Photosynthesis

(The Light Reaction)

CC-12
UNIT-2

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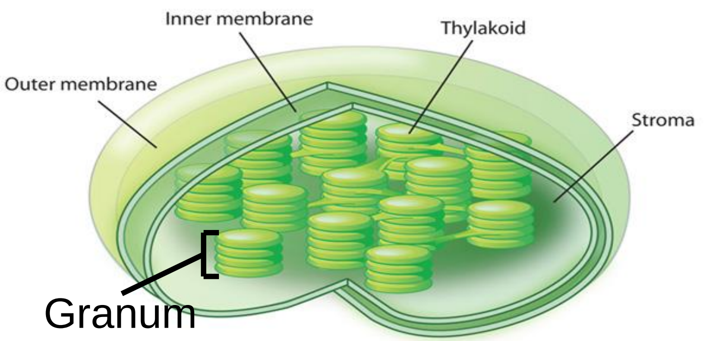
Photosynthesis-An Overview

The net overall equation for photosynthesis is:

$6CO_2 + 6H_20$ + light $C_6H_{12}0_6 + 0_2$

Photosynthesis occurs in 2 "stages":

1. **The Light Reactions (or Light-Dependent Reactions)**
2. **The Calvin Cycle (or Calvin-Benson Cycle or Dark Reactions or Light-Independent Reactions)**



Definition

Process whereby light energy from the Sun is transformed into chemical energy, and used to synthesise larger (complex) organic molecules from inorganic substances

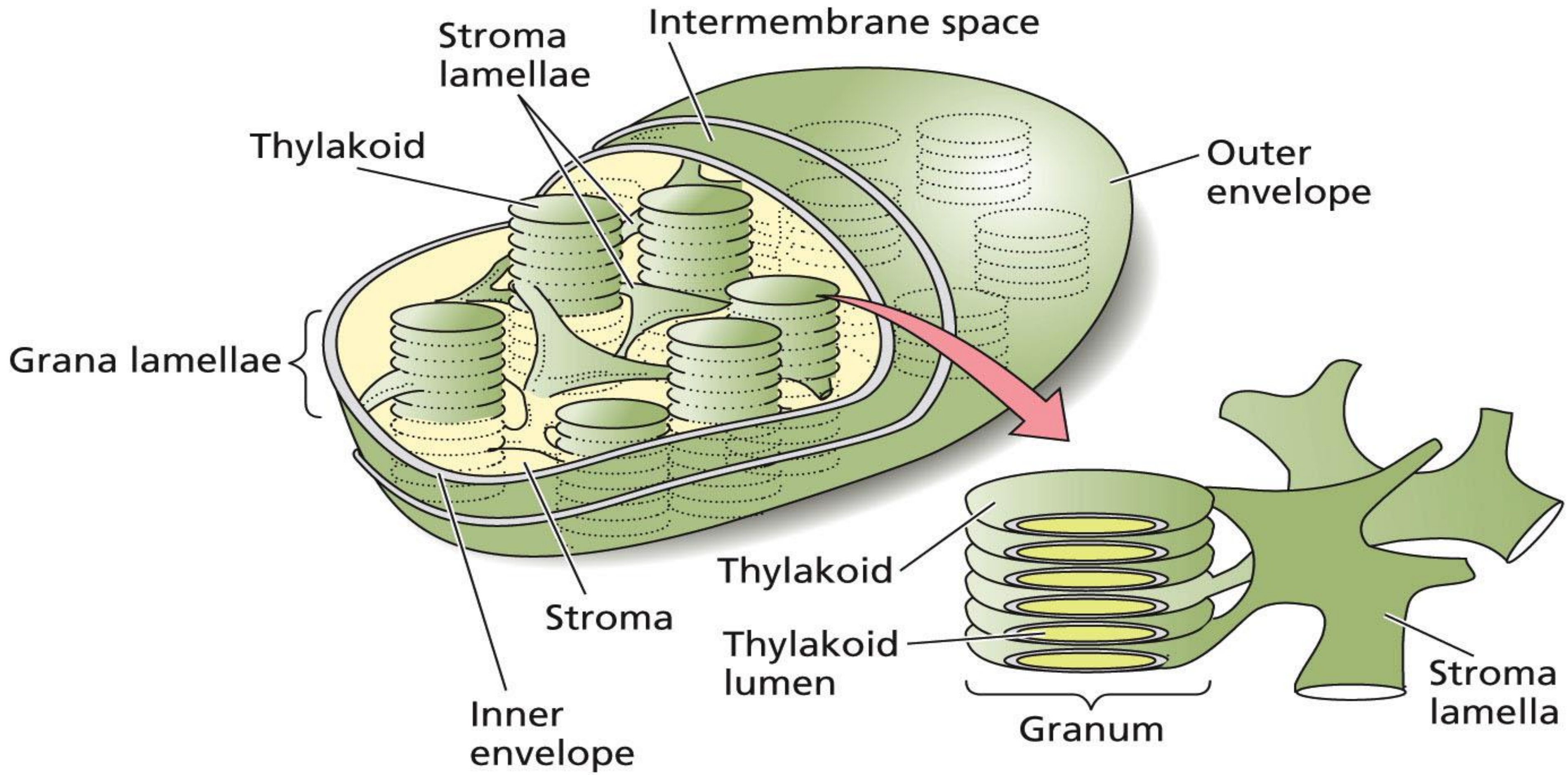
Forms the basis of most food chains.

Chemical equation (overall - simplified)

$$6H_2O + 6CO_2 \xrightarrow[\text{Chlorophyll}]{\text{Light energy}} C_6H_{12}O_6 + 6O_2$$

Glucose

Chloroplast



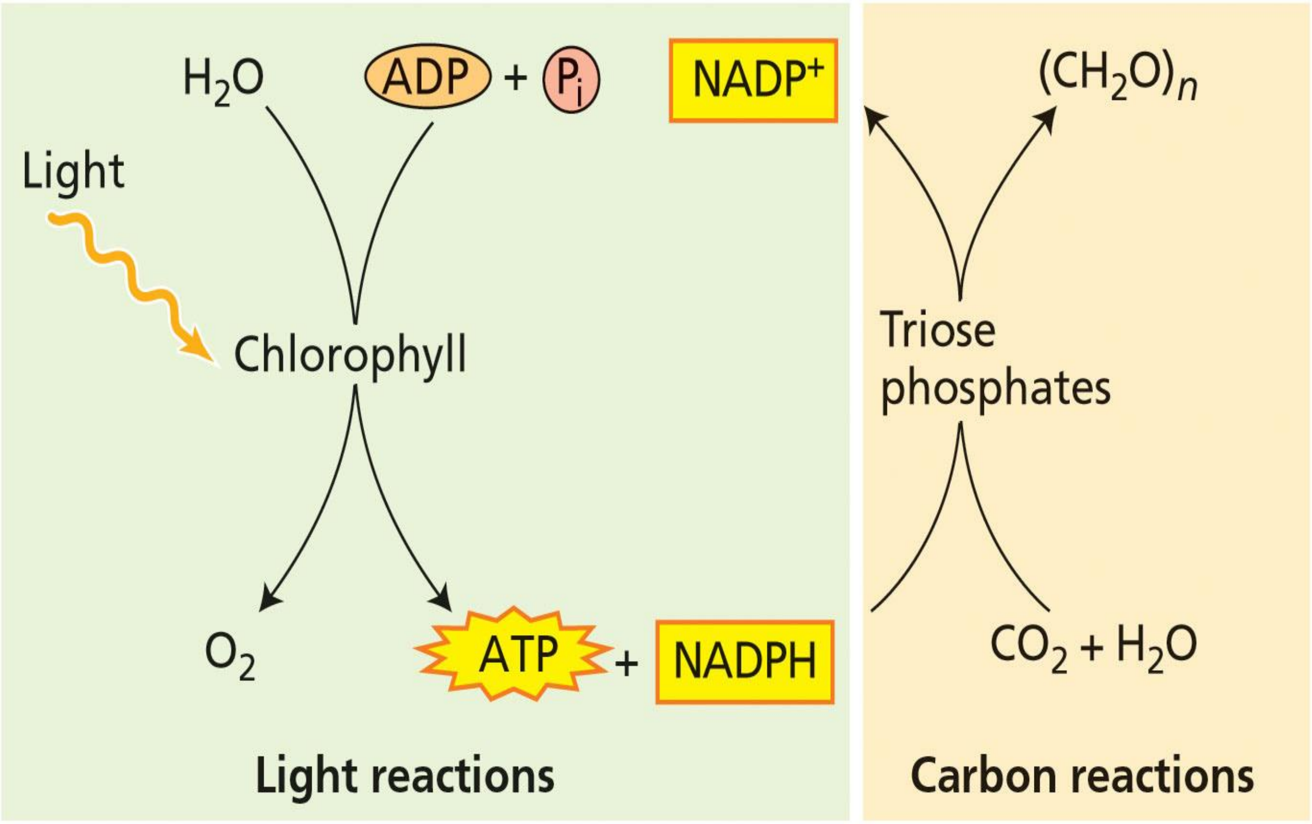
Oxidation & reduction in photosynthesis

- When compounds are oxidised **energy** is released.
- If this release of energy is **COUPLED** to biological reactions then **WORK** can be done.
- Similarly when compounds are reduced energy has to be put into the system.
- In photosynthesis the source of electrons for reducing $CO_2 \rightarrow CH_2O$ is **water**.
- The source of energy is **light**.

Photosynthesis

Photosynthesis is divided into 2 stages-

Light Energy oxidizes H_2O



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Reductant & Energy are used to reduce CO_2

Stroma lamellae
Unstacked membrane

Thylakoid

Grana lamellae
Stacked membranes

Light reaction
occur here

Carbon
reduction
reaction occur
here

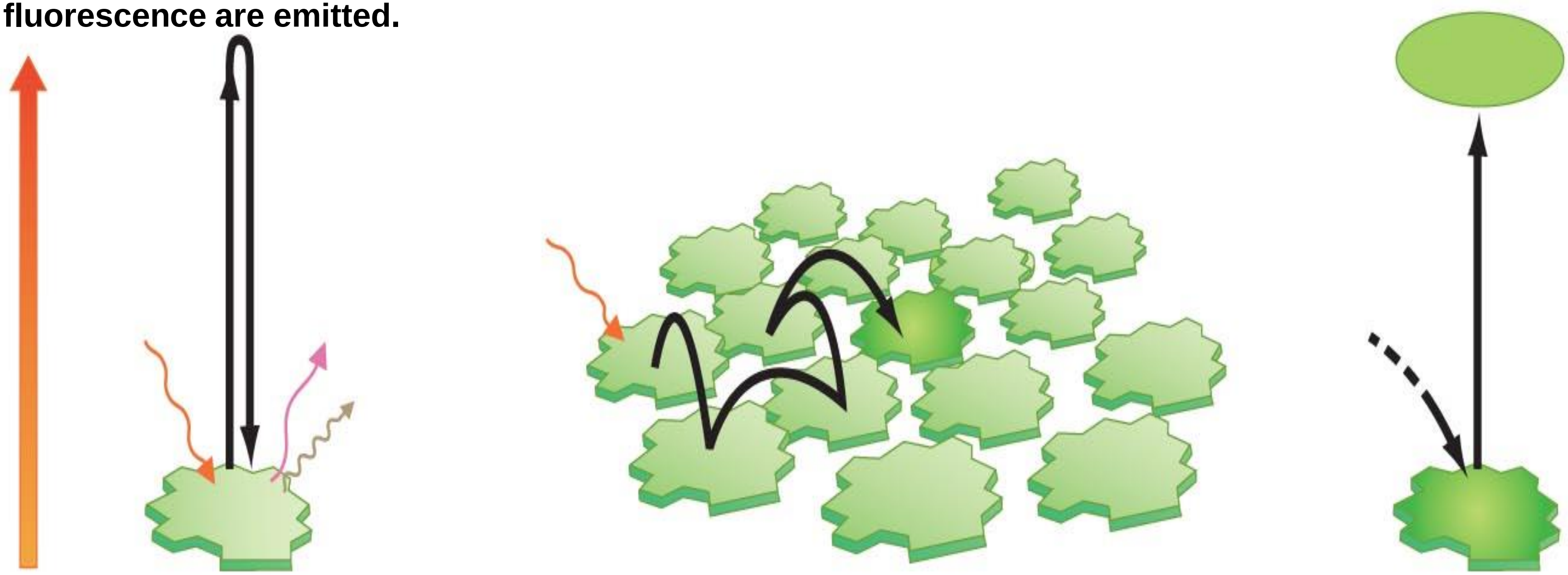
Stroma

The Fate of Excited Energy

FLUORESCENCE
Electron drops back down to lower energy level; heat and fluorescence are emitted.

RESONANCE
Energy in electron is transferred to nearby pigment.

REDUCTION/OXIDATION
Electron is transferred to a new compound.



The energy of the excited state causes chemical reactions to occur. The photochemical reactions of photosynthesis are among the fastest known chemical reactions. This extreme speed is necessary for photochemistry to compete with the other possible reactions of the excited state.

Pigments

Pigments are molecules that absorb light energy.

Different pigments absorb light of different wavelengths.

