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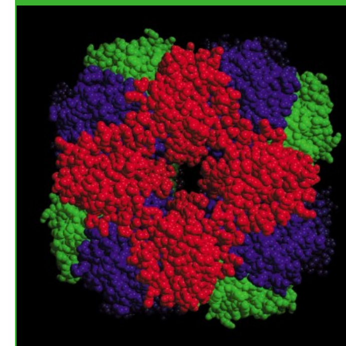


Photosynthesis

Katerina Dadakova, Department of Biochemistry

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

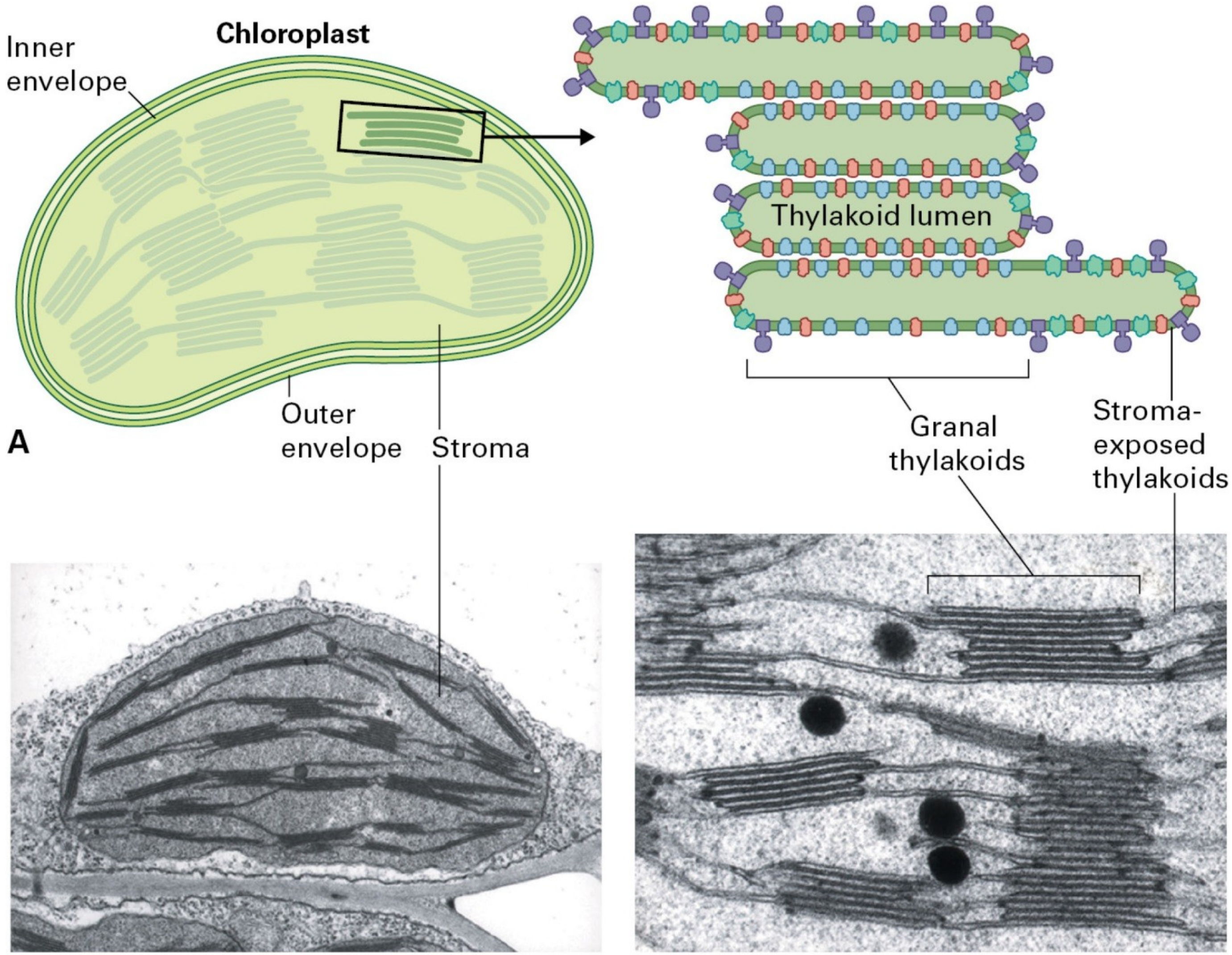
Using light energy to synthesize organic compounds from inorganic precursors

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

Oxygenic photosynthesis

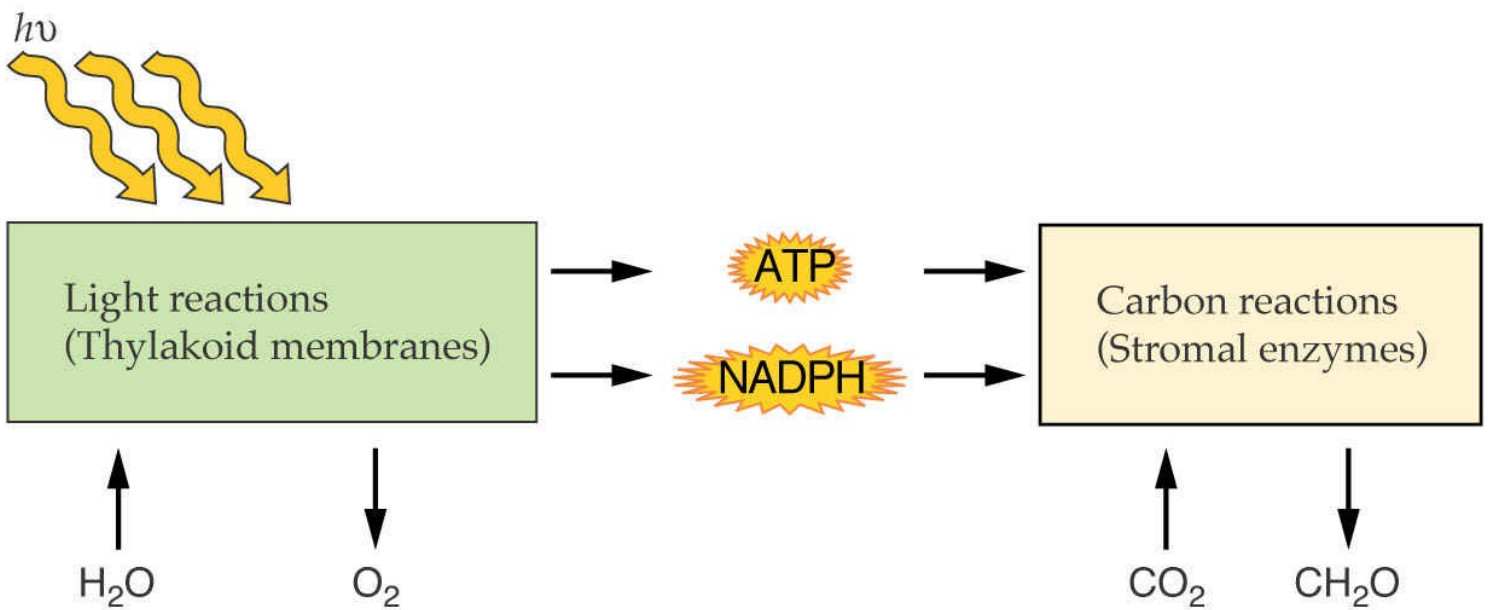
The free energy change is $\Delta G = +2840$ kJ per mol of glucose formed

Plant chloroplast



Two phases of photosynthesis

Water oxidation and CO_2 reduction are not obligately linked.

