

METABOLISMUS

ŽIVOT

- růst
- rozmnožování
- vývoj a diferenciacce
- dráždivost
- pohyb

Látková přeměna - intermediální metabolismus

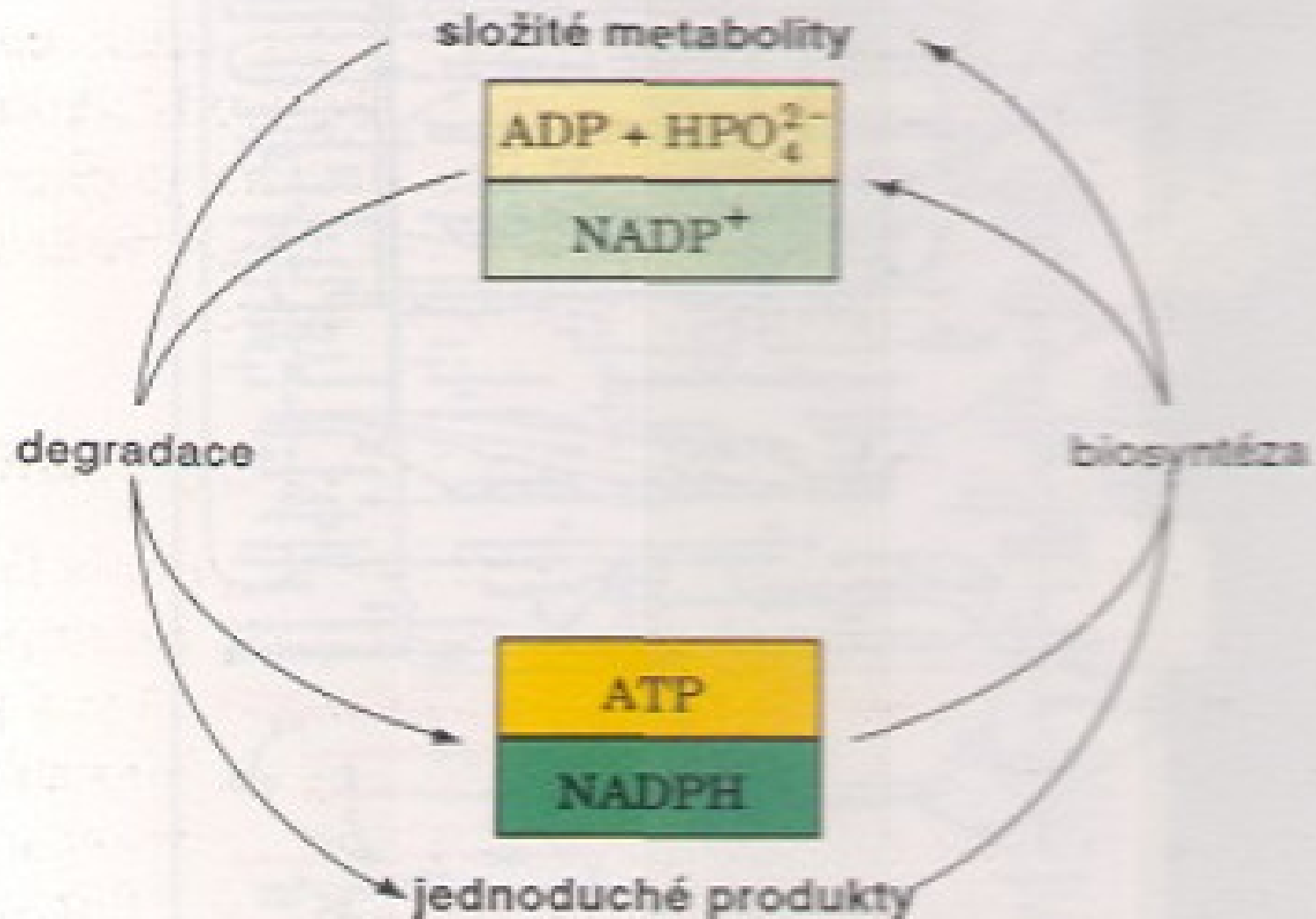
Funkce - zajišťování energie

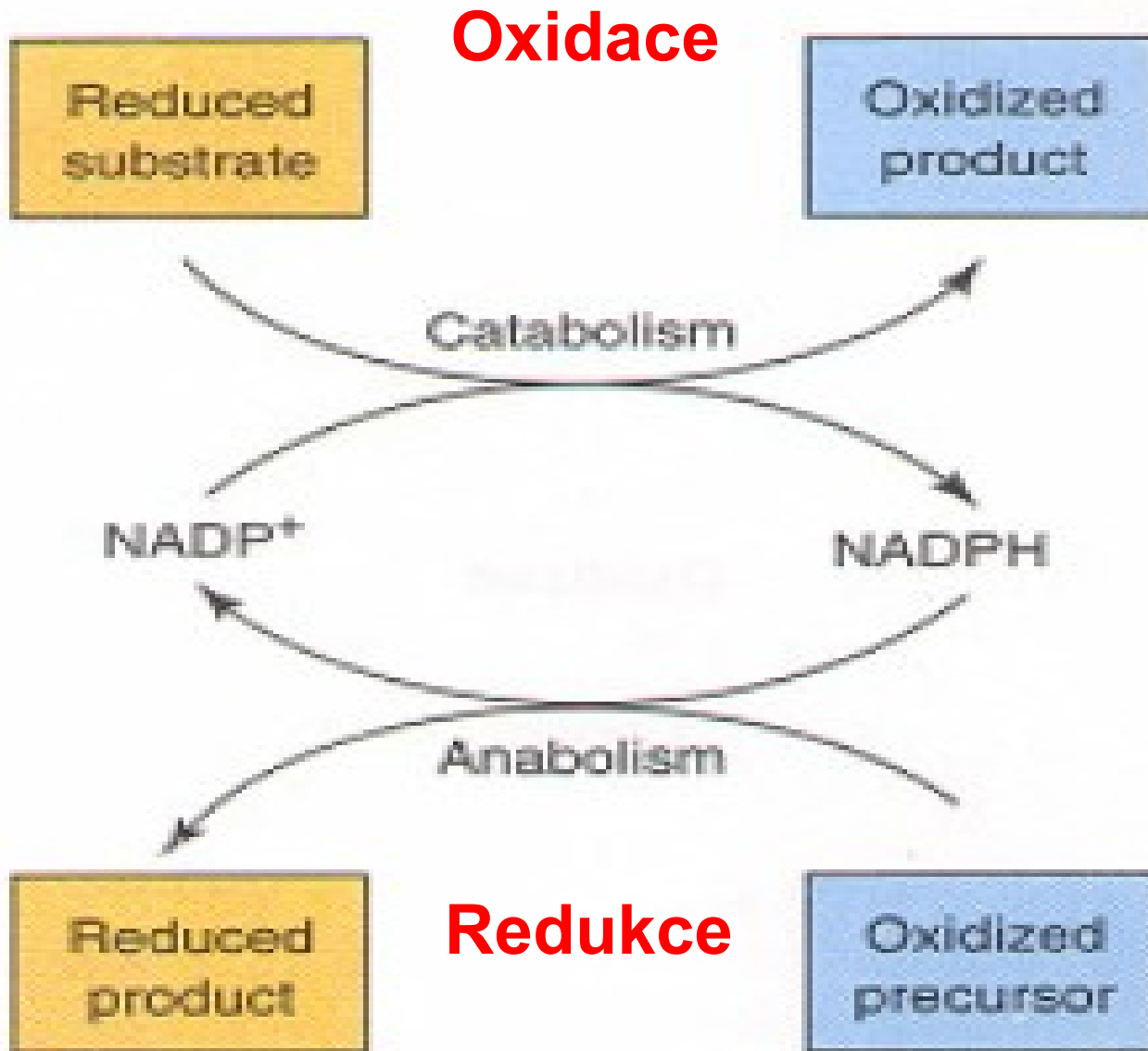
- zajišťování stavebního materiálu

Procesy - rozkladné - katabolické - disimilační

- biosyntetické - anabolické - asimilační

- amfibolické - obojí





Rozdělení organismů podle metabolismu

A. Podle zdroje přijímané energie

fototrofy - sluneční energie

chemotrofy - oxidace chemických látek

B. Podle zdroje stavebního materiálu

autotrofy - anorganické látky

heterotrofy - organické látky

C. Podle donoru elektronů

organotrofy - organické látky

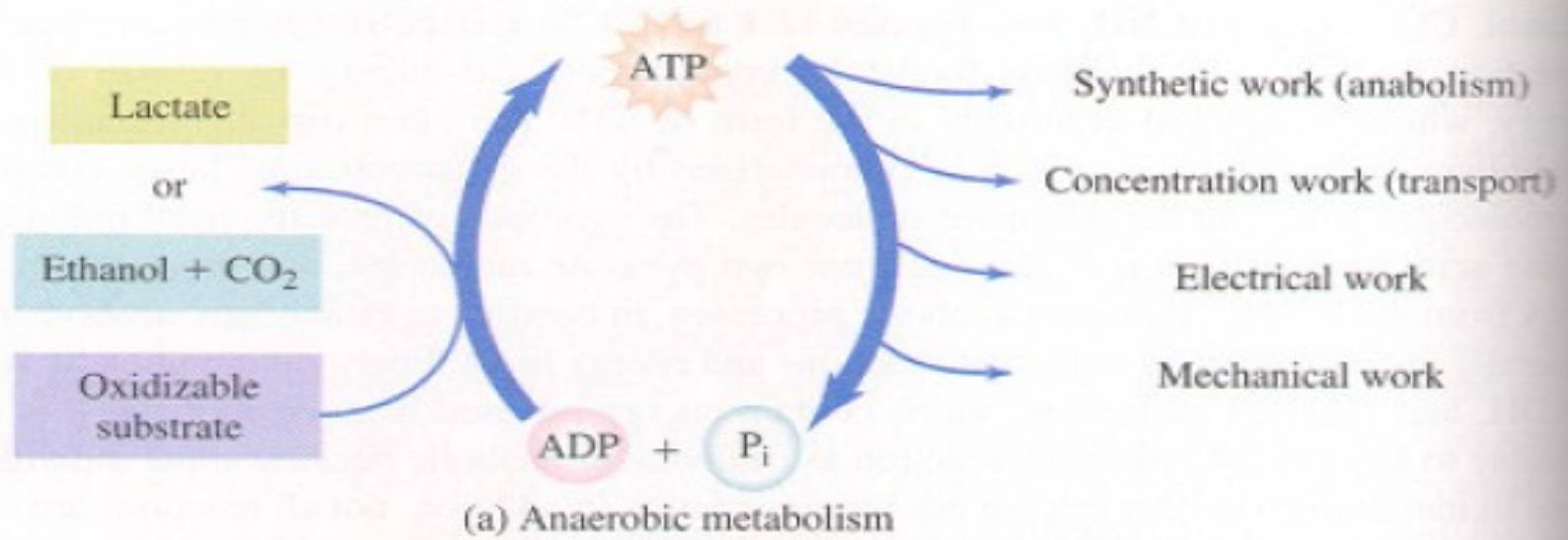
litotrofy - anorganické látky

D. Podle konečného akceptoru elektronů

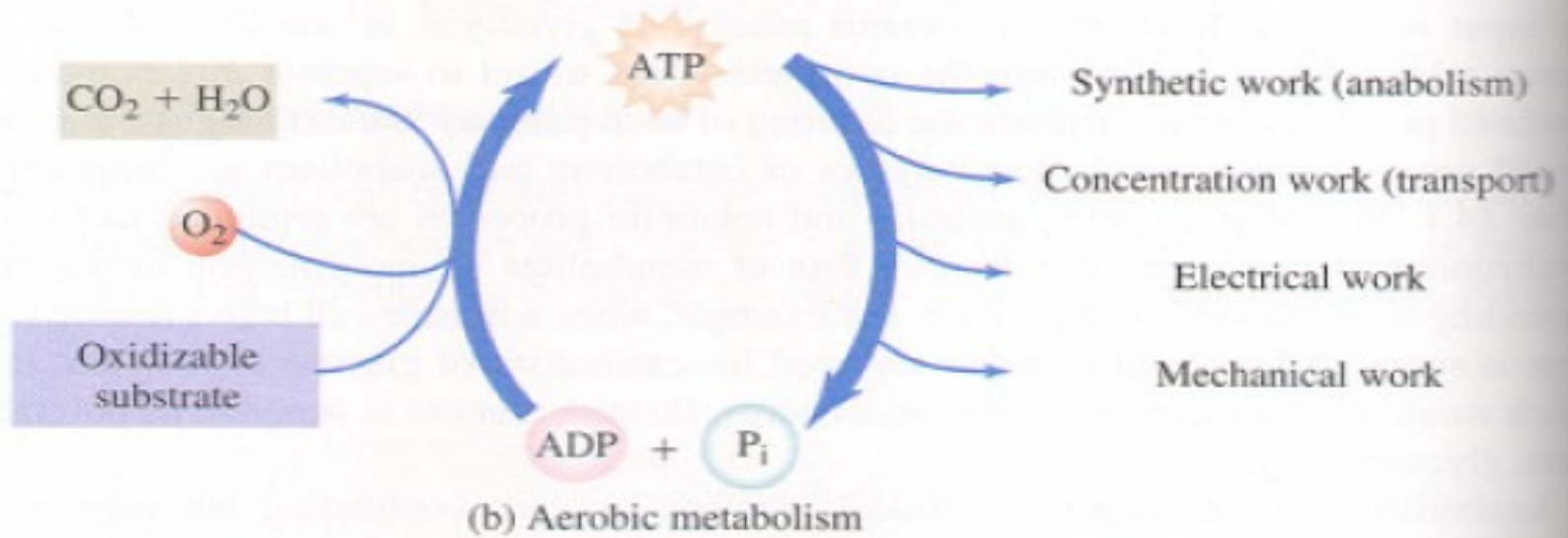
aeroby - O_2

anaeroby - NO_3^- , SO_4^{2-}

fermentace - elektrony jsou předávány na jiné organické látky

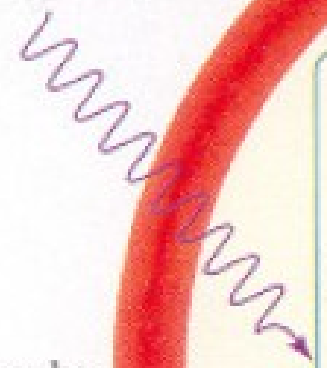


Fermentace



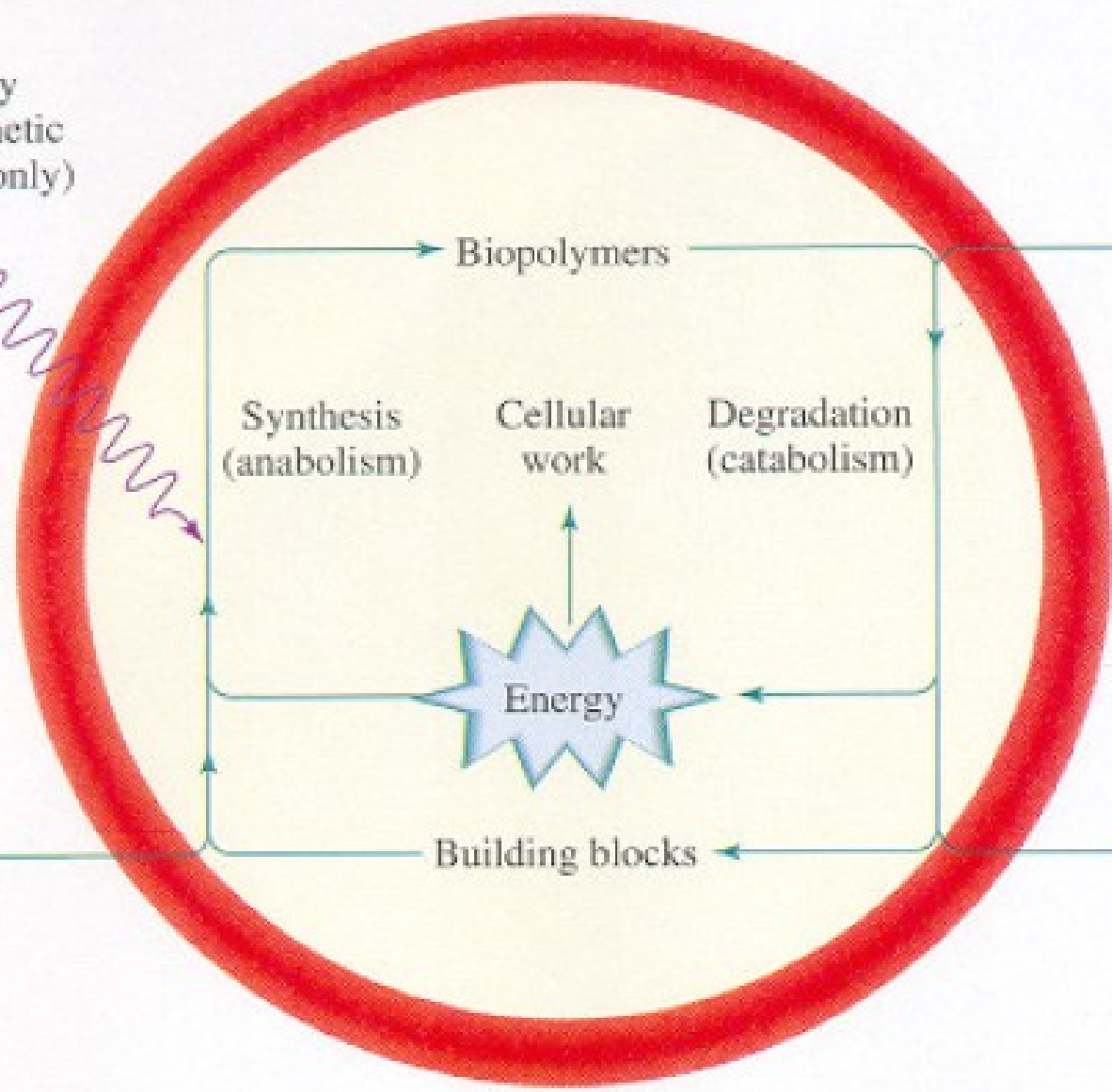
Respirace

Light energy
(photosynthetic
organisms only)



Autotrophs

Food
(CO₂)



Food

Heterotrophs

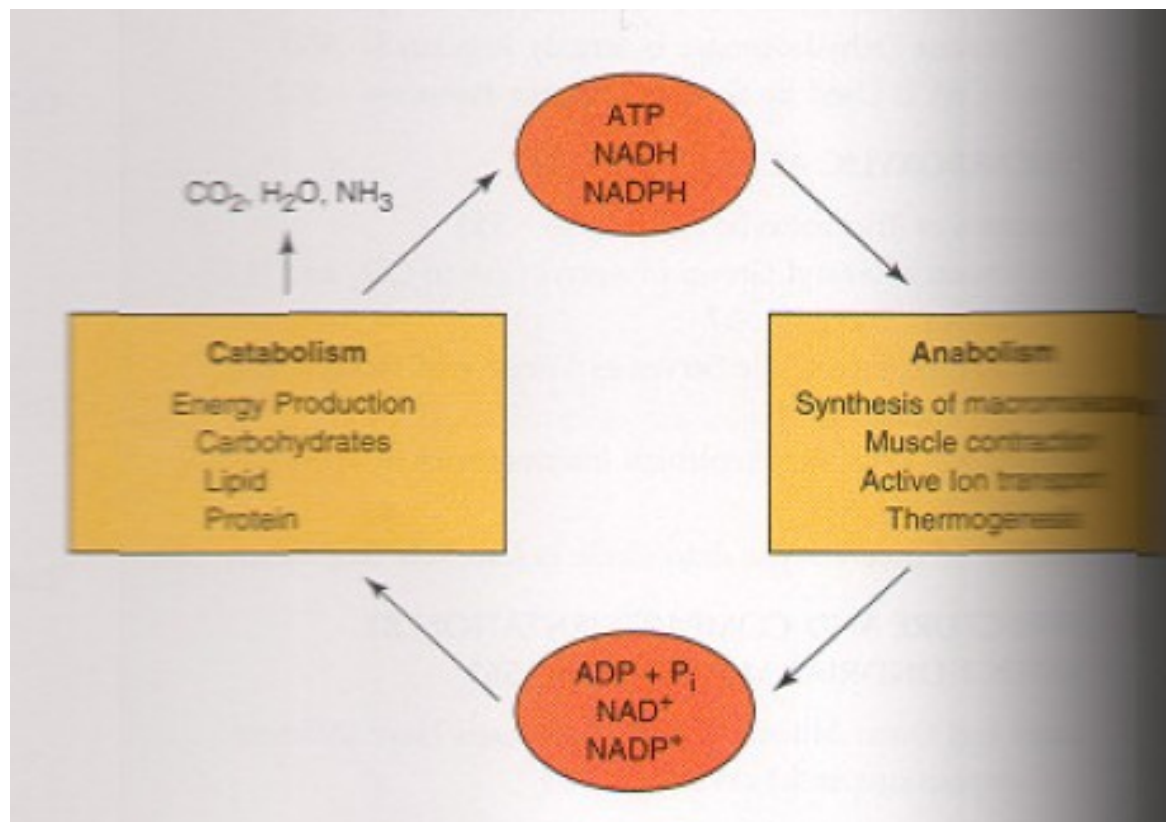
Energy

Building blocks

Wastes

Metabolismus

H. KREBS - tři fáze metabolismu



Katabolismus - degradační fáze metabolismu - konvergentní

- Funkce**
- produkce energie
 - poskytuje prekurzory
 - poskytuje NADPH

1. Fáze - složité molekuly štěpeny na stavební jednotky **0 % energie**
2. Fáze - stavební jednotky převedeny na C₁ a C₂ látky **30 % energie**
3. Fáze - citrátový cyklus + dýchací řetězec **70 % energie**

Katabolismus

I.fáze

0 %



Anabolismus - biosyntetická fáze metabolismus - divergentní

Funkce - zajišťování stavebního materiálu pro funkci a růst

1. Fáze - citrátový cyklus poskytuje prekurzory
2. Fáze - z prekurzorů jsou syntetizovány stavební jednotky
3. Fáze - ze stavebních jednotek jsou syntetizovány
biopolymery

Bioenergetika

1. *Chemická energie*
2. *Mechanická - pohybová energie*
3. *Osmotická - transportní energie*
4. *Elektrická energie*
5. *Strukturní energie*
6. *Regulační energie*
7. *Tepelná energie*
8. *Světelná energie*

Chemická energie - energie vazeb a strukturního uspořádání
chemických sloučenin

Enthalpie H - reakční teplo při konstantním tlaku

$\Delta H < 0$ - reakce exogenní

$\Delta H > 0$ - reakce endogenní

Gibbsova energie G - změna energie při konstantním tlaku a teplotě

$$\Delta G = \Delta H - T\Delta S$$

$$\Delta G^0 = -RT \ln K$$

$$\Delta G^0 = -nF \Delta E^0$$

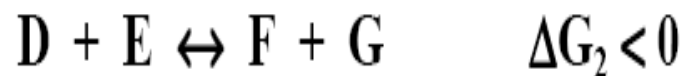
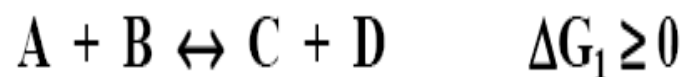
$$\Delta G^0 = \Delta H^0 - T\Delta S^0$$

$$\Delta G^0 = \sum G^0_{\text{produktů}} - \sum G^0_{\text{vychoz. Látek}}$$

$\Delta G < 0$ - reakce exergonické

$\Delta G > 0$ - reakce endergonické

Spřažení reakcí



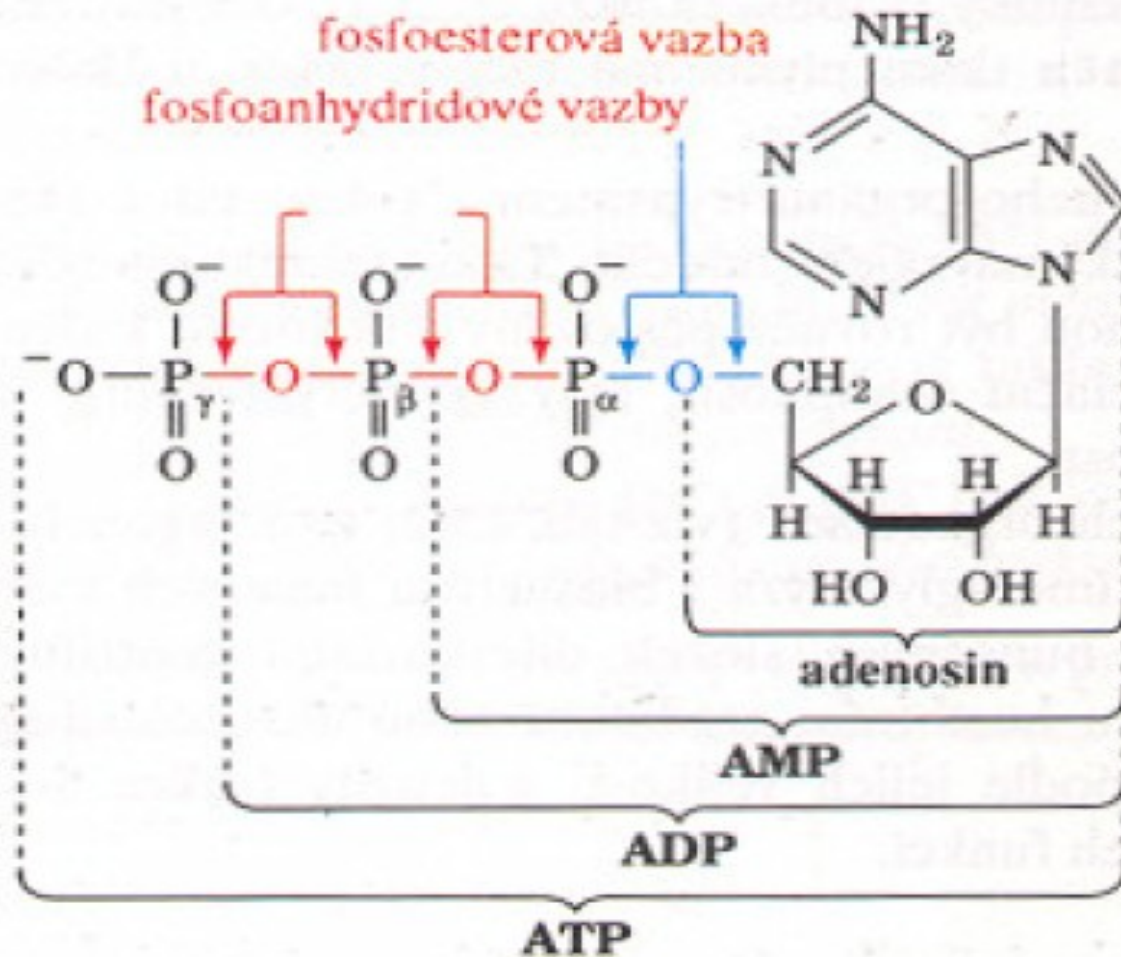
$$\Delta G = \Delta G_1 + \Delta G_2$$

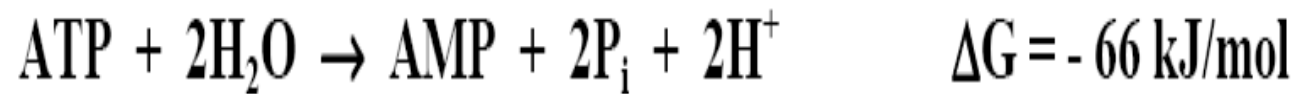
Makroergické sloučeniny - makroergická vazba

1. při procesech uvolňování energie jsou schopny část této energie zachytit a uchovat
2. při procesech vyžadujících energii mohou svým rozkladem tuto uchovanou energii uvolnit a předat

ATP - univerzální přenašeč energie

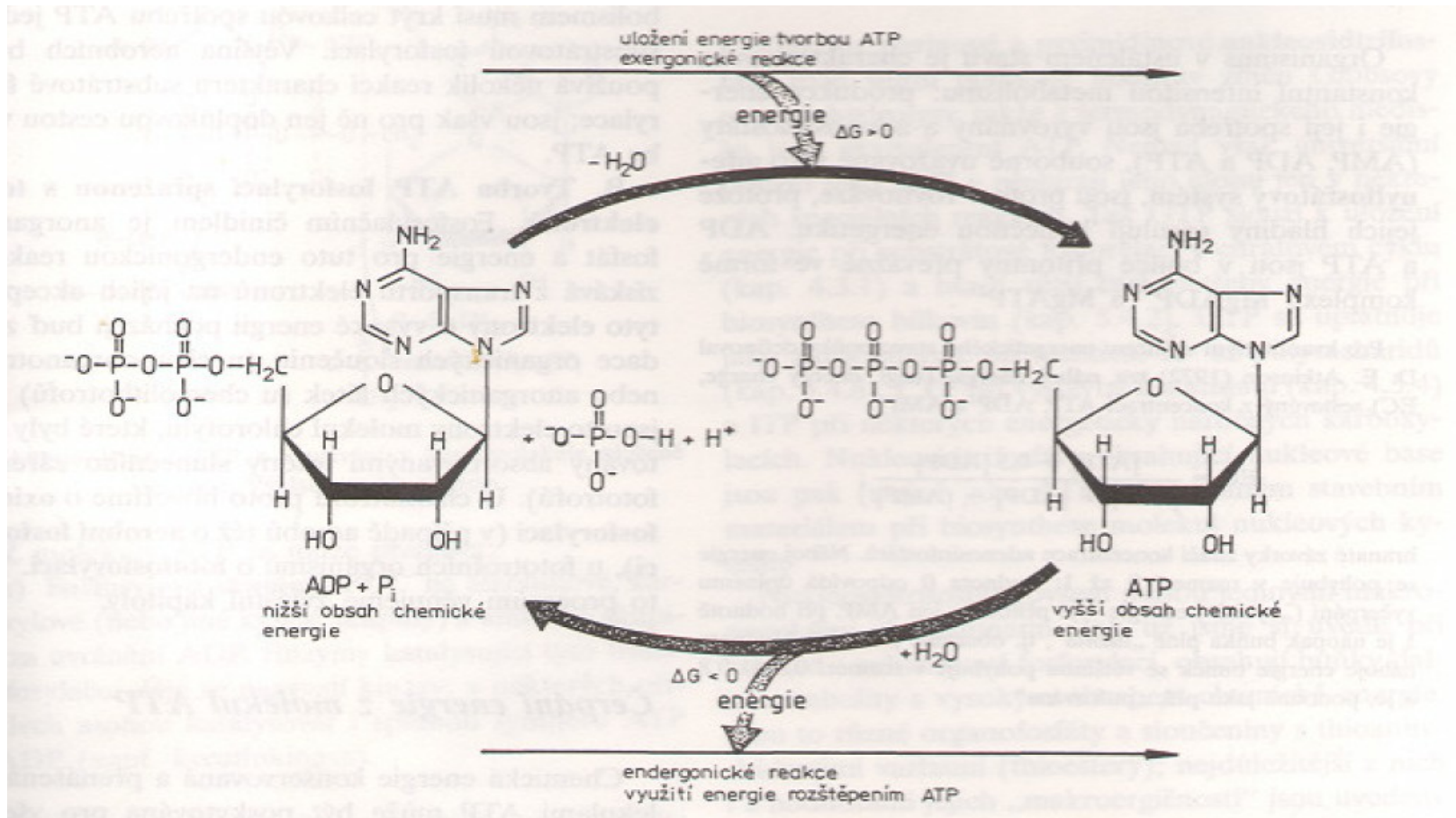
LIPMANN a KALCKAR 1941





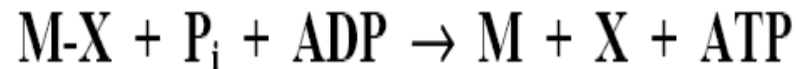
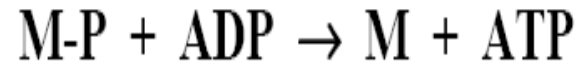
ATP - univerzální přenašeč energie

LIPMANN a KALCKAR 1941



Tvorba ATP

1. *Substrátová fosforylace*



2. *Fosforylace spřažena s tokem elektronů*

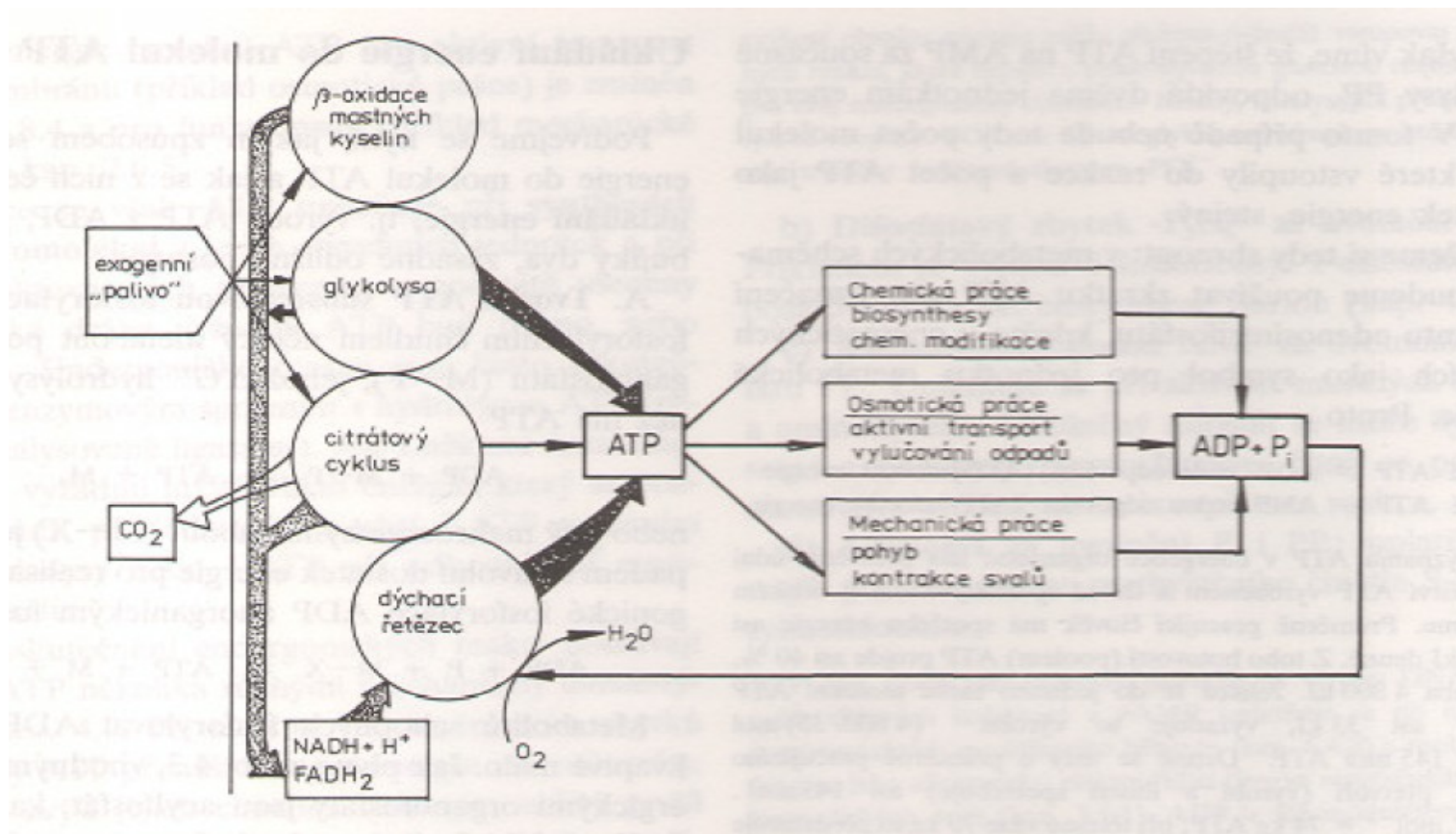
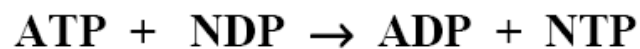
- oxidační fosforylace
- fotofosforylace

3. *Adenylátkinasovou reakcí*



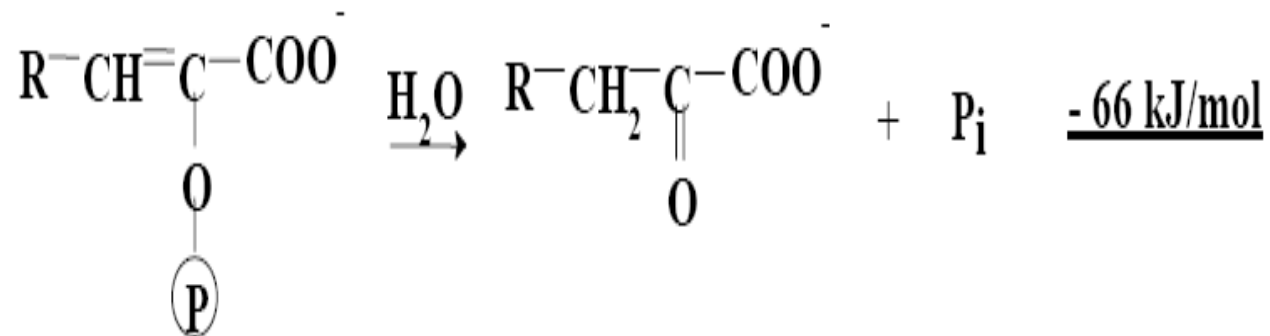
Spotřeba ATP

- Biosyntetické reakce
- Počáteční stádia odbourávání živi
- Fyziologické procesy
- Vzájemné přeměny nukleotidů

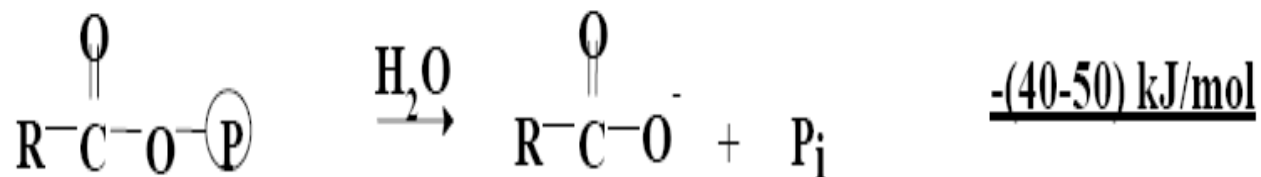


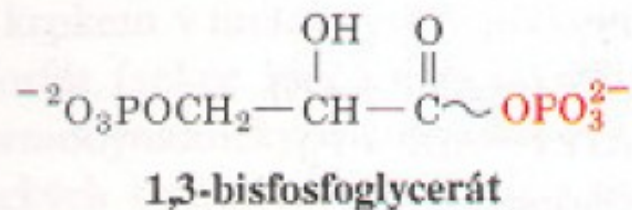
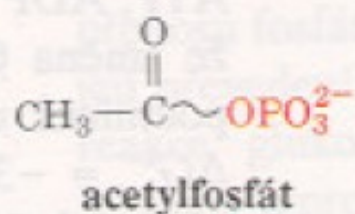
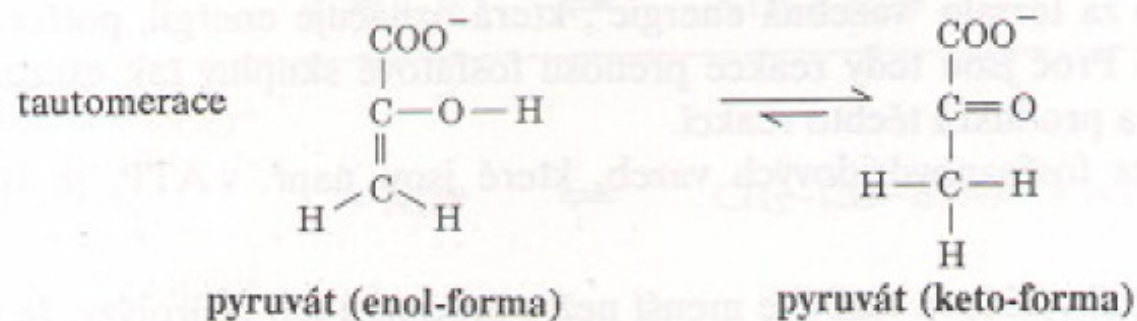
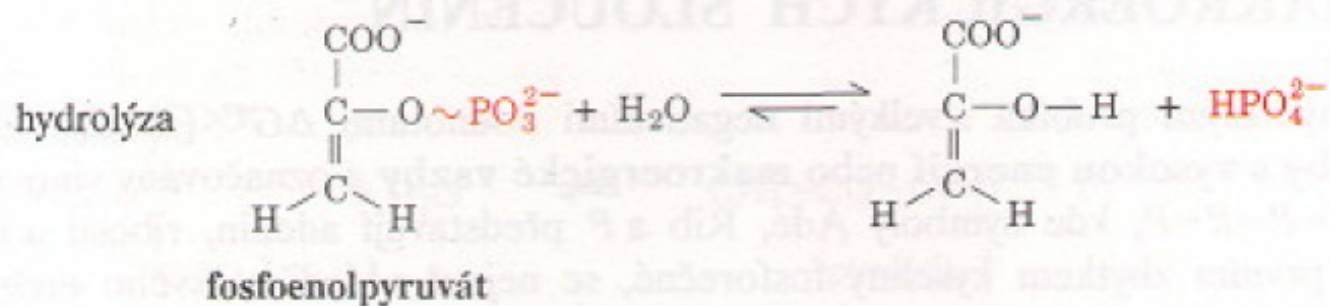
Další makroergické sloučeniny

ENOYLFOSFÁTY

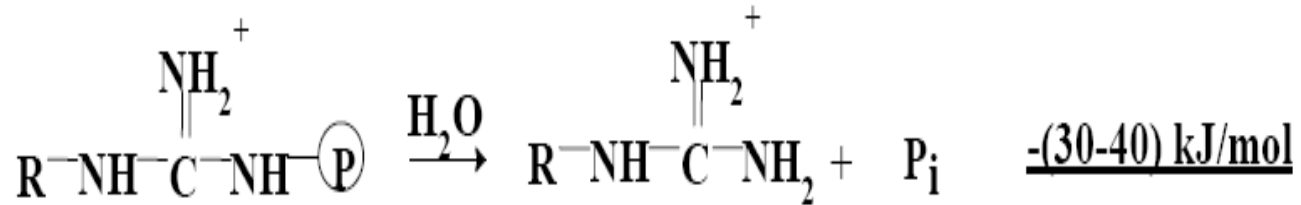


ACYLFOSFÁTY

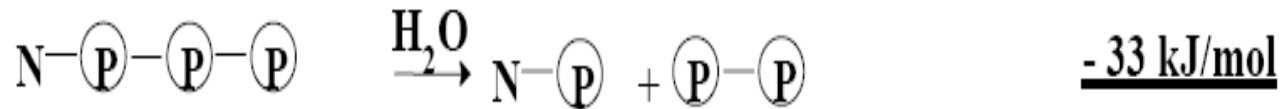
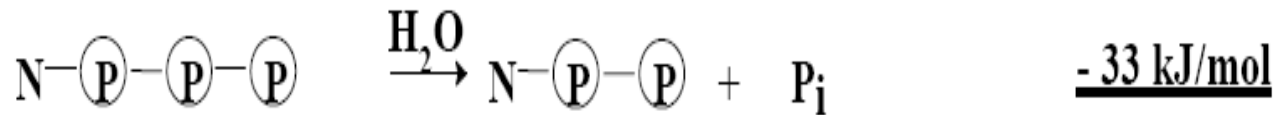


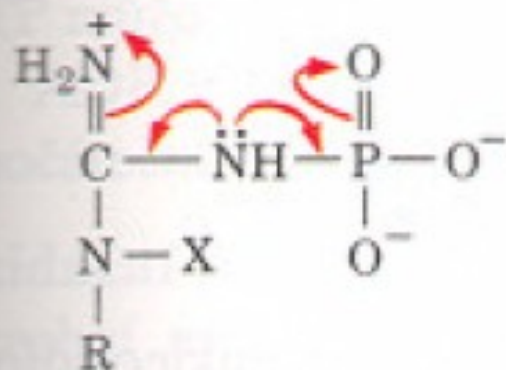


GUANIDIUMFOSFÁTY



NUKLEOTIDY

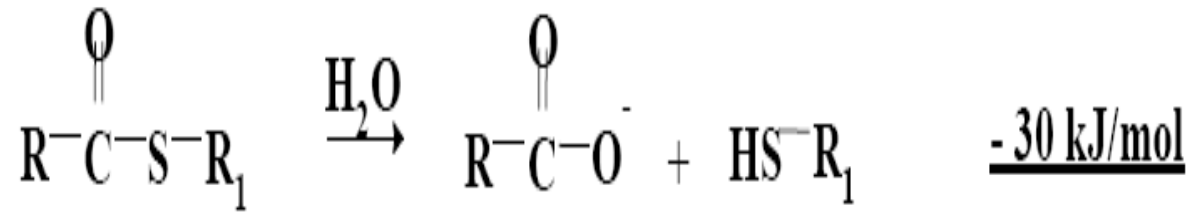




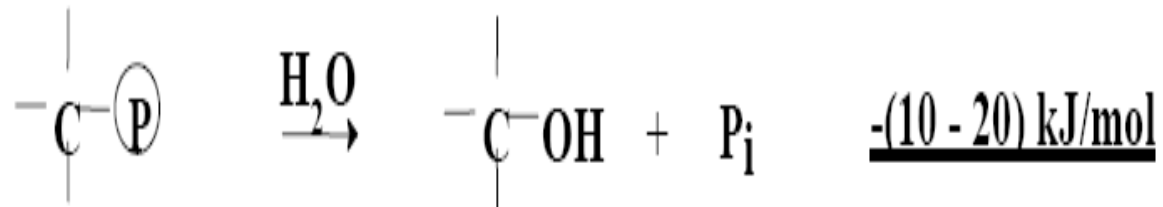
$\text{R} = \text{CH}_2 - \text{CO}_2^-$; $\text{X} = \text{CH}_3$ fosfokreatin

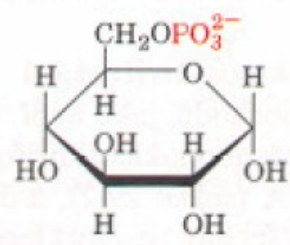
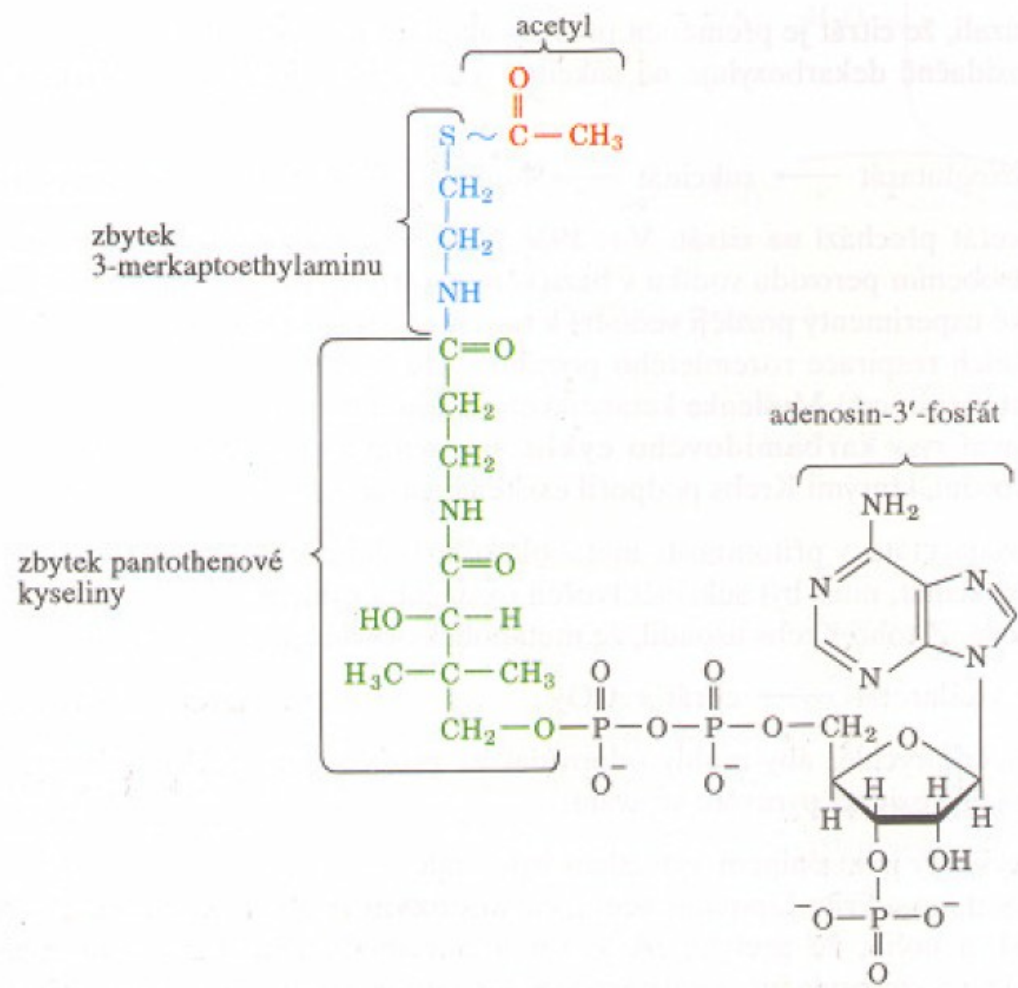
$\text{R} = \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \overset{\text{NH}_3^+}{\underset{|}{\text{CH}}} - \text{CO}_2^-$; $\text{X} = \text{H}$ fosfoarginin

ACYLTHIOESTERY

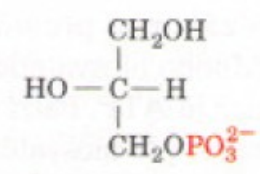


FOSFOMONOESTERY





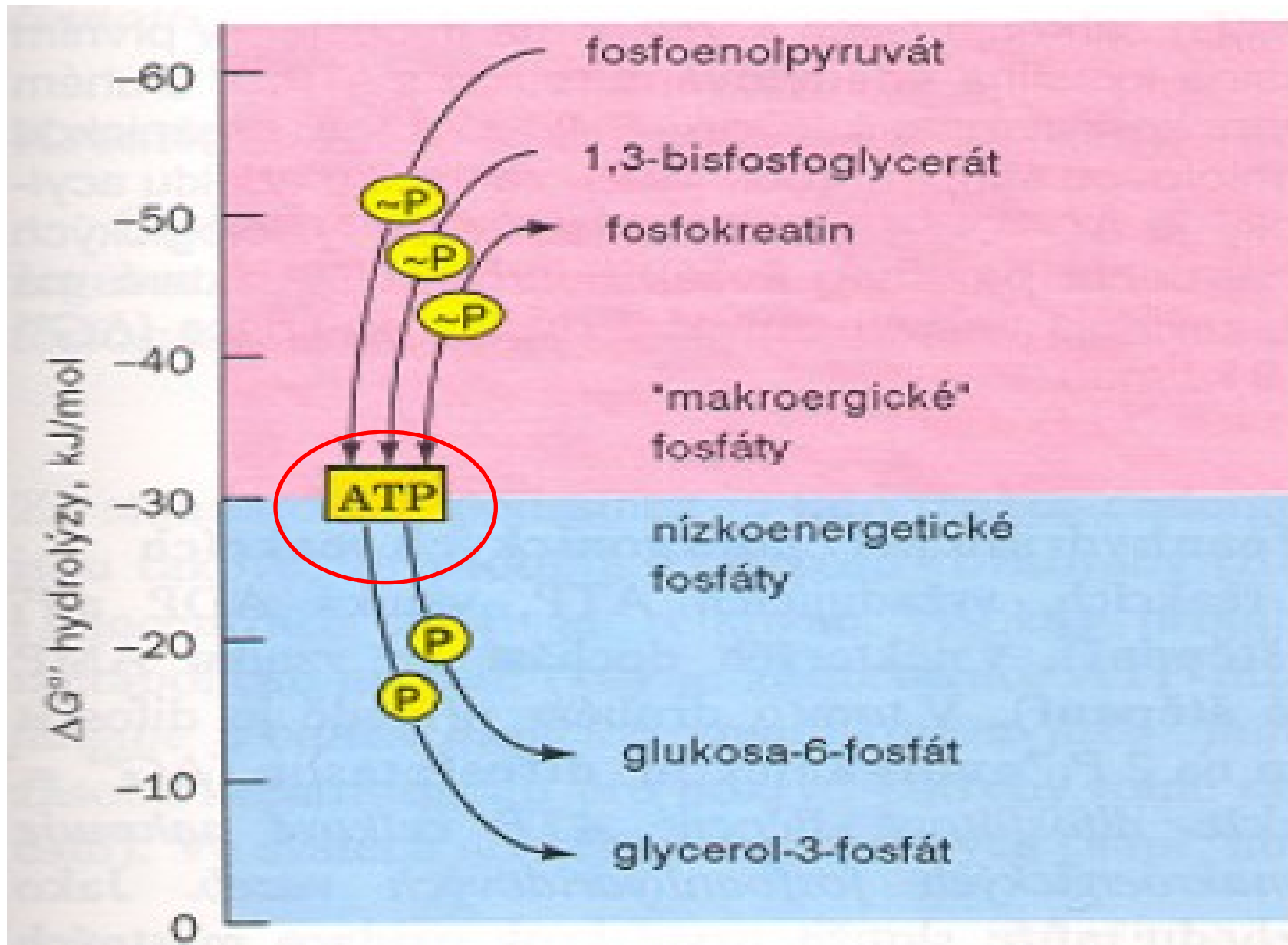
α -D-glukosa-6-fosfát



L-glycerol-3-fosfát

Phosphorylated Compounds	ΔG° (kJ/mol) ^a	Phosphoryl Group Transfer Potential
Phosphoenolpyruvate	- 61.9	Highest
1,3-Biphosphoglycerate	- 49.3	↓
Phosphocreatine	- 43.0	
ATP	- 30.5	
ADP	- 30.5	
Glucose 1-phosphate	- 20.9	
Glucose 6-phosphate	- 13.8	
Glycerol 1-phosphate	- 9.2	

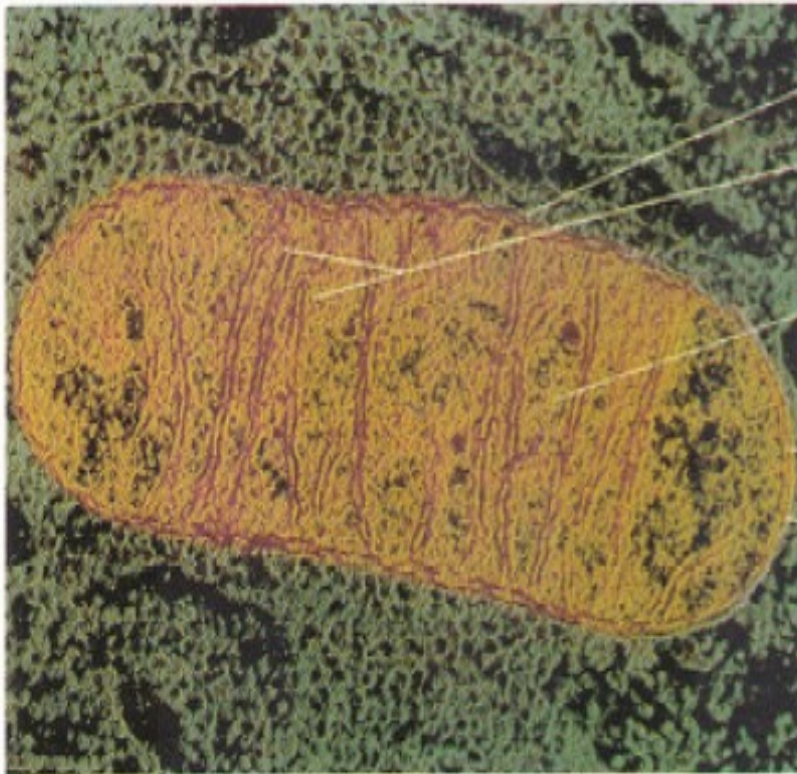
^aThese values are for hydrolysis reactions (the transfer potential of the phosphoryl group to H₂O).



