Photosynthesis

The term photosynthesis means “synthesis using light”. The words come from Greek; *photo* meaning “Light” and *synthesis* meaning “putting together”

Photosynthetic organisms use solar energy too synthesize carbon compounds that cannot be formed without the input of energy. More specifically, light energy drives the synthesis of carbohydrates and generation of oxygen from carbon dioxide and water:

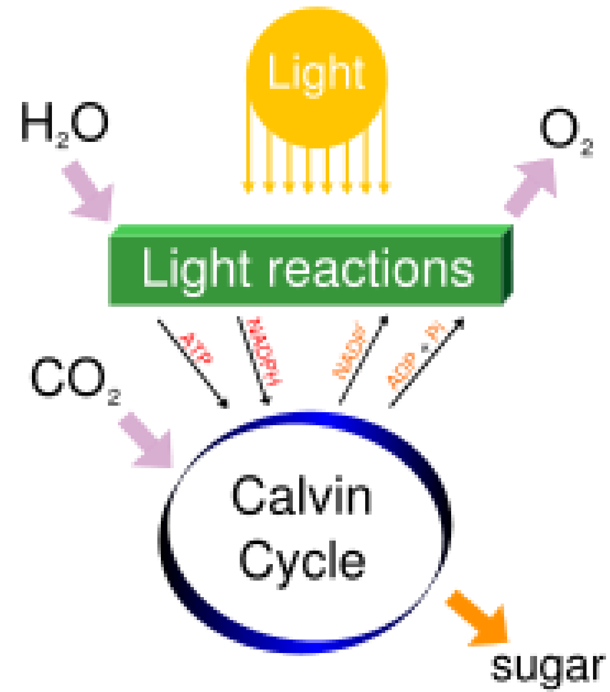
$$6\ CO_2 + 6\ H_2O + \text{photons} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

This process is arguably the most important biochemical pathway since nearly all life on Earth either directly or indirectly depends on it. It is a complex process occurring in higher plants, phytoplankton, algae, as well as bacteria such as cyanobacteria. Photosynthetic organisms are also referred to as *photoautotrophs*.

Photosynthesis occurs in two stages. In the first phase, **light-dependent reactions** or **photosynthetic reactions** (also called the *Light reactions*) capture the energy of light and use it to make high-energy molecules. During the second phase, the **light-independent reactions** (also called the Calvin-Benson Cycle, and formerly known as the *Dark Reactions*) use the high-energy molecules to capture carbon dioxide (CO_2) and make the precursors of carbohydrates.

In higher plants, leaf mesophyll cells are the most active photosynthetic tissue. The mesophyll cells have many chloroplasts, which contain the specialized light-absorbing green pigments, the chlorophylls.

The light reactions take place in the thylakoids of chloroplasts.
The carbon fixation reaction takes place in the stroma of chloroplasts.

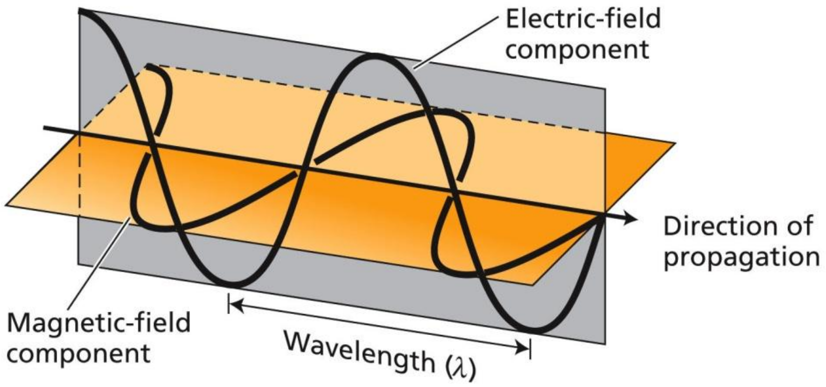


Photosynthesis splits water to liberate O_2 and fixes CO_2 into sugar

Light has properties of both particle and wave

Wave is characterized by a wave-length denoted by λ, which is the distance between two wave crests

The frequency (ν) is the number of wave crests that pass an observer in a given time



Light is a transverse electromagnetic wave

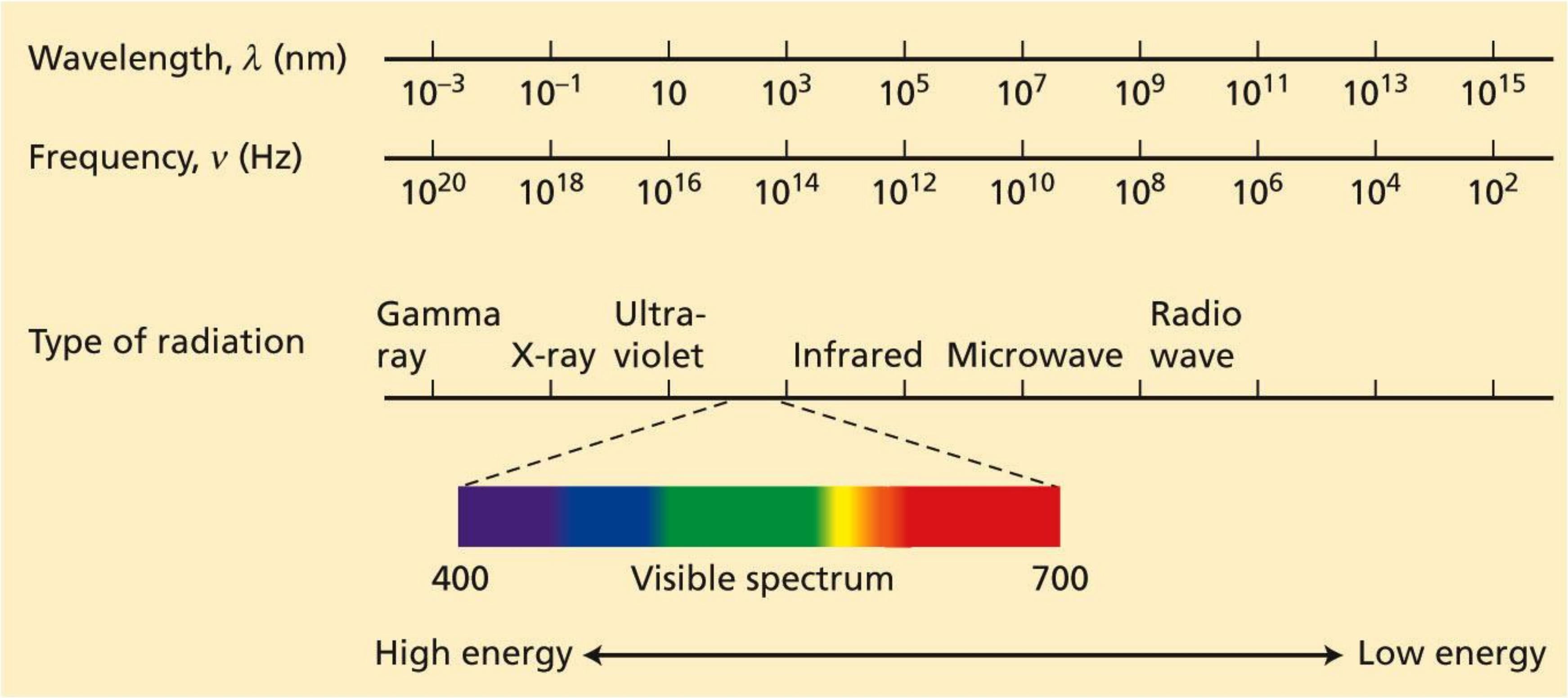
The speed of any wave can be calculated by the following equation:

