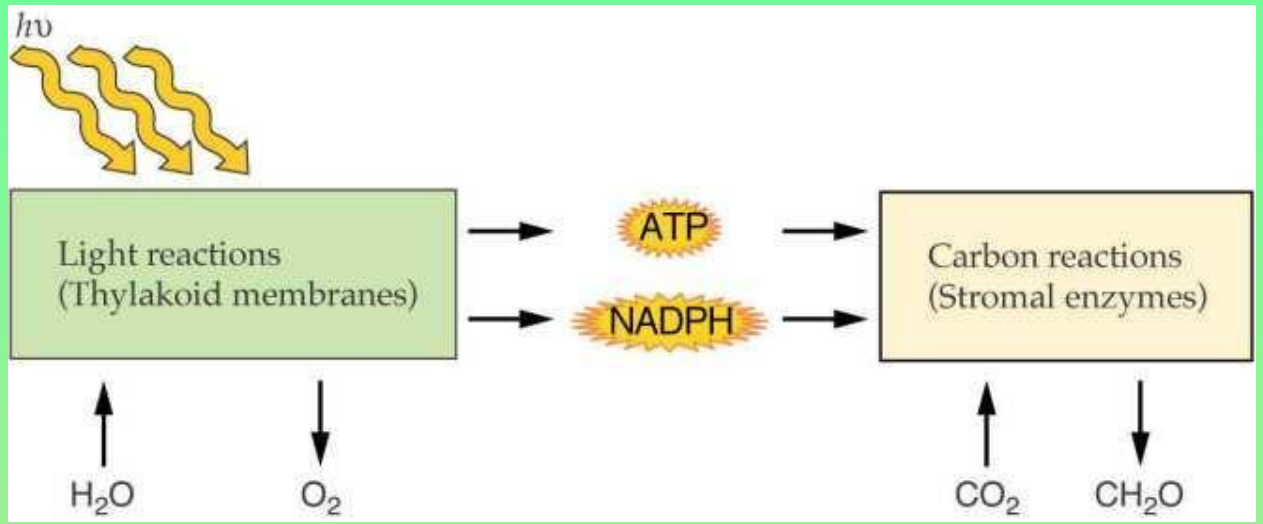
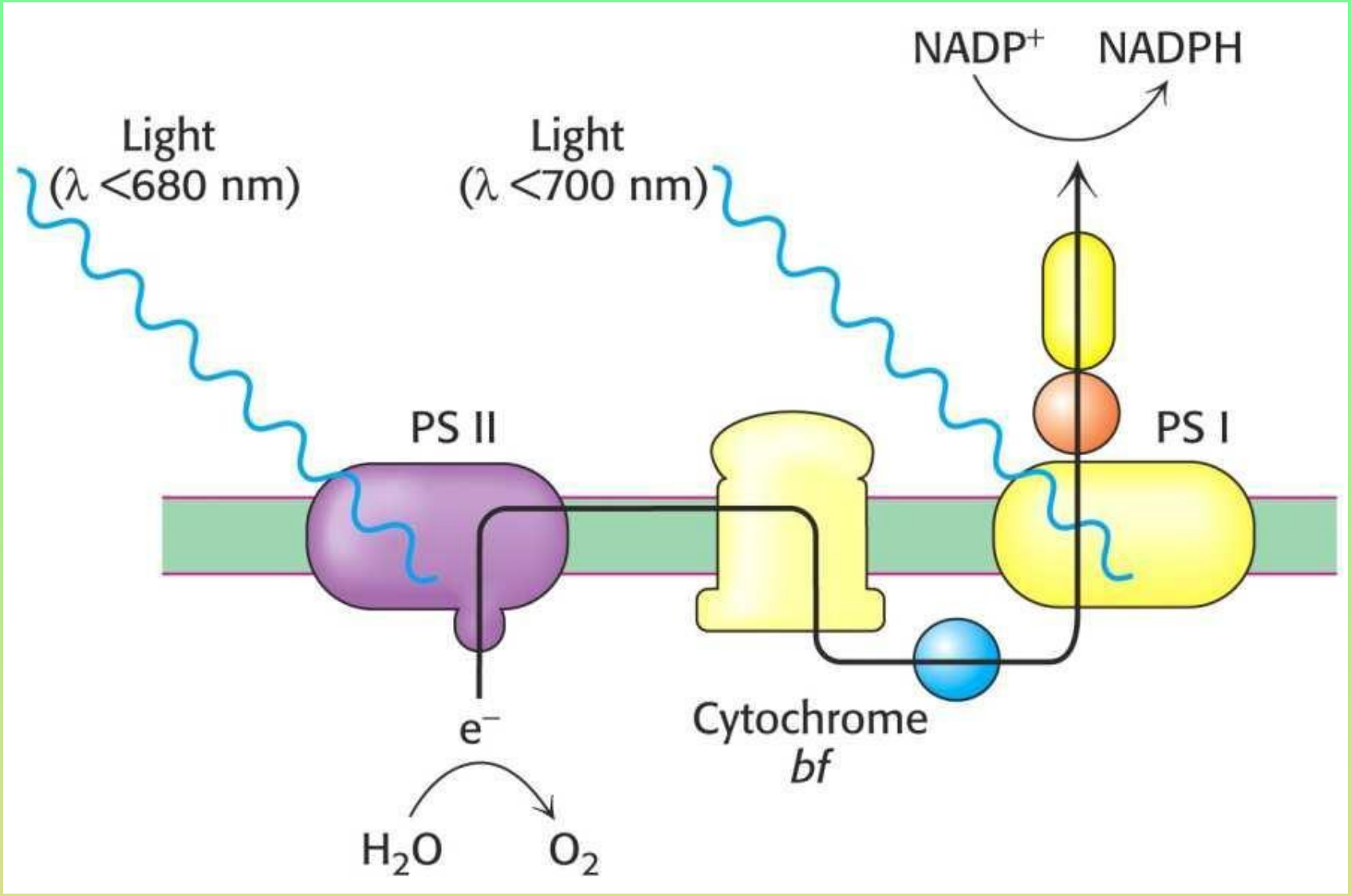
Photosynthesis



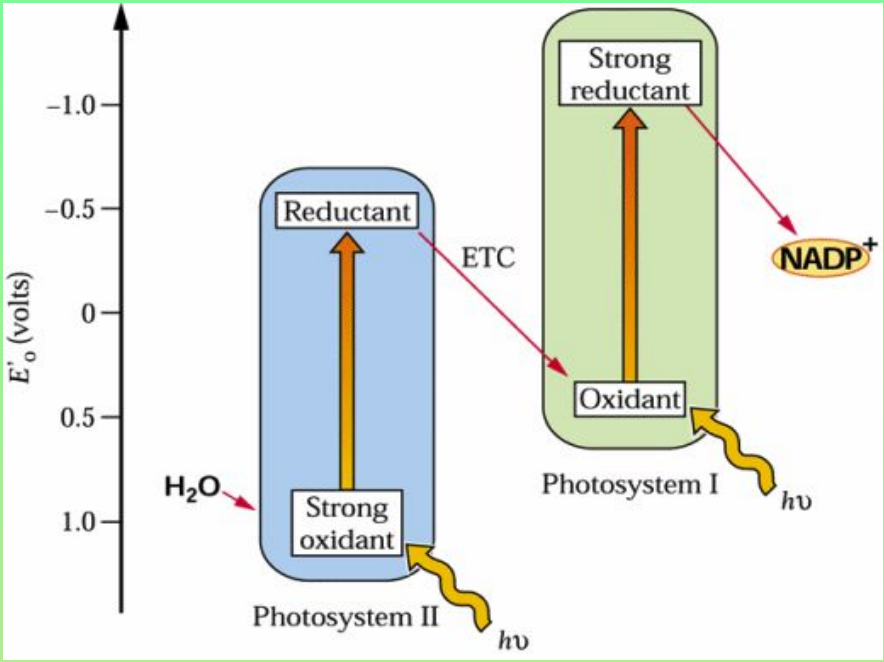
$6\ H_2O + 6\ NADP^+ + 9\ ADP + 9\ P_i + light \rightarrow 6\ O_2 + 6\ NADPH + 9\ ATP$

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

Two photosystems generate a proton gradient and NADPH in oxygenic photosynthesis



Oxidants and reductants in photosysnthetic electron transfer chain



Oxidace vody
Redukce NADP

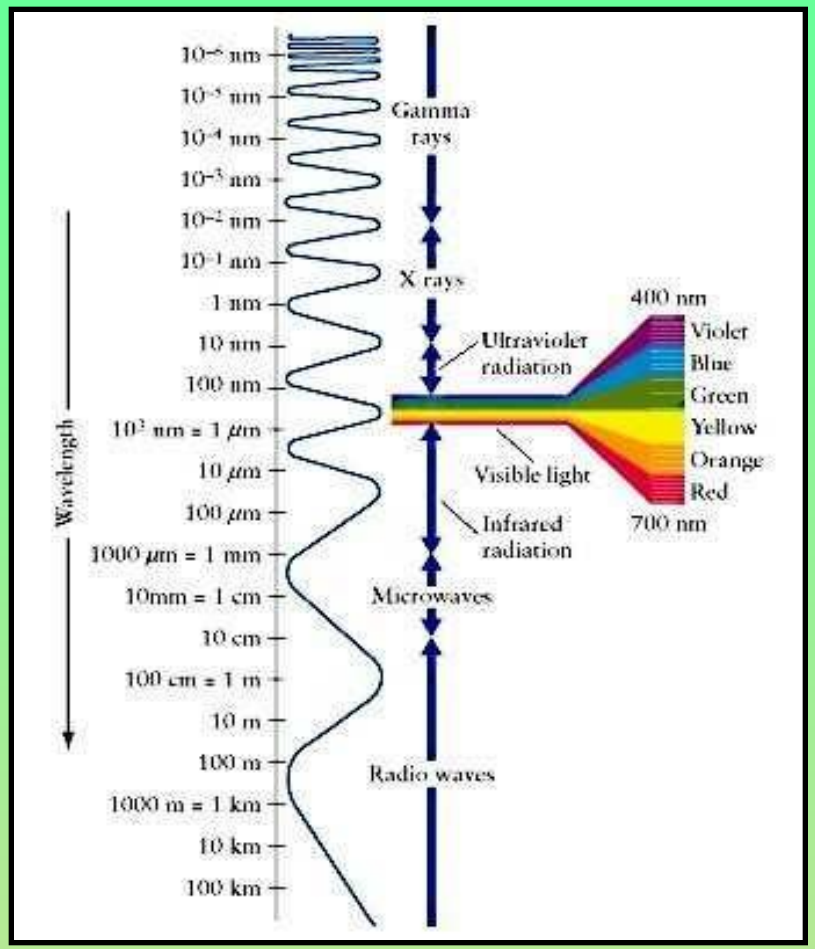
Energie fotonu = $h\nu = h\ c/\lambda$
Einstein (1905)

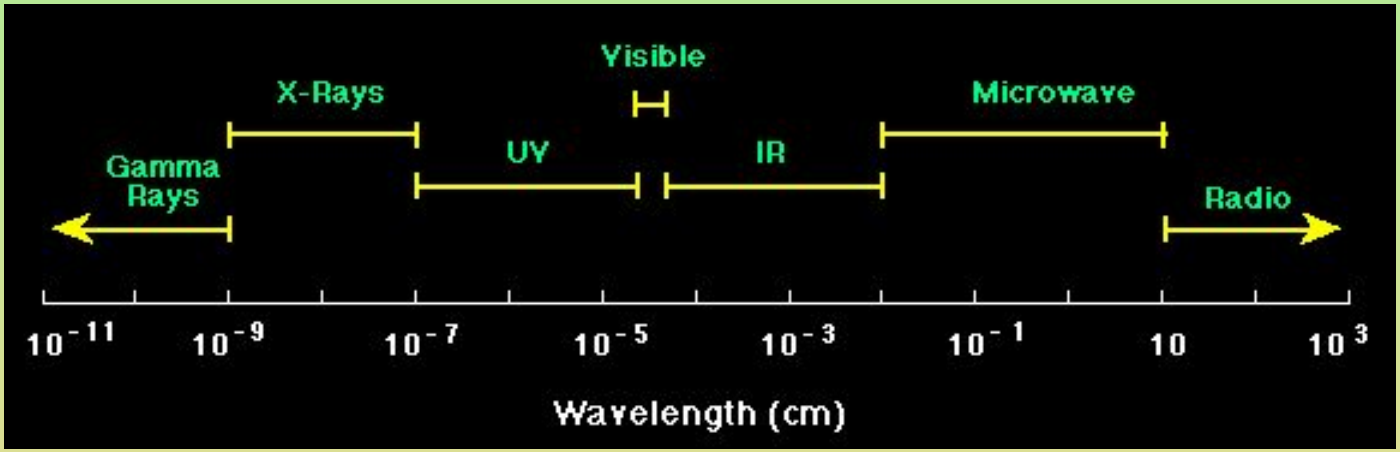
h = Planckova konstanta 6.626 x 10^{-34} joule s^{-1}
ν = kmitočet /frekvence (Hz)
λ= vlnová délka (nm)
c= rychlost světla