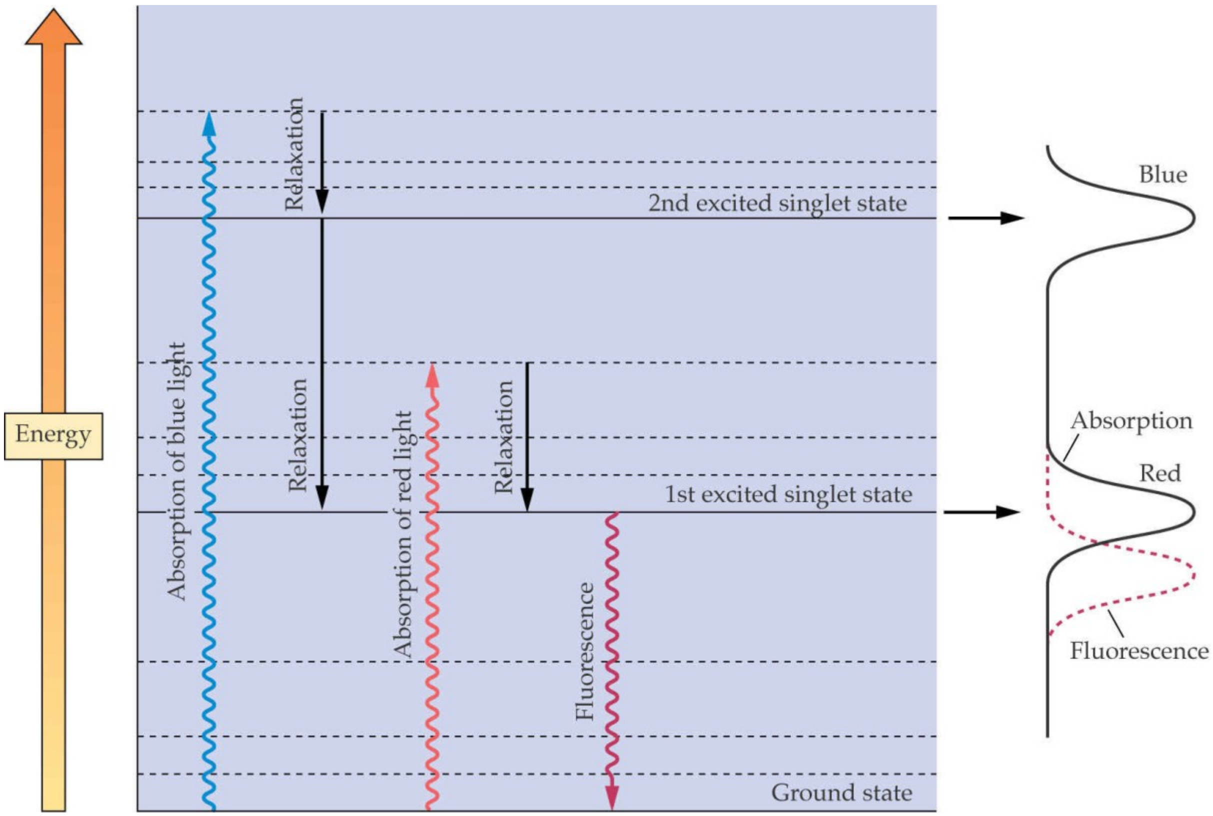


Light absorption

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

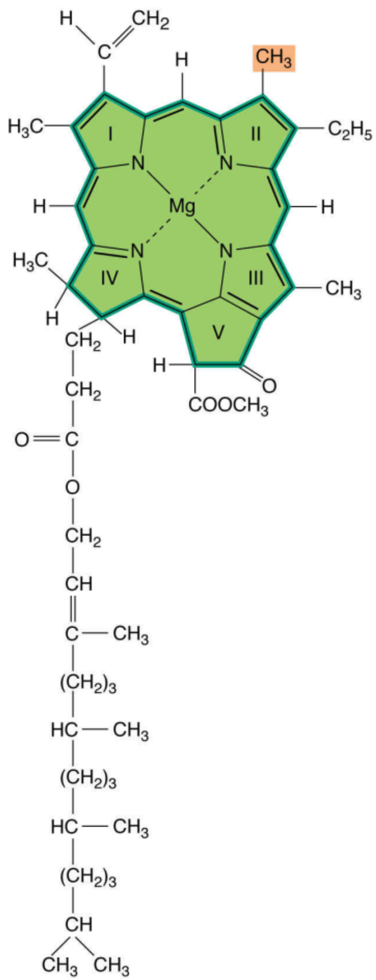
Mechanisms of energy release:

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

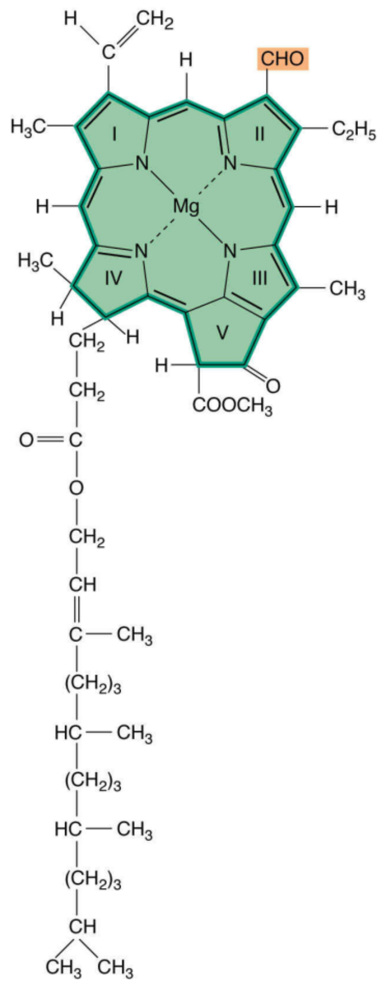
$$\text{pigment} + \text{acceptor} \xrightarrow{h\nu} \text{pigment}^* + \text{acceptor} \longrightarrow \text{pigment}^+ + \text{acceptor}^-$$