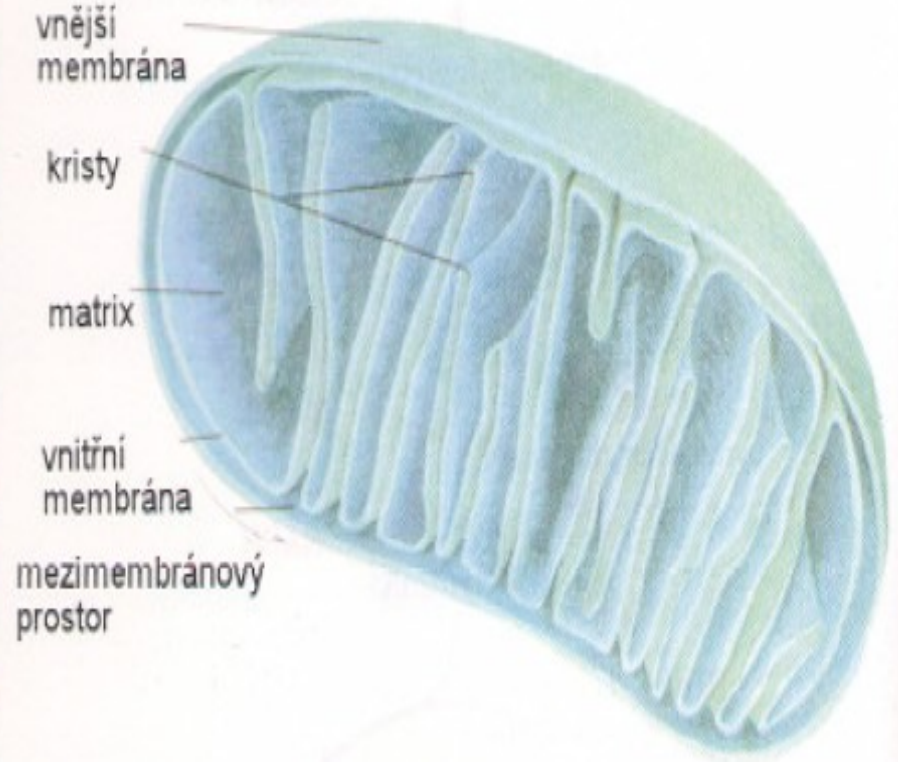
DÝCHACÍ ŘETĚZEC A OXIDAČNÍ FOSFORYLACE



Mitochondrie

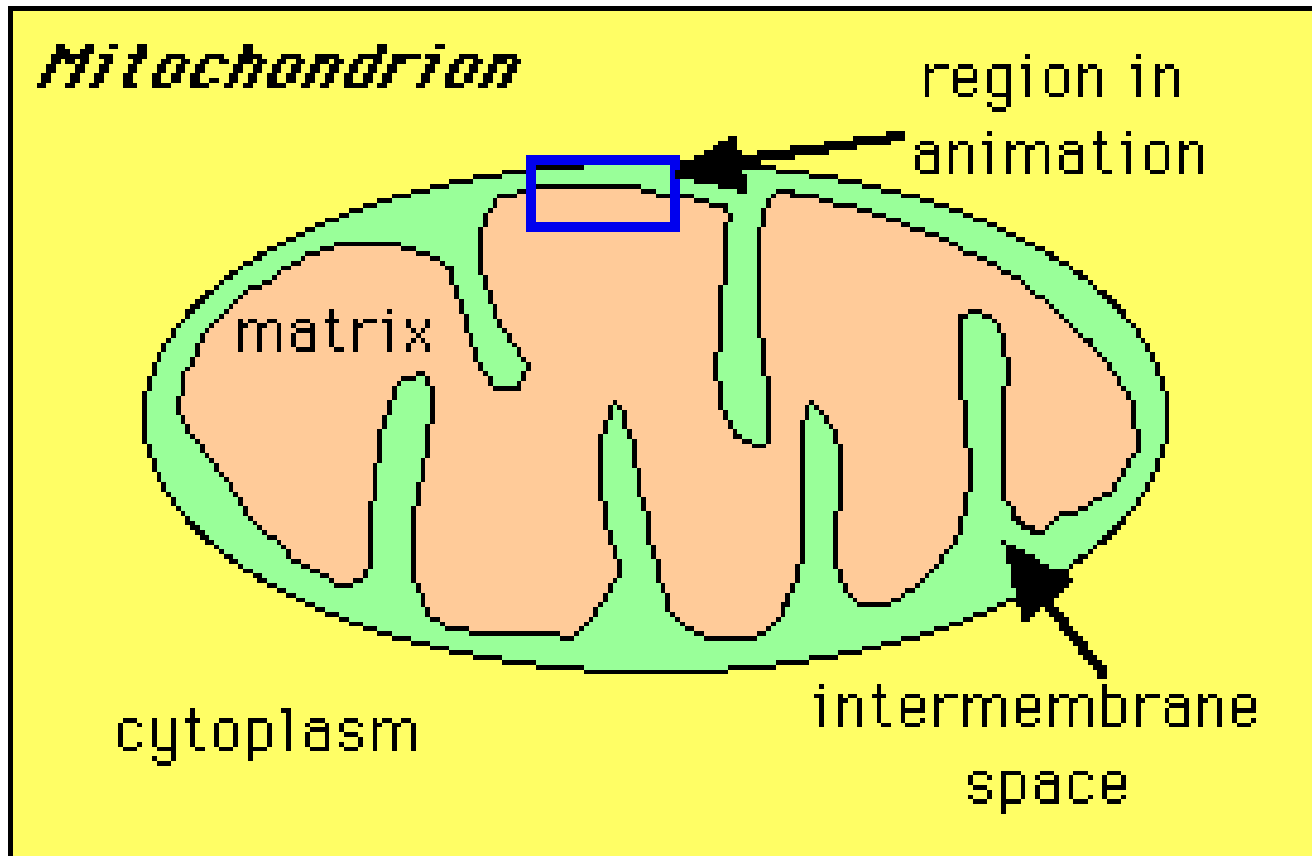


(a)

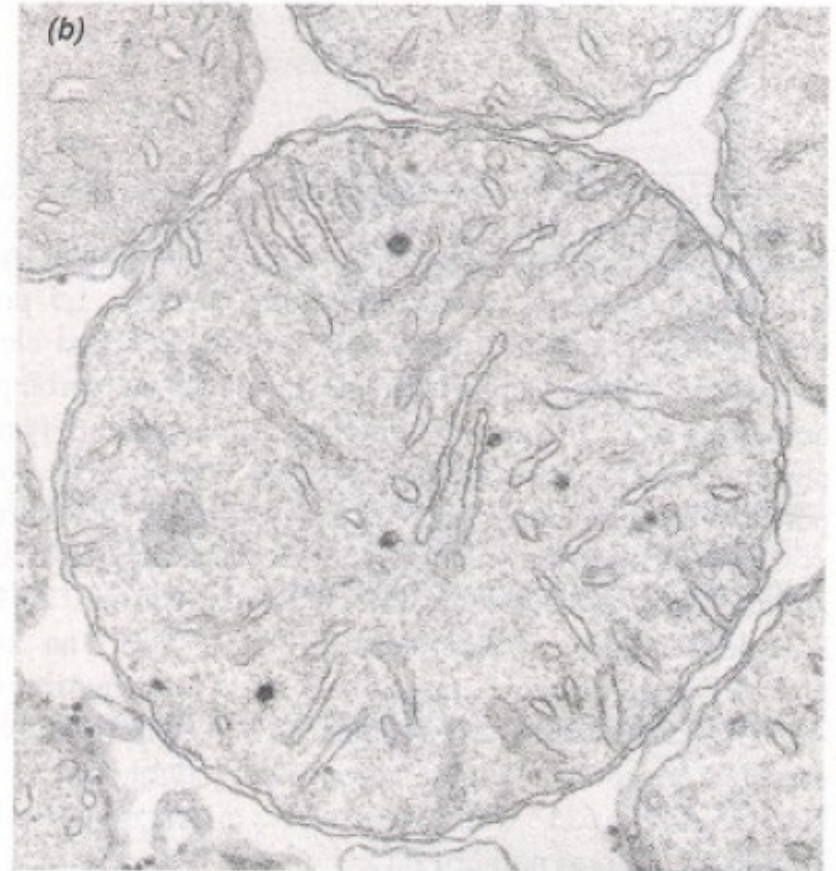


(b)

Lokalizace



Mitochondrie

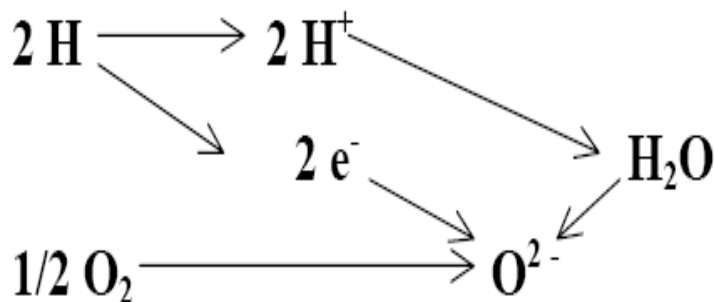


DÝCHACÍ ŘETĚZEC A OXIDAČNÍ FOSFORYLACE

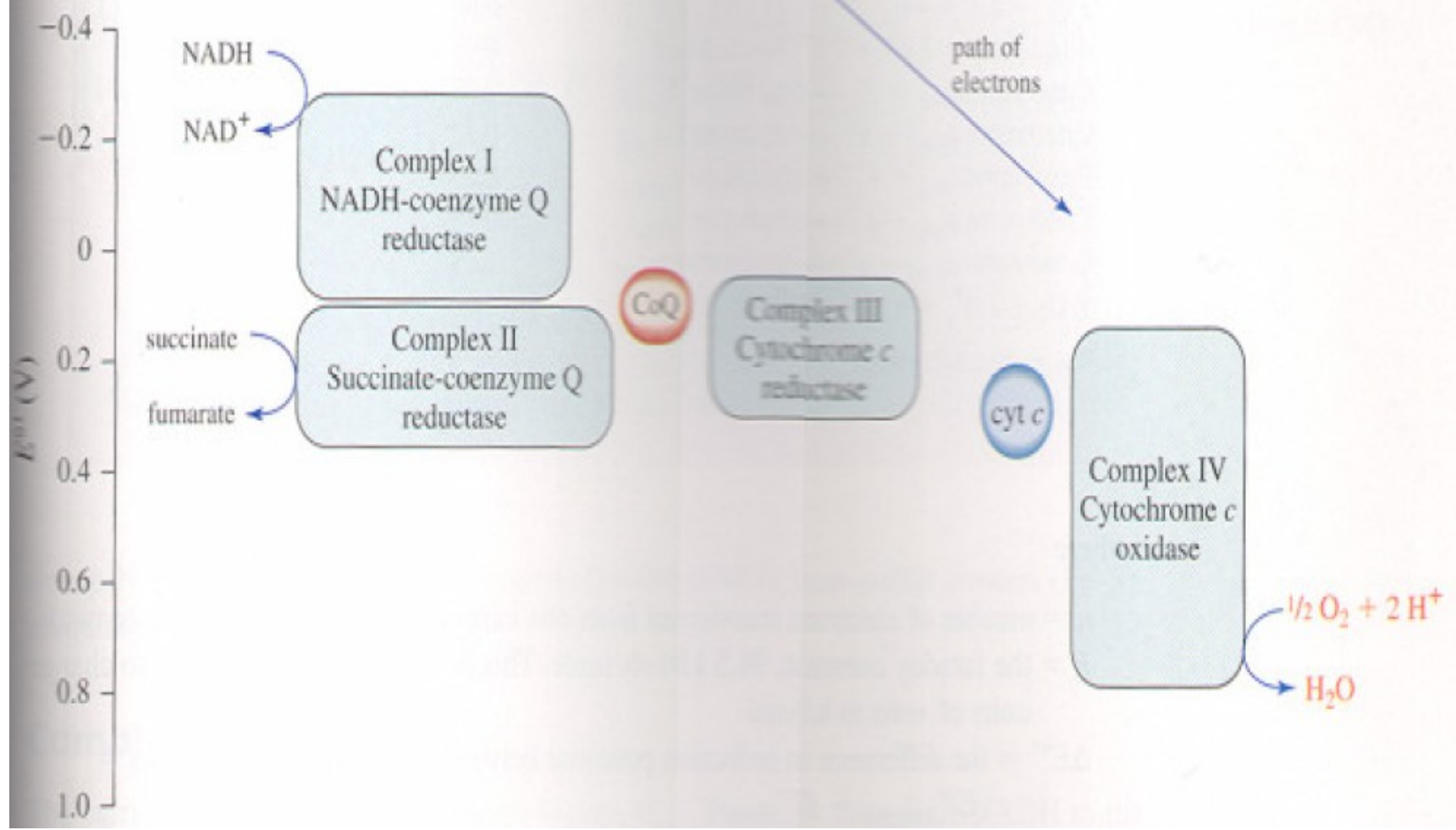
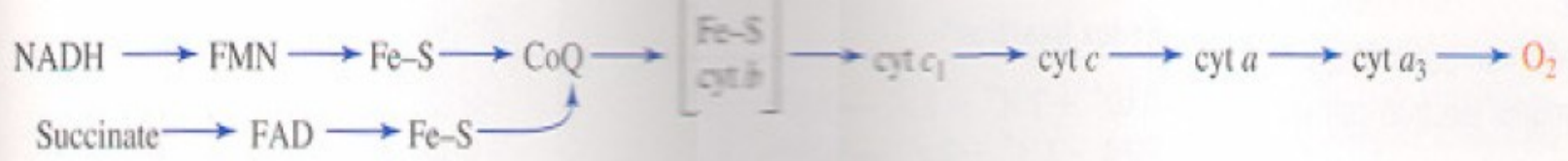


Aerobní respirace

NADH →
FADH₂ →



Živočichové
Rostliny
Některé bakterie



Complex I

NADH dehydrogenase
FMN
Fe-S centers

NADH:ubiquinone (Q)
oxidoreductase

Mobilní
přenašeč

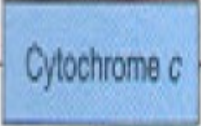


Complex III

Cytochrome bc₁ complex
2 b-type hemes
Rieske Fe-S center
c-type heme (cyt c₁)

Ubiquinol (QH₂):cytochrome c
oxidoreductase

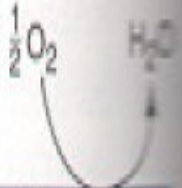
Mobilní
přenašeč



Complex IV

Cytochrome aa₃ complex
2 a-type hemes
Cu ions

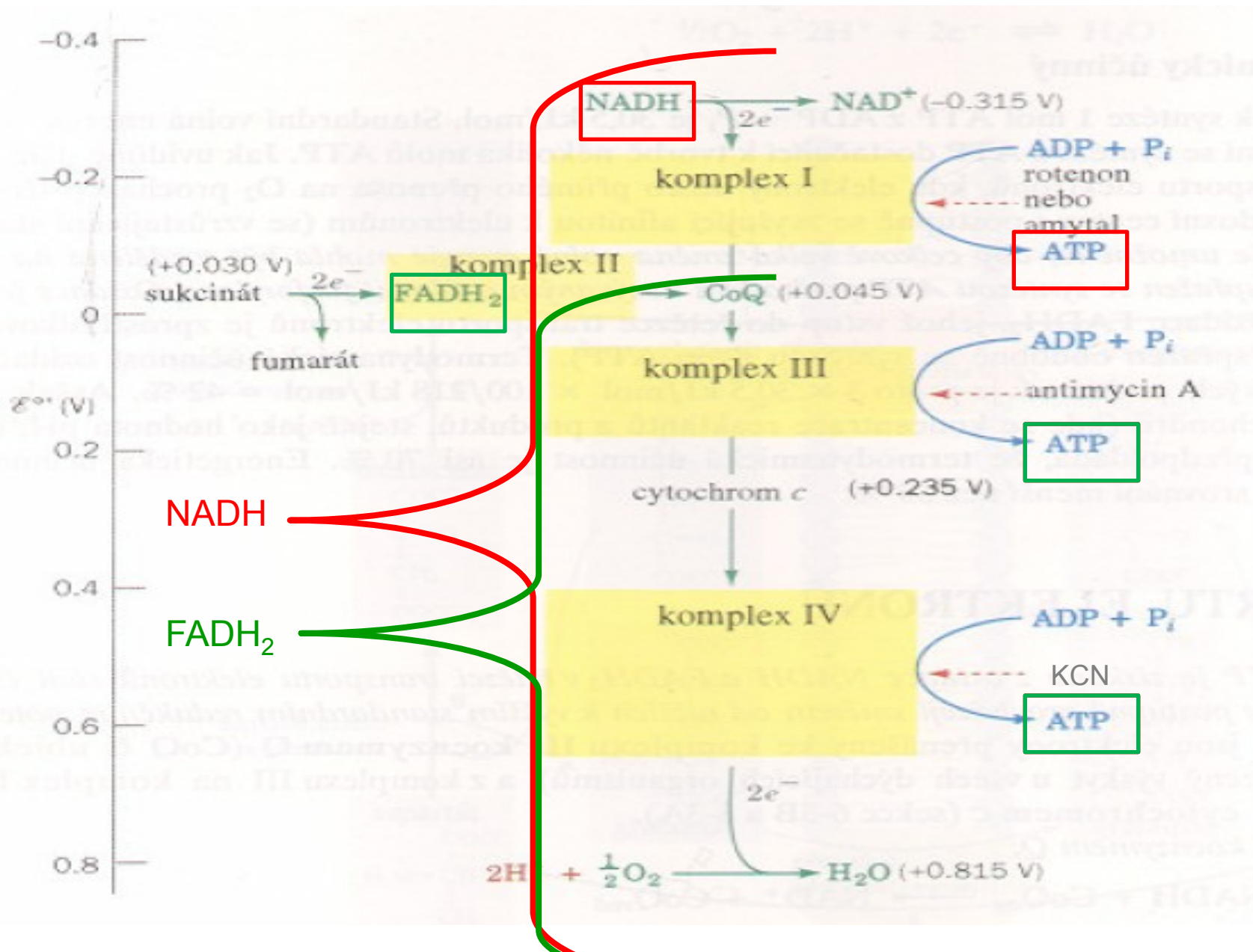
Cytochrome c oxidase



Complex II

Succinate dehydrogenase
FAD (covalent)
Fe-S centers
b-type heme

Succinate:ubiquinone (Q)
oxidoreductase

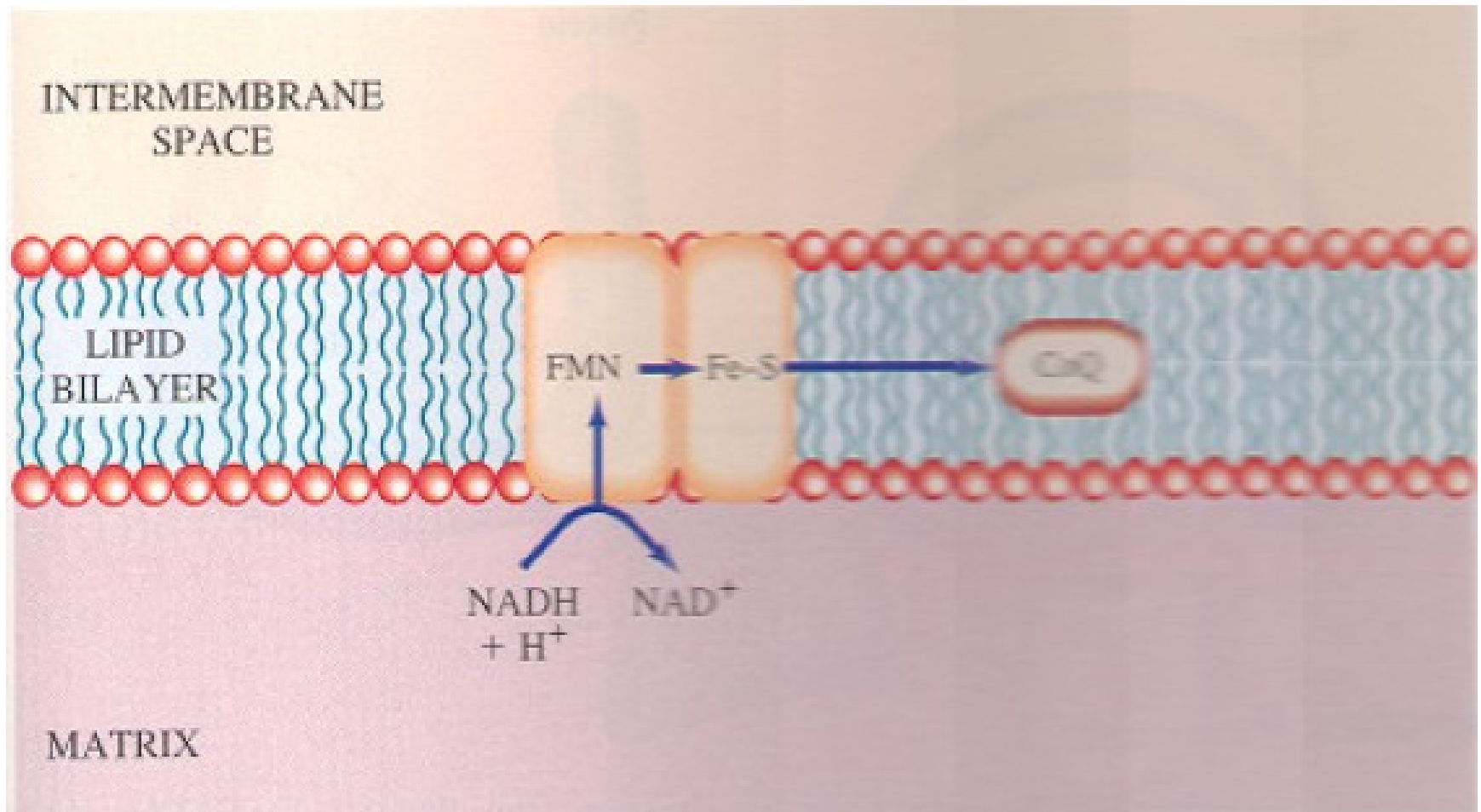


$$\Delta G = -nF\Delta E^{\circ}$$

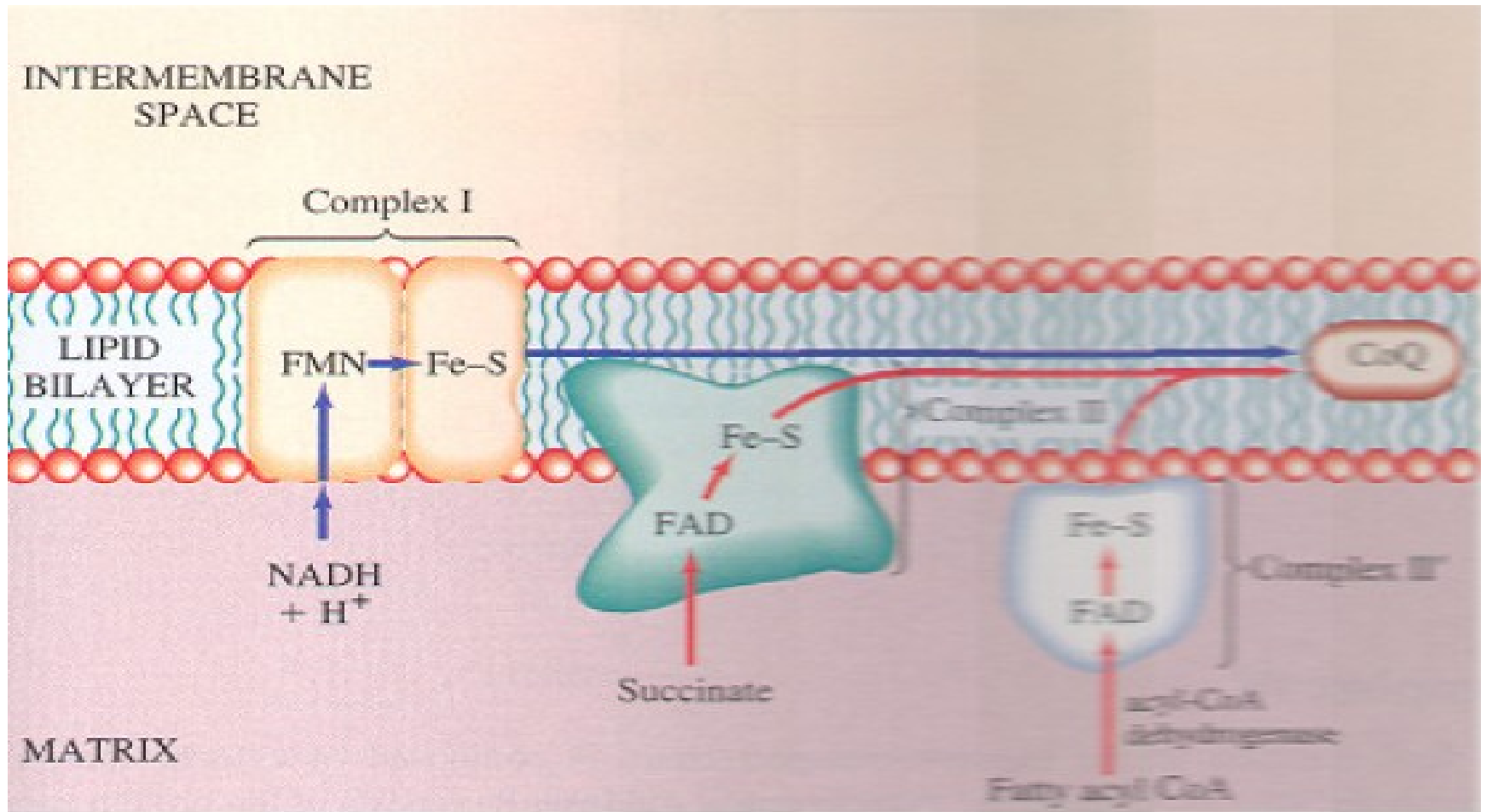
$$\Delta E^{\circ} = E_2^{\circ} - E_1^{\circ} \text{ — green —}$$

$$0,18 \text{ V} \sim + 35 \text{ kJ/mol}$$

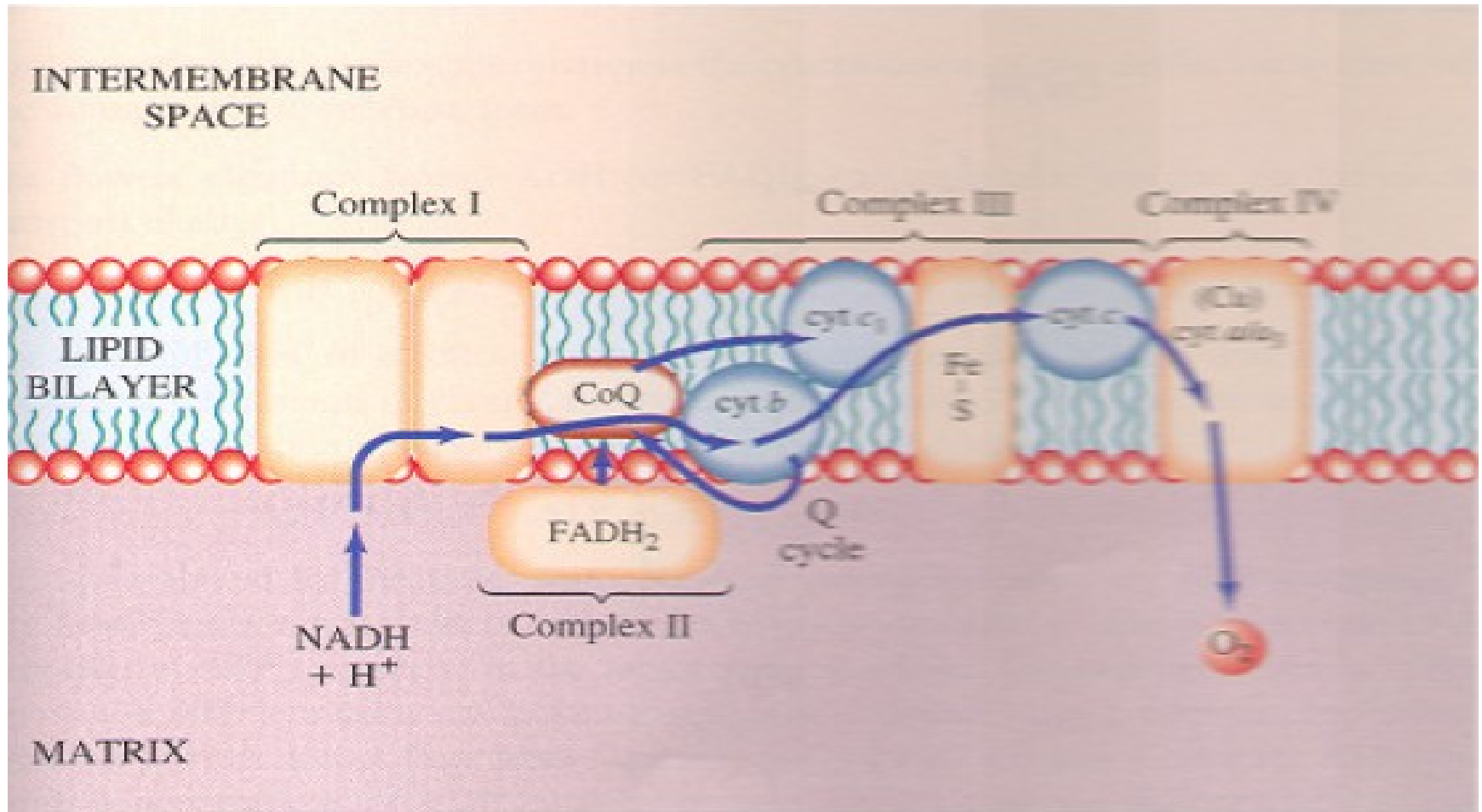
Komplex I



Komplex II

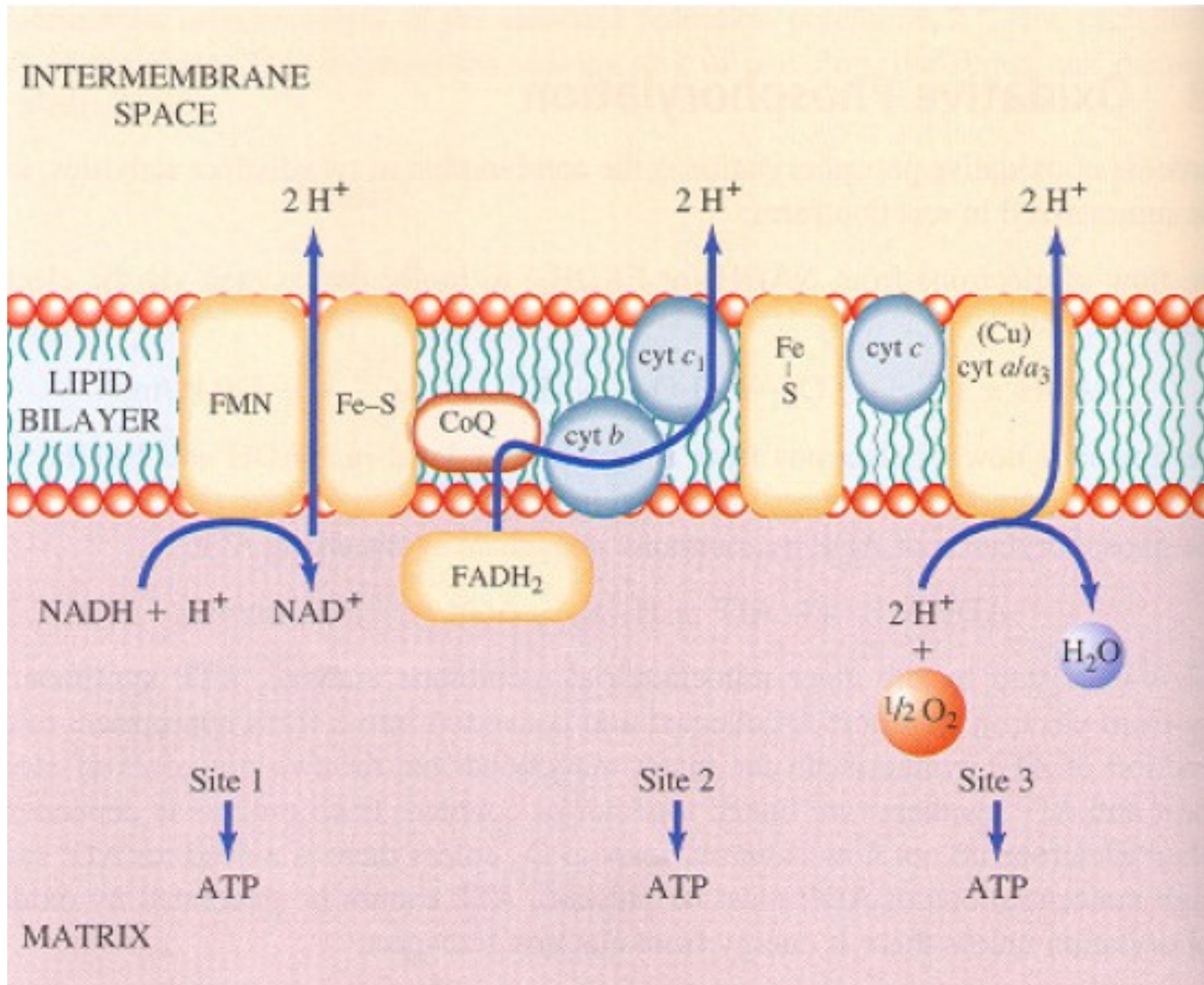


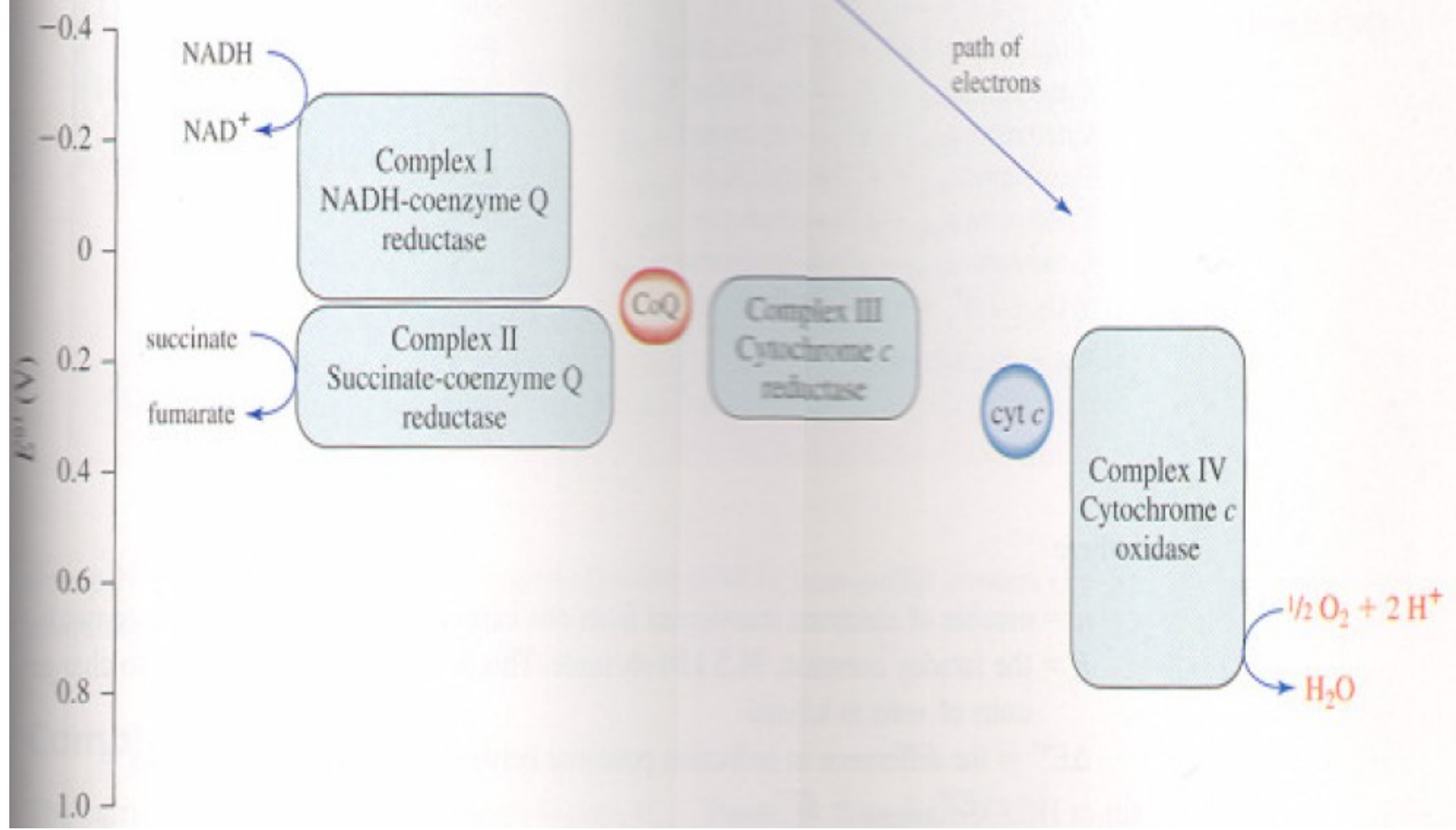
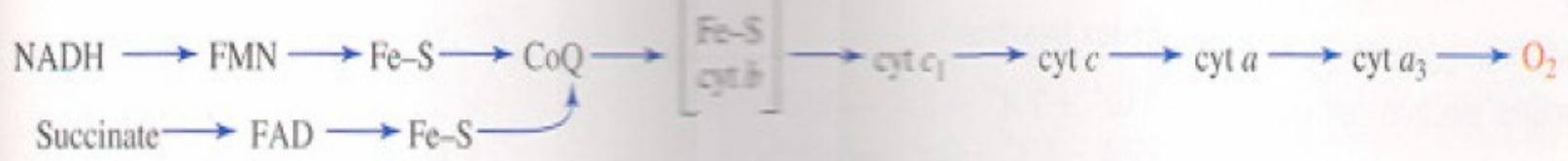
Komplex III a IV