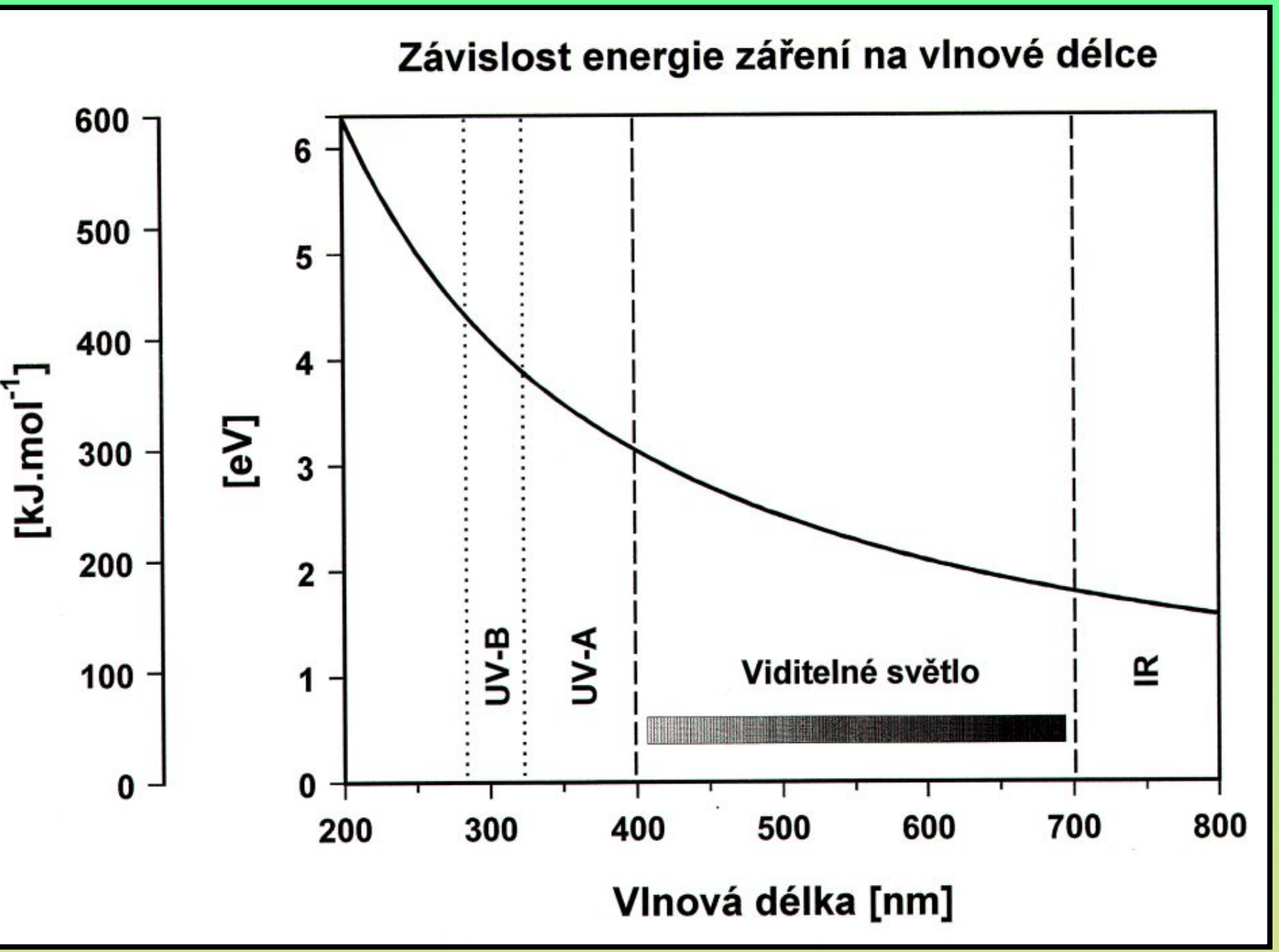
Energie ∞ 1/vlnová délka

430 nm light	1 foton	3.0 eV
670 nm light	1 foton	1.7 eV

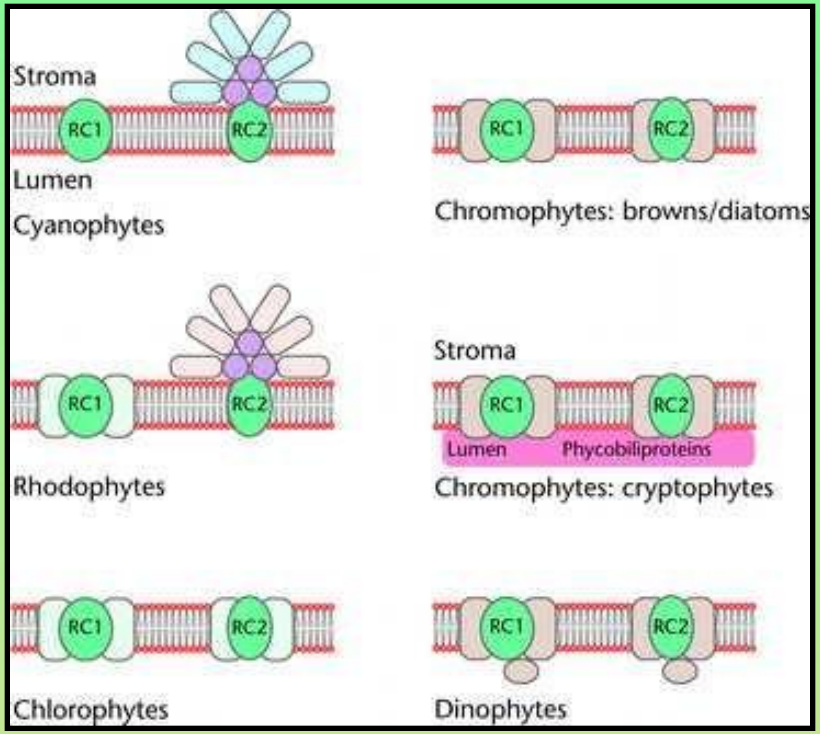
1 eV = energie potřebná k přenesení 1 e^-
rozdílem potenciálů 1V






Závislost energie záření na vlnové délce
[kJ.mol-1]
600
500
400
300
200
100
0
[eV]
6
5
4
3
2
1
0
UV-B
UV-A
Viditelné světlo
IR
200
300
400
500
600
700
800
Vlnová délka [nm]

Variabilita světlosběrných antén



Rhodophyta	Chlorophyll a; phycoerythrobilin
Chlorophyta	Chlorophylls a & b
Chromophyta	Chlorophylls a, c_1, c_2; fucoxanthin
Haptophyta	Chlorophylls a, c_1, c_2; fucoxanthin
Dinophyta	Chlorophylls a, c_2; peridinin
Cryptophyta	Chlorophylls a, c_2; phycocyanobilin
Euglenophyta	Chlorophylls a, b

Fotosyntetické pigmenty:

- Porfyriny – (bakterio)chlorofyly, feofytiny
  - fykobiliny
- Polyisopreny – karotenoidy (karoteny, xanthofyly)

Funkce fotosyntetických pigmentů

- Zachycení a přenos fotonů
  - (B)chlorofyly a,b,c,d,e, fykobiliny, xanthofyly
- Fotochemická přeměna energie – RC
  - Chlorofyl a, Bchl a, Bchl b
- Ochrana před triplety a nadměrnou excitací
  - Karoteny, xanthofyly
- Strukturní funkce
  - Karoteny, xanthofyly