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

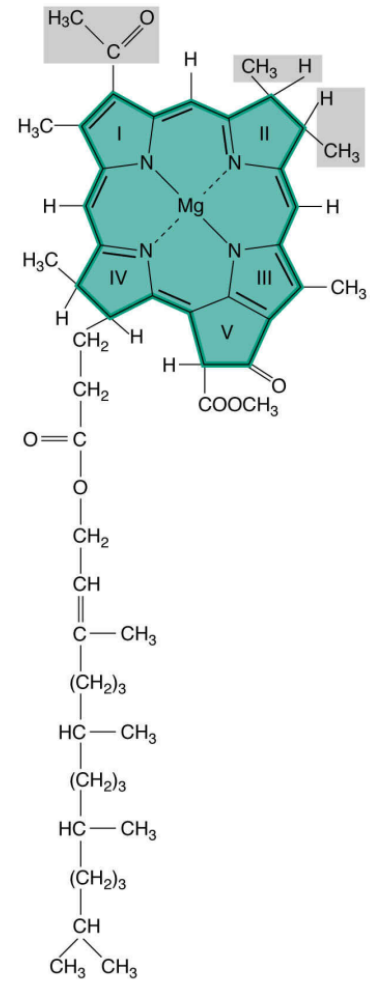
Light absorption



Chlorophyll a



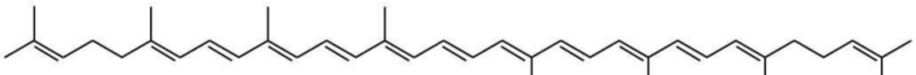
Chlorophyll b



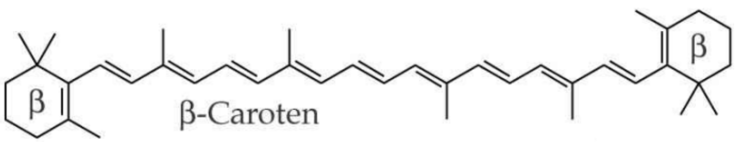
Bacteriochlorophyll

Light absorption

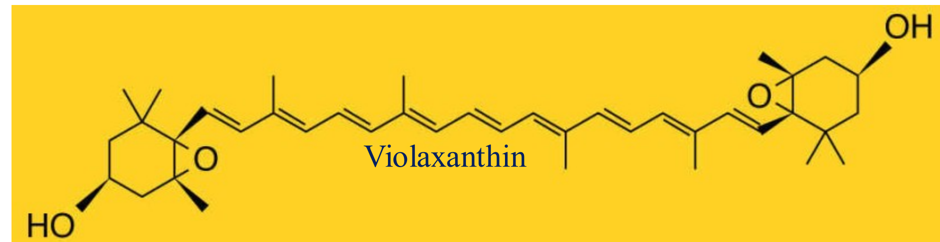
Carotenoids



Lycopen

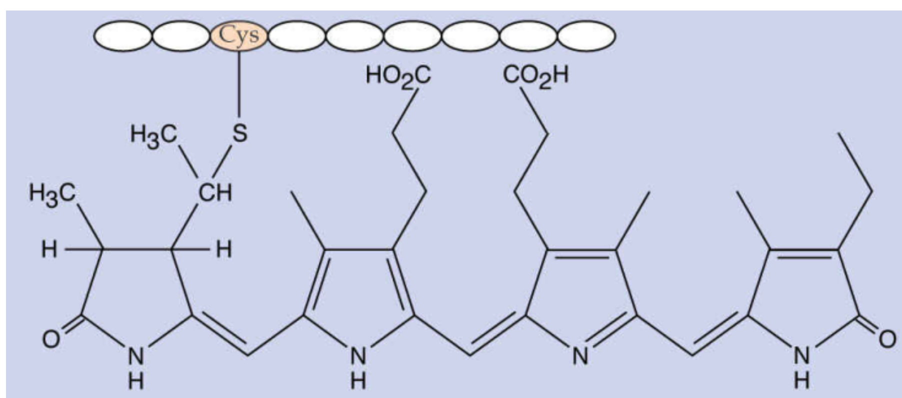


β-Caroten



Violaxanthin

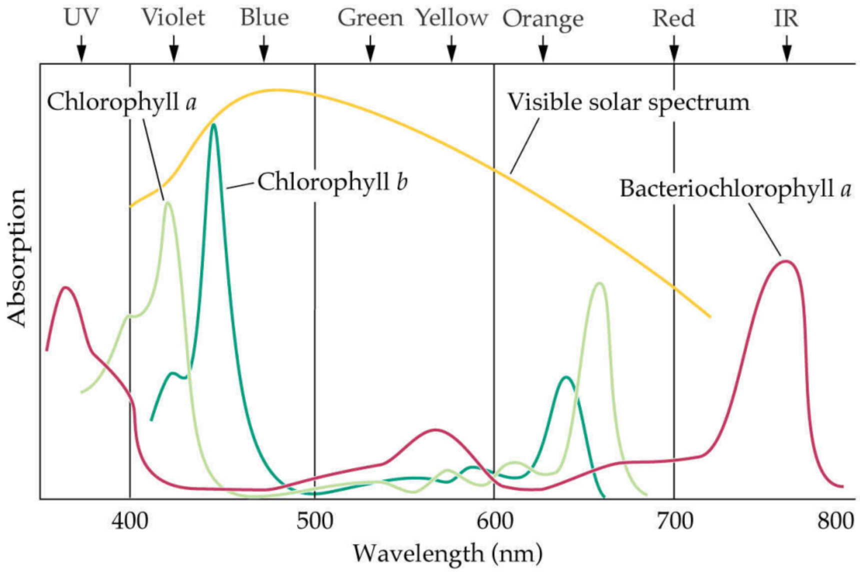
Phycobilins



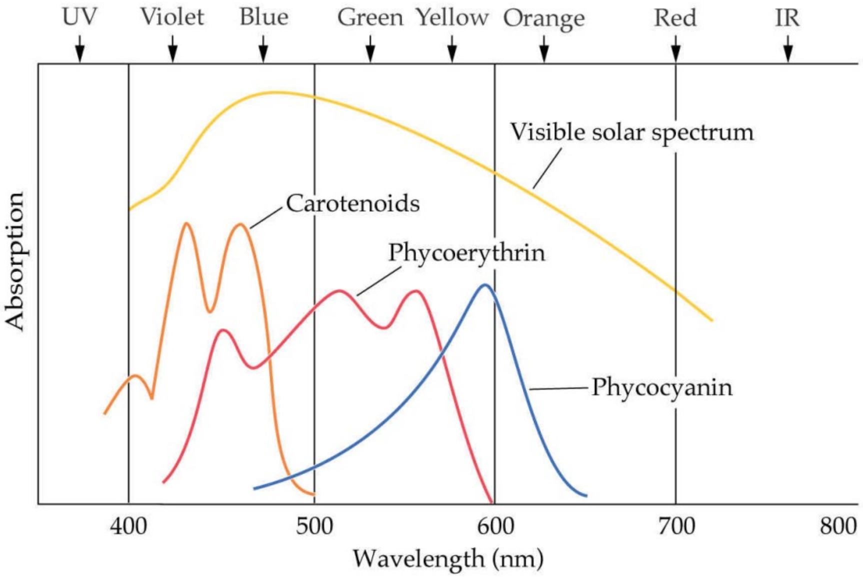
Phycocyanobilin

Light absorption

Chlorophylls



Other pigments



The reaction center complex

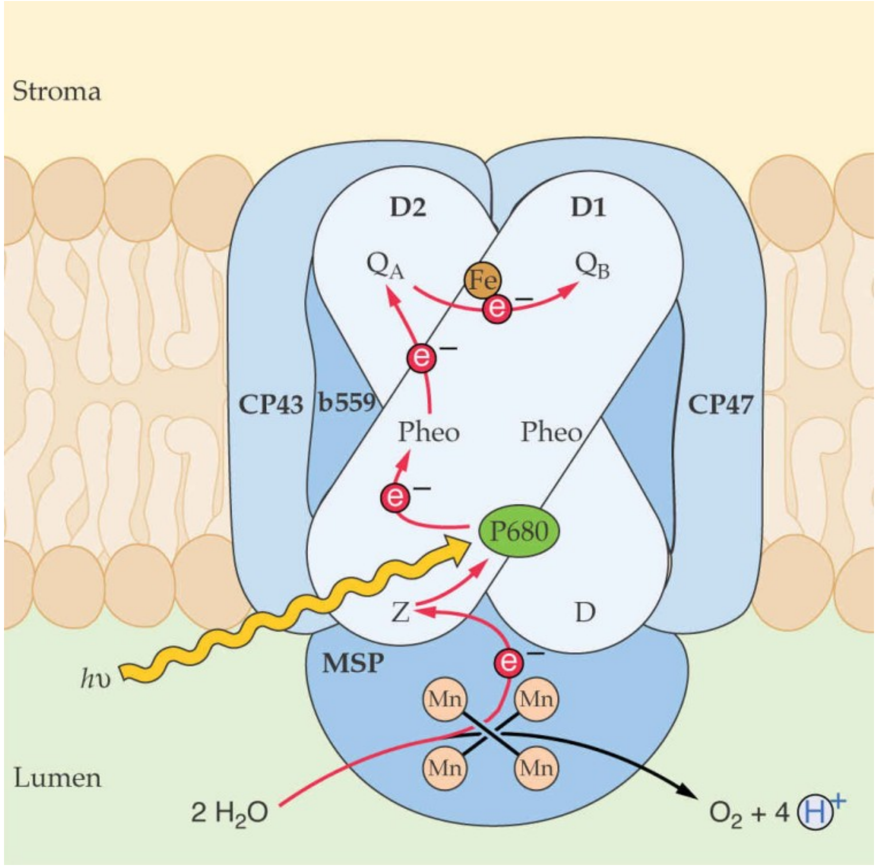
- Reaction centers are integral membrane protein complexes involved in conversion of light energy into chemical products
- Plants contain two different reaction center complexes: Photosystem I and Photosystem II
- Reaction centers contain both chlorophyll and electron acceptor molecules

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)

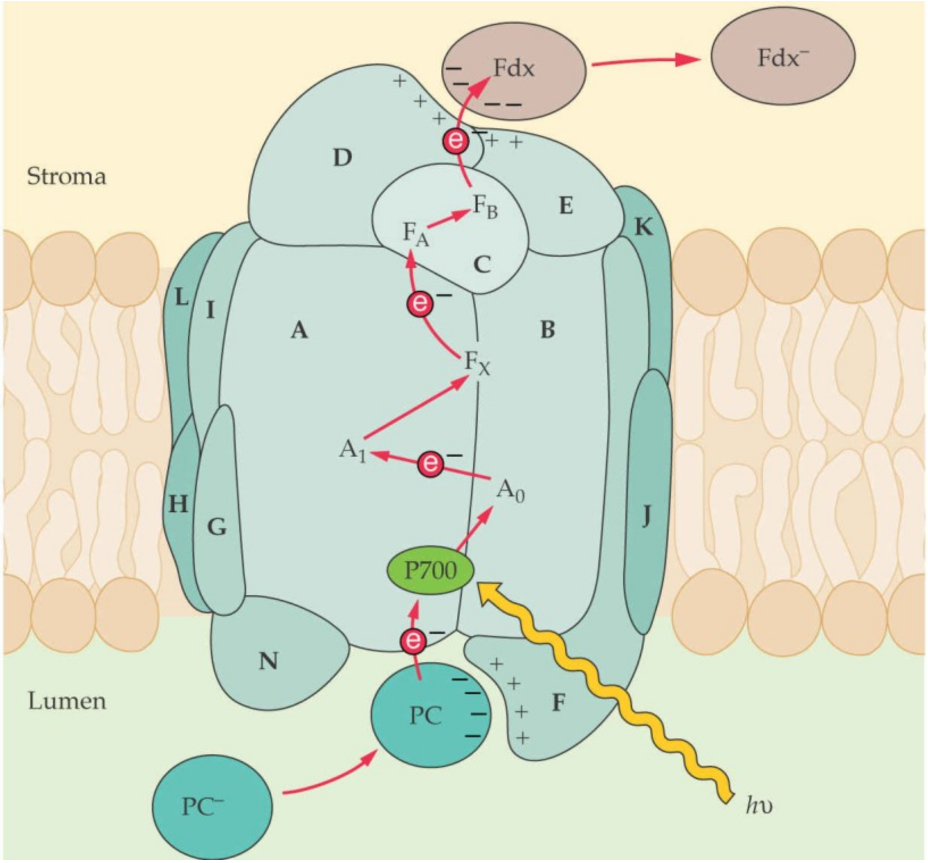
$$\mathrm{Chl}\ A_O A_1 A_2 \xrightarrow{h\nu} \mathrm{Chl}^* A_O A_1 A_2 \longrightarrow \mathrm{Chl}^+ A_O^- A_1 A_2 \longrightarrow \mathrm{Chl}^+ A_O A_1^- A_2 \longrightarrow \mathrm{Chl}^+ A_O A_1 A_2^-$$

