2. Photosynthesis of green plants

2.1 Water

2.2 The antenna system

2.3 The Z-scheme

Photosynthesis of green plants

Molecular oxygen is a prerequisite of animal and therefore also human life on earth.

Only primitive organisms have survived over hundreds of millions of years without oxygen. Oxygen was even toxic for these early anaerobic creatures because it is able to oxidize other molecules.

Why and how did green plants start to produce oxygen in the photosynthesis process, despite of the fact that it is toxic?

From Bild der Wissenschaft, April 1990, p. 92.

The why has to do with the energy household of the plants.

Any life on earth is in the end powered by solar energy.

Cells can, however, not use or store this energy directly; they must first transform it into chemical energy.

Redox reactions, which means displacement of electrons, play an important role in this chemical energy transformation process.

Hence, cells need a source of electrons for living.
All green plants use the same source for electrons, namely

Water

as reducing agent!

2.1 Water

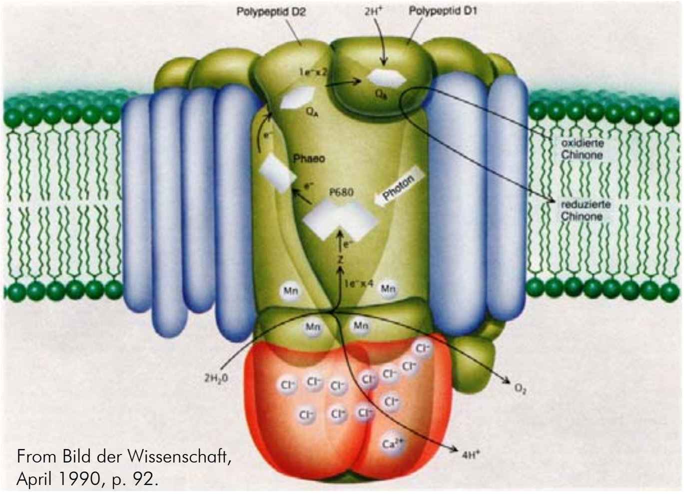
Some photosynthetically active cells have learned to withdraw electrons from water about three billion years ago.

They developed the ability to decompose two molecules of water into four electrons, four protons and one molecule of oxygen.

The electrons and protons were used for the energy household of the cells.

The oxygen was a by-product which, however, was essential to make highly organized living creatures possible.

The oxygen production in the cells is not yet fully understood. We know, however, that it takes exclusively place in the photosystem II.
The primary reactions take place inside of the thylakoid mebrane (T-M).
The essential function of the PS II is to separate + and – charges.
The electron transfer takes place in the RC: D1, D2, Cytochrome.
The RC is supplied with electronic excitation energy by means of the *antenna system.*

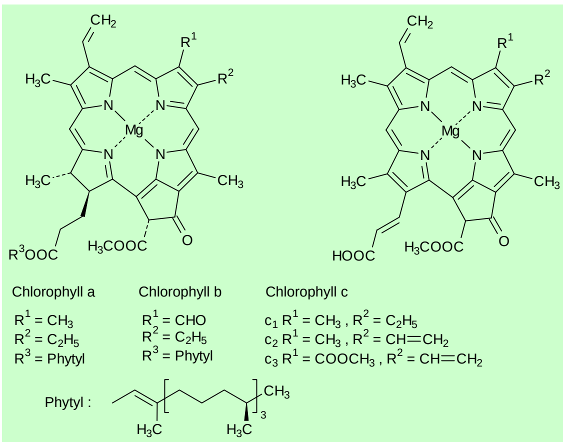


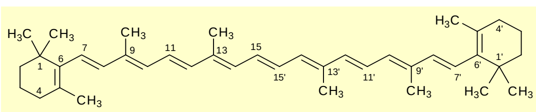
From Bild der Wissenschaft, April 1990, p. 92.