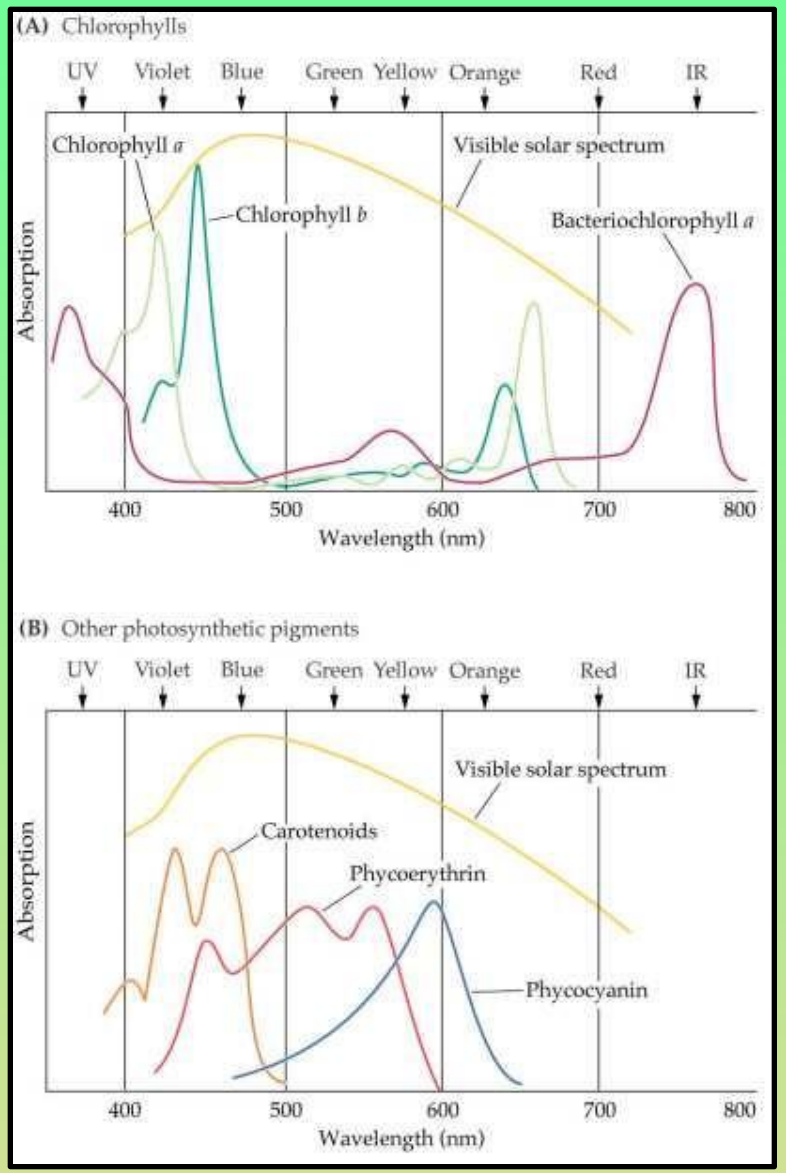
Zachycení energie

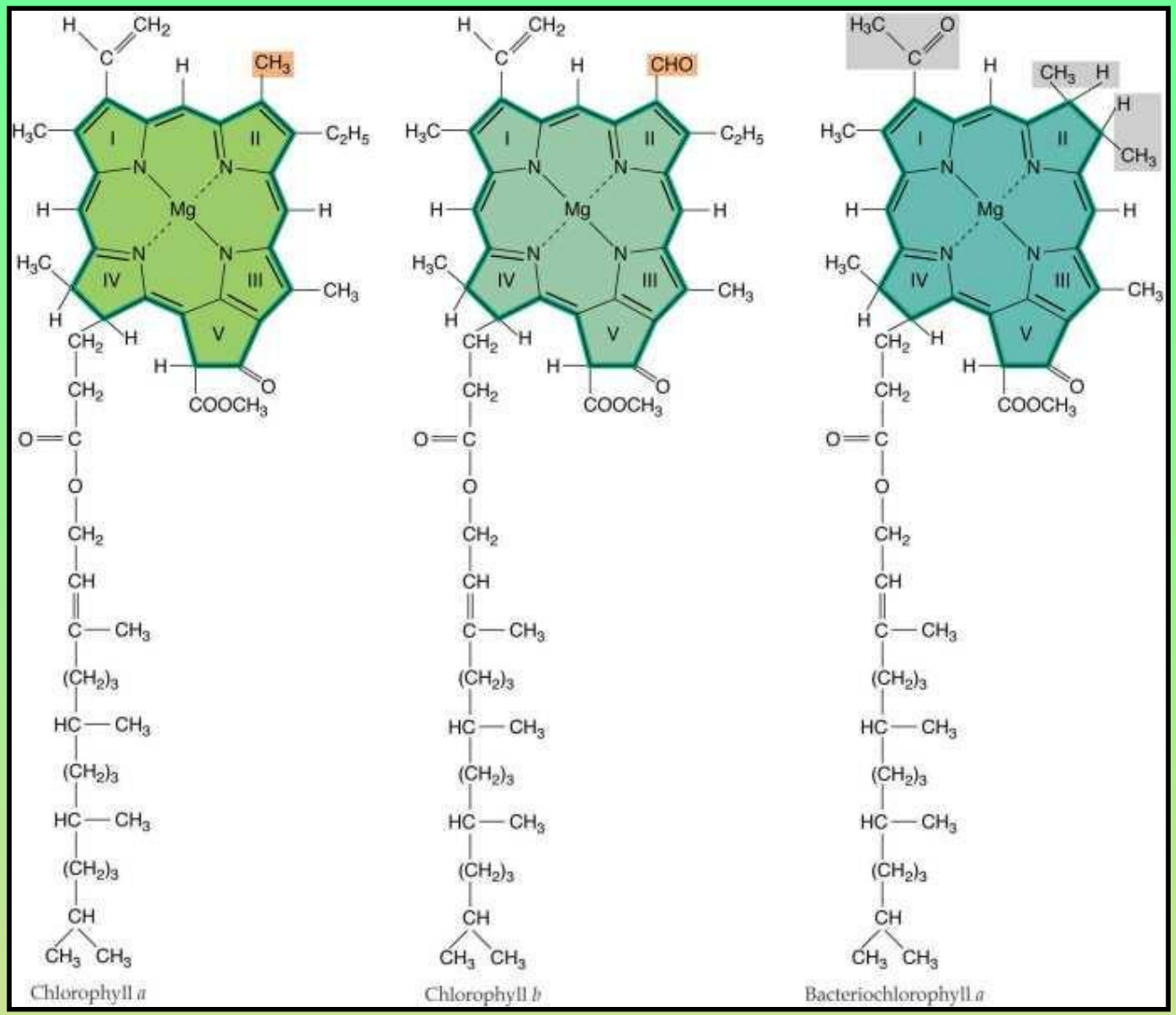
↓

Přenos energie

↓

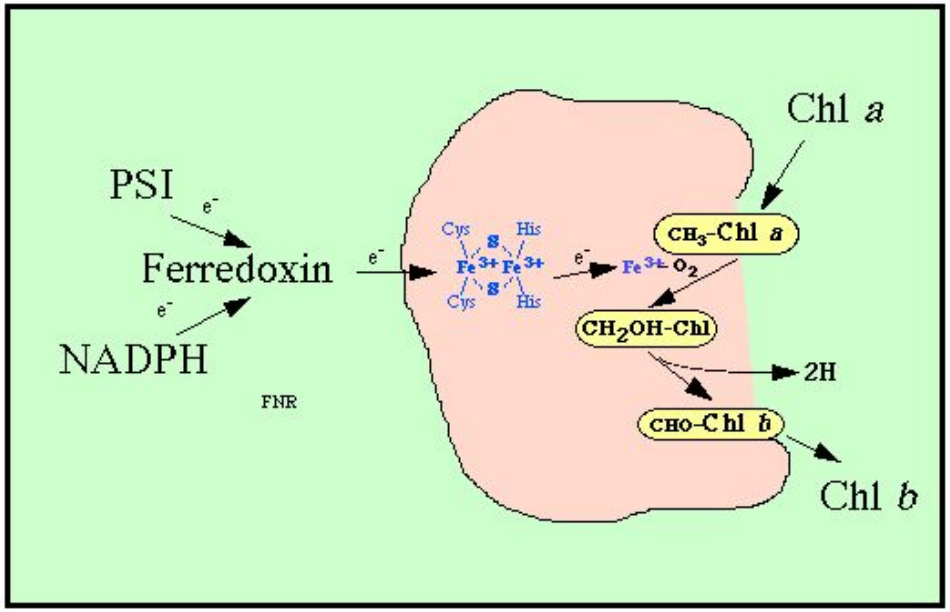
Využití energie

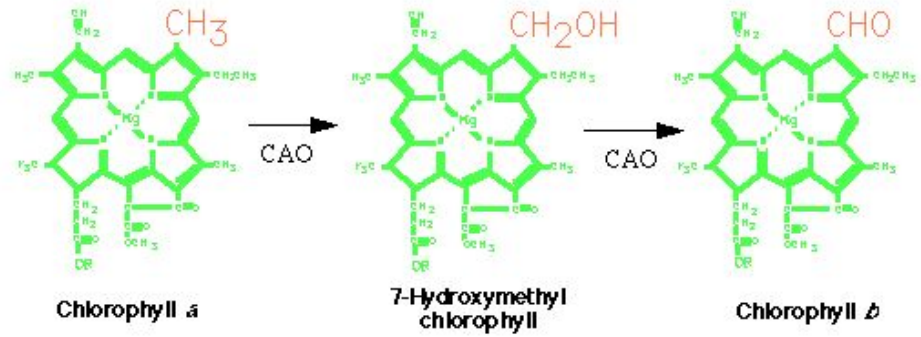


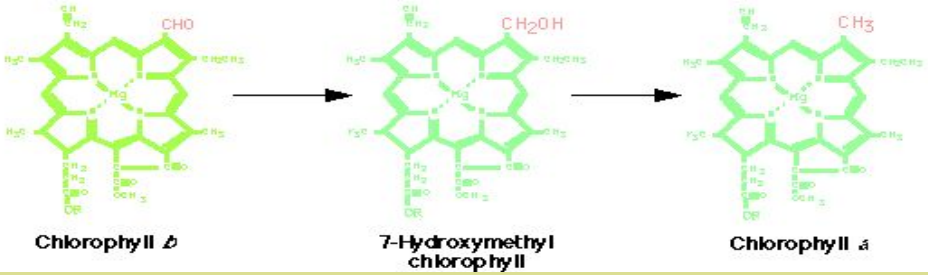


Prochlorophytes?

Chlorophyll *a* Oxygenase



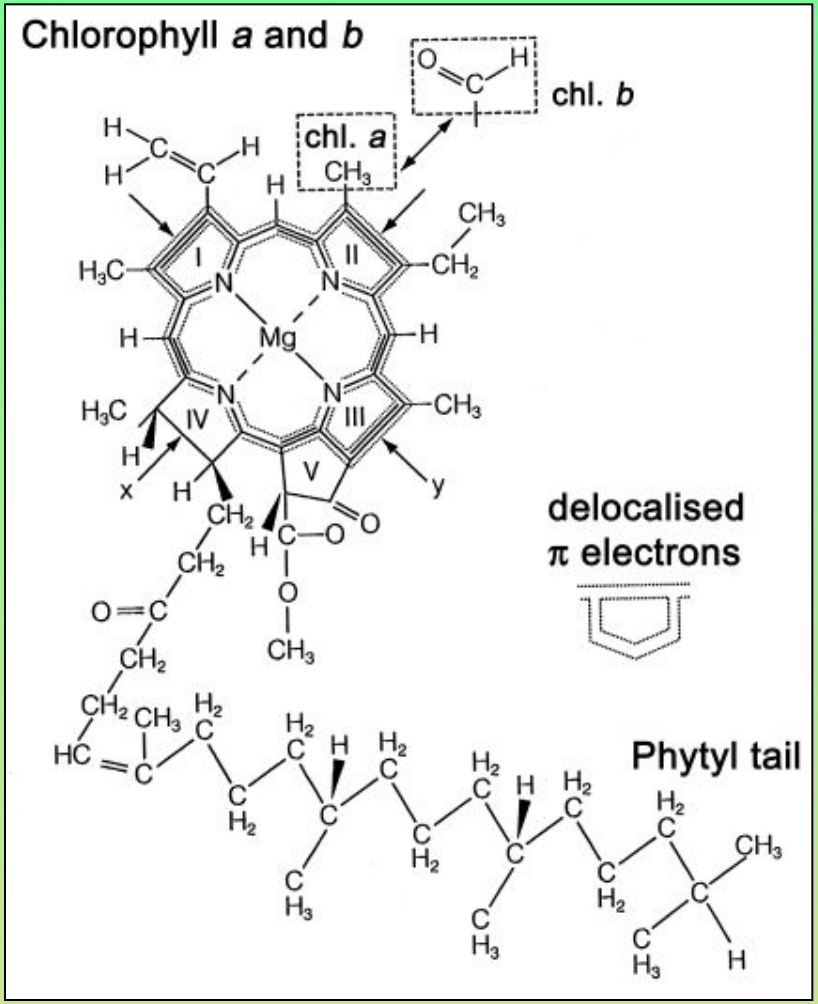




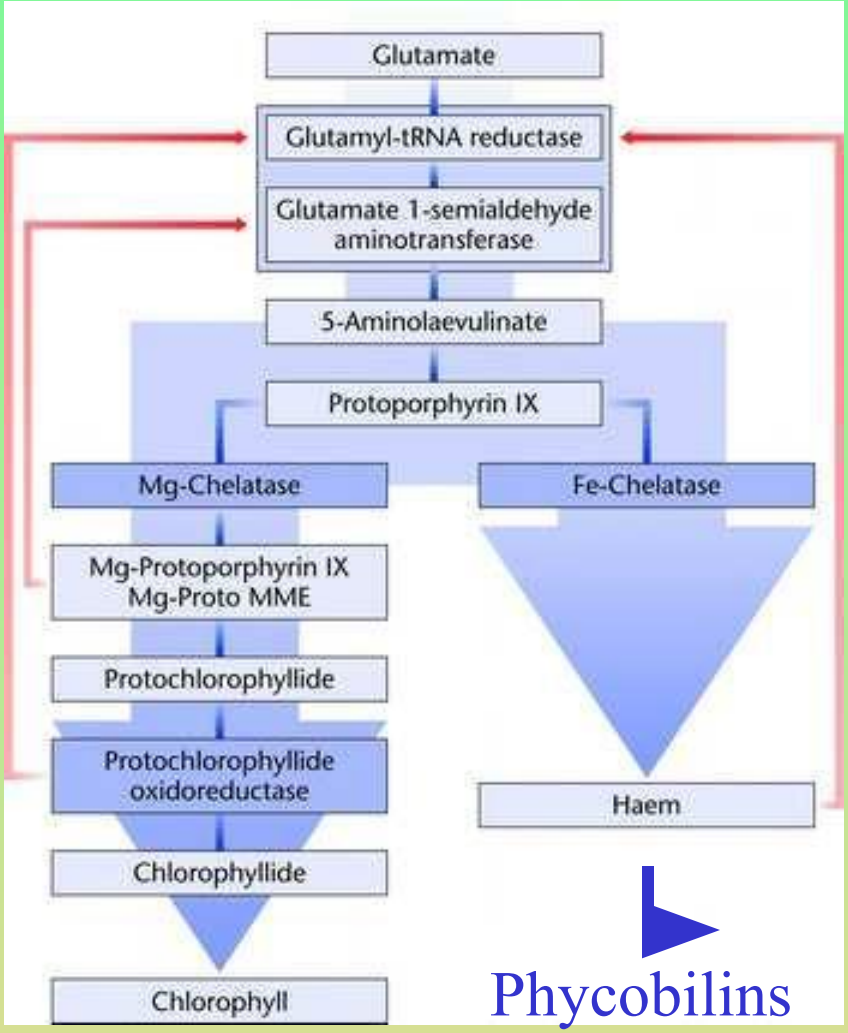
Chlorofyly

- Porfyrinová „hlava“:
  tetrapyrol + Mg

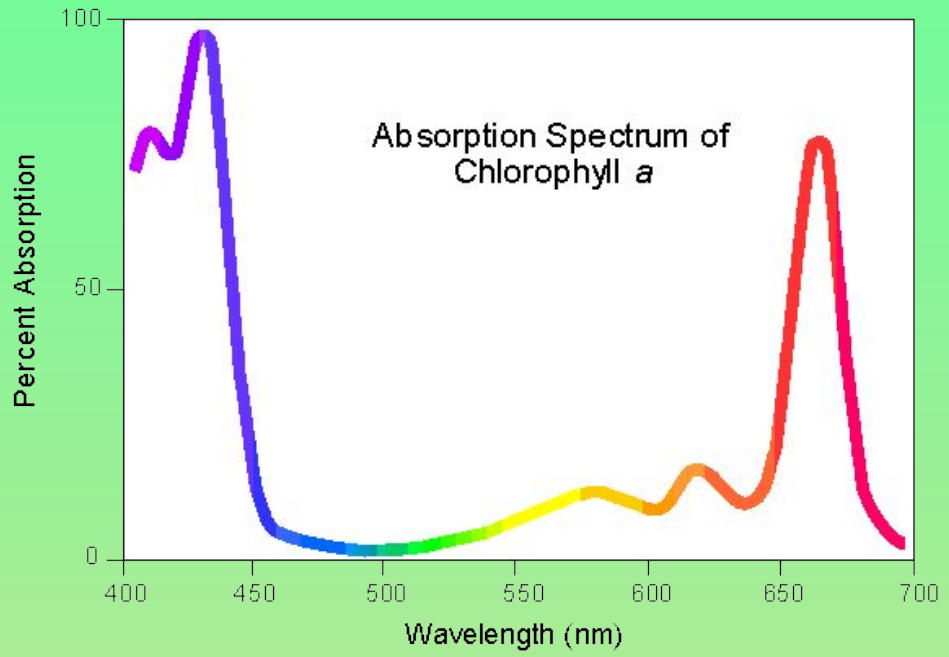
- Phytolový řetězec – „ocásek“
  ukotvení v membráně