Structural models of reaction centers

PSII center

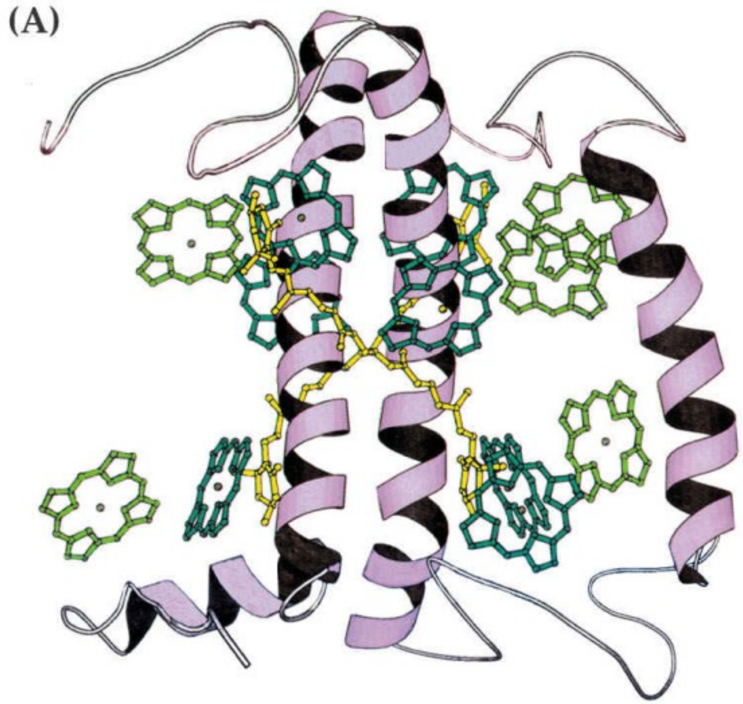


PSI center

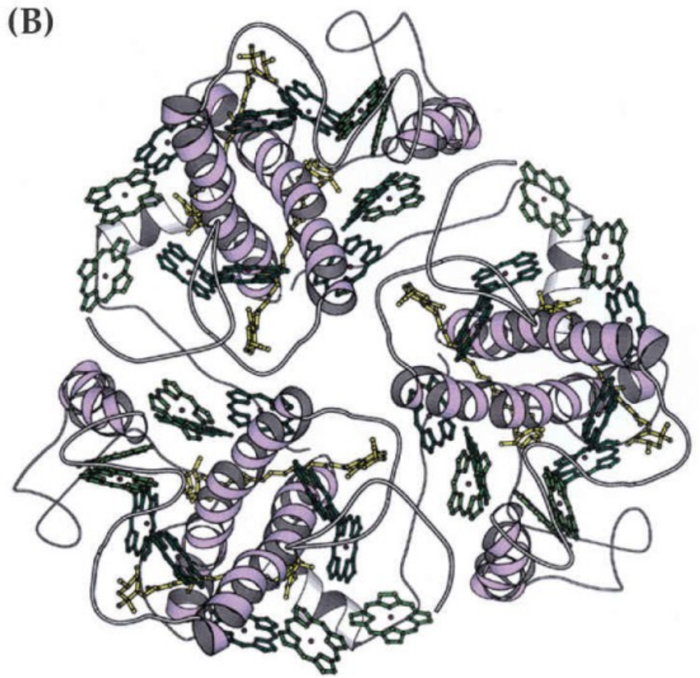


Light harvesting

LHC-II structure

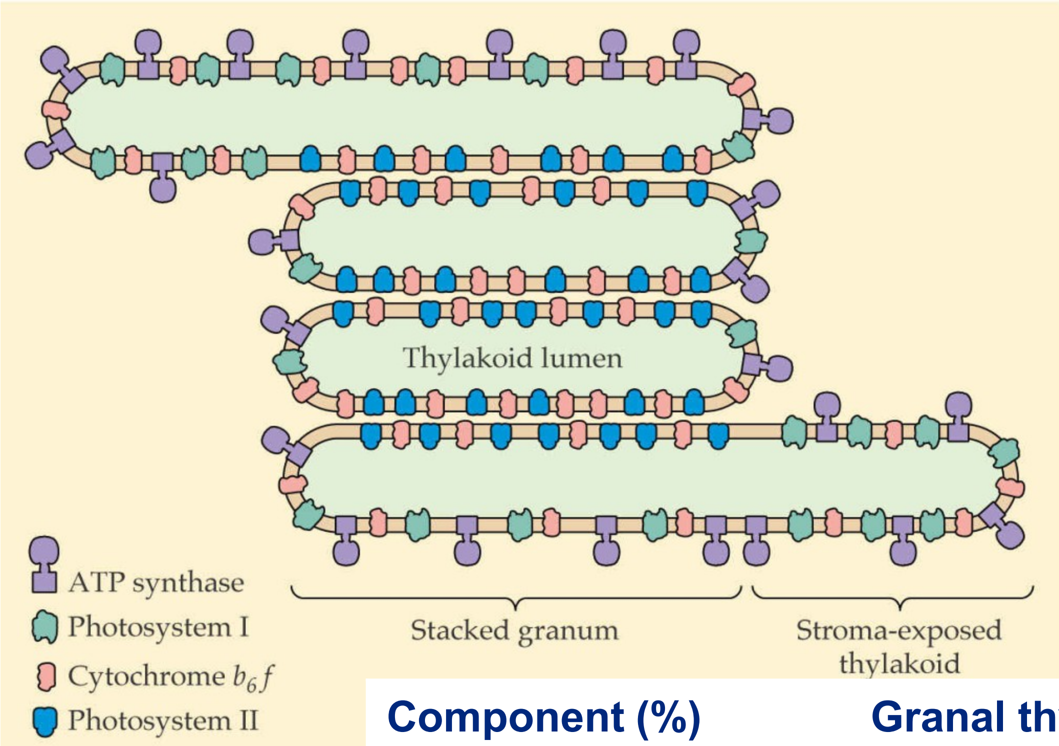


Monomer



Trimer

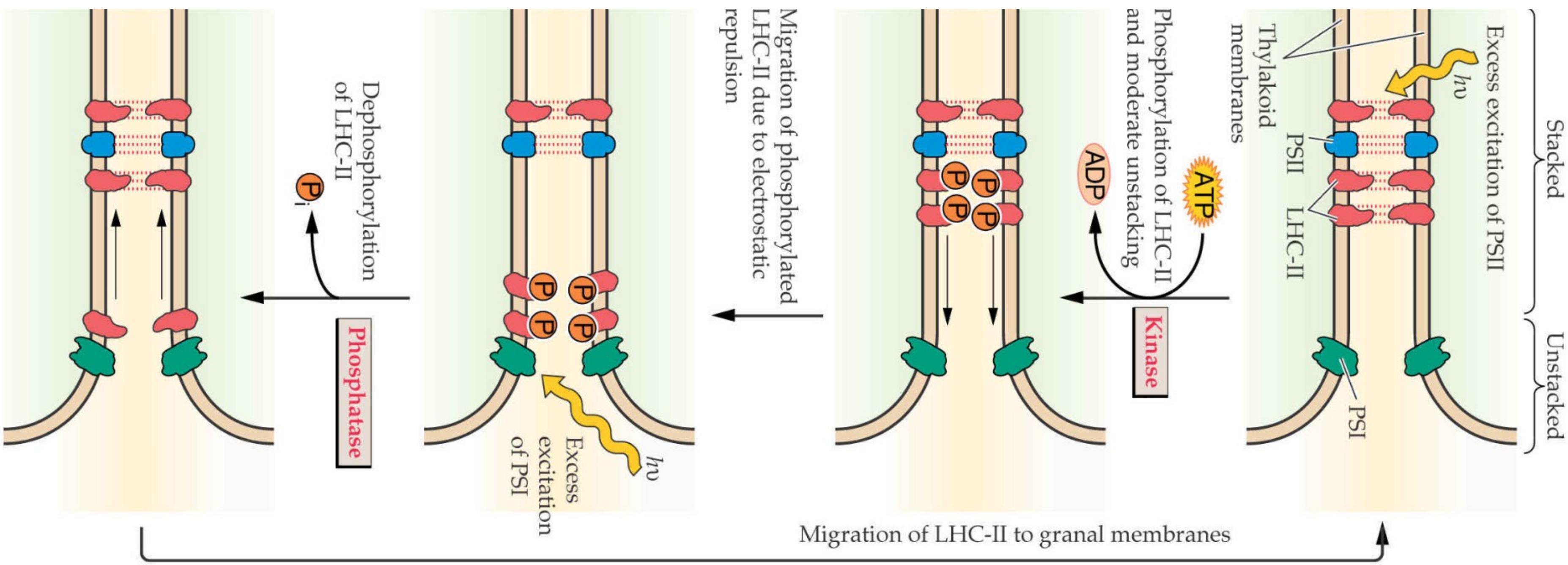
Organization of the thylakoid membrane



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

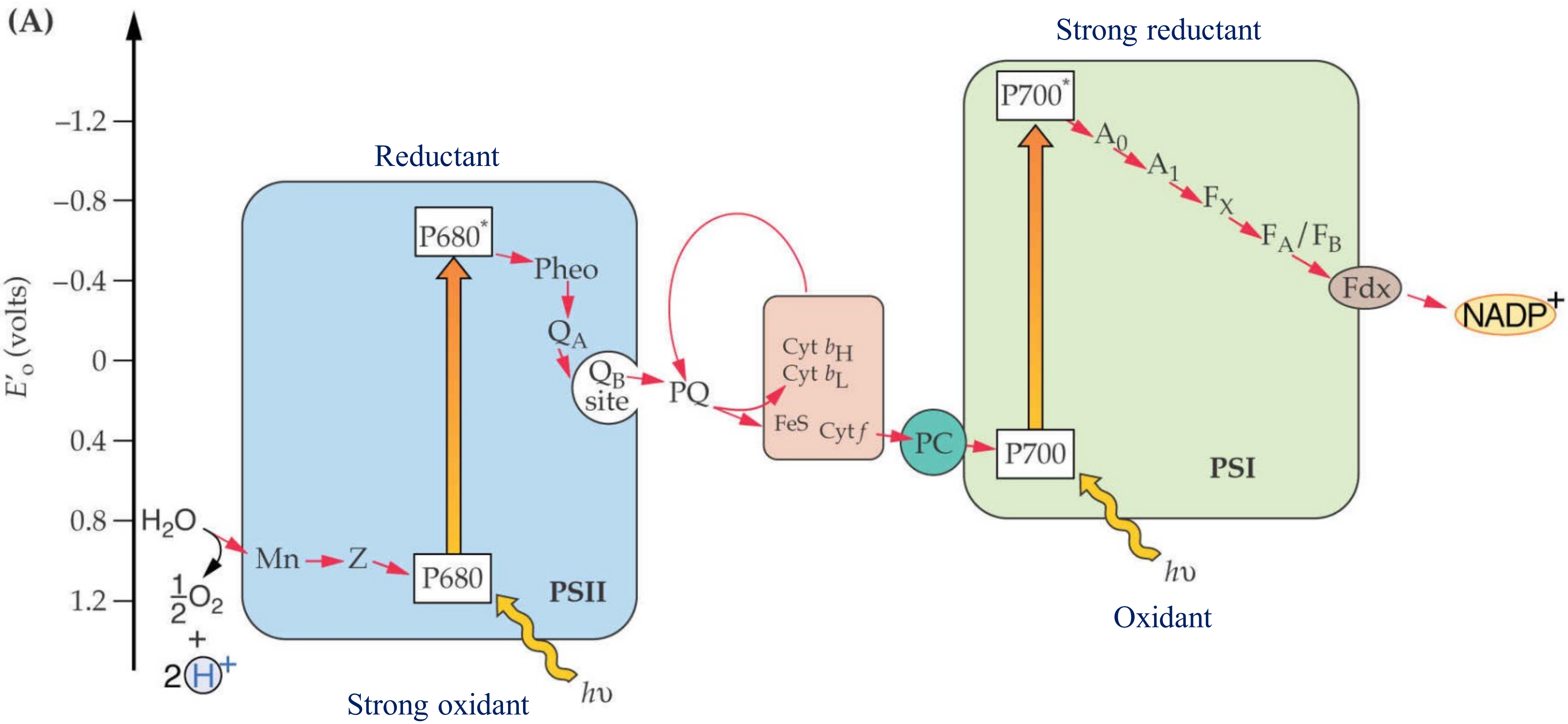
Energy distribution between PSI and PSII

