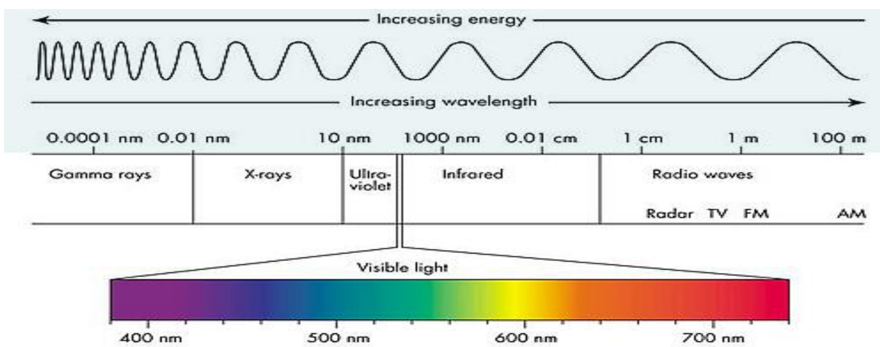
Photosynthesis: The Light reactions

Life on earth ultimately depends on energy derived from the sun. Photosynthesis is the only process of biological importance that can harvest this energy. The term photosynthesis means literally "synthesis using light." photosynthetic organisms use solar energy to synthesize carbon compounds that cannot be formed without the input of energy. More specifically, light energy drives the synthesis of carbohydrates from carbon dioxide and water with the generation of oxygen:

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

When Molecules Absorb or Emit Light, They Change Their Electronic State

Chlorophyll appears green to our eyes because it absorbs light mainly in the red and blue parts of the spectrum, so only some of the light enriched in green wavelengths (about 550 nm) is reflected into our eyes. In autumn, green leaves of certain plants change colors; brilliant reds, yellows, oranges, and browns. The pigments that reflect those colors were in the leaf all along. They were masked by the dominant chlorophyll A. In the fall the plants stop making chlorophyll A and that allows the accessory pigments to appear.



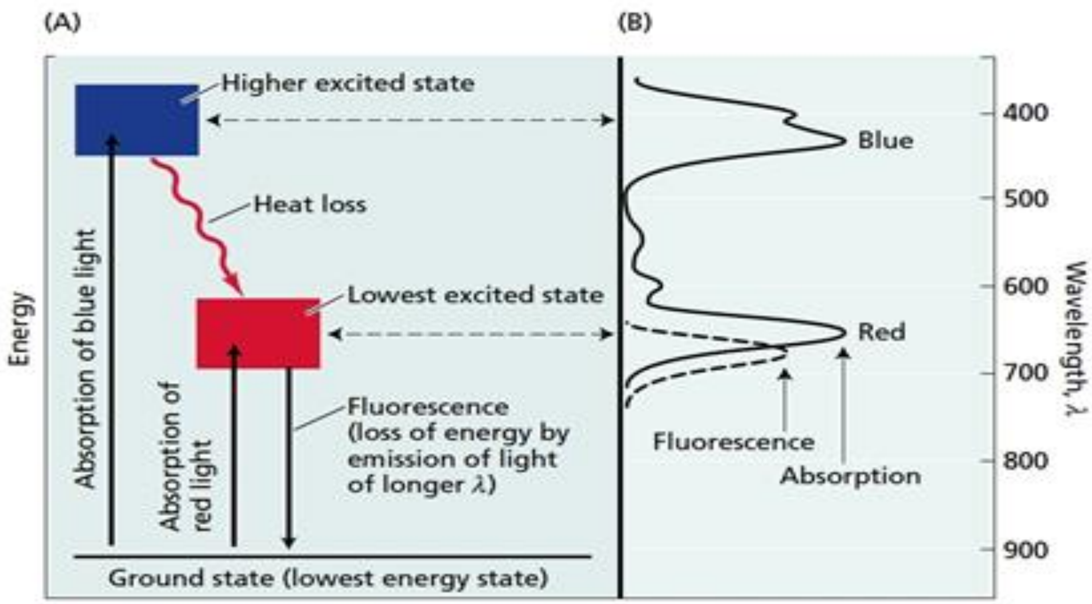
The absorption of light is represented by the following Equation, in which chlorophyll (Chl) in its lowest-energy, or ground, state absorbs a photon (represented by hn) and makes a transition to a higher-energy, or excited, state:

$$Chl + hn \rightarrow Chl^*$$

The distribution of electrons in the excited molecule is somewhat different from the distribution in the ground state molecule. Absorption of blue light excites the chlorophyll to a higher energy state than absorption of red light because the energy of photons is **higher** when their wavelength is shorter.

In the higher excited state, chlorophyll is extremely **unstable**, very rapidly gives up some of its energy to the surroundings as heat, and enters the lowest excited state, where it can be stable for a maximum of several nanoseconds (**9–10 s**). In the lowest excited state, the excited chlorophyll has four alternative pathways for disposing of its available energy.

1. Excited chlorophyll can **re-emit a photon** as **light** but at a longer wavelength and thereby return to its ground state, a process known as **fluorescence**.
2. The excited chlorophyll can **return** to its ground state by directly converting its excitation energy into **heat,** with **no emission** of a photon.
3. **Chlorophyll** may participate **in energy transfer**, during which excited chlorophyll transfers its energy to another molecule.
4. A fourth process is **photochemistry**, in which the **energy of the excited** state causes chemical reactions to occur.

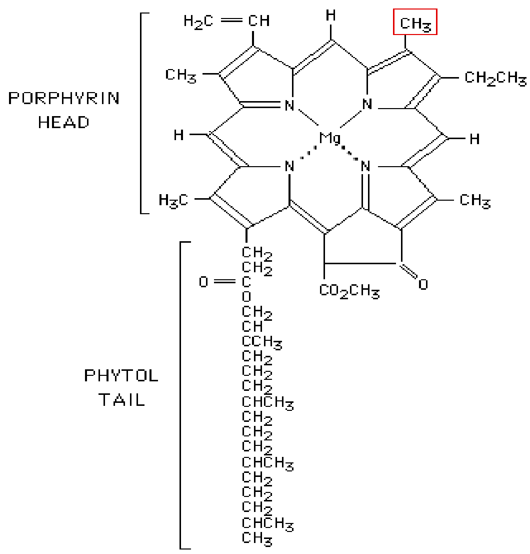


Photosynthetic Pigments Absorb the Light That Powers Photosynthesis

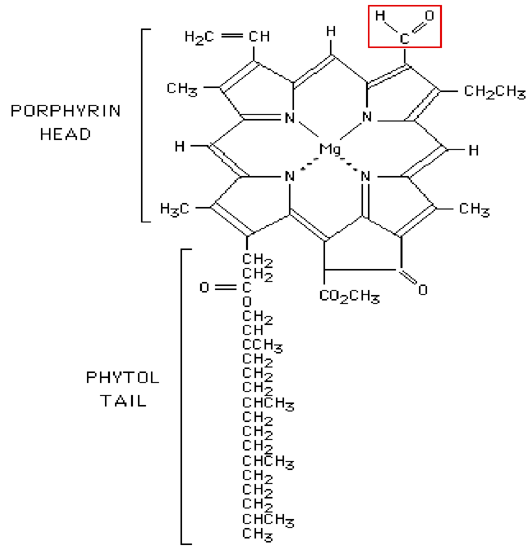
The energy of sunlight is first absorbed by the pigments of the plant. All pigments active in photosynthesis are found in the chloroplast.