$$c=\lambda\nu$$

Light is also a particle, which we call a photon. Each photon contains an amount of energy which is called a quantum. The energy (*E*) of a photon depends on the frequency of the light according to an equation known as Planck's law:

$$E=h\nu$$

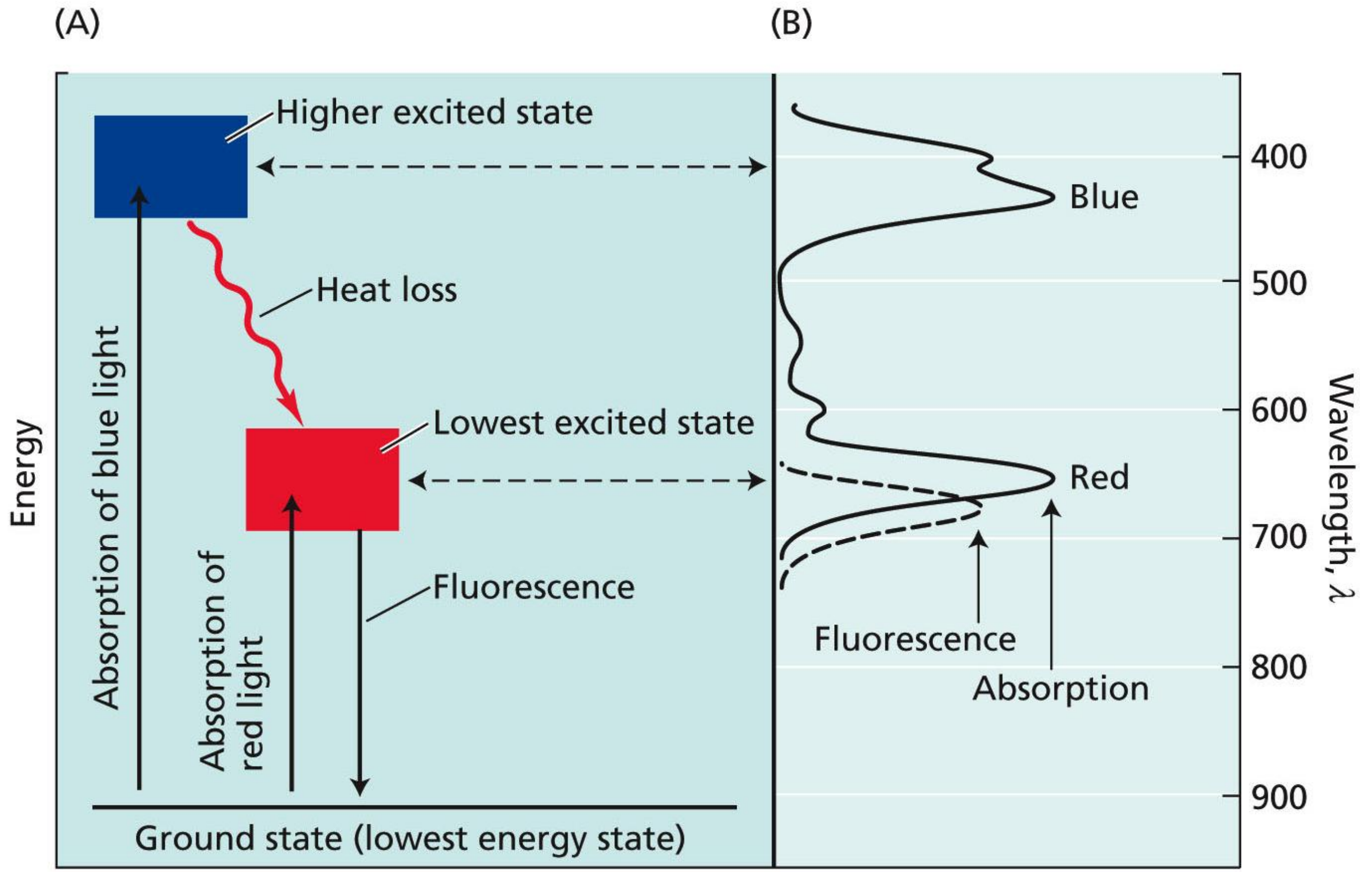
Electromagnetic spectrum



PLANT PHYSIOLOGY, Fourth Edition, Figure 7.2

Chlorophylls absorb light mainly in red and blue parts of the spectrum. Once it absorbs light it change its energy state.

Chl + hν ⟶ *Chl* *



PLANT PHYSIOLOGY, Fourth Edition, Figure 7.5

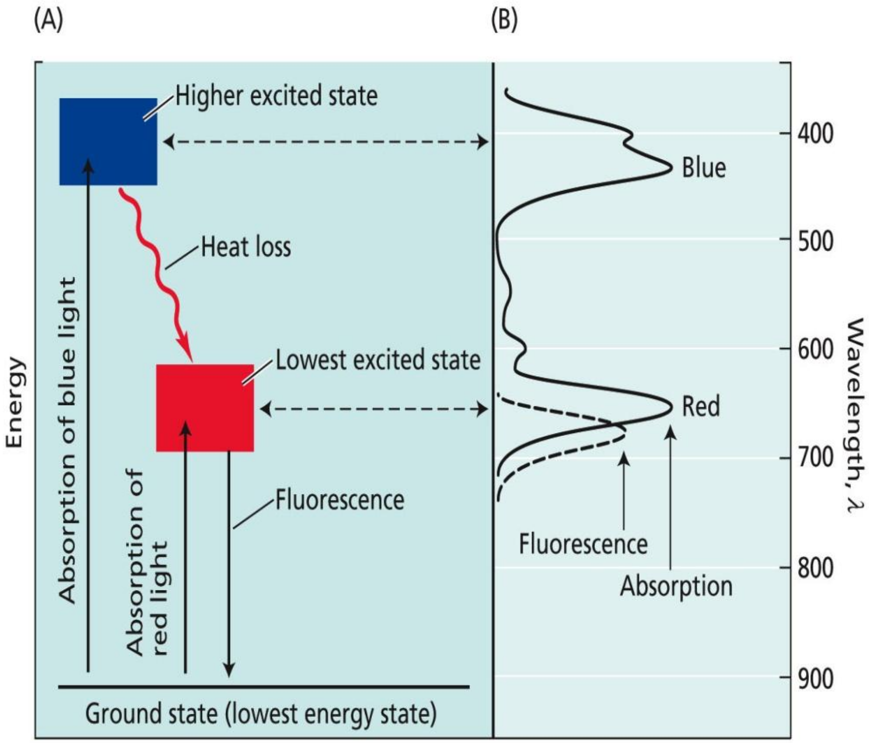
Four processes can happen while the chlorophyll return to its ground state from excited state