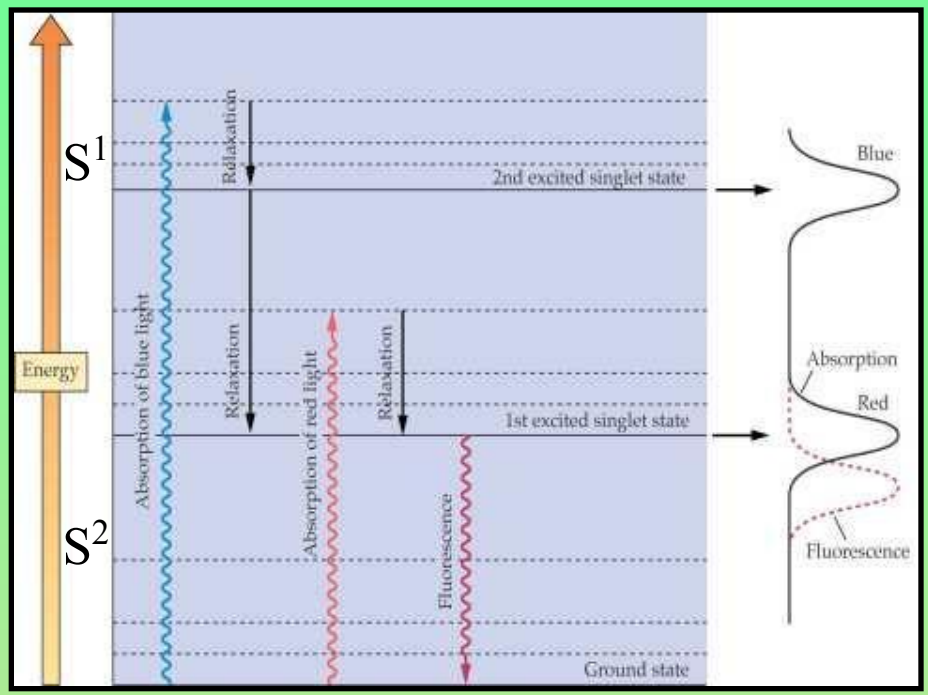


Regulace syntézy tetrapyrolů



Absorbce světla

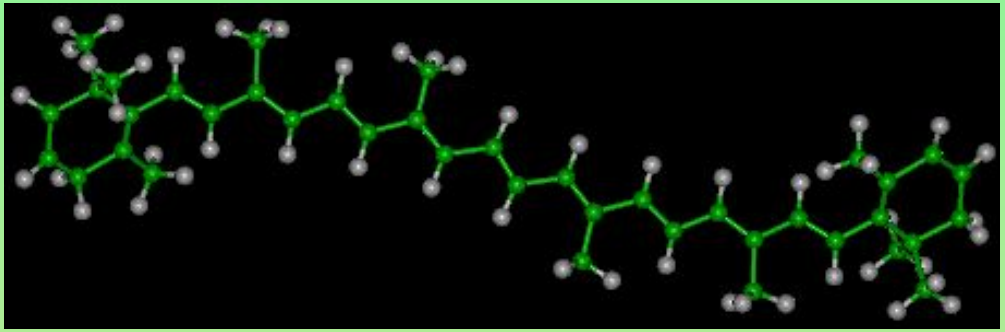


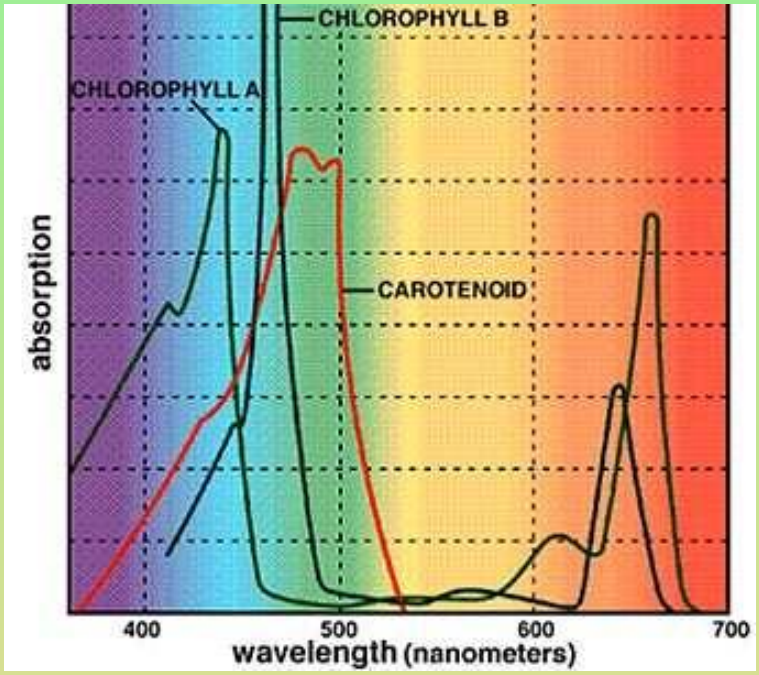


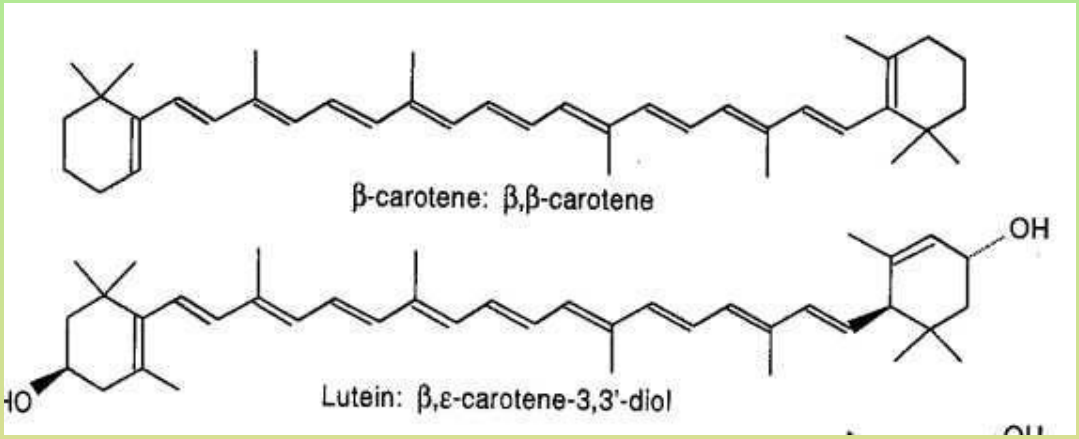
- Absorbce přesune e^- do vyššího excitovaného stavu
- Pokud je nestabilní, energie se ztratí ve formě tepla (S^1 na S^2)
- S^1 může energii
  rezonančně předat (RET) nebo vyzářit jako fluorescenci

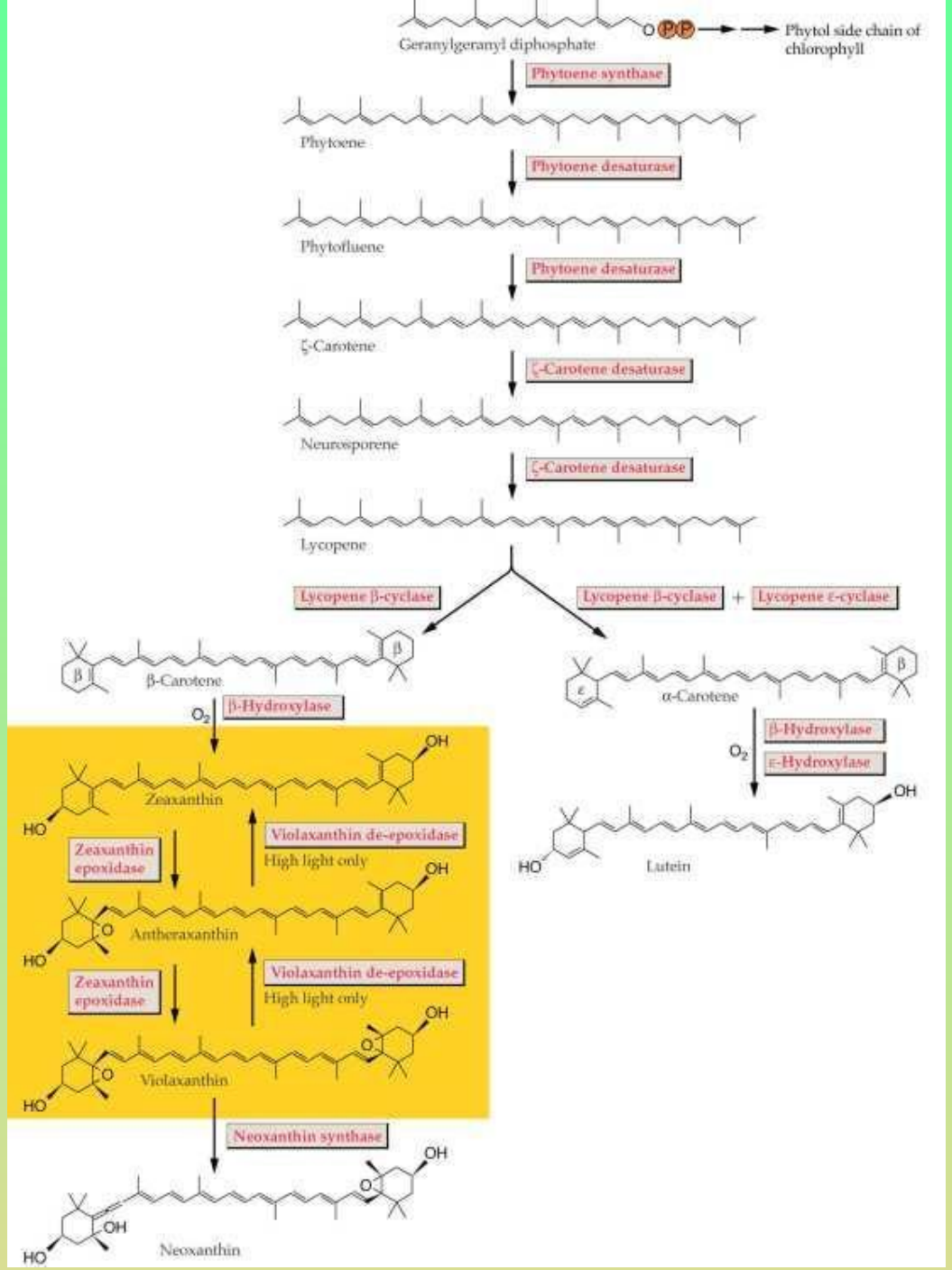
Karotenoidy

Pomocné pigmenty, strukturní funkce a disipace energie
Tetraterpeny (40 C) vytvořené z 8 isoprenových jednotek, délka 30 A
Systém konjugovaných dvojných vazeb, symetrie, terminální alicyklické kruhy
Xanthofyly + atomy kyslíku

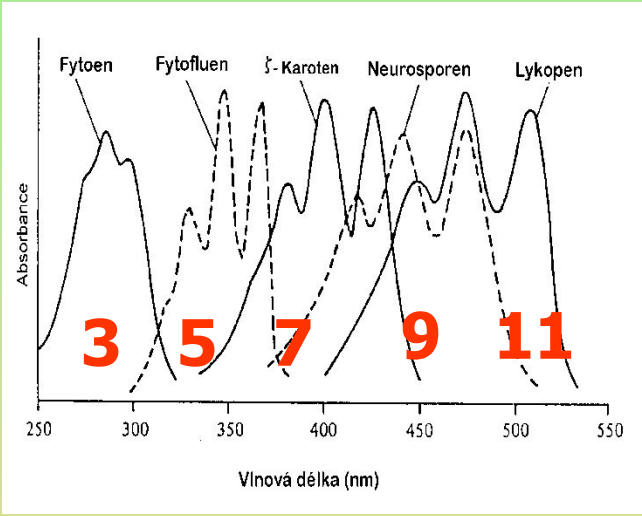







Geranylgeranyl diphosphate
Phytol side chain of chlorophyll
Phytoene synthase
Phytoene
Phytoene desaturase
Phytofluene
Phytoene desaturase
ζ-Carotene
ζ-Carotene desaturase
Neurosporene
ζ-Carotene desaturase
Lycopene
Lycopene β-cyclase
Lycopene β-cyclase + Lycopene ε-cyclase
β-Carotene
α-Carotene
β-Hydroxylase
β-Hydroxylase
ε-Hydroxylase
Zeaxanthin
Zeaxanthin epoxidase
Violaxanthin de-epoxidase
High light only
Antheraxanthin
Zeaxanthin epoxidase
Violaxanthin de-epoxidase
High light only
Violaxanthin
Lutein
Neoxanthin synthase
Neoxanthin

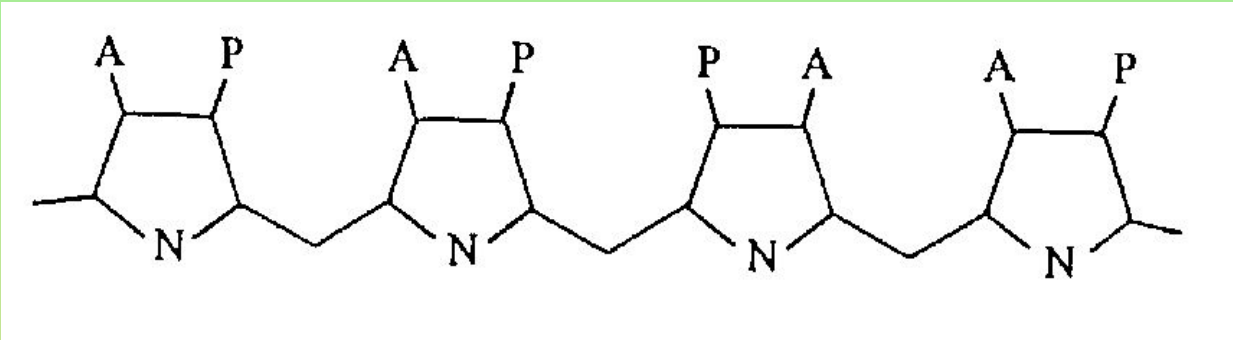

crtP
Phytoene
Phytofluene
ζ-Carotene
Neurosporene
Lycopene
β-Carotene
Zeaxanthin


Fytoen
Fytofluen
ζ-Karoten
Neurosporen
Lykopen
Absorbance
3
5
7
9
11
250
300
350
400
450
500
550
Vlnová délka (nm)

Fykobiliny

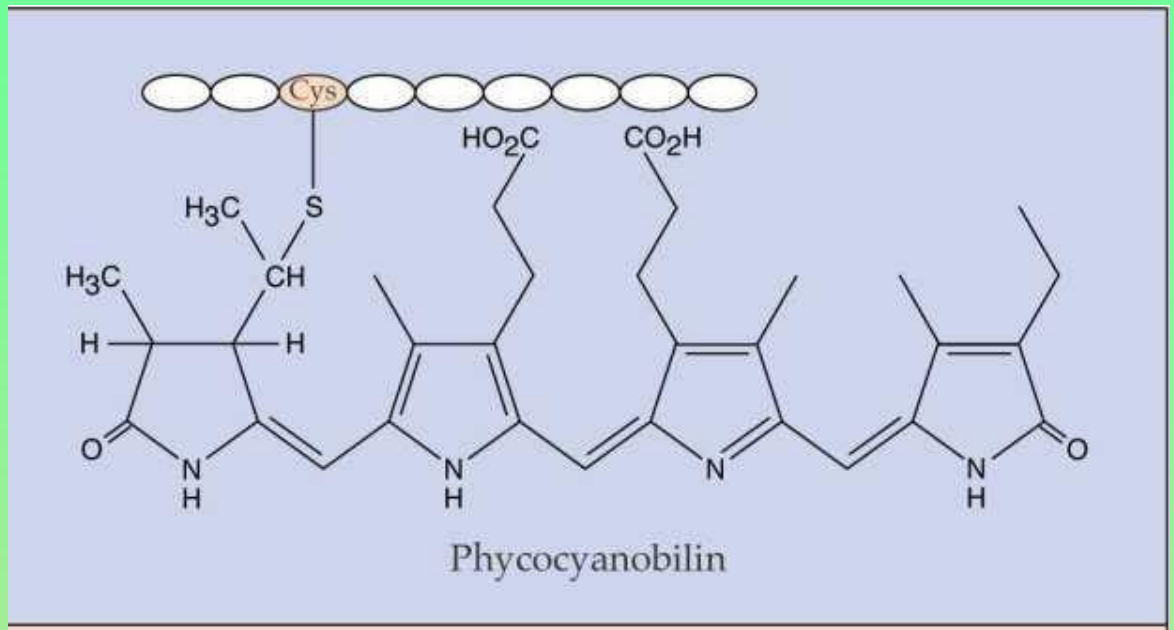
Lineární tetrapyroly, vznikají oxidačním otevřením tetrapyrolového kruhu

