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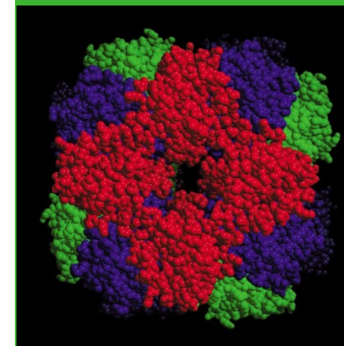


Photosynthesis

Katerina Dadakova, Department of Biochemistry

Figures adopted from Buchanan et al., Biochemistry & molecular biology of plants

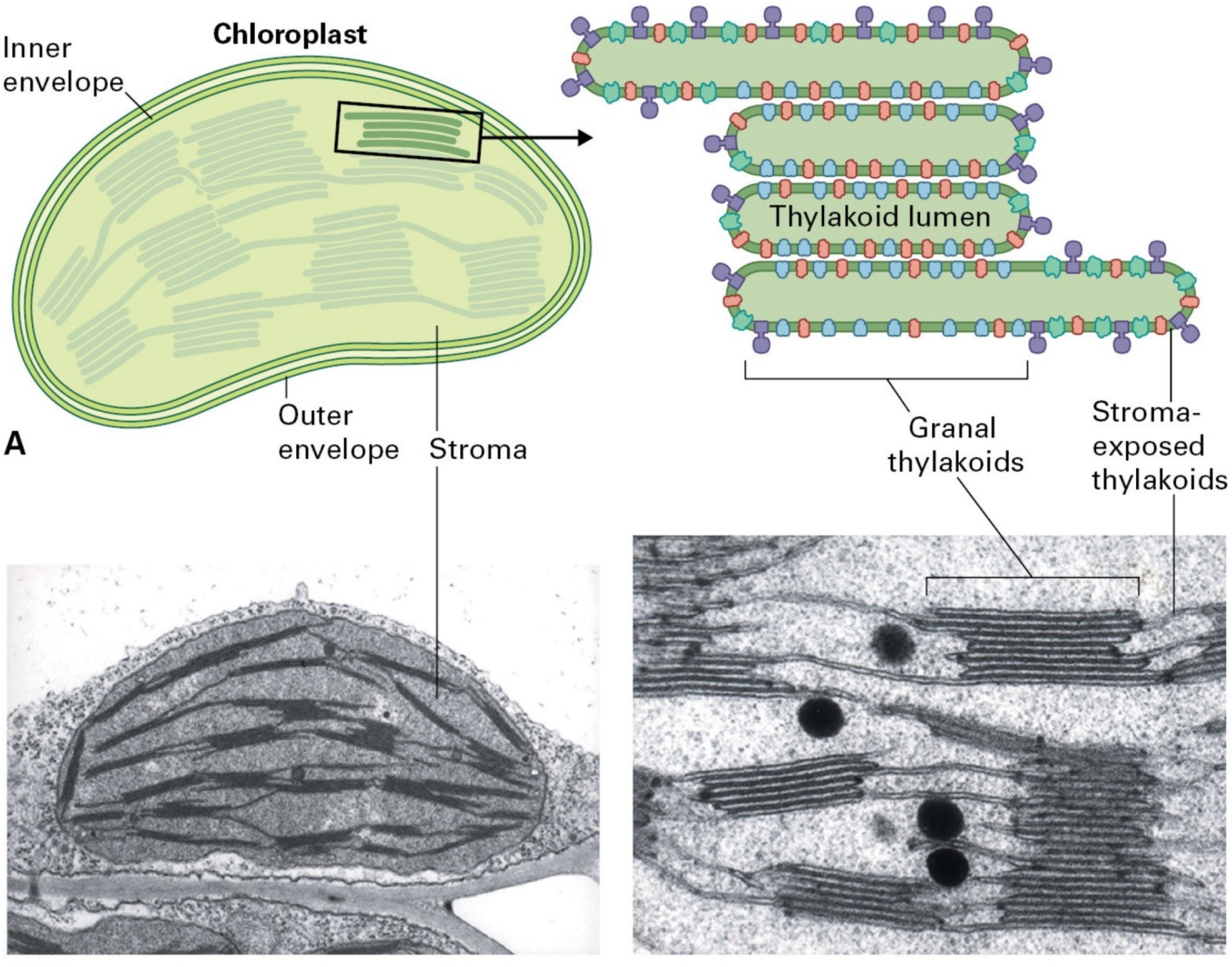
Using light energy to synthesize organic compounds from inorganic precursors

$$CO_2 + 2H_2O \xrightarrow{h\nu} (CH_2O) + O_2 + H_2O$$

Oxygenic photosynthesis

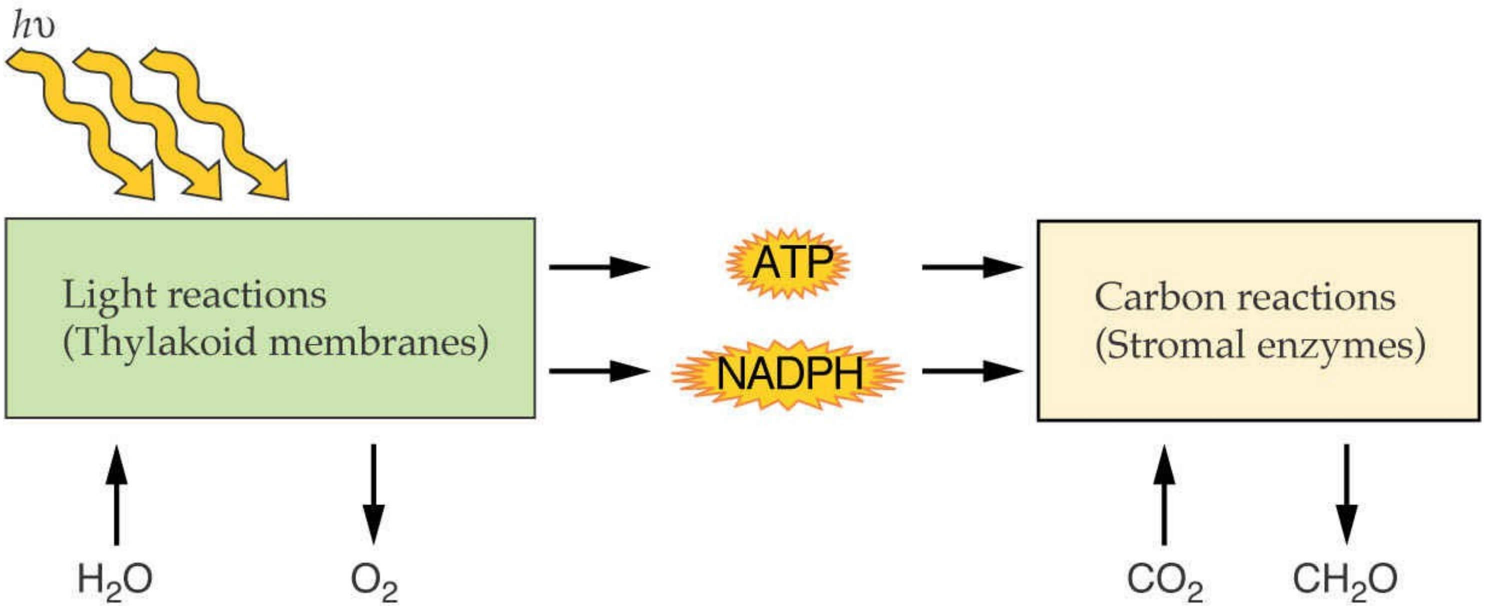
The free energy change is $\Delta G = +2840$ kJ per mol of glucose formed

Plant chloroplast



Two phases of photosynthesis

Water oxidation and CO_2 reduction are not obligately linked.

