen}$$

The conversion of usable sunlight energy into chemical energy is associated with the action of the green pigment chlorophyll.

Chlorophyll is a complex molecule. Several modifications of chlorophyll occur among plants and other photosynthetic organisms. All photosynthetic organisms have chlorophyll a. Accessory pigments absorb energy that chlorophyll a does not absorb. Accessory pigments include chlorophyll b (also c, d, and e in algae and protistans), xanthophylls, and carotenoids (such as beta-carotene). Chlorophyll a absorbs its energy from the violet-blue and reddish orange-red wavelengths, and little from the intermediate (green-yellow-orange) wavelengths.



Chlorophyll

All chlorophylls have:

- a lipid-soluble hydrocarbon tail ($C_{20}H_{39}$ -)
- a flat hydrophilic head with a magnesium ion at its centre; different chlorophylls have different side-groups on the head

The tail and head are linked by an ester bond.

Leaves and leaf structure

Plants are the only photosynthetic organisms to have leaves (and not all plants have leaves). A leaf may be viewed as a solar collector crammed full of photosynthetic cells.

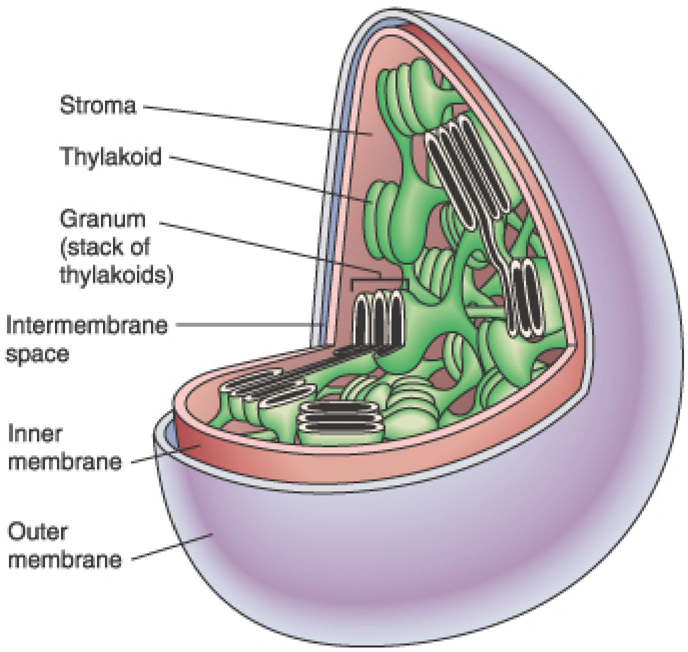
The raw materials of photosynthesis, water and carbon dioxide, enter the cells of the leaf, and the products of photosynthesis, sugar and oxygen, leave the leaf.

Water enters the root and is transported up to the leaves through specialized plant cells known as xylem vessels. Land plants must guard against drying out and so have evolved specialized structures known as **stomata** to allow gas to enter and leave the leaf. Carbon dioxide cannot pass through the protective waxy layer covering the leaf (**cuticle**), but it can enter the leaf through the **stoma** (the singular of stomata), flanked by two guard cells. Likewise, oxygen produced during photosynthesis can only pass out of the leaf through the opened stomata. Unfortunately for the plant, while these gases are moving between the inside and outside of the leaf, a great deal of water is also lost. Cottonwood trees, for example, will lose 100 gallons (about 450 dm^3) of water per hour during hot desert days.

The structure of the chloroplast and photosynthetic membranes

The thylakoid is the structural unit of photosynthesis. Both photosynthetic prokaryotes and eukaryotes have these flattened sacs/vesicles containing photosynthetic chemicals. Only eukaryotes have chloroplasts with a surrounding membrane.

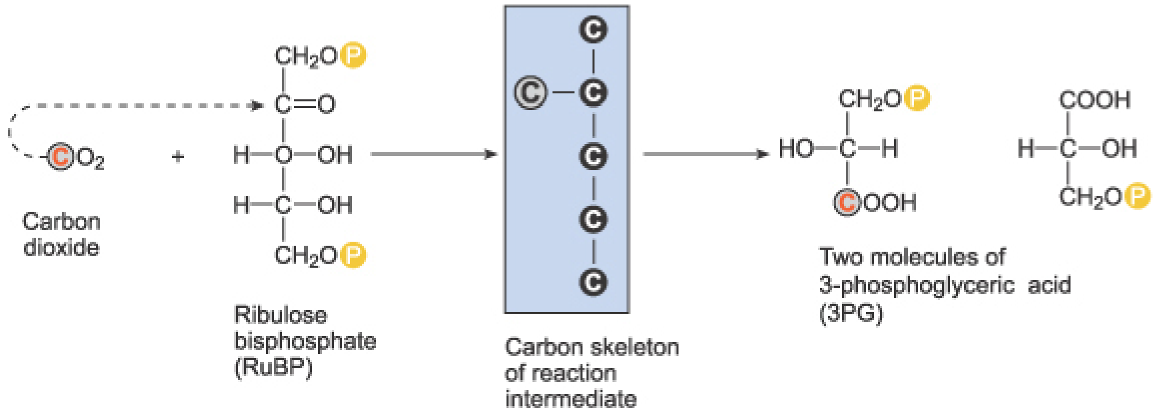
Thylakoids are stacked like pancakes in stacks known collectively as grana. The areas between grana are referred to as stroma. While the mitochondrion has two membrane systems, the chloroplast has three, forming three compartments.