ve vodě rozpustné

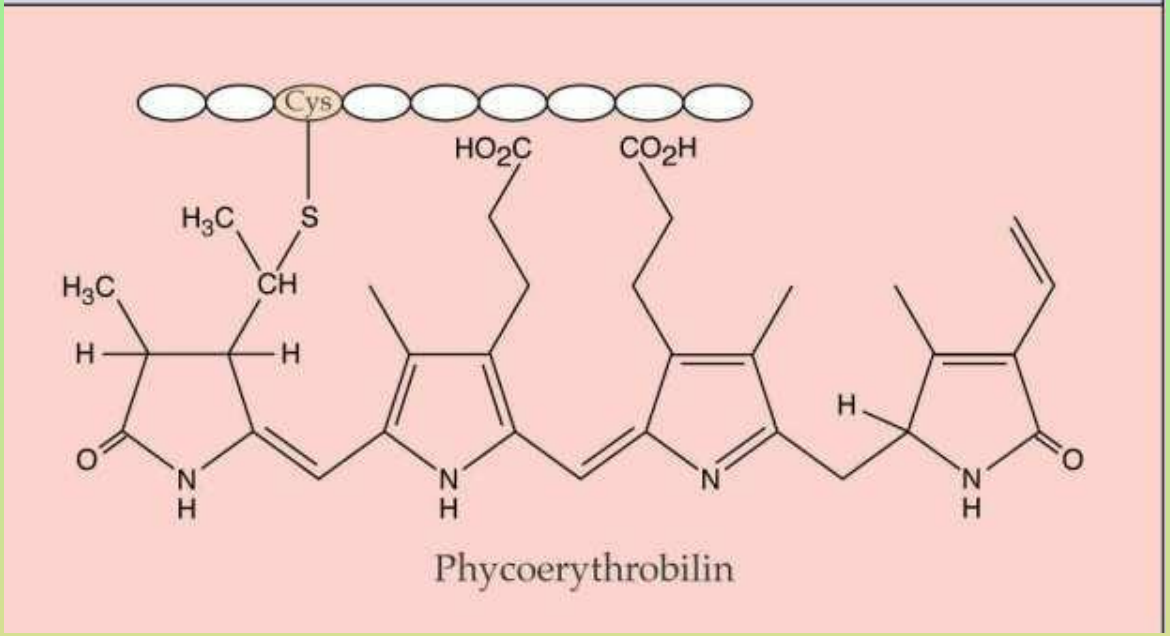


Two classes of phycobilins: **phycocyanin (left) and phycoerythrin (right).**

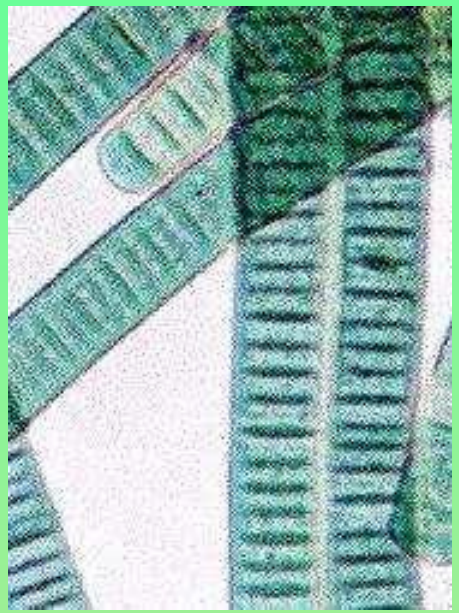
Kovalentní thioetherová vazba mezi cysteinem a vinylovým řetězcem

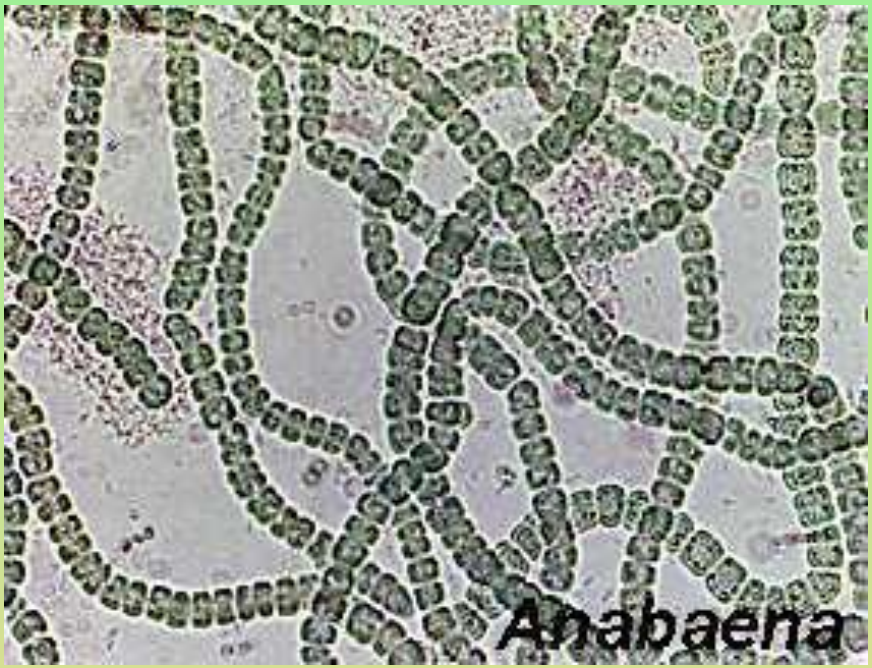


Phycocyanobilin

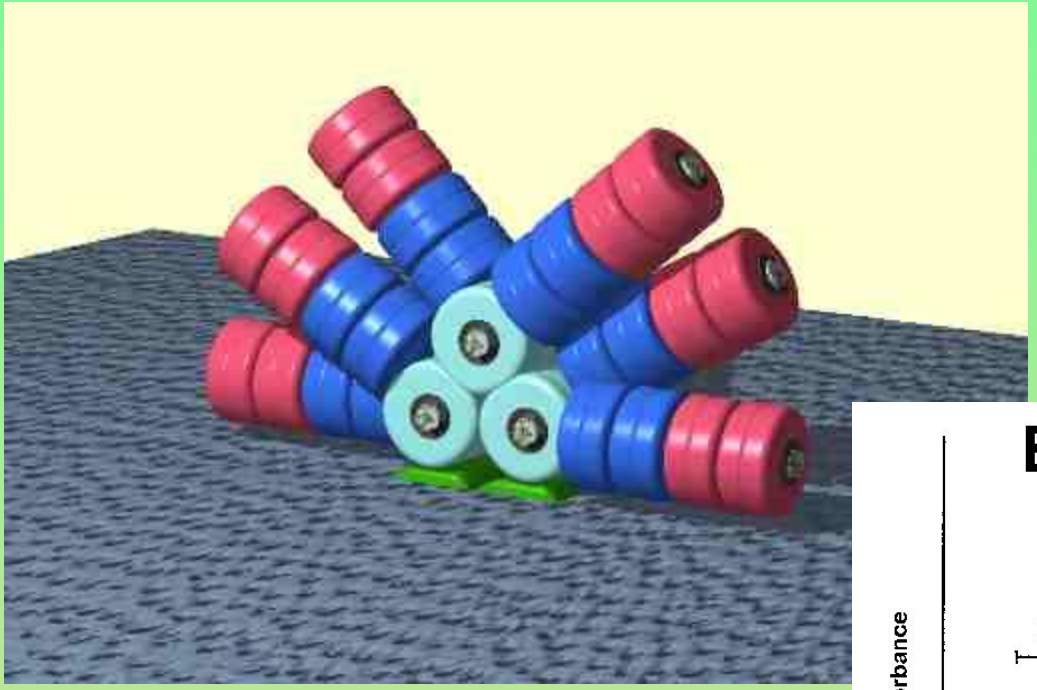


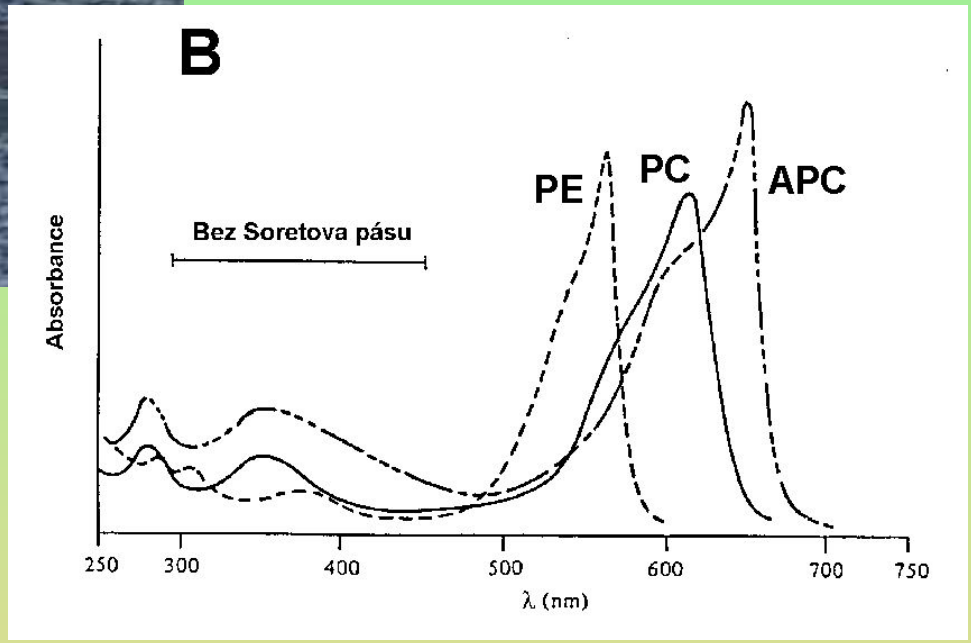
Phycoerythrobilin

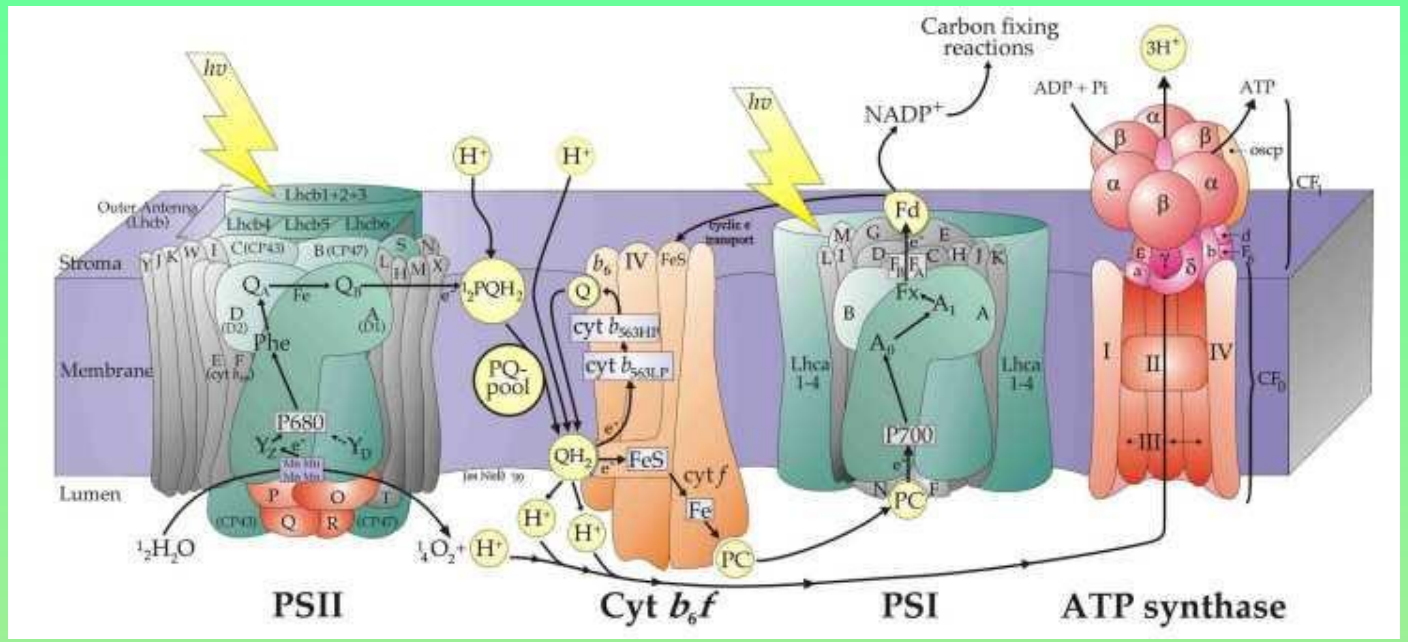


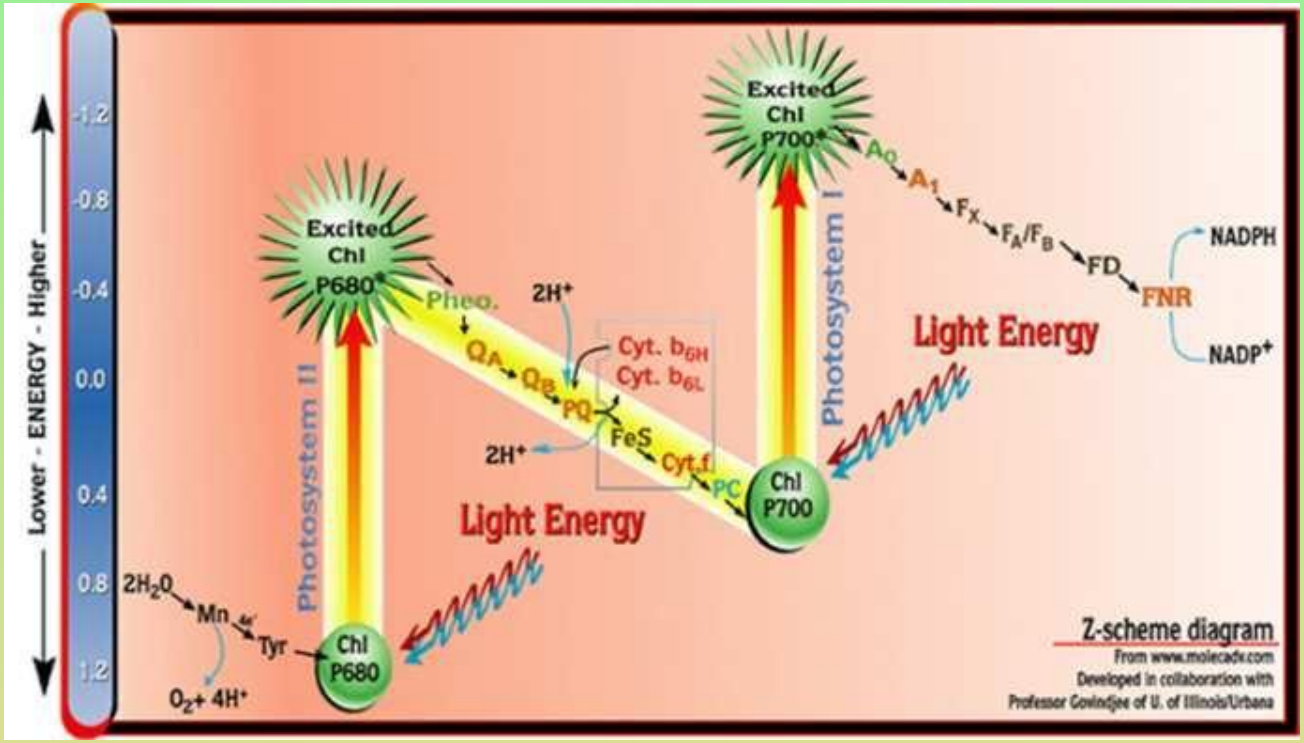

Anabaena

Cyanobacterial phycobilisomes






Carbon fixing reactions
NADP+
3H+
ADP + Pi
ATP
hν
hν
H+
H+
Outer Antenna (Lhcb)
Lhcb1+2+3
Lhcb4
Lhcb5
Lhcb6
Stroma
Membrane
Lumen
Phe
P680
PQ-pool
cyt b563H
cyt b563L
cyt f
FeS
Fe
PC
Fd
P700
Lhca 1-4
Lhca 1-4
oscp
CF1
CF0
PSII
Cyt b6f
PSI
ATP synthase