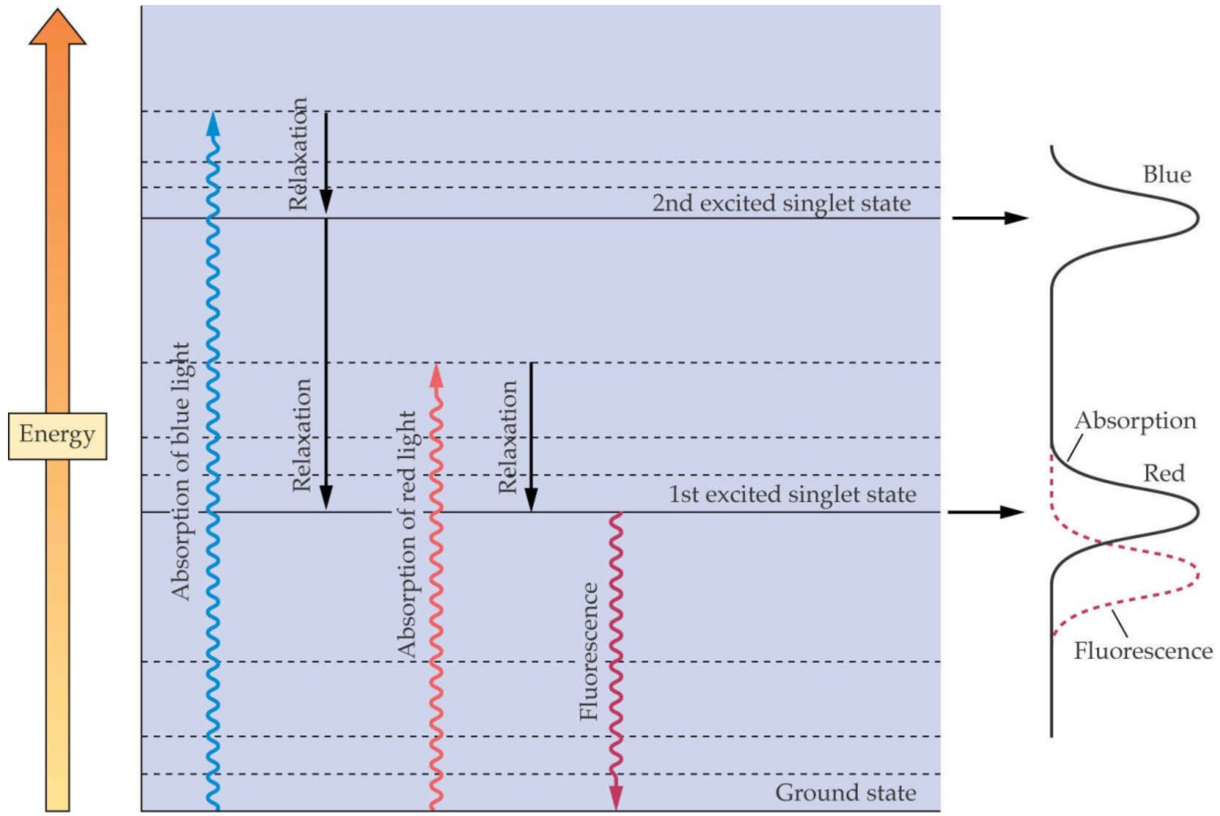


Light absorption

The energy of a photon is inversely proportional to its wavelength

$$E = hc/\lambda$$

Energy levels in the molecule of the light-absorbing pigment chlorophyll



Light absorption

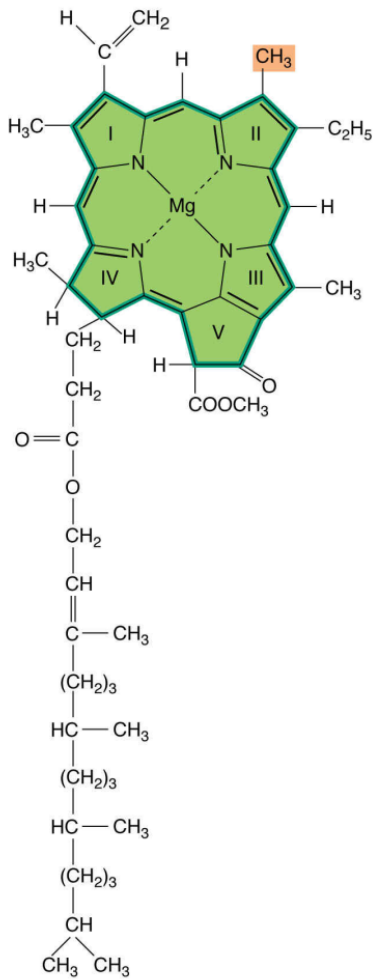
Mechanisms of energy release:

- relaxation
- fluorescence
- energy transfer
- charge separation (photochemistry)

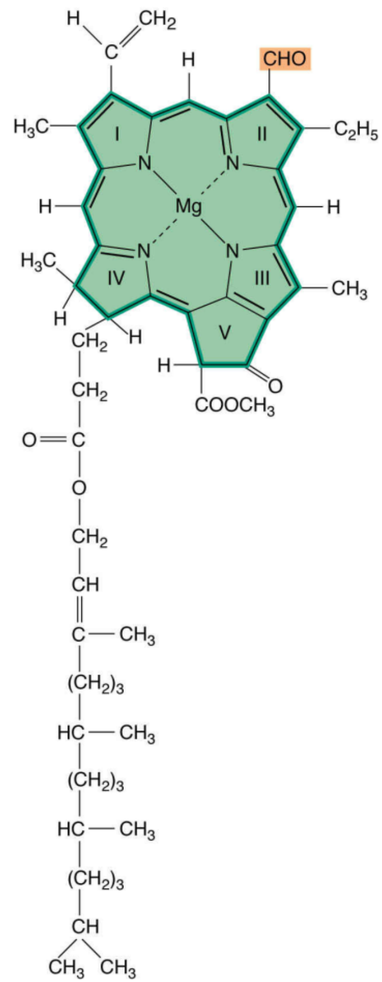
$$\text{pigment} + \text{acceptor} \xrightarrow{h\nu} \text{pigment}^* + \text{acceptor} \longrightarrow \text{pigment}^+ + \text{acceptor}^-$$