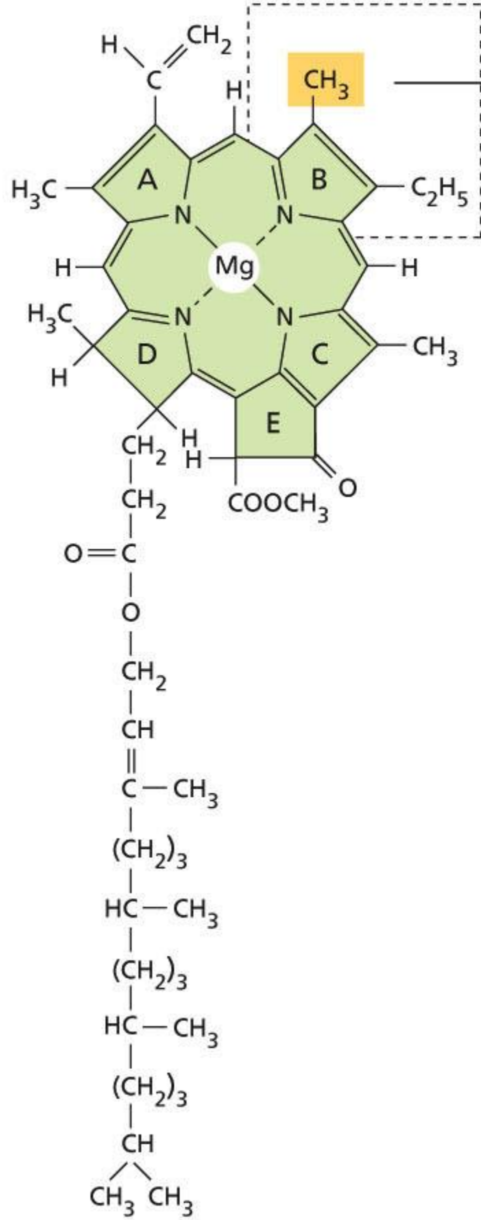
Major photosynthetic pigments:

- **Chlorophyll A**
- **Chlorophyll B**
- **Carotenoids**
  - **Xanthophyll**
  - **Carotenes**

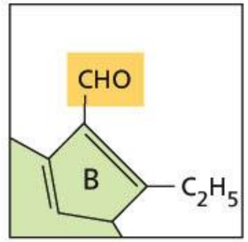
Table 11.1. Distribution of Photosynthetic Pigments in Plant Kingdom.

Pigment	Distribution in Plant Kingdom
(1) Chlorophylls Chlorophyll-a	All photosynthesizing plants except bacteria.
Chlorophyll-b	Higher plants and green algae
Chlorophyll-c	Diatoms, dinoflagellates and brown algae
Chlorophyll-d	In some red algae
Chlorophyll-e	In *Tribonema* and zoospores of *Vaucheria*
Bacteriochlorophyll-a	Purple and green bacteria
Bacteriochlorophyll-b	In a strain of purple bacterium *Rhodopseudomonas*
Bacteriochlorophyll-c, d & e (Chlorobium chlorophyll or Bacterioviridin)	Green bacteria
Bacteriochlorophyll-g	Heliobacteria
(2) Carotenoids* Carotenes	Mostly in algae and higher plants
Xanthophylls (Carotenols)	Mostly in algae and higher plants
(3) Phycobillins Phycoerythrins	In blue-green and red algae
Phycocyanins	In blue-green and red algae
Allophycocyanin	In blue-green and red algae

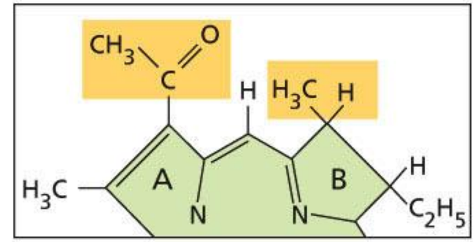
(A) Chlorophylls



Chlorophyll *a*

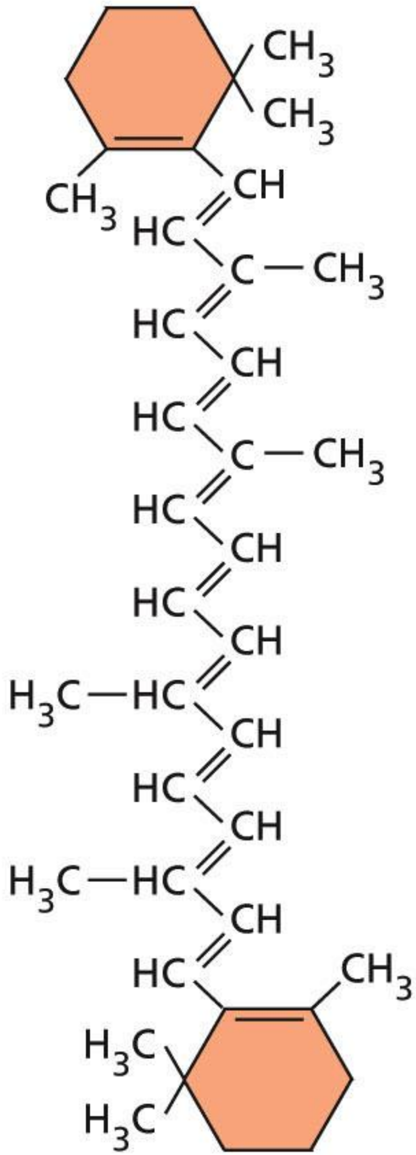


Chlorophyll *b*



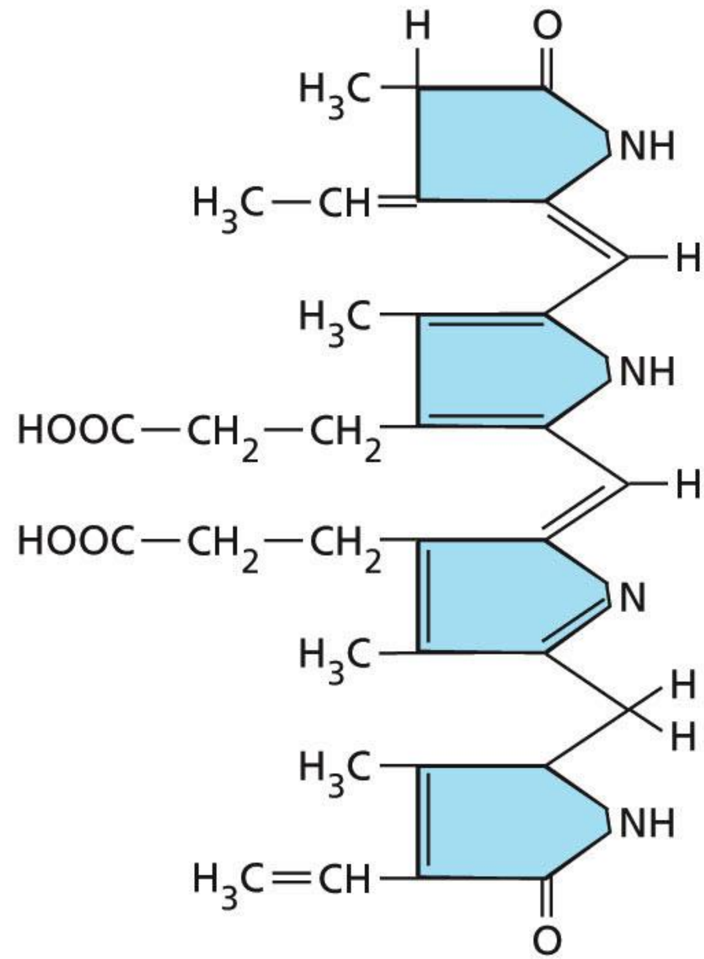
Bacteriochlorophyll *a*

(B) Carotenoids



β-Carotene

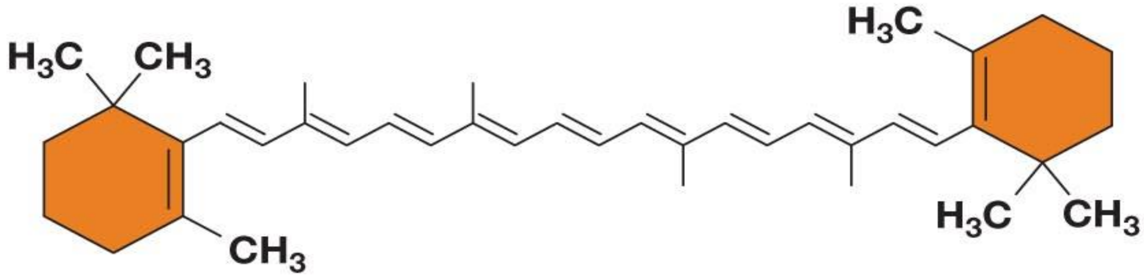
(C) Bilin pigments



Phycoerythrobilin

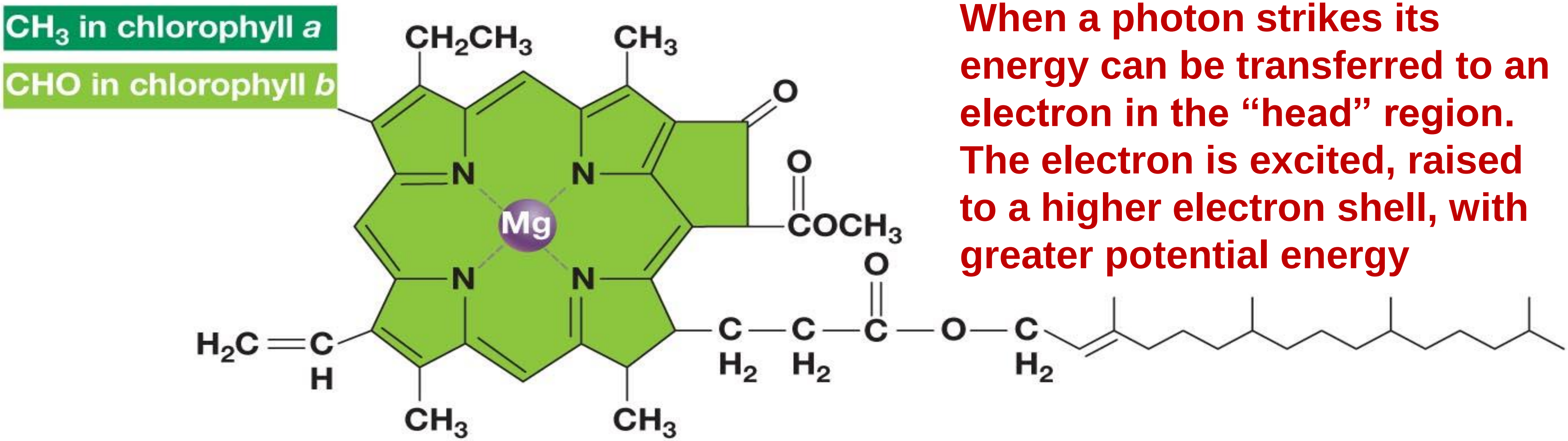
Chlorophyll is the most abundant pigment in the chloroplast. All eukaryotic photosynthetic organisms contain both chlorophyll *a* and chlorophyll *b.*

(a)



Carotenoids transfer energy from photons to chlorophyll. They also can quench free radicals by accepting or stabilizing unpaired electrons and so protect chlorophyll molecules

(b)

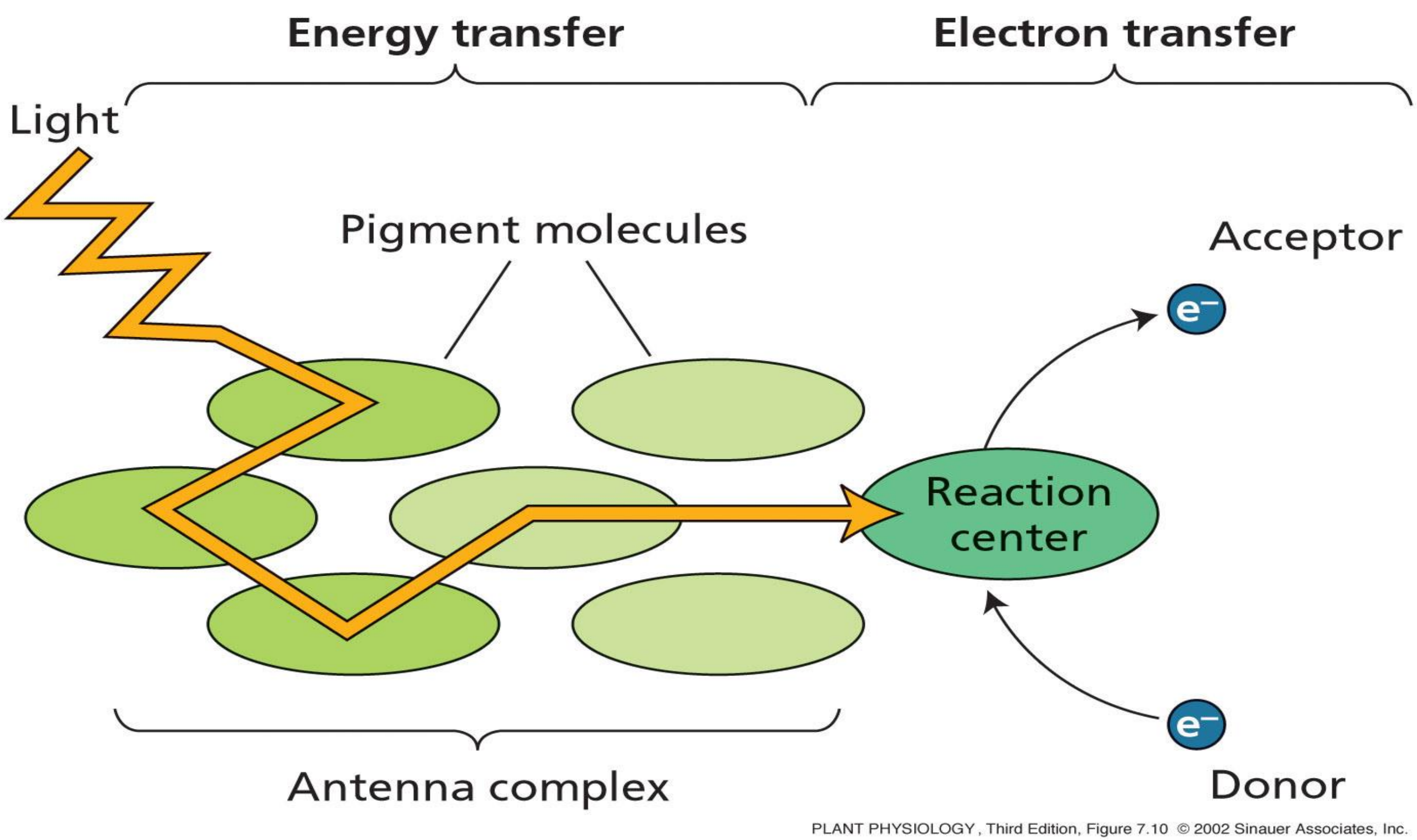


When a photon strikes its energy can be transferred to an electron in the "head" region. The electron is excited, raised to a higher electron shell, with greater potential energy

Photosynthesis - light

Pigments (chlorophylls and carotenoids) exist in antenna complexes

- Harvest and transfer light energy to chlorophylls at the reaction centre .
- energy is transferred from pigment to pigment by resonance transfer.
- At the reaction centre energy is converted to chemical (redox) energy.