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

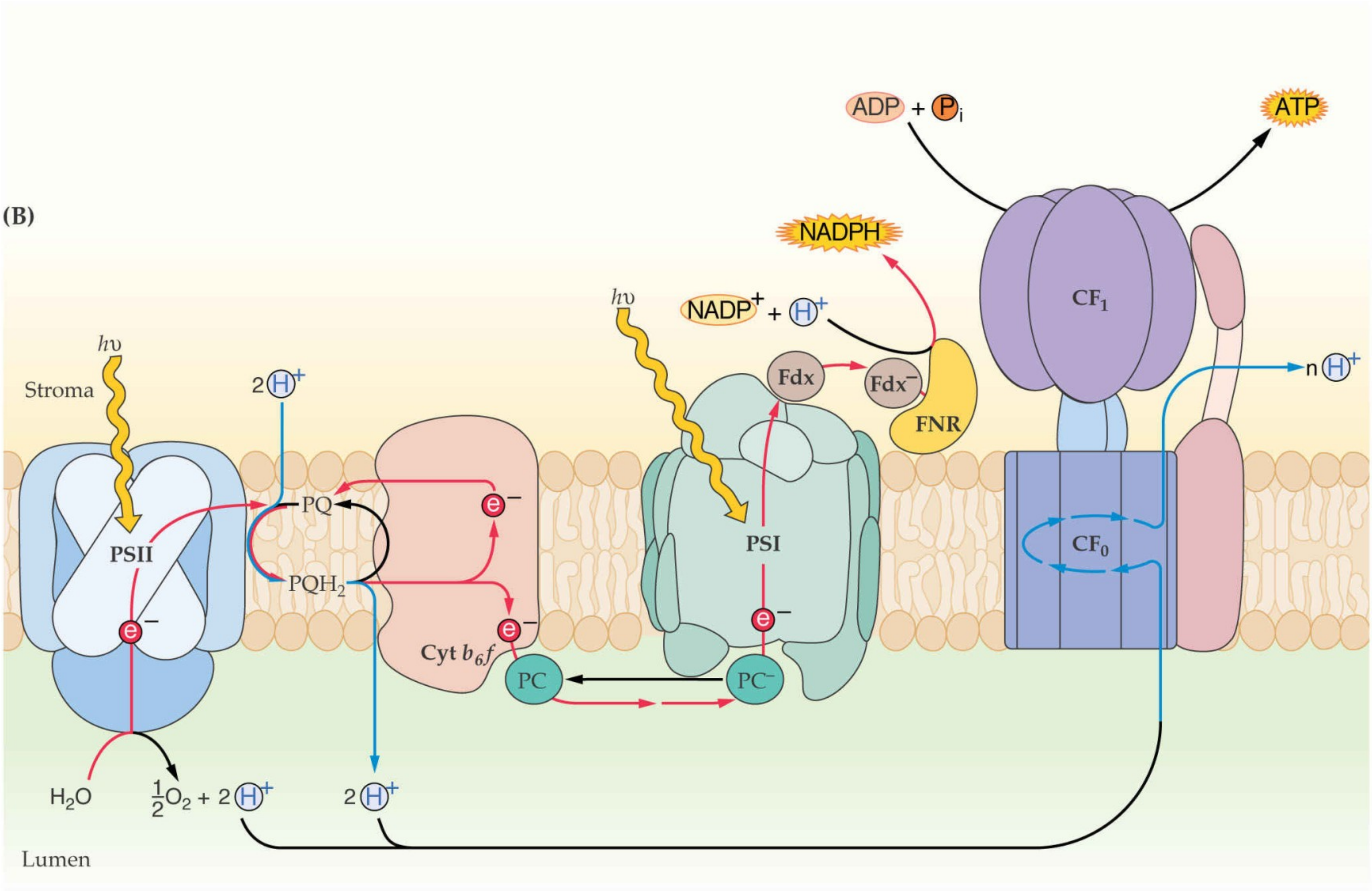


Electron transport pathways

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



Electron transport pathways



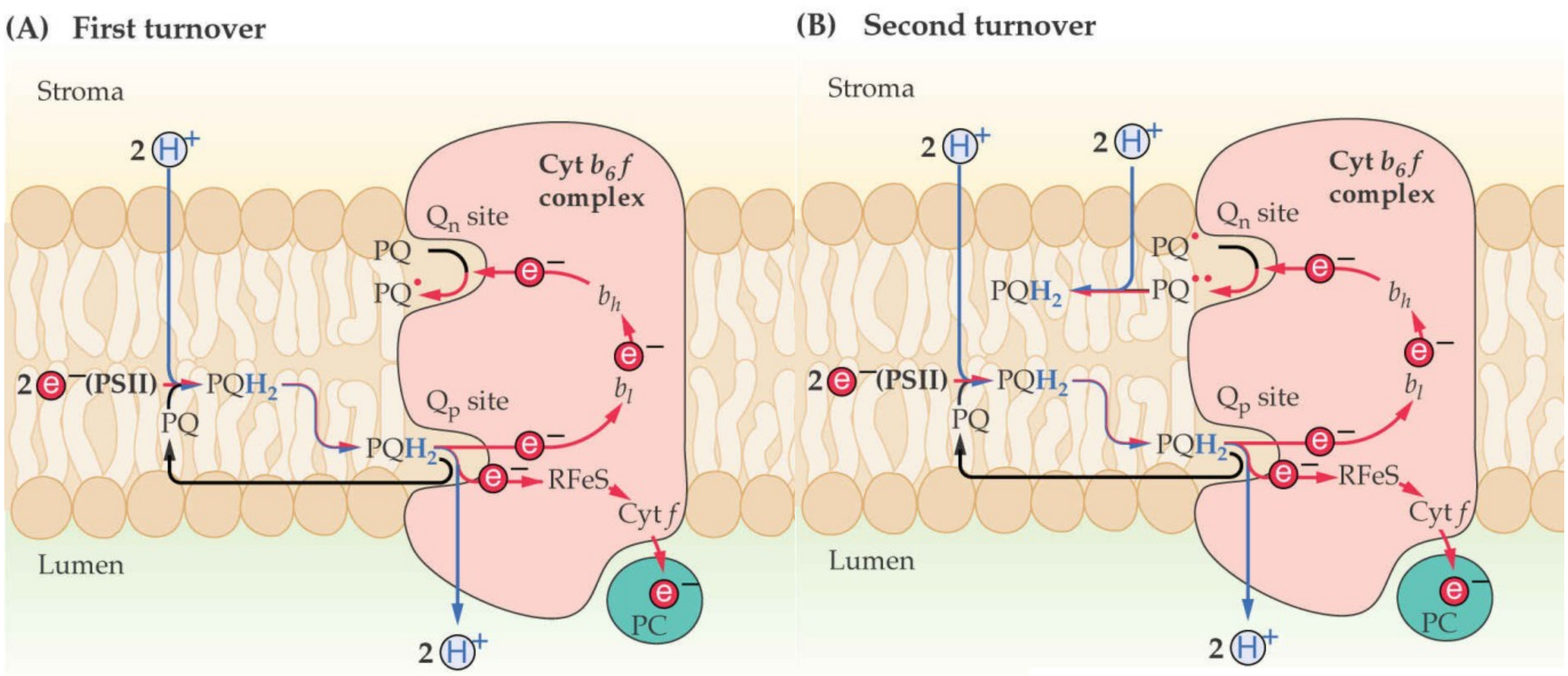
PSII

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

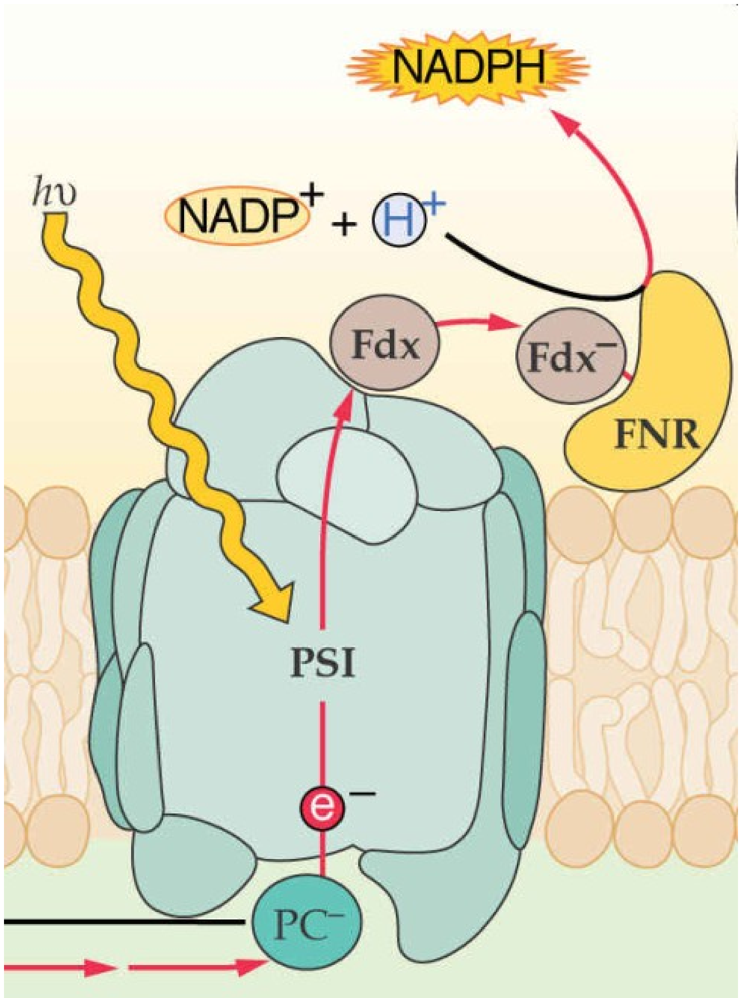
$$Q_B^{2-} + 2H^+ \longrightarrow Q_BH_2$$