Φ = number of products formed photochemically / number of quanta absorbed

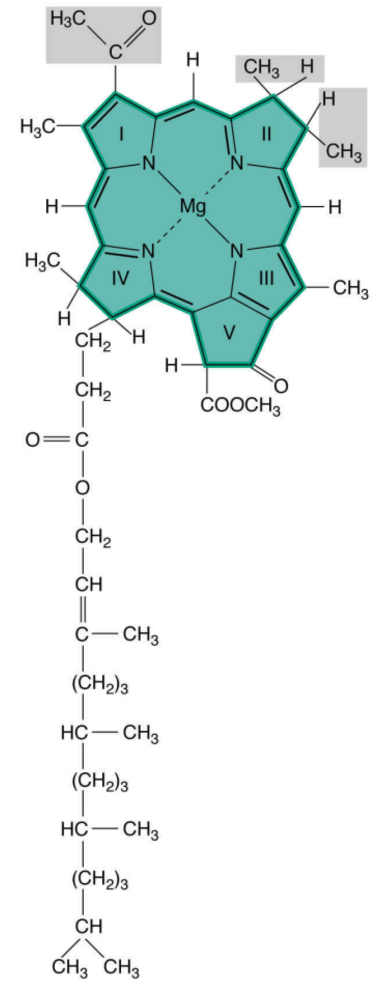
Light absorption



Chlorophyll a



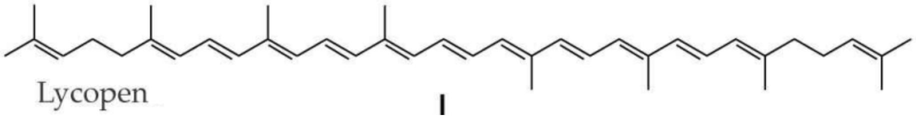
Chlorophyll b

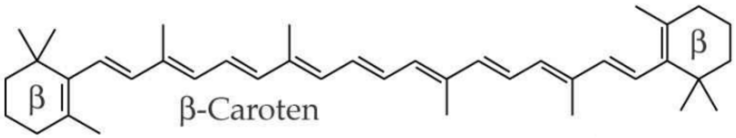


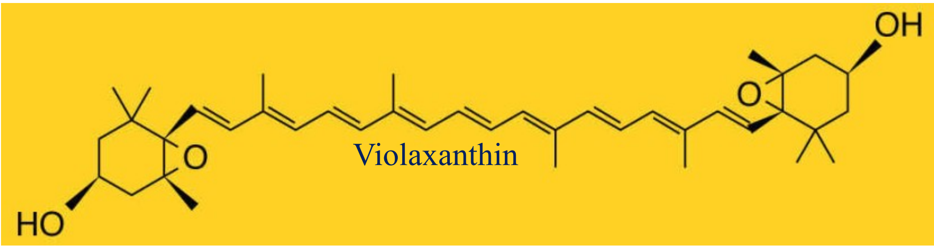
Bacteriochlorophyll

Light absorption

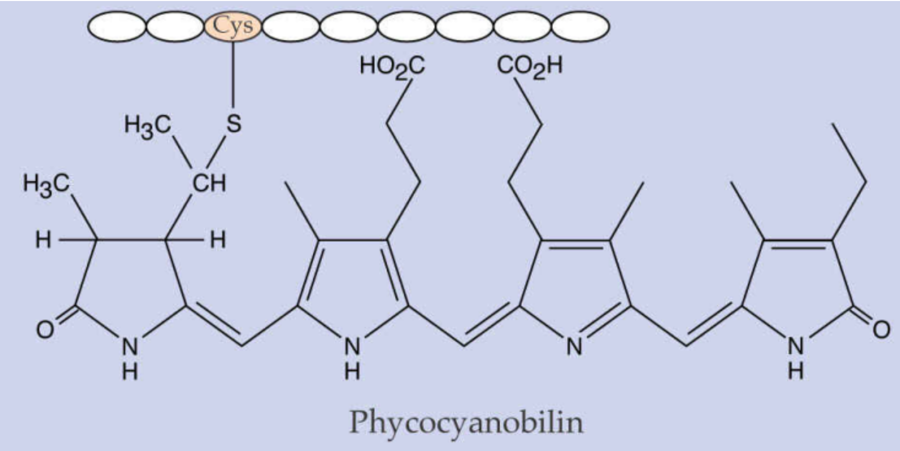
Carotenoids





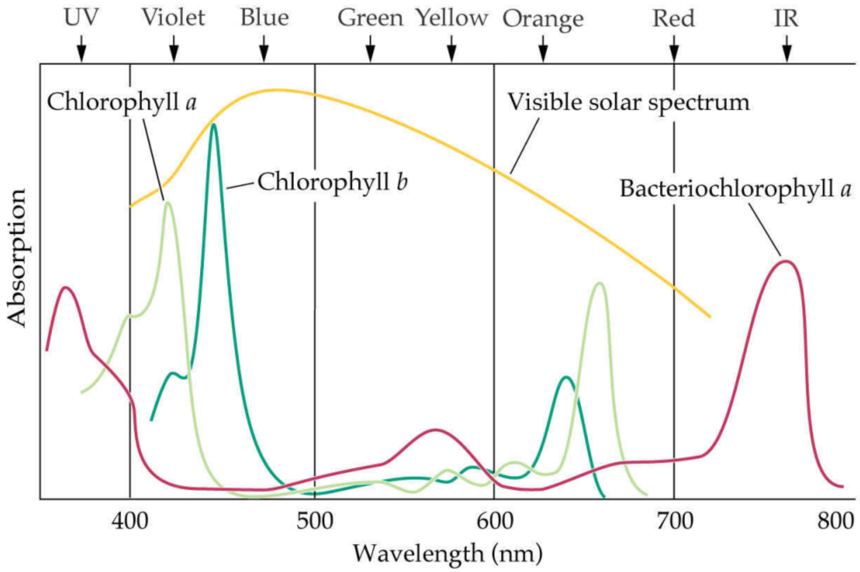


Phycobilins

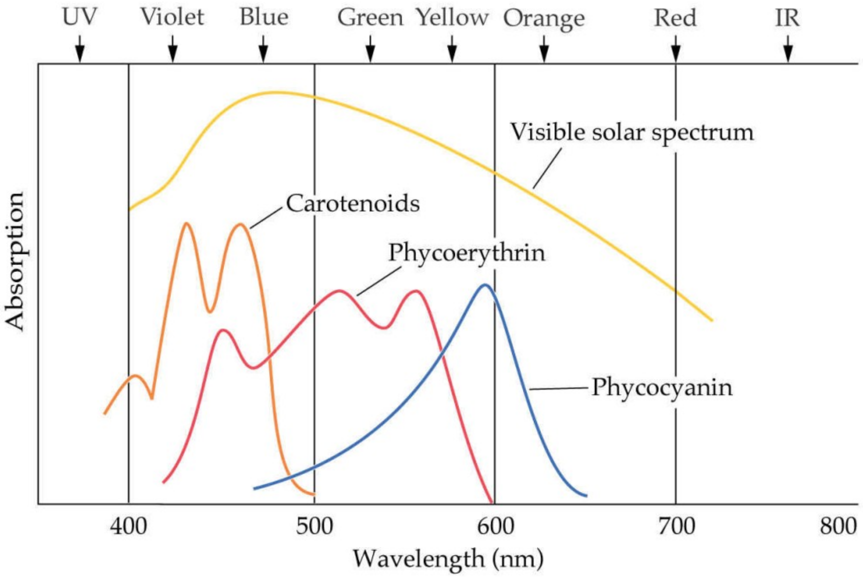


Light absorption

Chlorophylls

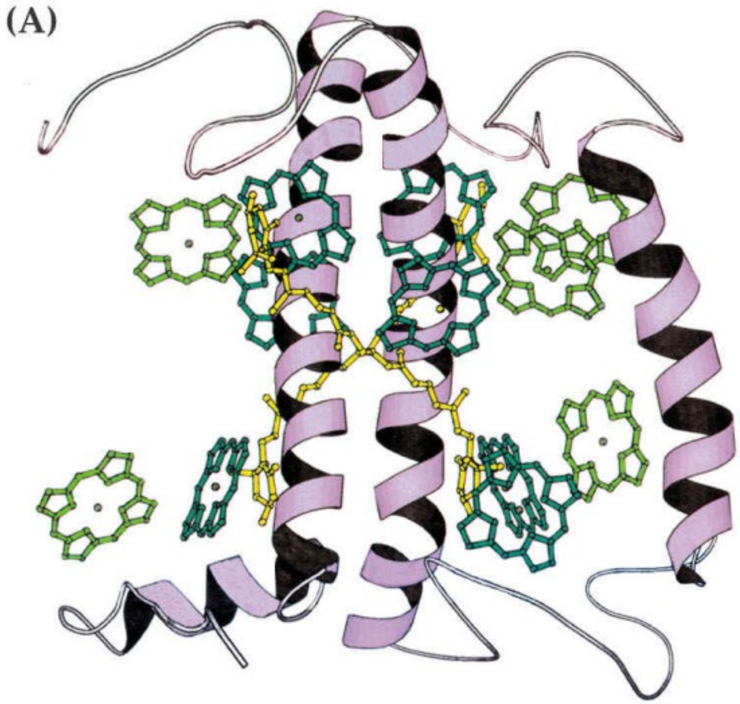


Other pigments

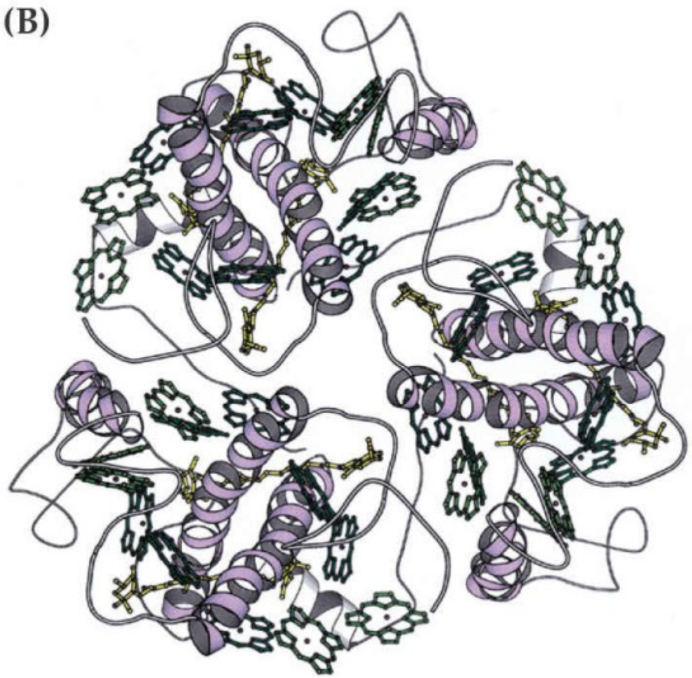


Light harvesting

LHC-II structure



Monomer



Trimer

The reaction center complex

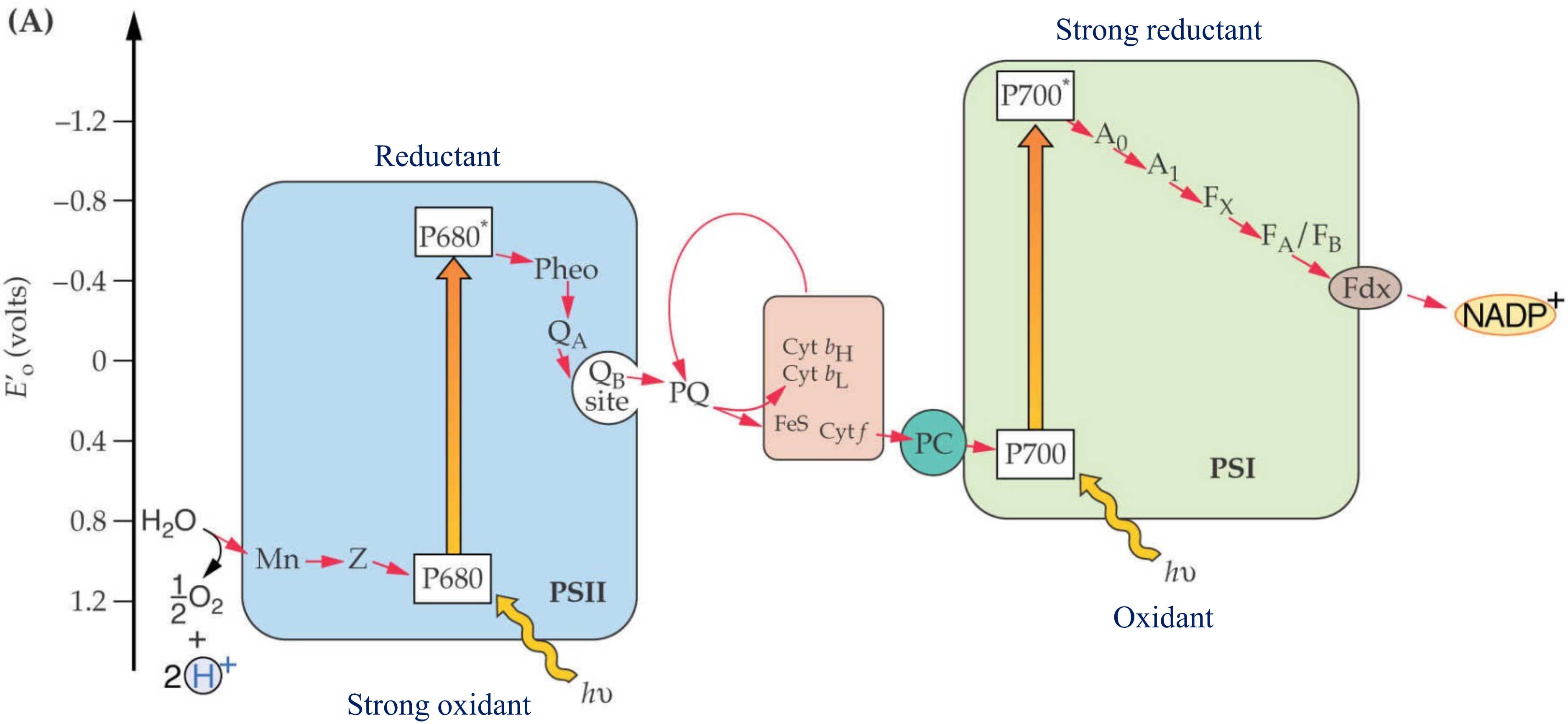
- Reaction centers are integral membrane protein complexes involved in conversion of light energy into chemical products
- Plants contain two different reaction center complexes: Photosystem I and Photosystem II
- Reaction centers contain both chlorophyll and electron acceptor molecules

Carrier	PSI	PSII
Chl	P700	P680
A_0	Chlorophyll a	Pheophytin a
A_1	Phylloquinone	Plastoquinone (Q_A)
A_2	Fe-S center	Plastoquinone (Q_B)