Chlorophylls a and **b** are **abundant in green plants**, and **c** and **d** are found in some protists and cyanobacteria. All chlorophylls have a complex **ring structure** that is chemically related to the **porphyrin**-like groups found in **haemoglobin** and **cytochromes**. In addition, a **long hydrocarbon tail** is almost always attached to the ring structure. The ring structure contains some **loosely bound electrons** and is the part of the molecule involved in **electron transitions and redox reactions**.

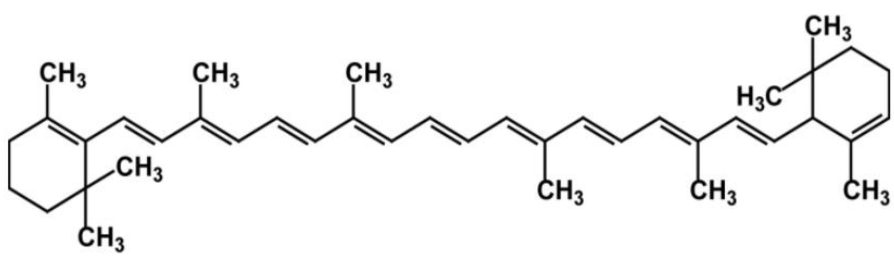
The different types of **carotenoids** found in photosynthetic organisms are all **linear molecules** with **multiple conjugated double bonds**. Absorption bands in the **400** to **500 nm** region give carotenoids their characteristic **orange color**. The color of carrots, for example, is due to the carotenoid β-carotene. Carotenoids are integral constituents of the thylakoid membrane and are usually associated intimately with both antenna and reaction center pigment proteins. The light absorbed by the carotenoids is transferred to chlorophyll for photosynthesis; because of this role they are called accessory pigments.



CHLOROPHYLL *a*



CHLOROPHYLL *b*



Organization of the photosynthetic apparatus

Photosynthesis occurs in **green parts** of the plant, mostly the leaves, sometimes the green stems and floral buds. The leaves contain specialized cells called **mesophyll cells** which contain the chloroplast the pigment containing organelle. These are the actual sites for photosynthesis. The most striking aspect of the structure of the chloroplast is the extensive system of internal membranes known as thylakoids. All the chlorophyll is contained within this membrane system, which is the site of the light reactions of photosynthesis. Two membranes contain and protect the inner parts of the chloroplast. They are appropriately named the **outer** and **inner membranes**. The inner membrane surrounds the **stroma** and the **grana** (stacks of **thylakoids**). One **thylakoid stack** is called a **granum**. The stacks of thylakoid sacs are connected by **stroma lamellae**. The chloroplast also contains its own DNA, RNA, and ribosomes.

What occurs in an oxidation-reduction reaction?

1. **Oxidation**: When an atom or molecule **loses an electron**, it is known as **oxidation**. We say the substance has been **oxidized**.
2. **Reduction:** If an atom or molecule **gains an electron**, it is called **reduction**. We say the substance has been **reduced**.

Hydrogen atoms often tag along with electrons as they are passed. So often a reduced substance will not only gain an electron but a hydrogen atom as well.

The light reaction and Photosystem:

The light reaction is the conversion of light energy into chemical energy in the thylakoid membrane using **photosystems**.