Antennal pigment/ reaction centre complexes are also referred to as photosystems

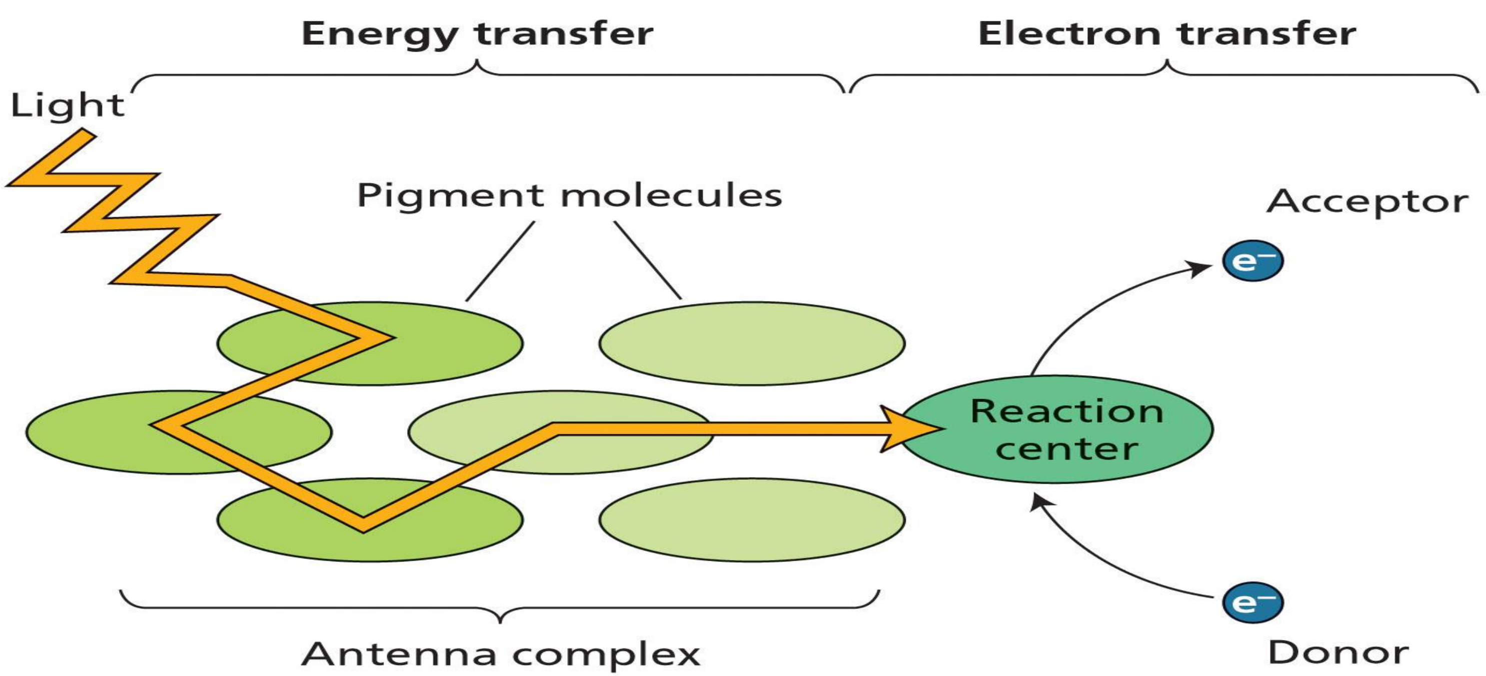
There are 2 photosystems-

- **PSI**
- **PSII**

Light strikes the antenna complex and it is channelled towards the **reaction centre**

The **electrons** are excited by the light energy in the reaction centre

The electrons are picked up by **electron acceptors**



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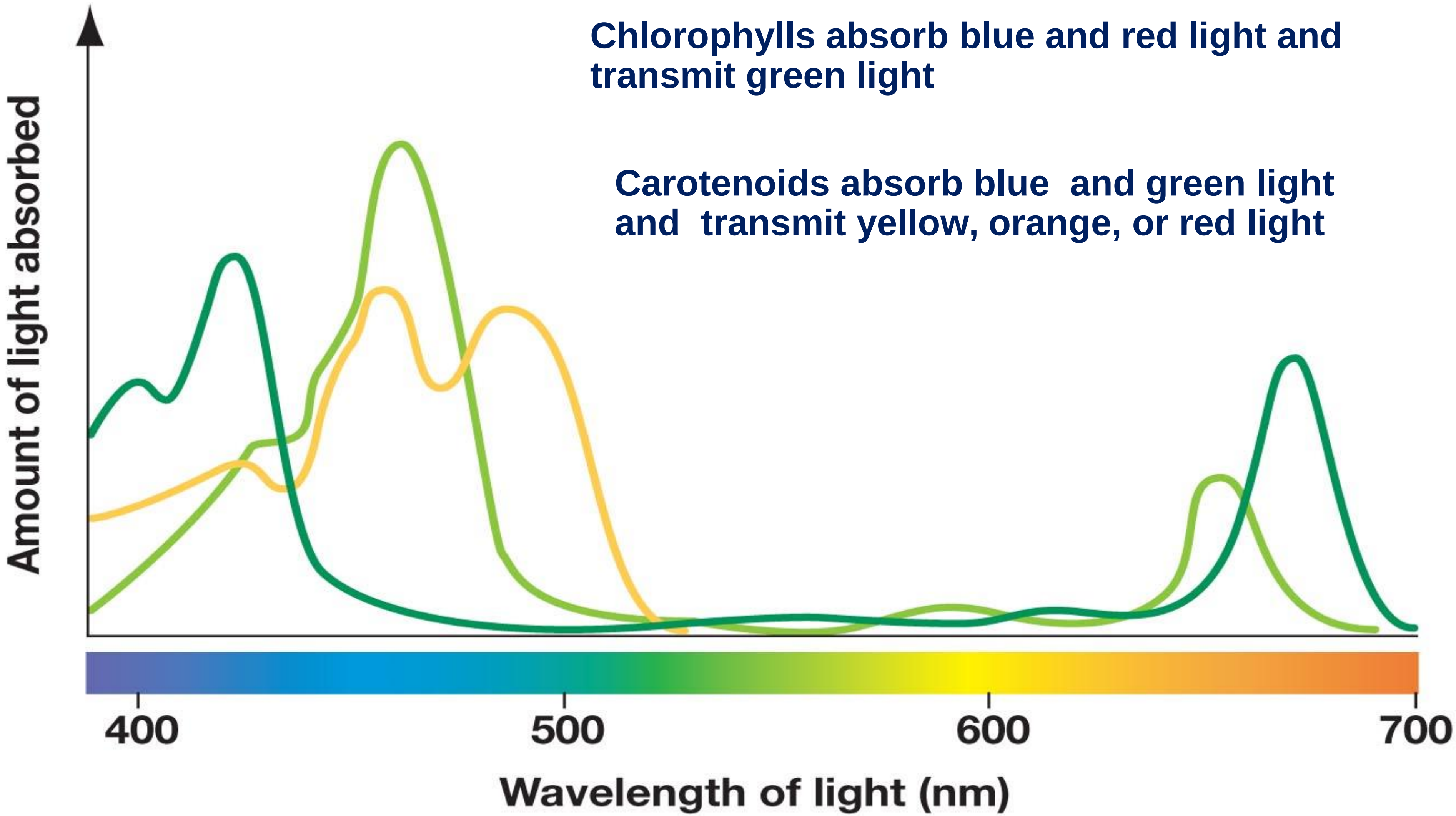
(a)

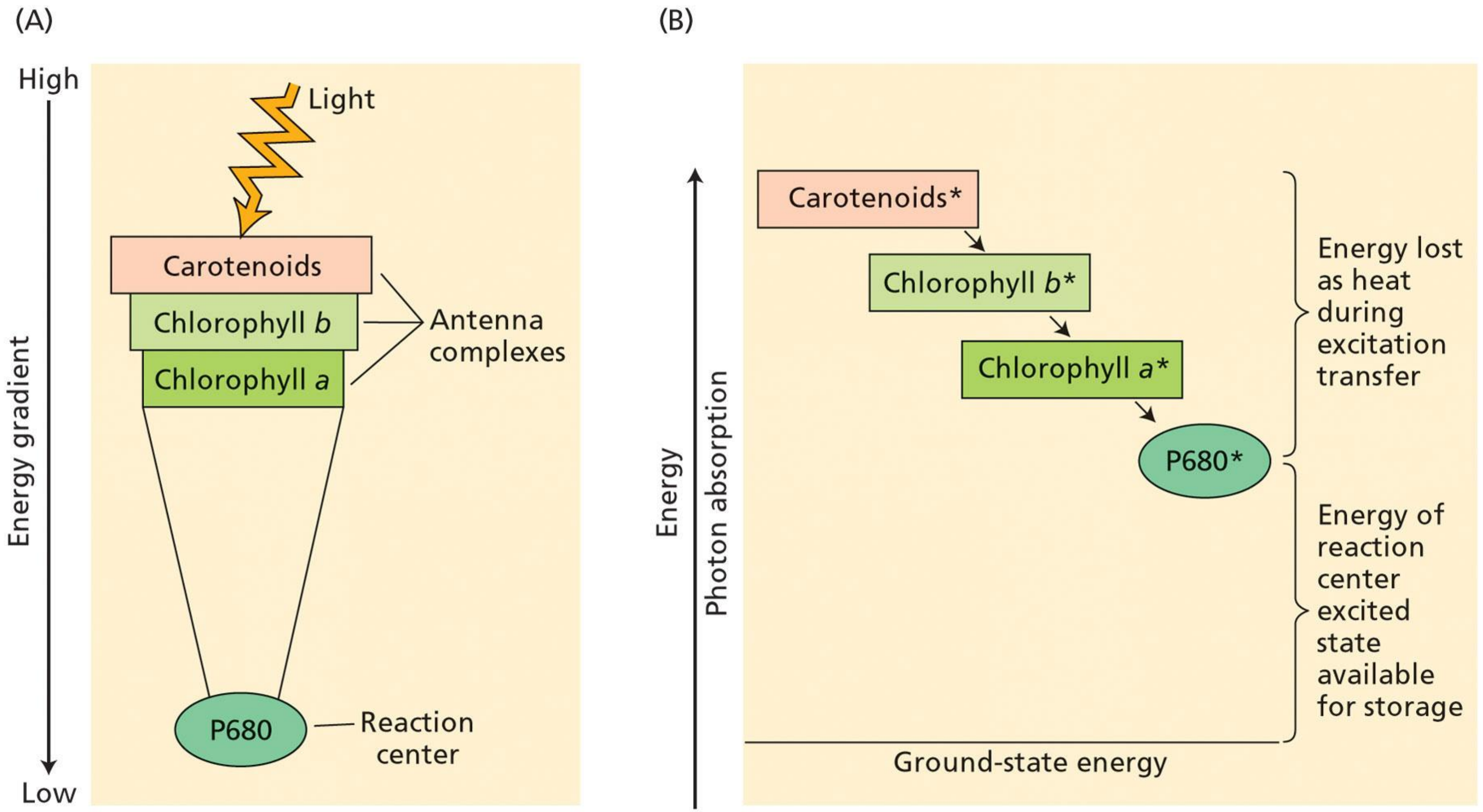
Chlorophylls absorb blue and red light and transmit green light

Carotenoids absorb blue and green light and transmit yellow, orange, or red light