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

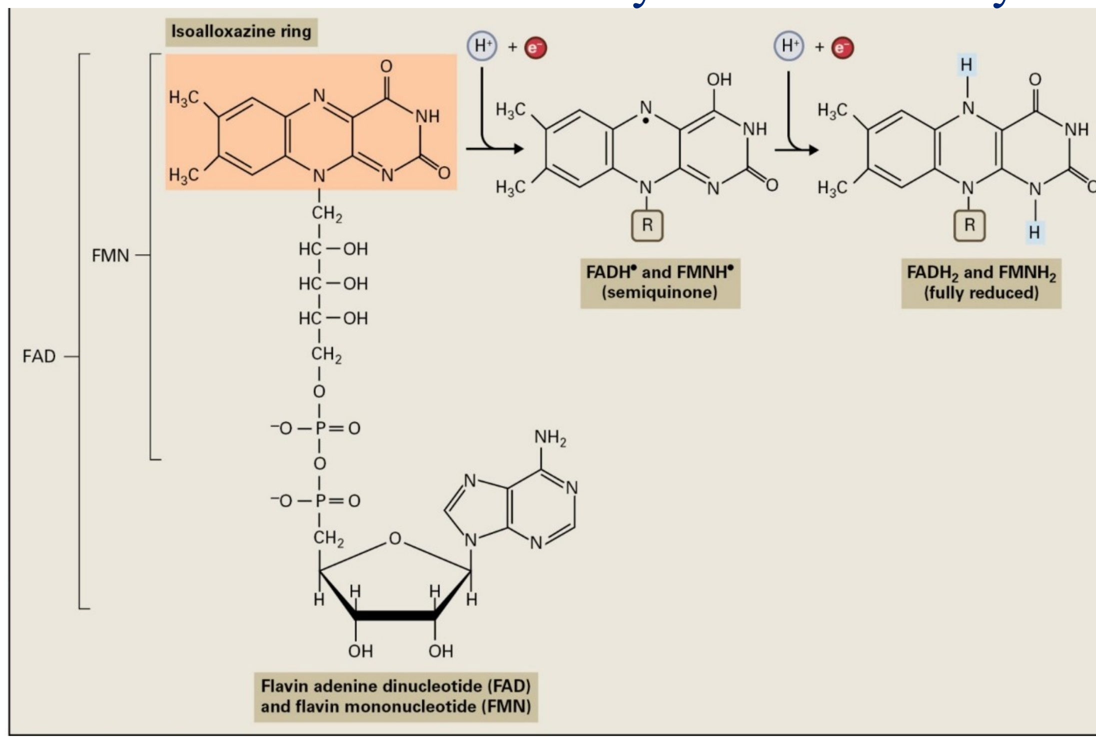
Cytochrome b_6f



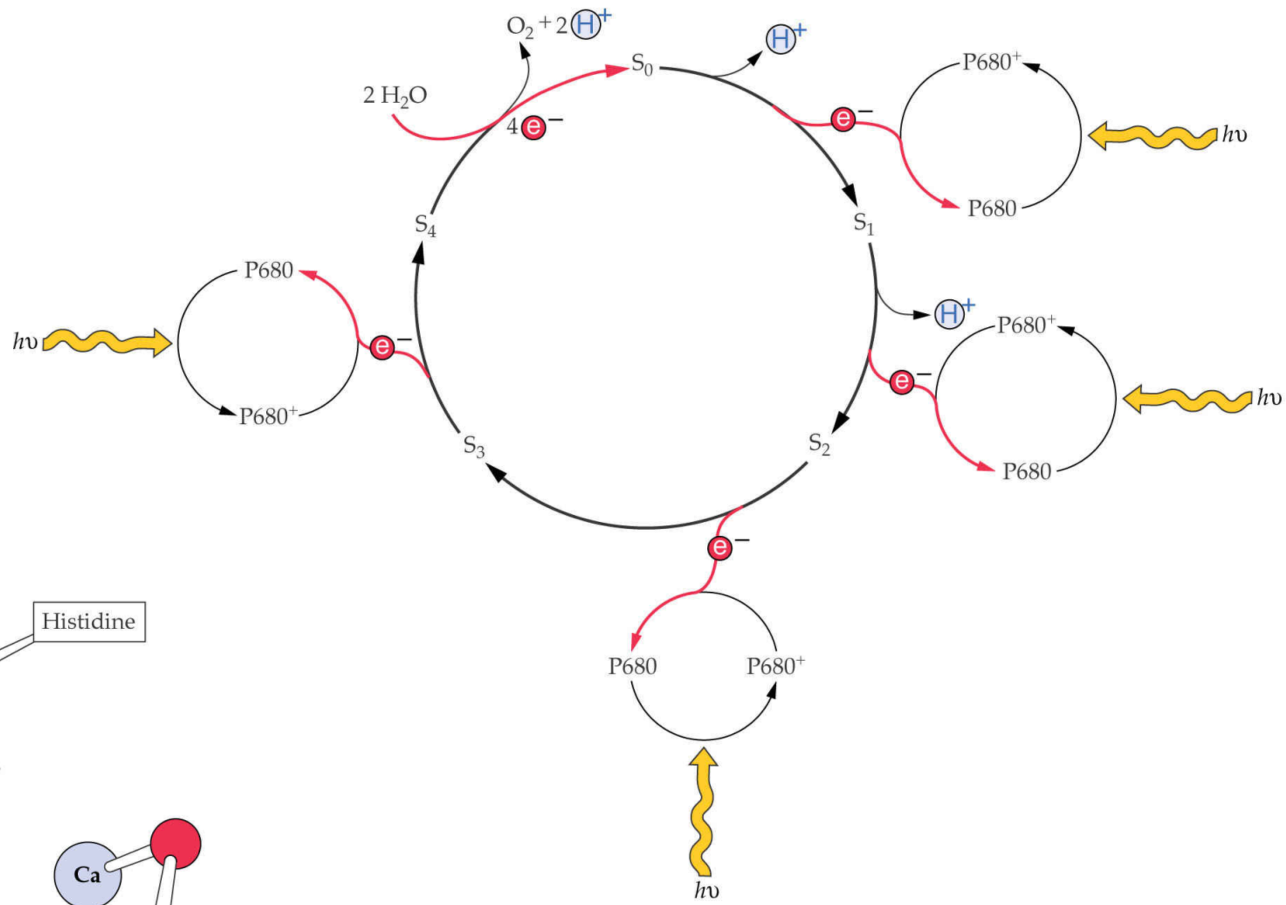
PSI

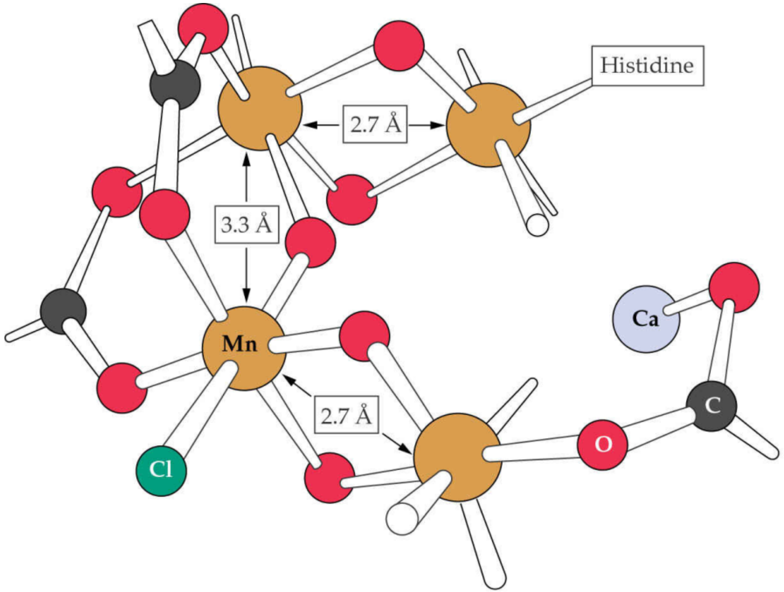


Structure and redox chemistry of flavin coenzymes



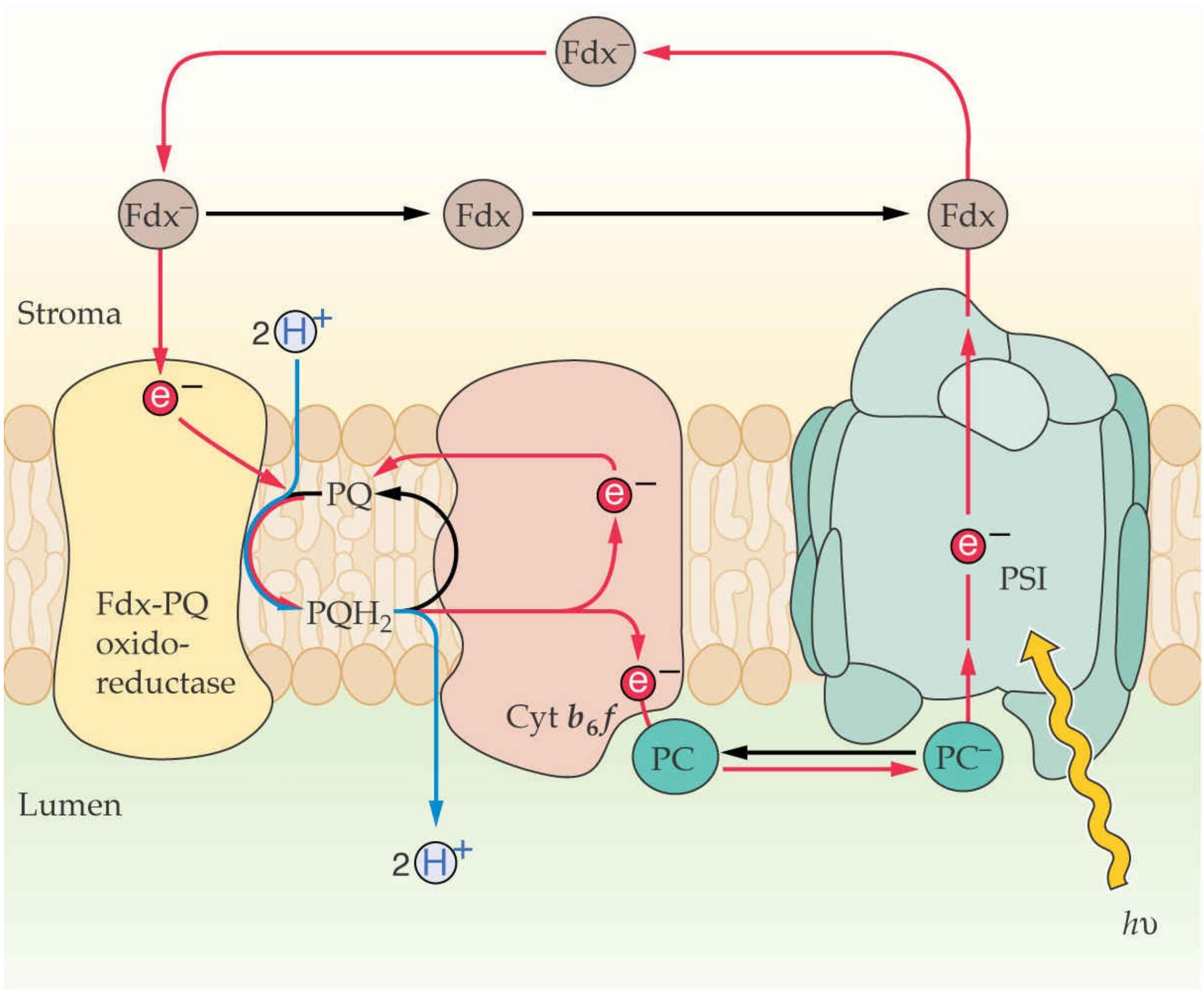
Oxidation of water





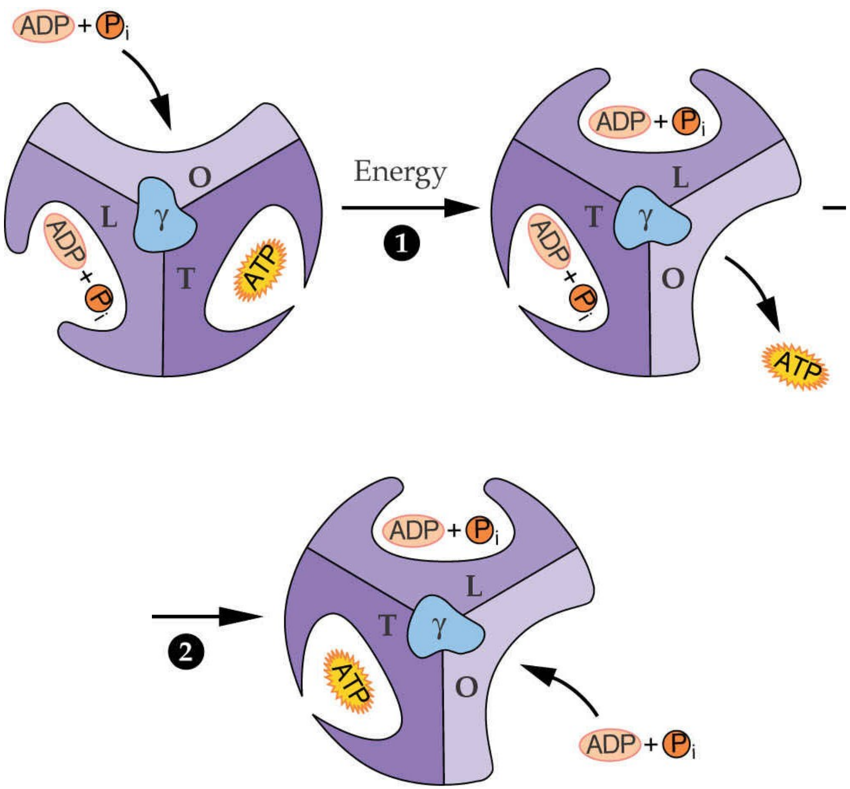
$$2H_2O \longrightarrow O_2 + 4H^+ + 4e^-$$