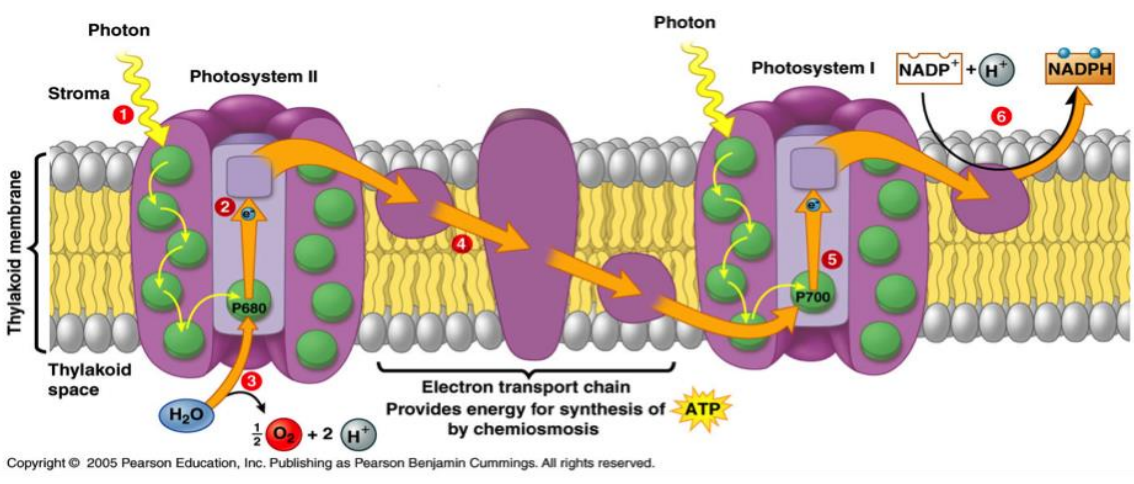
Each photosystem composed of The **COMBINATION** of the **antenna** molecules, **reaction center**, and **primary electron acceptor.**

The pigment molecules (chlorophylls **a** and **b**, and the **carotenoids**) in a leaf are CLUSTERED TOGETHER in assemblies of **200-300 molecules** to form **antenna** to capture light energy. When one of these pigments absorbs a photon of light, an **excited electron** is generated that is passed from **pigment molecule** to pigment molecule until it reaches a special chlorophyll a molecule (the **reaction center**) in the antenna assembly. The reaction center is associated with another molecule called the **primary electron acceptor** that will act as the **FIRST electron-carrier** in an electron-transport chain.

There are actually **TWO** kinds of photosystems in the thylakoid membrane:

1. **Photosystem II**: has a reaction center called P680 (a chlorophyll a molecule that preferentially absorbs light of 680 nm wavelength).
2. **Photosystem I**: has a reaction center called P700 (a chlorophyll a molecule that preferentially absorbs light of 700 nm wavelength).

These two photosystems are LINKED TOGETHER in the light reactions.



The function of the light reactions:

To produce **ATP** and **NADPH** that will be used in the Calvin Cycle ("dark reactions") to drive synthesis of glucose.

1. **Water** is **split** to yield both electrons and hydrogen atoms (H) that will be carried by the "electron shuttle" NADPH. Oxygen (O_2) is produced as water is split.
   PRODUCTS of the light reactions are: ATP, NADPH, and O_2

Electron transport chain in photosynthesis

After receiving light **PSII** absorbs light energy and passes it on to its **reaction center**, **P680**. When **P680 absorbs light**, it is **excited** and its electrons are transferred to an electron acceptor molecule (**Primary electron acceptor** i.e. **pheophytin**) and itself comes to the ground state. However by losing an electron **P680** is **oxidized** and in turn it splits water molecule to release O_2. This **light dependent splitting of water** is called **photolysis.** Thus the oxidized P680 regains its lost electrons from water molecules. The electrons are finally passed onto the reaction center **P700** or **PSI**. During this process, energy is released and stored in the form of ATP.

Similarly, **PSI** also gets **excited** when it absorbs light and **P700** (Reaction center of PSI) gets oxidized as it transfers its electrons to another primary acceptor molecule. While the oxidized **P700 draws** its electrons from **PSII**, the reduced primary acceptors molecule of PSI transfers its electrons via other electron carrier to **NADP** (Nicotinamide Adenine Dinucleotide Phosphate) to produce **$NADPH_2$** a strong reducing agent. Thus we see that there is a continuous flow of electrons from the H_2O molecules to PSII to PSI, and finally to the NADP molecule which is reduced to $NADPH_2$. $NADPH_2$ is then utilized in reduction of CO_2 to carbohydrates in dark reaction (Calvin cycle).