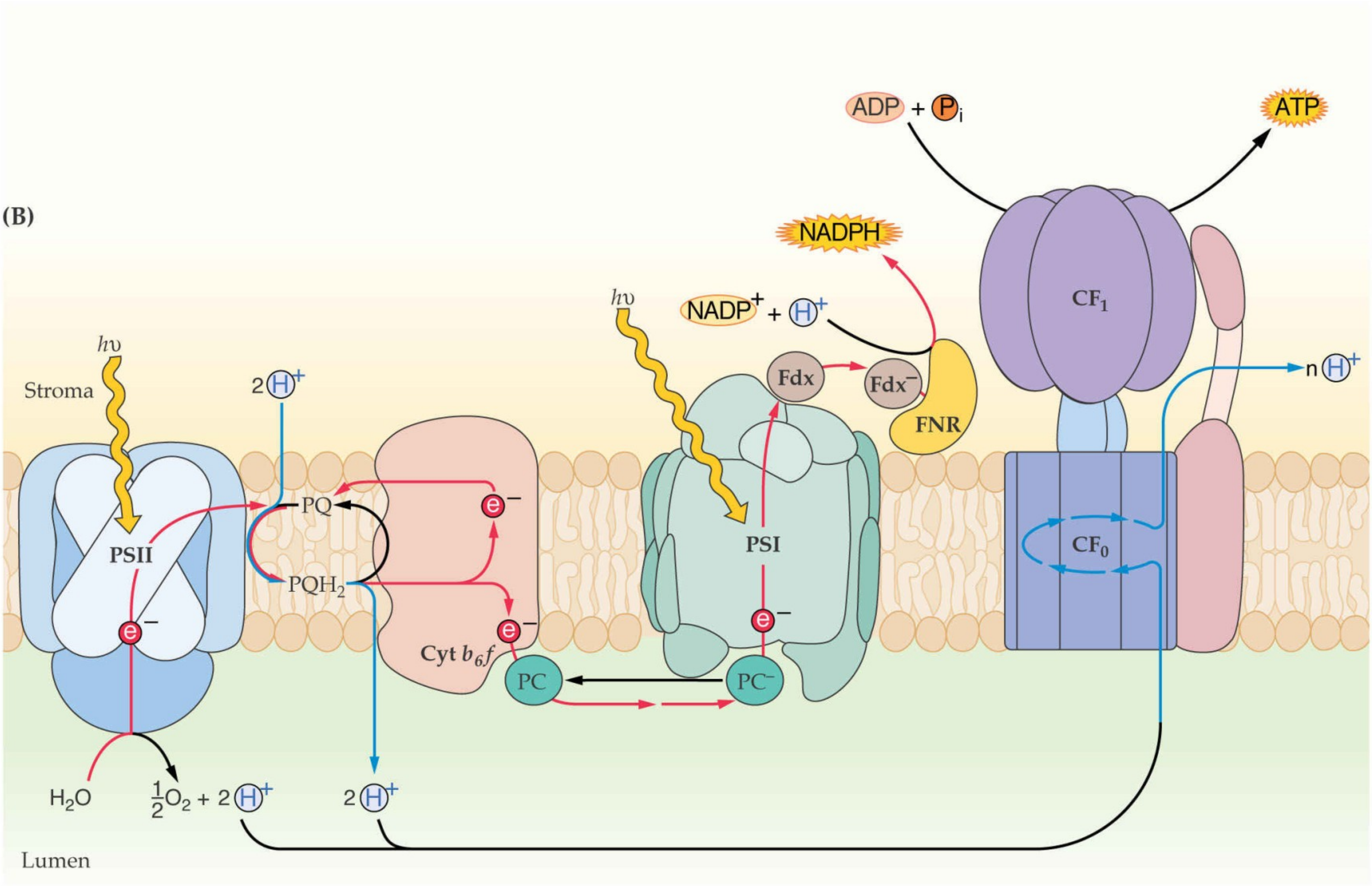
$$\text{Chl } A_O A_1 A_2 \xrightarrow{h\nu} \text{Chl}^* A_O A_1 A_2 \longrightarrow \text{Chl}^+ A_O^- A_1 A_2 \longrightarrow \text{Chl}^+ A_O A_1^- A_2 \longrightarrow \text{Chl}^+ A_O A_1 A_2^-$$

Electron transport pathways

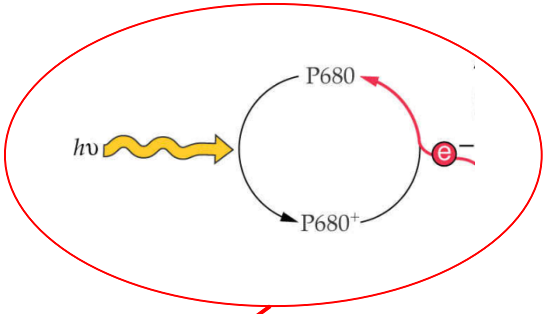
The chloroplast noncyclic electron transport chain produces O_2, NADPH, and ATP and involves the cooperation of PSI and PSII

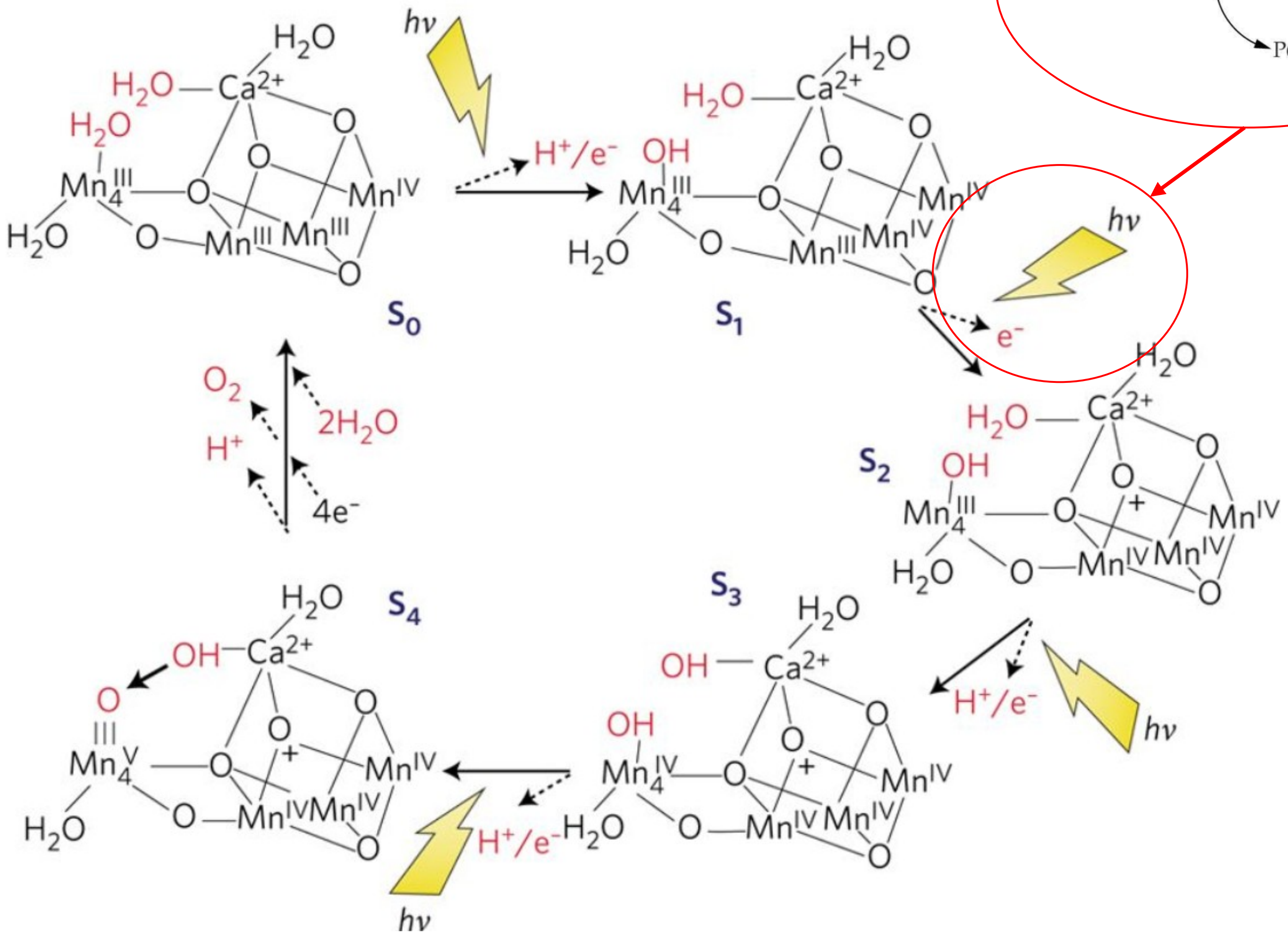


Electron transport pathways



Oxidation of water

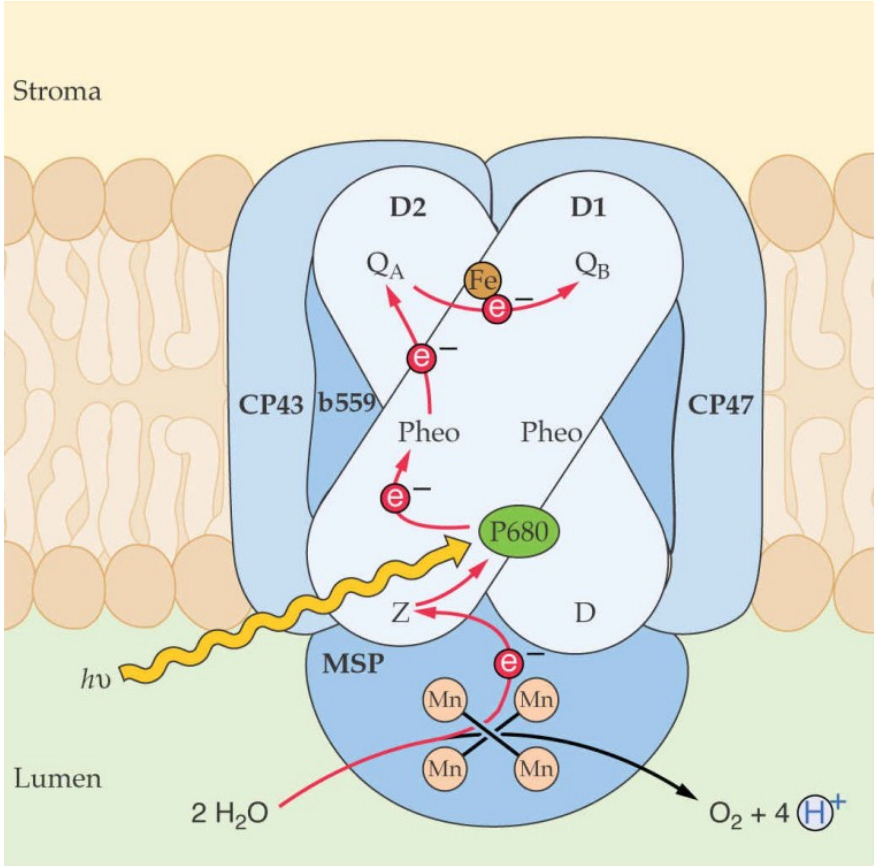




Barber, Nature Plants 3 (2017)