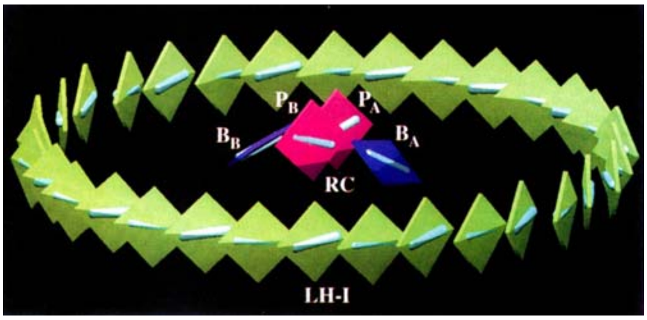
Photosystem II

2.2 The Antenna System

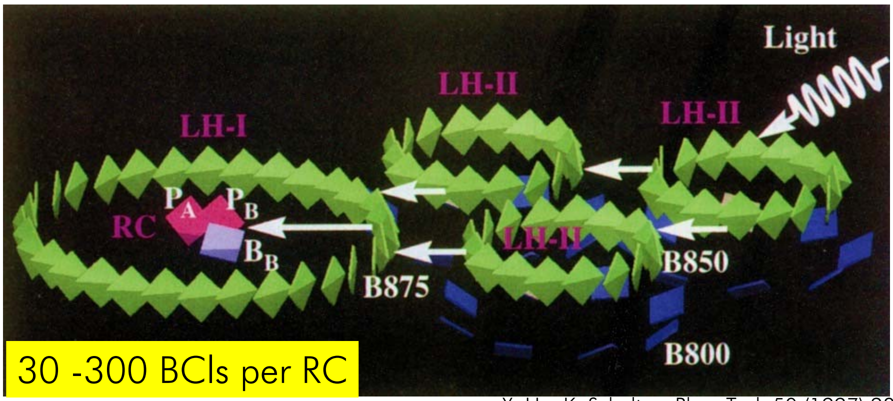
The antenna system is essentially composed of chlorophyll molecules, carotenoids, and of the proteins which build the framework.







X. Hu, K. Schulten, Phys. Tod. 50 (1997) 28



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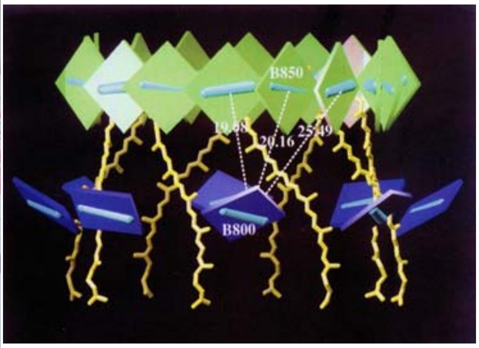
RC = reaction centre
PA,PB = special pair

B800
B850
B875

These numbers are the absorption edges in nm.