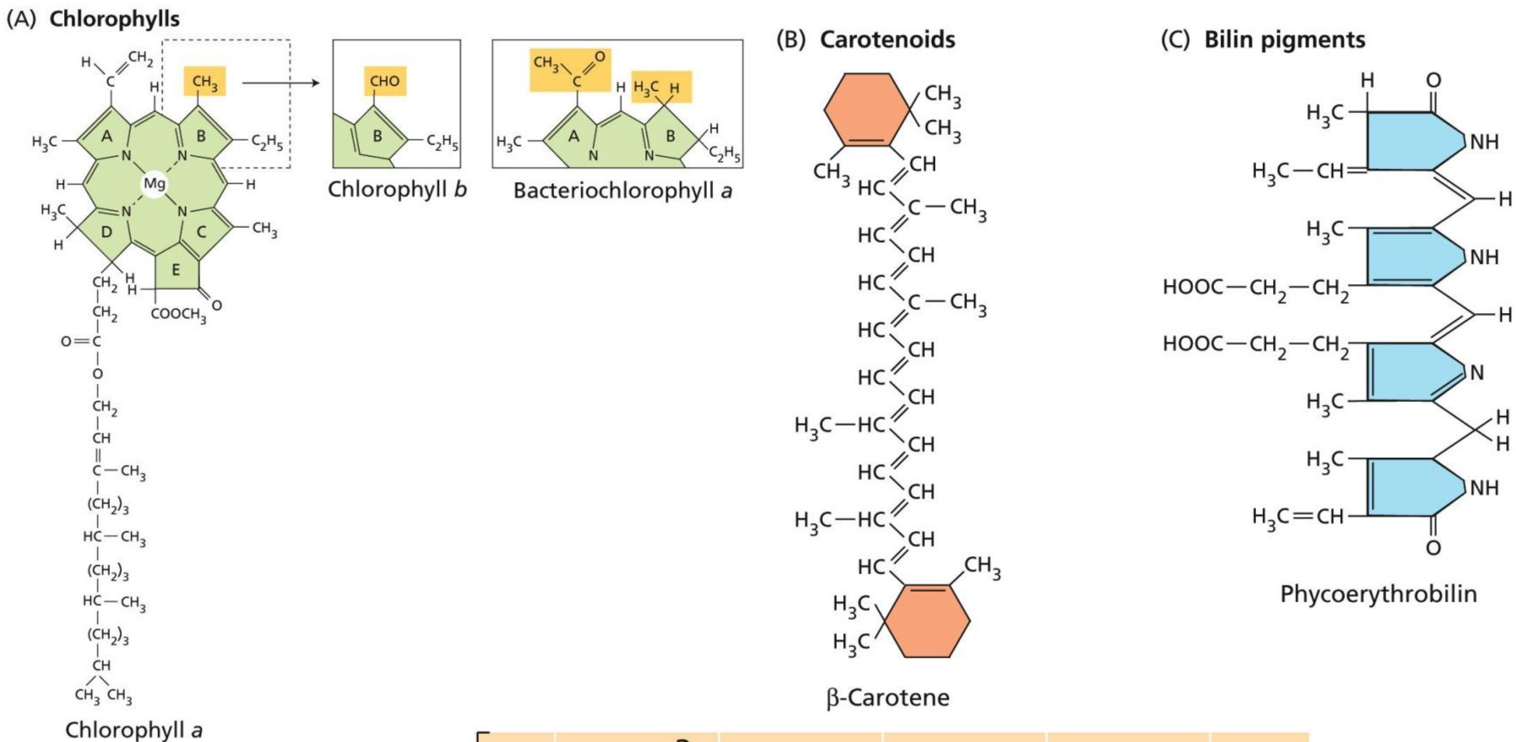
1. Excited chlorophyll can re-emit a photon and thereby return to its ground state, a process known as fluorescence.

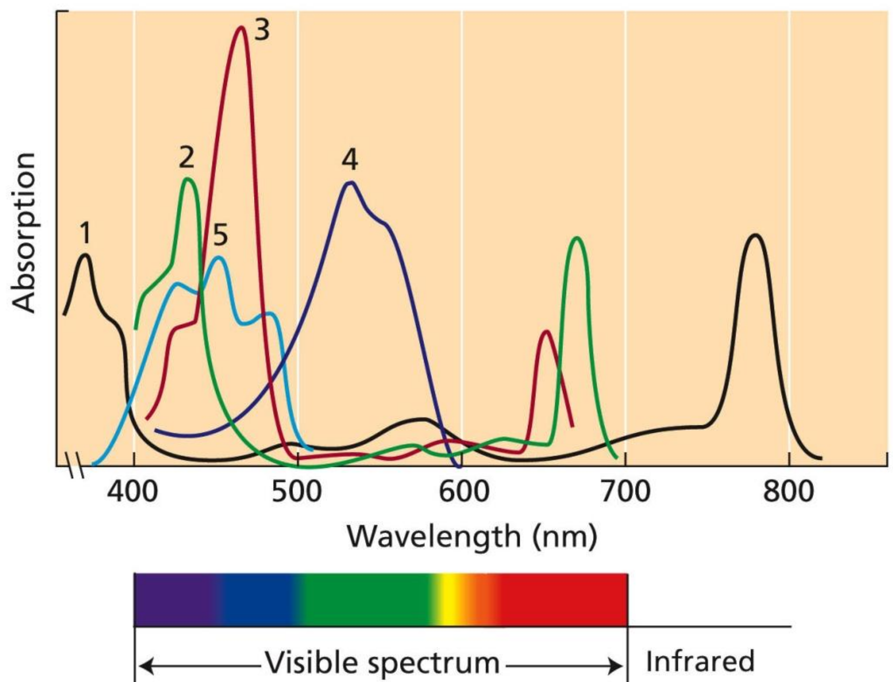
2. The excited chlorophyll can return to its ground state by directly converting its excitation energy into heat, without emitting a photon.

3. Chlorophyll may participate in energy transfer, during which an excited chlorophyll transfers its energy to another molecule.