Lower - ENERGY - Higher
-1.2
-0.8
-0.4
0.0
0.4
0.8
1.2
Excited Chl P680*
Pheo.
QA
QB
PQ
2H+
Cyt. b6H
Cyt. b6L
FeS
Cyt.f
PC
Chl P700
Photosystem II
Photosystem I
Light Energy
Light Energy
2H2O
Mn
Tyr
Chl P680
O2+ 4H+
Excited Chl P700*
A0
A1
FX
FA/FB
FD
FNR
NADPH
NADP+
Z-scheme diagram
From www.molecadx.com
Developed in collaboration with
Professor Govindjee of U. of Illinois/Urbana

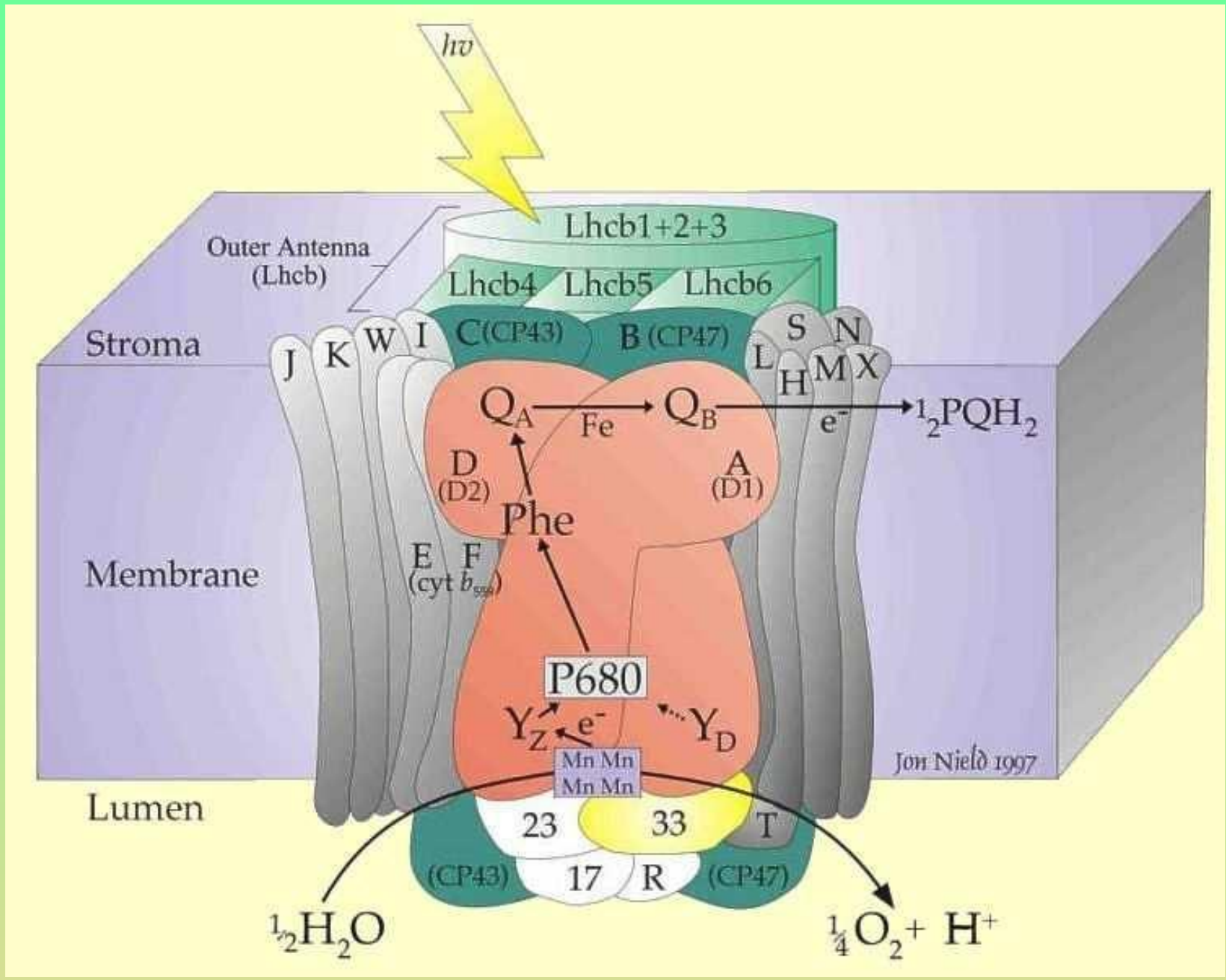
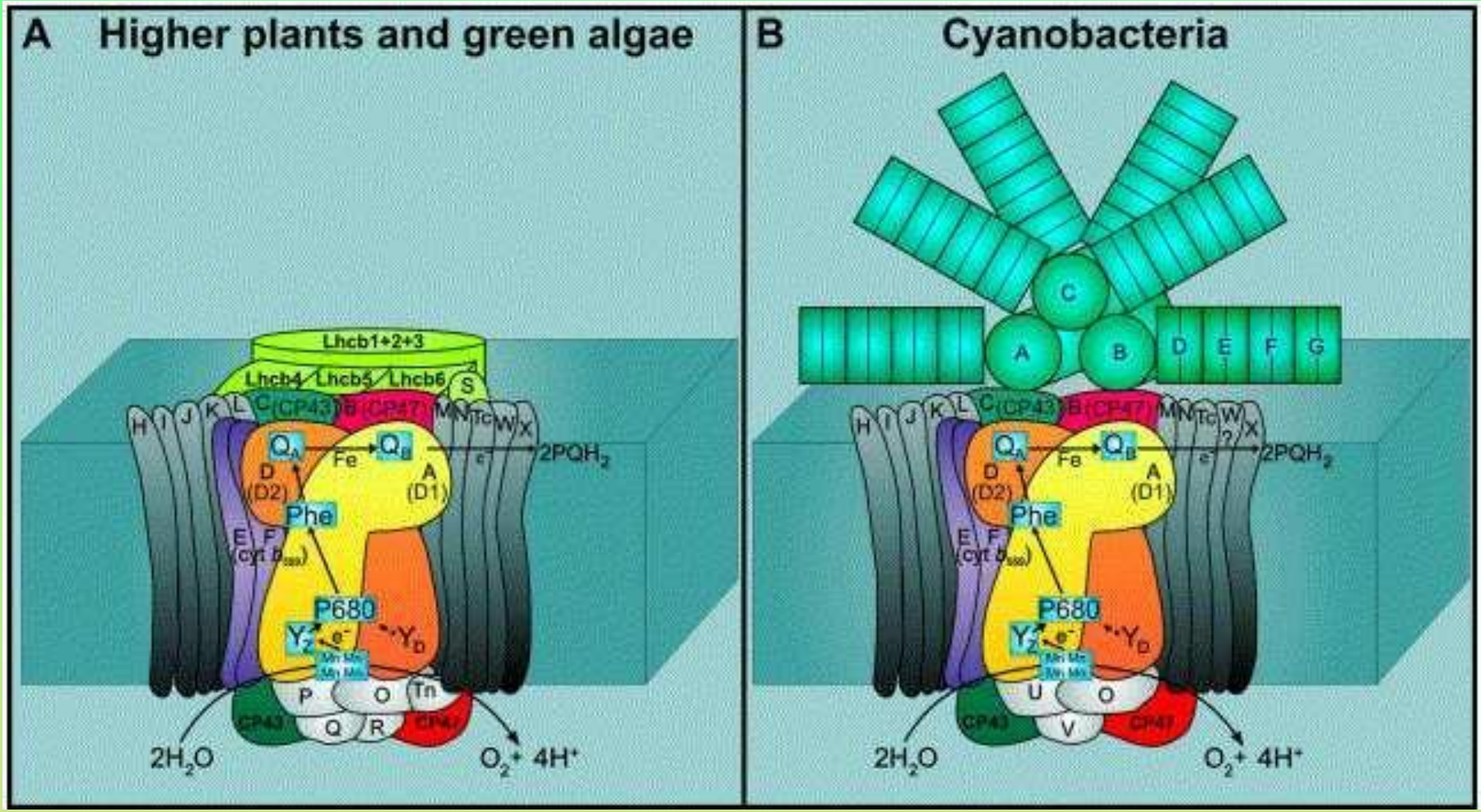
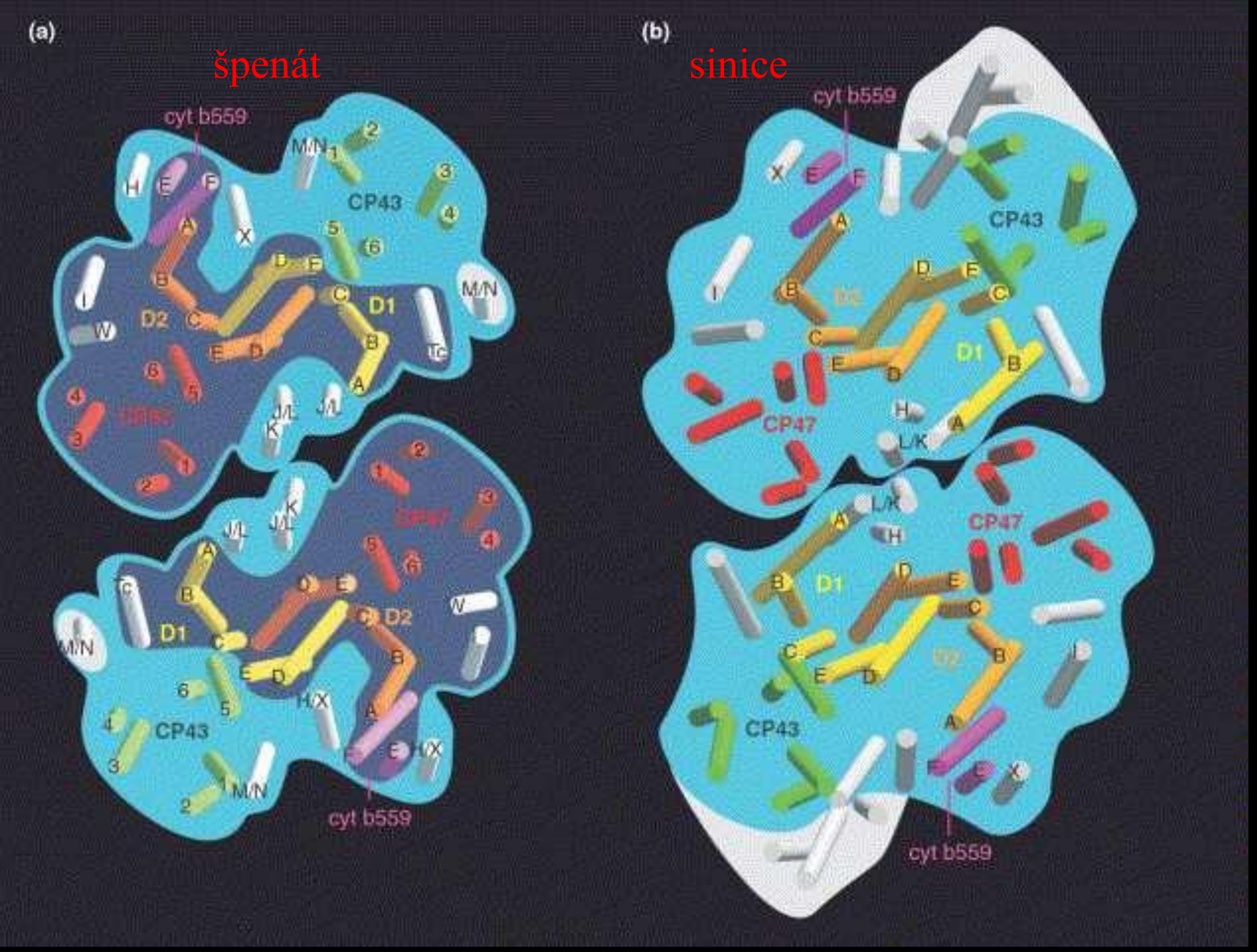

hν
Outer Antenna
(Lhcb)
Lhcb1+2+3
Lhcb4
Lhcb5
Lhcb6
Stroma
J
K
W
I
C(CP43)
B (CP47)
L
S
N
H
M
X
Q_A
Fe
Q_B
e^-
$^1_2PQH_2$
D
(D2)
A
(D1)
Phe
E
F
(cyt b_{559})
Membrane
P680
Y_Z
e^-
Y_D
Mn Mn
Mn Mn
Jon Nield 1997
Lumen
23
33
T
(CP43)
17
R
(CP47)
$^1_2H_2O$
$^1_4O_2$ + H^+