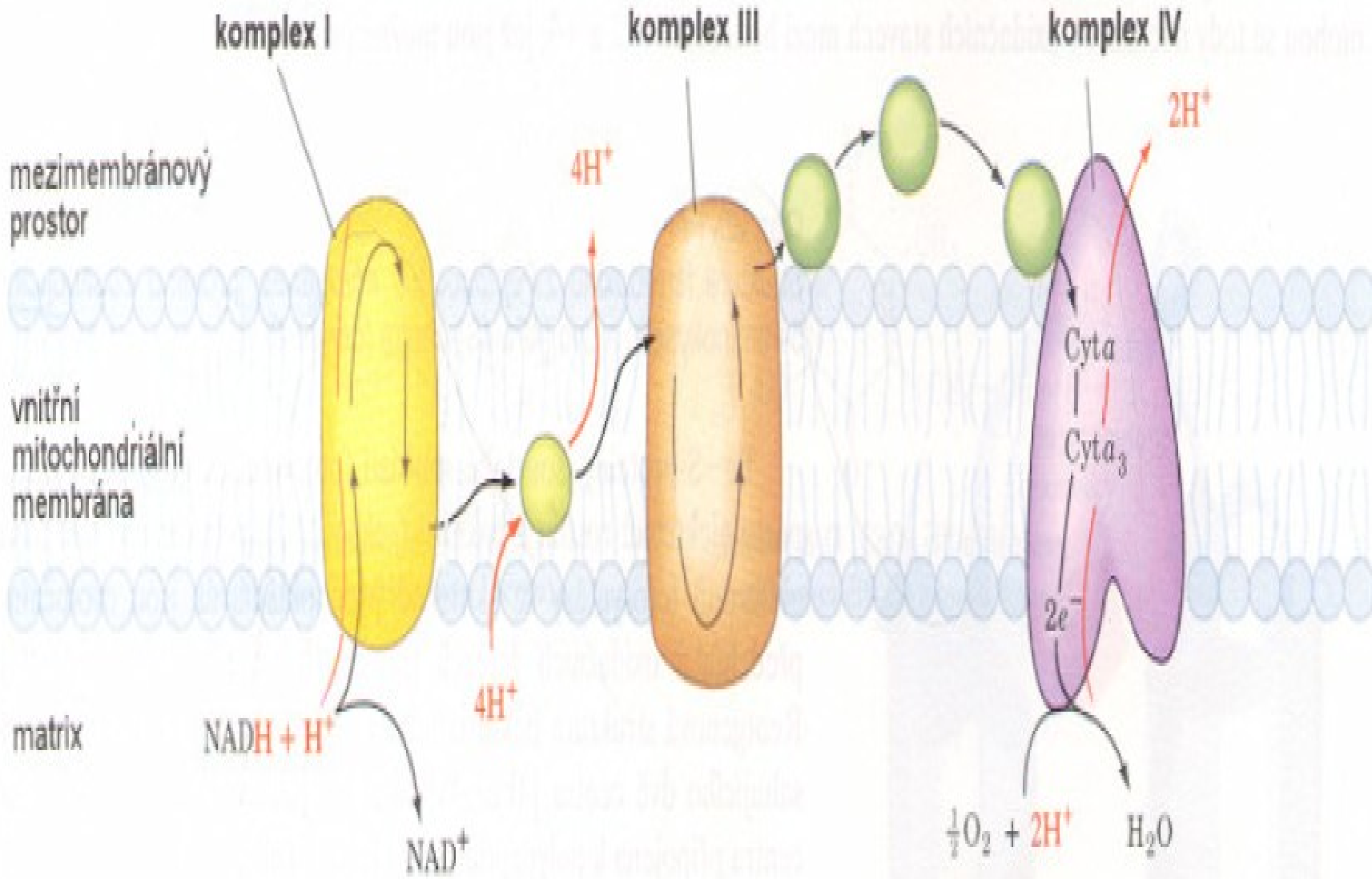


Chemiosmotická teorie

Mitchell 1961

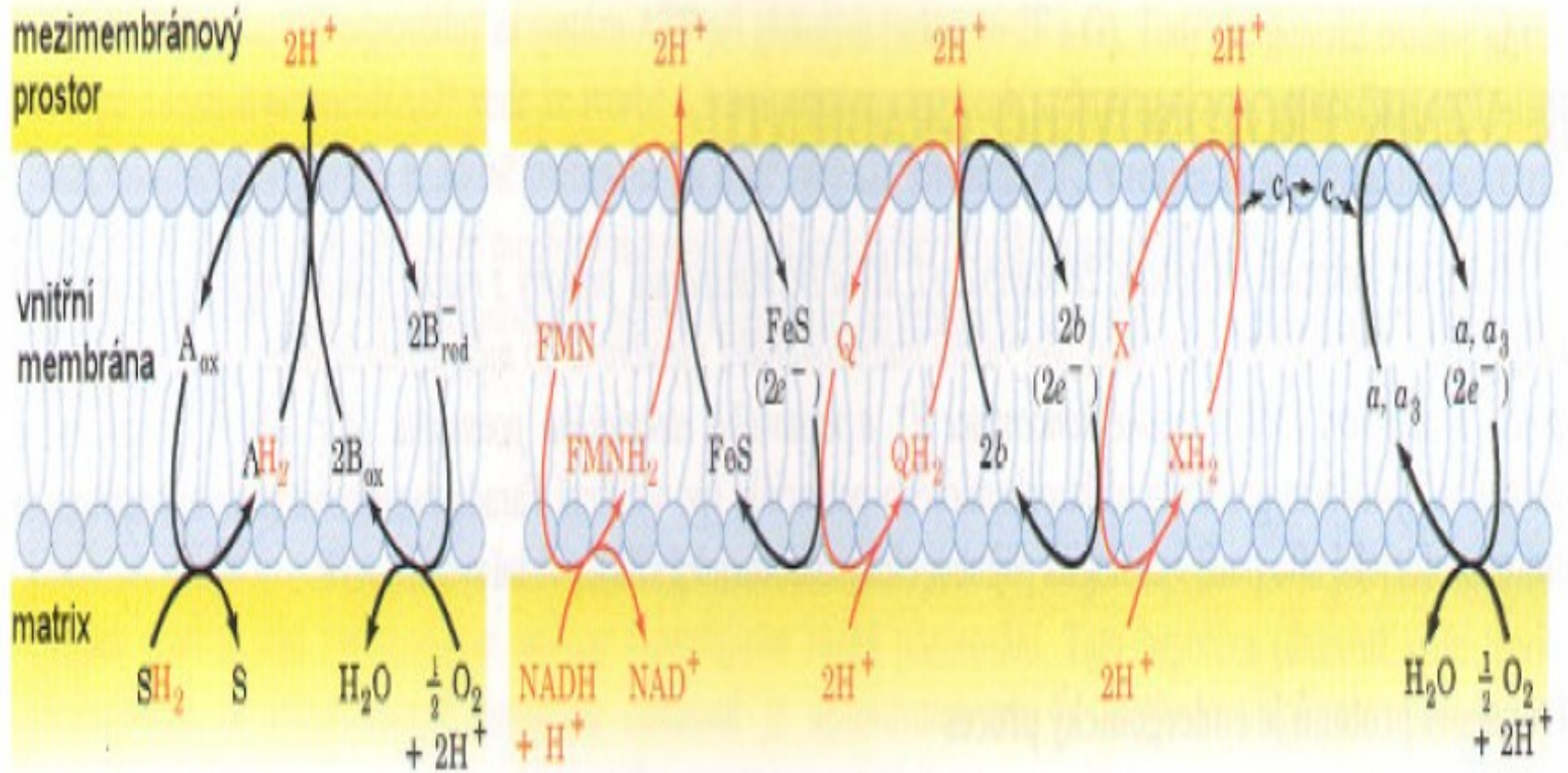




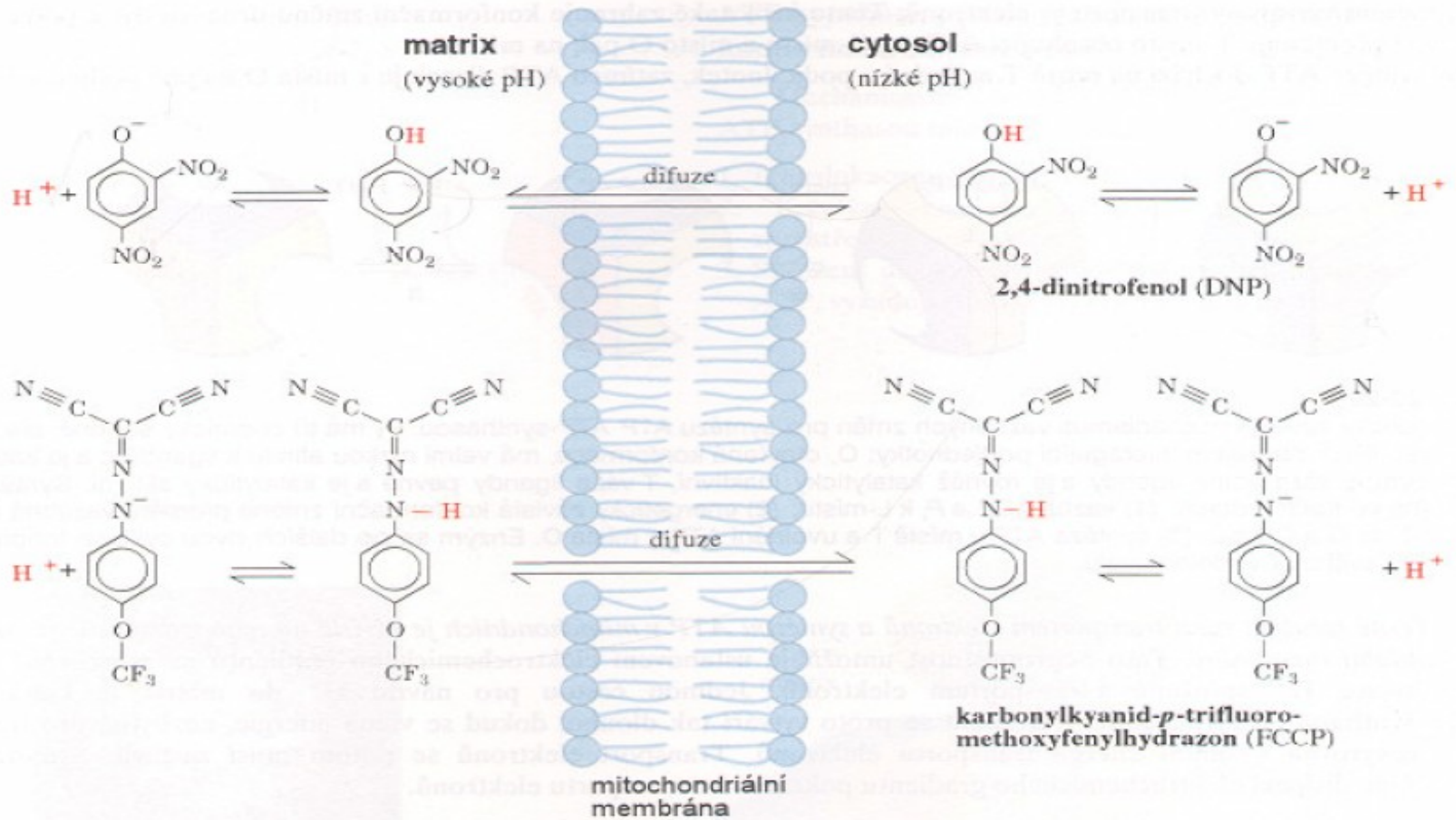


jednoduchá
(a) redoxní
smyčka

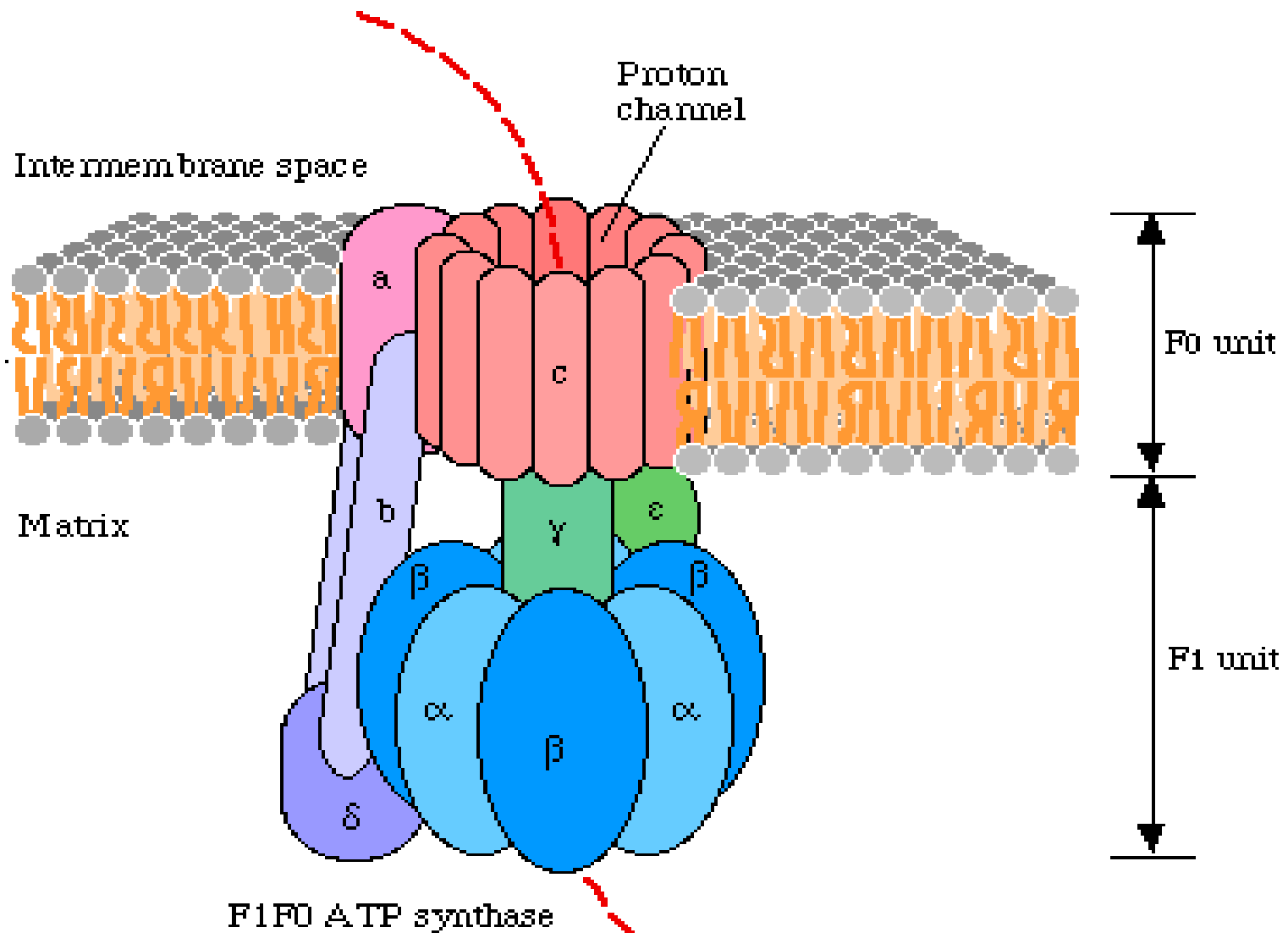
soustava
(b) redoxních
smyček

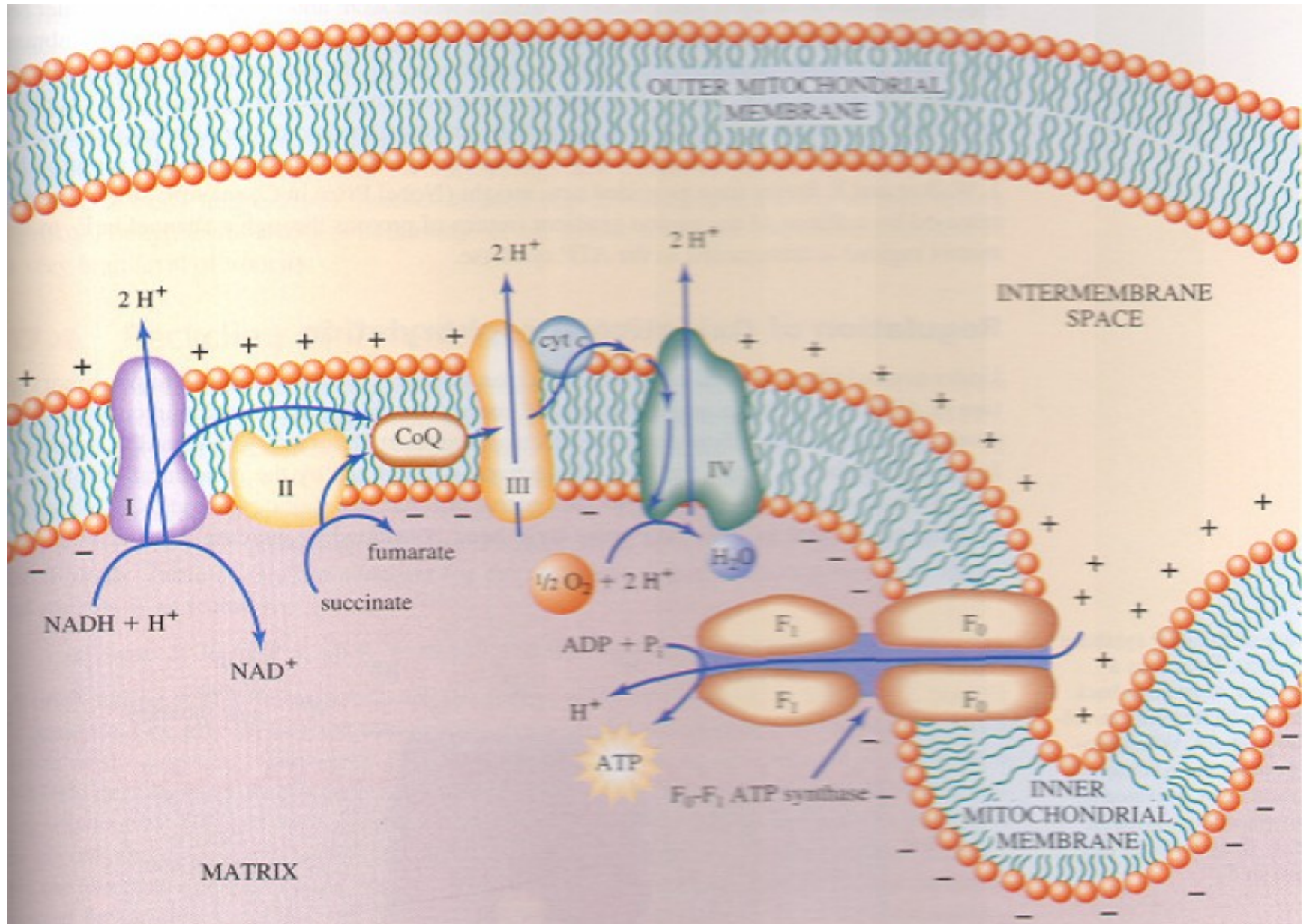


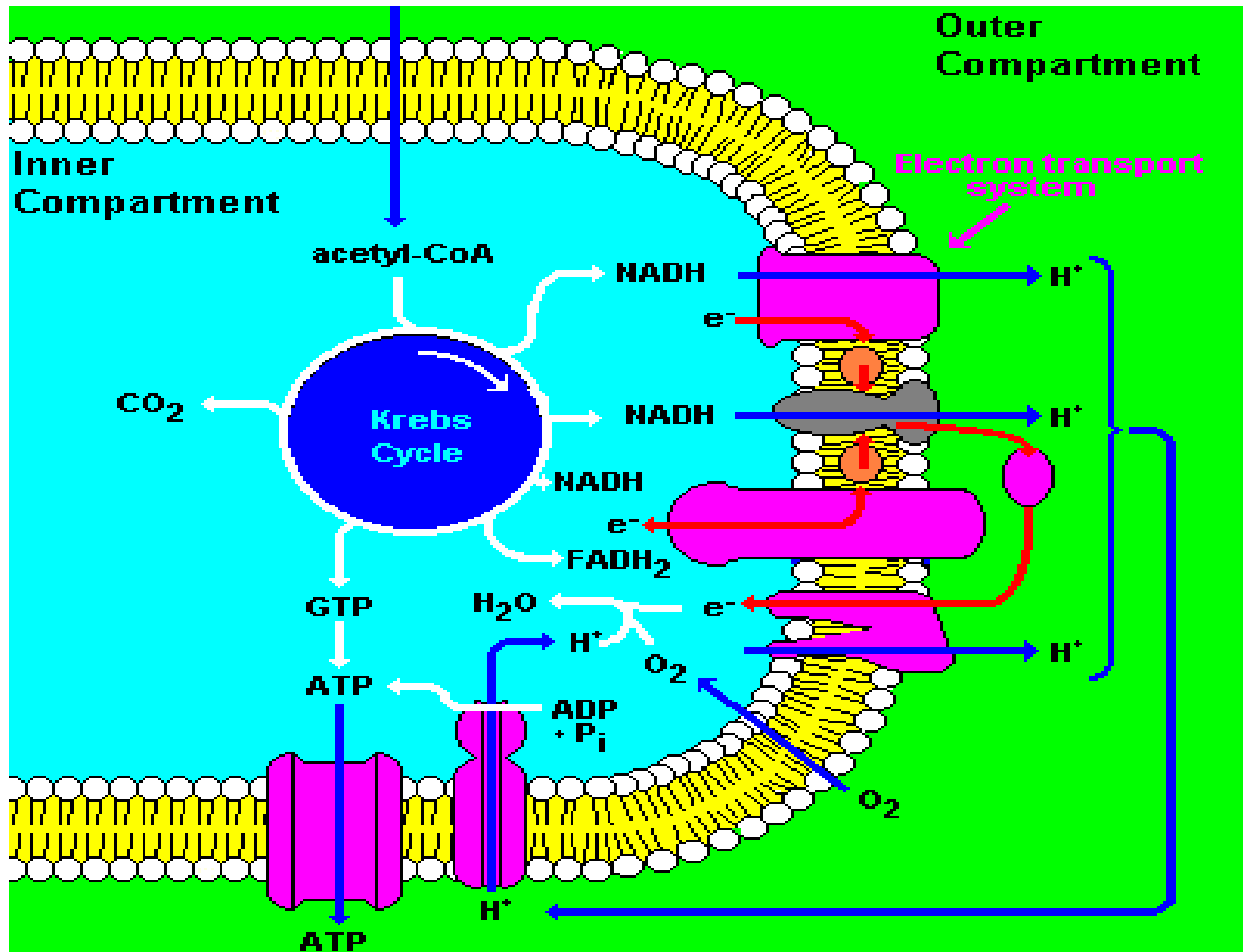
Rozpojovače



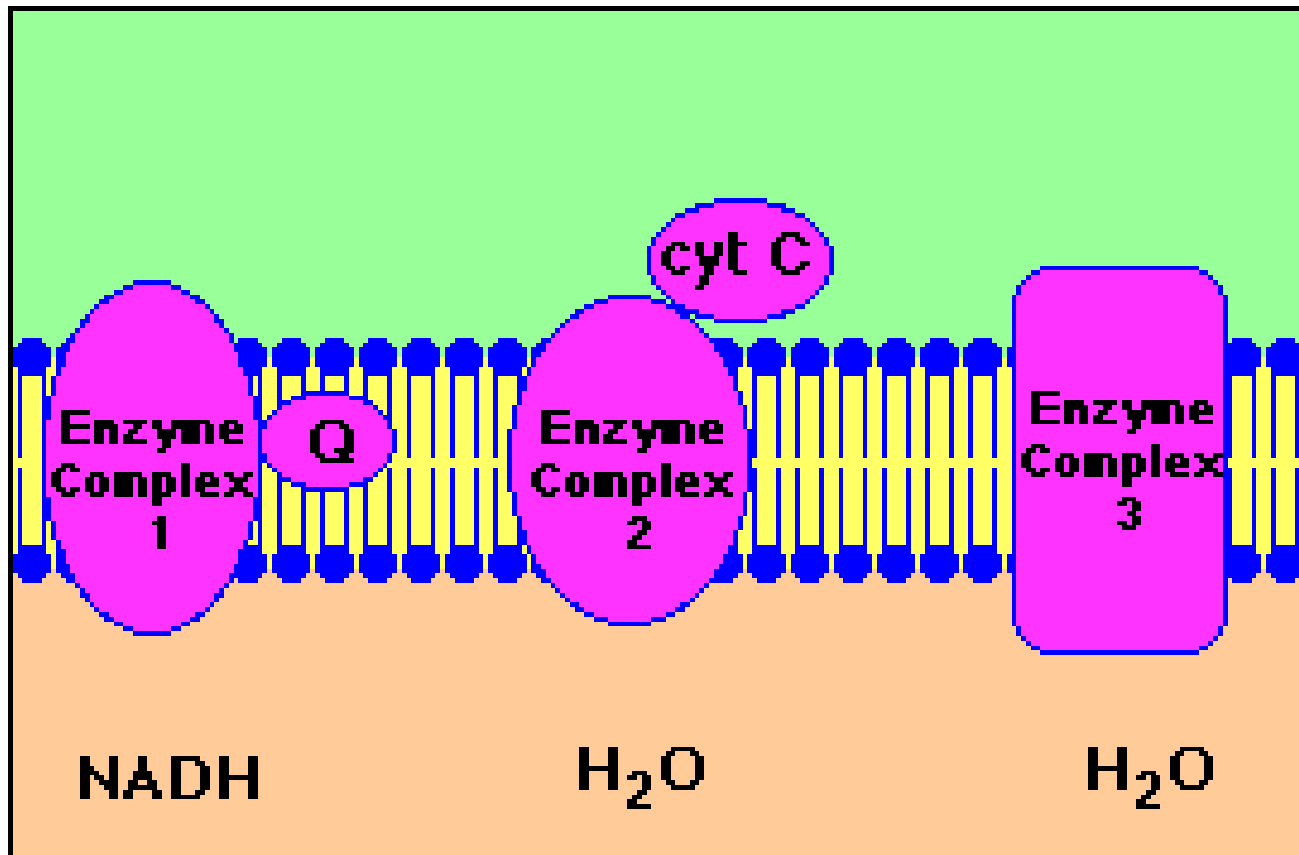
ATPase



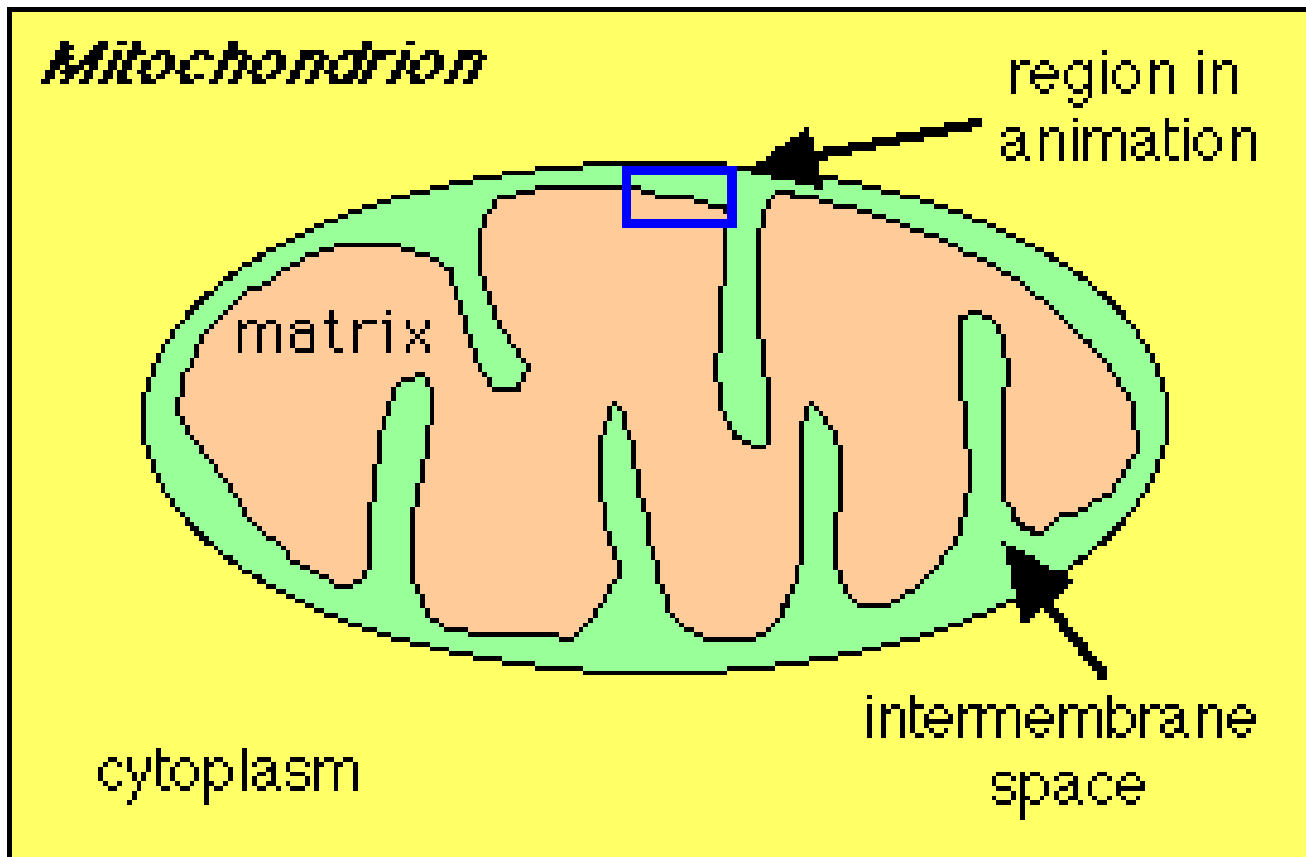




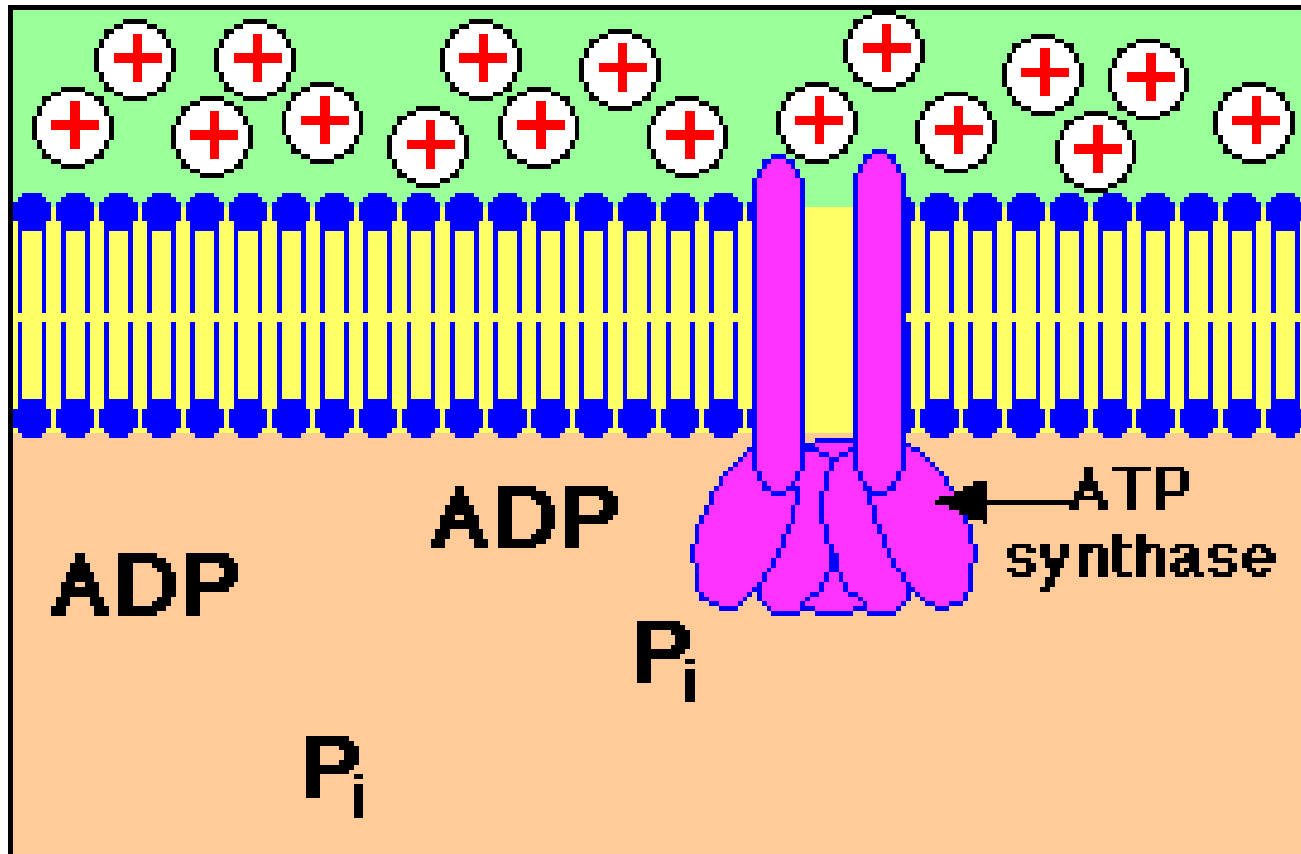
Transport elektronů



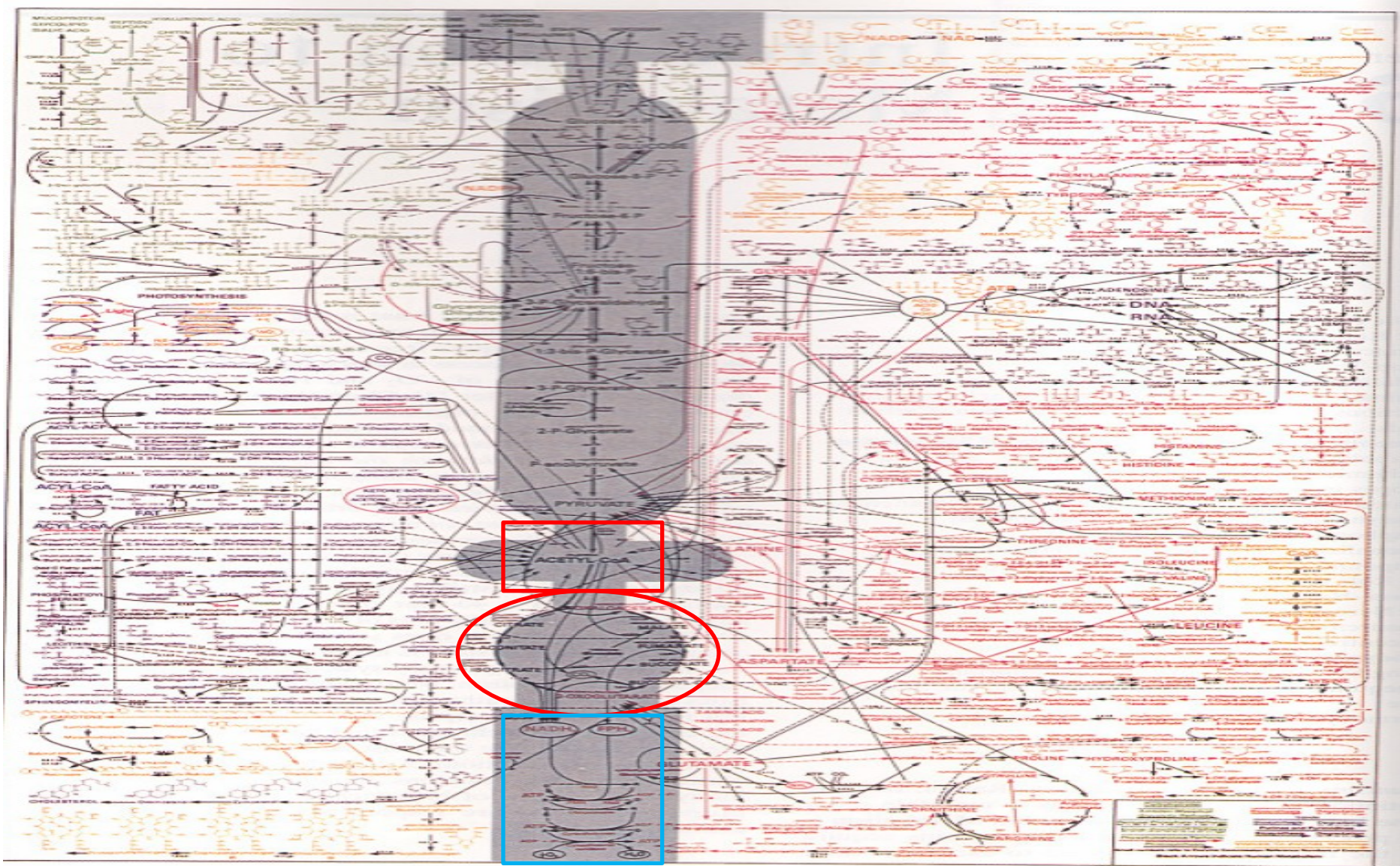
Lokalizace



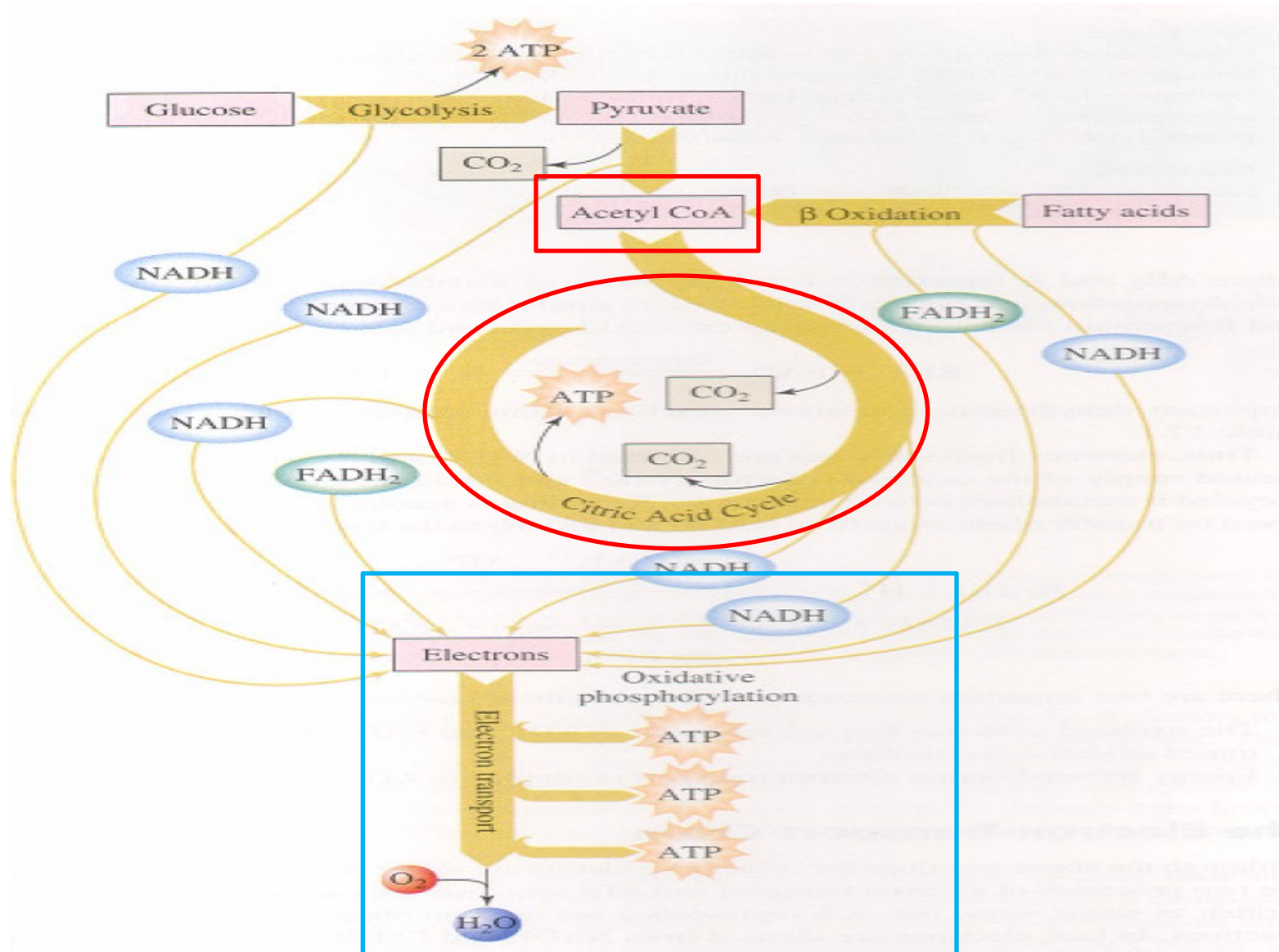
ATPase



Metabolické dráhy

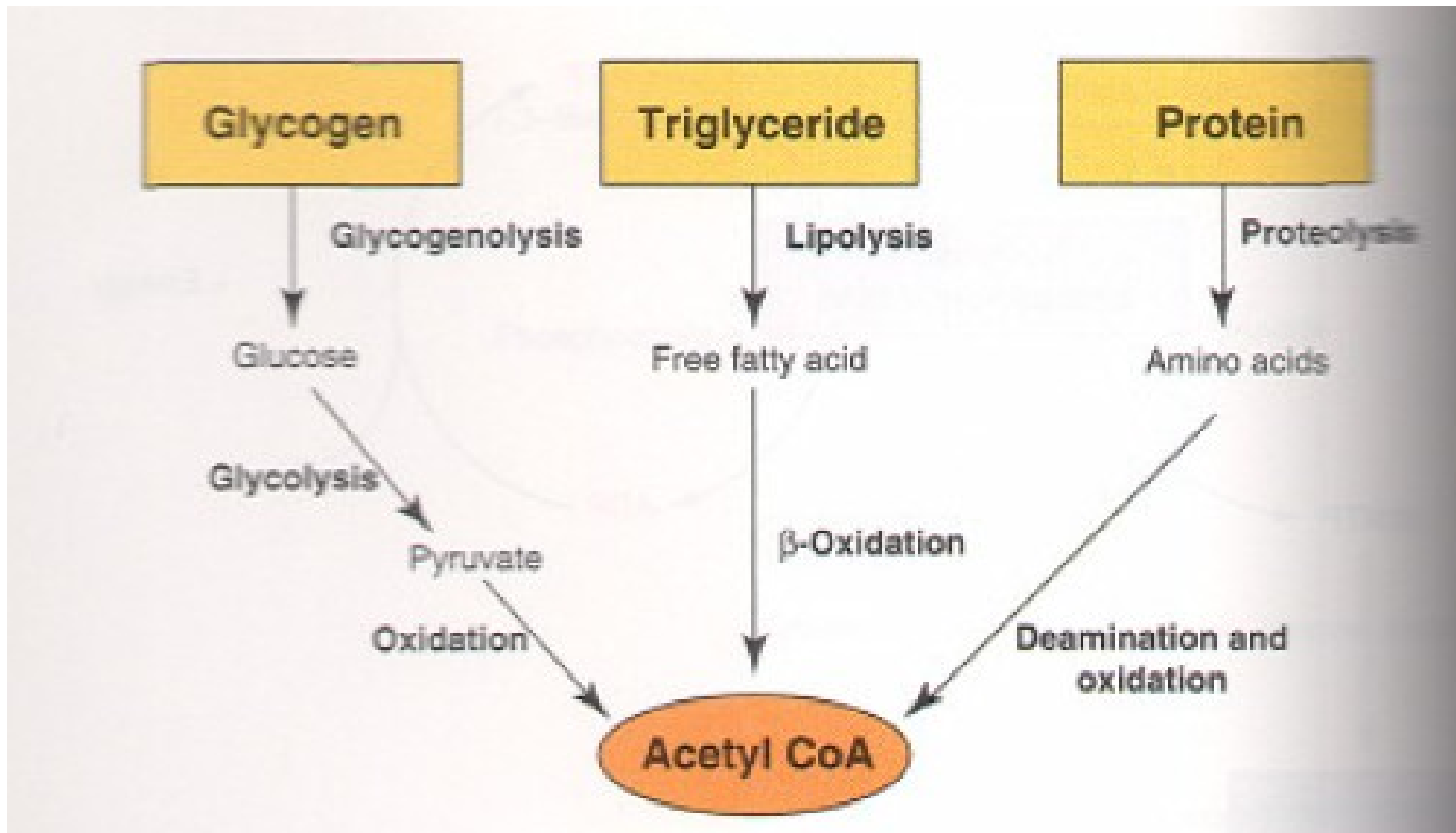


Metabolické dráhy



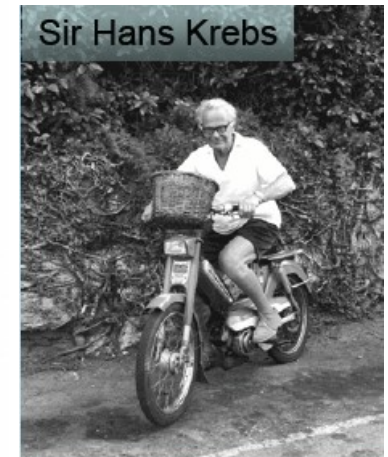
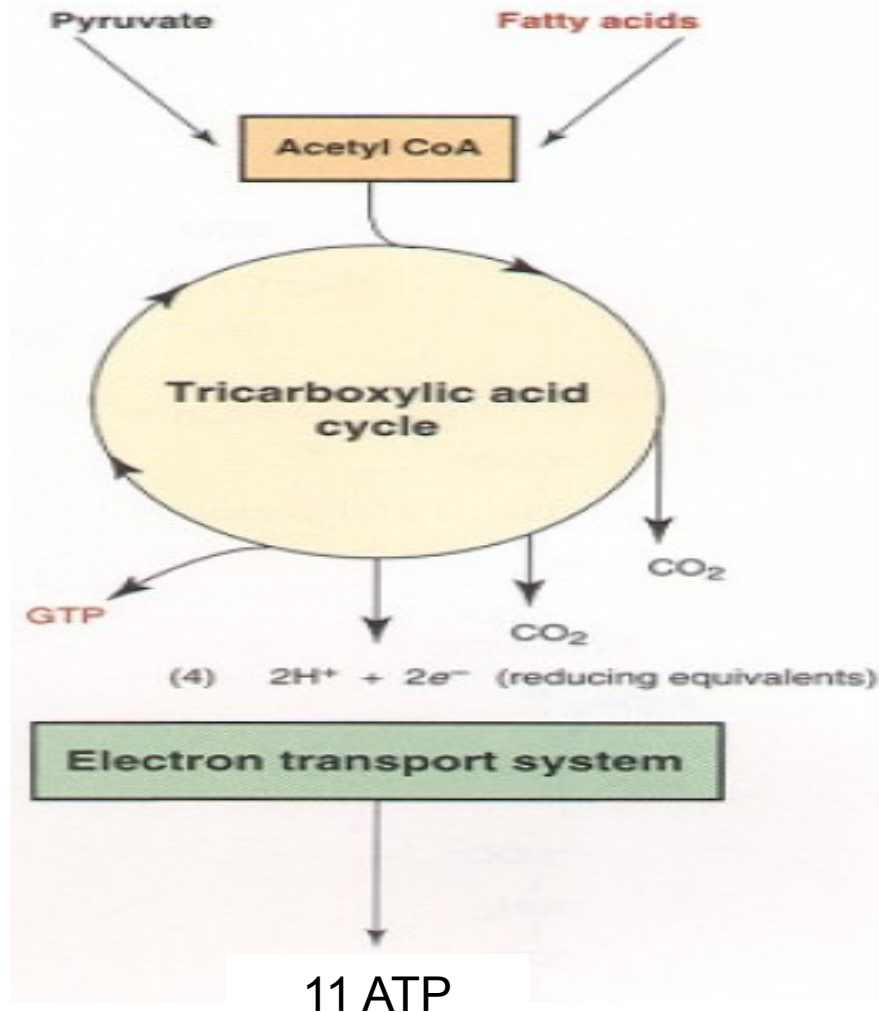
CITRÁTOVÝ CYKLUS

H.Krebs (1937) - Krebsův cyklus, cyklus trikarboxylových kyselin



CITRÁTOVÝ CYKLUS

H.Krebs (1937) - Krebsův cyklus, cyklus trikarboxylových kyselin



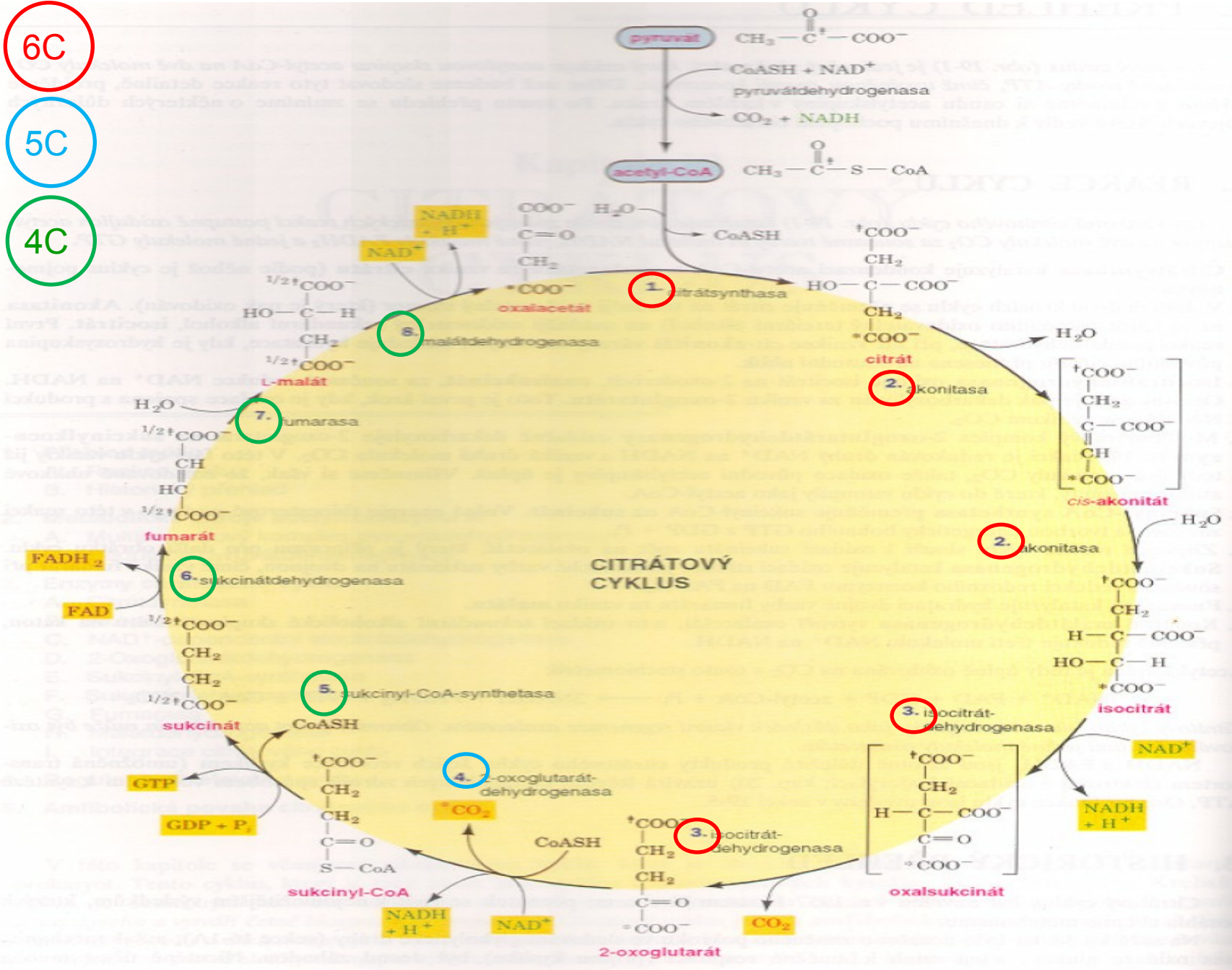
Sir Hans Krebs

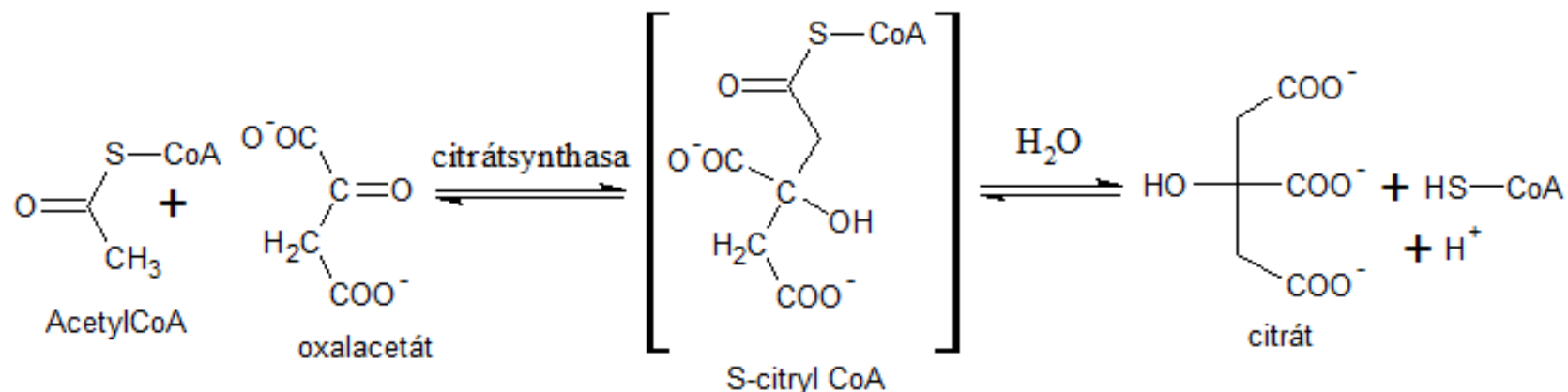
1953 NC

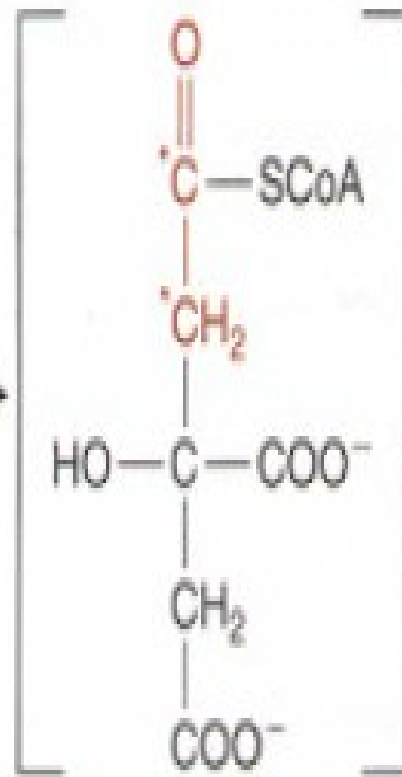
6C

5C

4C

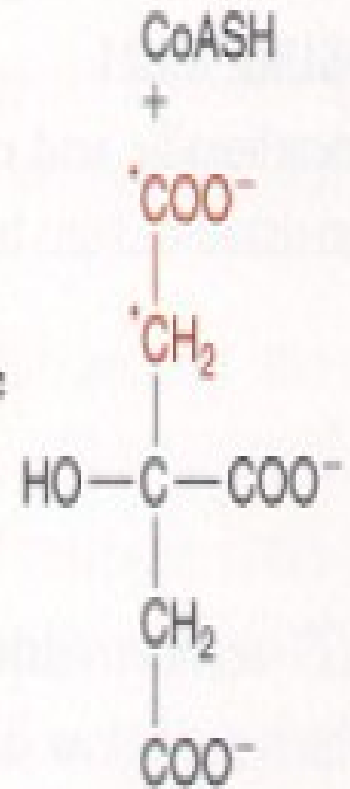






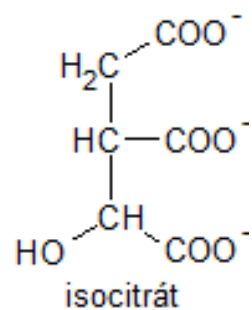
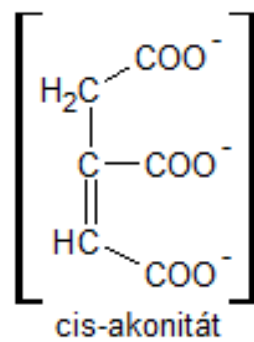
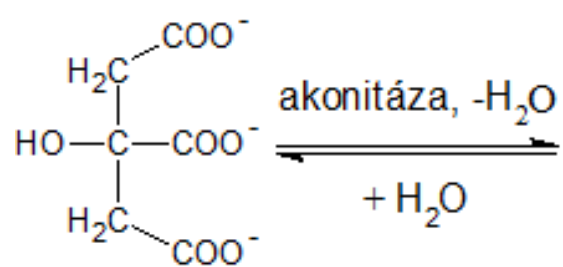
Enzyme-bound