4. The fourth process is called phytochemistry, in which the energy of the excited state causes chemical reactions too occur.



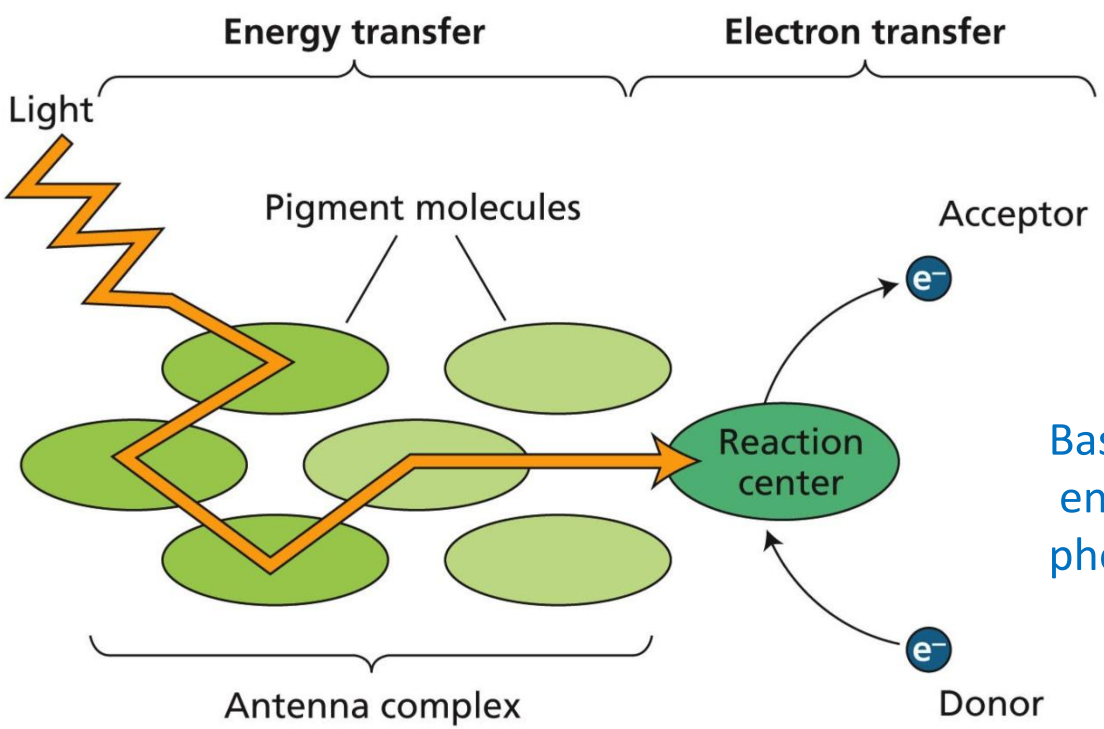




The absorption spectra of photosynthetic pigments

A portion of light energy absorbed by chlorophylls and carotenoids is eventually stored as chemical energy. This conversion from one form to another is a complex process and depends on the cooperation between many pigment molecules and a group of electron transfer protein

The majority of the pigments serve as an antenna complex, collecting lights and transferring the energy to the reaction center complex where the chemical oxidation and reduction reactions leading to long-term energy storage



Basic concept of energy transfer during photosynthesis

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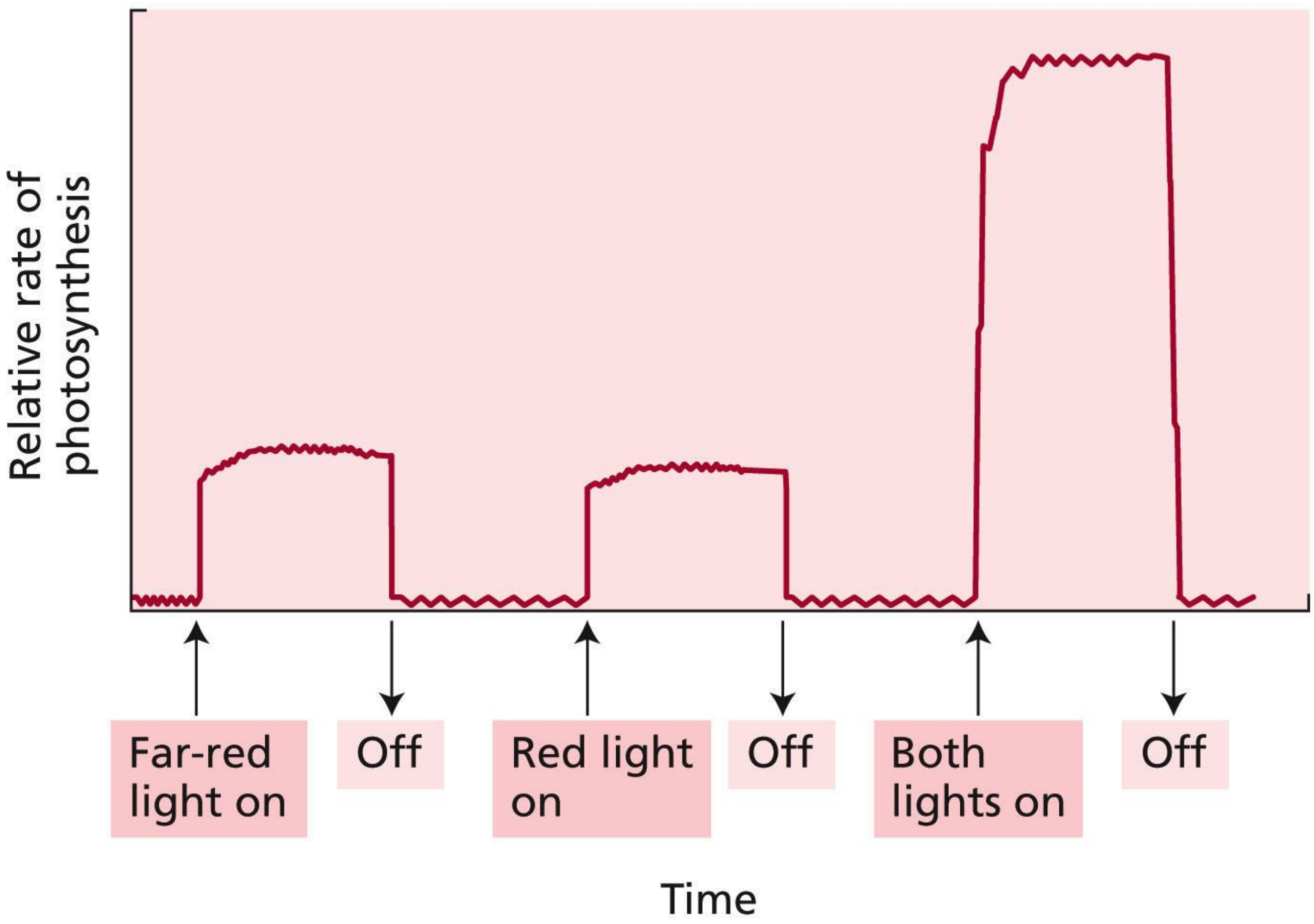
Discovery of two photosystems in oxygen evolving organisms