Photosynthesis - light

Light energy moves down an energy gradient towards the reaction centre-



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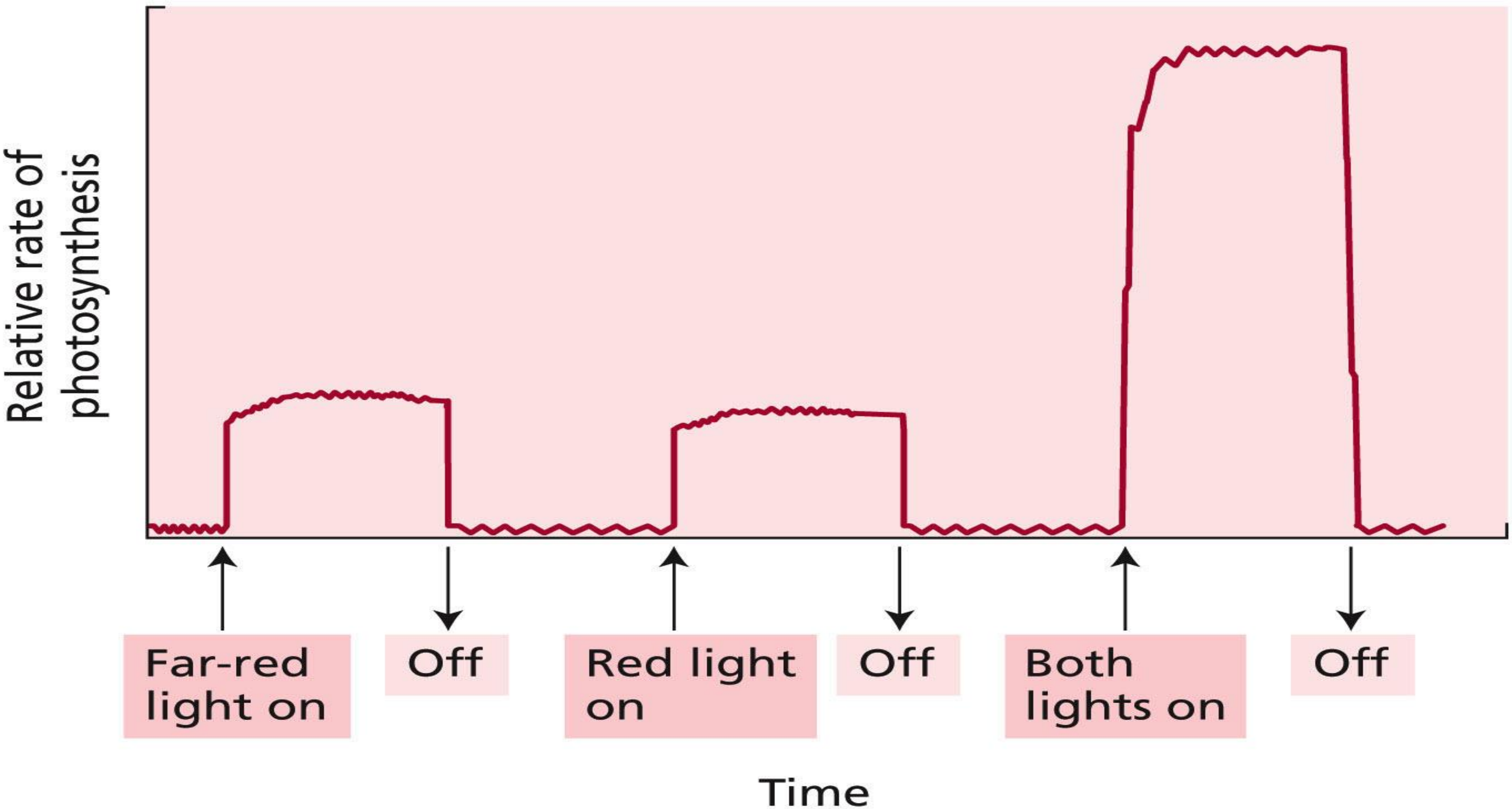
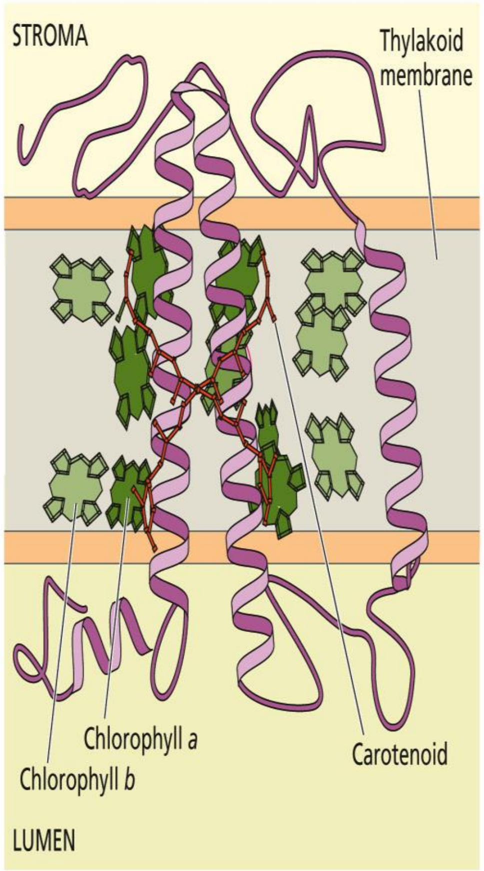
Red light enhancement effect (~1950s) :
2 photochemical complexes (~1960)



LHC-II

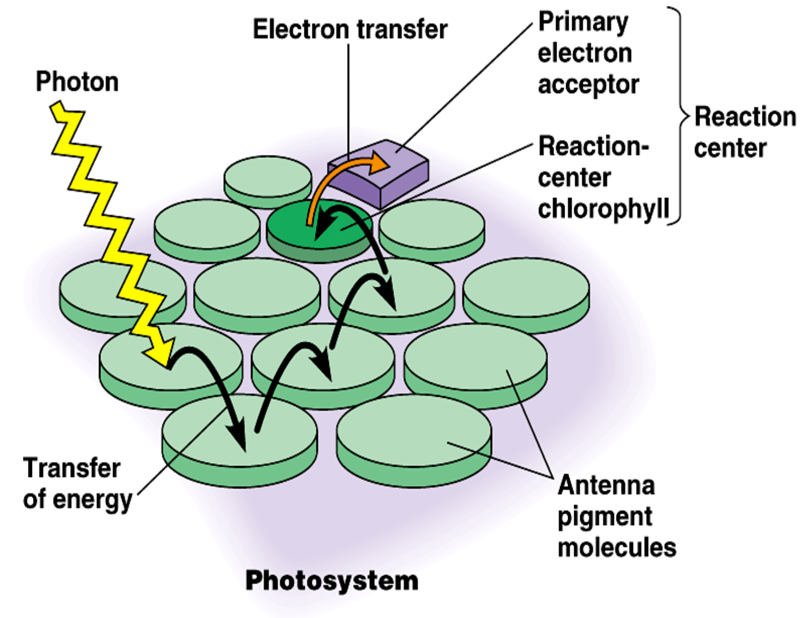


STROMA
Thylakoid membrane
Chlorophyll a
Chlorophyll b
Carotenoid
LUMEN

Pigment system

The light reactions of photosynthesis involve the use of *photosystems.*

- **A photosystem is a cluster of pigment molecules bound to proteins, along with a primary electron acceptor.**
- **2 photosystems are involved:**
- **Photosystem II (P680)**
  - •Absorbs light best at a wavelength of 680nm
- **Photosystem I (P700)**
  - •Absorbs light best at a wavelength of 700nm



Two Pigment Systems

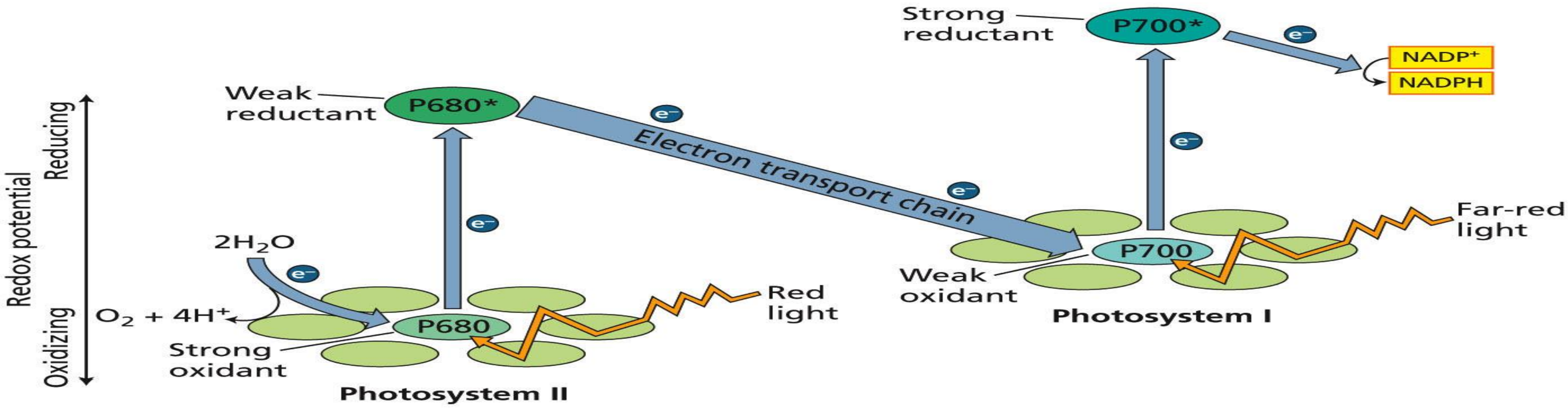
There are two processes in photosynthesis that capture light and produce energy rich compounds that are used in carbon fixation. These are termed

Photosystem I, and

Photosystem II

These processes are linked in what is termed the Z scheme of photosynthesis.

The Z refers to changes in redox potential of electrons.



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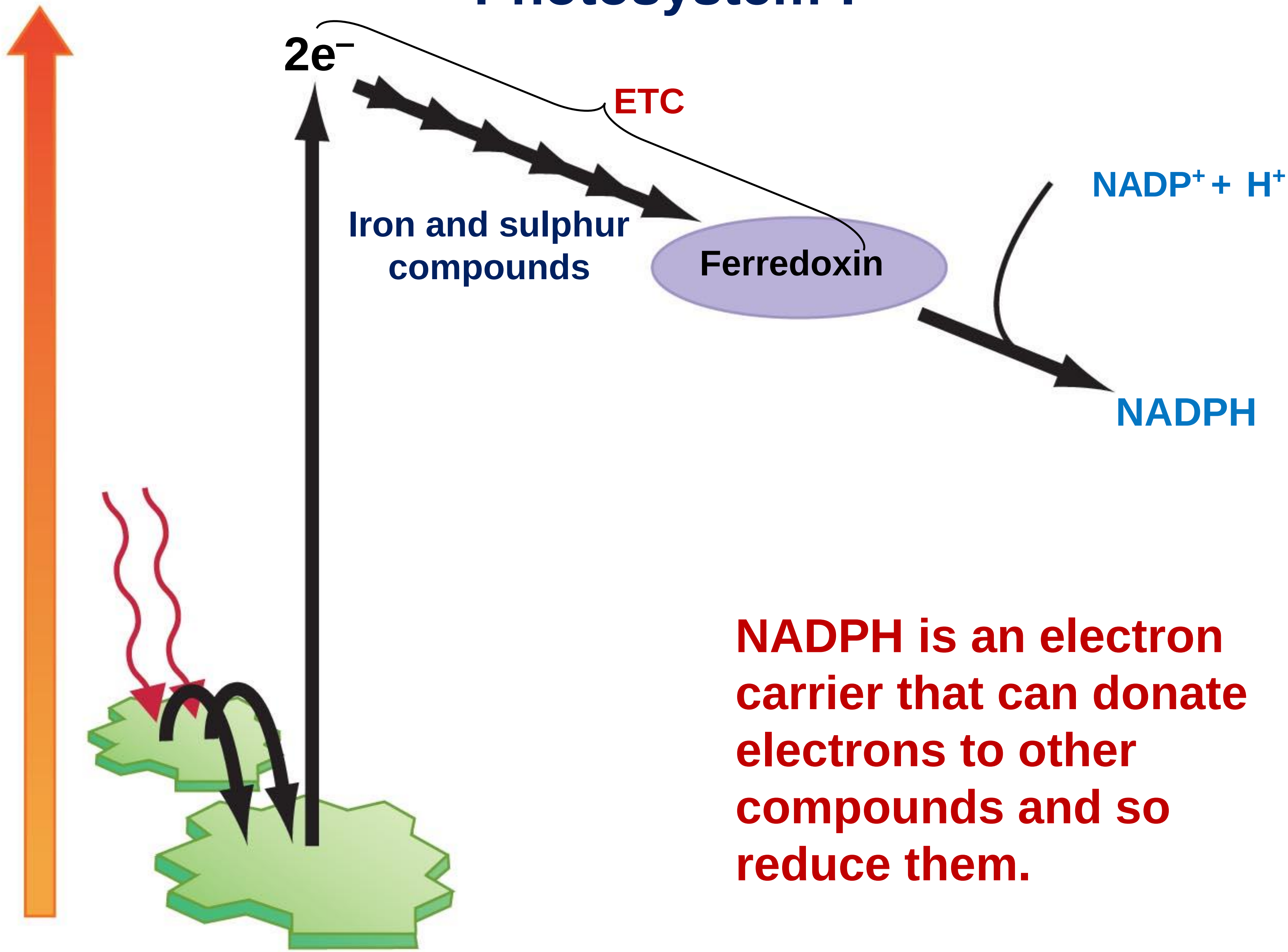
Photosystem-I