citroyl-SCoA



Citrate

CITRATE SYNTHASE



100

150

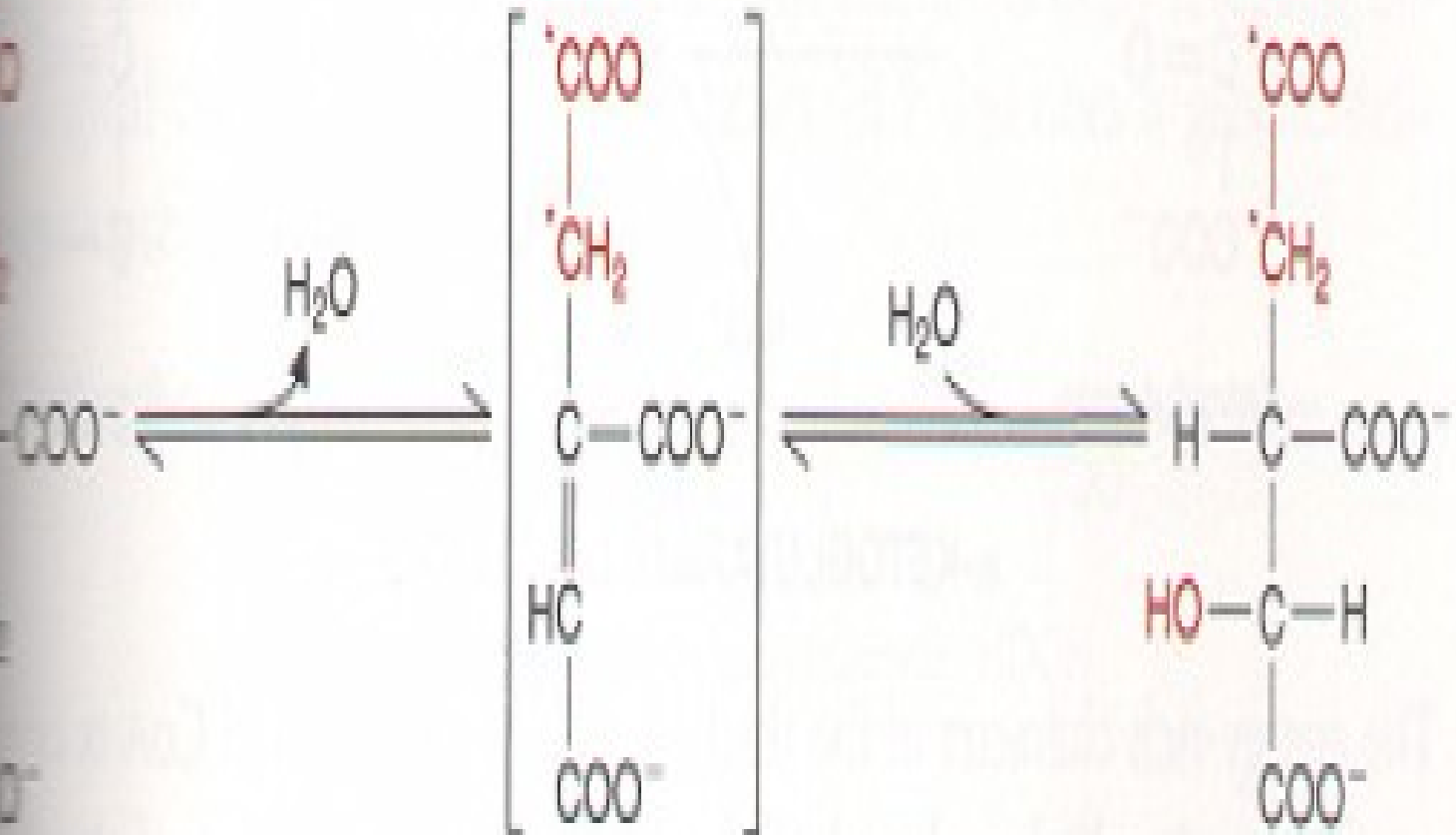
200

250

200

150

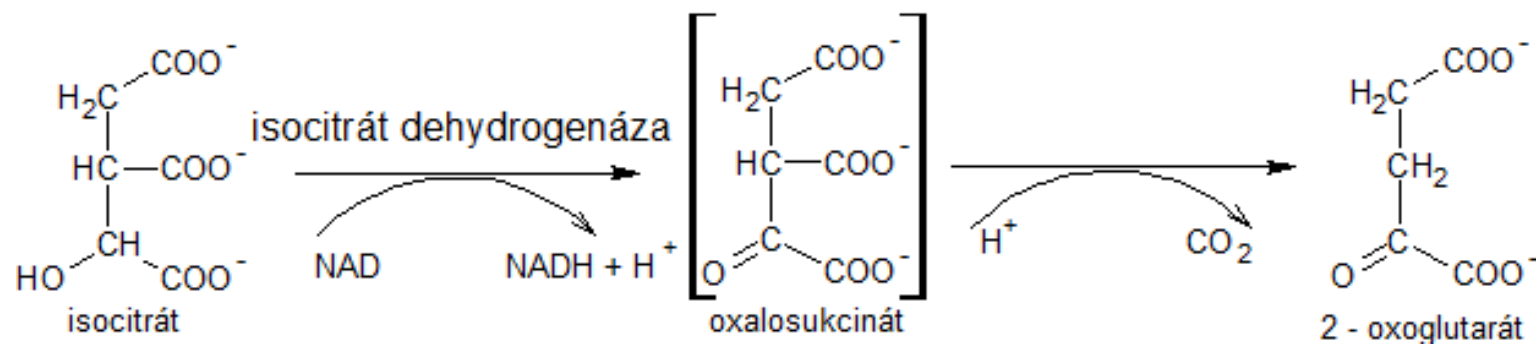
100

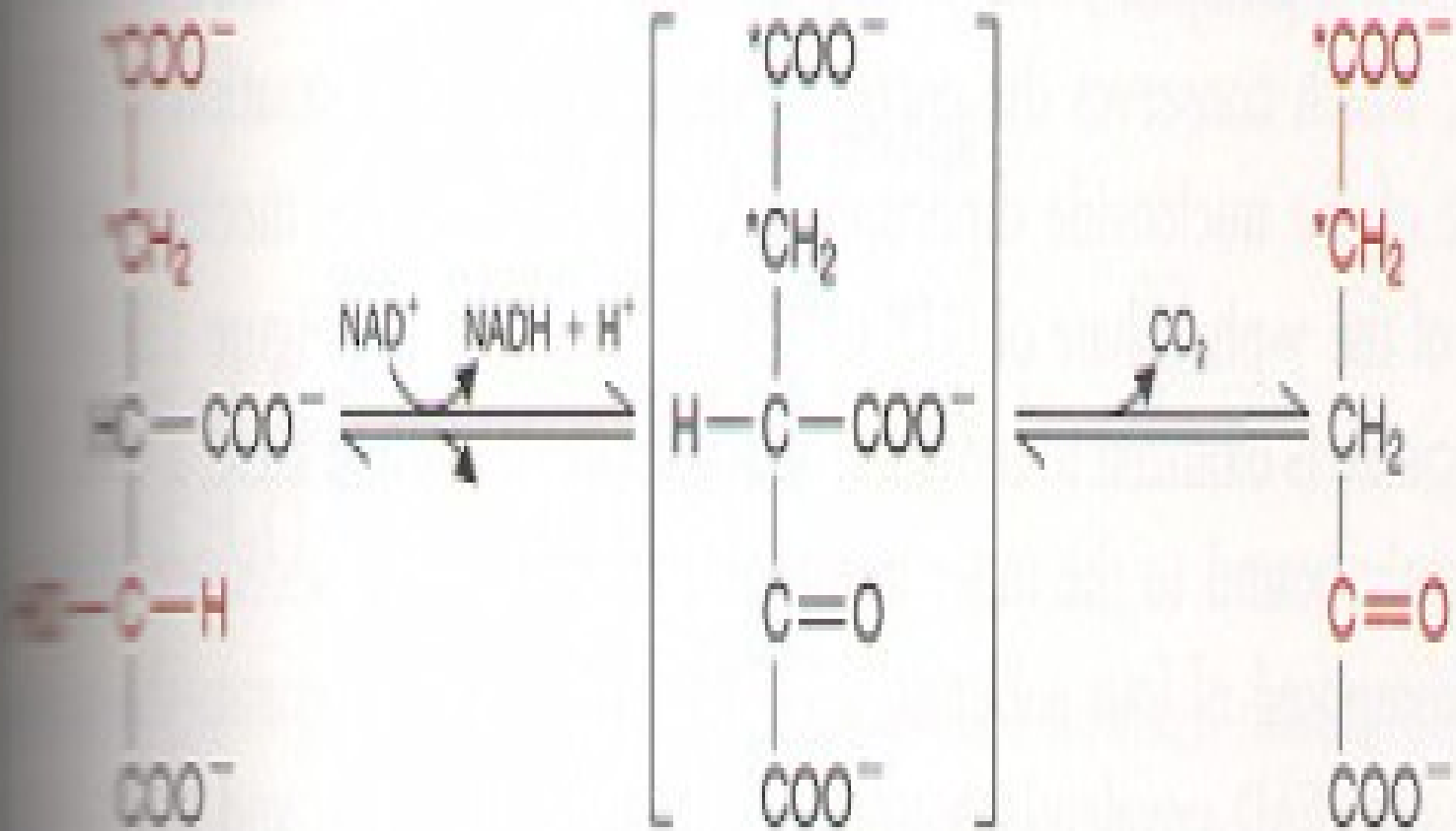


cis-Aconitate

Isocitrate

ACONITASE



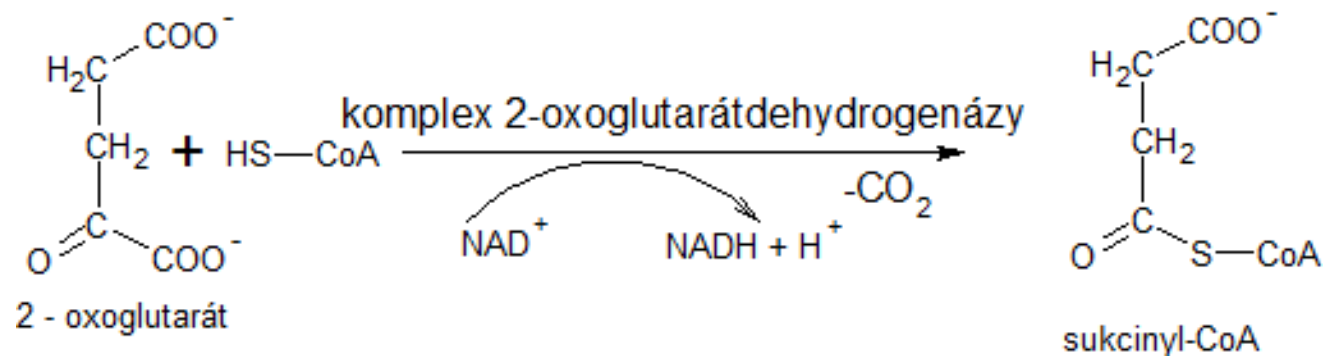


isocitrate

Oxalosuccinate

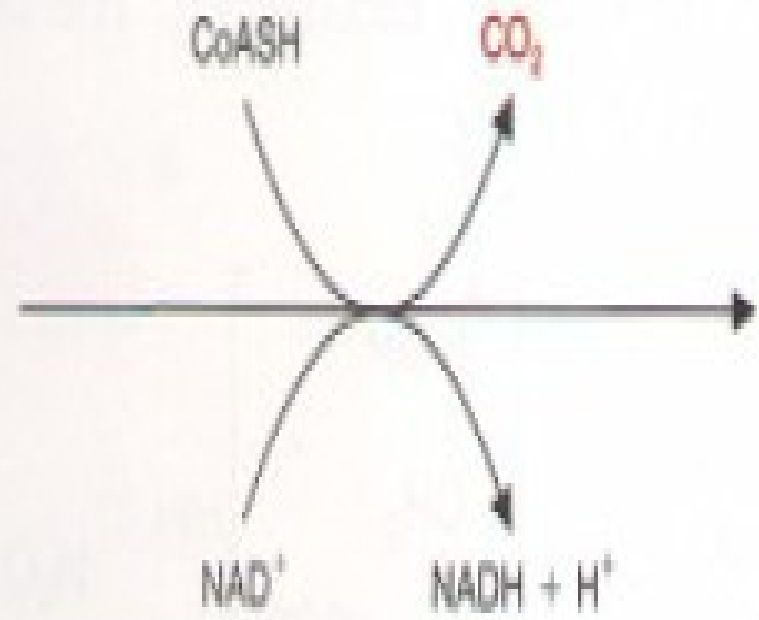
α -Ketoglutarate

ISOCITRATE DEHYDROGENASE



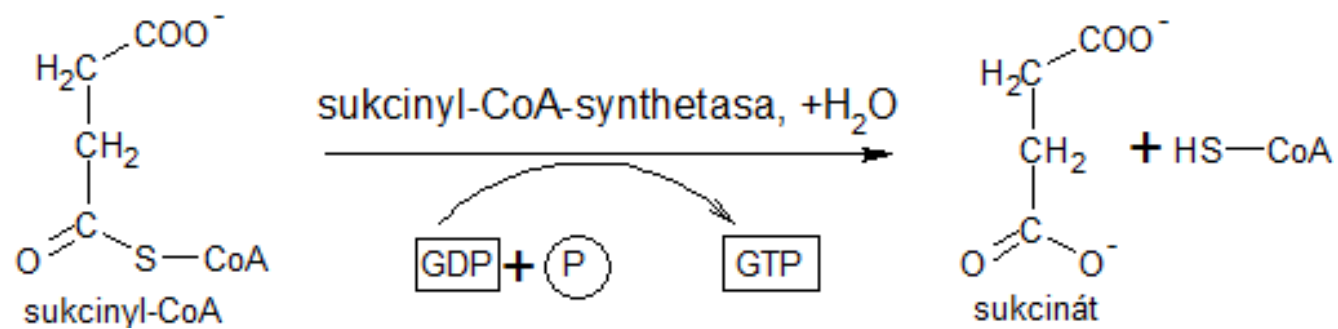


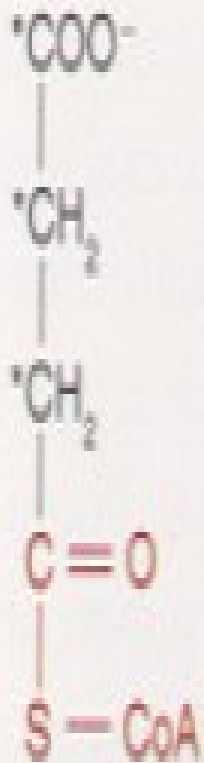
α -Ketoglutarate



Succinyl CoA

α -KETOGLUTARATE DEHYDROGENASE



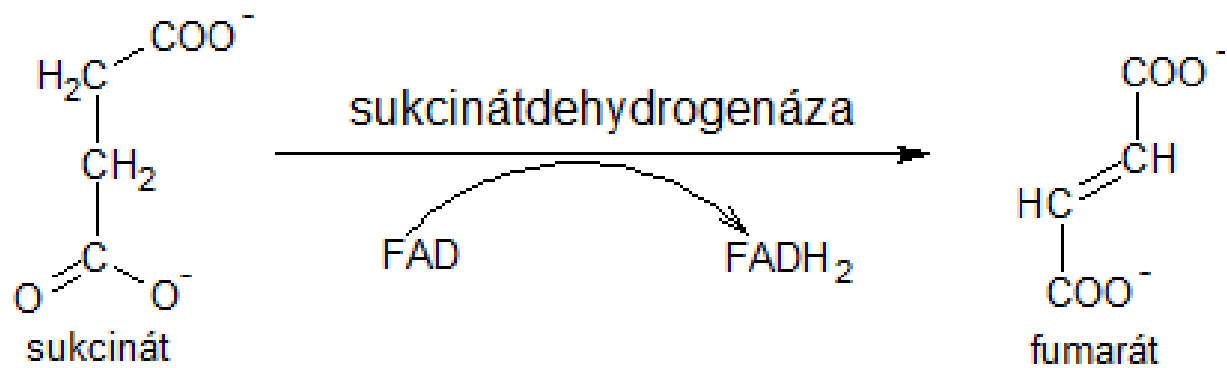


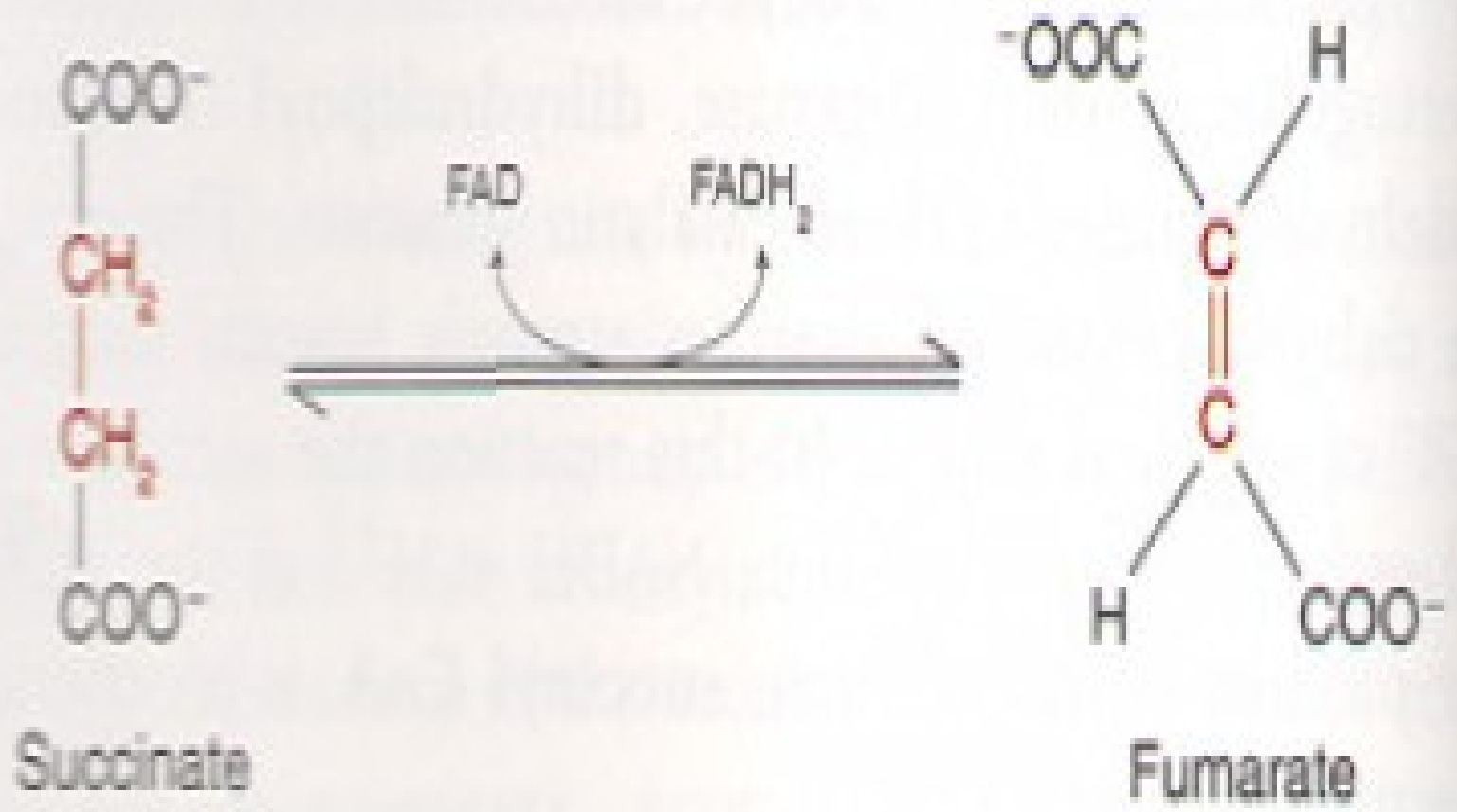
Succinyl CoA



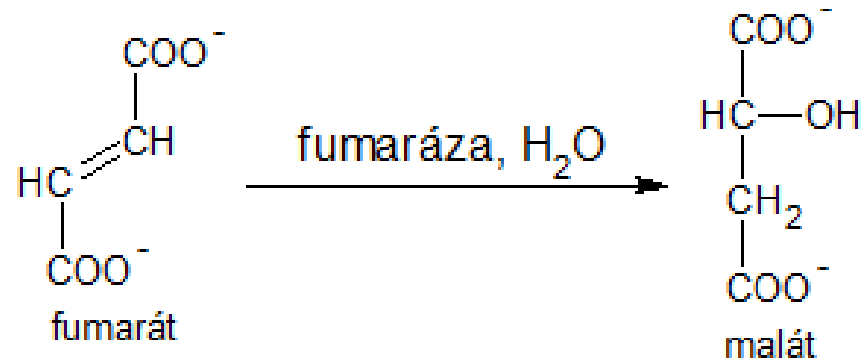
Succinate

SUCCINYL CoA SYNTHETASE



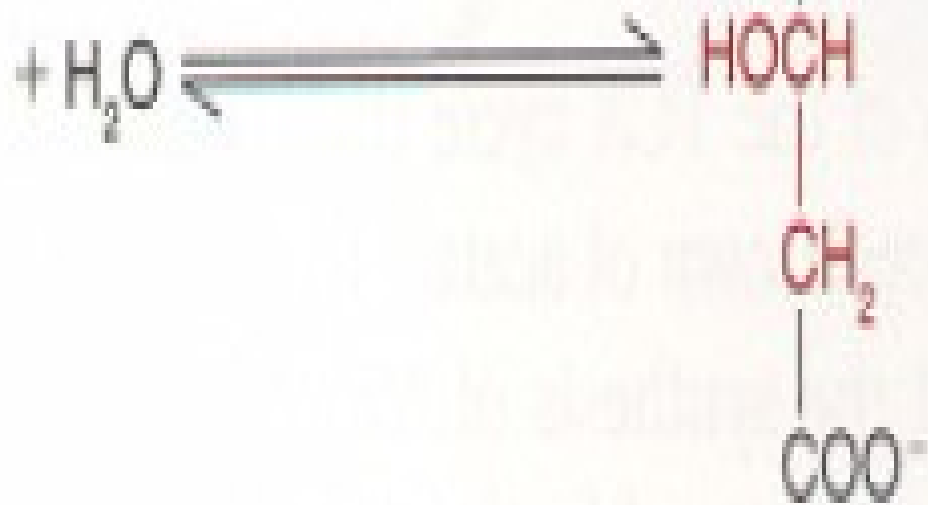


SUCCINATE DEHYDROGENASE



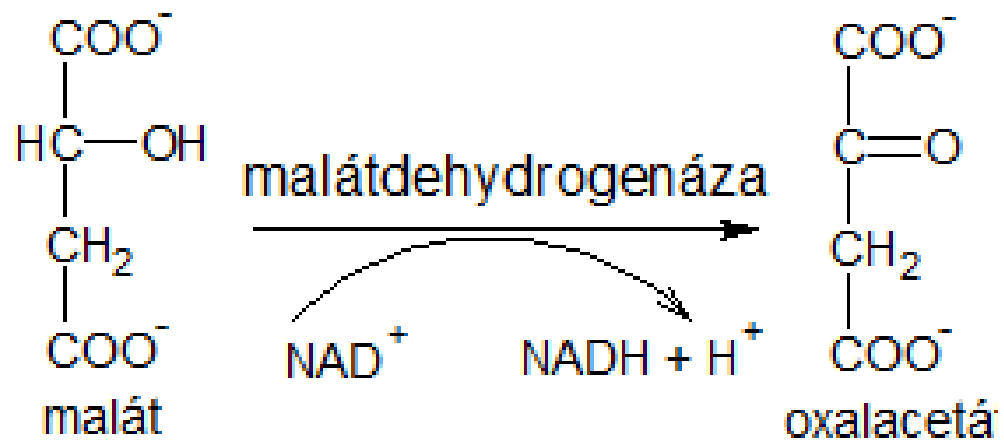


Fumarate



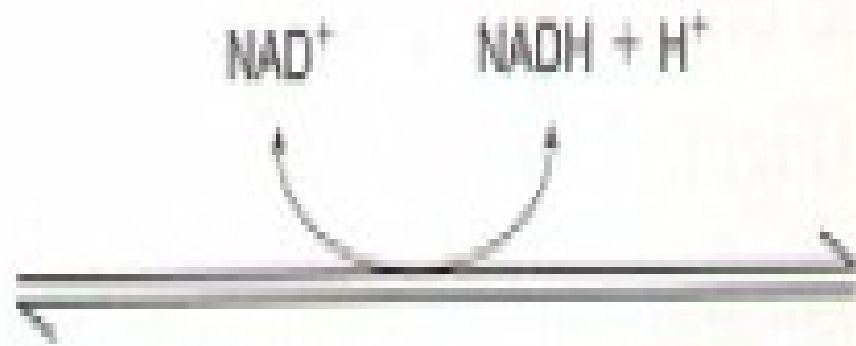
L-Malate

FUMARASE





L-Malate



Oxaloacetate

MALATE DEHYDROGENASE

acetyl-CoA

NADH

NAD⁺

oxalacetát

malátdehydrogenasa

citrát

malát

CITRÁTOVÝ CYKLUS

isocitrát

isocitrát-
dehydrogenasa

NAD⁺

NADH

FADH₂

FAD

sukcinátde-
hydrogenasa

sukcinát

2-oxoglutarát-
dehydrogenasa

2-oxoglutarát

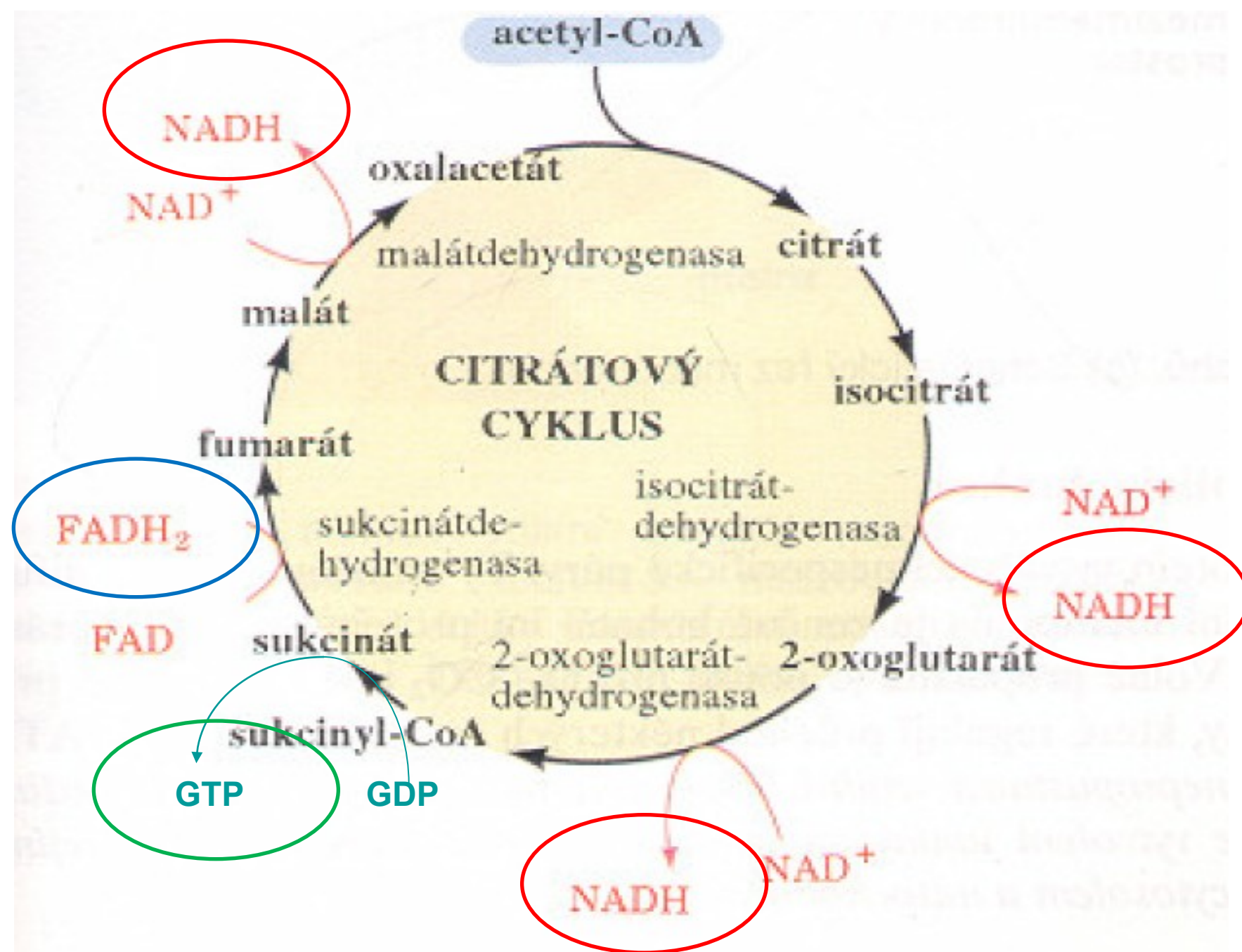
sukcinyl-CoA

GTP

GDP

NADH

NAD⁺



Bilance cyklu :



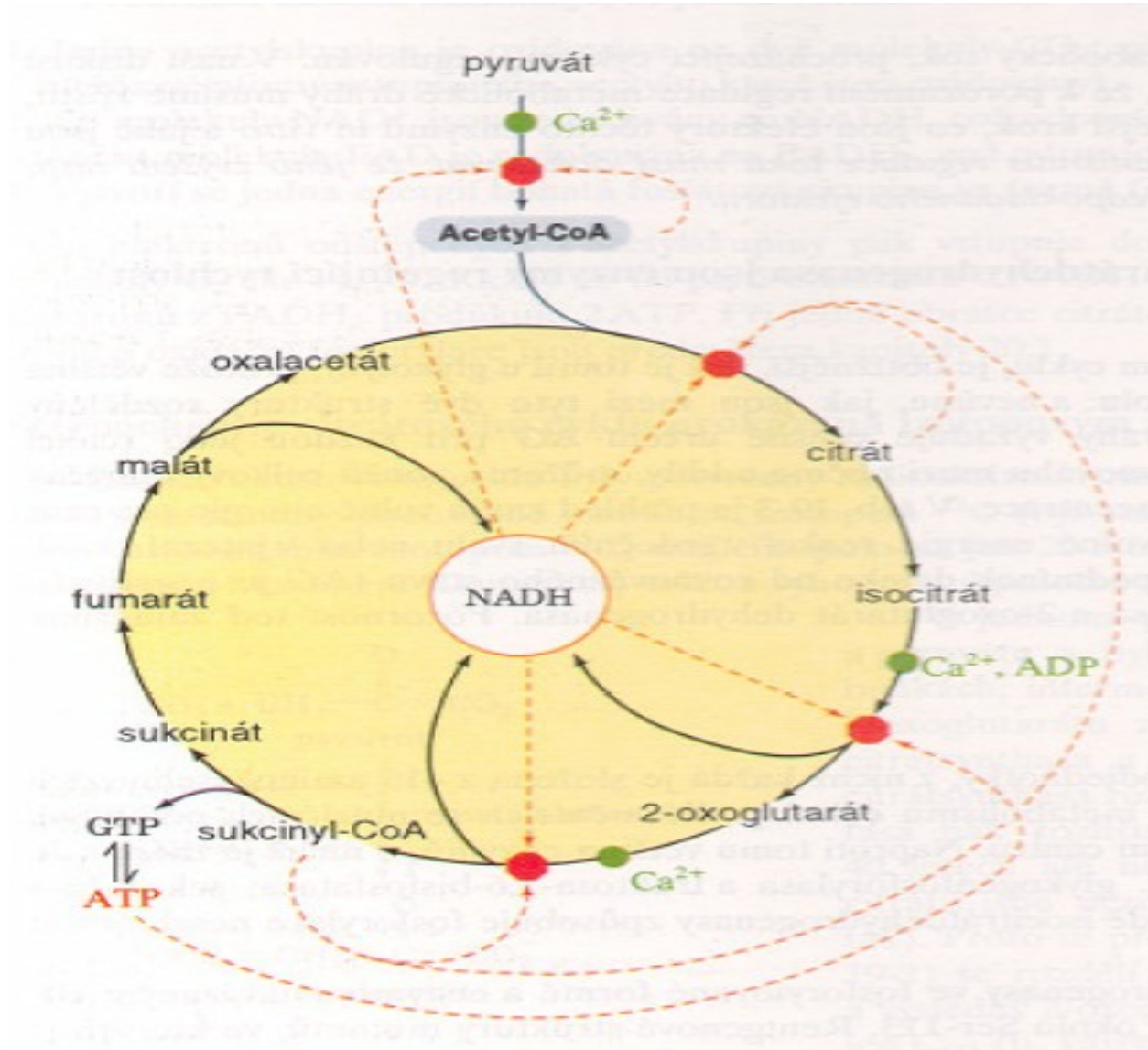
3 NADH	3 x 3 ATP	9 ATP
--------	-----------	-------

1 FADH ₂	1 x 2 ATP	2 ATP
---------------------	-----------	-------

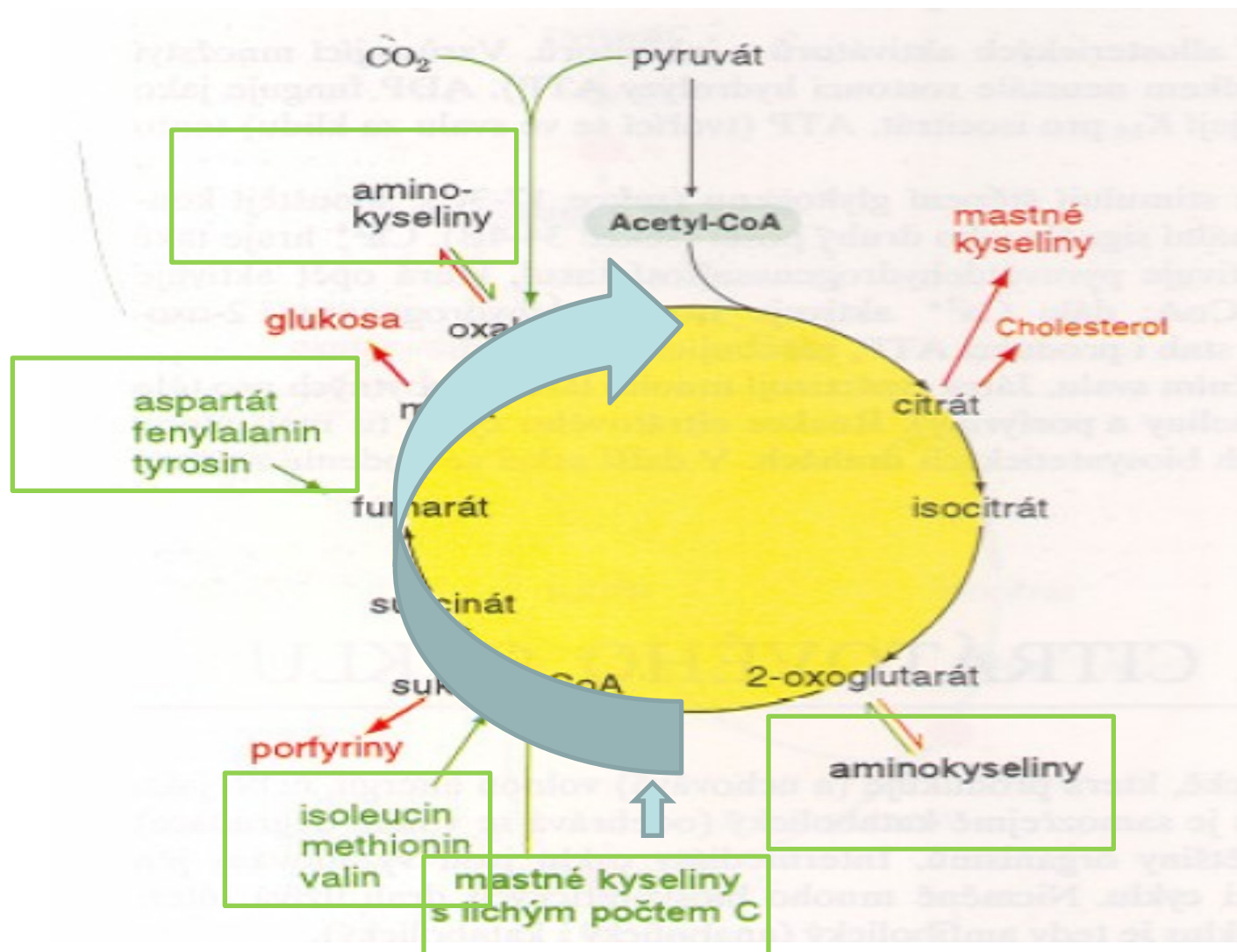
1 GTP	1 x 1 ATP	1 ATP
-------	-----------	-------

CELKEM	12 ATP/AcetylCoA
--------	------------------

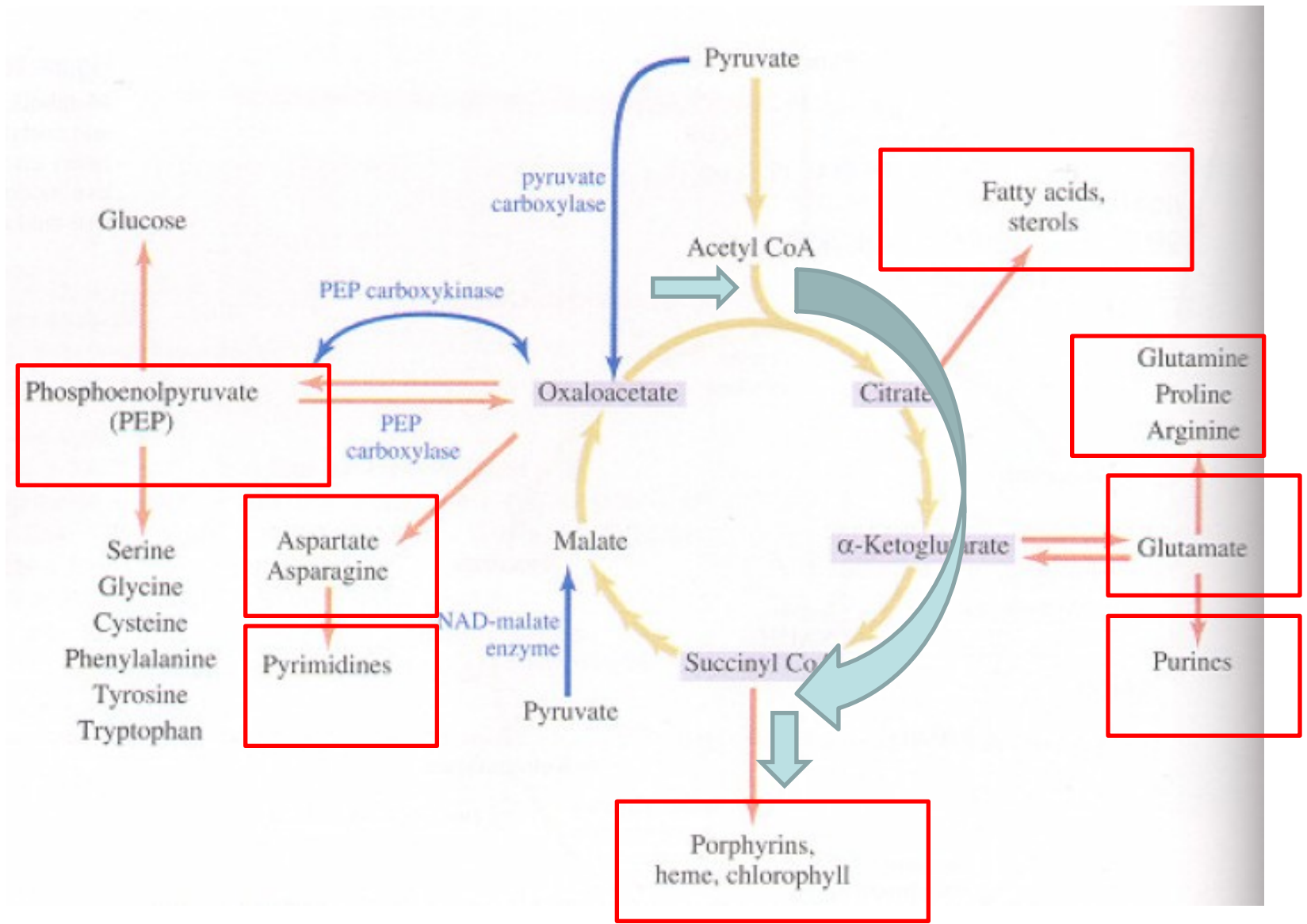
Regulace



Odbourávání jiných živin



Amfibolická povaha cyklu



Anaplerotické reakce

Table 16.5

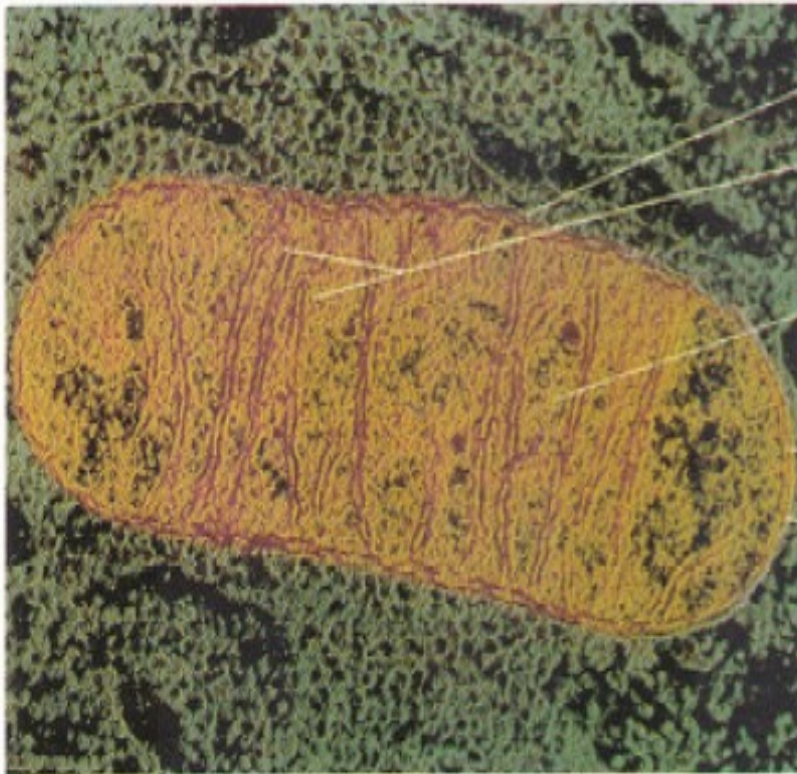
Anaplerotic reactions to replenish the citric acid cycle intermediates oxaloacetate and malate

Enzyme	Reaction	Comments
Pyruvate carboxylase	$\text{Pyruvate} + \text{CO}_2 + \text{ATP} + \text{H}_2\text{O} \rightleftharpoons \text{oxaloacetate} + \text{ADP} + \text{P}_i$	Also the starting point for gluconeogenesis
PEP carboxykinase	$\text{Phosphoenolpyruvate} + \text{CO}_2 + \text{GDP} \rightleftharpoons \text{oxaloacetate} + \text{GTP}$	The reverse reaction is important in gluconeogenesis
PEP carboxylase	$\text{Phosphoenolpyruvate} + \text{CO}_2 \rightleftharpoons \text{oxaloacetate} + \text{P}_i$	Found in higher plants and bacteria
NAD-malate enzyme	$\text{Pyruvate} + \text{CO}_2 + \text{NADH} + \text{H}^+ \rightleftharpoons \text{malate} + \text{NAD}^+$	Found in plants and microorganisms

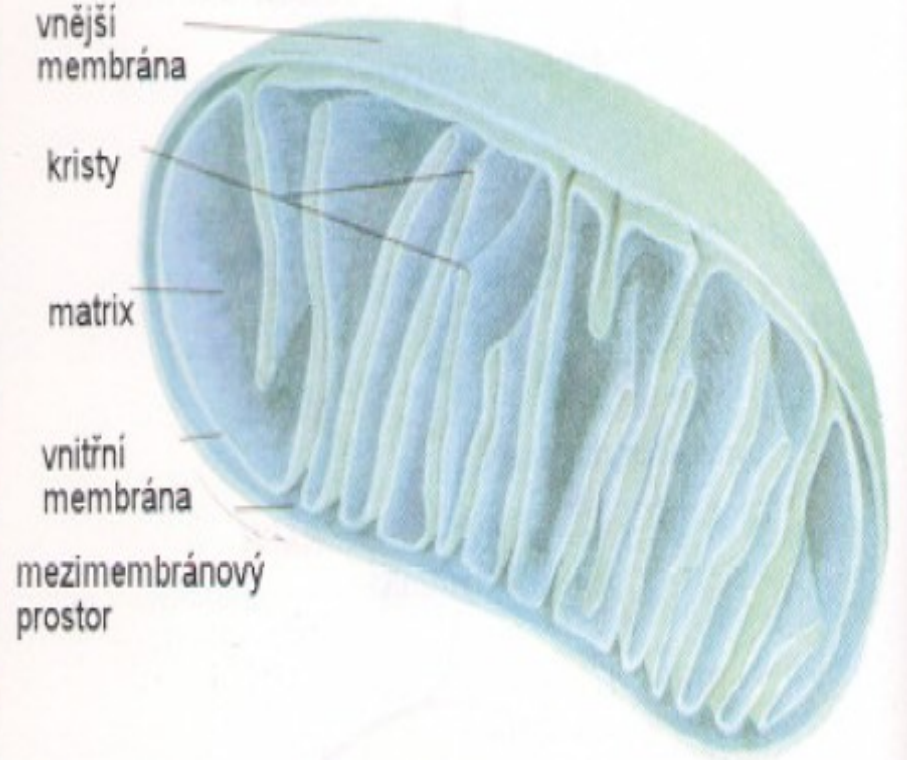
Table 16-5 Concepts in Biochemistry, 3/e

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Lokalizace citrátového cyklu



(a)



(b)

METABOLISMUS SACHARIDŮ

Štěpení oligosacharidů a polysacharidů

A. Štěpení sacharidů při trávení potravy

Hydrolyticky

α – amylasa	sliny, pankreas	škrob	Dextriny, maltosa, glukosa
amyloglukosidasa	střeva	glykogen	maltosa
maltasa	"	maltosa	glukosa
laktasa	"	laktosa	glukosa, galaktosa
sacharasa	"	sacharosa	glukosa fruktosa
celulasy	houby, bakterie	celulosa	glukosa

B. Štěpení rezervních polysacharidů

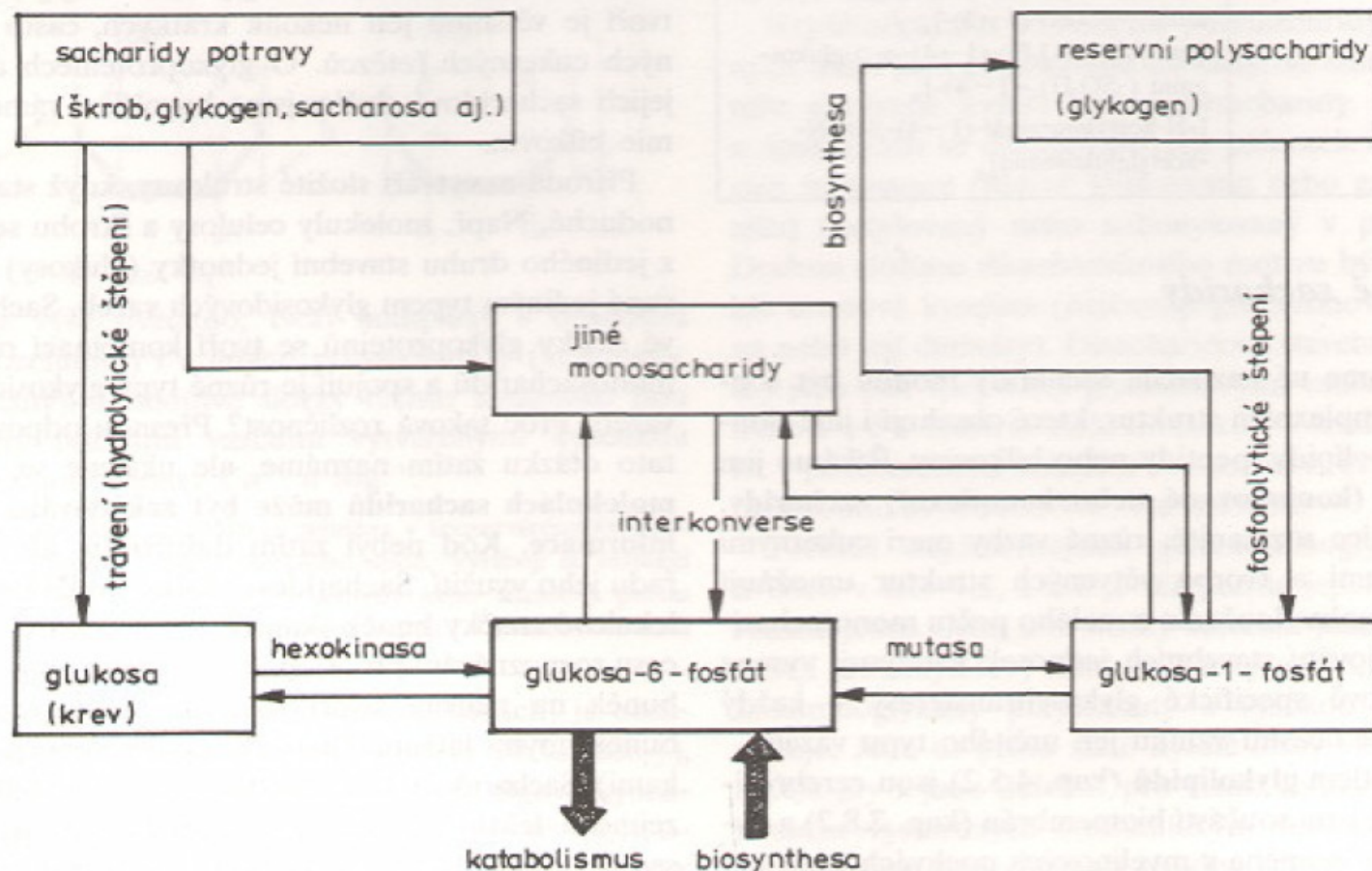
Fosforyloticky

Hydrolyticky

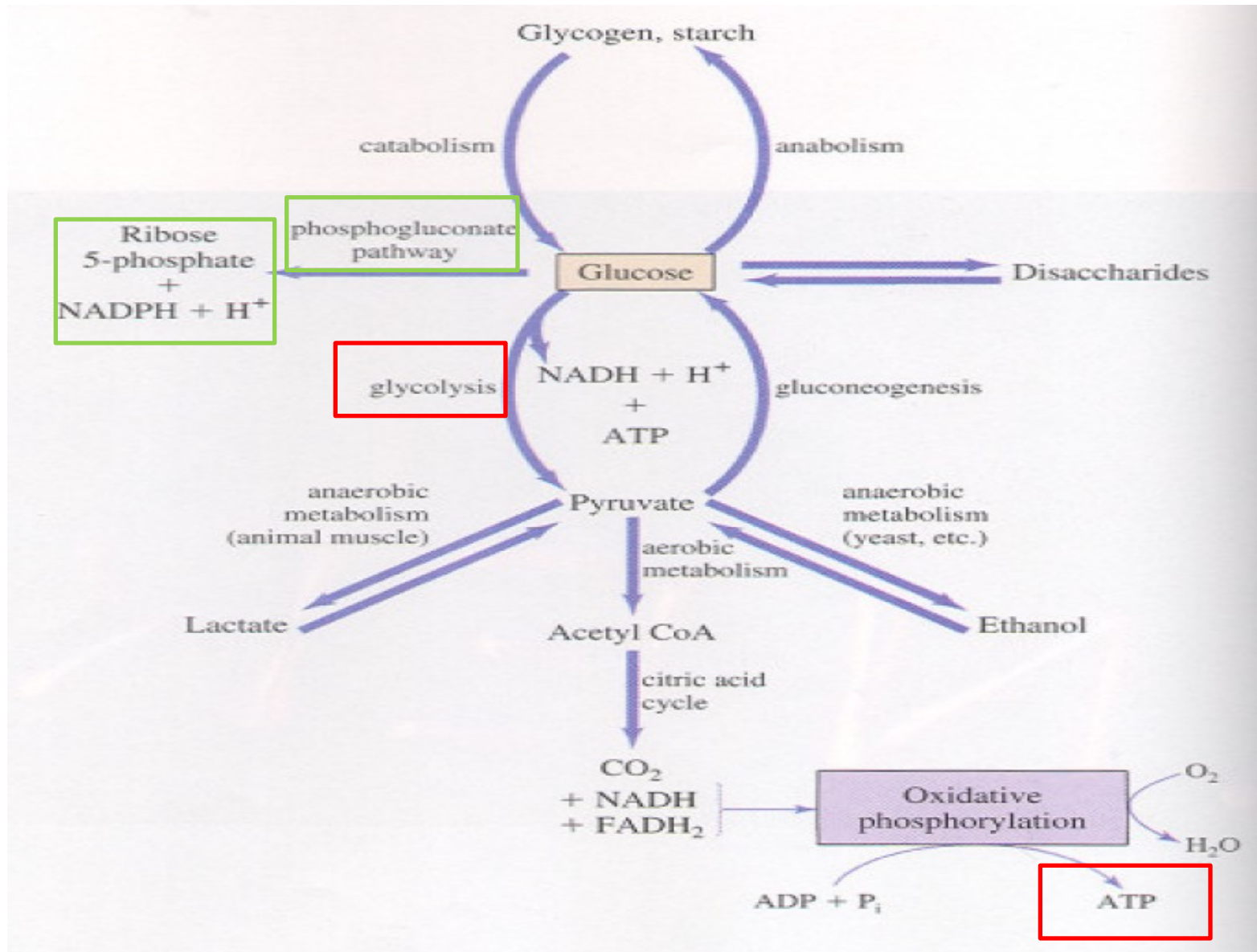
fosforylasa	játra	glykogen	glukosa-1-P
β – amylasa	rostliny	škrob	maltosa