Enhancement effect

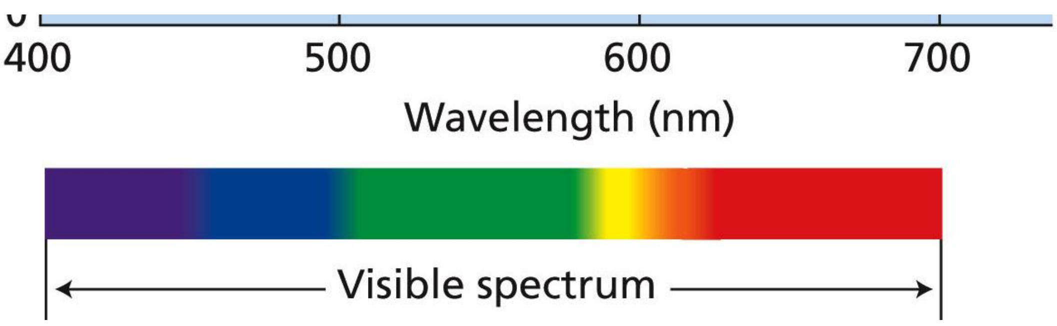
The **Photosystem I** (**PS-I**), absorbs preferentially far-red light of wavelengths greater than 680 nm

The **photosystem II** (**PS-II**), absorbs red light of 680 nm well and is driven very poorly by far-red light.

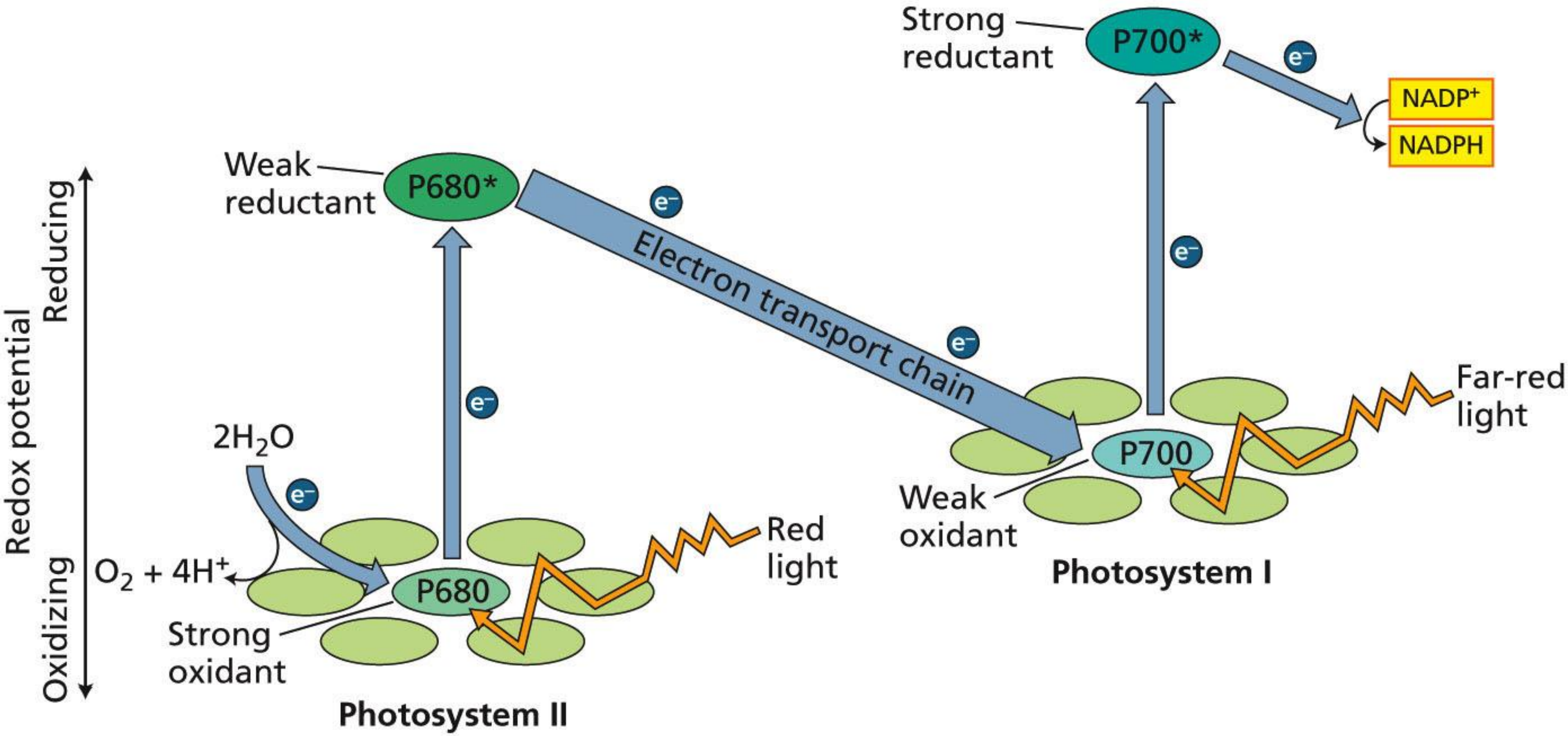
This wavelength dependence explains the enhancement effect. PSI and PSII operate in series to carry out the early energy storage reactions of photosynthesis

Photosystem I produces a strong reductant, capable of reducing $NADP^+$, and a weak oxidant.

Photosystem II produces a very strong oxidant, capable of oxidizing water, and a weaker reductant than the one produced by photosystem I.