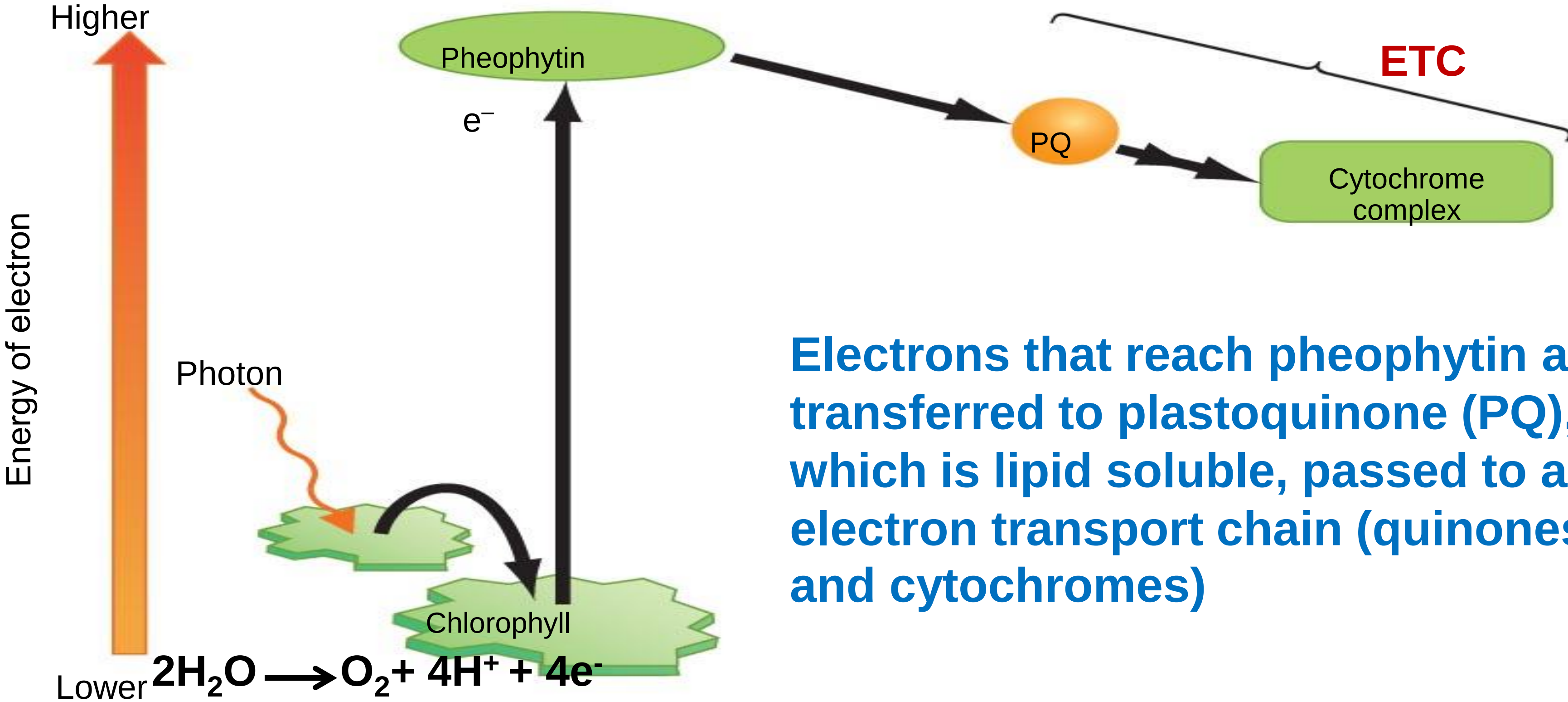
NADPH is an electron carrier that can donate electrons to other compounds and so reduce them.

Photosystem II

In photosystem II, excited electrons feed an electron transport chain.

Pheophytin has the structure of chlorophyll but without the Mg in the porphyrin-like ring and acts as an electron acceptor.

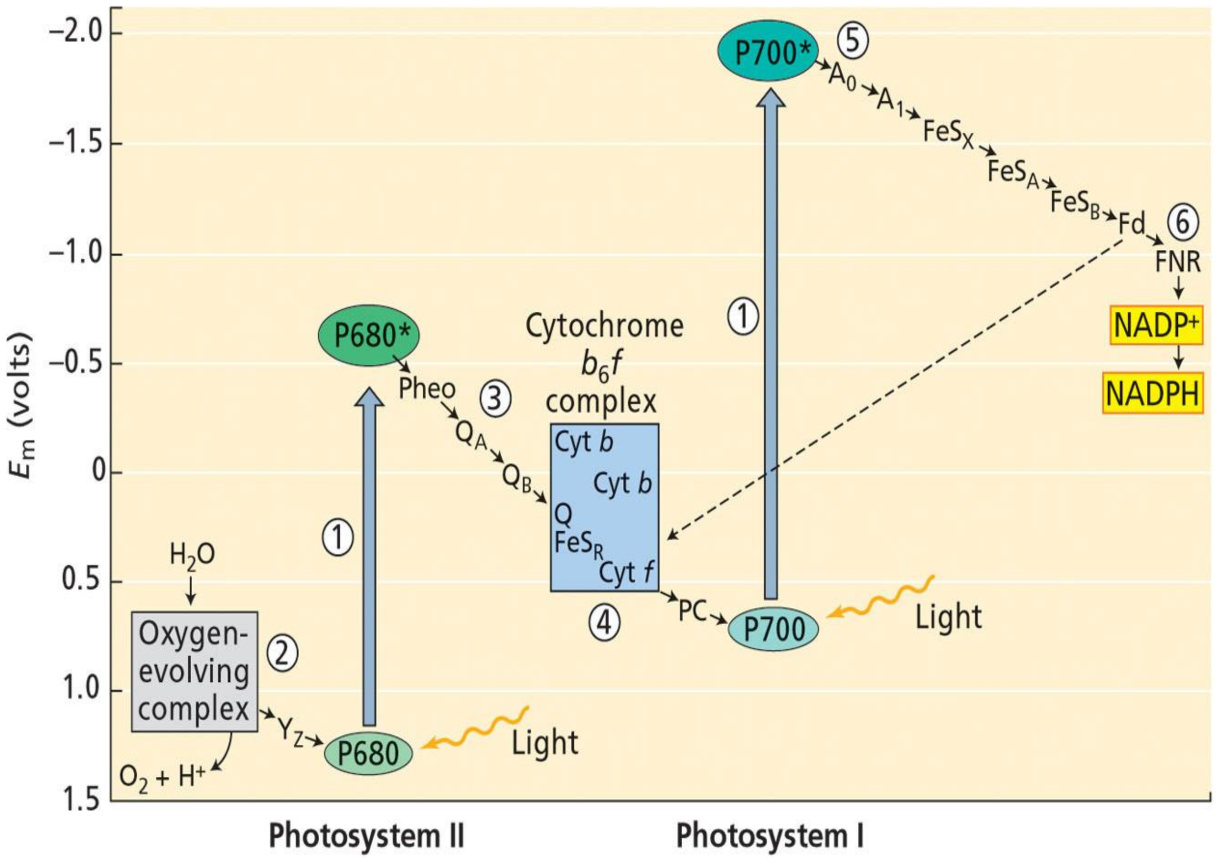
(a)



$2H_2O \longrightarrow O_2 + 4H^+ + 4e^-$

Electrons that reach pheophytin are transferred to plastoquinone (PQ), which is lipid soluble, passed to an electron transport chain (quinones and cytochromes)

The 'Z' Scheme



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1. **Photosystem II** [a group of pigment molecules] absorbs the energy in a **photon** [a particle of light], **exciting an electron** to a higher energy level.

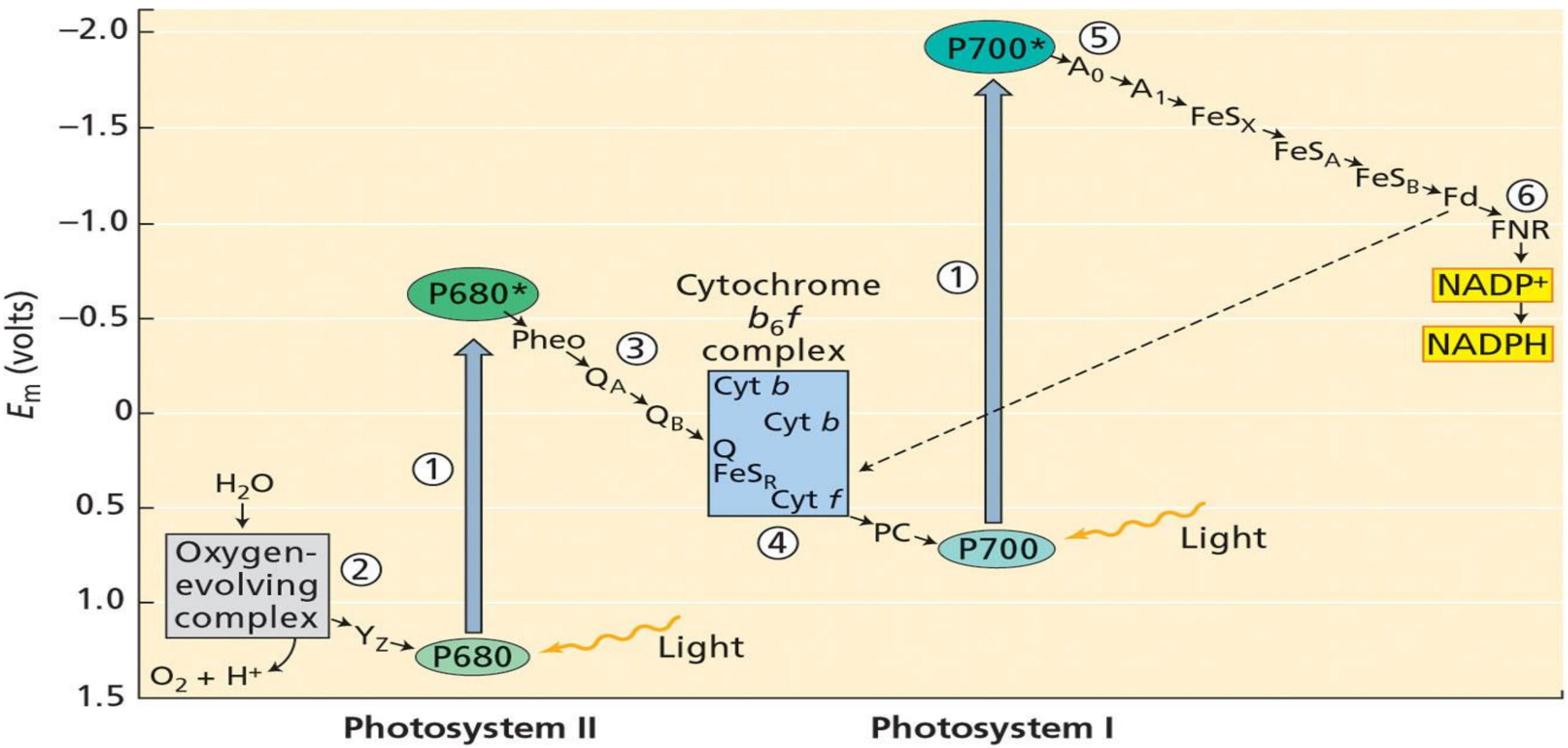
   Thus, PSII is now 1 electron SHORT of what it needs.

2. **This electron is replaced by *photolysis* – the splitting of water using light.**

   O_2 is released as a byproduct.

3. The excited electron travels down the electron transport chain, made of increasingly electronegative cytochromes, “losing energy” as it goes. This energy is used to build a concentration gradient of protons [chemiosmosis].

4. At the same time, Photosystem I [another group of pigment molecules] also absorbs light energy, exciting one of ITS electrons to a higher energy level.