Glukosa-6-fosfát - klíčový metabolit

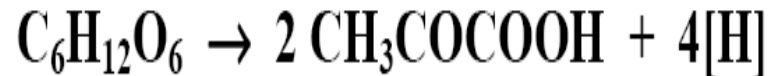
- Fosforylací glukosy z potravy
- Izomerací glukosa-1-fosfátu z tkáňového glykogenu
- Izomeracemi a epimeracemi jiných monosacharidů



METABOLISMUS SACHARIDŮ



GLYKOLÝZA



Historie :

- 19. stol. Paster - kvasinky

Buchner - kvasniční extrakt

- 1905 - 1910 Harden, Young

- 1940 Embden, Meyerhof, Parnas

GLYKOLÝZA



glukosa

$2\text{ADP} + 2\text{P}_i$

2NAD^+

fruktosa-1,6-bisfosfát

2ATP

2NADH

2 pyruvát

anaerobní mléčné kvašení

aerobní oxidace

anaerobní alkoholové kvašení

CITRÁTOVÝ CYKLUS

2NADH

2NADH

6O_2

2NADH

2NAD^+

2NAD^+

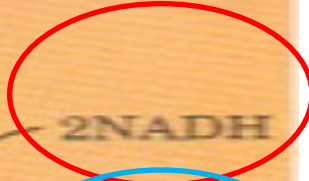
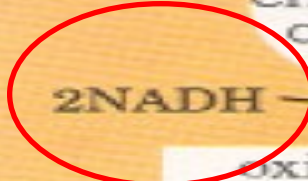
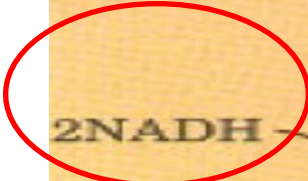
2NAD^+

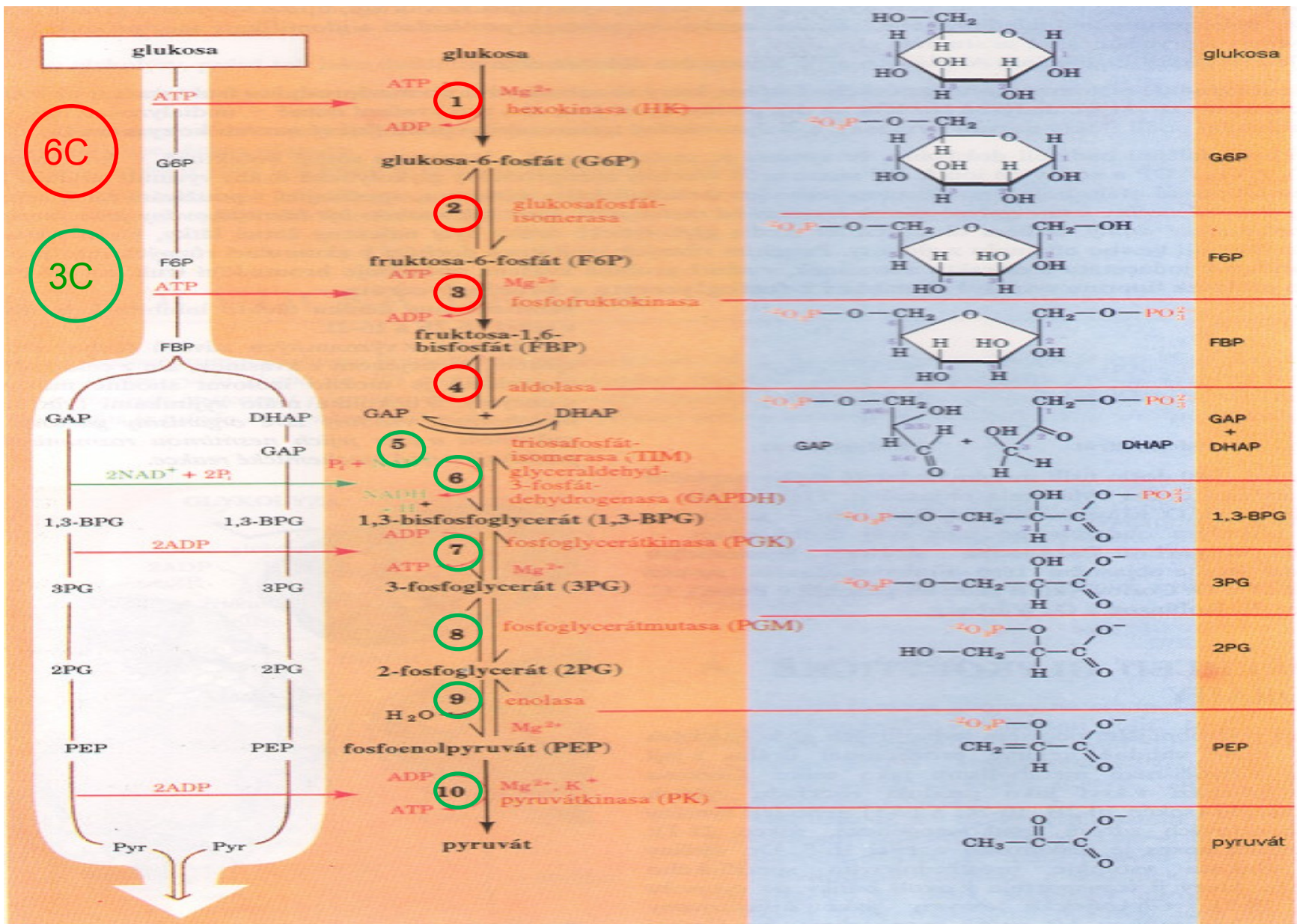
2 laktát

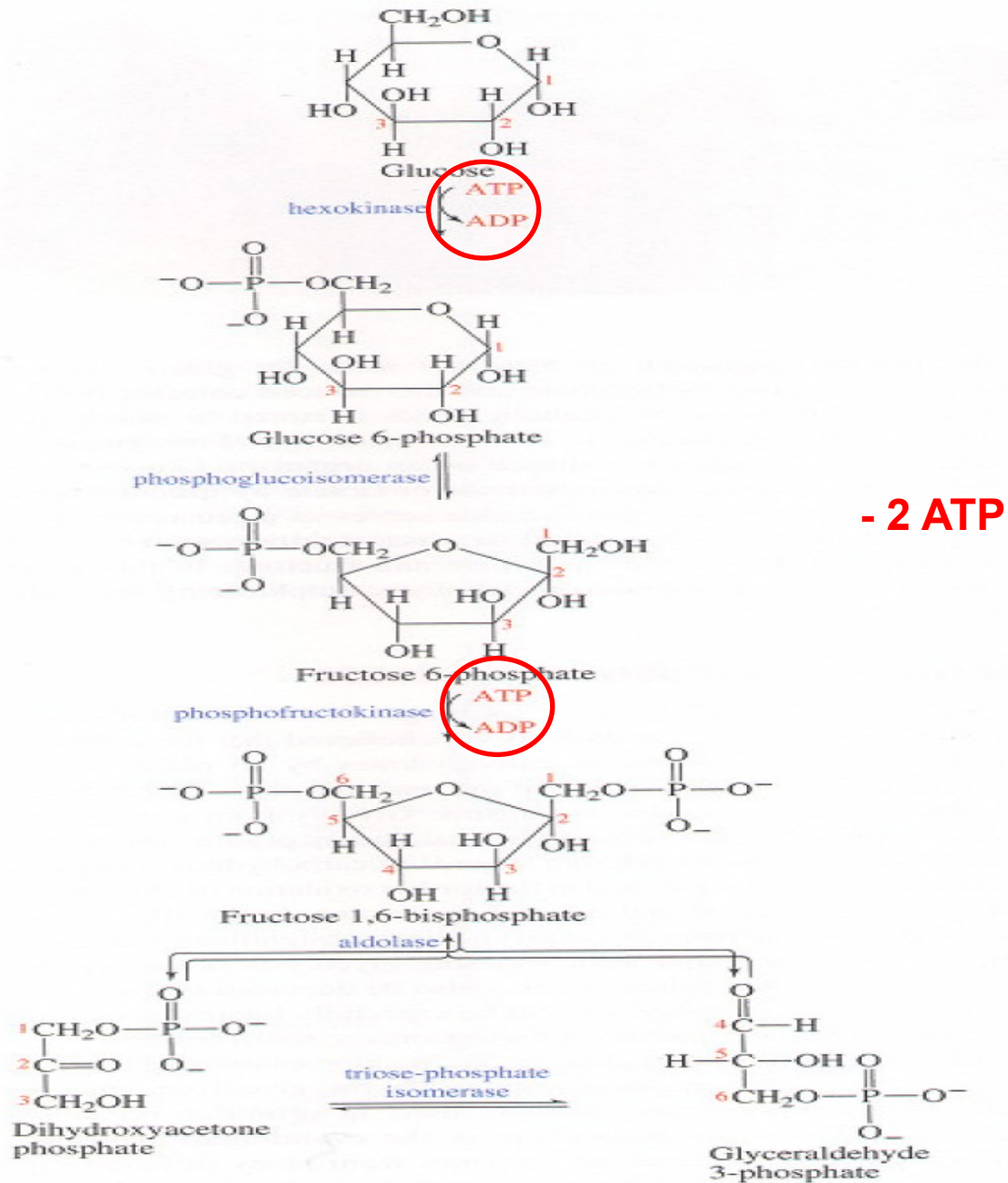
$6\text{CO}_2 + 6\text{H}_2\text{O}$

$2\text{CO}_2 + 2\text{ethanol}$

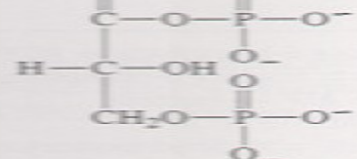
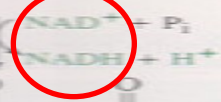
oxidační fosforylace





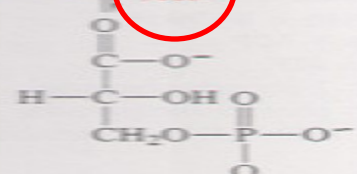


glyceraldehyde-3-phosphate dehydrogenase



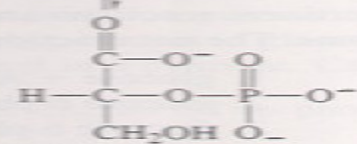
1,3-Bisphosphoglycerate

phosphoglycerate kinase



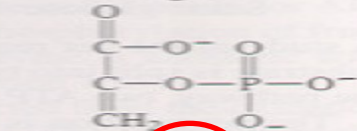
3-Phosphoglycerate

phosphoglycerate mutase



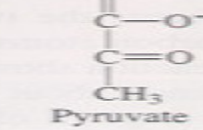
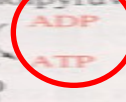
2-Phosphoglycerate

enolase



Phosphoenolpyruvate

pyruvate kinase

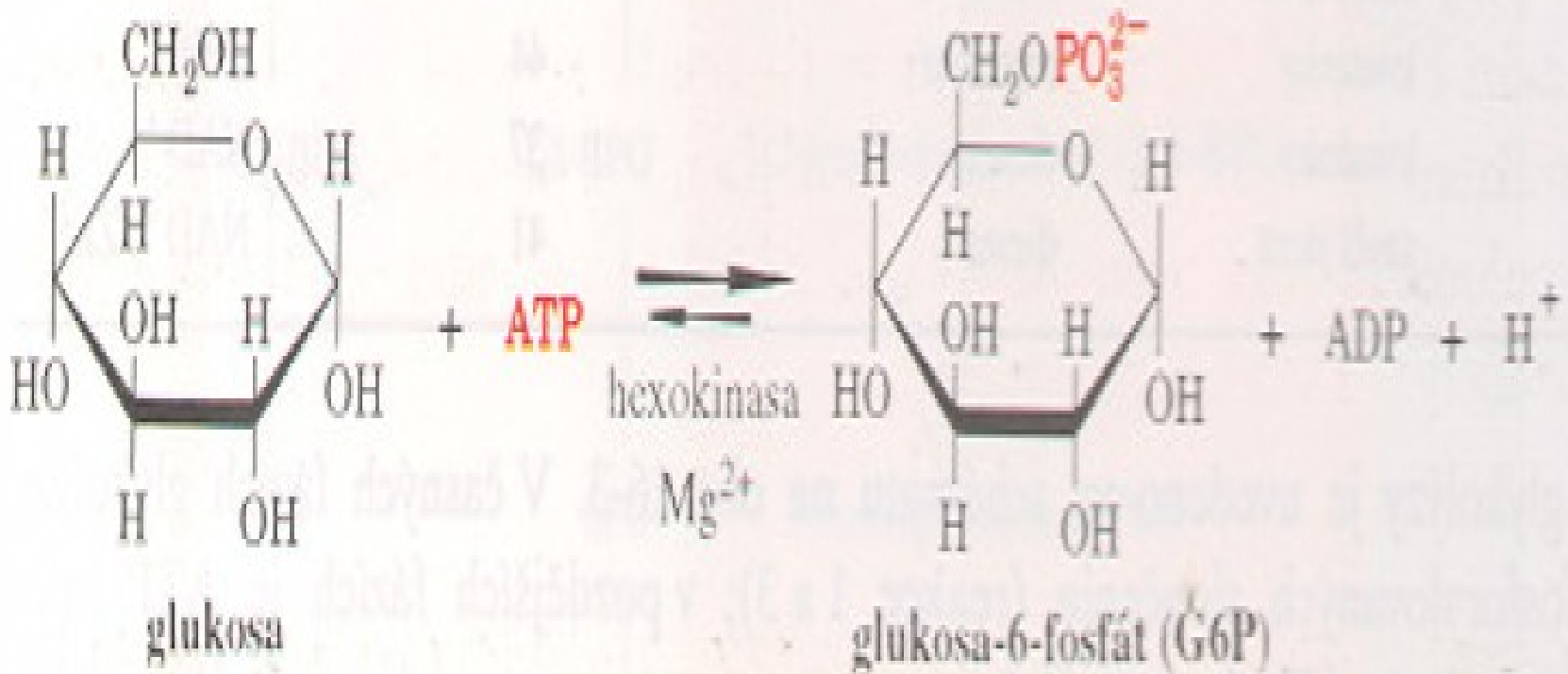


Pyruvate

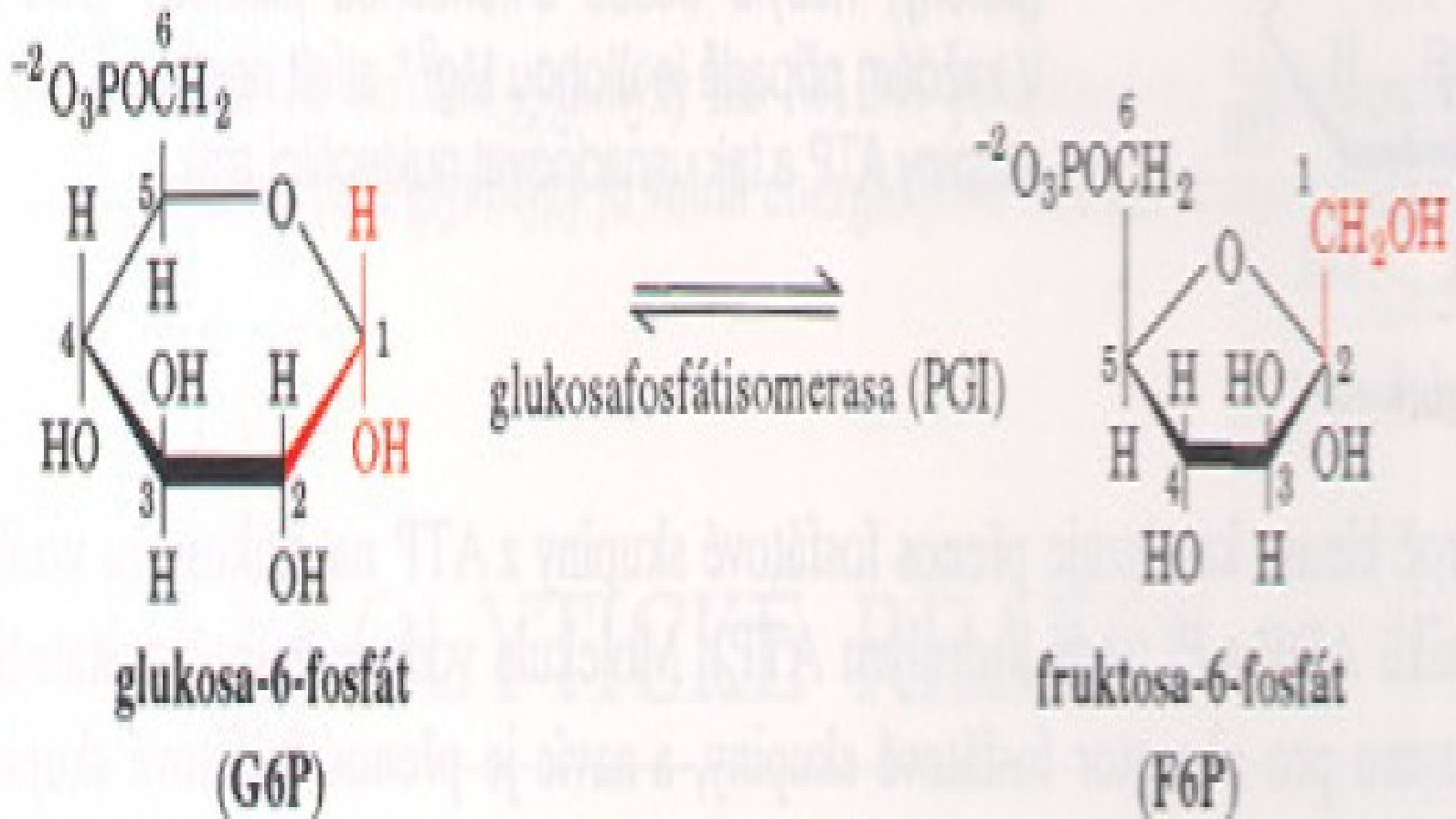
2 x

2 x (2ATP + NADH)

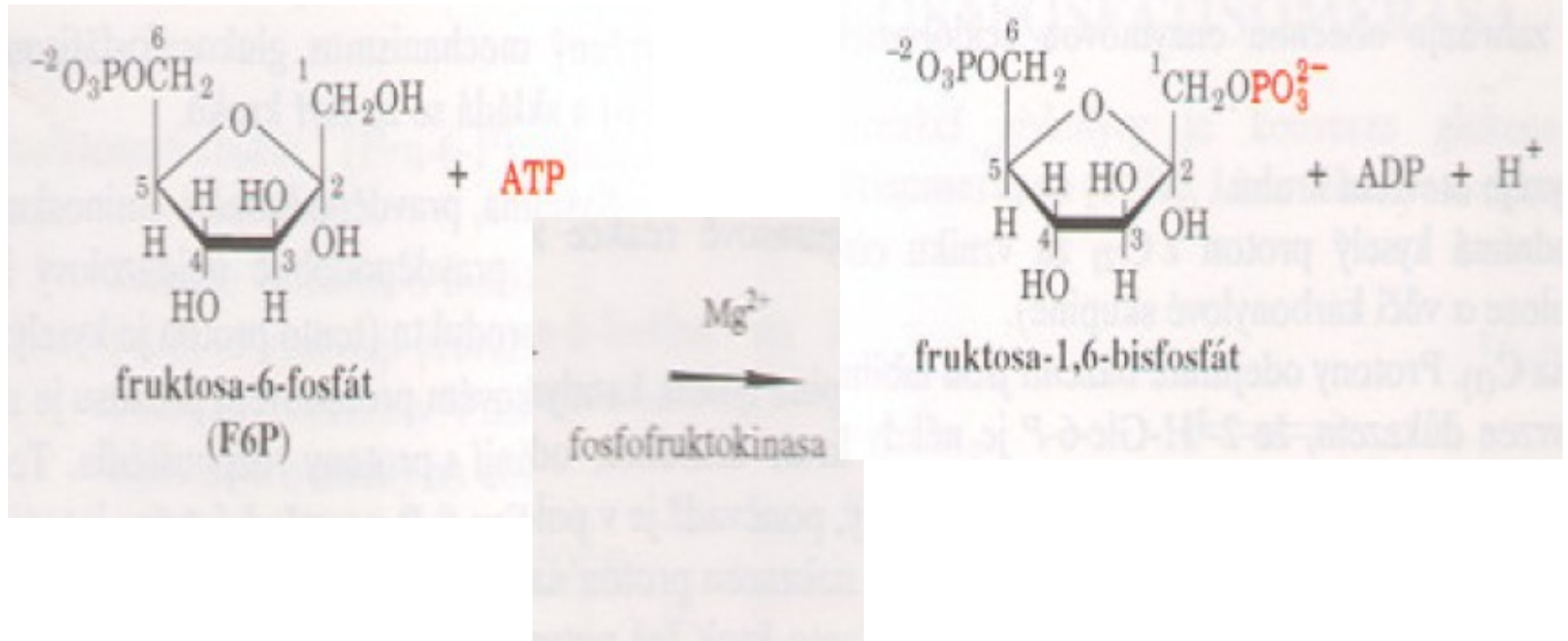
Hexokinasa -glukokinasa



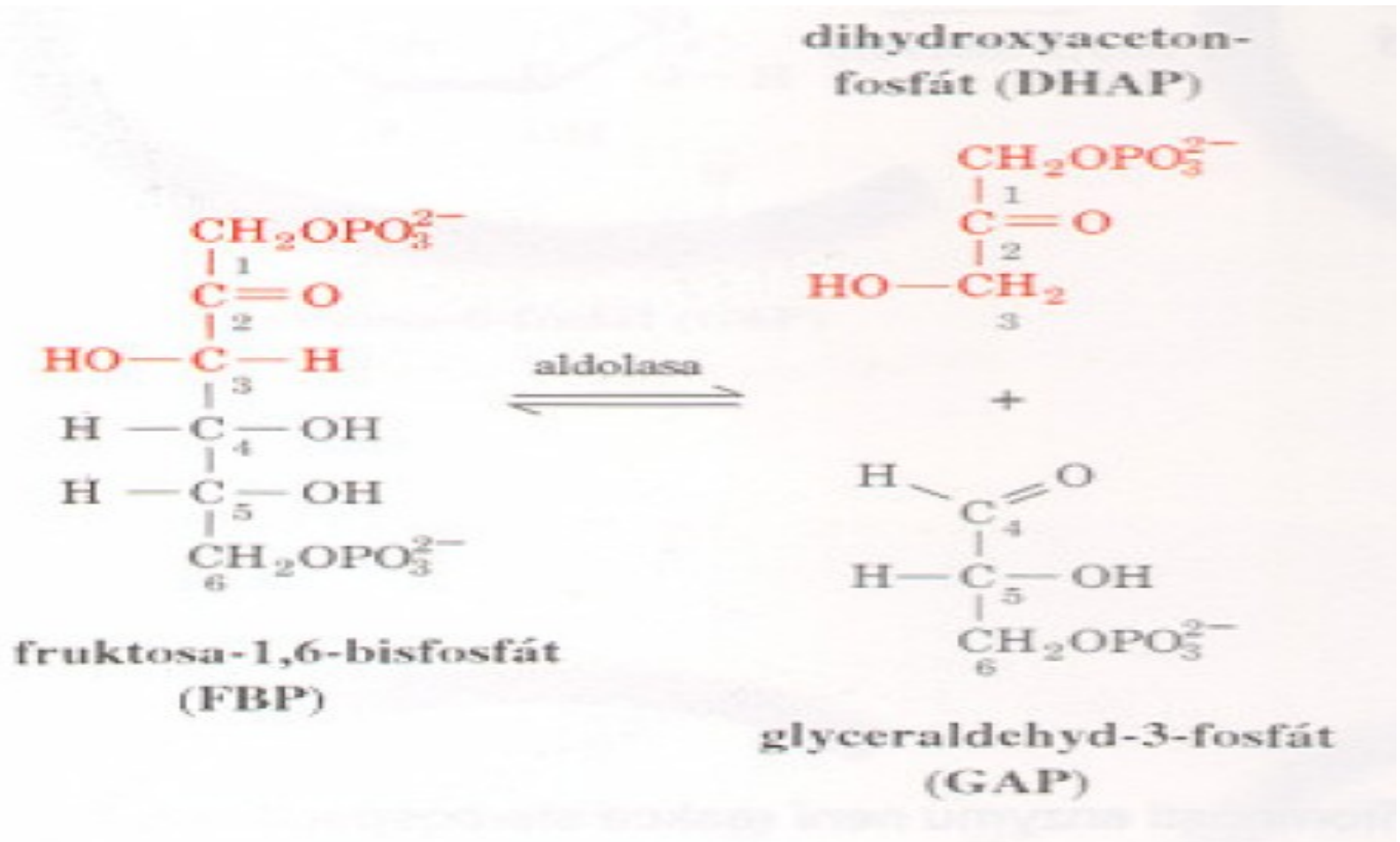
Glukosafosfátisomerasa



Fosfofruktokinasa

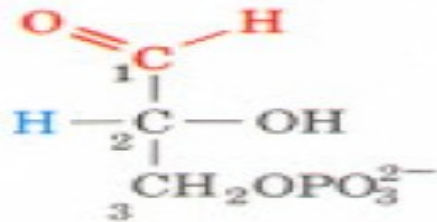


Aldolsa



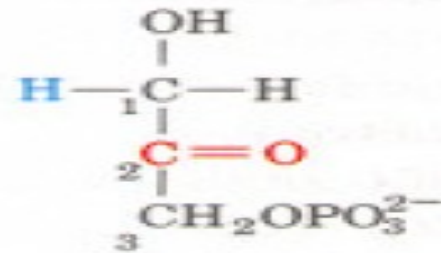
Triosafosfátisomerasa

4 %

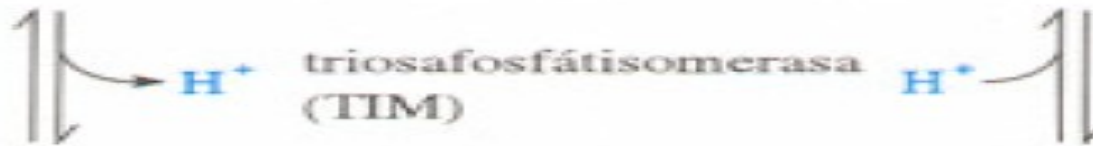


glyceraldehyd-3-fosfát
(aldosa)

96 %

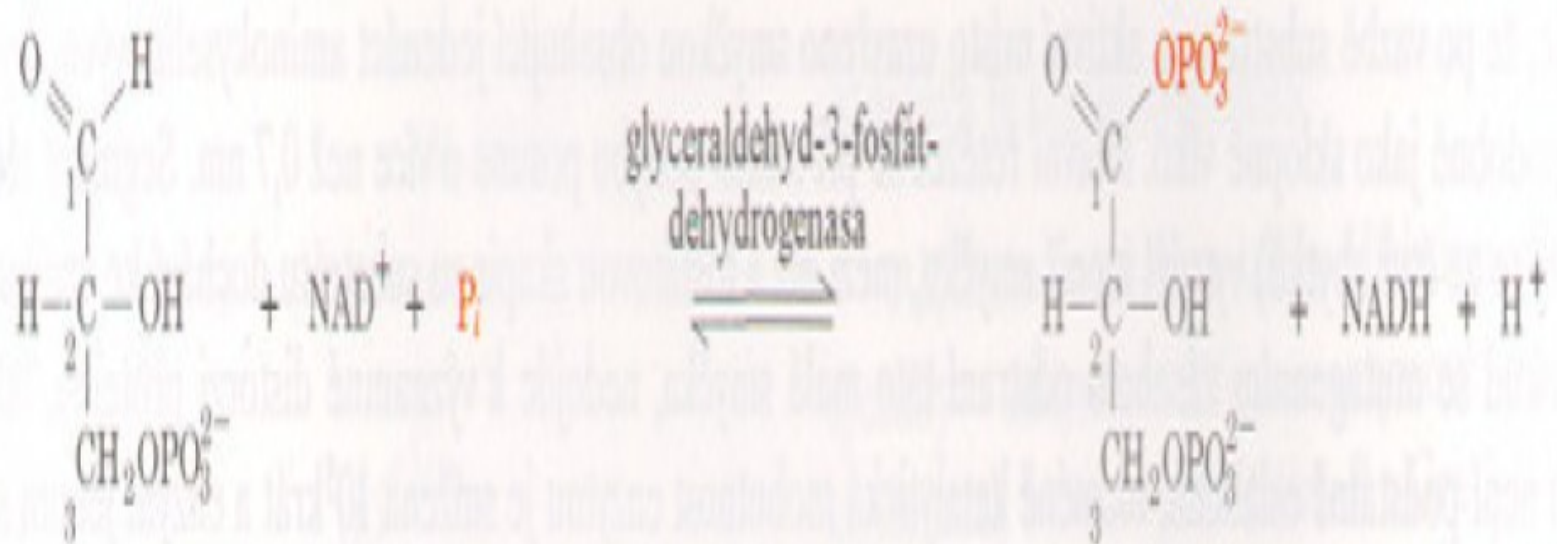


dihydroxyaceton-fosfát
(ketosa)



endiolový intermediát

Glyceraldehyd-3-fosfát-dehydrogenasa

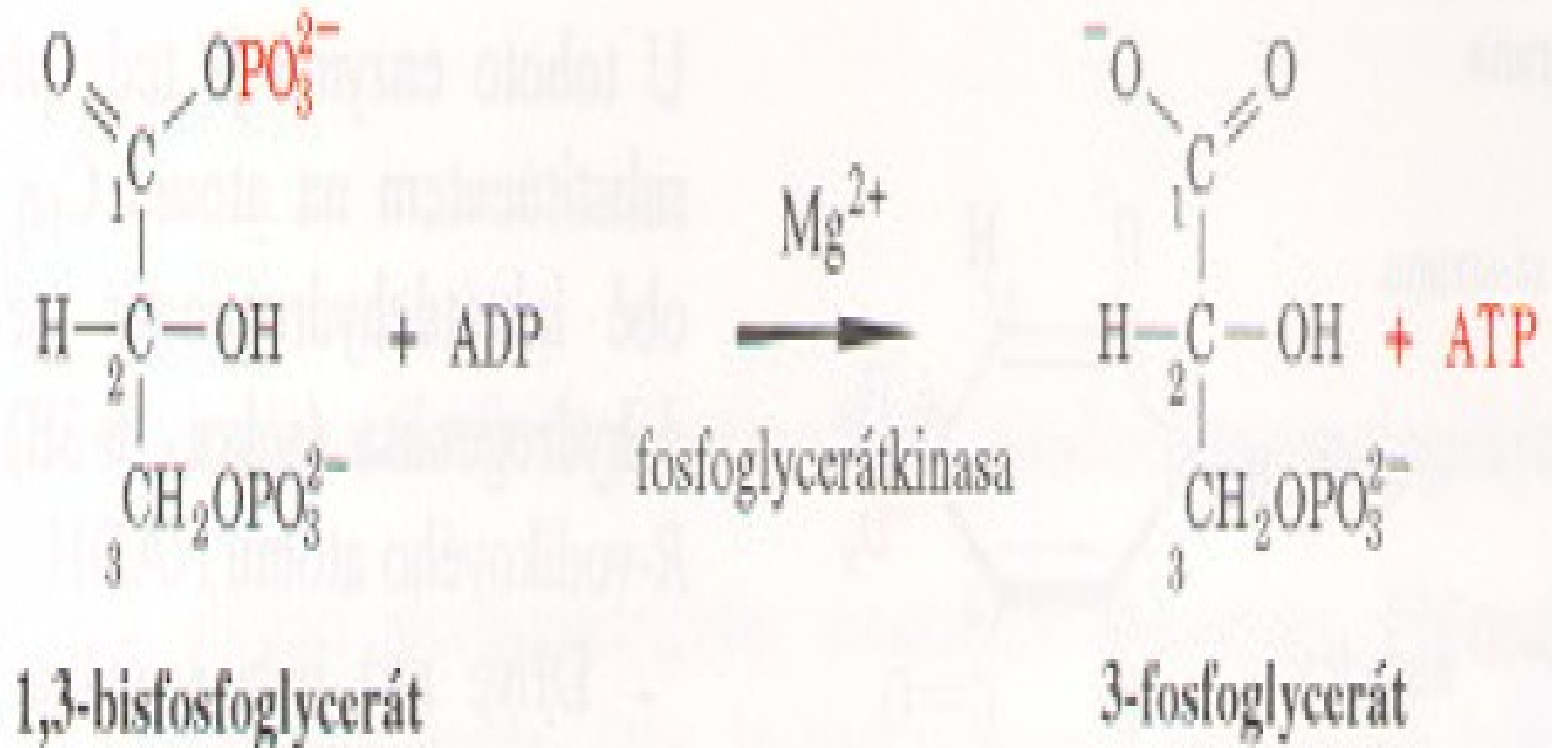


glyceraldehyd-3-fosfát

(GAP)

1,3-bisfosfoglycerát

Fosfoglycerátkinasa



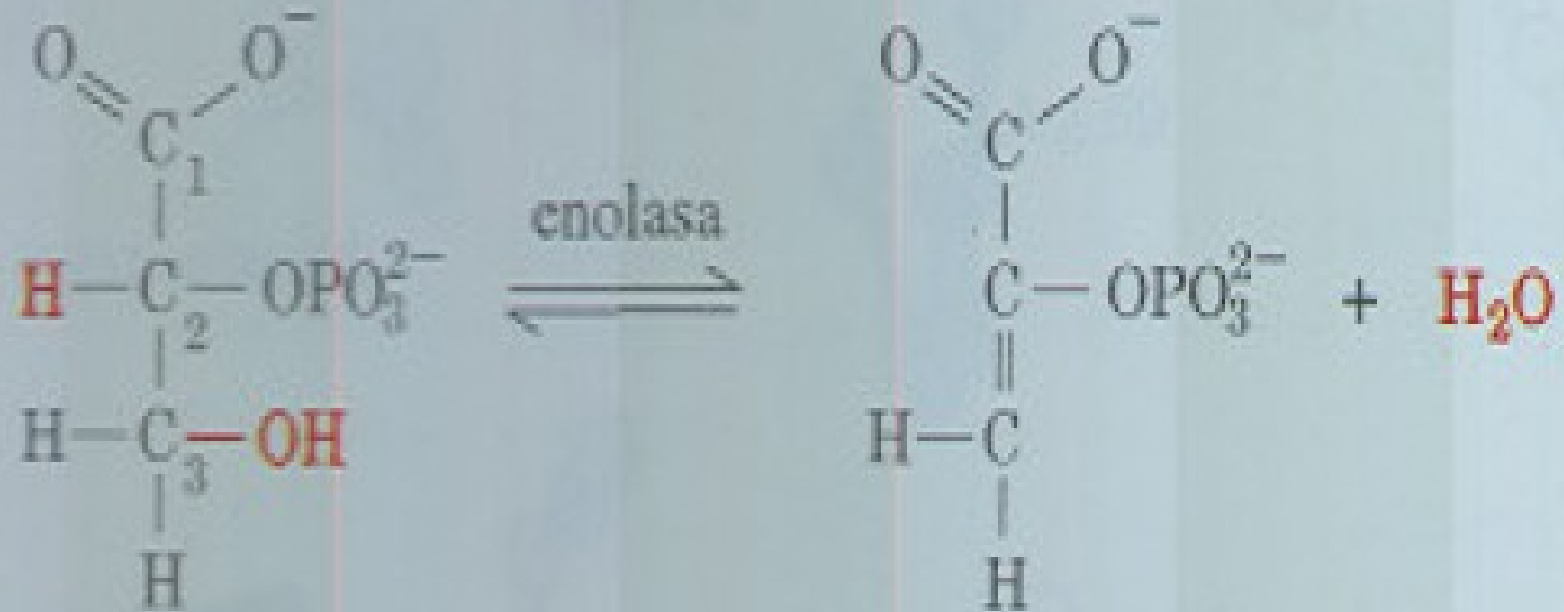
Fosfoglycerátmutasa



3-fosfoglycerát

2-fosfoglycerát

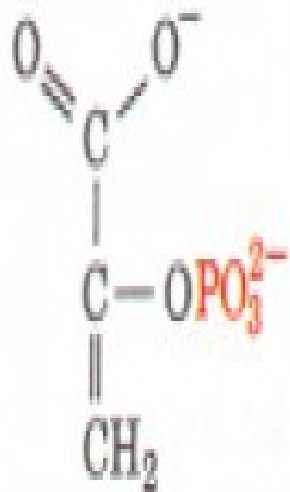
Enolasa



2-fosfoglycerát

fosfoenolpyruvát

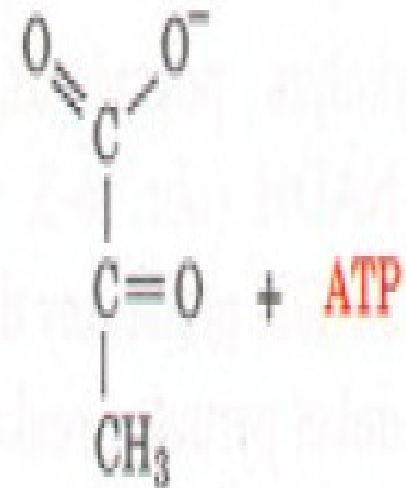
Pyruvátkinasa



fosfoenolpyruvát



pyruvátkinasa



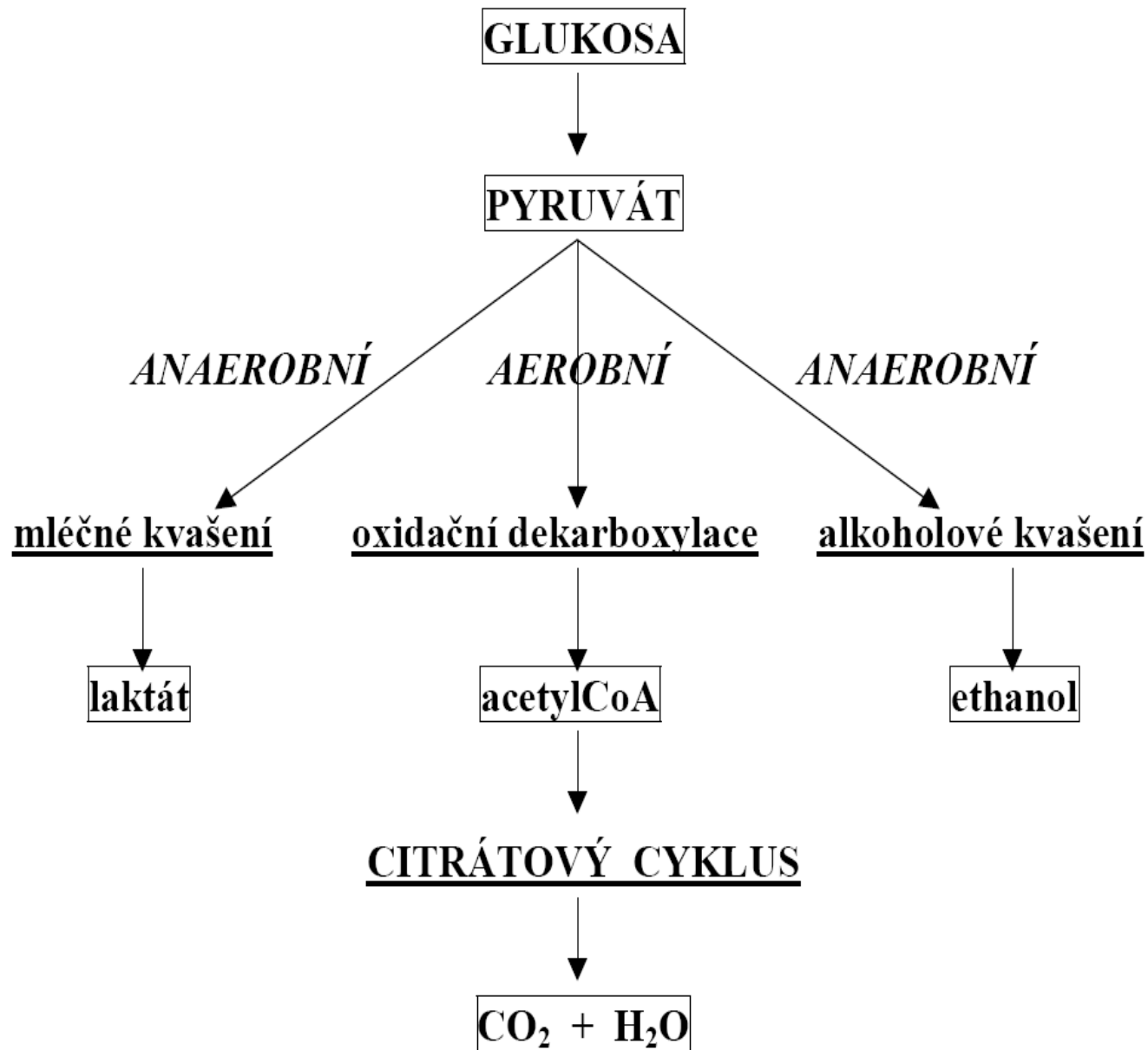
pyruvát

Bilance glykolýzy

glukosa + 2 NAD⁺ + 2 ADP + 2 Pi

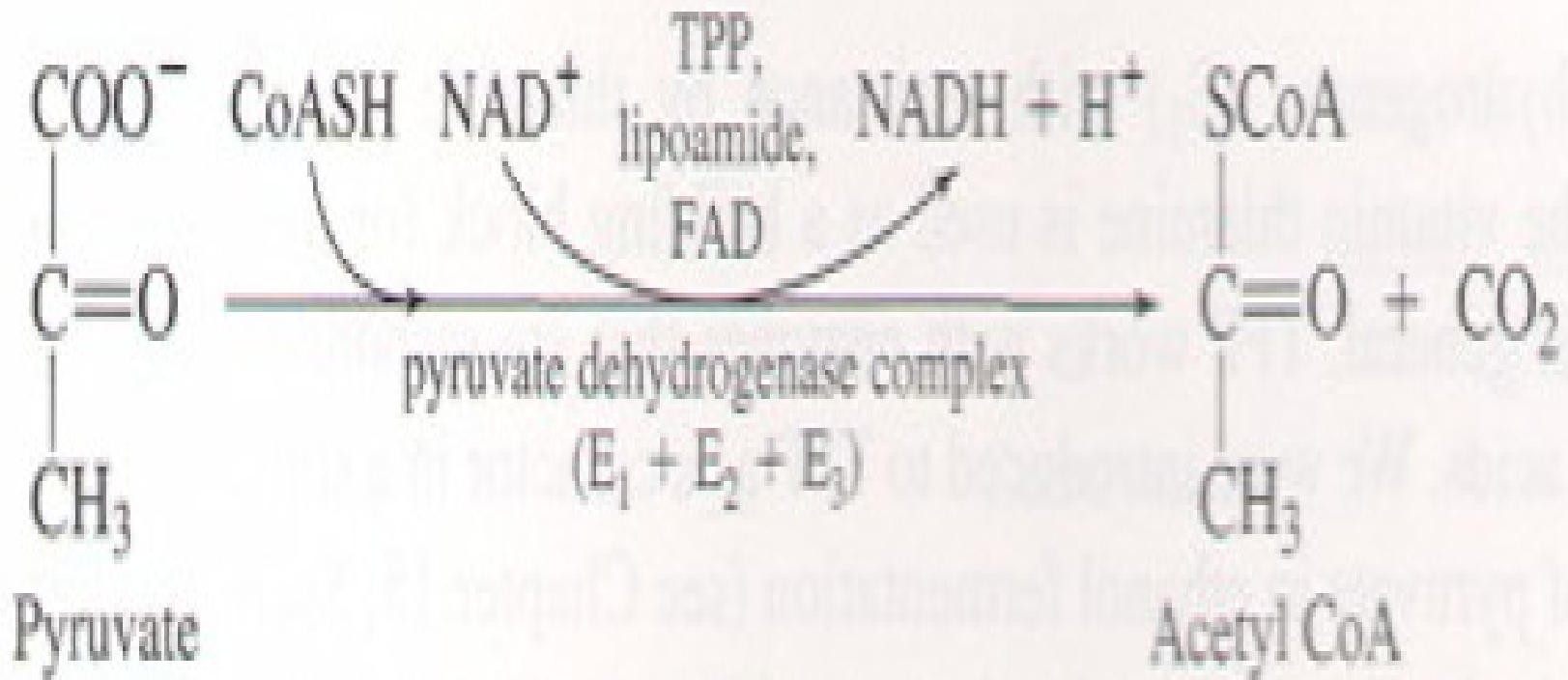
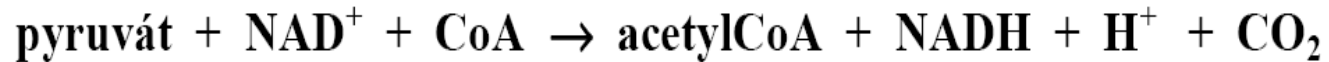
→