Z scheme of photosynthesis

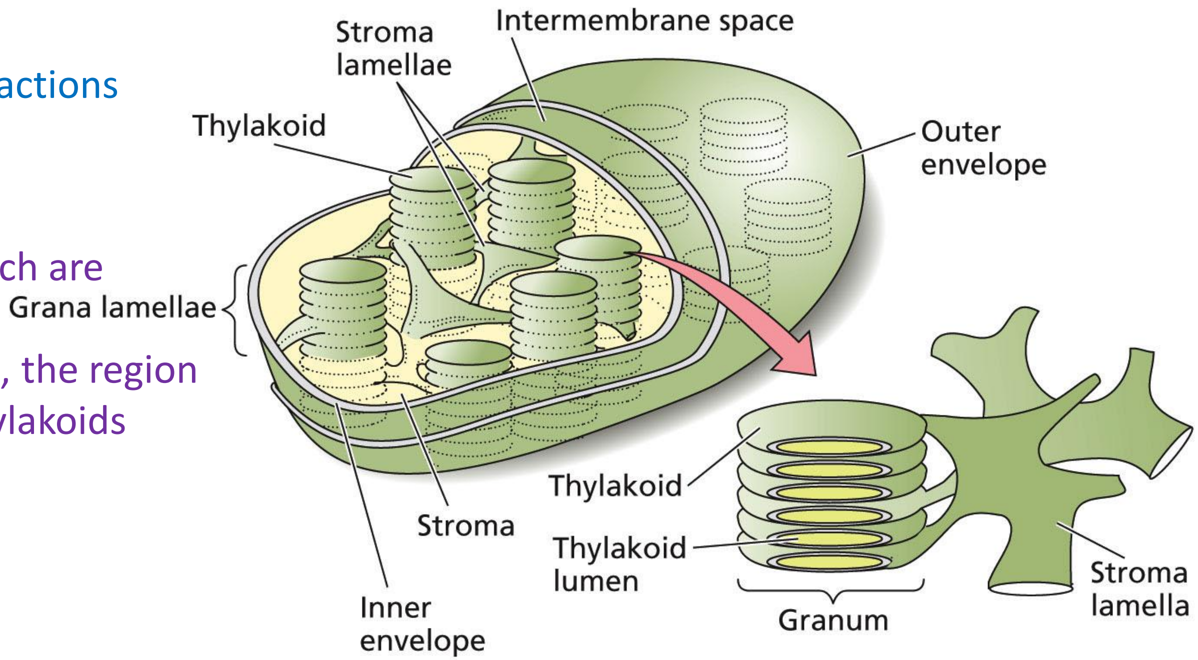


Chloroplast is the site of photosynthesis

All the chlorophyll is contained
Within the thylakoid membrane system.

Thylakoid is the site of the light reactions of photosynthesis

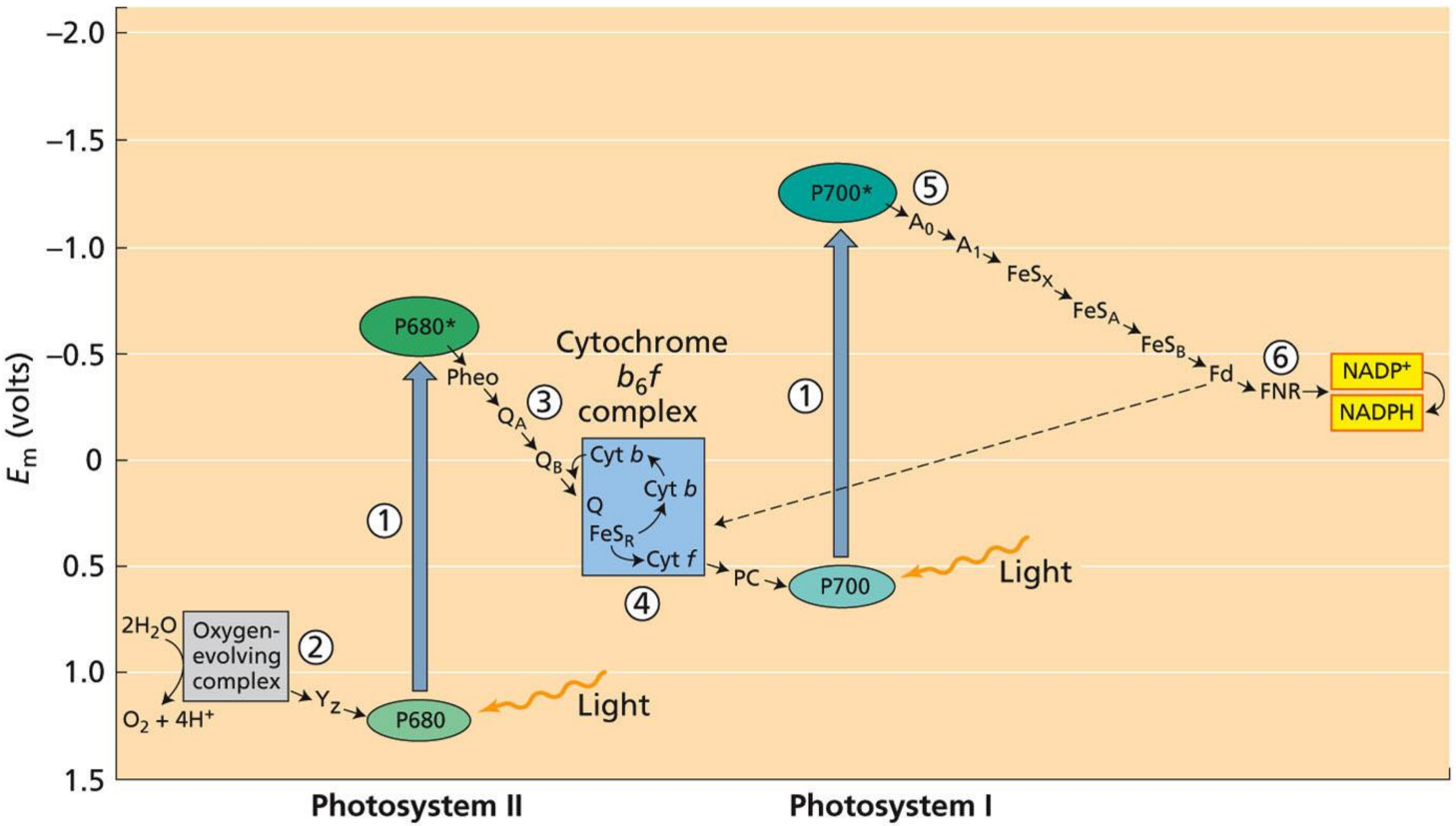
The carbon fixation reactions, which are catalyzed by water-soluble enzymes, take place in the stroma, the region of the chloroplasts outside the thylakoids



The photosystems I and II are spatially separated in the thylakoid membrane. The PSII reaction center. aong with its antenna chlorophylls and associated electron transport proteins, is located predominantly in the grana lamellae.
The PSI and its associated antenna and electro transport proteins are found almost exclusively in the stroma lamella and at the edges of grana lamella

Reaction mechanism of Photosynthesis

Almost all the chemical processes that make up the light reactions of photosynthesis are carried out by four major protein complexes: photosystem II, cytochrome b_6f complex, photosystem I, and the ATP synthase. These four integral membrane complexes are vectorially oriented in the thylakoid membrane.