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

PSII

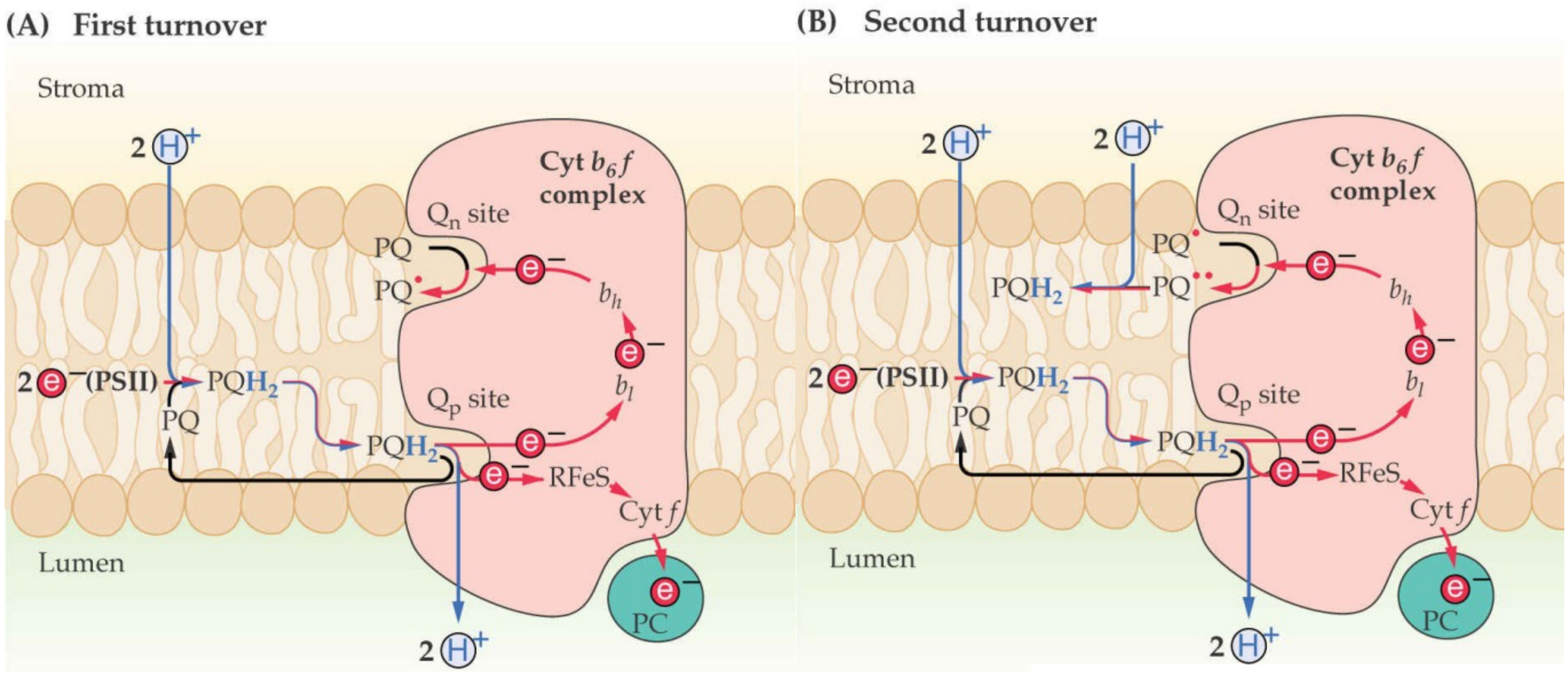


1. P680 $\longrightarrow$ Q_A $\quad Q_B$
2. $P680^+$ $\quad Q_A^-$ $\longrightarrow$ Q_B
3. P680 $\longrightarrow$ Q_A $\quad Q_B^-$
4. $P680^+$ $\quad Q_A^-$ $\longrightarrow$ Q_B^-

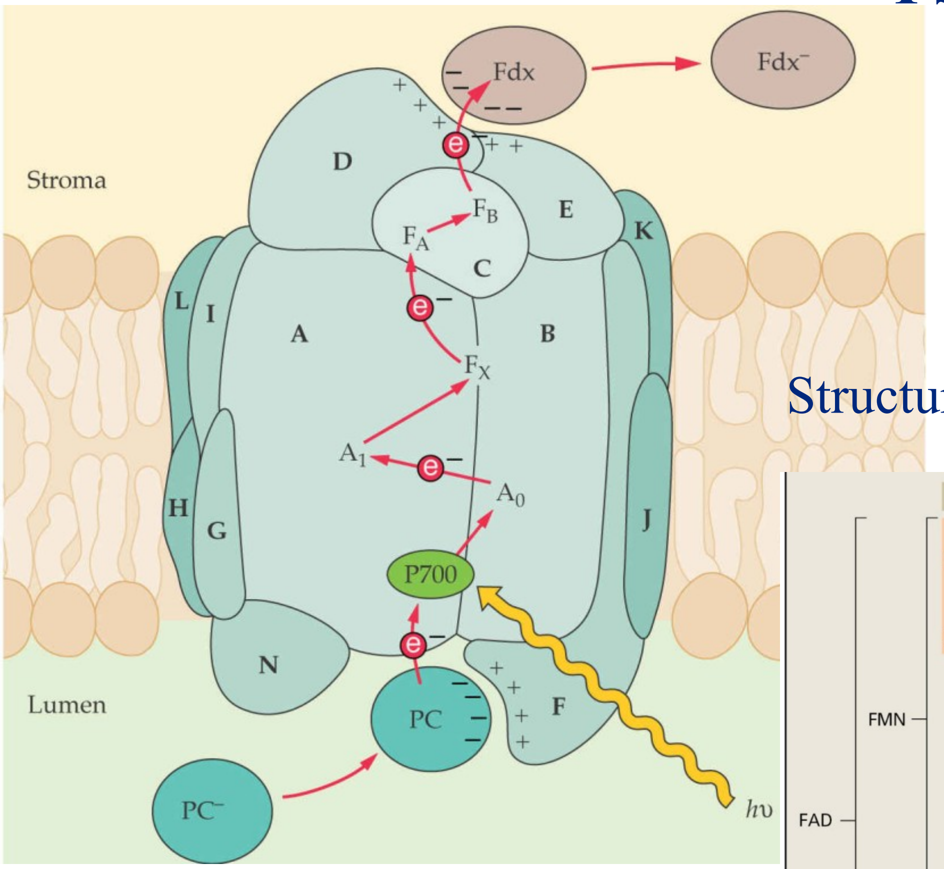
$Q_B^{2-} + 2H^+ \longrightarrow Q_BH_2$