2 pyruvát + 2 ATP + 2 NADH + 2 H⁺ + 2 H₂O

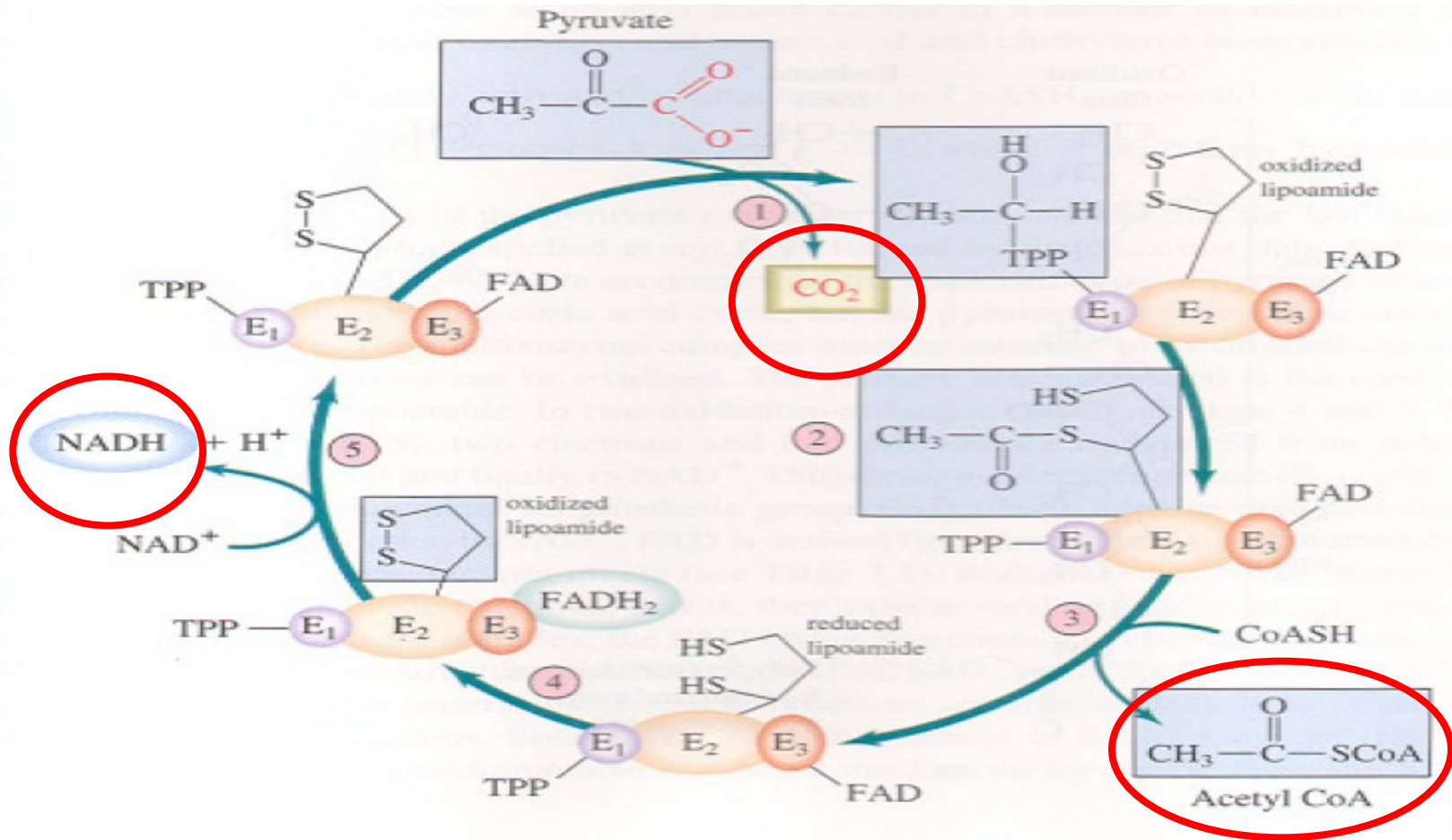


Aerobní odbourávání

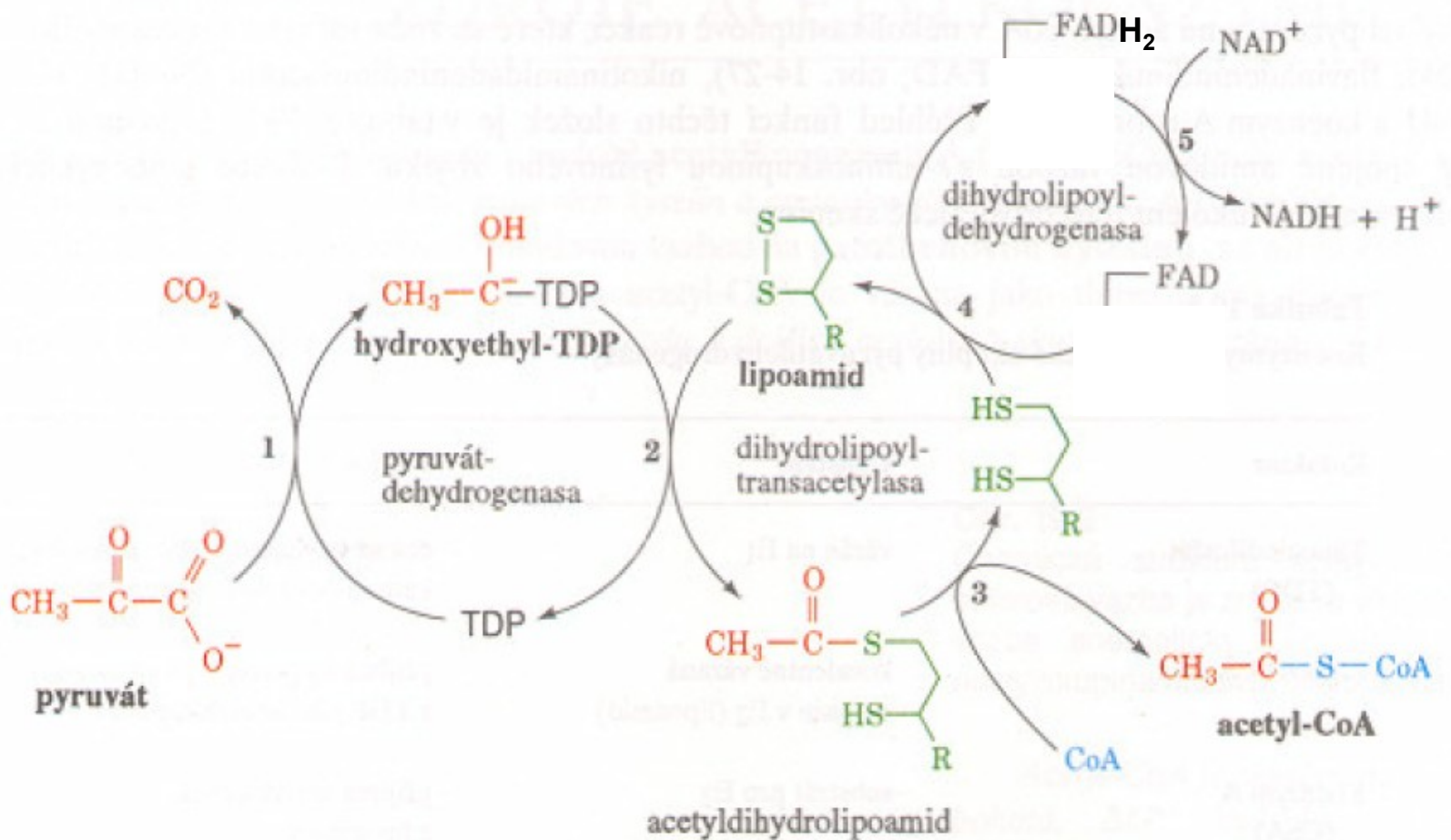
Oxidační dekarboxylace :



Pyruvátdehydrogenasa

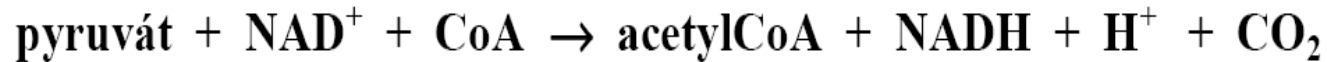


Pyruvátdehydrogenasa

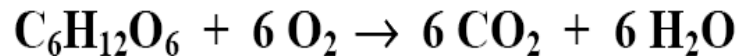


Aerobní odbourávání

Oxidační dekarboxylace :



Bilance aerobní glykolýzy :

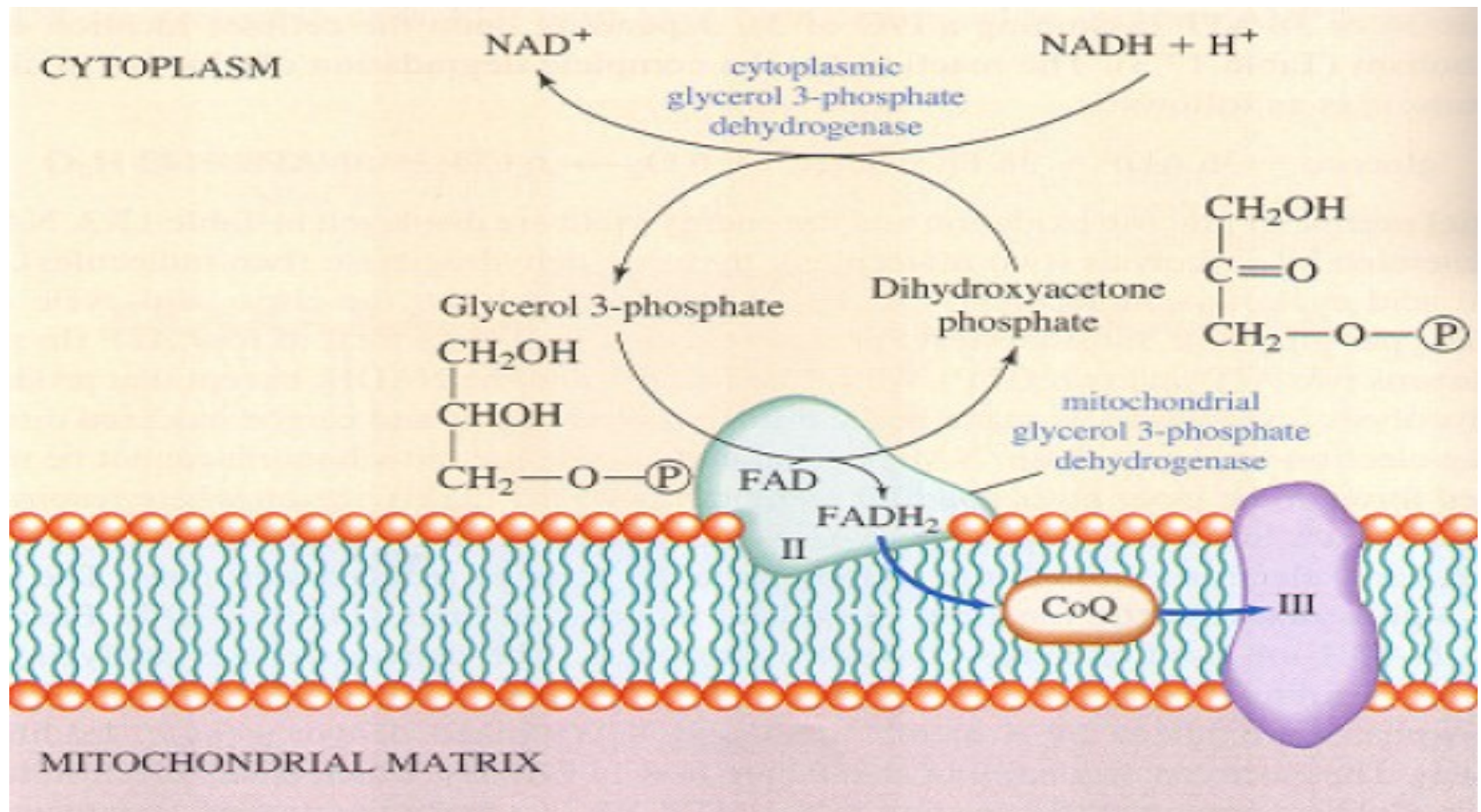


Glykolýza	1 ATP + 1 NADH	(4-1) ATP
Oxidační dekarboxylace	1 NADH	3 ATP
Citrátový cyklus	1 ATP 3 NAD + FADH ₂	12 ATP
CELKEM	18 ATP/ triosu tj.	36 ATP/ glukosu tj. 40 %

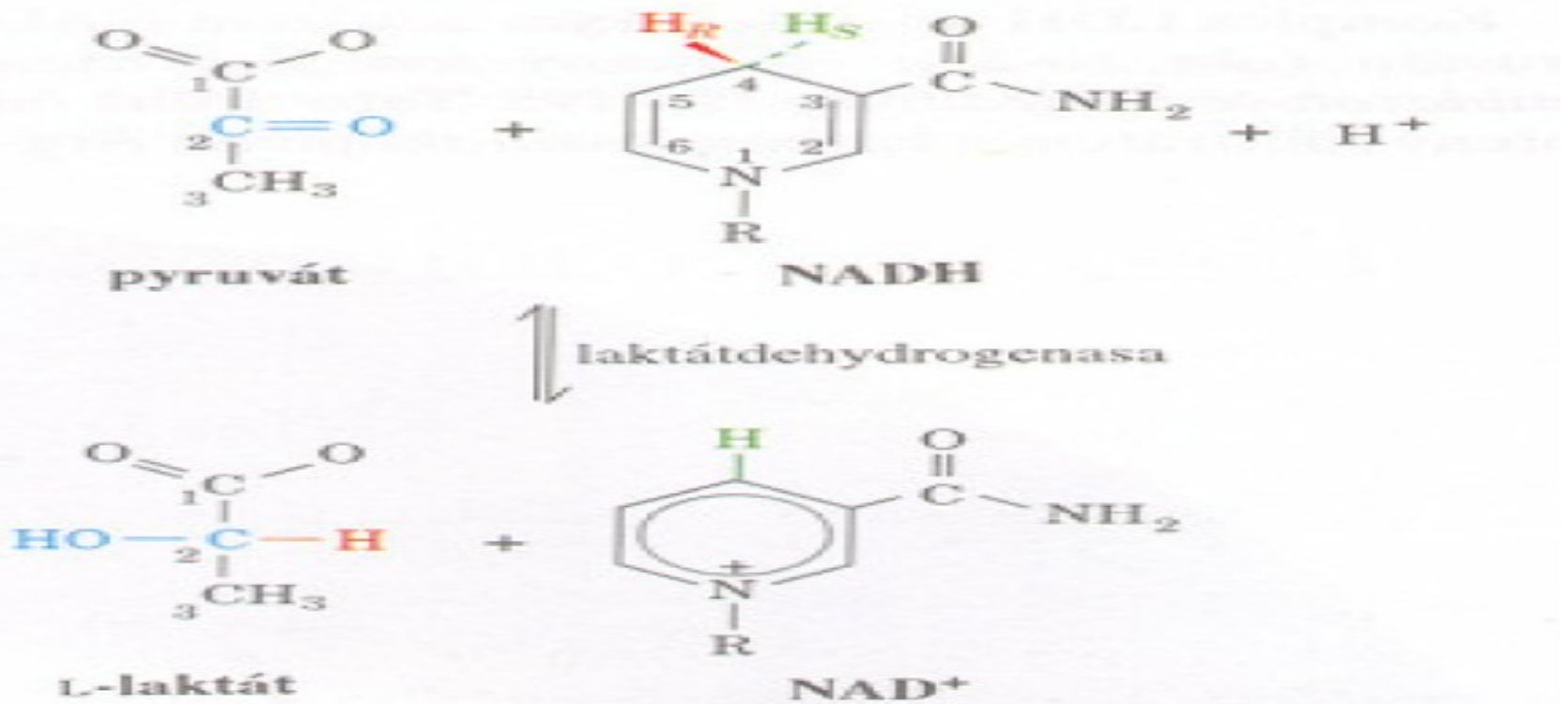
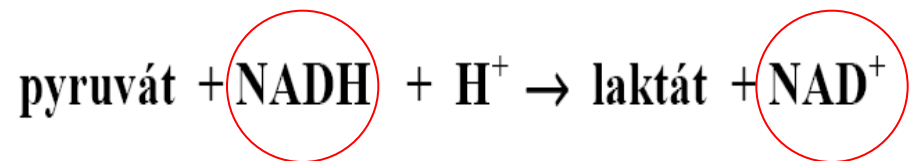
CYT

MIT

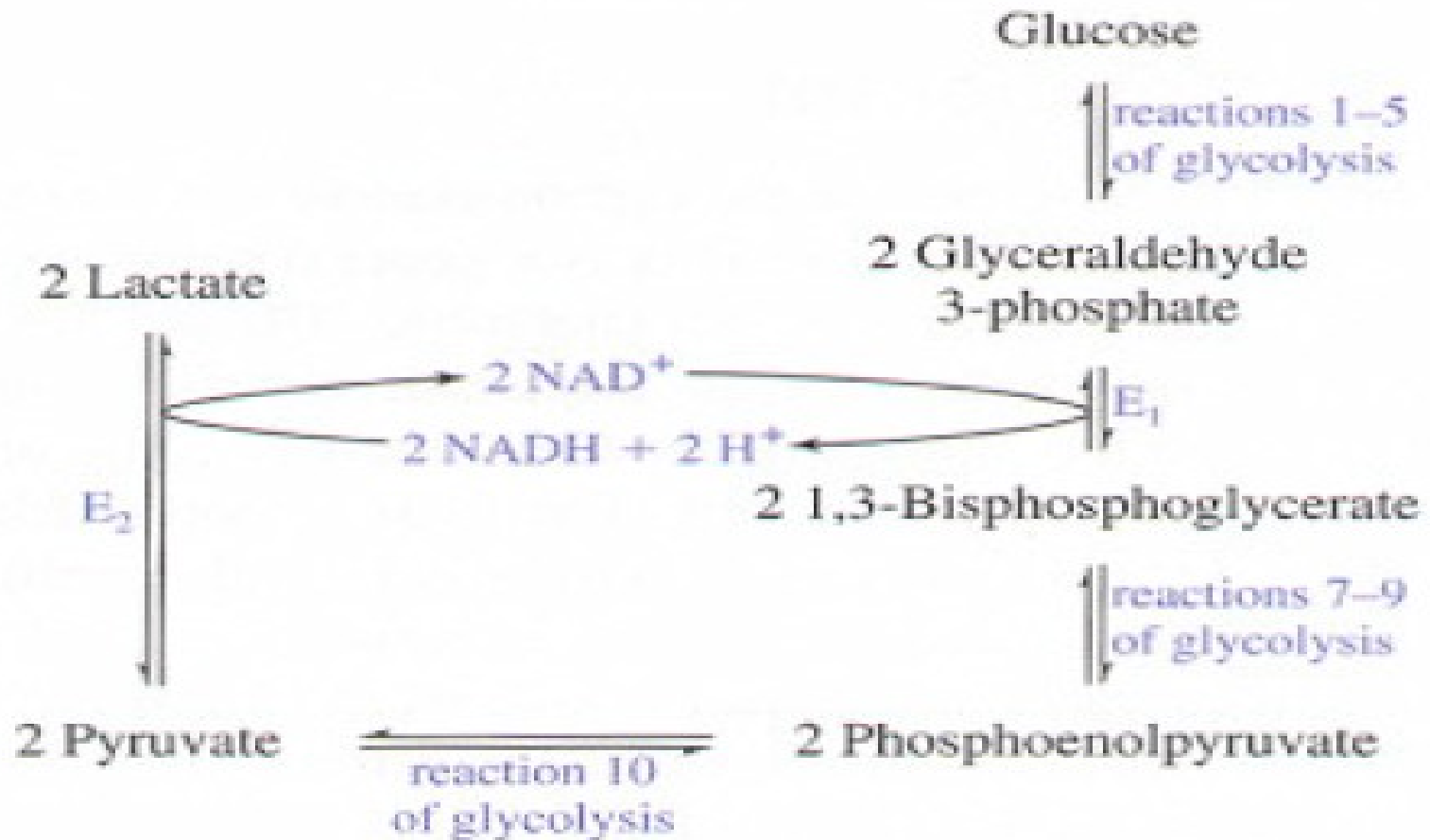
G-3-P DH člunek



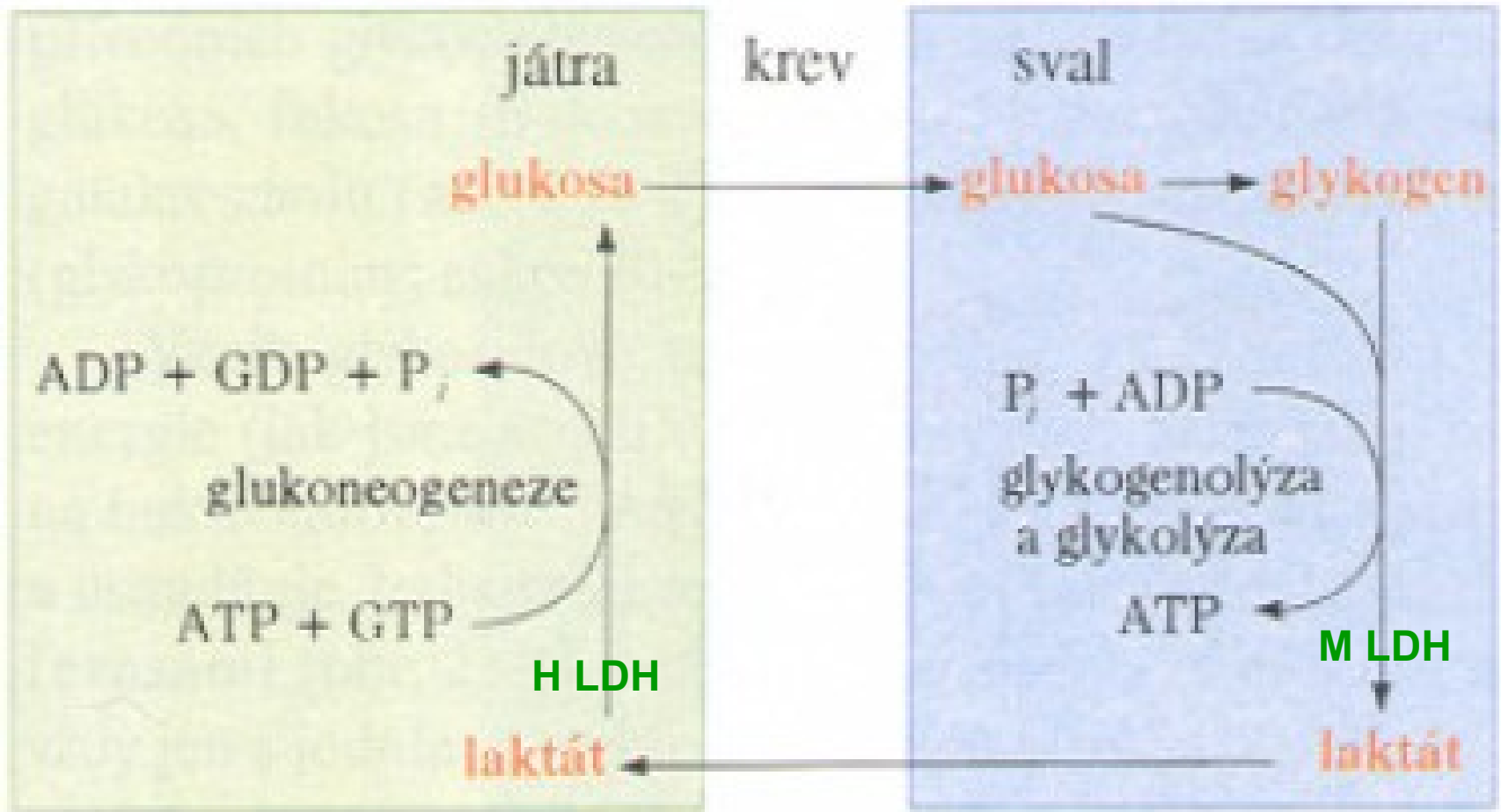
Mléčné kvašení



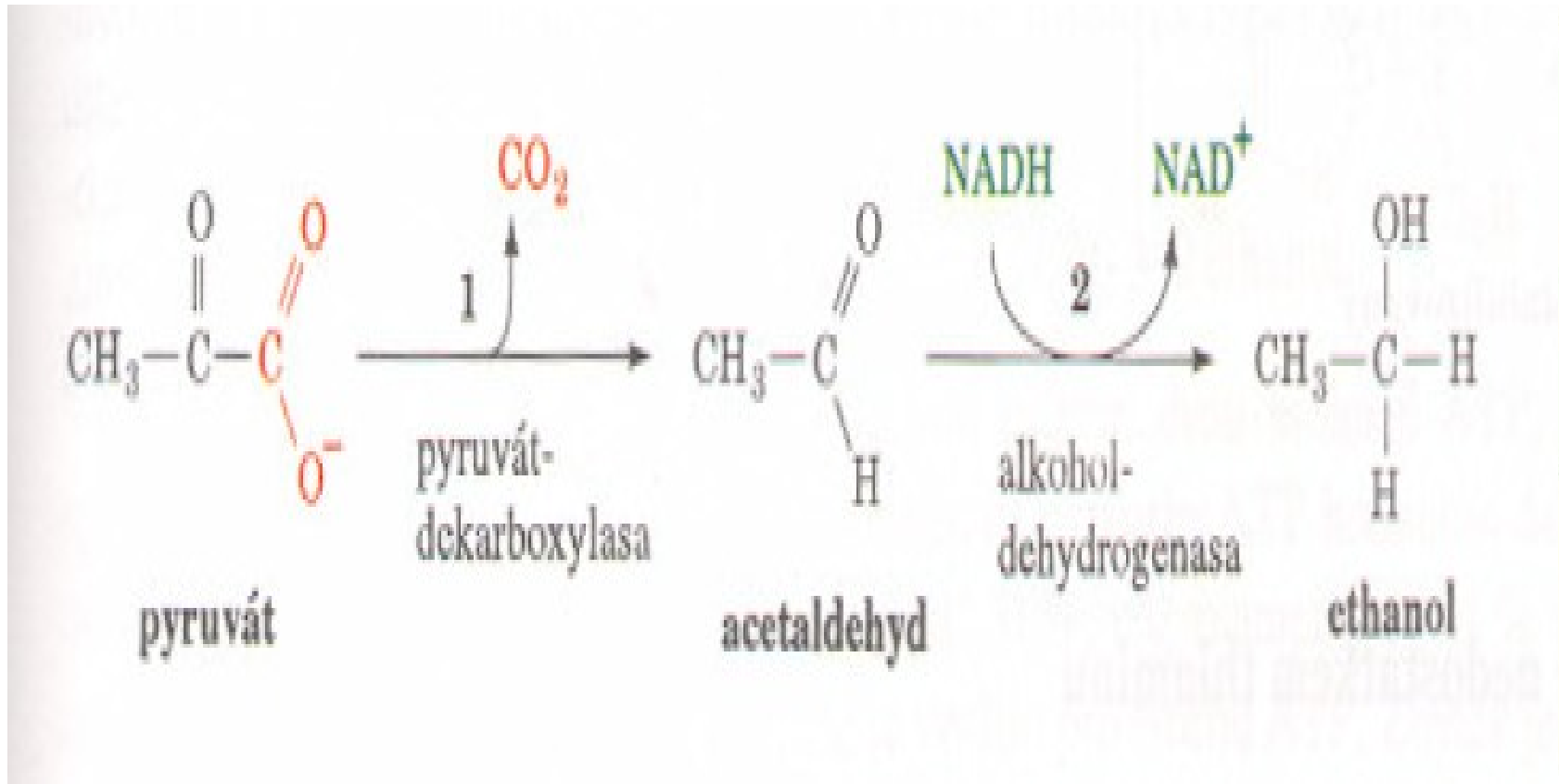
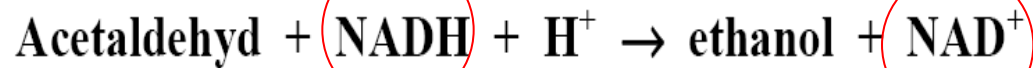
Mléčné kvašení



Coriho cyklus



Alkoholové kvašení



Další druhy kvašení

• Mléčné - *Lactobacterium*
glukosa → laktát

• Propionové - *Propionibacterium*
glukosa → k. propionová

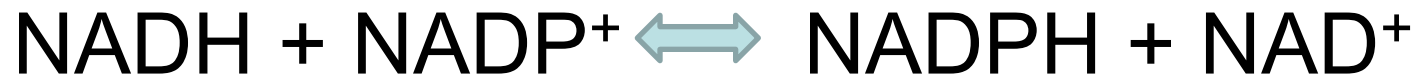
• Máselné - *Clostridium*
glukosa → k. máselnou

• Octové - *Acetobacter* O_2
glukosa → k. octová

• Citronové - *Aspergillus* CO_2
glukosa → k. citronová

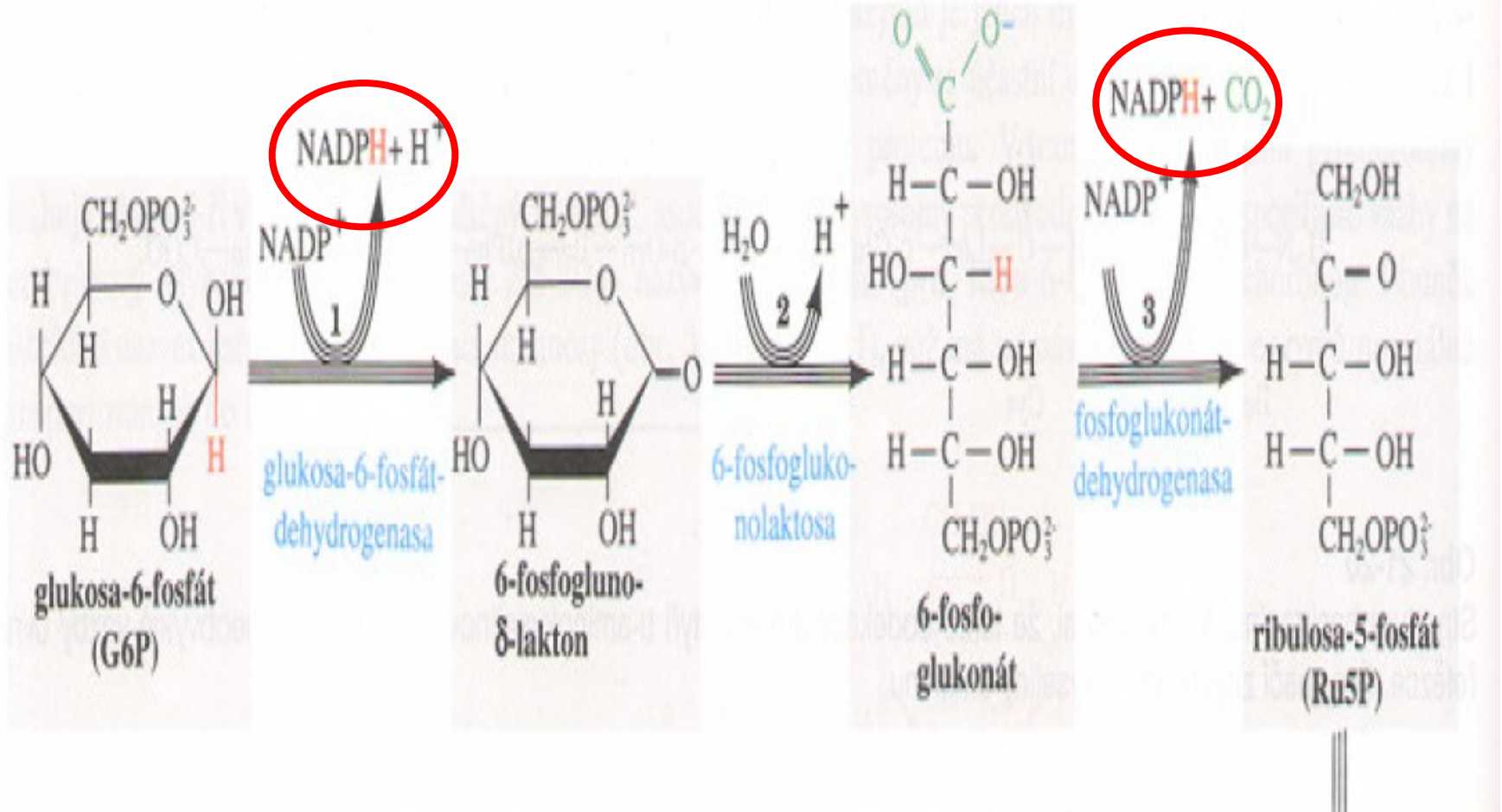
pravé

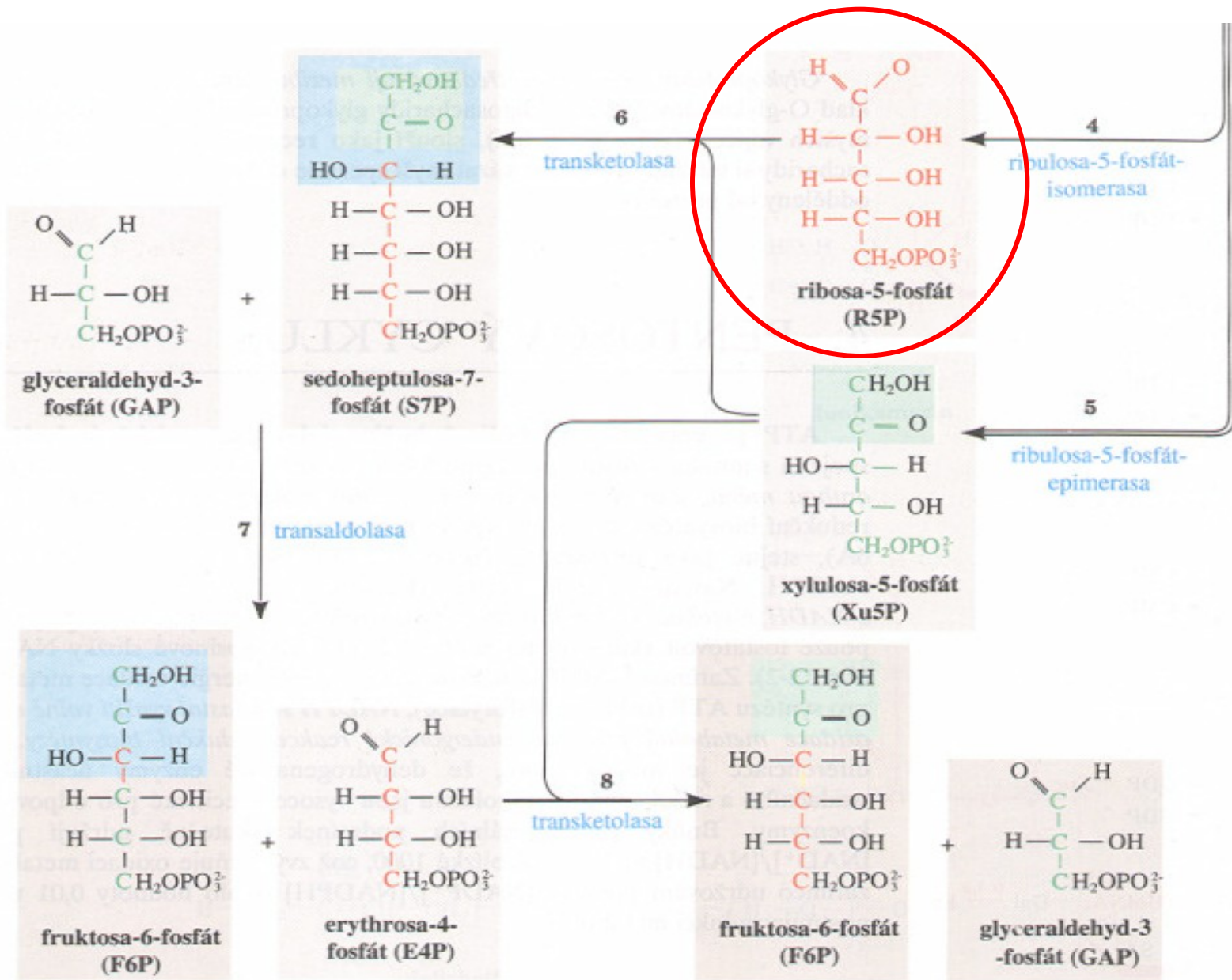
nepravé

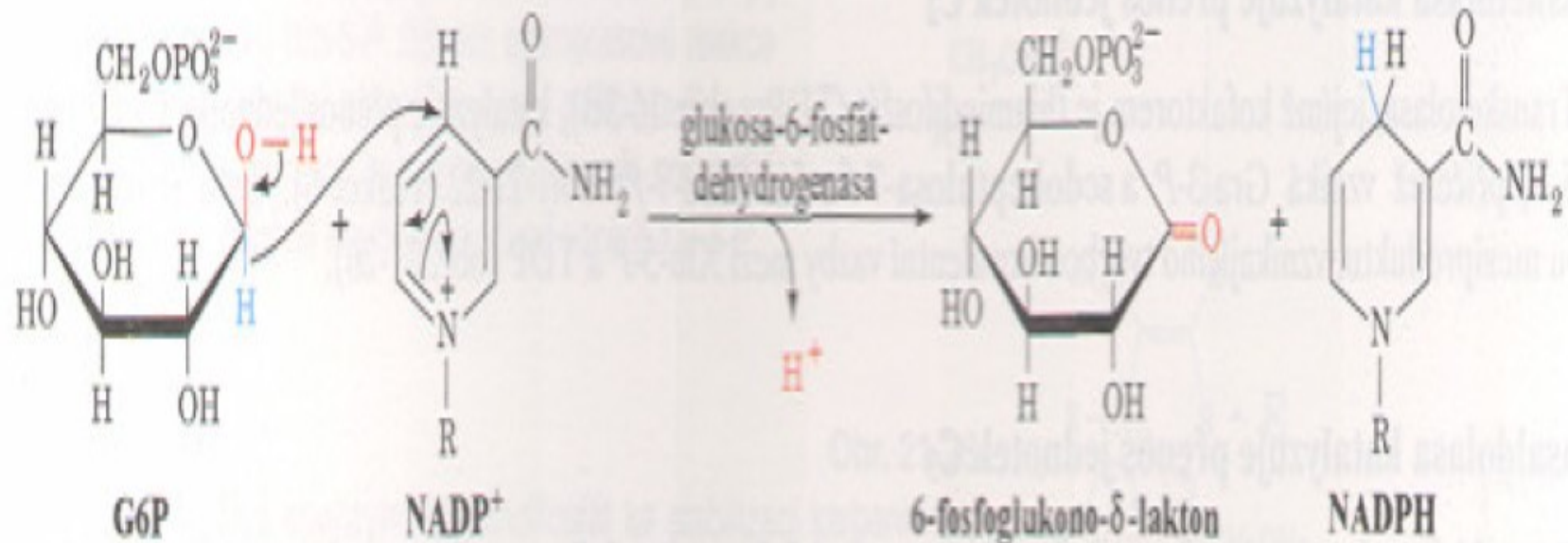


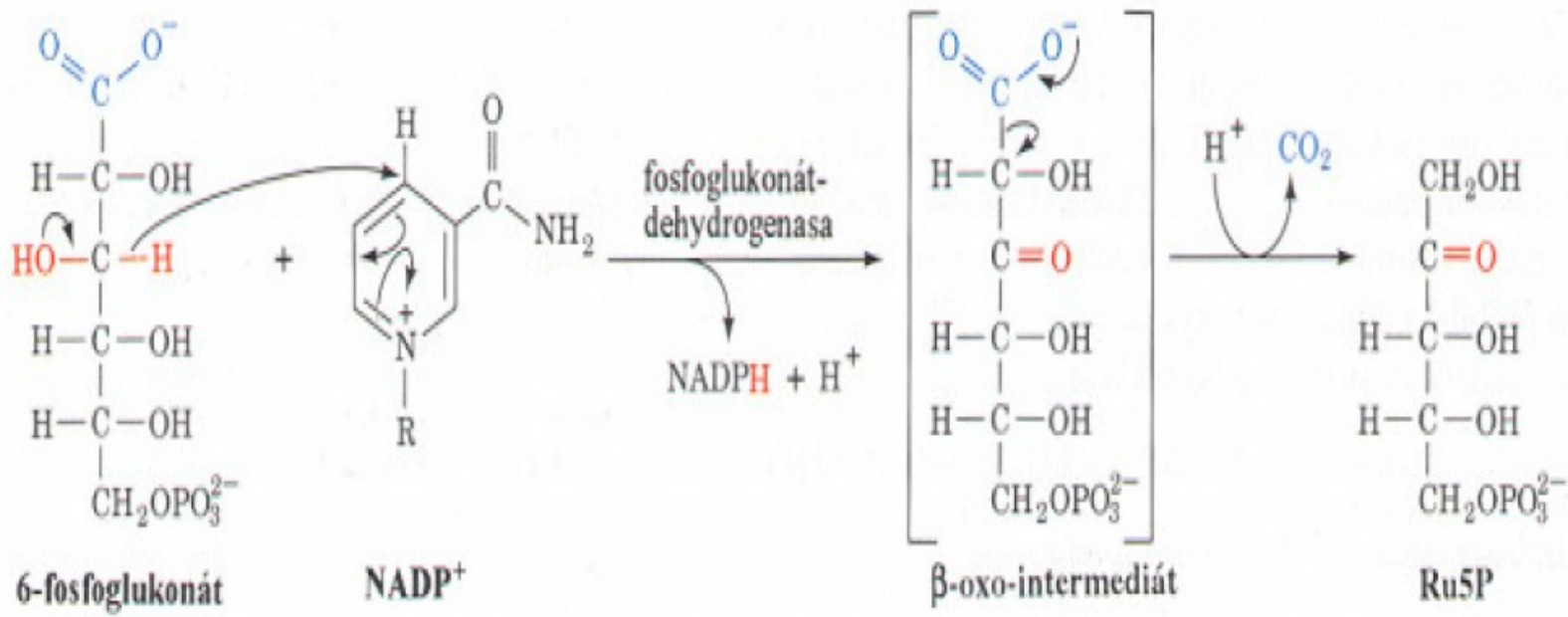
- Heterotrofy – pentozový cyklus
- Autotrofy - fotosyntéza

Pentosový cyklus

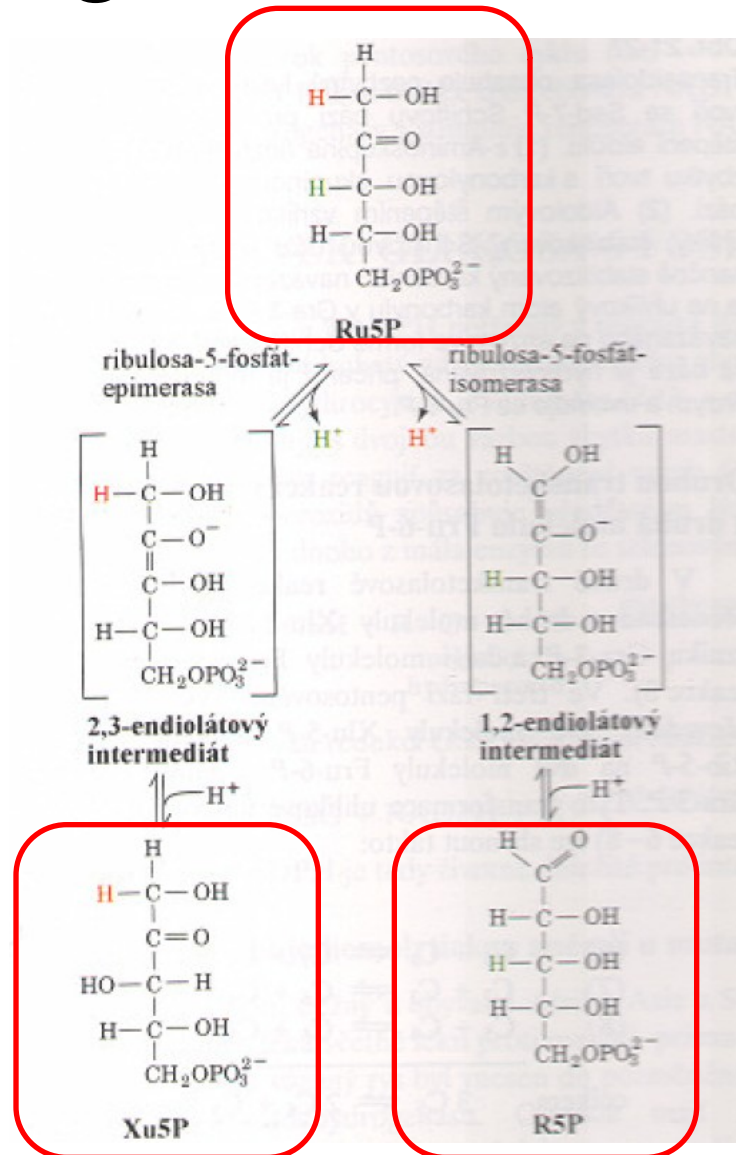


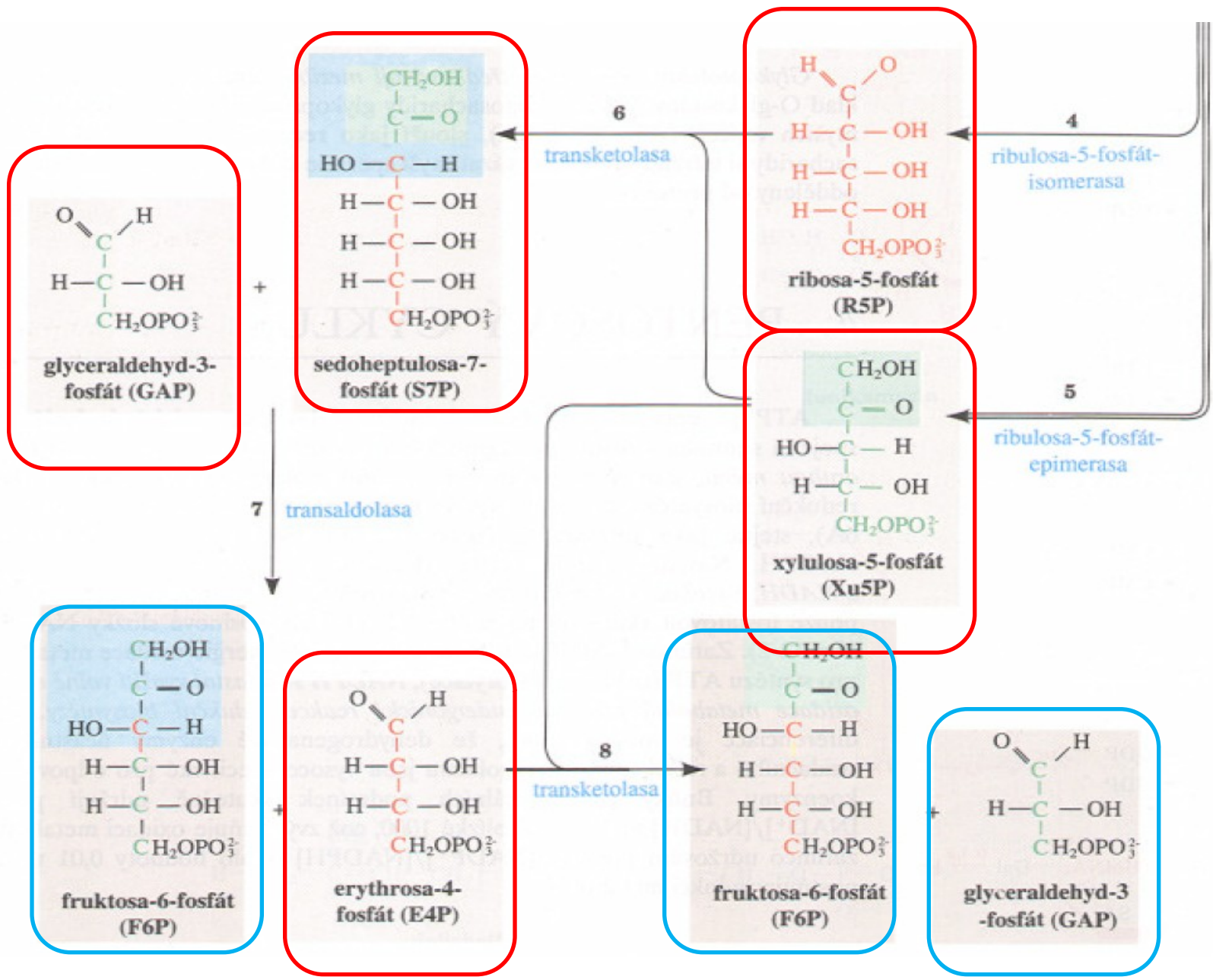


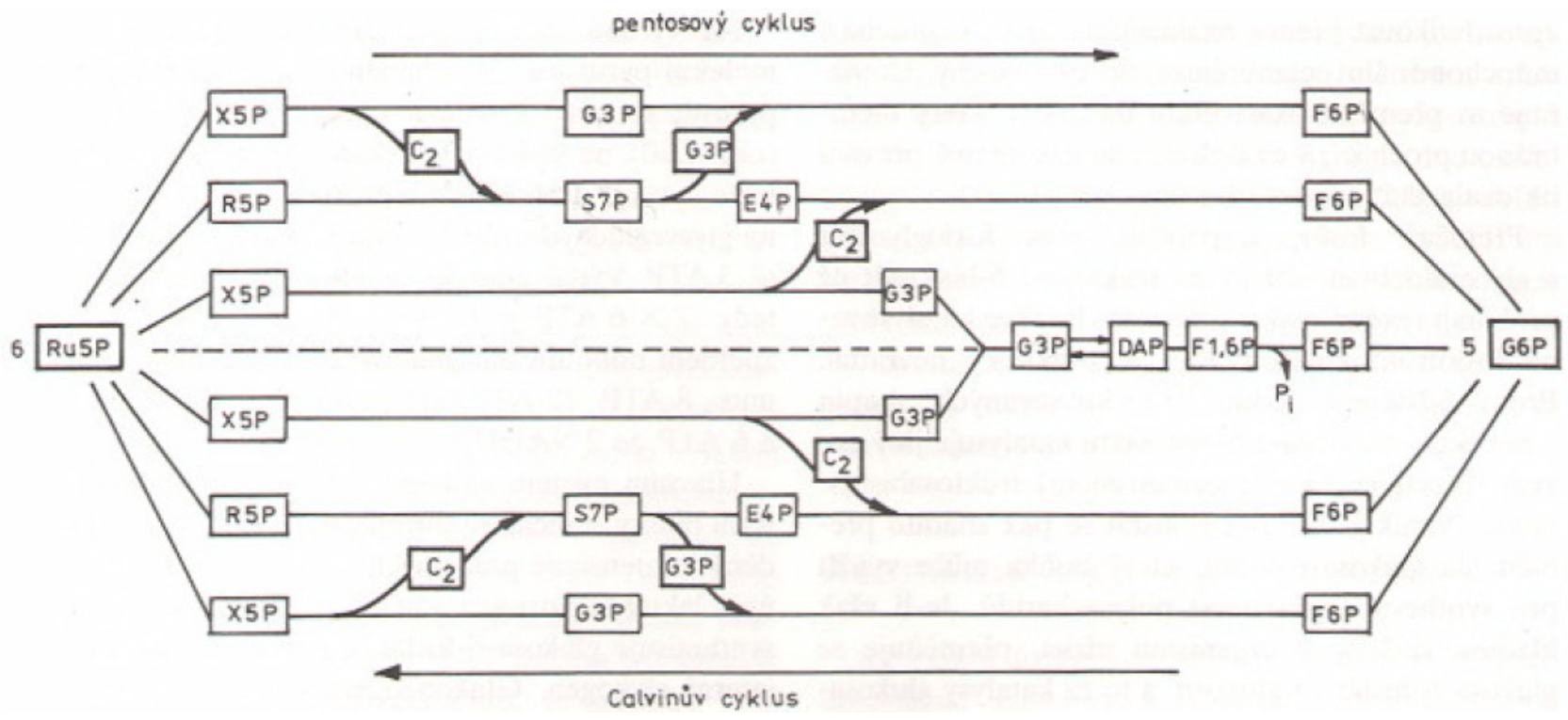


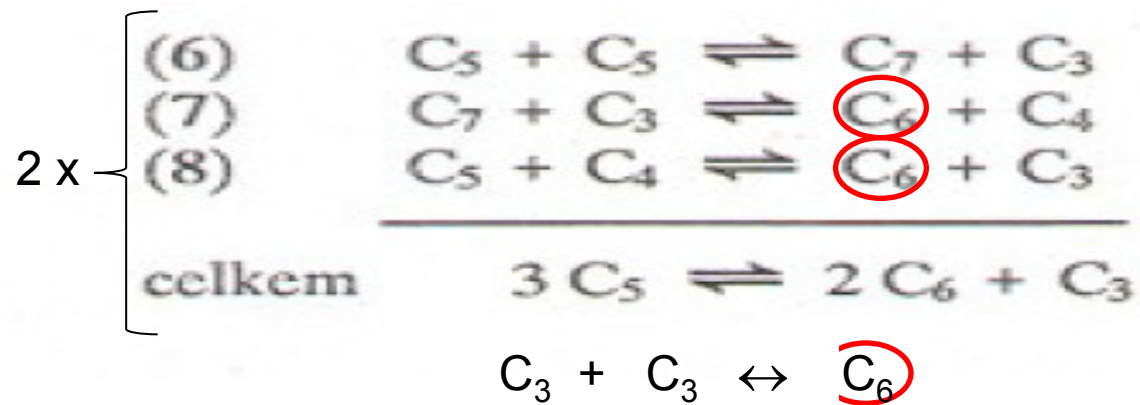


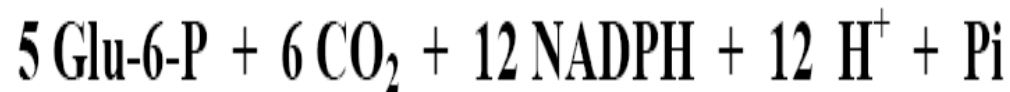
Regenerační fáze







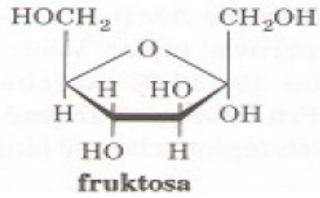




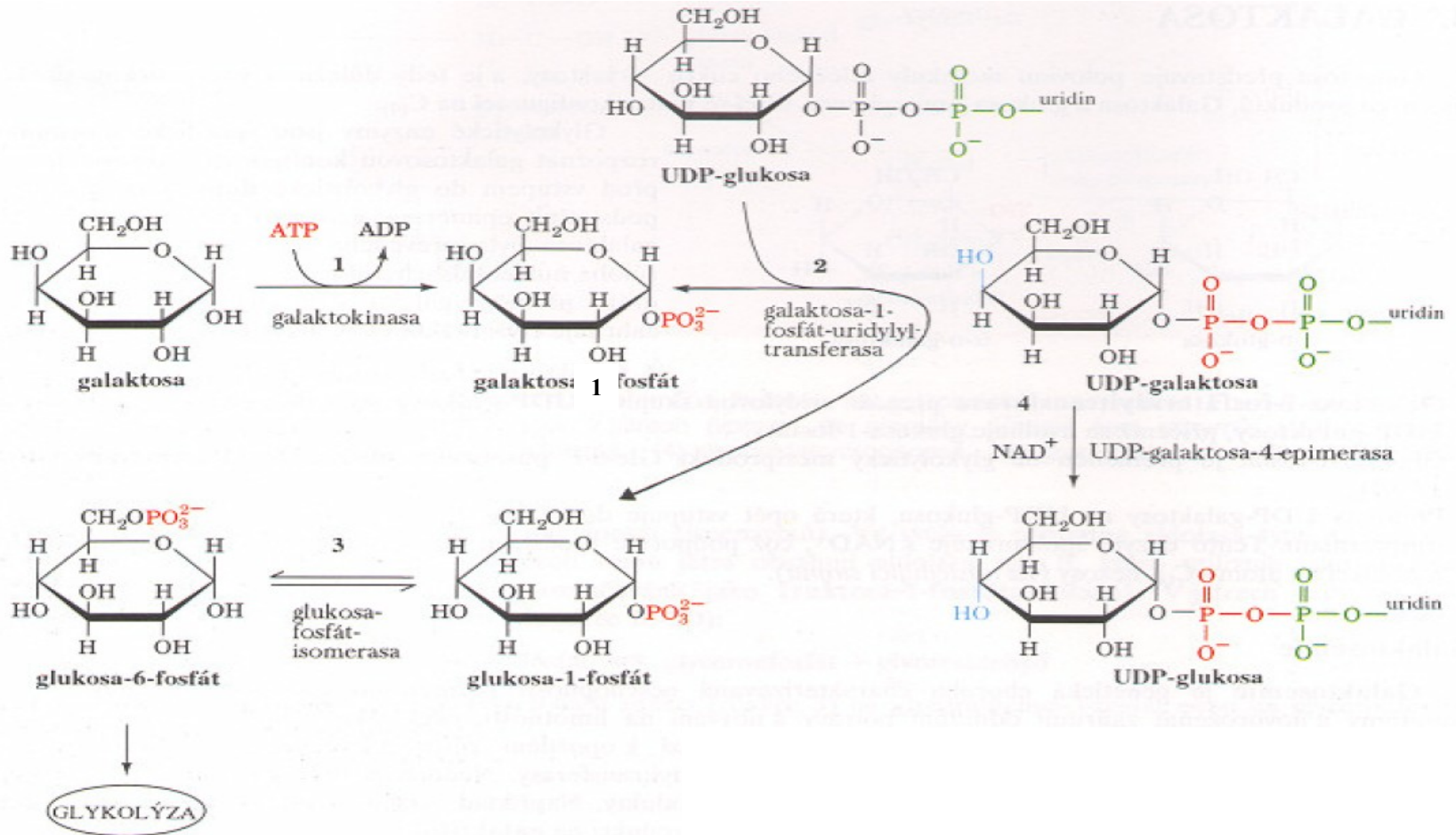
glykolýza	-	36 ATP
pentosový cyklus	-	36 ATP