Steps in photosynthesis:

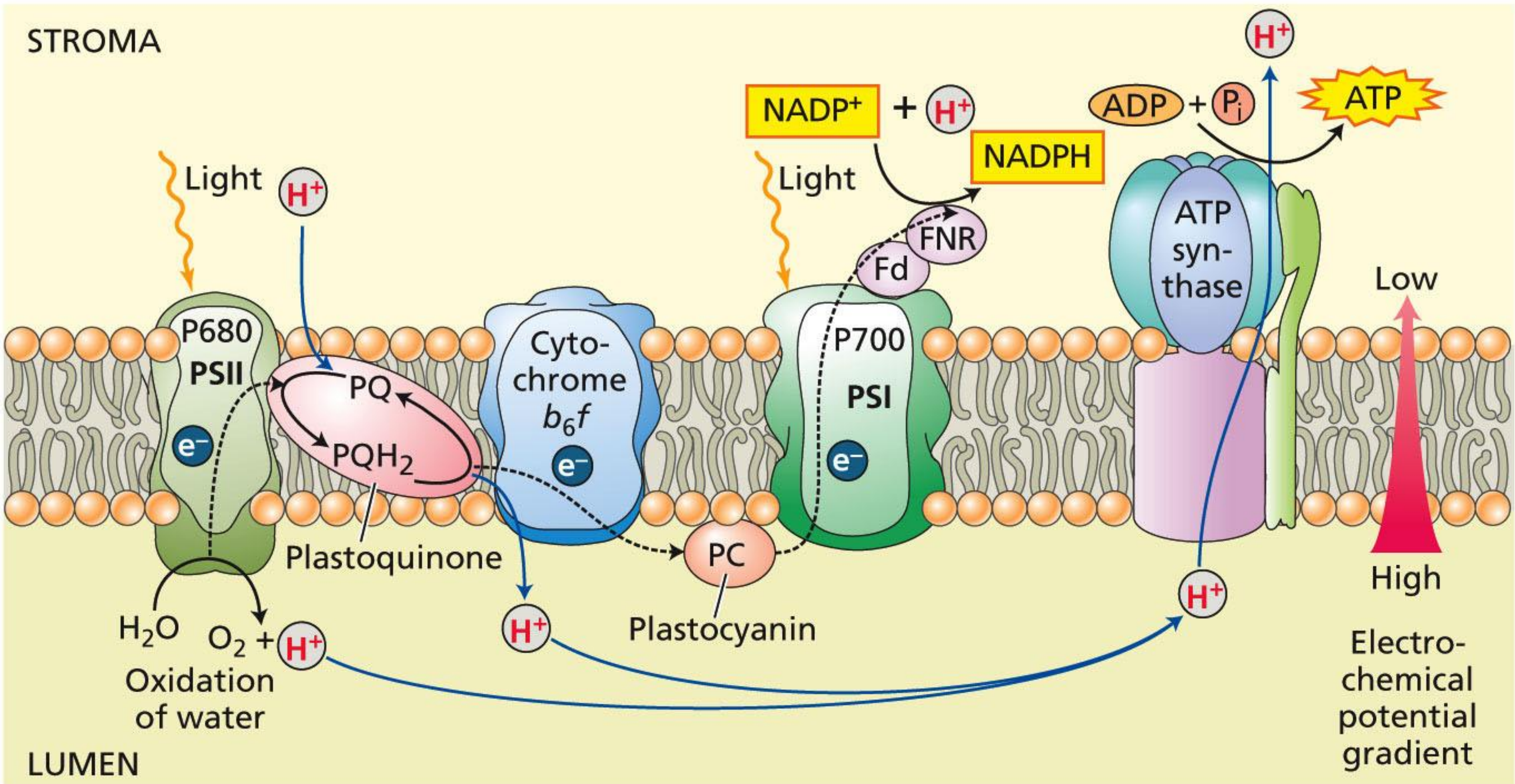
- Photons excite the specialized chlorophyll of the reaction centers, (P680 for PSII,, and P700 for PSI) and an electron is ejected. The electron then passes through a series of electron carriers and eventually reduces P700 or $NADP^+$.

- PSII oxidizes water to O_2 in the thylakoid lumen and in the process releases protons into the lumen

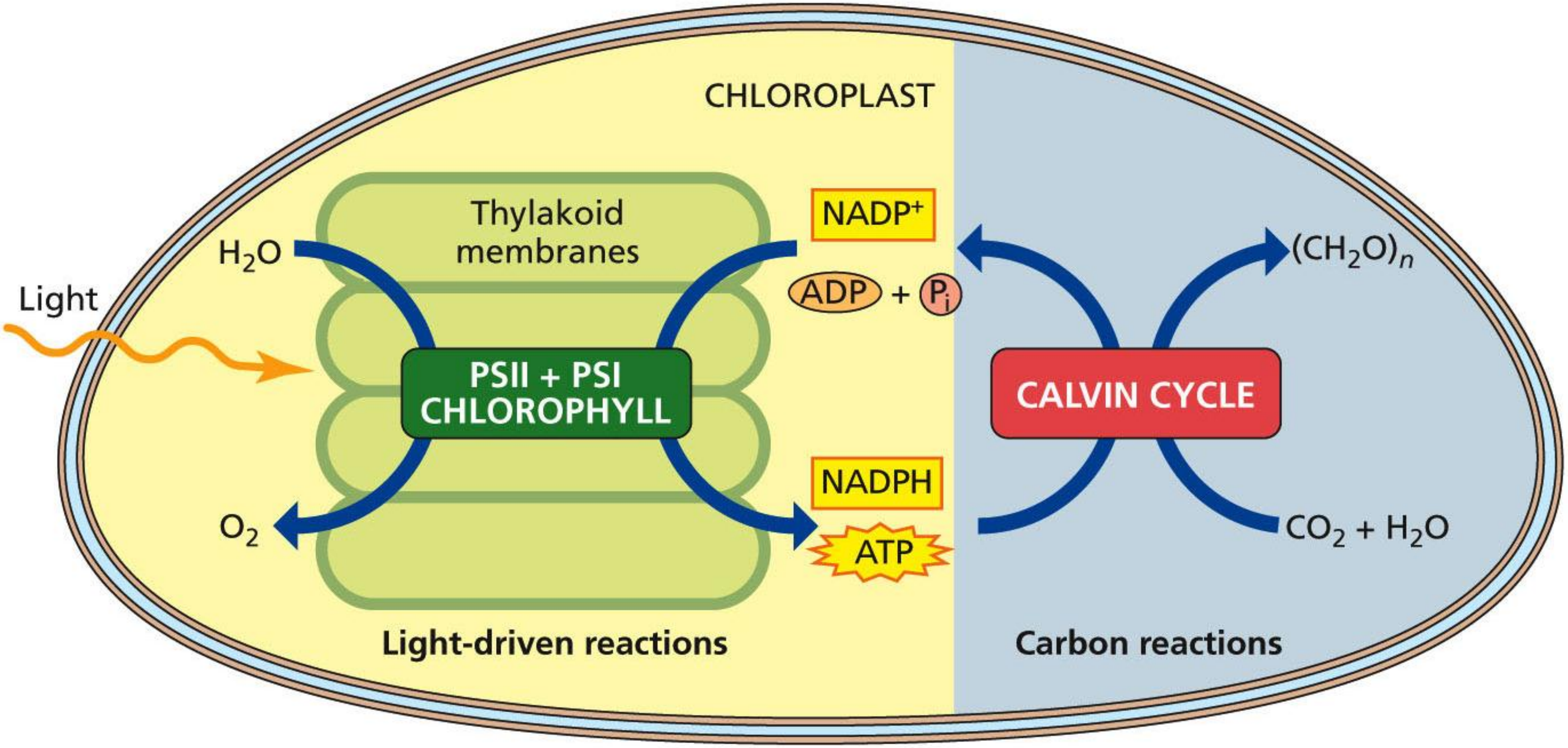
- Cytochrome b_6f oxidizes plastohydroquinone molecules that were reduced by PSII and delivers electrons to PSI