$$QH_2 + 2PC_{ox} + 2H^+_{stroma} \longrightarrow Q + 2PC_{red} + 4H^+_{lumen}$$

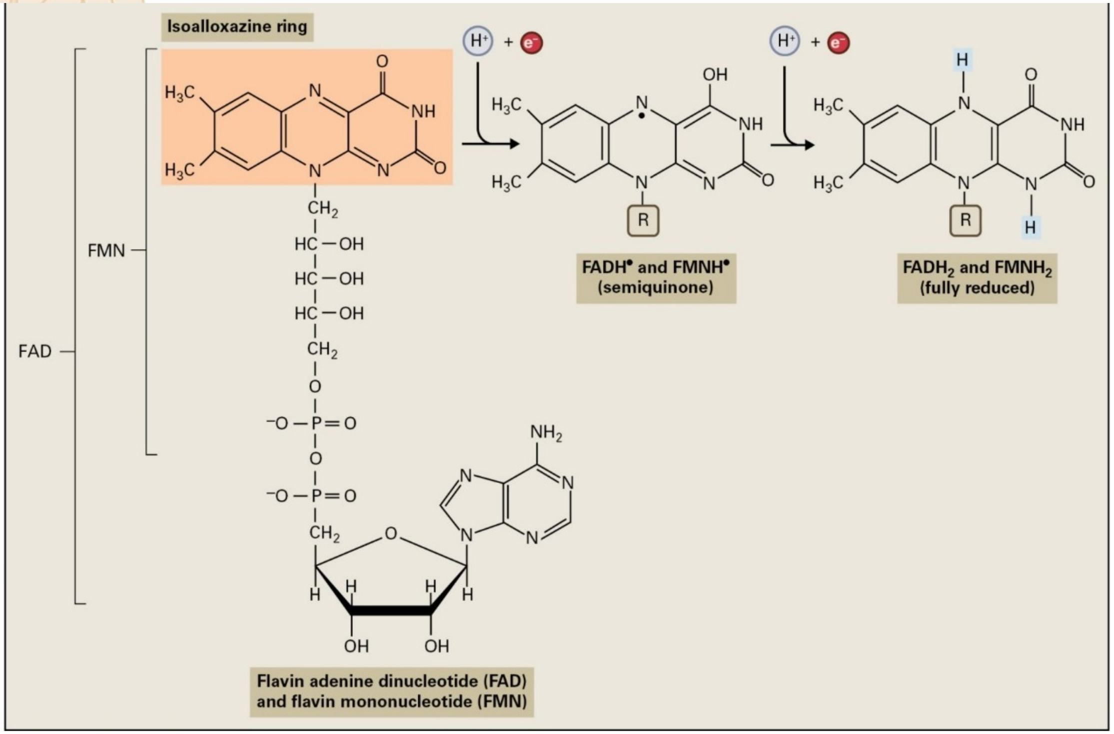
Cytochrome b_6f



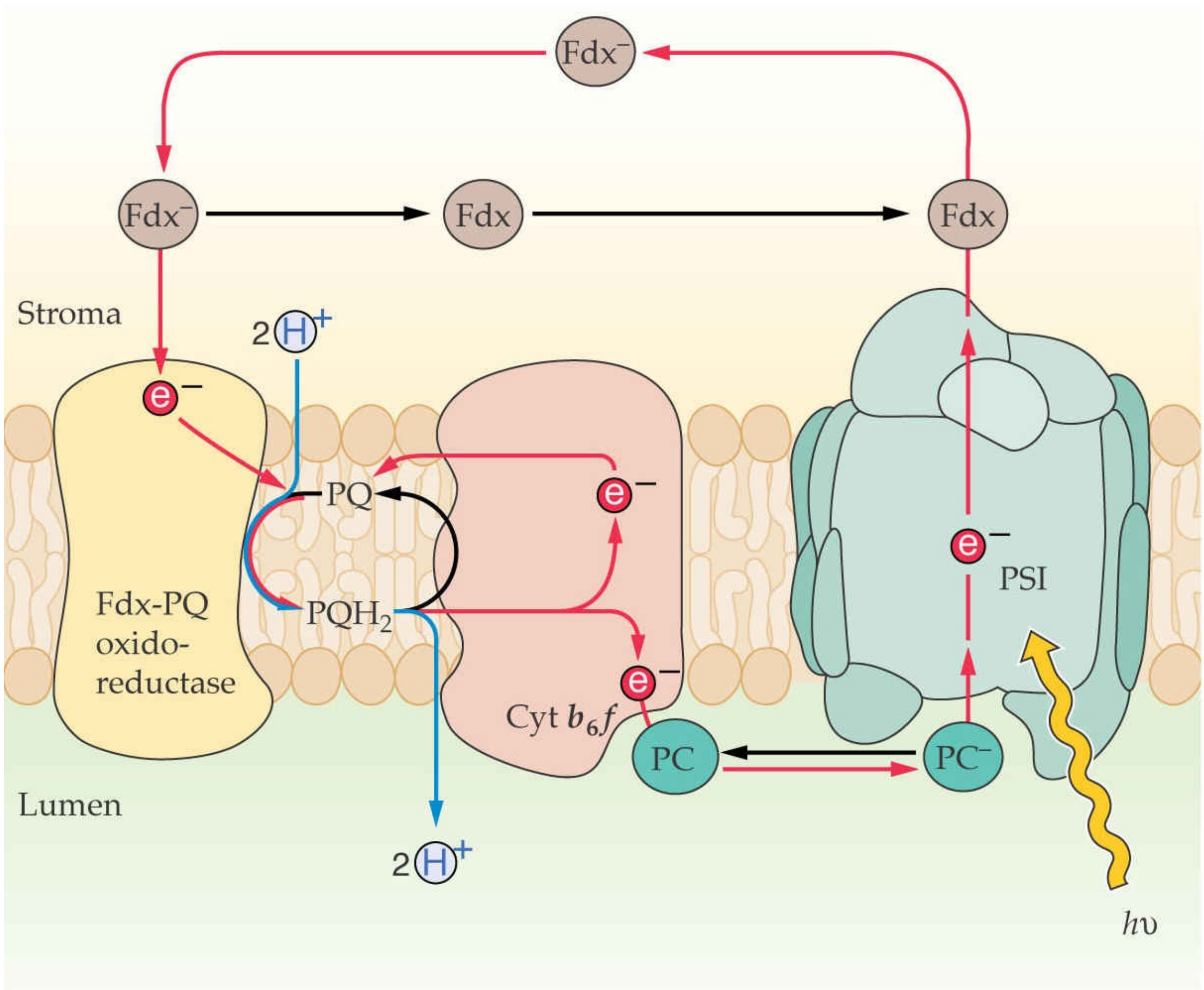
PSI



Structure and redox chemistry of flavin coenzymes

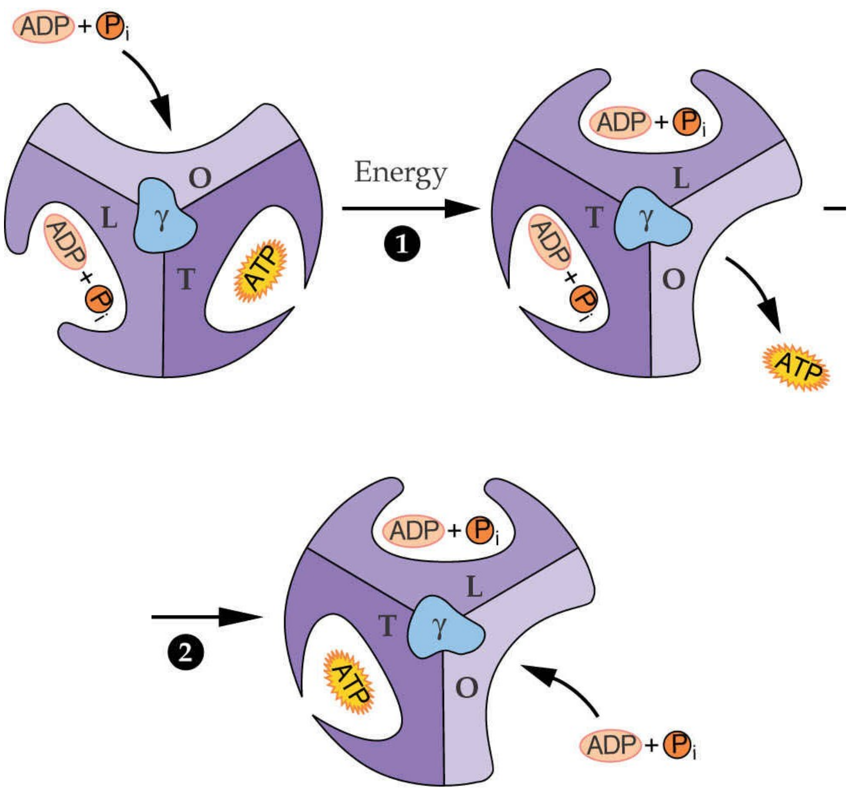


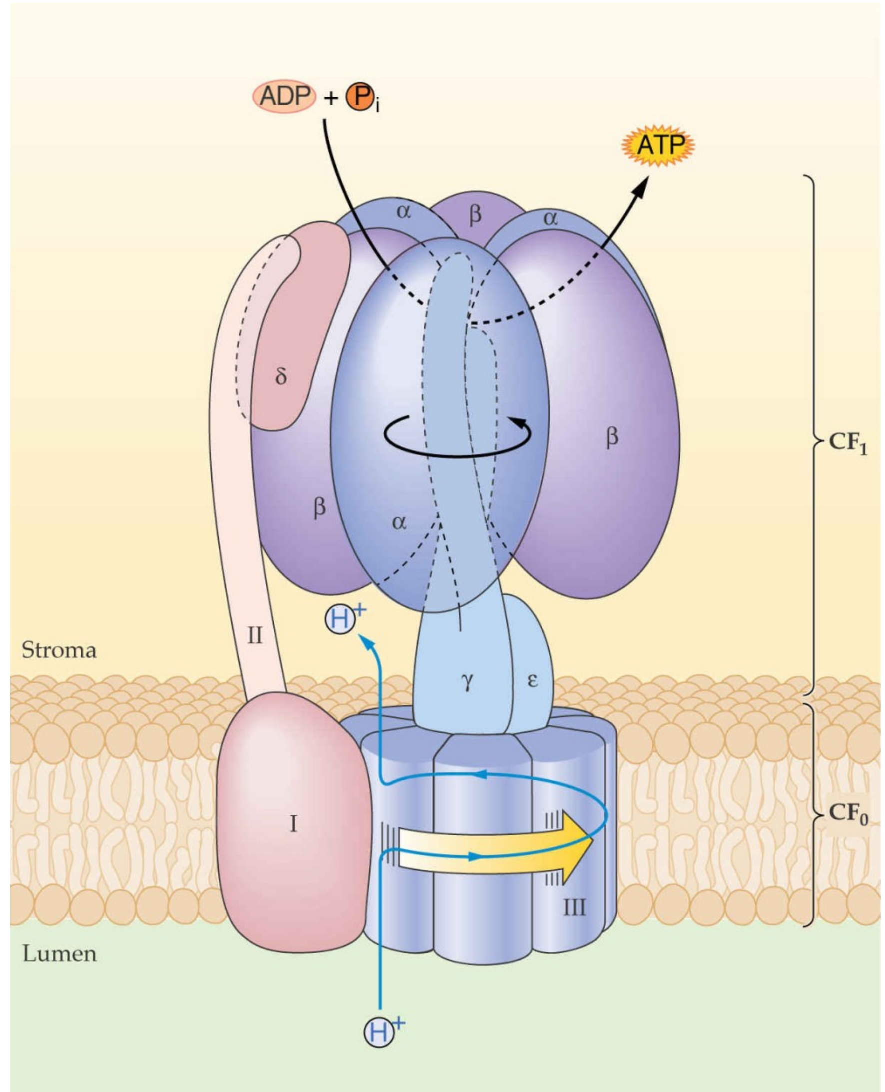
Cyclic electron transport chain



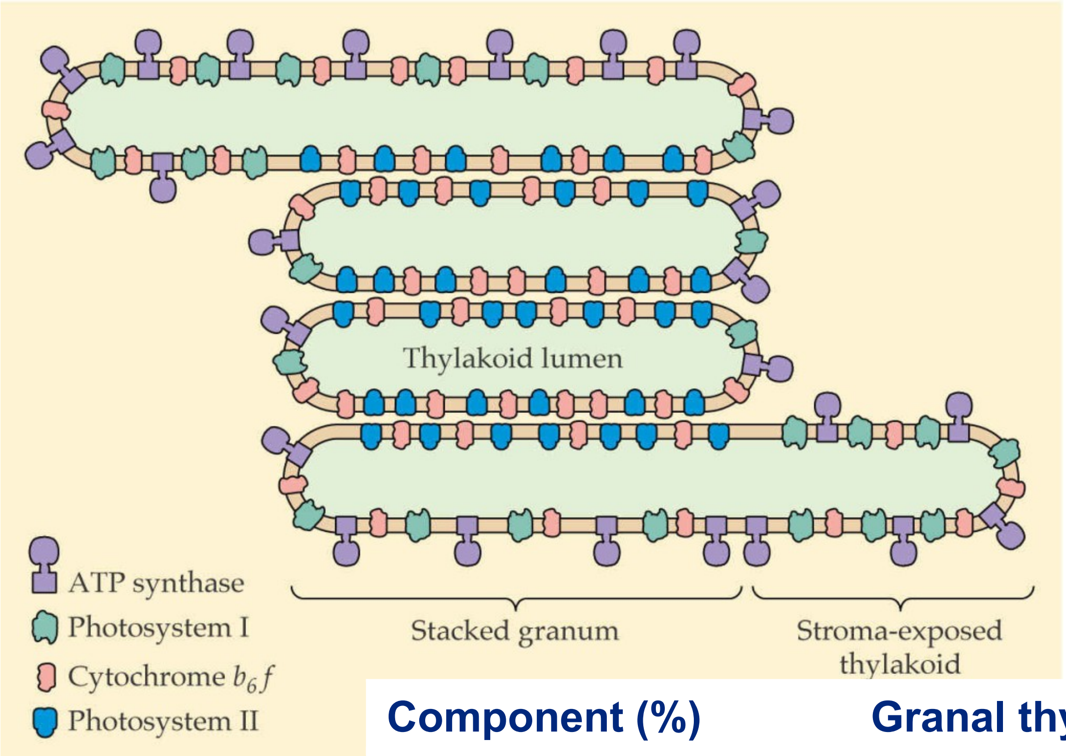
ATP synthesis in chloroplasts

Chloroplasts synthesize ATP by a chemiosmotic mechanism driven by a proton gradient