CYT

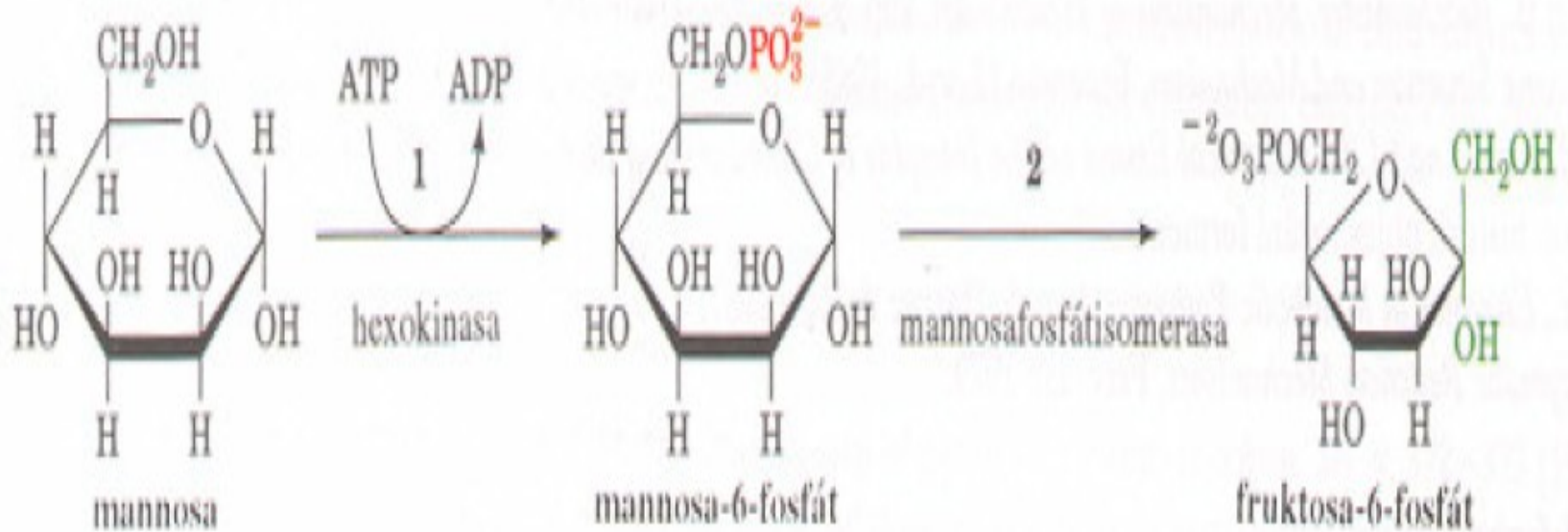
Fruktosa



Galaktosa

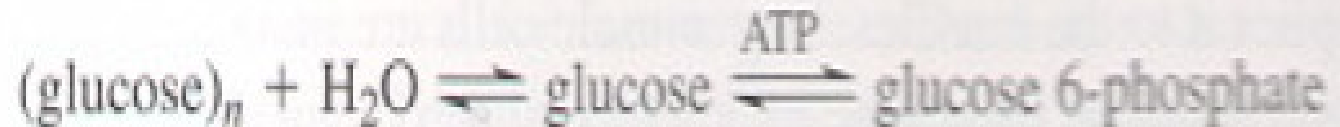


Manosa



Glykogen

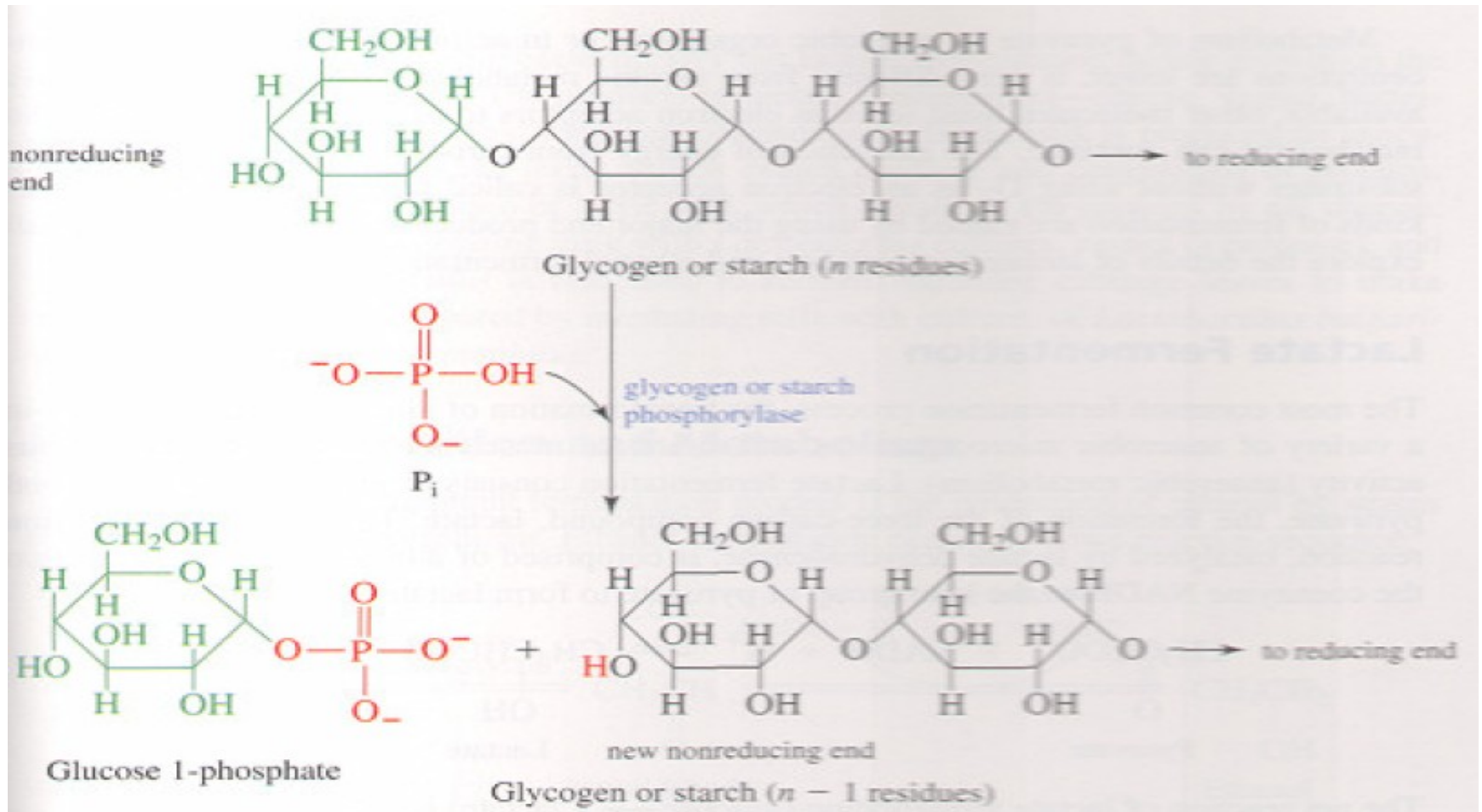
Hydrolytic cleavage catalyzed by amylase:

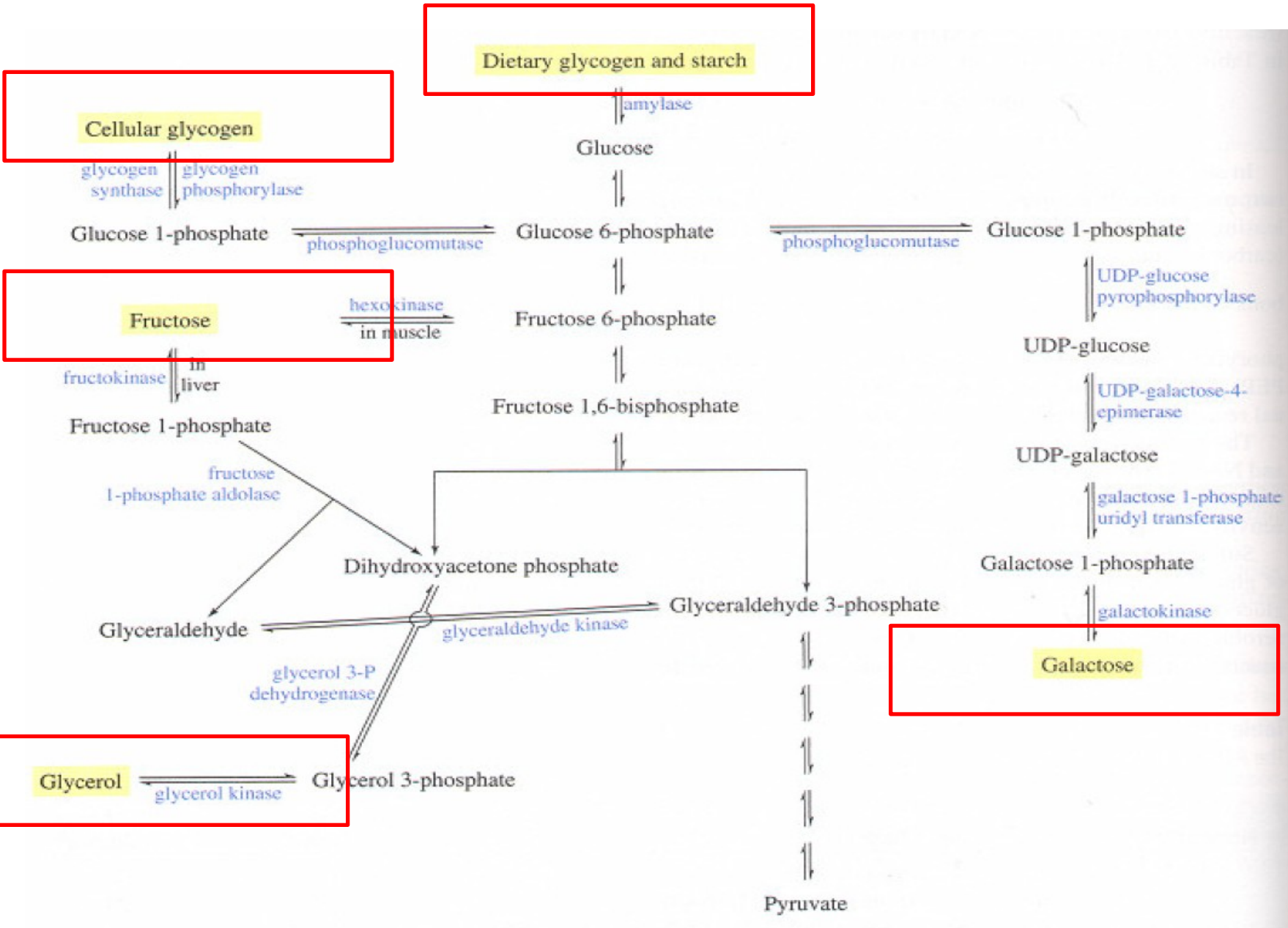


Phosphorolytic cleavage catalyzed by phosphorylase:



Glykogen



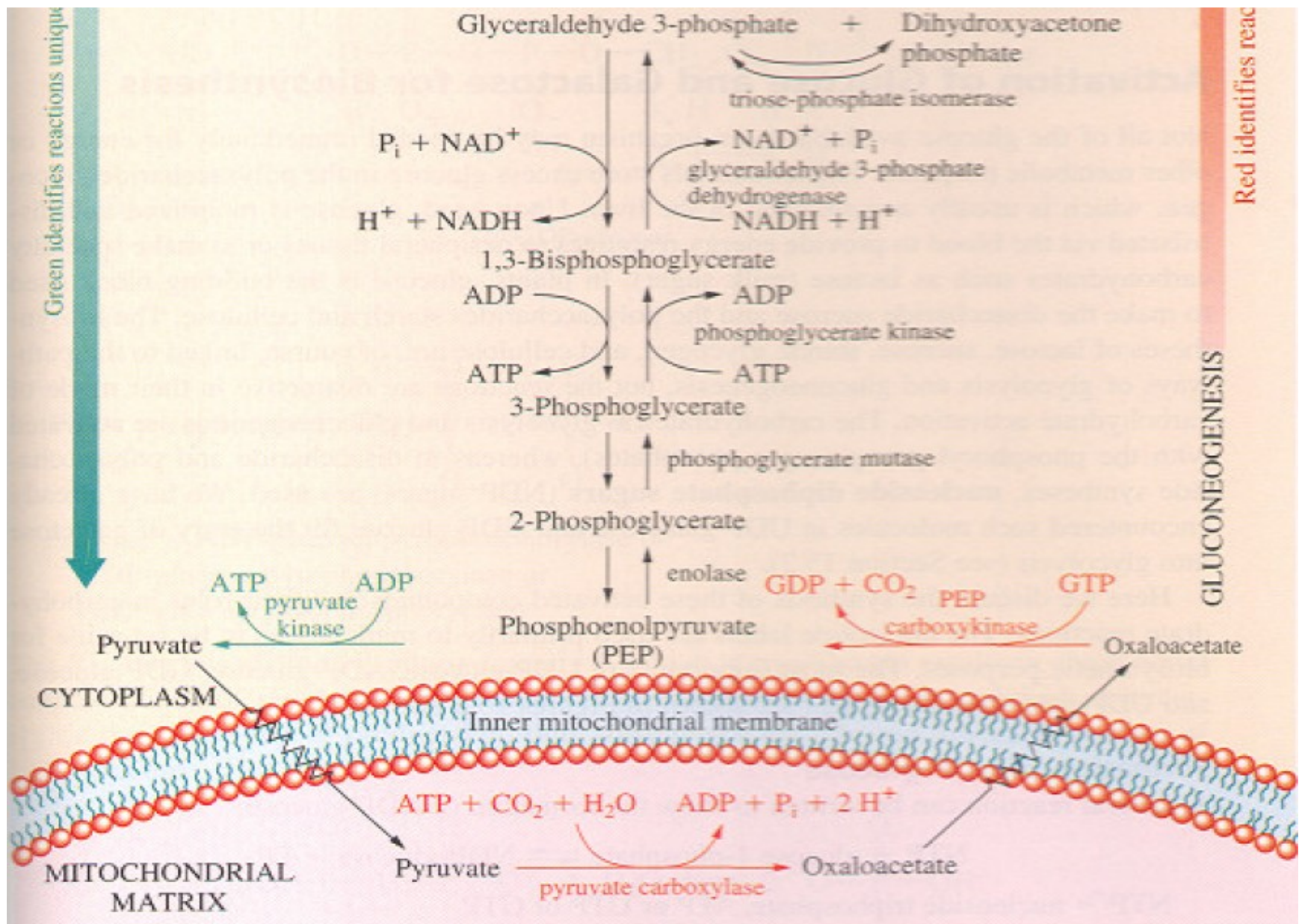


BIOSYNTÉZA SACHARIDŮ

- Glukoneogenese
- Fotosyntéza

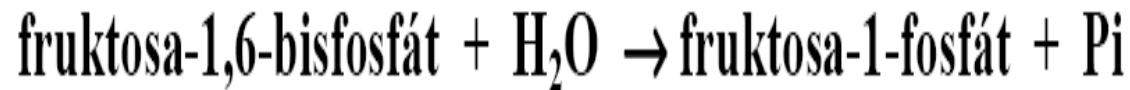
Glukoneogenese

1. Vznik fosfoenolpyruvátu



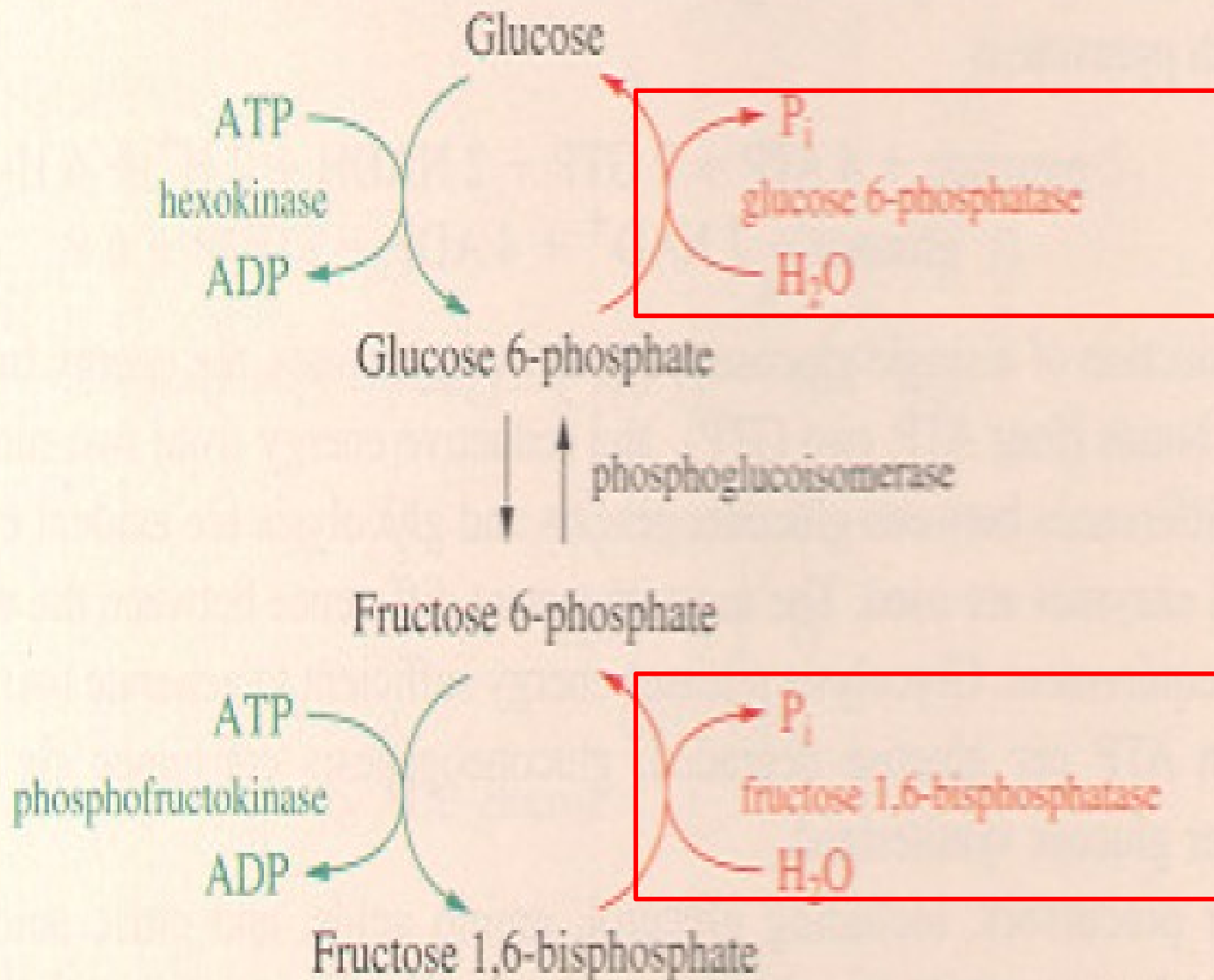
2. *Hydrolytické reakce*

A. fruktosabisfosfatasa

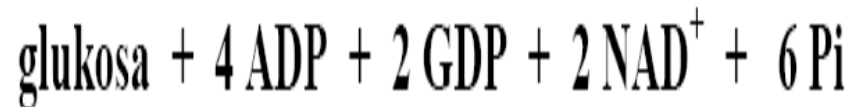
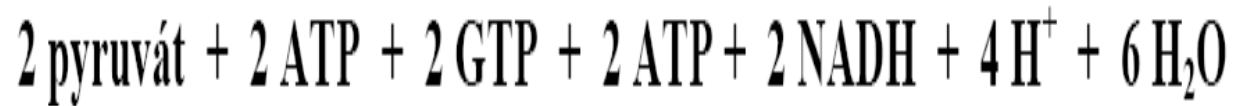


B. glukosafosfatasa



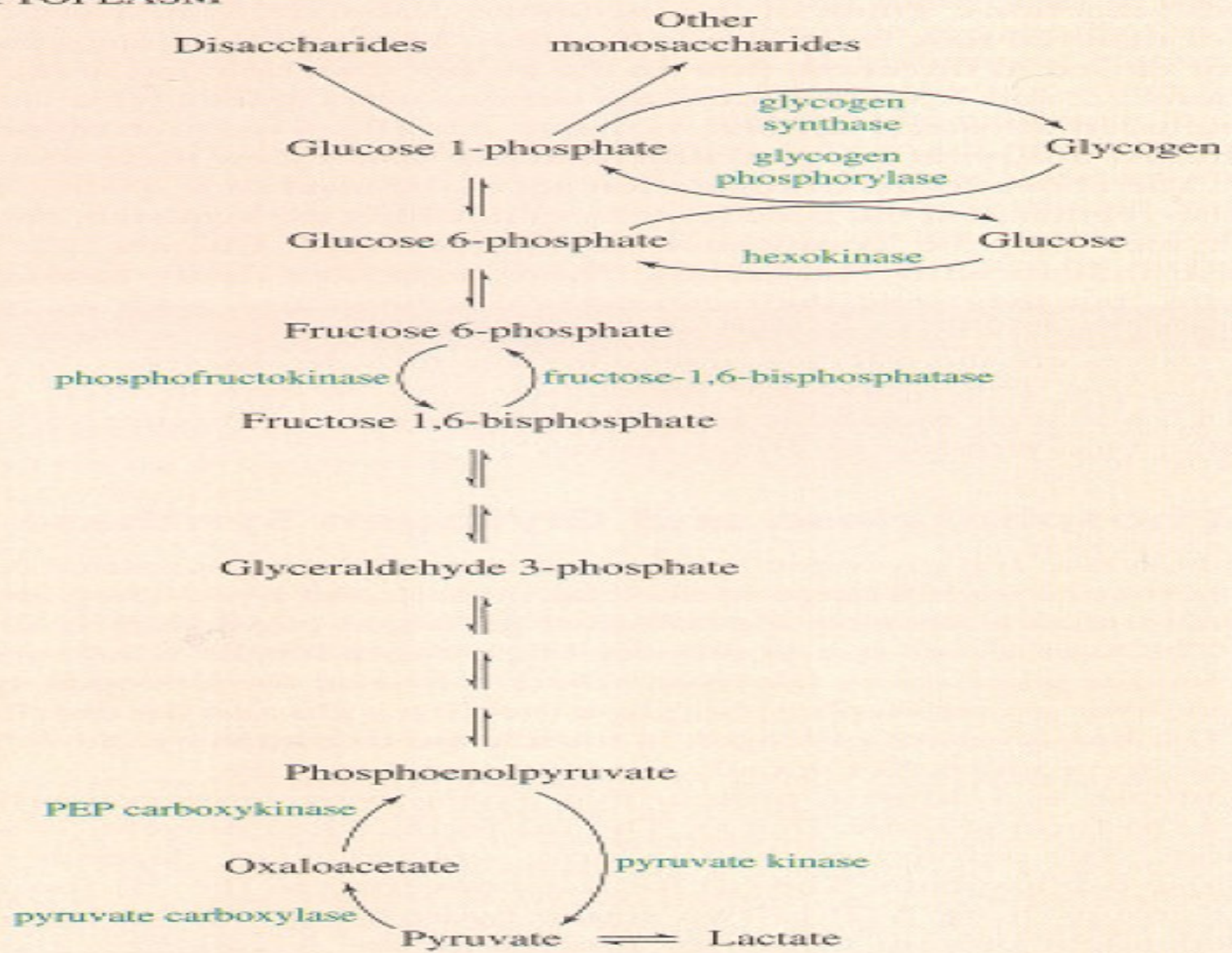


Bilance glukoneogenese



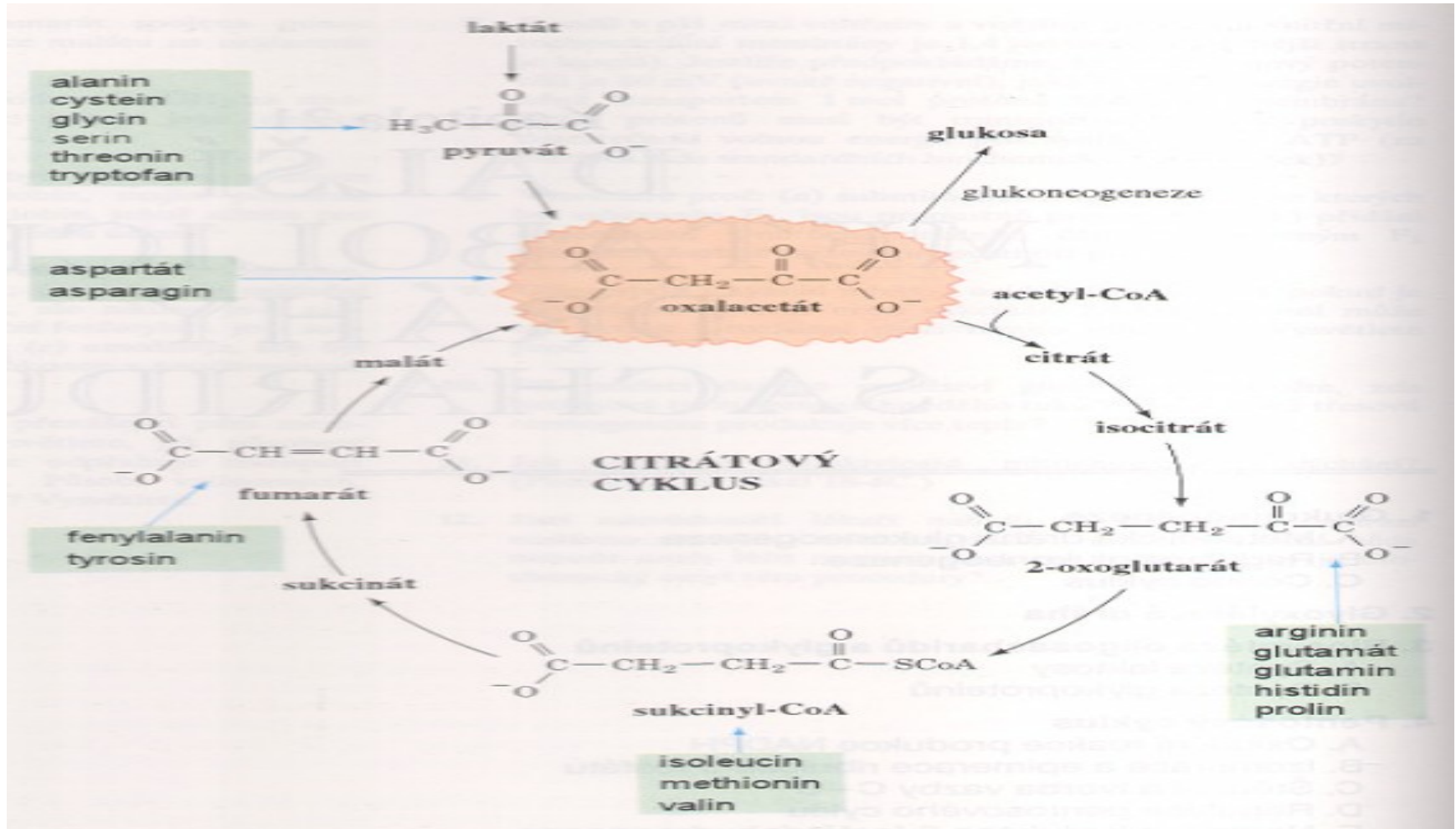
$$\text{glykolysa (8 ATP) - glukoneogenese (12 ATP) = -4 ATP}$$

CYTOPLASM



Biosyntéza glukosy z dalších prekurzorů

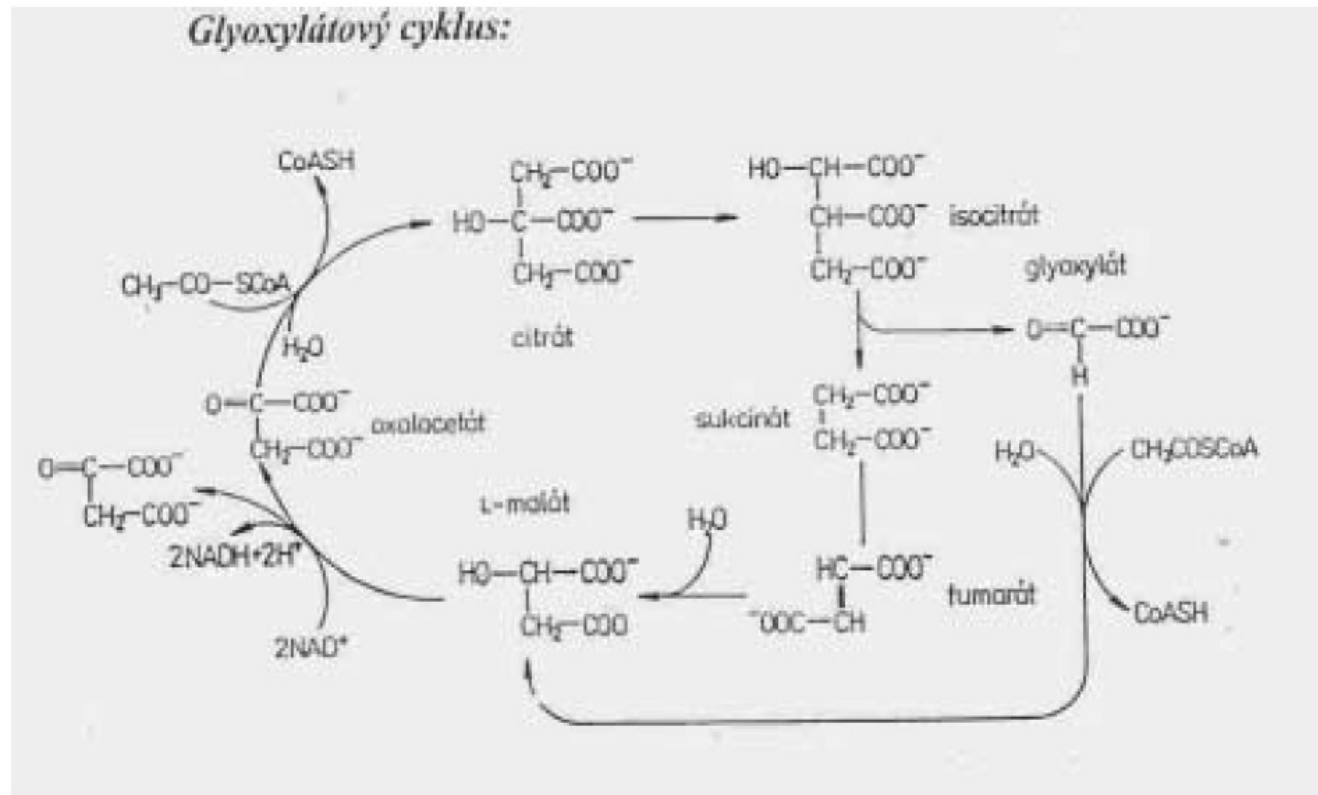
- glukogenní aminokyseliny - pyruvát a meziprodukty citrátového cyklu



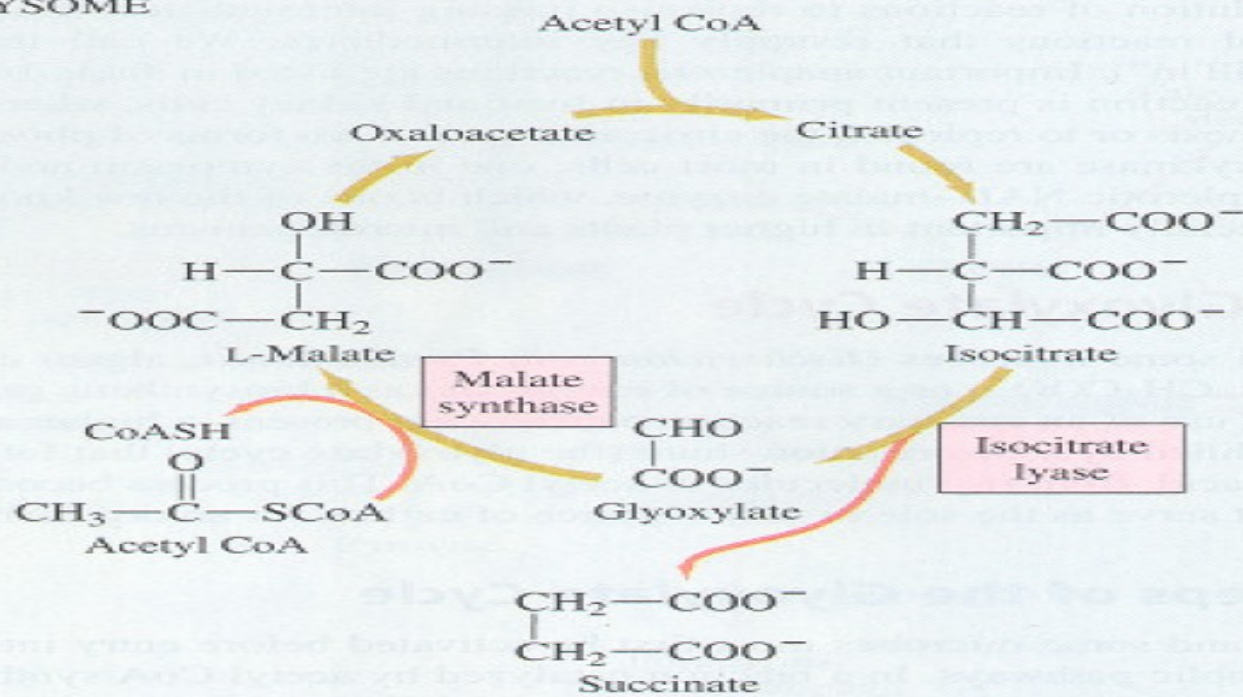
Biosyntéza glukosy z dalších prekurzorů

- lipidy - glycerol a acetylCoA

Glyoxylátový cyklus:



GLYOXYYSOME



MITOCHONDRIA

Succinate → Fumarate → L-Malate

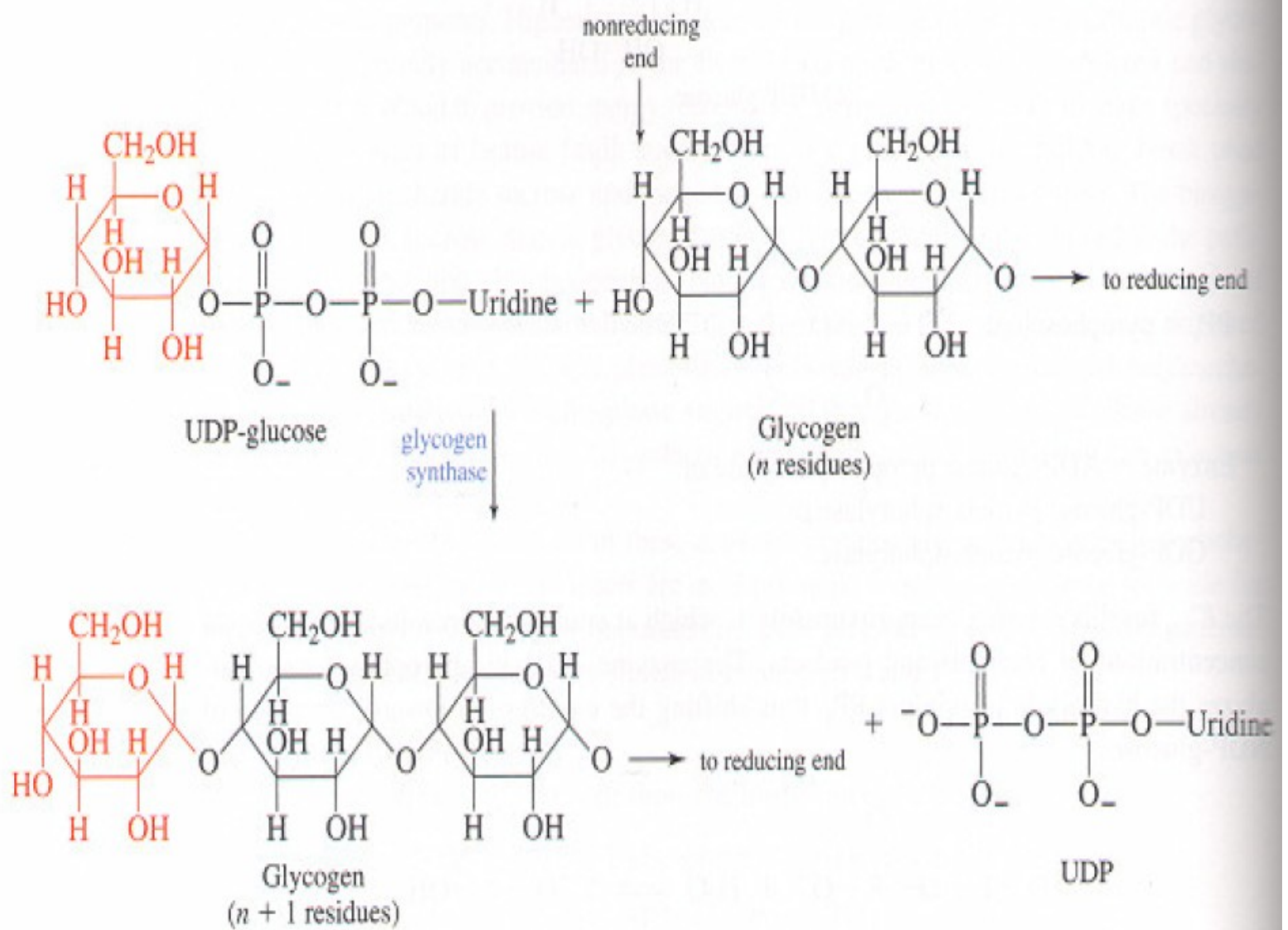
CYTOPLASM

Phosphoenolpyruvate ← Oxaloacetate ← L-Malate

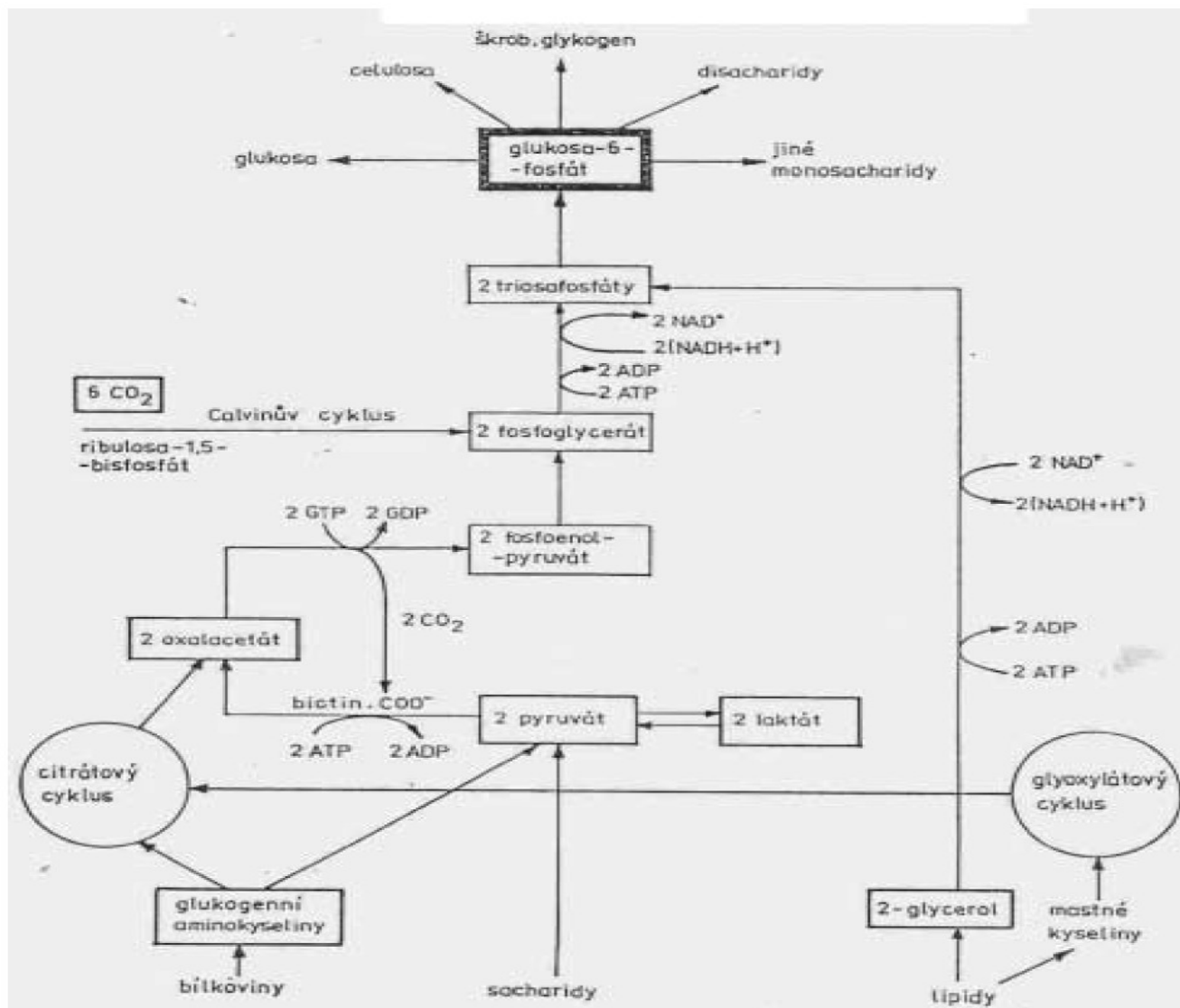
(Gluconeogenesis)

Glucose

Biosyntéza oligo- a polysacharidů



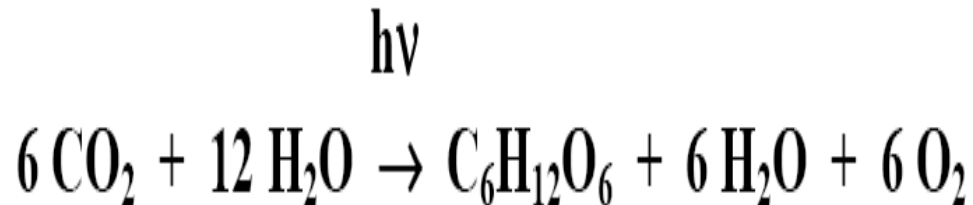
BIOSYNTÉZA SACHARIDŮ



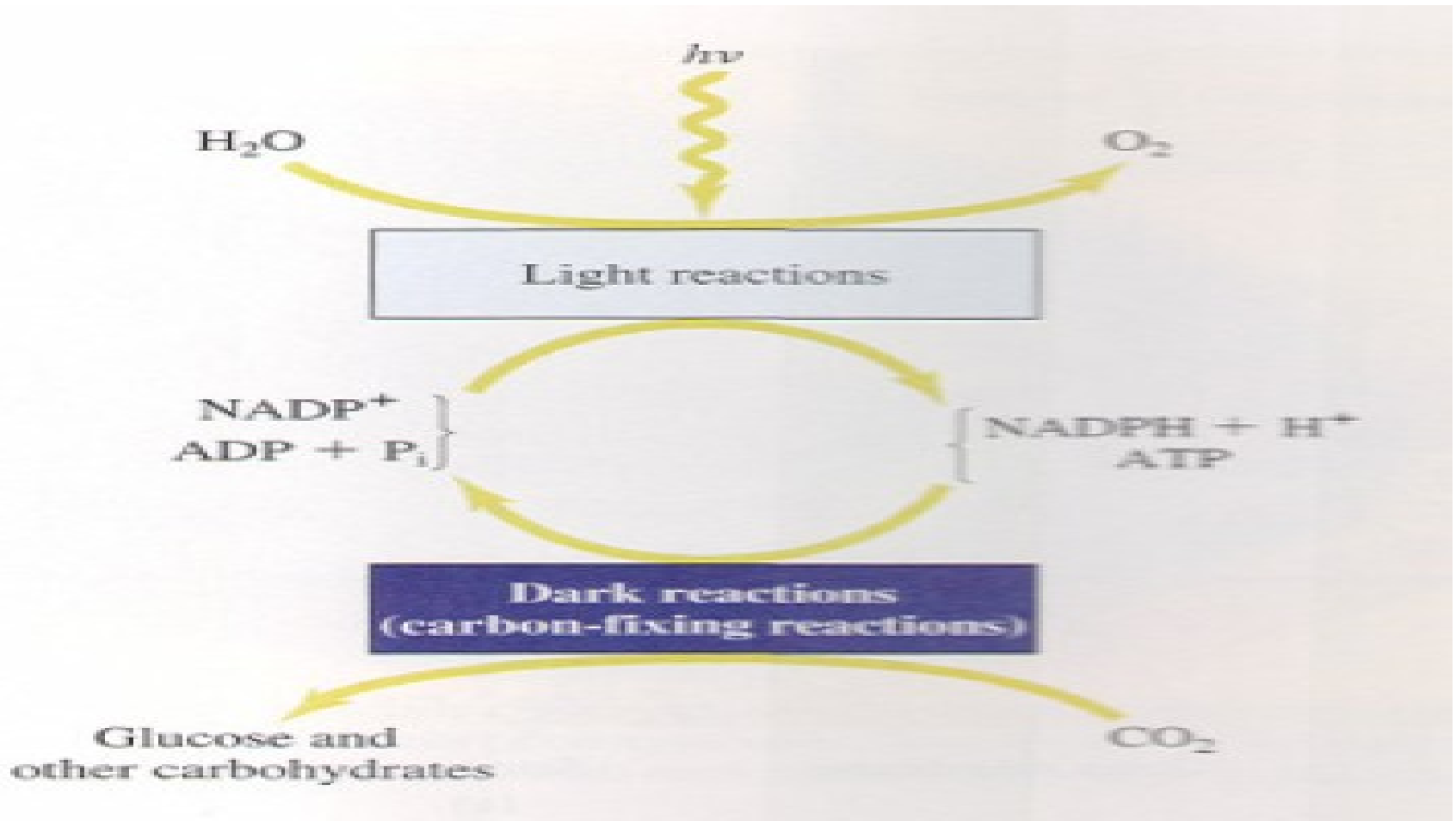
FOTOSYNTÉZA

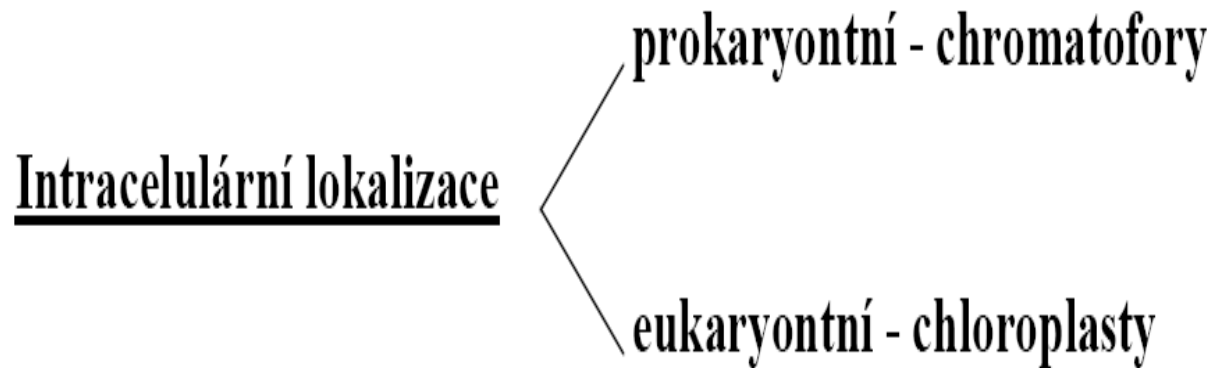
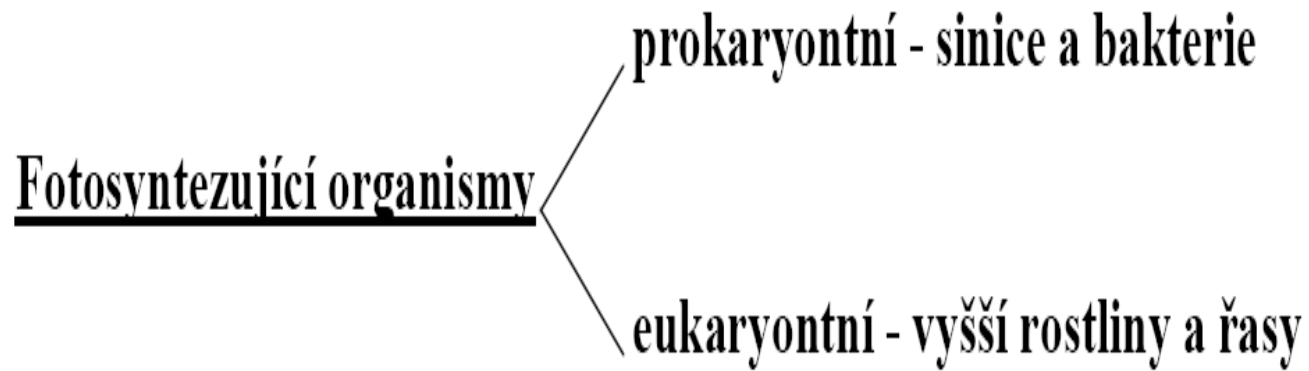
Význam :