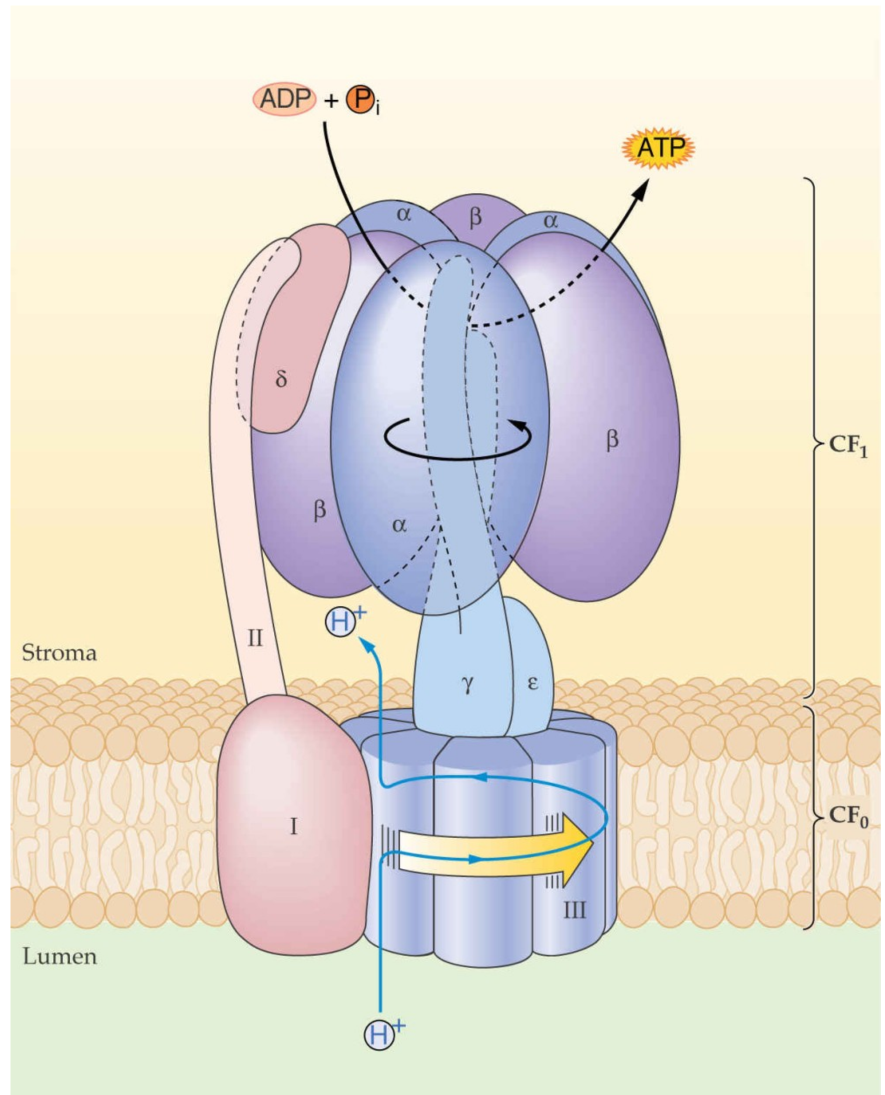
Cyclic electron transport chain



ATP synthesis in chloroplasts

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



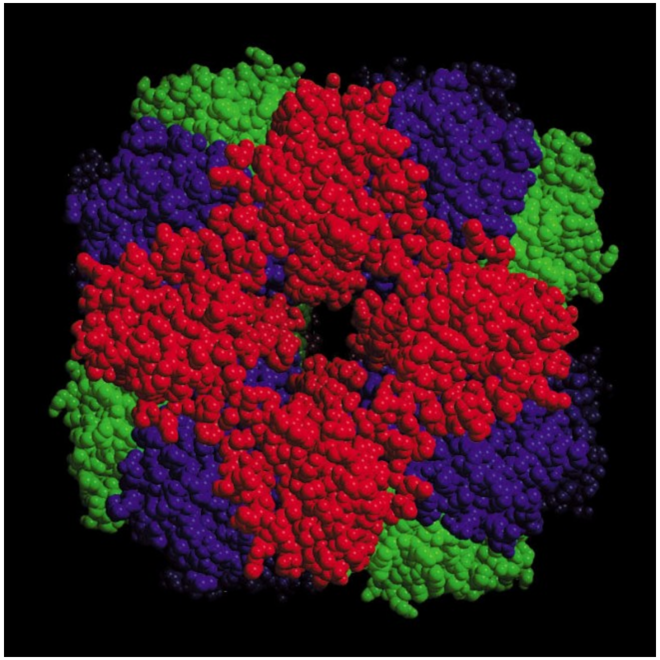


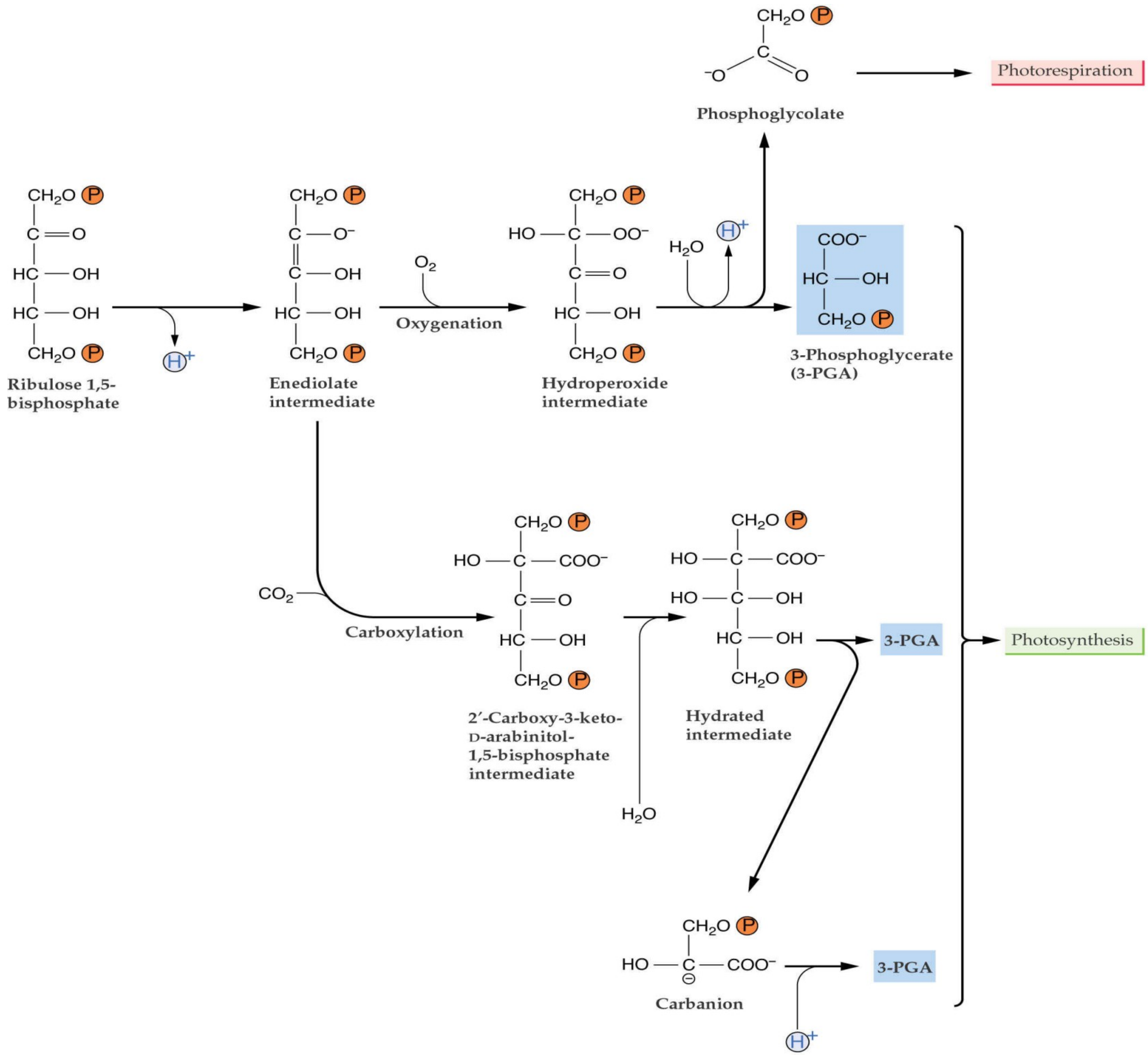
Carbon reactions in C_3 plants

- 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.