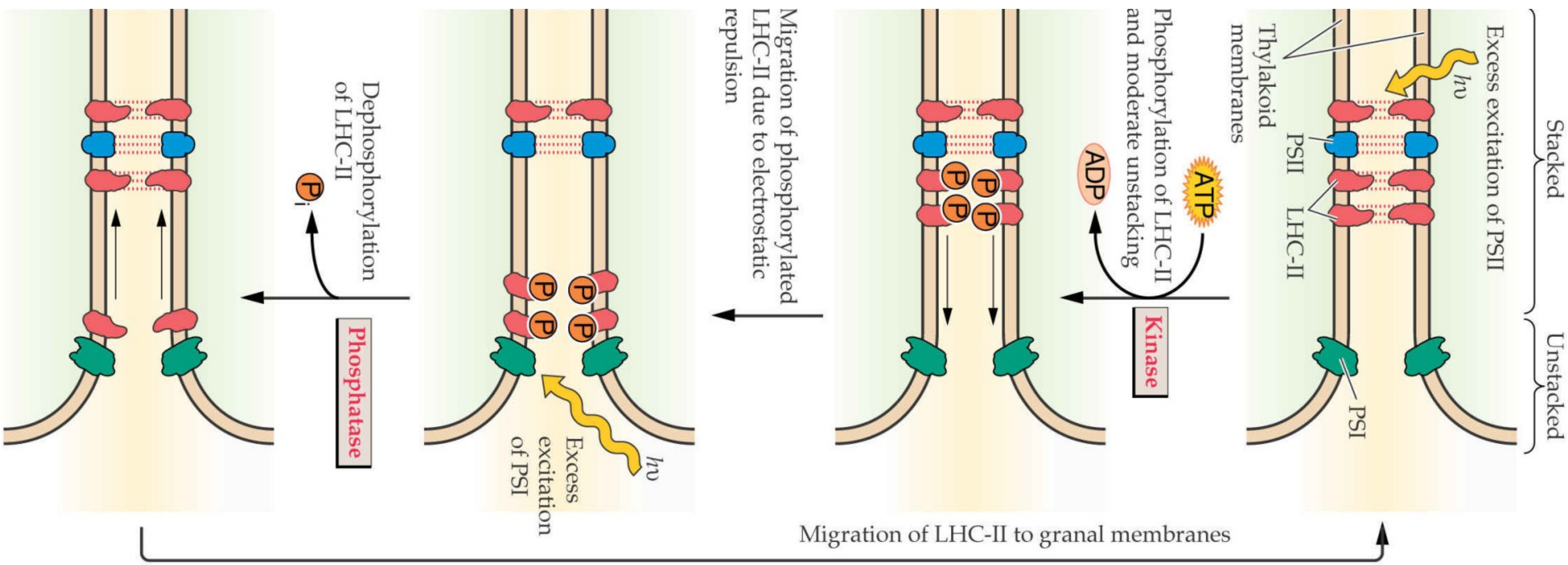
Organization of the thylakoid membrane



Component (%)	Granal thylakoids	Stromatal thylakoids
PSII	85	15
PSI	10	90
Cytochrome b_6f complex	50	50
LHC-II	90	10
ATP synthase	0	100
Plastocyanin	40	60

Energy distribution between PSI and PSII

Balanced excitation of both photosystems is required for maximum electron transfer efficiency

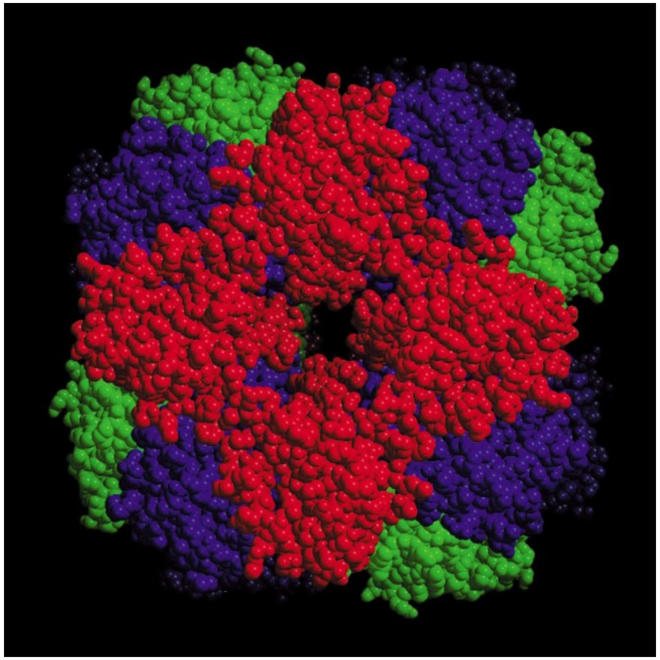


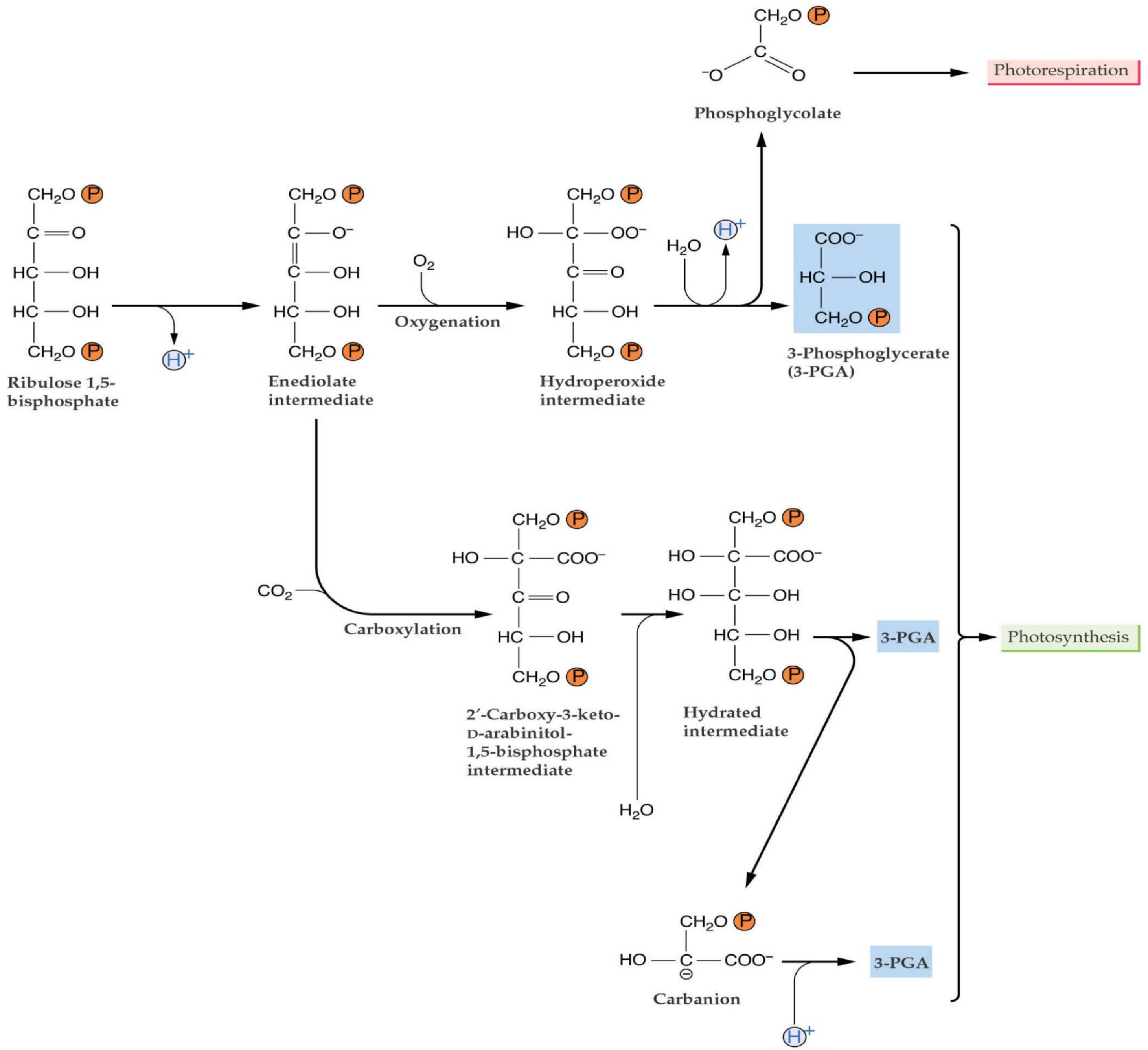
Carbon reactions in C_3 plants

- C_3 plants produce a three-carbon compound as the first stable product.

- In these plants, photosynthetic carbon fixation is catalyzed by a single enzyme, Rubisco.