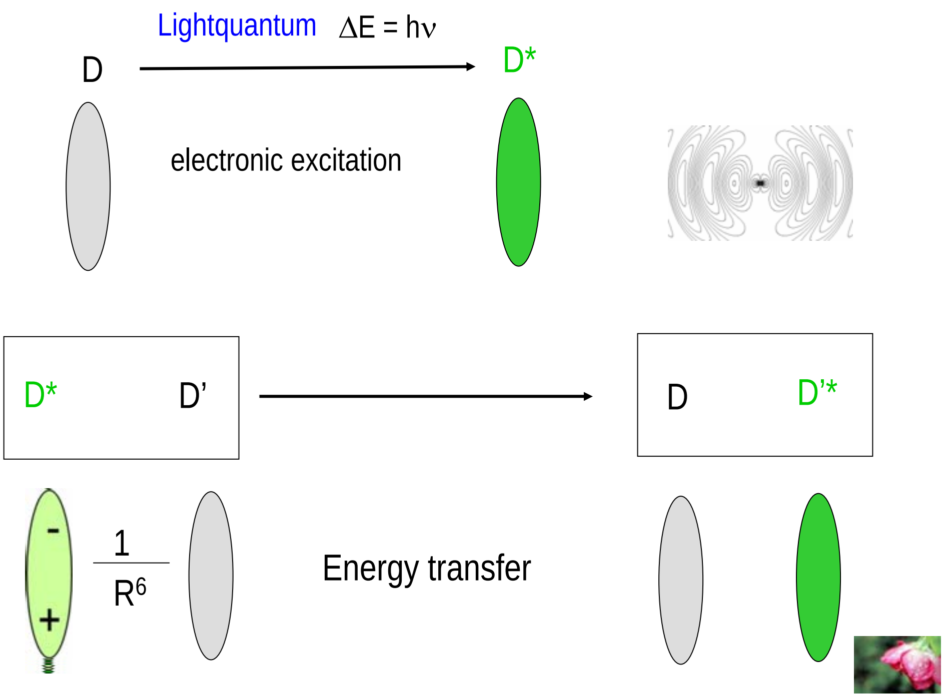


LH-II

Blue: α-helices formed by 56 amino acids

Purple: α-Helices formed by 45 amino acids

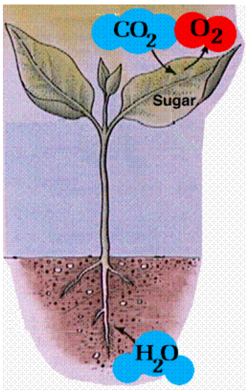
X. Hu, K. Schulten
Phys. Tod. 50 (1997) 28



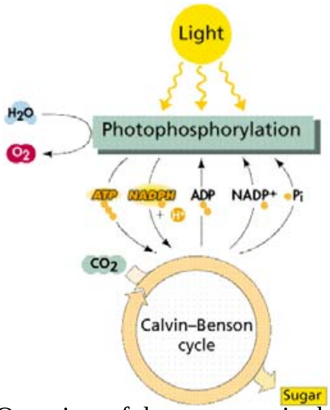
Electronic Excitation Energy Transfer.
Lecture 2
Photosynthesis of green plants

2.3 The Z-scheme

Photosynthesis is a two stage process. The first process requires the direct energy of light to make energy carrier molecules that are used in the second process. The dark reaction occurs when the products of the light reaction are used to form C-C covalent bonds of carbohydrates. It can usually occur in the dark, if the energy carriers from the light process are present. Recent evidence suggests that a major enzyme of the dark reaction is indirectly stimulated by light, thus this term is somewhat of a misnomer.



$$6H_2O + 6CO_2 \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2$$

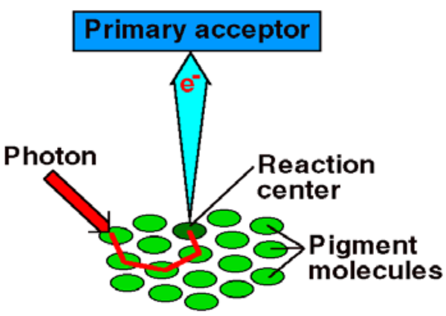


Overview of the two steps in the photosynthesis process. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates.