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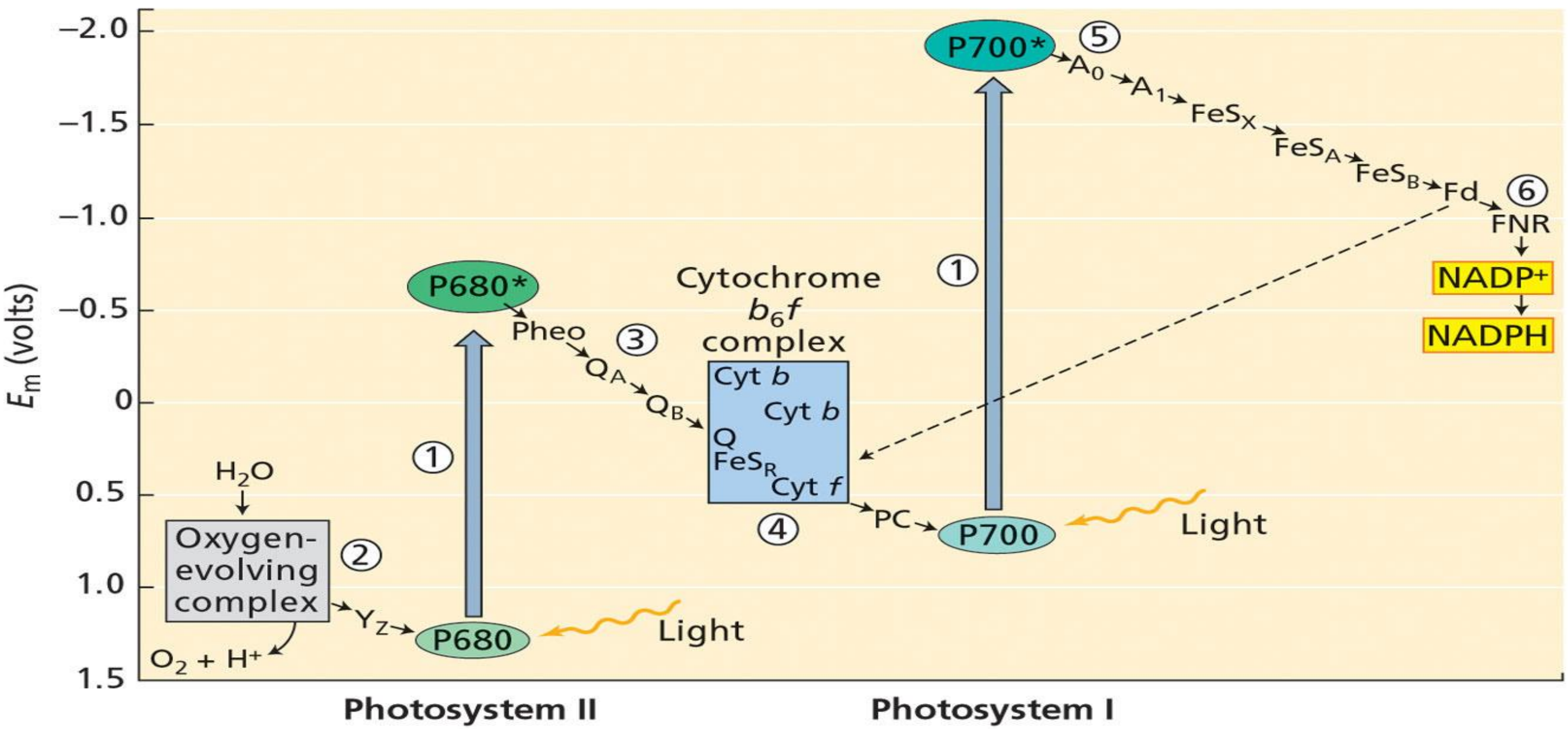
5. The electron lost from Photosystem I is replaced by the electron that was excited and subsequently lost from Photosystem II.
6. The excited electron from Photosystem I travels down another electron transport chain, "losing energy" as it goes, and ultimately REDUCES $NADP^+$ to NADPH [an electron carrier].



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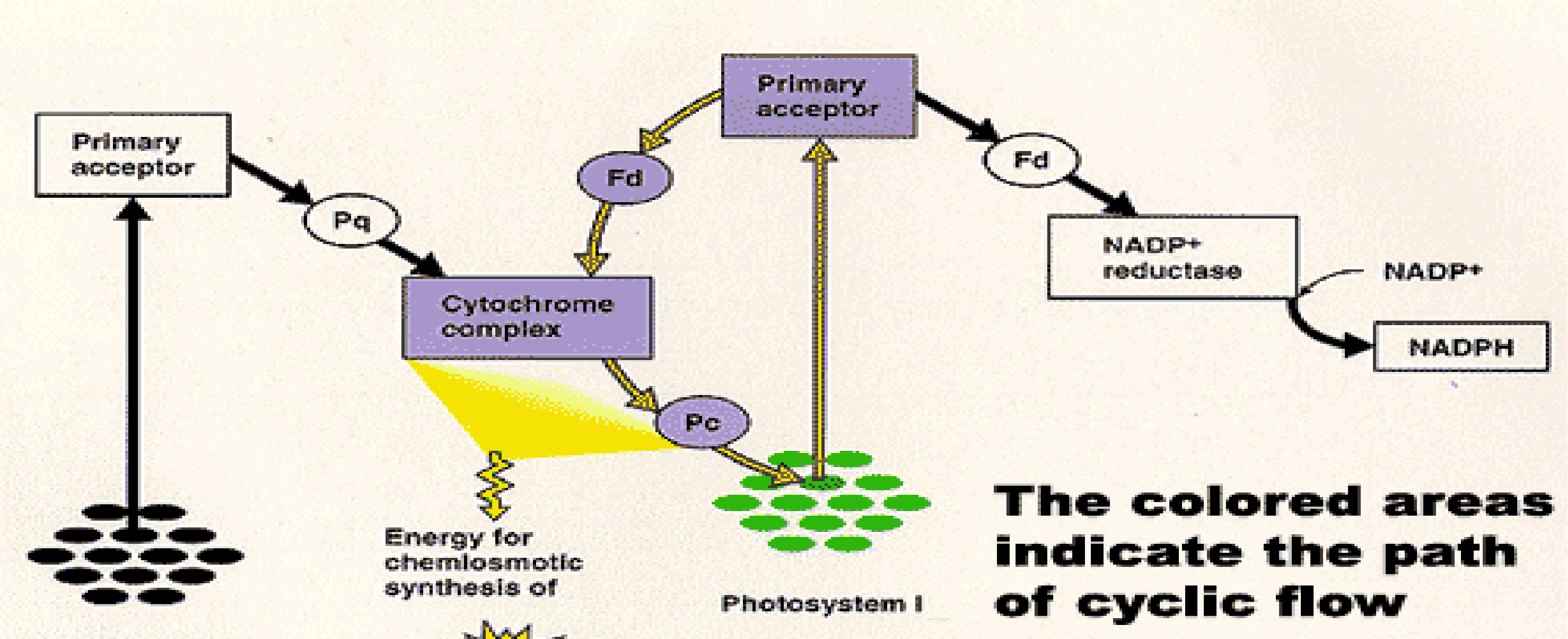
Cyclic electron flow

Most photosynthetic bacteria & all photosynthetic eukaryotes use cyclic phosphorylation.

Cyclic electron flow produces ATP, but does *not* produce NADPH.

- **Only photosystem I is used**
- **Electrons are “recycled”**
- **Water is *not* split**



Non-Cyclic Electron Flow

1. Two photosystems (PS II & PS I) are used.

2. Water is split through photolysis to replace the "lost" electron.

3. Oxygen is released.

4. NADPH is produced.

5. ATP is produced.

Cyclic Electron Flow

1. Only 1 photosystem (PS I) is used.

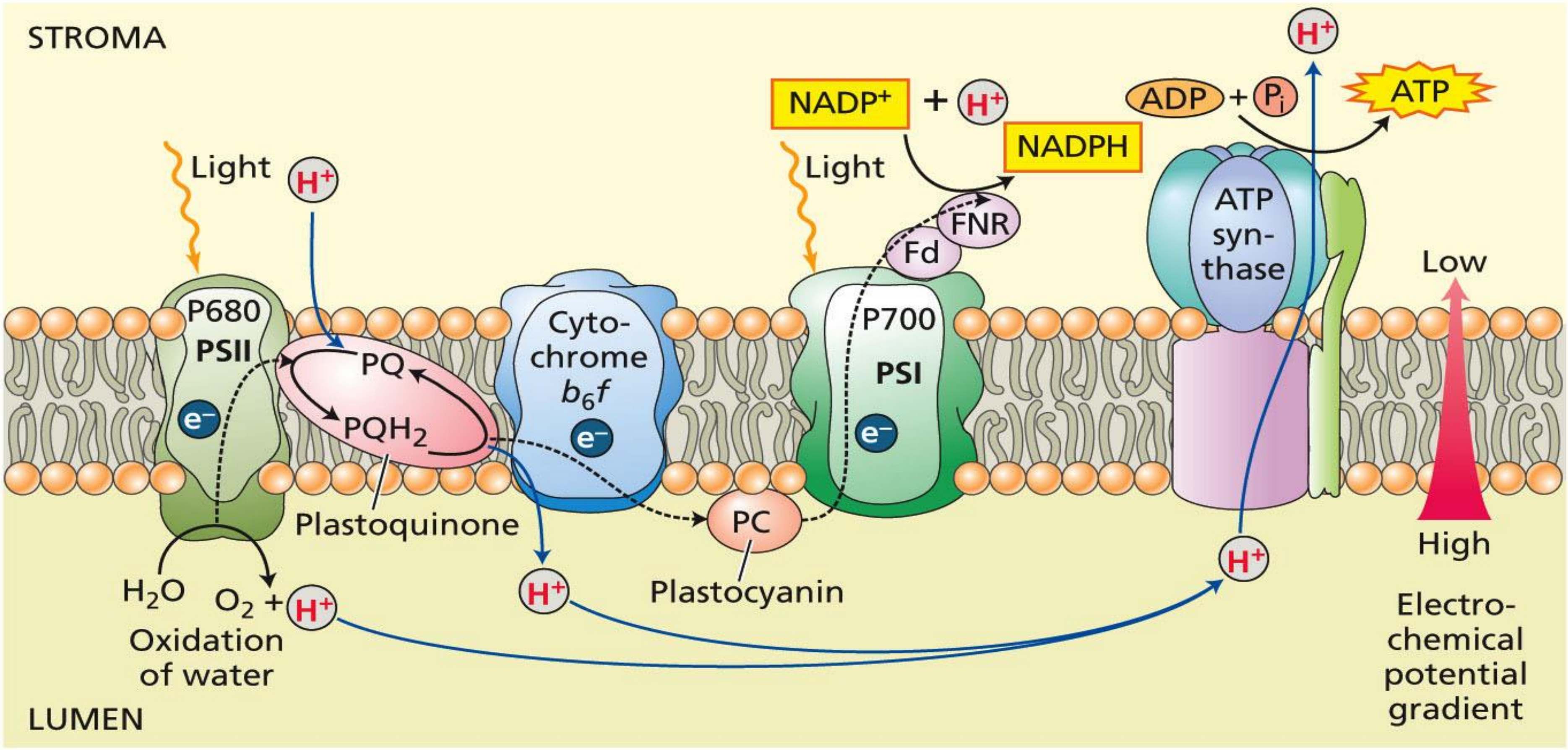
2. Water is not split to replace electrons – the electron is "recycled" back to the photosystem.

3. Oxygen is *not* released.

4. NADPH is *not* produced.

5. ATP is produced.

Photosynthetic ETC and photophosphorylation

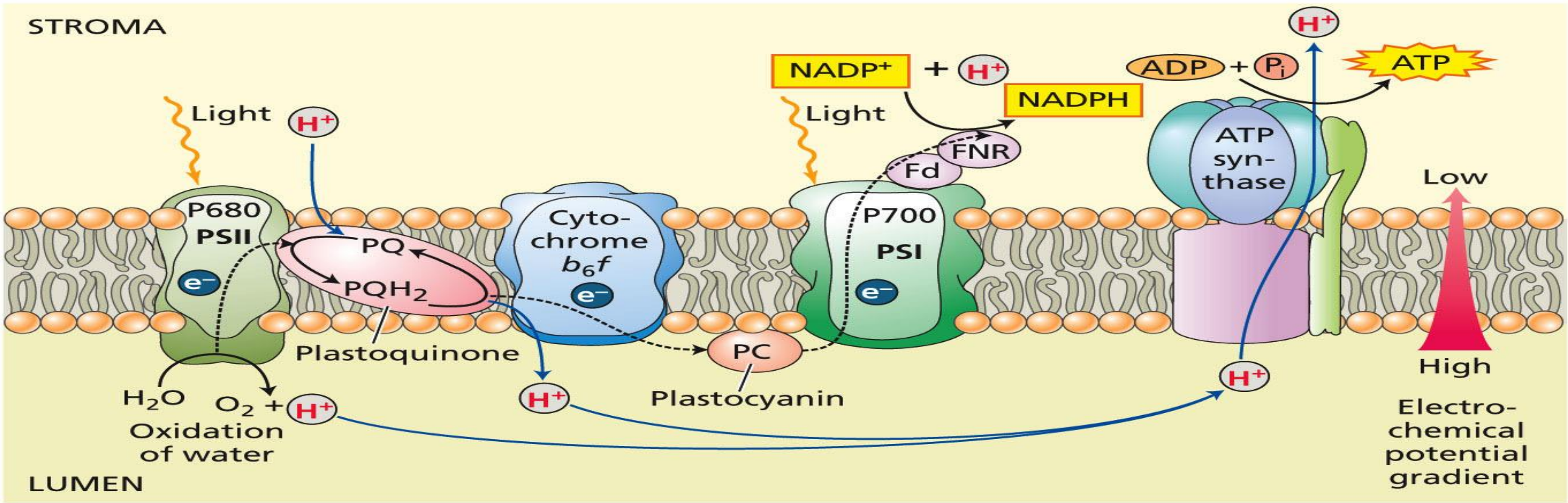


PLANT PHYSIOLOGY, Fourth Edition, Figure 7.22

Chemiosmosis

Protons (H^+) are pumped from the STROMA into the THYLAKOID SPACE, across the thylakoid membrane.