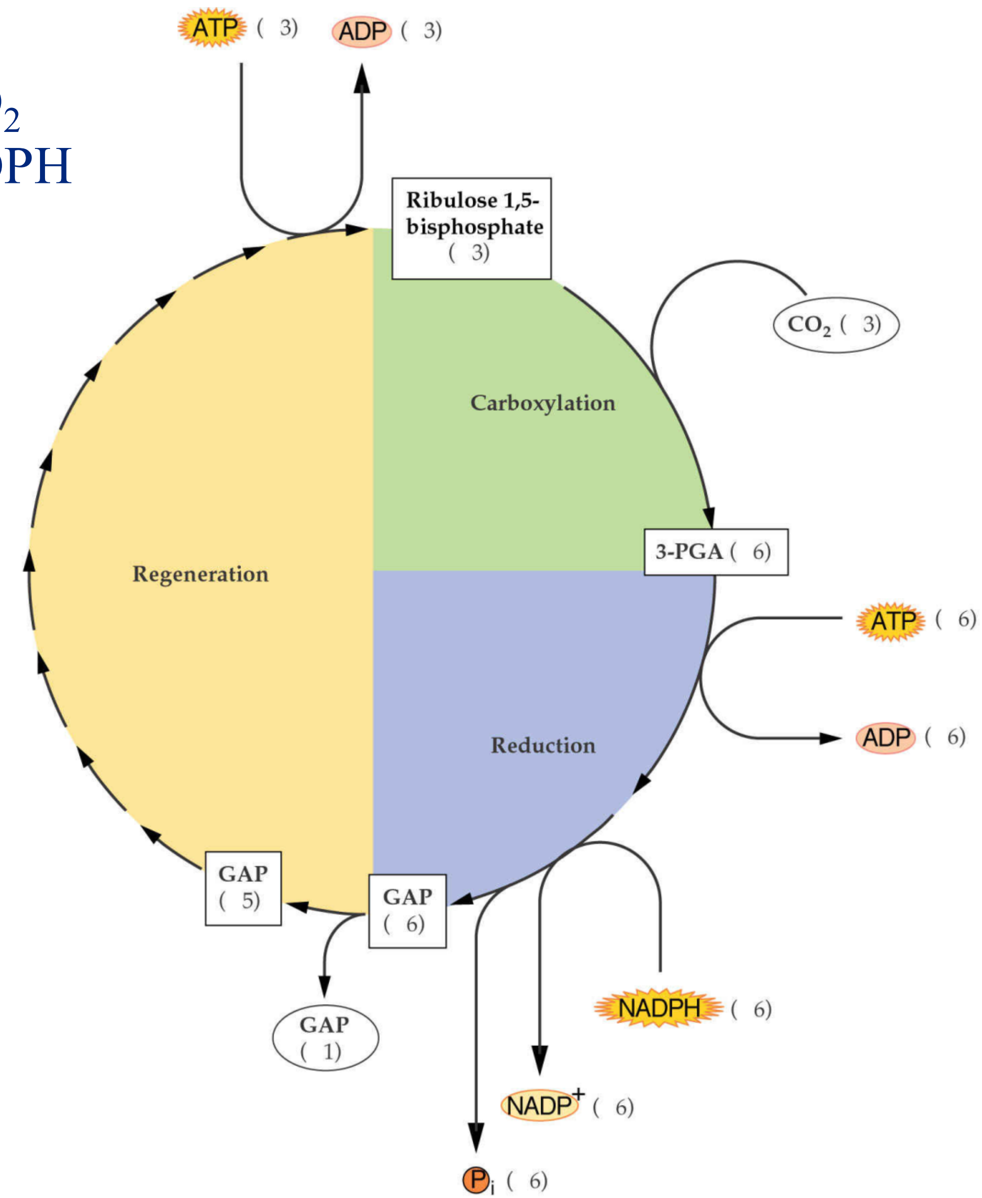
- Rubisco, probably the most prevalent protein on Earth, constitutes up to half the protein of the chloroplast stroma




CH2O P
-O C O
Phosphoglycolate
Photorespiration
CH2O P
C O
HC OH
HC OH
CH2O P
Ribulose 1,5-bisphosphate
H+
CH2O P
C O−
C OH
HC OH
CH2O P
Enediolate intermediate
O2
Oxygenation
CH2O P
HO C OO−
C O
HC OH
CH2O P
Hydroperoxide intermediate
H2O
H+
COO−
HC OH
CH2O P
3-Phosphoglycerate (3-PGA)
CO2
Carboxylation
CH2O P
HO C COO−
C O
HC OH
CH2O P
2′-Carboxy-3-keto-D-arabinitol-1,5-bisphosphate intermediate
H2O
CH2O P
HO C COO−
HO C OH
HC OH
CH2O P
Hydrated intermediate
3-PGA
Photosynthesis
CH2O P
HO C COO−
Carbanion
3-PGA
H+

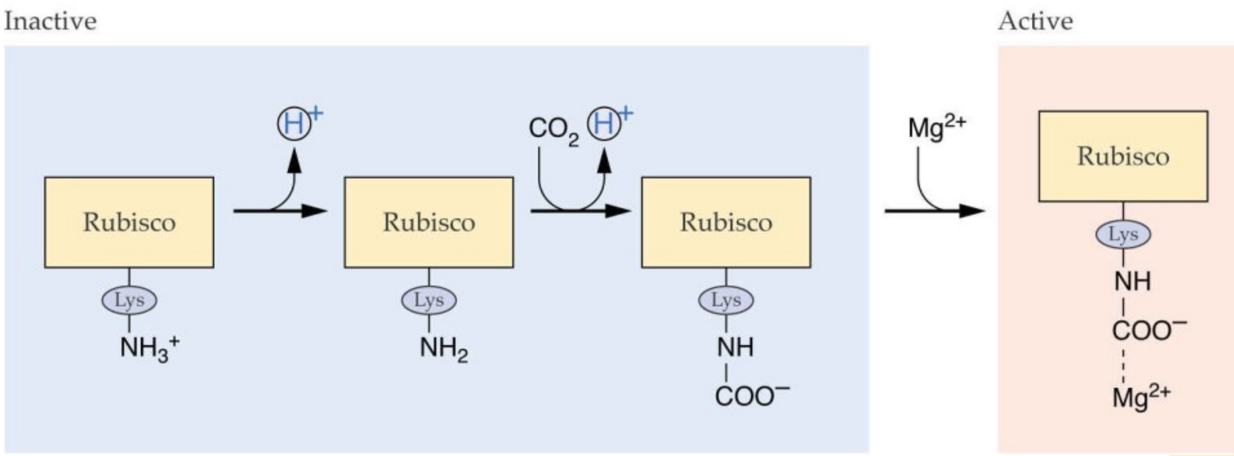
Carbon reactions (Calvin cycle)

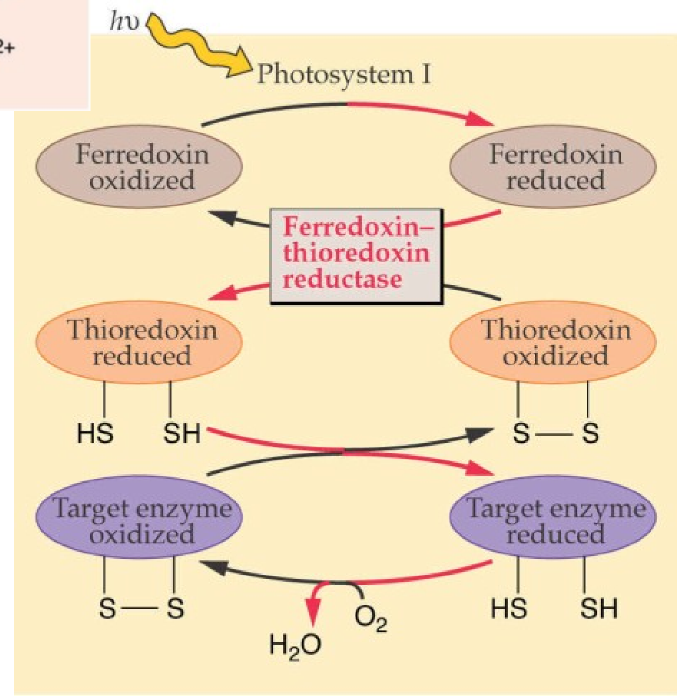
Fixation of one molecule of CO_2 requires two molecules of NADPH and three of ATP.



The Calvin cycle regulation

Activation of Rubisco by carbamylation





The ferredoxin-thioredoxin system

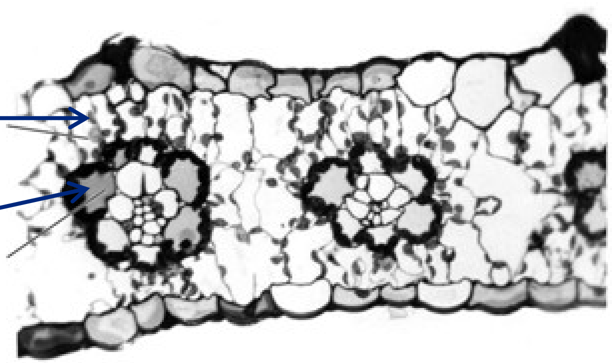
C_4 fixation mechanism

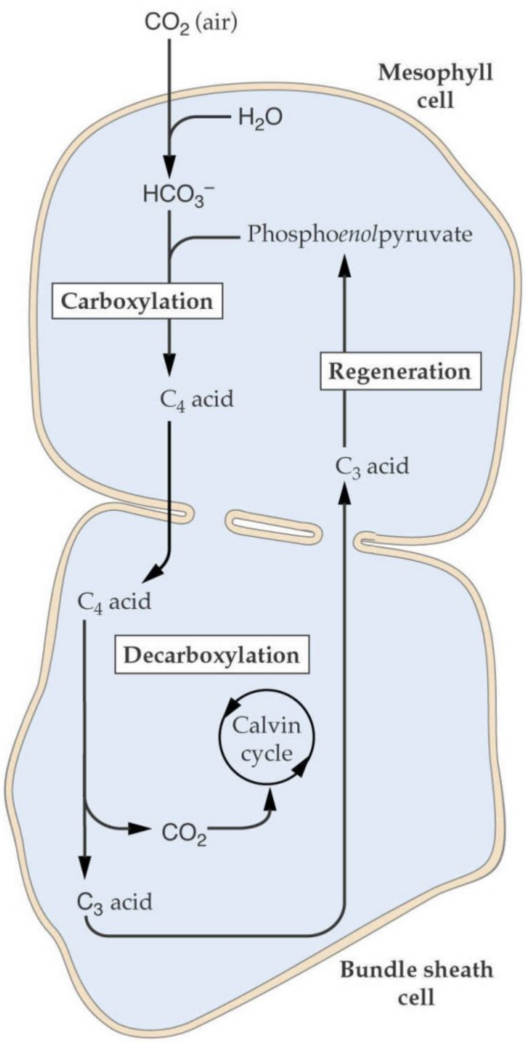
- C_4 plants contain two distinct CO_2-fixing enzymes

- 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