- PSI reduces NADP+ to NADPH in the stroma by the action of ferridoxin (Fd) and the flavoprotein ferredoxin-NADP reductase (FNR)

- ATP synthase produces ATP as protons diffuse back through it from the lumen into the stroma


STROMA
Light
H+
P680
PSII
e−
PQ
PQH2
Plastoquinone
H2O
O2 + H+
Oxidation of water
Cyto-chrome b6f
e−
H+
PC
Plastocyanin
Light
NADP+ + H+
NADPH
FNR
Fd
P700
PSI
e−
H+
ADP + Pi
ATP
ATP syn-thase
H+
Low
High
Electro-chemical potential gradient
LUMEN

Carbon Fixation



The most important pathway that contributes in CO_2 fixation is called Calvin cycle. This pathway is present in many prokaryotes and all photosynthetic eukaryotes, from the most primitive to the most advanced angiosperms.

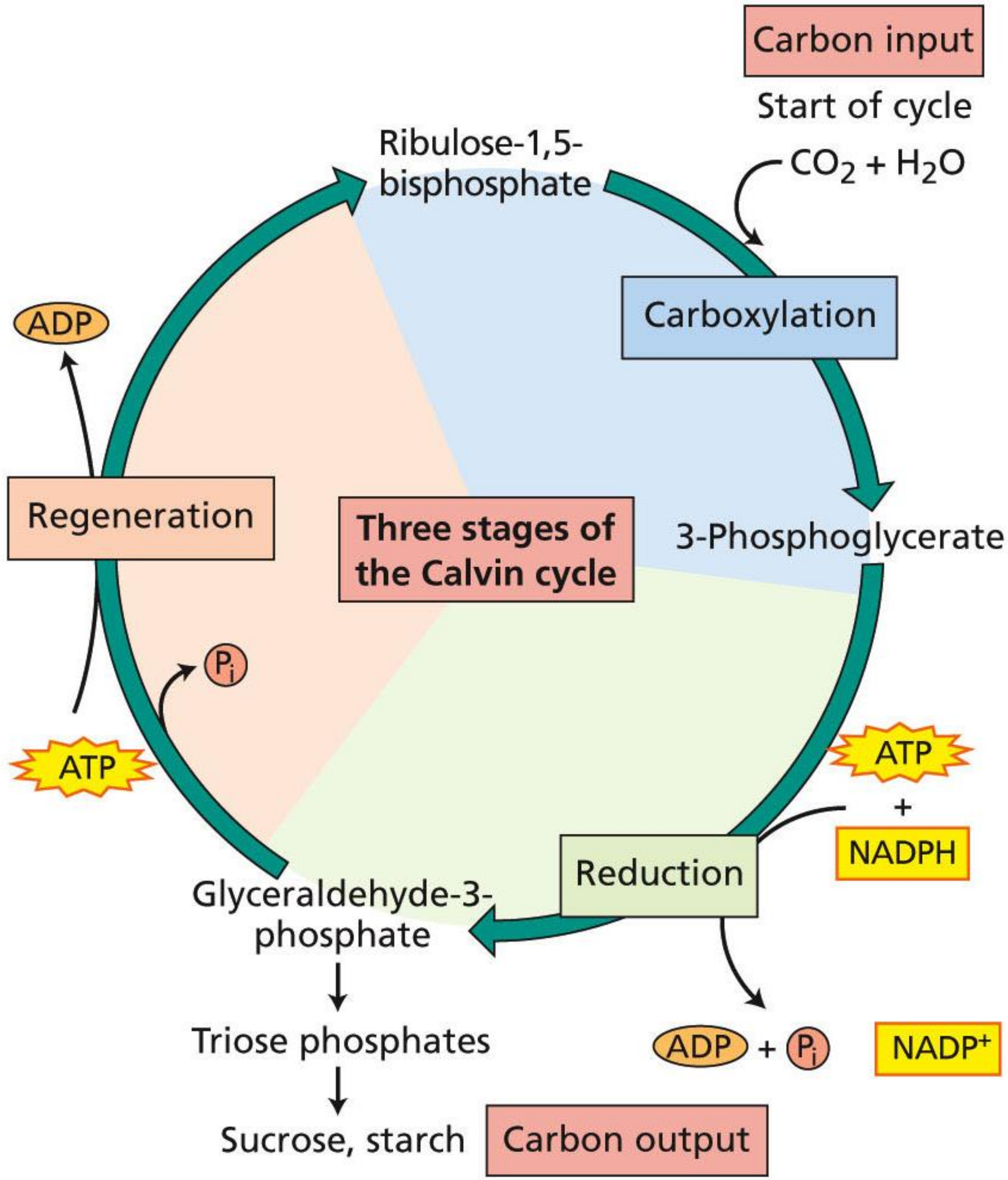
The Calvin cycle was elucidated by a series of elegant experiments by M Calvin, A. Benson, J.A. Bassham, and colleagues in the 1950s. In 1961, Calvin received Nobel prize for this work.

Calvin Cycle proceeds in three stages:

1. Carboxylation of the CO_2 acceptor ribulose-1,5-bisphosphate, which forms two molecules of 3-phoshphoglycerate, the first stable intermediate of the Calvin cycle.

2. Reduction of 3-phosphoglycerate,, which yields glyceraldehyde-3-phosphate, a carbohydrate

3. Regeneration of the CO_2 acceptor ribulose-1,5-bisphosphate from glyceraldehyde-3-phosphate


Carbon input
Start of cycle
$CO_2 + H_2O$
Ribulose-1,5-bisphosphate
Carboxylation
3-Phosphoglycerate
ATP
+
NADPH
Reduction
ADP + P_i
$NADP^+$
Glyceraldehyde-3-phosphate
Triose phosphates
Sucrose, starch
Carbon output
Three stages of the Calvin cycle
Regeneration
ADP
ATP
P_i