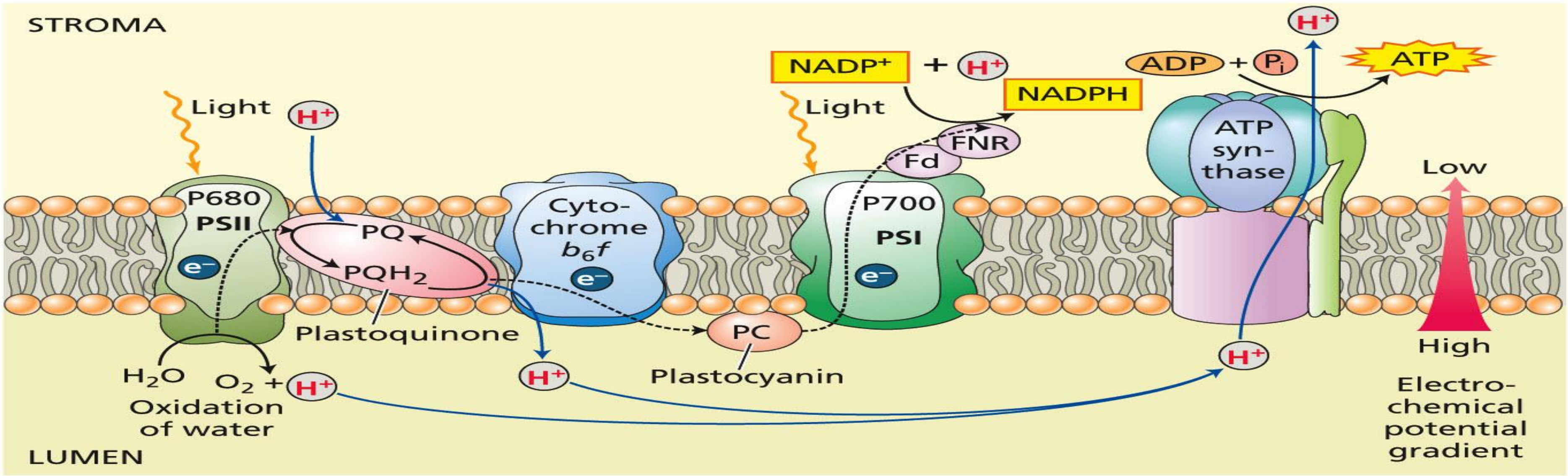
- **This builds up a concentration of H^+ in the thylakoid space.**
- **This concentration gradient represents POTENTIAL ENERGY.**



Chemiosmosis

In chemiosmosis, protons diffuse back to the stroma through ATP synthase.

- **This is known as the proton motive force.**
- **This causes ATP synthase to spin (like a turbine) and forces ADP and a phosphate group together.**
- **This forms ATP.**



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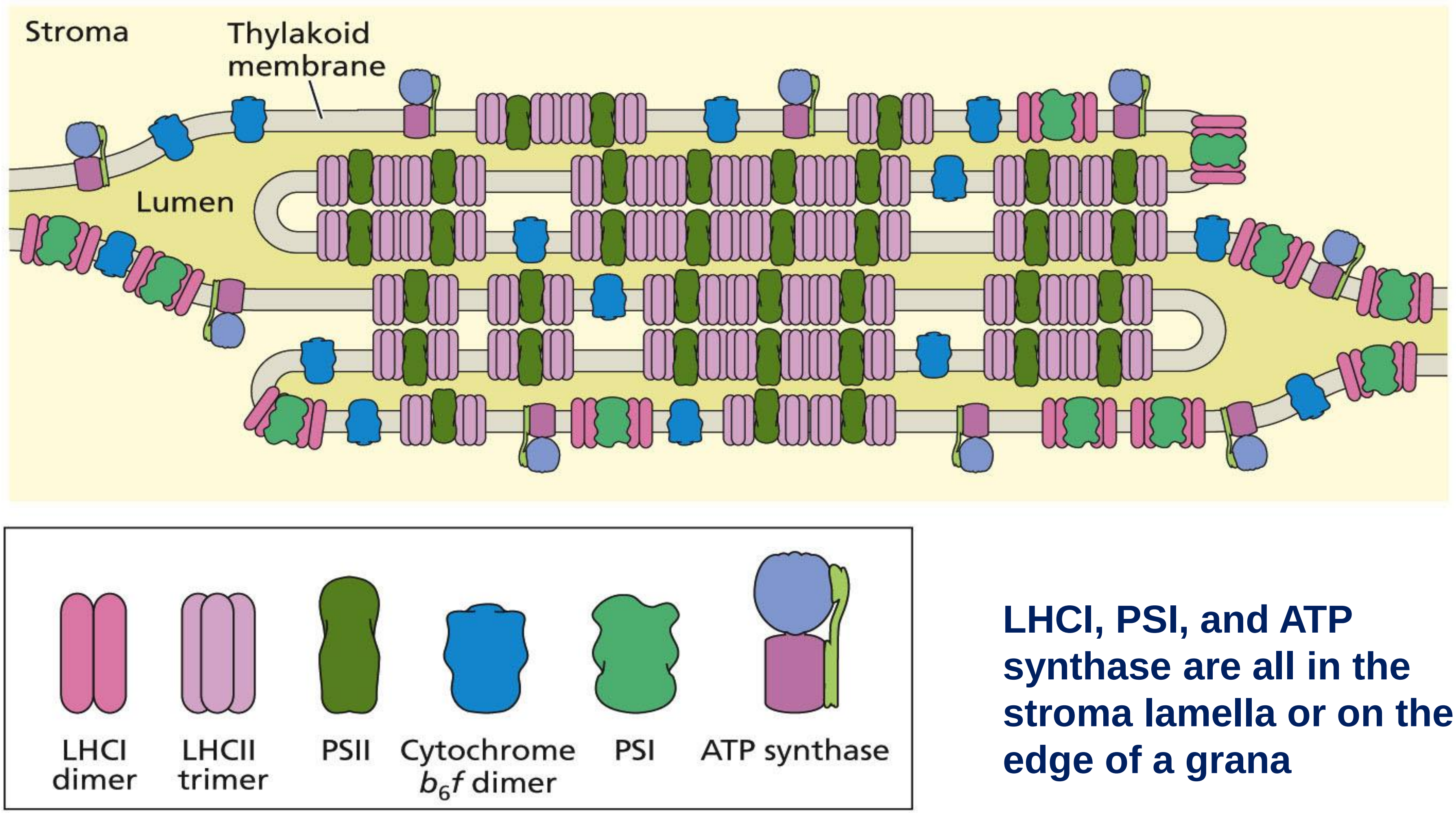
Organization and structure of the four major protein complexes



LHCI, PSI, and ATP synthase are all in the stroma lamella or on the edge of a grana

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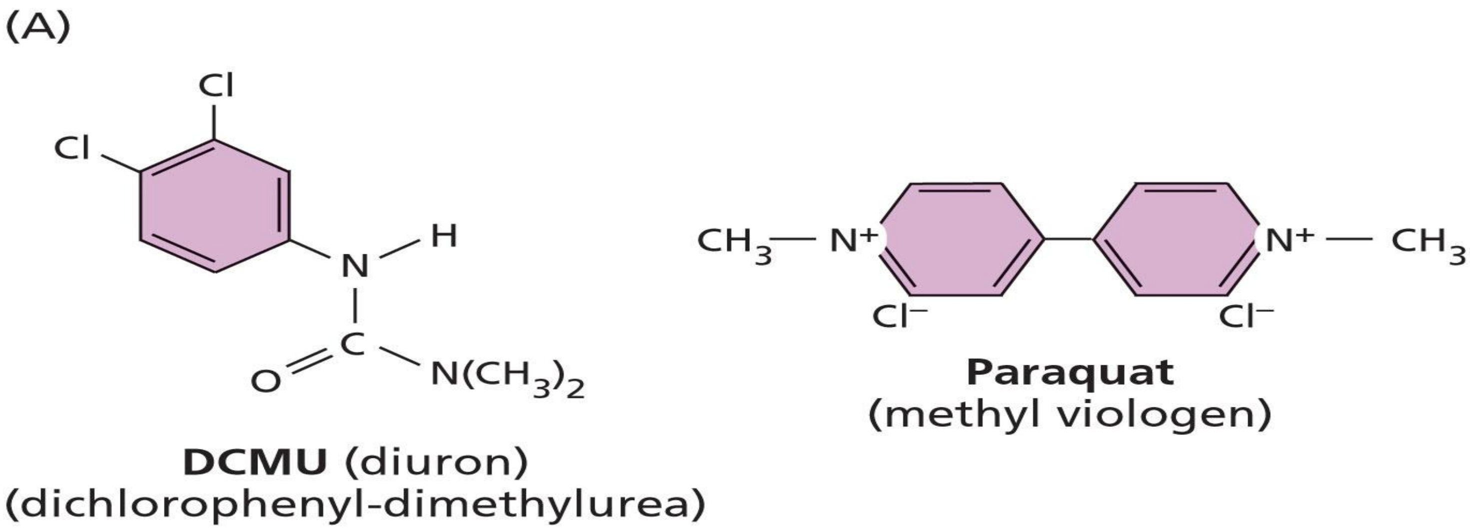
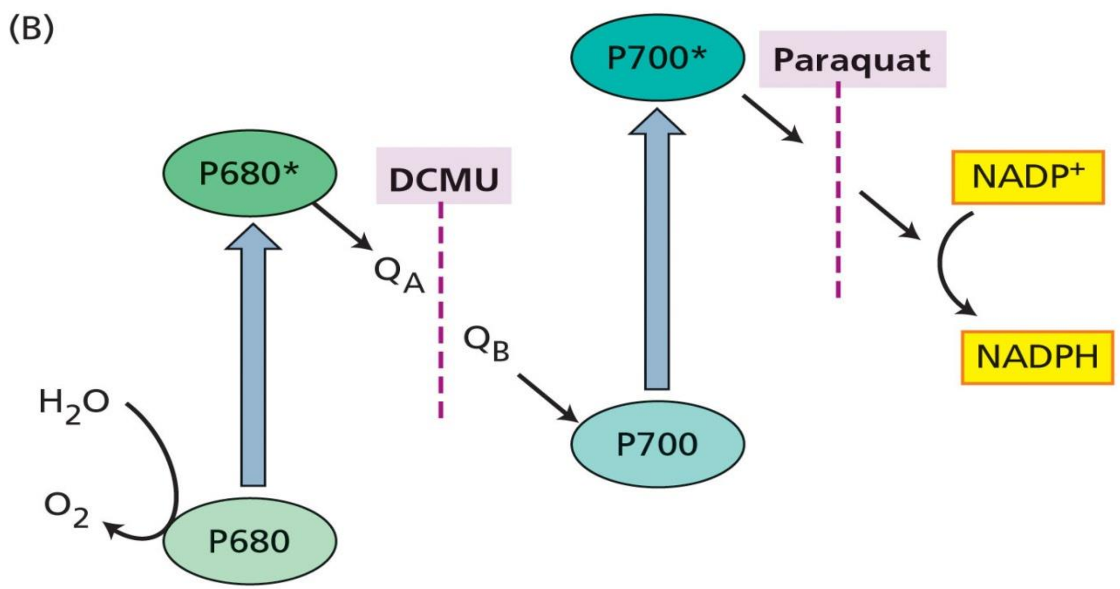
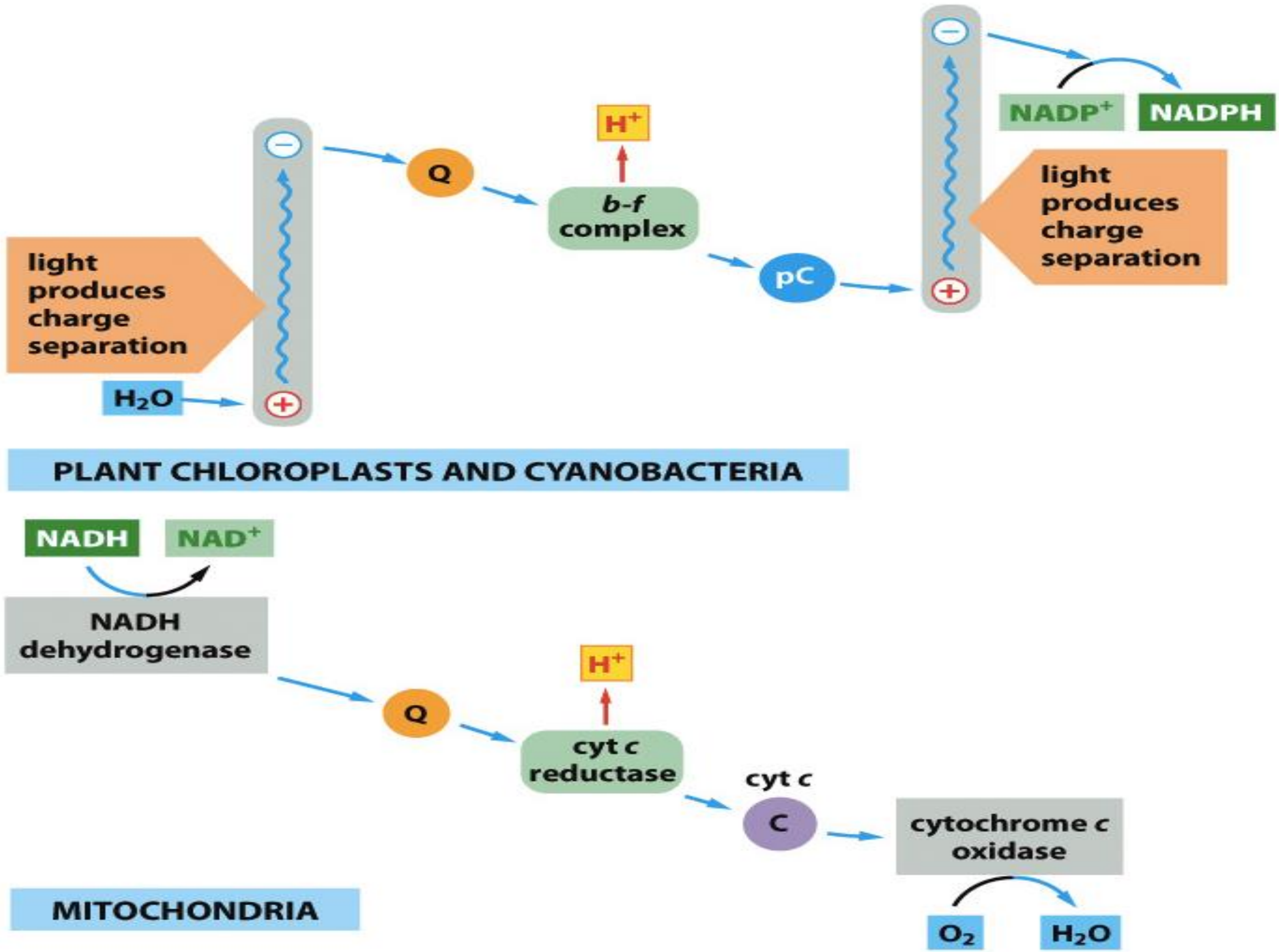
Some herbicides block e⁻ flow