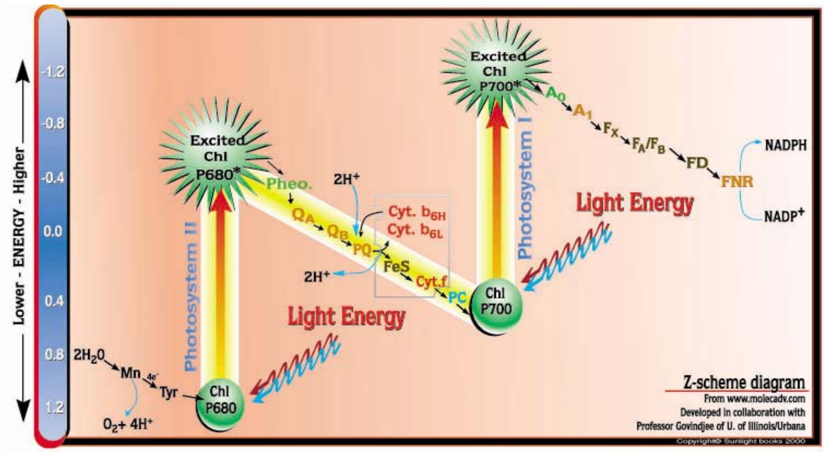
In the Light Reactions light strikes chlorophyll a in such a way as to excite electrons to a higher energy state. In a series of reactions the energy is converted (along an electron transport process) into ATP and NADPH. Water is split in the process, releasing O_2 as a by-product of the reaction. The ATP and NADPH are used to make C-C bonds in the Dark Reactions. In these Reactions, CO_2 is captured and modified by the addition of hydrogen to form carbohydrates ($[CH_2O]_n$). The incorporation of CO_2 into organic compounds is known as carbon fixation. The energy for this comes from the first phase of the photosynthetic process.

Photosystems are arrangements of chlorophyll and other pigments packed into thylakoids. Many prokaryotes have only one photosystem, Photosystem II (so numbered because, while it was most likely the first to evolve, it was the second one discovered).

Eukaryotes have Photosystem II plus Photosystem I. Photosystem I uses chlorophyll a, in the form referred to as P700. Photosystem II uses a form of chlorophyll a known as P680.



Action of a photosystem



Picture from Govindjee and Rajni Govindjee University of Illinois at Urbana-Champaign.

The Z-scheme is an energy diagram for electron transfer in the light reactions of plant photosynthesis. It applies equally well to photosynthesis by algae and cyanobacteria. It is called Z-Scheme because the diagram, when first drawn, was in the form of the letter "Z". The vertical energy scale shows each molecule's ability to transfer an electron to the next one from left to right. The ones at the top transfer electrons easily to the ones below them as it is a "downhill" reaction, energy-wise. However, for electron transfer from those at the bottom to those above them it is an "uphill" reaction and requires input of outside energy. The Z scheme shows the pathway of electron transfer from water to $NADP^+$.

Mn is the manganese center, a complex containing 4 manganese atoms. Tyr is a special tyrosine molecule, which shuttles electrons to the "reaction center" of PSII. Chl P680 is the reaction center pair of chlorophyll *a* molecules of PSII. Excited Chl P680* has reached this state by absorbing a photon of light energy. Pheo is a pheophytin molecule, which is a chlorophyll with its central Mg^{2+} ion having been replaced by two H^+. It is the primary electron acceptor of PSII, whereas P680 is the primary electron donor. Q_A is a plastoquinone molecule, which is the primary stable electron acceptor of PSII, and it accepts and transfers one electron at a time. Q_B is a loosely bound plastoquinone molecule. It accepts 2 electrons and then takes on 2 protons, before it detaches and becomes mobile and called PQ. PQ is the detached plastoquinone. It is mobile within the hydrophobic core of the thylakoid membrane. FeS is the Rieske iron-sulfur protein. Cyt β_{6L} and Cyt β_{6H} are 2 cytochrome β_6 molecules (of lower and higher energy). PC is plastocyanin, a highly mobile copper protein. Chl P700 and excited Chl P700* are respectively the ground energy state and the excited energy state of the chlorophyll molecule of the "reaction center" of PSI. AO is a special chlorophyll *a* molecule that is the primary electron acceptor of PSI, whereas P700 is the primary electron donor of PSI. A_1 is a phylloquinone (vitamin K) molecule. F_X, F_A, and F_B are three separate immobile iron-sulfur protein centers. FD is ferredoxin, a somewhat mobile iron-sulfur protein. FNR is the enzyme ferredoxin-NADP oxidoreductase, which contains the active group, called FAD (flavin adenine dinucleotide). $NADP^+$ is the oxidized form of nicotinamide adenine dinucleotide phosphate. NADPH is its reduced form.

Another way to draw the Z-scheme.