Table 6.2 Subunit structure of photosystem 2

Subunit name	Gene	Gene location[a]	Mass (kDa)[b]	Cofactors	Function
PSII-A (D1)	*psbA*	C	39	chlorophyll, pheophytin, quinone, β-carotene, Fe	Core reaction center of photosystem 2
PSII-B (D2)	*psbD*	C	39	chlorophyll, pheophytin, quinone, β-carotene, Fe	Core reaction center of photosystem 2
PSII-E (cyt *b*-559α)	*psbE*	C	9	heme	Core reaction center of photosystem 2
PSII-F (cyt *b*-559β)	*psbF*	C	4	heme	Core reaction center of photosystem 2
PSII-I	*psbI*	C	4		Core reaction center of photosystem 2
PSII-B (CP47)	*psbB*	C	56	chlorophyll, β-carotene	Core antenna
PSII-C (CP43)	*psbC*	C	51	chlorophyll, β-carotene	Core antenna
PSII-H	*psbH*	C	8	phosphate	Photoprotection, Q_A to Q_B regulation
PSII-J	*psbJ*	C	4		Assembly of photosystem 2
PSII-K	*psbK*	C	4		?
PSII-L	*psbL*	C	4		Role in Q_A binding
PSII-M	*psbM*	C	4		?
PSII-N	*psbN*	C	5		Role in PS2 stability
PSII-T (ycf8)	*psbT*	C	3		Role in PS2 stability
PSII-W[c]	*PsbW*	N	6		?
PSII-X	*psbX*	C	4		Role in Q_A function
PSII-Y (ycf32)	*PsbY*	N	4		Mn binding?
PSII-Z (ycf9)	*psbZ*	C	9		Antenna-reaction center interaction
PSII-O (OE33)	*PsbO*	N	27		Stabilizes Mn cluster, Ca^{2+} and Cl^- binding
PSII-P (OE26)[c]	*PsbP*	N	20		Ca^{2+} and Cl^- binding
PSII-Q (OE16)[c]	*PsbQ*	N	17		Ca^{2+} and Cl^- binding
PSII-R[c]	*PsbR*	N	10		?
PSII-S (CP22)	*PsbS*	N	22	chlorophyll, carotenoids	Antenna regulation by xanthophyll cycle
PSII-U[d]	*psbU*		14		?
PSII-V (cyt c-550)[d]	*PsbV*		15	heme	Role in O_2 evolution
LHCII-outer[c]	*Lhcb1*	N	30	chlorophyll, carotenoids	Antenna function
LHCII-outer[c]	*Lhcb2*	N	31	chlorophyll, carotenoids	Antenna function
LHCIIa-outer[c]	*Lhcb3*	N	25	chlorophyll, carotenoids	Antenna function
LHCII-inner (CP29)[c]	*Lhcb4*	N	35	chlorophyll, carotenoids	Antenna function
LHCII-inner (CP26)[c]	*Lhcb5*	N	36	chlorophyll, carotenoids	Antenna function
LHCII-inner (CP24)[c]	*Lhcb6*	N	18	chlorophyll, carotenoids	Antenna function

Reverse genetics


A Higher plants and green algae
Lhcb1+2+3
Lhcb4
Lhcb5
Lhcb6
S
H
I
J
K
L
C (CP43)
B (CP47)
MN
Tc
W
X
Q_A
Q_B
Fe
D (D2)
A (D1)
Phe
E F (cyt b_{559})
P680
Y_Z
e^-
Y_D
Mn Mn Mn Mn
P
O
Tn
CP43
Q
R
CP47
$2H_2O$
$O_2 + 4H^+$
$2PQH_2$
B Cyanobacteria
C
A
B
D
E
F
G
U
V
?


(a)
špenát
cyt b559
M/N
CP43
D1
D2
CP47
cyt b559
(b)
sinice
cyt b559
CP43
D1
CP47
CP47
D1
CP43
cyt b559

The Photosystem II complex - *Thermosynechococcus elongatus*

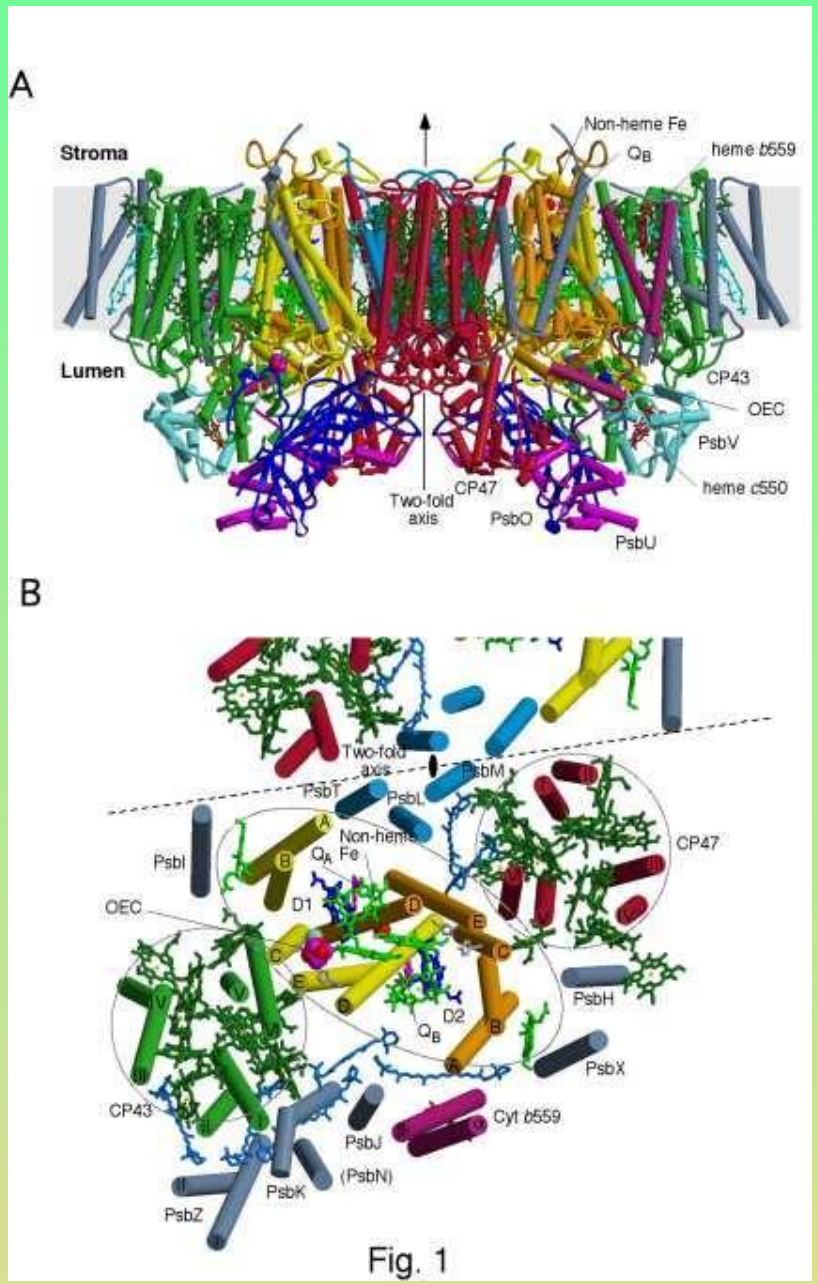
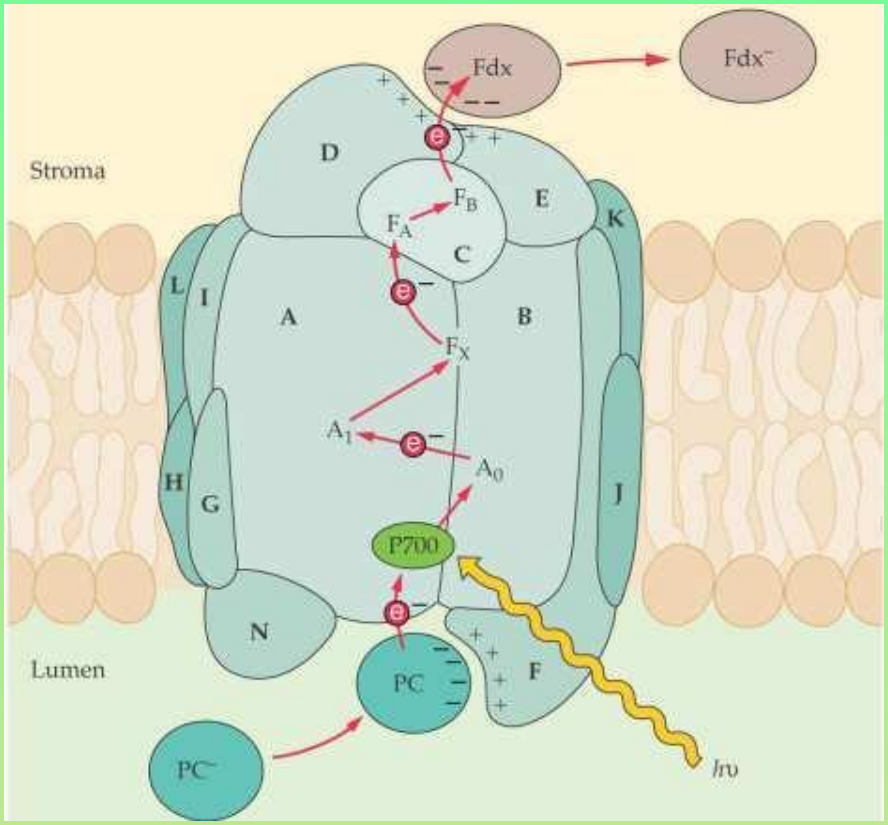
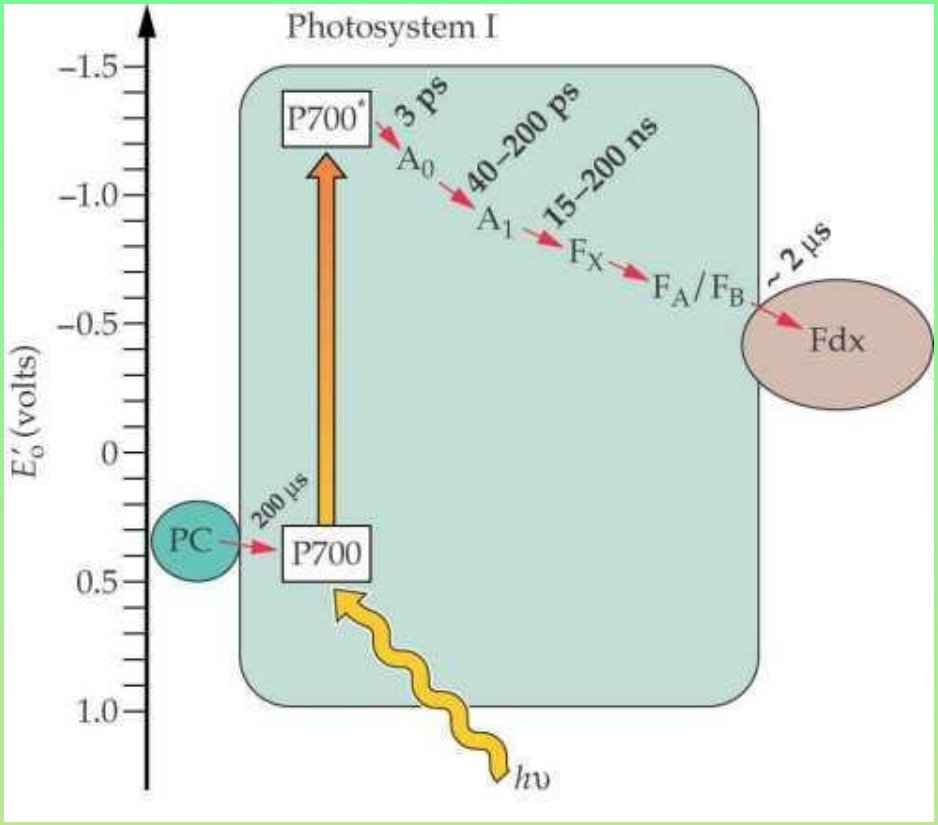
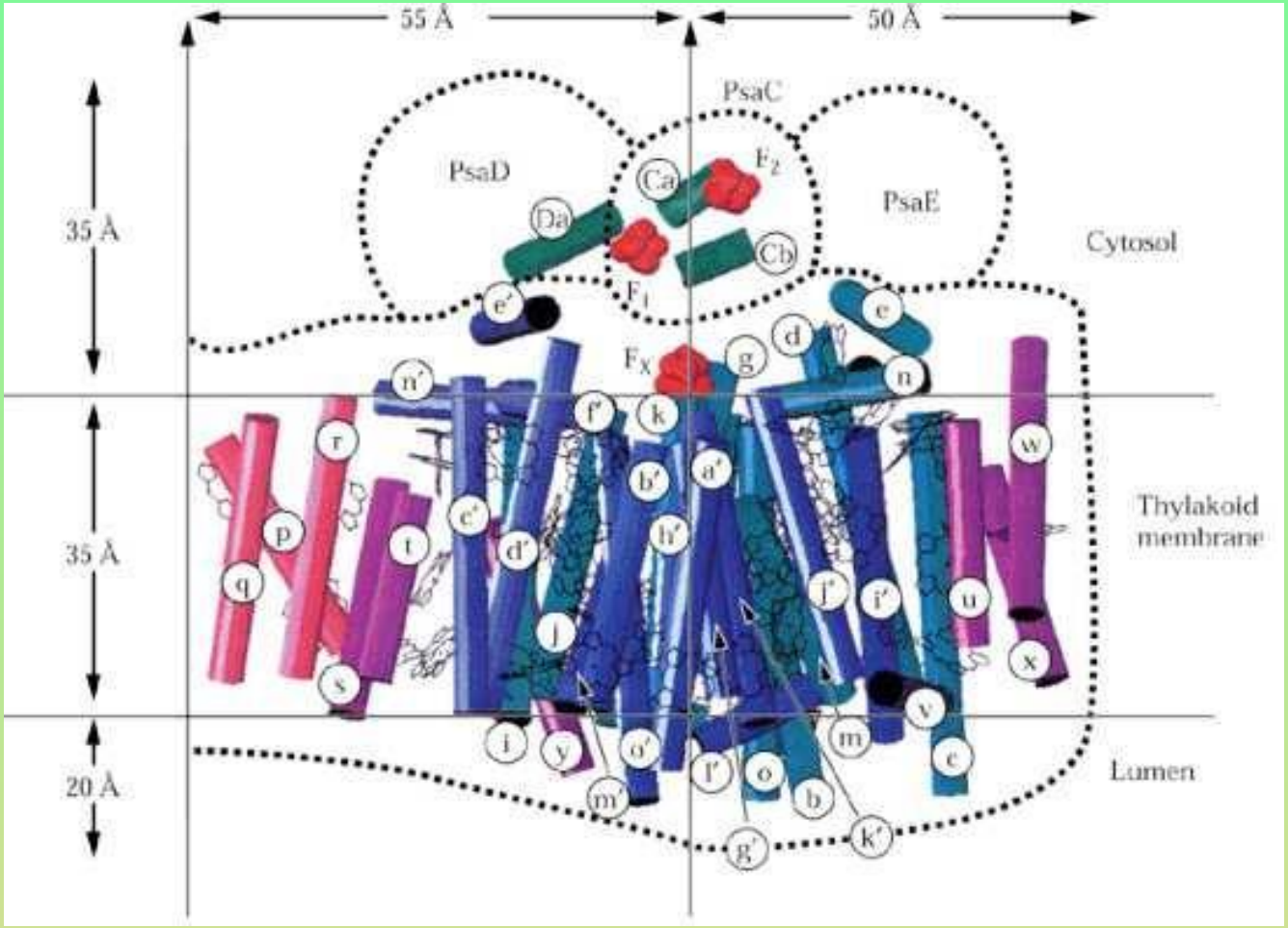