Structure of a chloroplast

Of each pair of GALP molecules produced:

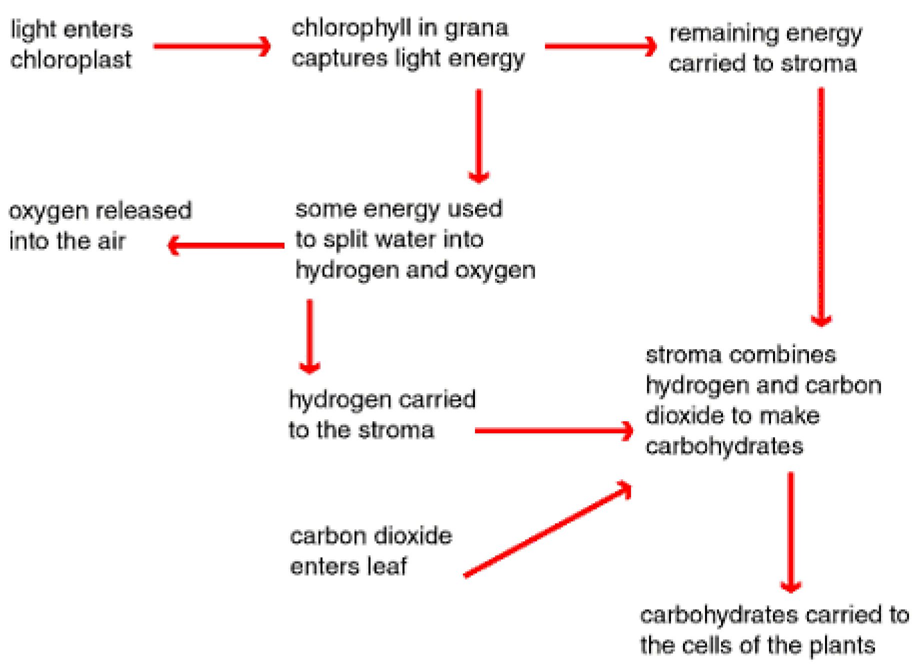
- one molecule is the initial end product of photosynthesis; it is quickly converted to glucose and other carbohydrates, lipids or amino acids
- one molecule forms RuBP through a series of chemical reactions



The first steps in the Calvin cycle

The first stable product of the Calvin Cycle is phosphoglycerate (PGA), a 3-C chemical. The energy from ATP and NADPH energy carriers generated by the photosystems is used to phosphorylate the PGA. Eventually there are 12 molecules of glyceraldehyde phosphate (also known as phosphoglyceraldehyde or PGAL, a 3-C), two of which are removed from the cycle to make a glucose. The remaining PGAL molecules are converted by ATP energy to reform six RuBP molecules, and thus start the cycle again.

Summary of stages of photosynthesis



Factors affecting the rate of photosynthesis

The main factors are light intensity, carbon dioxide concentration and temperature, known as limiting factors.

As light intensity increases, the rate of the light-dependent reaction, and therefore photosynthesis generally, increases proportionately. As light intensity is increased however, the rate of photosynthesis is eventually limited by some other factor. Chlorophyll a is used in both photosystems. The wavelength of light is also important. PSI absorbs energy most efficiently at 700 nm and PSII at 680 nm. Light with a high proportion of energy concentrated in these wavelengths will produce a high rate of photosynthesis.

An increase in the carbon dioxide concentration increases the rate at which carbon is incorporated into carbohydrate in the light-independent reaction and so the rate of photosynthesis generally increases until limited by another factor.

Photosynthesis is dependent on temperature. It is a reaction catalysed by enzymes. As the enzymes approach their optimum temperatures the overall rate increases. Above the optimum temperature the rate begins to decrease until it stops.

Test your knowledge

Take quiz on *Photosynthesis*