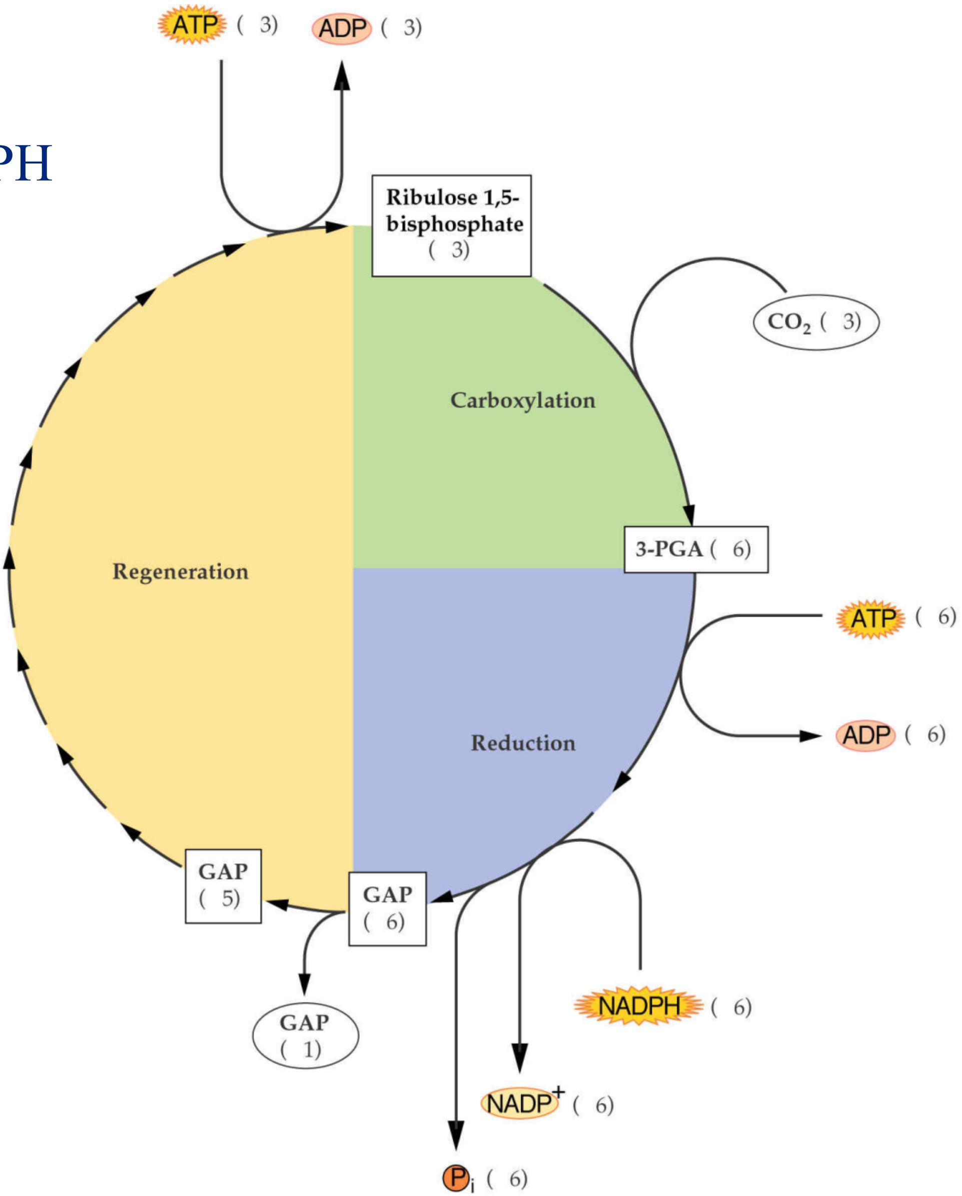
- Rubisco, probably the most prevalent protein on Earth, constitutes up to half the protein of the chloroplast stroma




Phosphoglycolate
Photorespiration
Oxygenation
3-Phosphoglycerate
(3-PGA)
Ribulose 1,5-
bisphosphate
Enediolate
intermediate
Hydroperoxide
intermediate
Carboxylation
2′-Carboxy-3-keto-
D-arabinitol-
1,5-bisphosphate
intermediate
Hydrated
intermediate
3-PGA
Photosynthesis
Carbanion
3-PGA

Carbon reactions (Calvin cycle)

Fixation of one molecule of CO_2 requires two molecules of NADPH and three of ATP.



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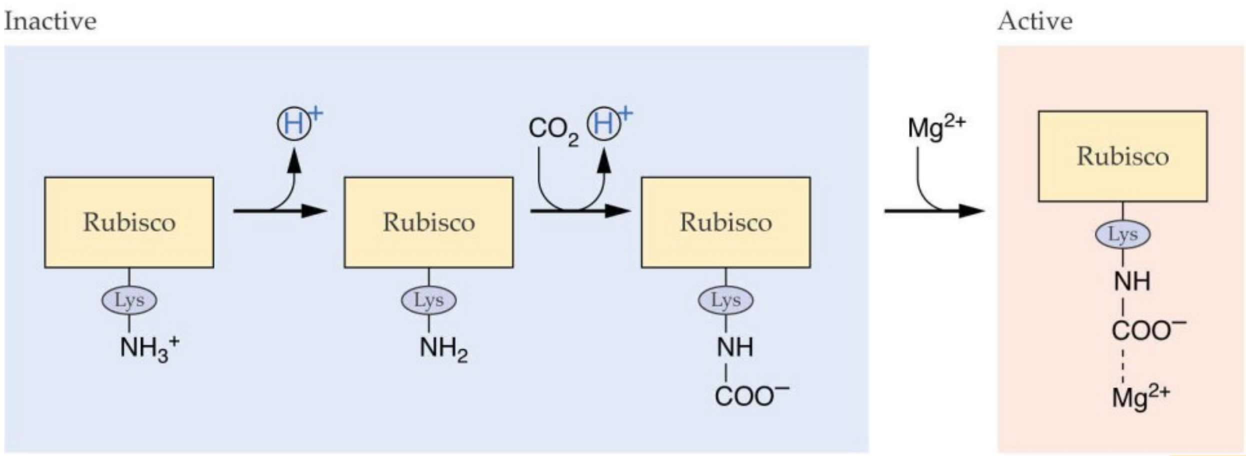
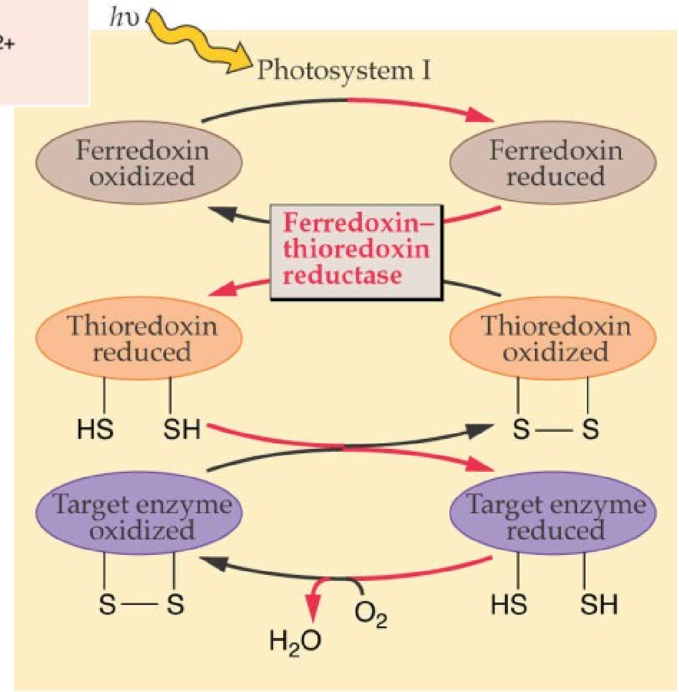
The Calvin cycle regulation

Activation of Rubisco by carbamylation





The ferredoxin-thioredoxin system

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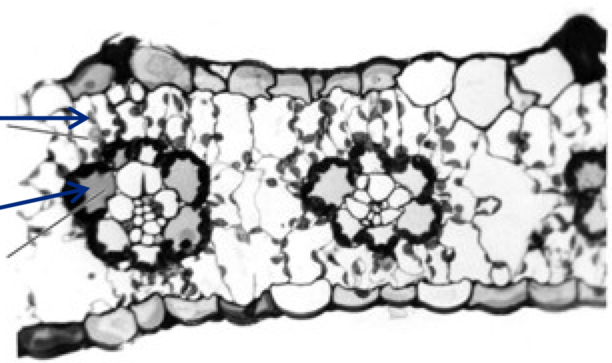
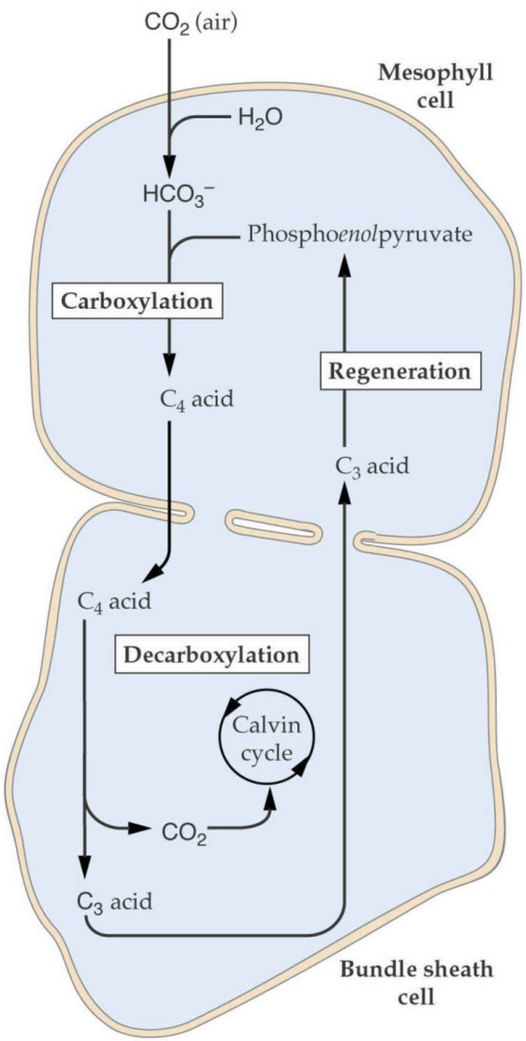
C_4 fixation mechanism

- C_4 plants contain two distinct CO_2-fixing enzymes
- They have specialized foliar anatomy:

Mesophyll cell

Bundle sheat cell





- They form four-carbon organic acids as the first products of CO_2 fixation

CAM fixation mechanism