Fig. 1

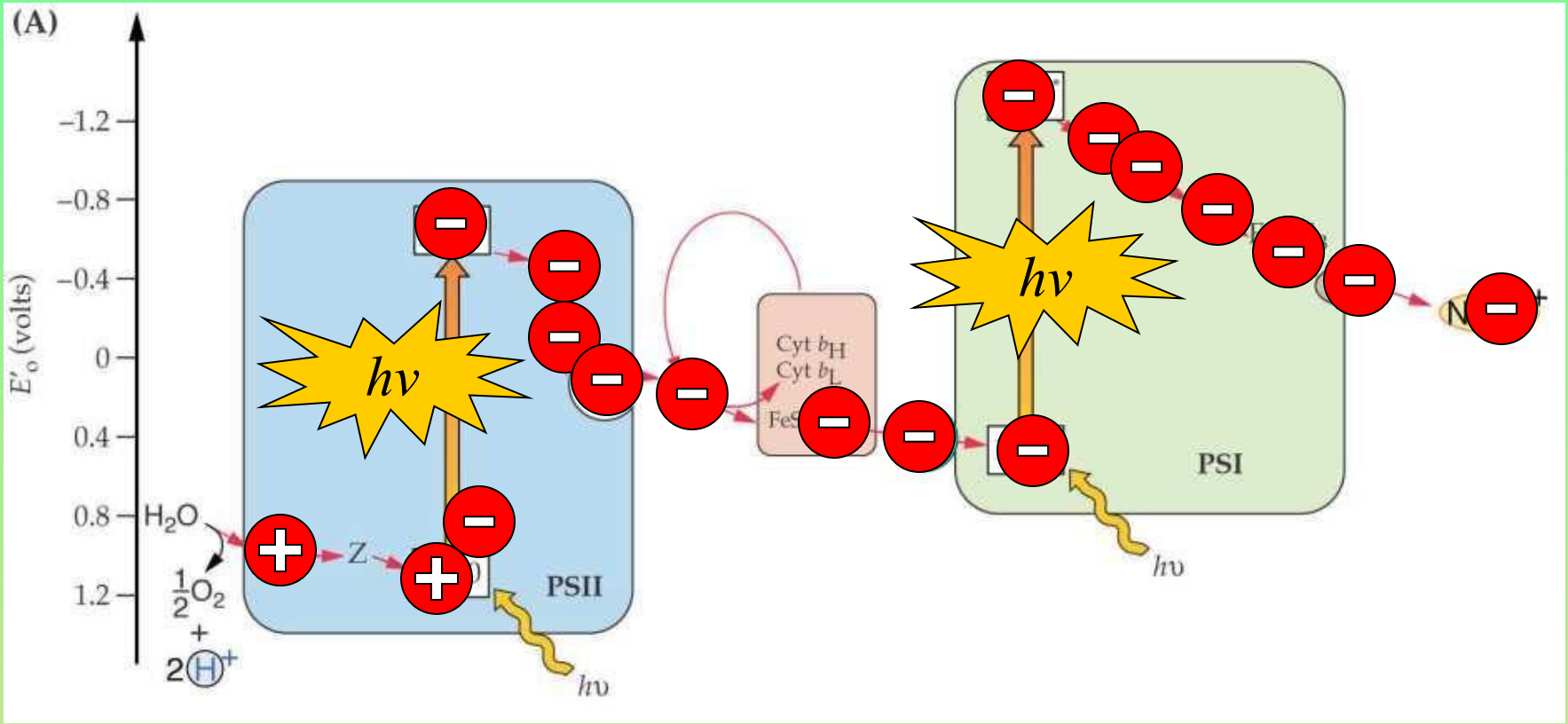

Fdx
Fdx⁻
Stroma
D
E
K
F_B
F_A
C
L
I
A
B
F_X
A_1
A_0
H
G
J
P700
N
Lumen
PC
F
PC⁻
hυ


Photosystem I
−1.5
−1.0
−0.5
0
0.5
1.0
E_o' (volts)
P700*
3 ps
A_0
40–200 ps
A_1
15–200 ns
F_X
F_A/F_B
~ 2 µs
Fdx
200 µs
PC
P700
hυ

The Photosystem I complex - 2.5 A structure

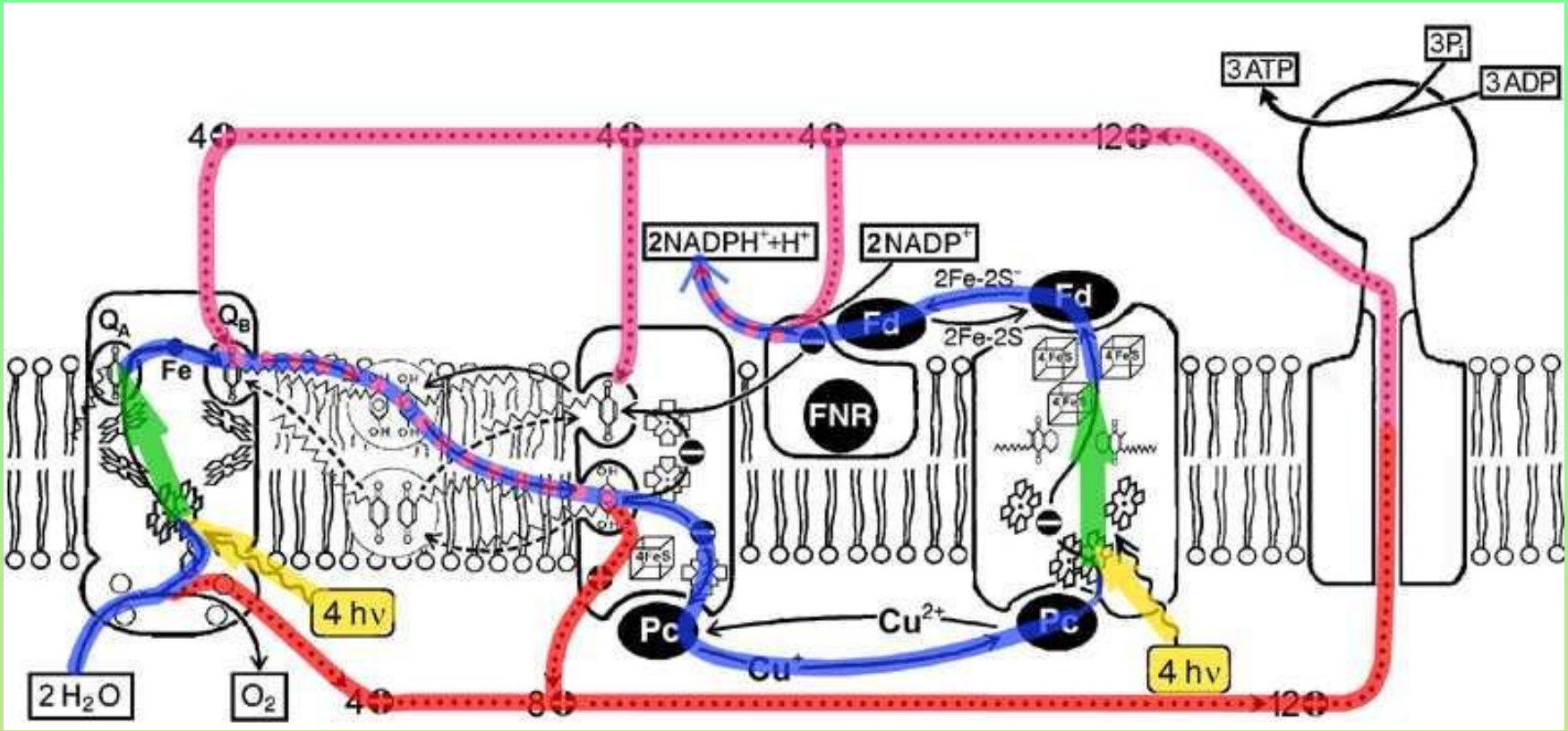


Z - scheme of photosynthesis



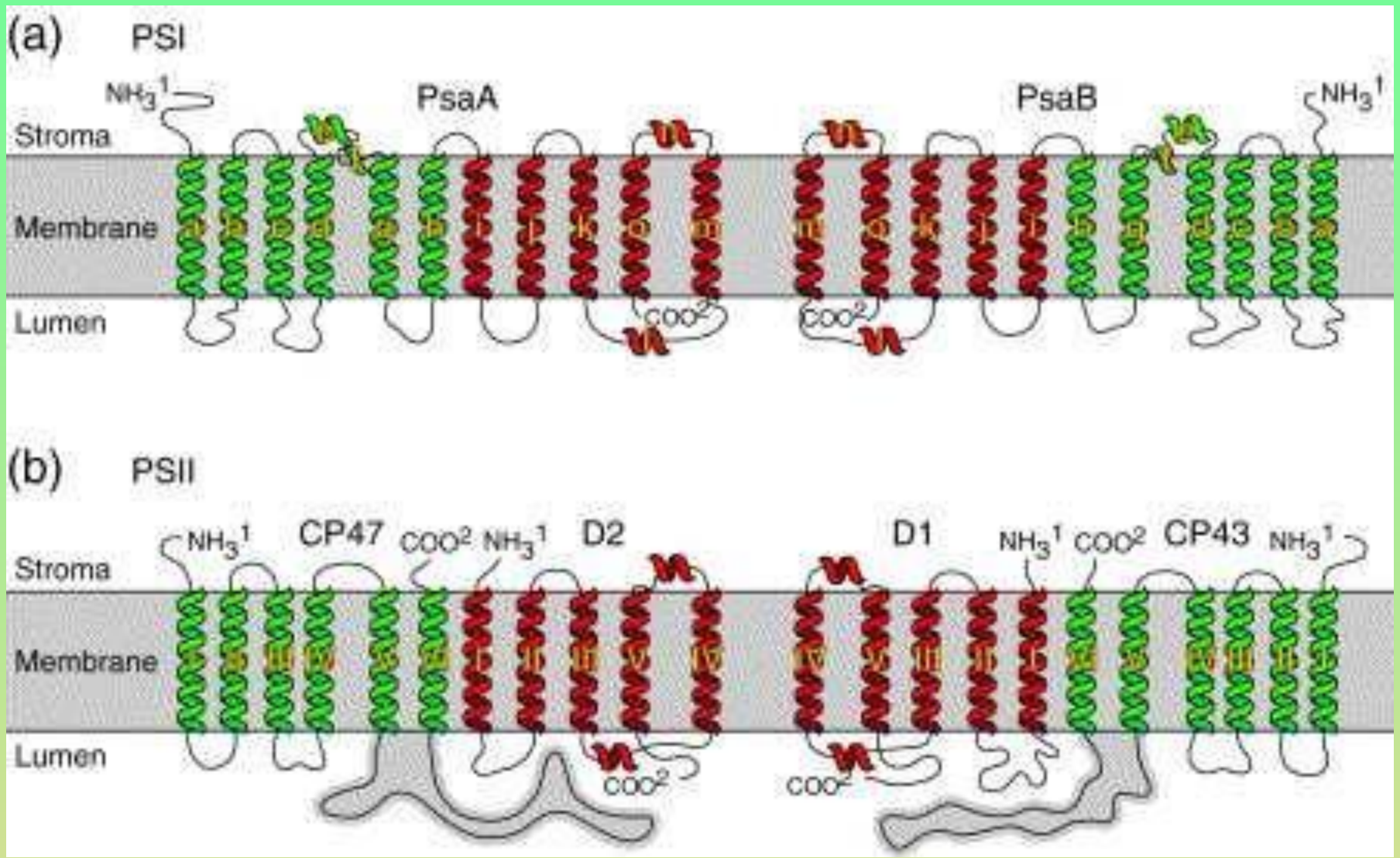
$$2\ H_2O + 2\ NADP^+ + 8\ h\nu \rightarrow O_2 + 2\ NADPH \cdot H^+$$

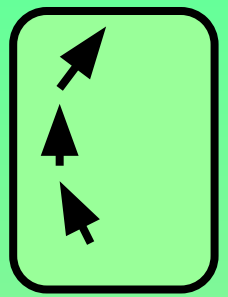
Electron transport



Chloroplast

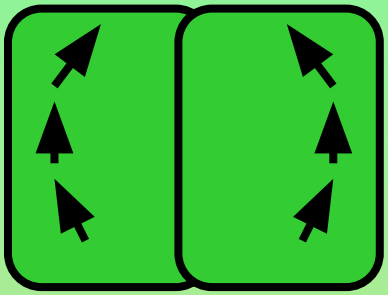
Evolution of photosynthesis


(a) PSI
NH_3^1
PsaA
PsaB
NH_3^1
Stroma
Membrane
Lumen
COO^2
COO^2
(b) PSII
NH_3^1
CP47
COO^2
NH_3^1
D2
D1
NH_3^1
COO^2
CP43
NH_3^1
Stroma
Membrane
Lumen
COO^2
COO^2



Monomeric Reaction Center

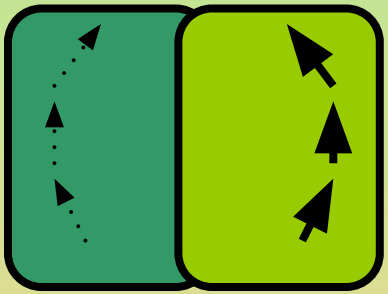
Evolutionary change



Homodimeric Reaction Center

Gene duplication

Divergence



Heterodimeric Reaction Center

Photosynthetic reaction centers are present in many phylogenetically distant organisms

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