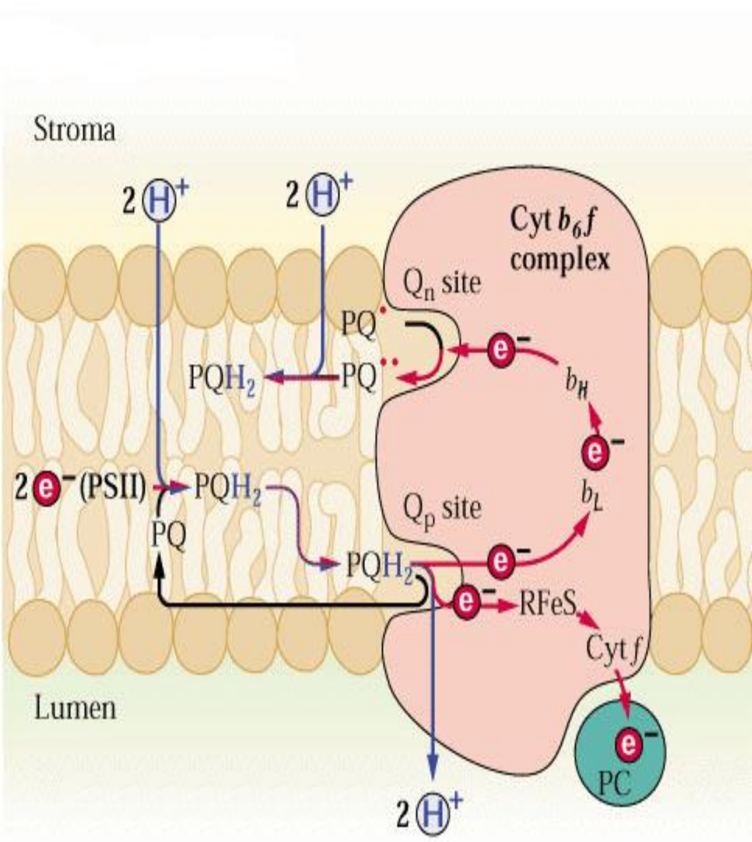


Electron transport chains in photosynthesis and respiration both use Q cycles



Q-CYCLE

- **Several models have been proposed to explain flow of protons and electrons through cytochrome b_6f complex of thylakoids in photosynthesis, but its precise mechanism is not yet fully understood.**
- **The most widely accepted model mechanism in this regard is known as Q-Cycle.**
- **In this mechanism, one of the two electrons from PQH_2 (produced by the action of PS II) passes in a linear way towards PSI while the other electron takes a cyclic route that increases the number of protons pumped across thylakoid membrane.**



Cytochrome b_6f complex

The cytochrome b_6f complex contains two b type hemes (cytochrome b) and one c type heme (called cyt.f).

It also contains a Rieske iron-sulphur protein ($Fe\text{-}S_R$) with a unique 2Fe-2S cluster (so named after its discoverer John S. Rieske) and two quinone oxidation-reduction sites.

Electron and proton flow through the cytochrome *b*6*f* complex

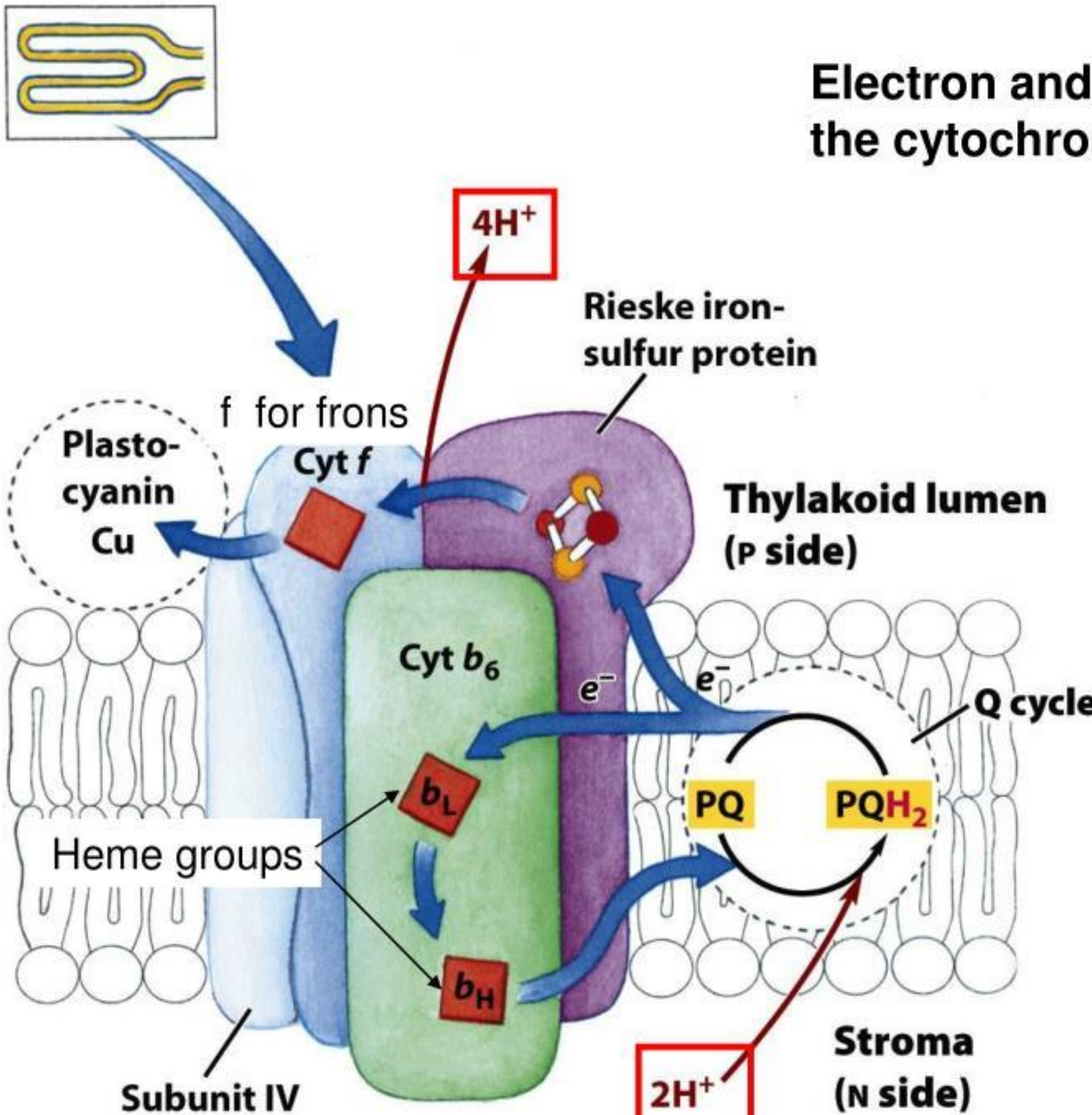


Figure 19-59c
Lehninger Principles of Biochemistry, Fifth Edition

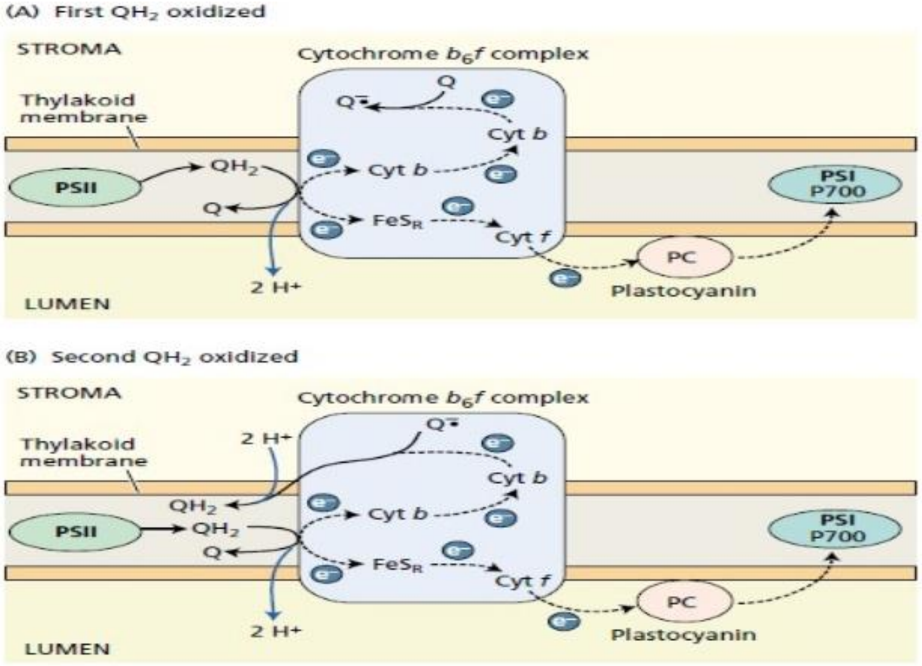
Plastoquinol (PQH2) formed in PSII is oxidized by the cytochrome *b*6*f* complex in a series of steps like those of the Q cycle in the cytochrome Complex III of mitochondria. One electron from PQH2 passes to the Fe-S center of the Rieske protein, the other to heme *b*L of cytochrome *b*6. The net effect is passage of electrons from PQH2 to the soluble protein plastocyanin, which carries them to PSI.

Mechanism of Q Cycle

(i) In the non-cyclic or linear process of Q-cycle, PQH_2 produced by the action of PSII is oxidized near the lumenal side of the complex releasing its two electrons one each to $Fe\text{-}S_R$ and one of the two b- type cytochromes and simultaneously expelling its two protons ($2H^+$) into the thylakoid lumen.

From $Fe\text{-}S_R$, the electron is transferred to oxidized PSI via PC.

The reduced b-type cytochrome gives its electron to another cyt. b which in turn reduces PQ to plastosemiquinone (PQ^-).

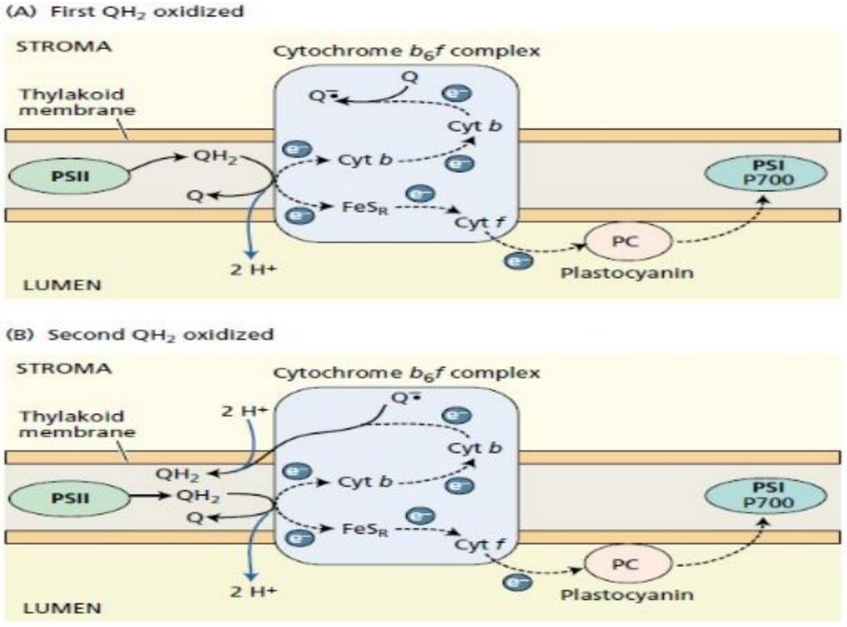


Mechanism of Q Cycle

(ii) In the cyclic process of the Q-Cycle, another PQH_2 from PS II is oxidized in a similar way expelling its two protons into the thylakoid lumen and one electron going to oxidize P700 via Fe-S_R, cyt. ƒ and PC.

The remaining electron goes through two b-type cytochromes and reduces plastosemiquinone.

The plastosemiquinone takes two protons ($2H^+$) from stroma and is reduced to plastohydroquinone (PQH_2).



Mechanism of Q Cycle

Thus, for each pair of electrons which are transferred to P700, two PQH_2 are oxidized to PQ state, four protons ($4H^+$) are expelled into the thylakoid lumen and one oxidized PQ is reduced to PQH_2 form.

The resulting H^+ gradient is believed to be the main driving force for photophosphorylation.