- zachycení sluneční energie a syntéza glukosy z CO_2 a H_2O
- produkce O_2

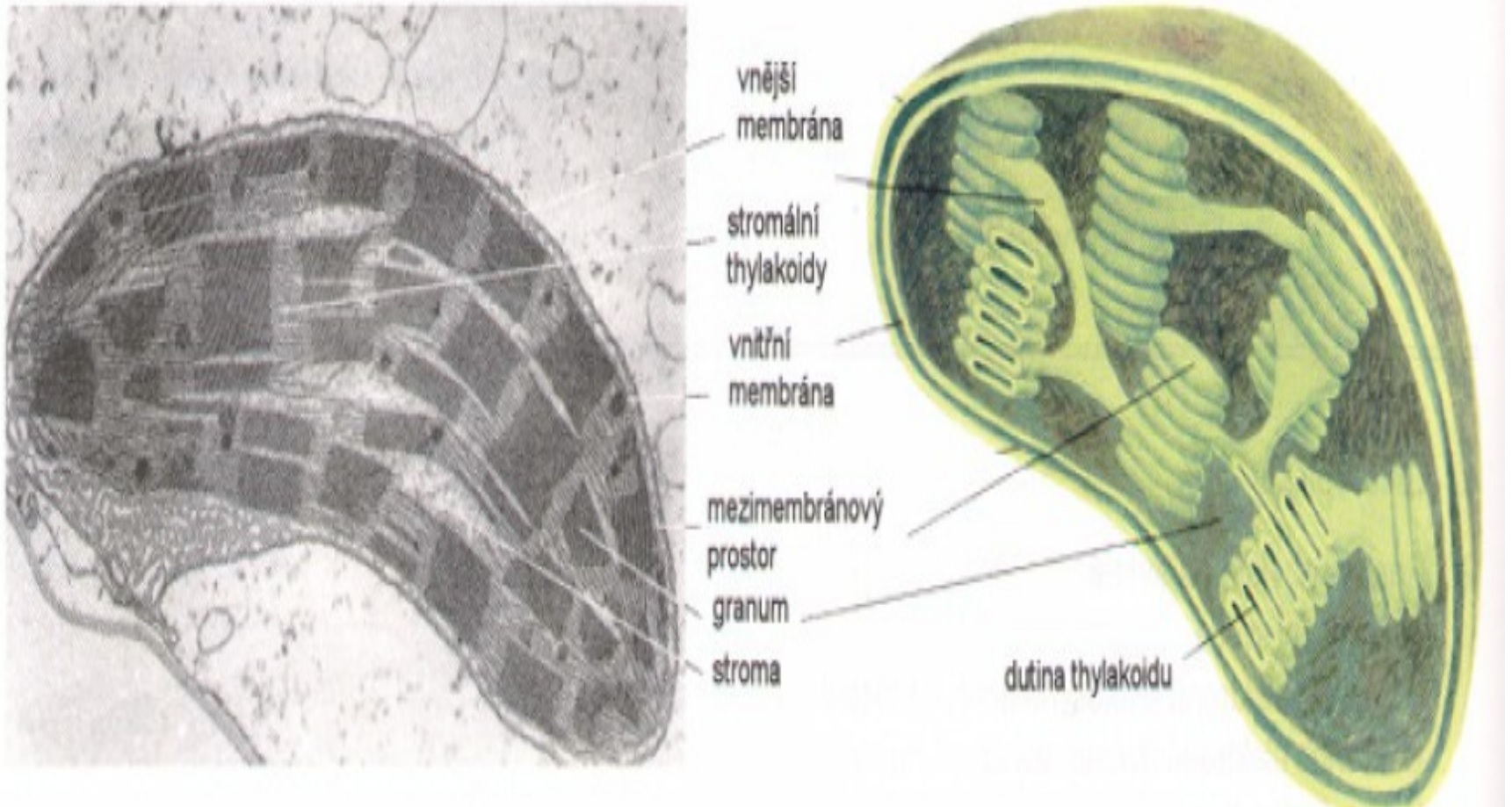


Světelná a temná fáze

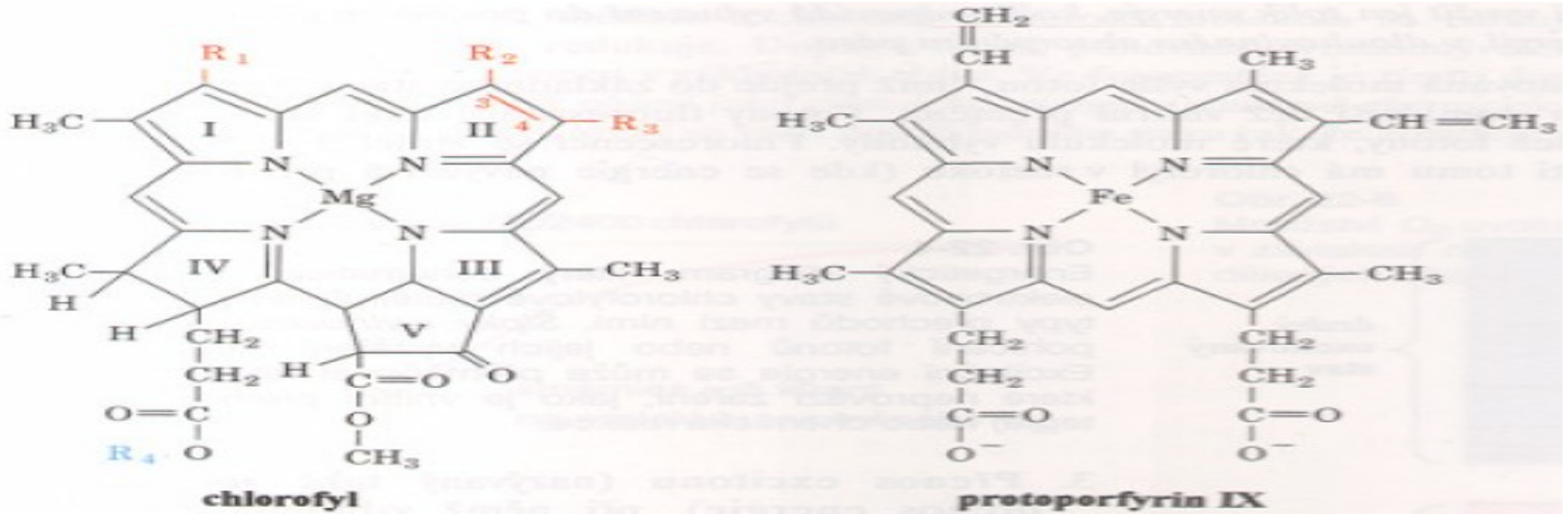




Chloroplast



Chlorofyly



	R_1	R_2	R_3	R_4
chlorofyl a	$-\text{CH}=\text{CH}_2$	$-\text{CH}_3$	$-\text{CH}_2-\text{CH}_3$	P
chlorofyl b	$-\text{CH}=\text{CH}_2$	$-\text{C}(=\text{O})-\text{H}$	$-\text{CH}_2-\text{CH}_3$	P
bakteriochlorofyl a	$-\text{C}(=\text{O})-\text{CH}_3$	$-\text{CH}_3^a$	$-\text{CH}_2-\text{CH}_3^a$	P or G
bakteriochlorofyl b	$-\text{C}(=\text{O})-\text{CH}_3$	$-\text{CH}_3^a$	$=\text{CH}-\text{CH}_3^a$	P

^a bez dvojn e vazby mezi polohami $C_{(3)}$ a $C_{(4)}$



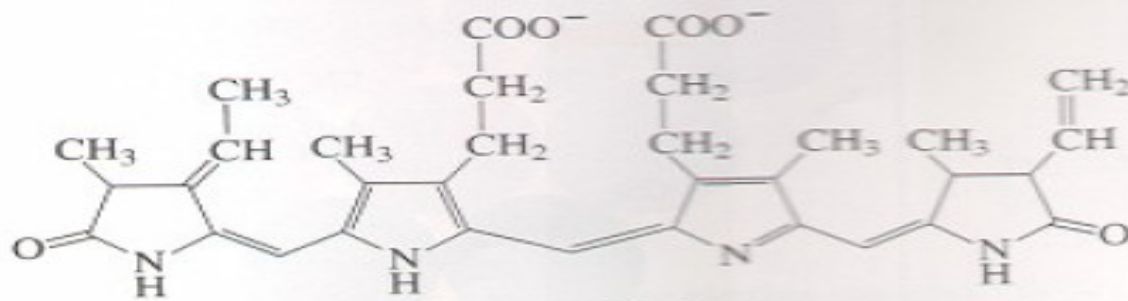
Pomocná barviva



(a) β -Carotene

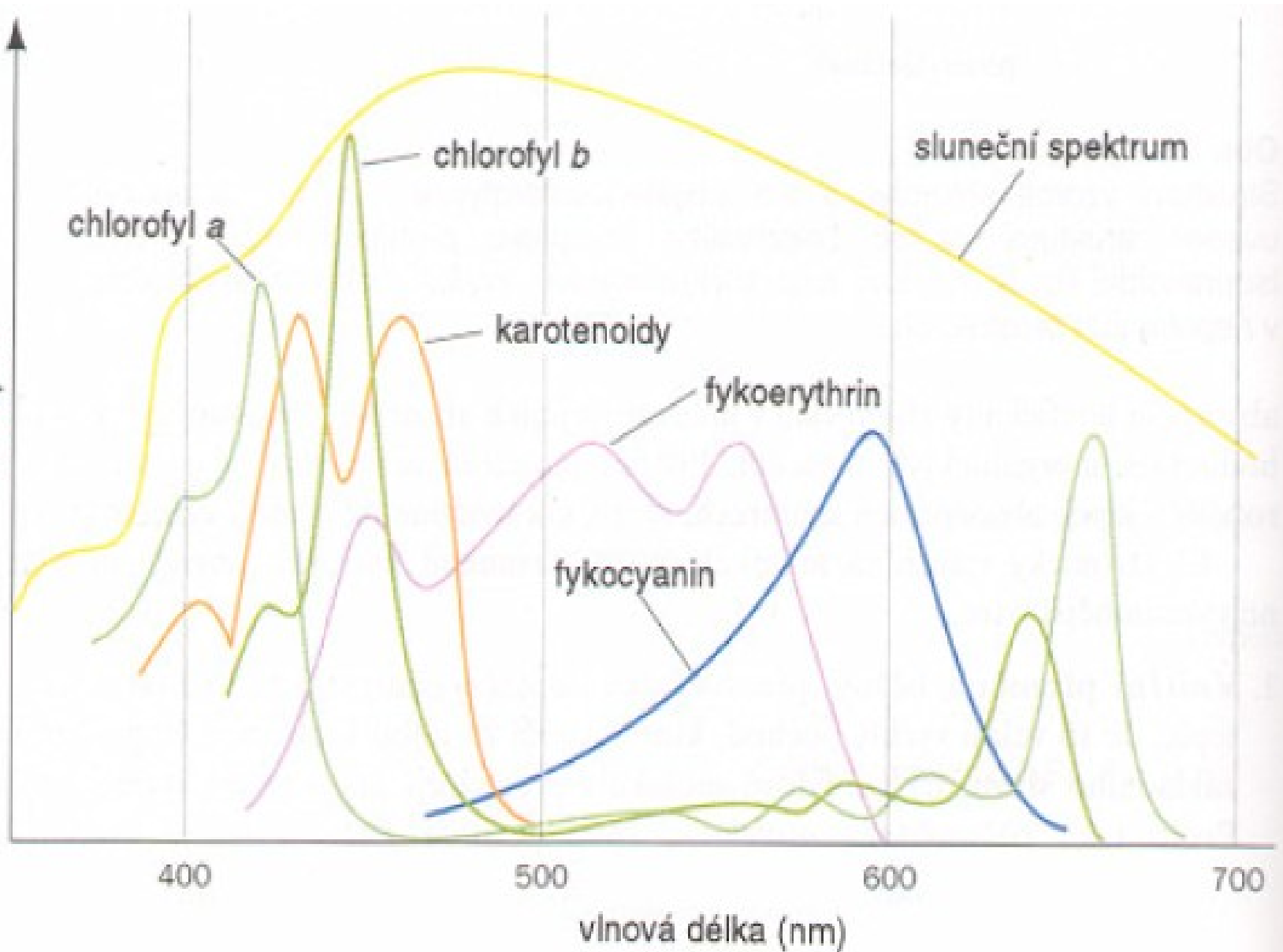


(b) Lutein



(c) Phycoerythrobilin

absorpce



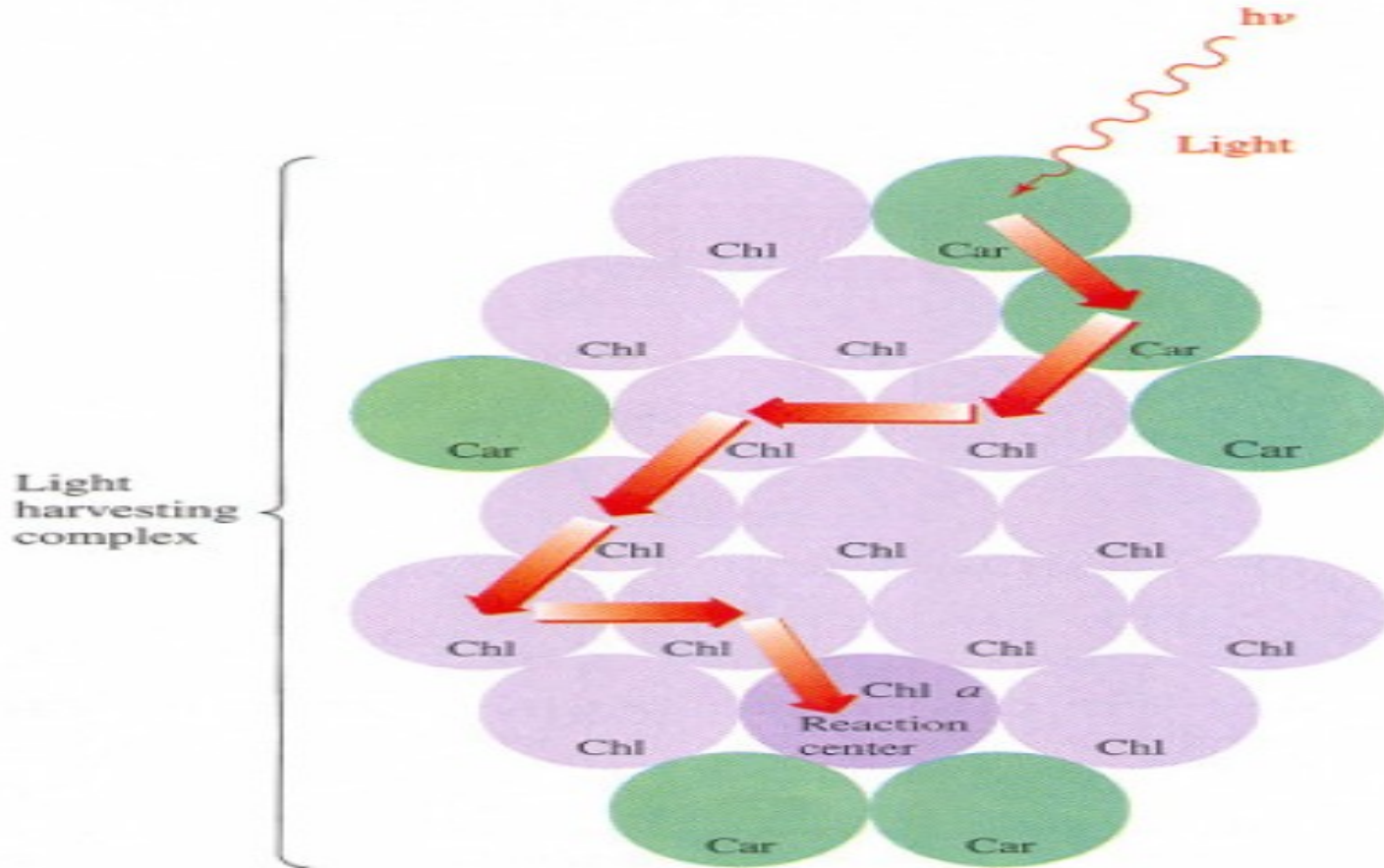
Světelná fáze

- proces zachycení záření
- cyklický tok elektronů - cyklická fotofosforylace → ATP
- necyklický tok elektronů - necyklická fotofosforylace → ATP,

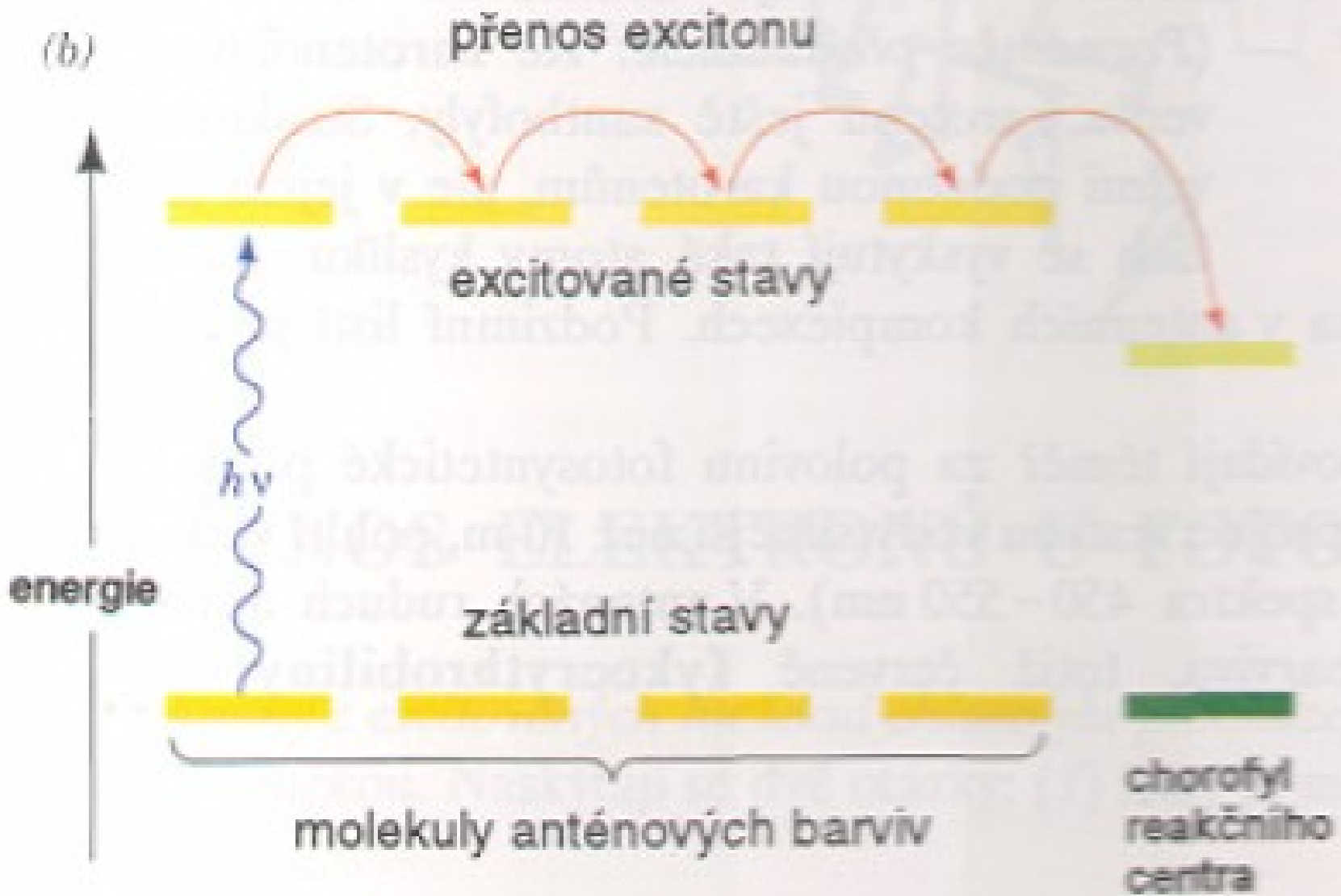
NADP

- fotolýza vody - $\text{H}_2\text{O} \rightarrow 2 \text{H}^+ + 2 \text{e}^- + \frac{1}{2} \text{O}_2$
- spřažení transportu elektronů se syntézou ATP

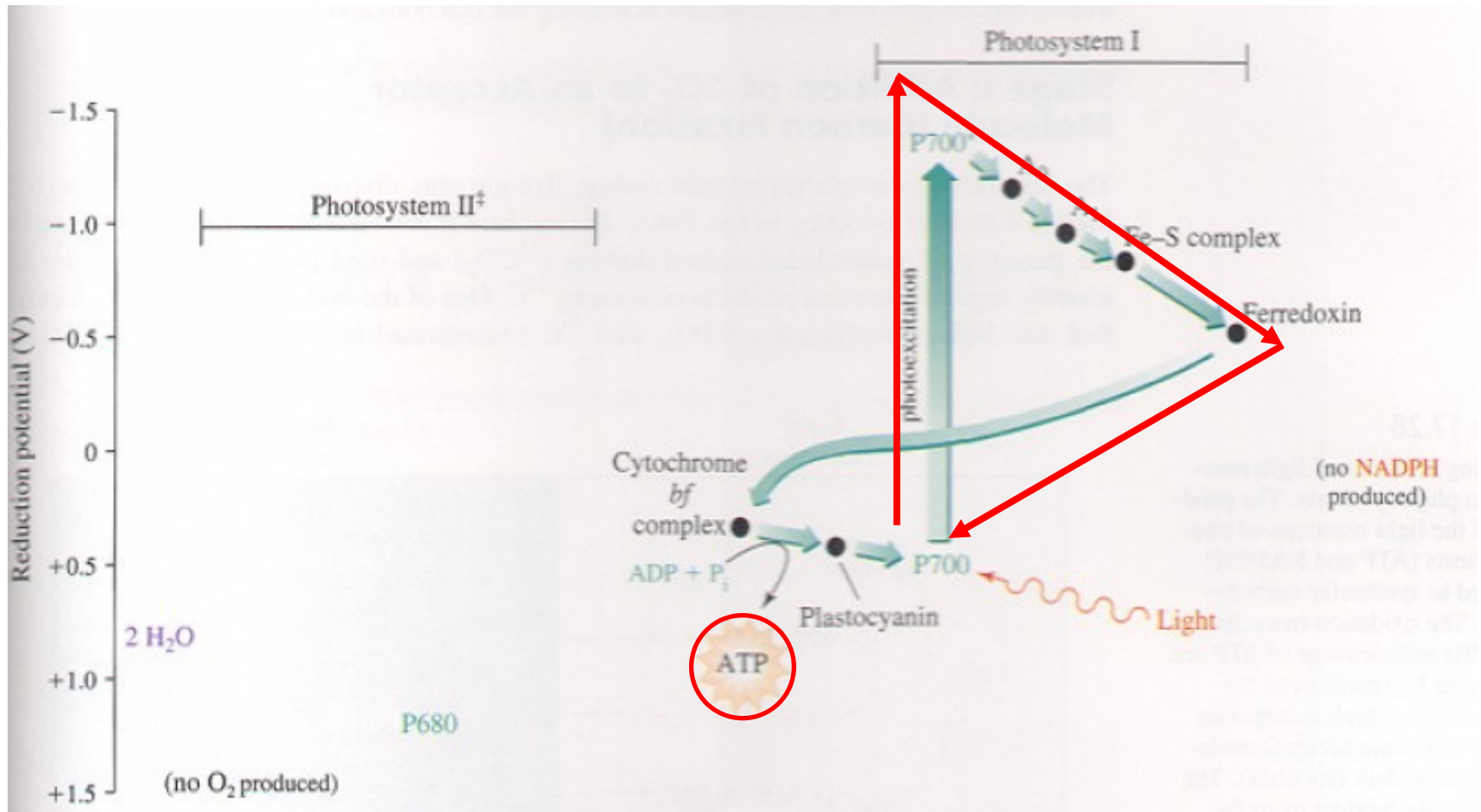
Proces zachycení záření kvantosomy



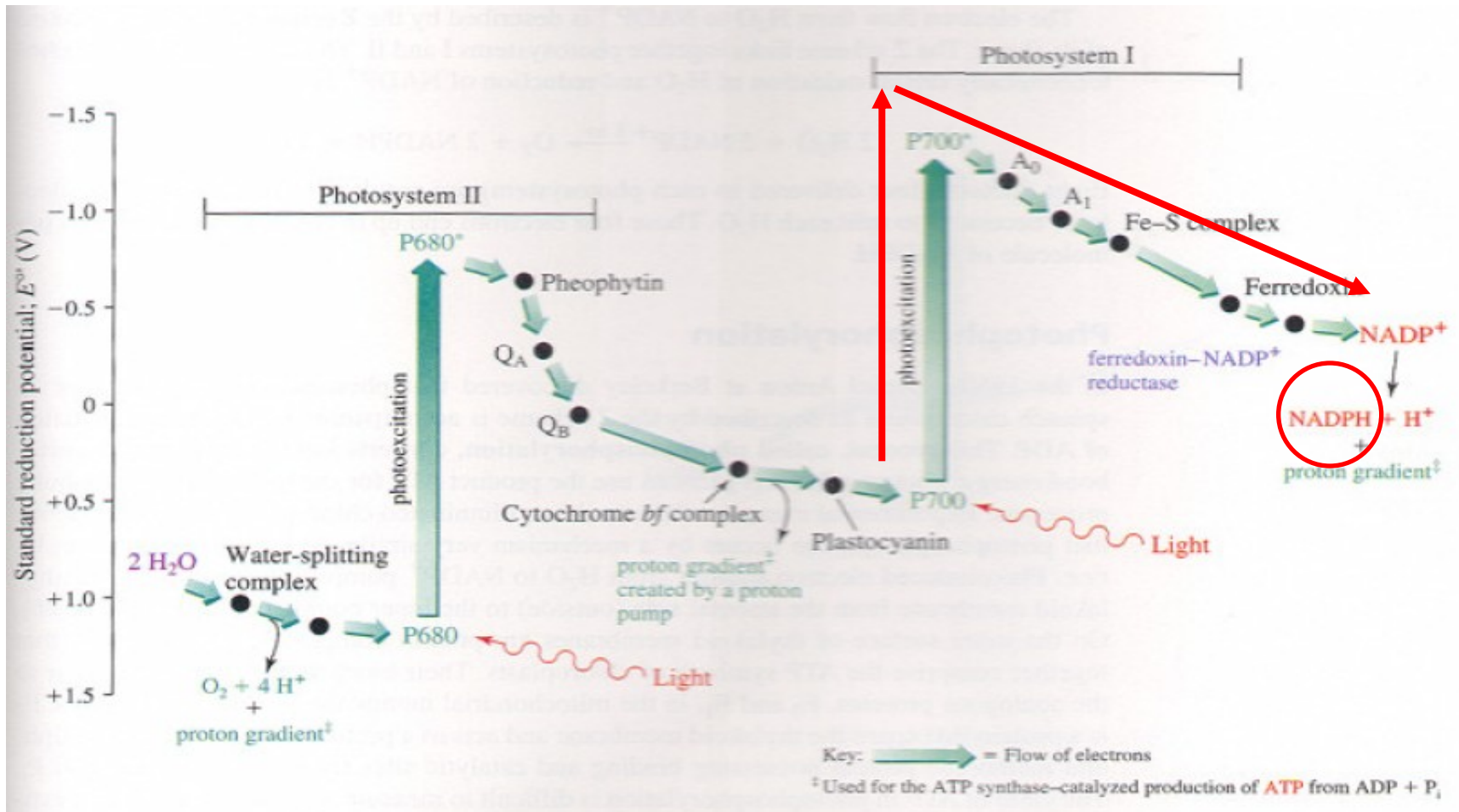
(b)



Cyklický tok- produkce ATP



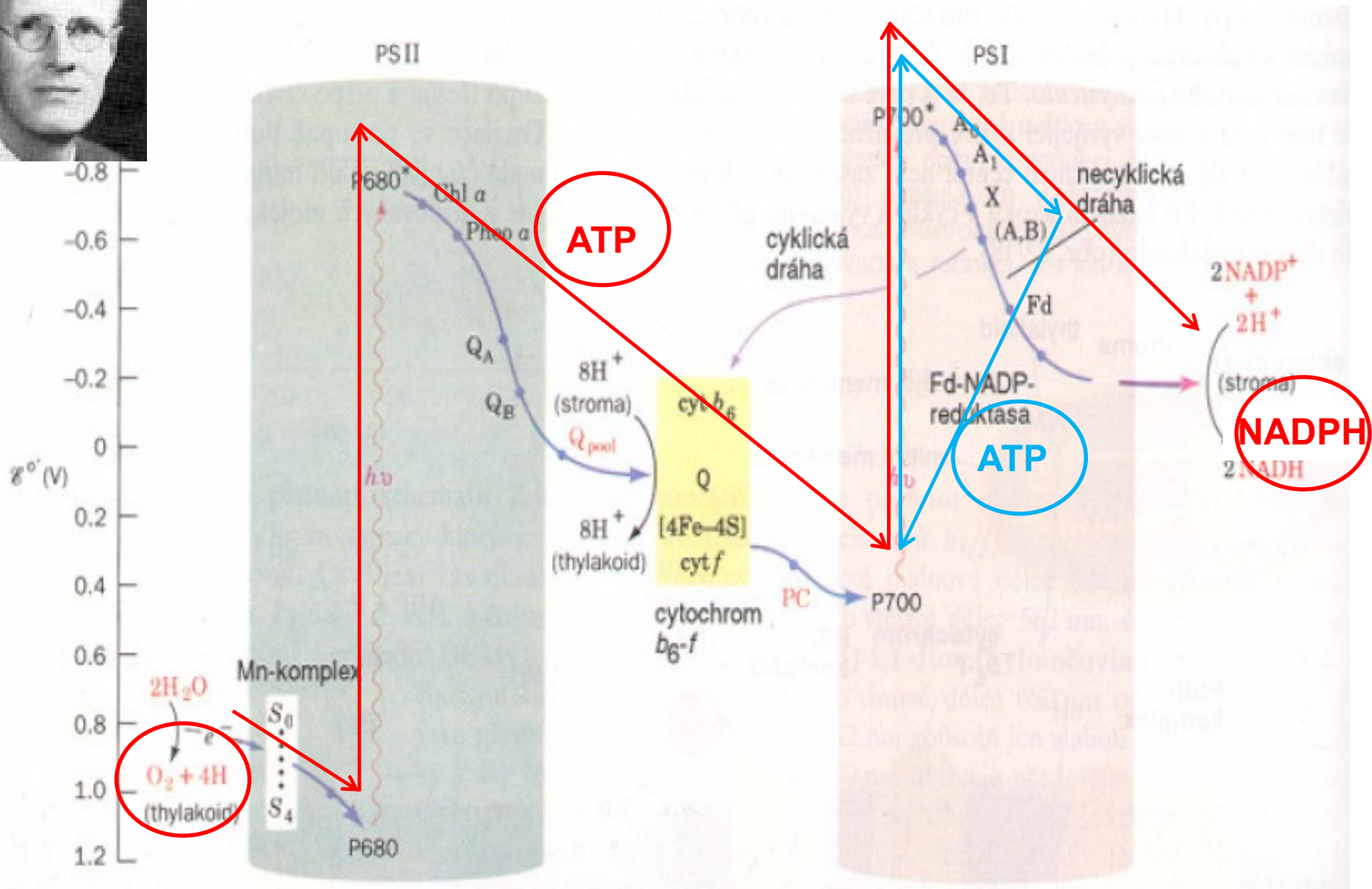
Necyklický tok- produkce NADPH



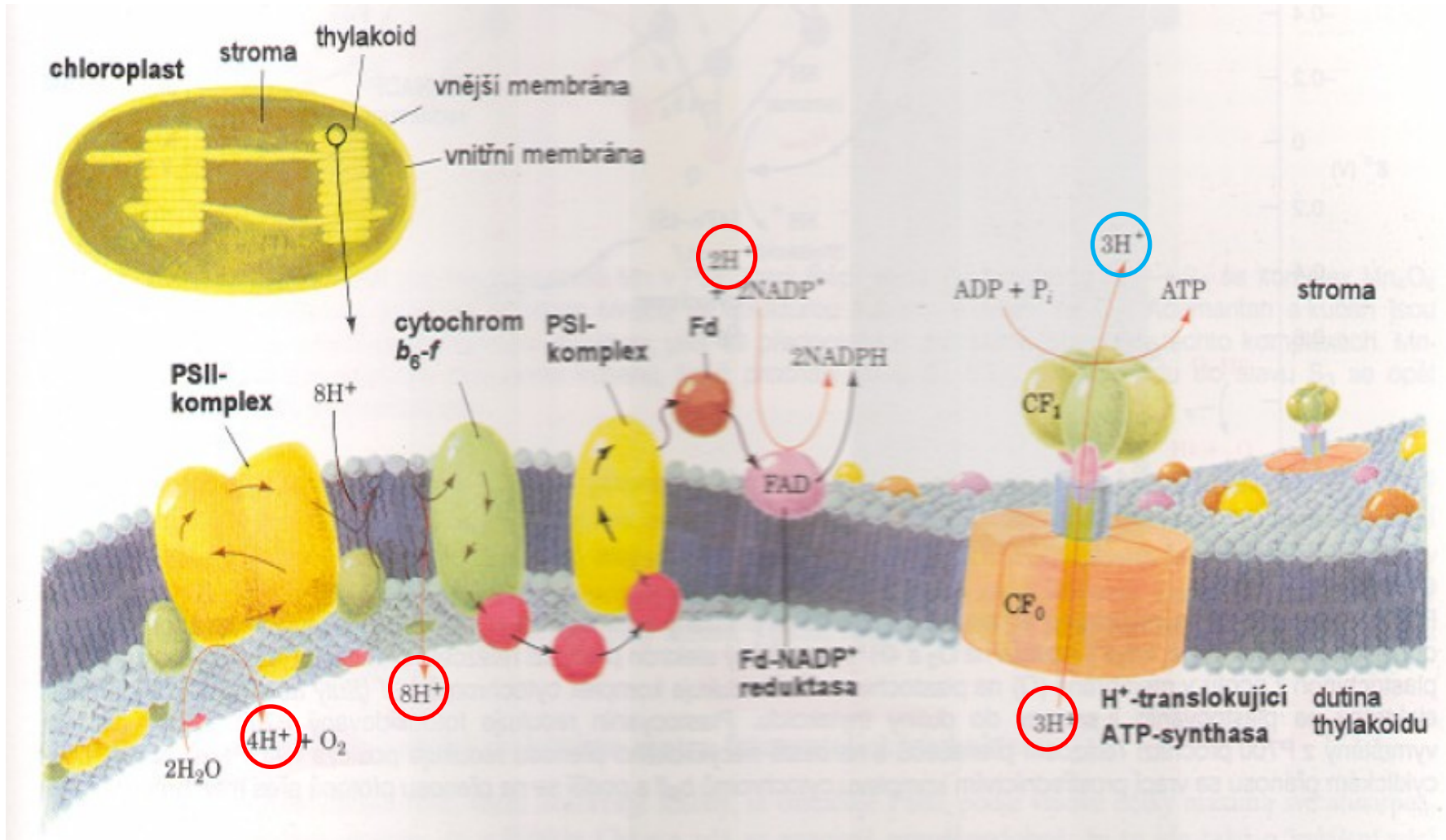


R.Emerson

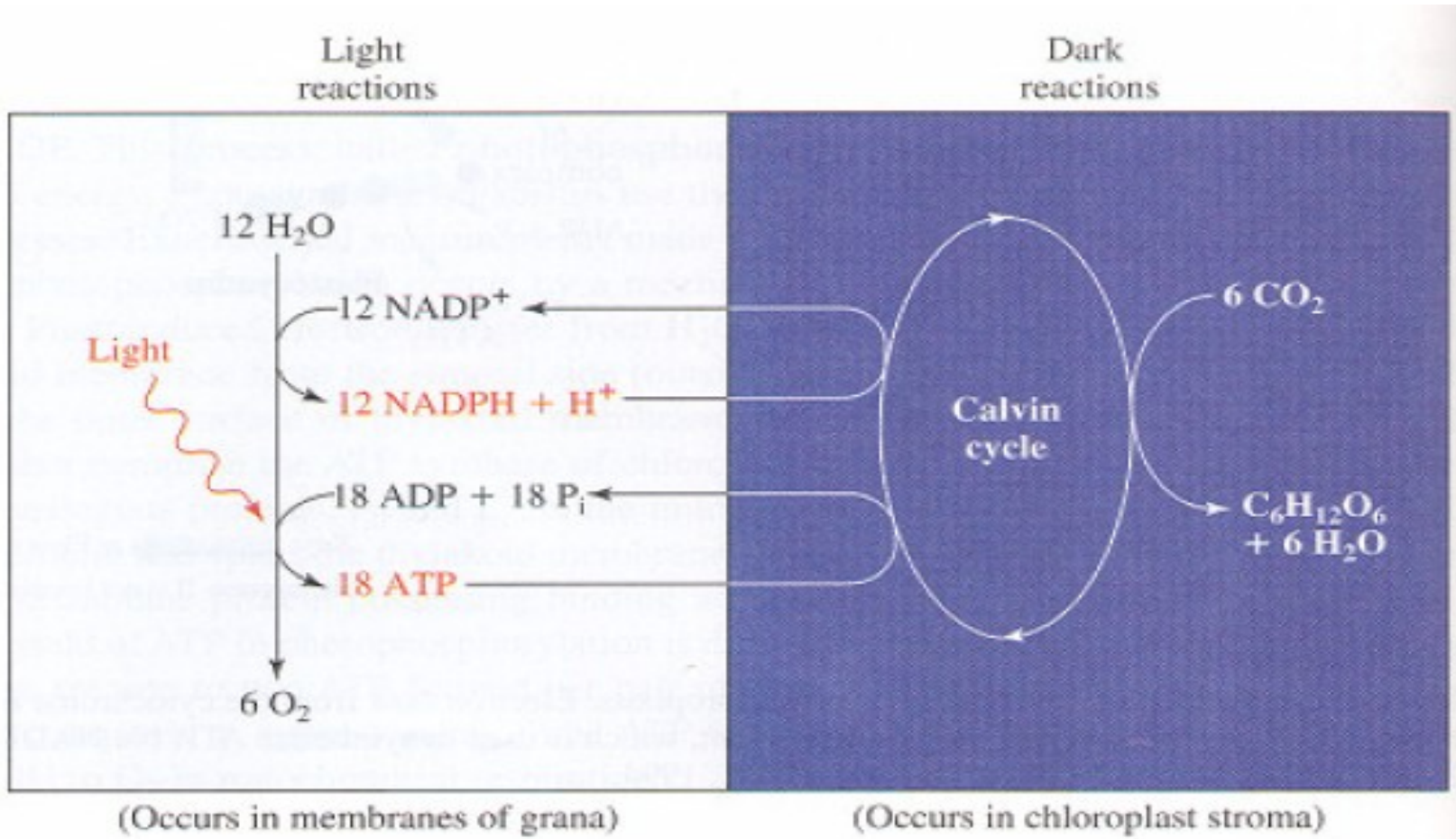
Schéma fotosystémů I a II



Spřažení toku elektronů a fotofosforylace

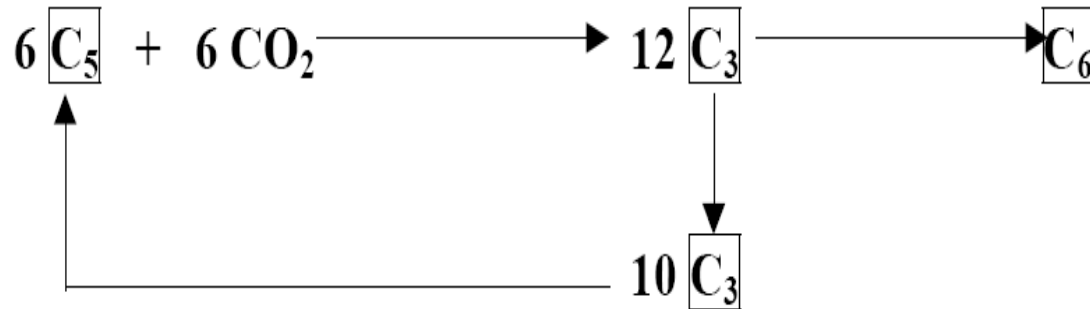


Světelná a temná fáze



Temná fáze

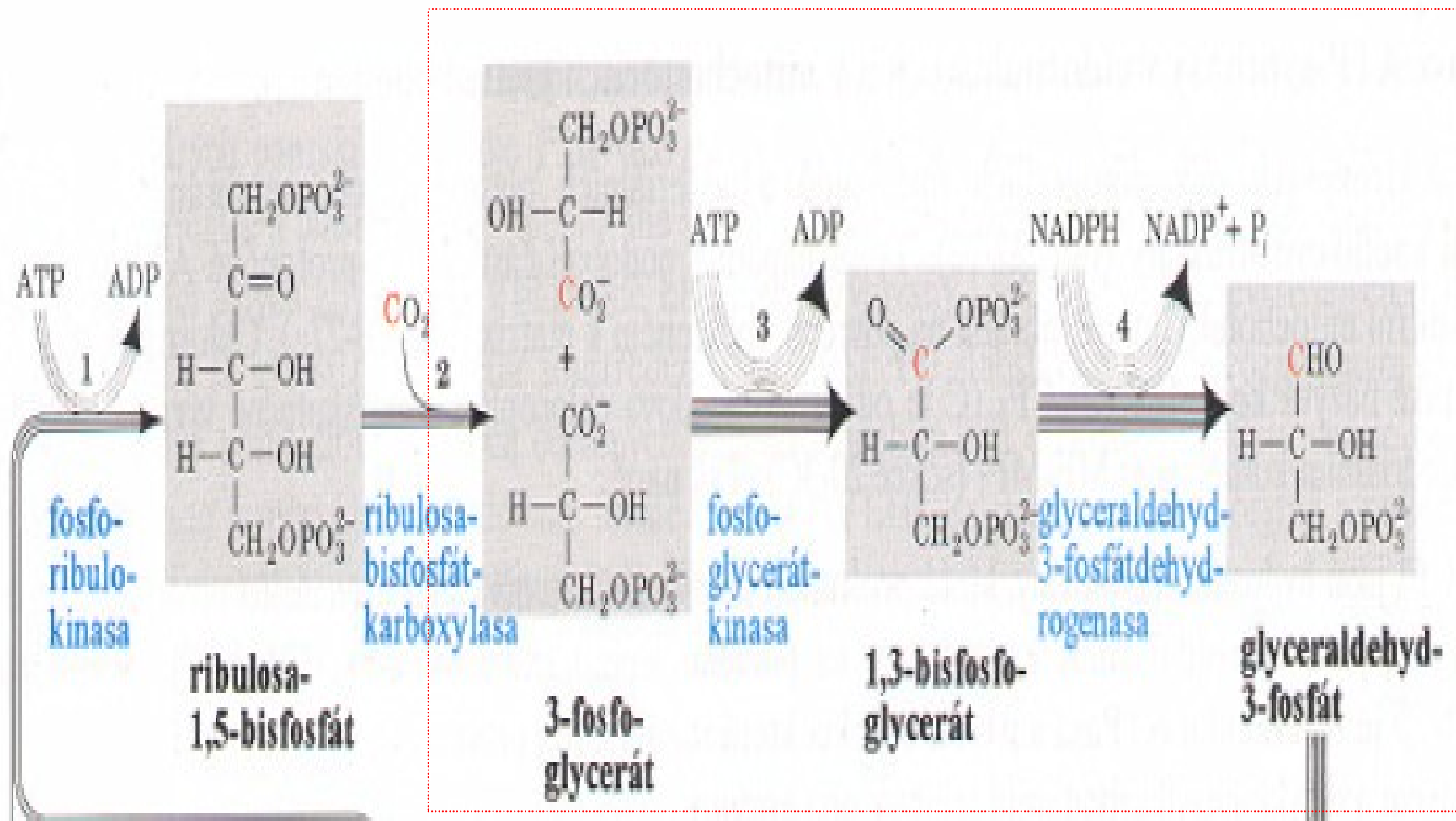
M.CALVIN



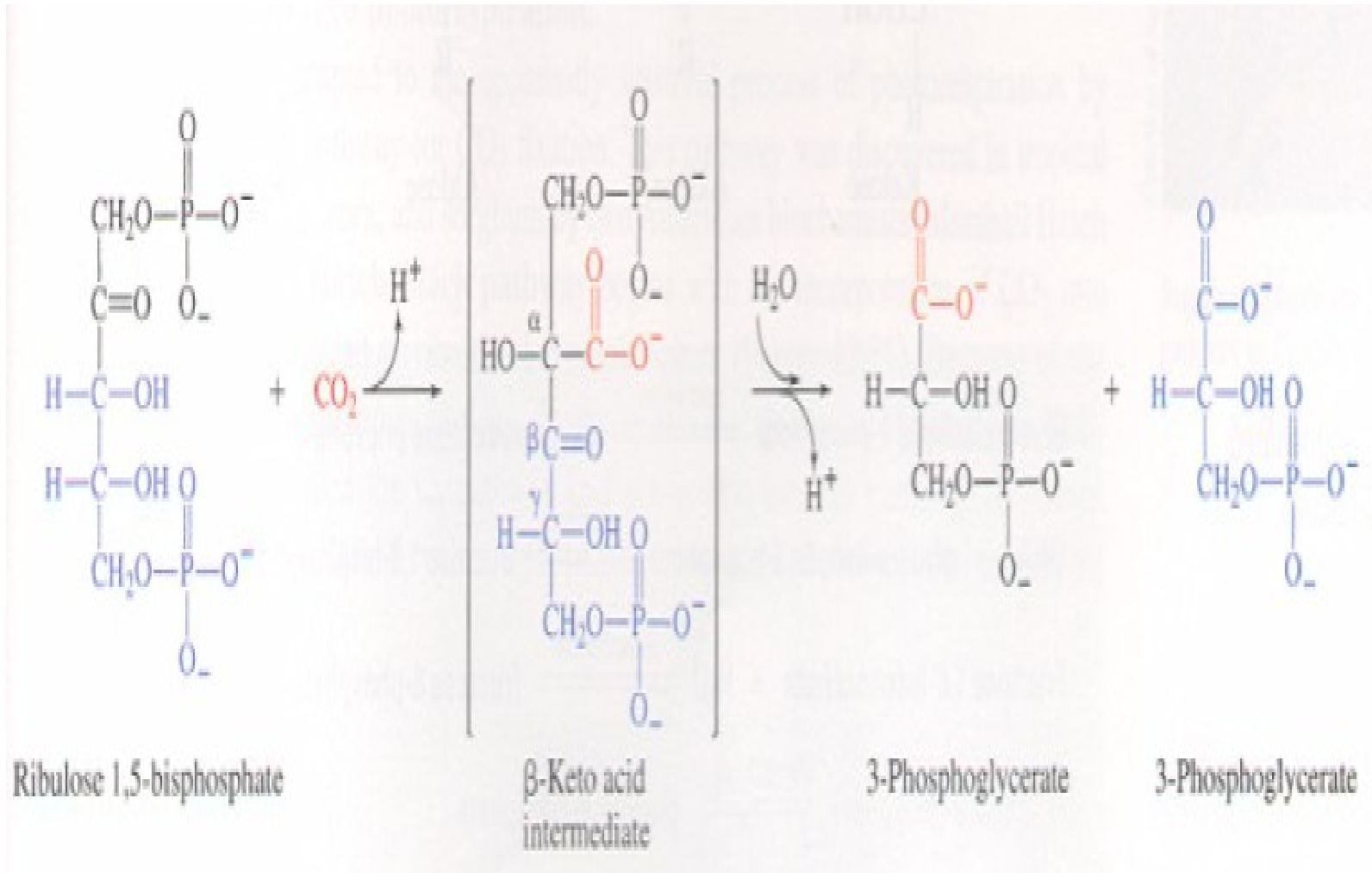
C₃ rostliny

- většina rostlin a řas
- akceptor CO₂ ribulosa-5-P
- produkt 3-P-glycerát

Calvinův cyklus

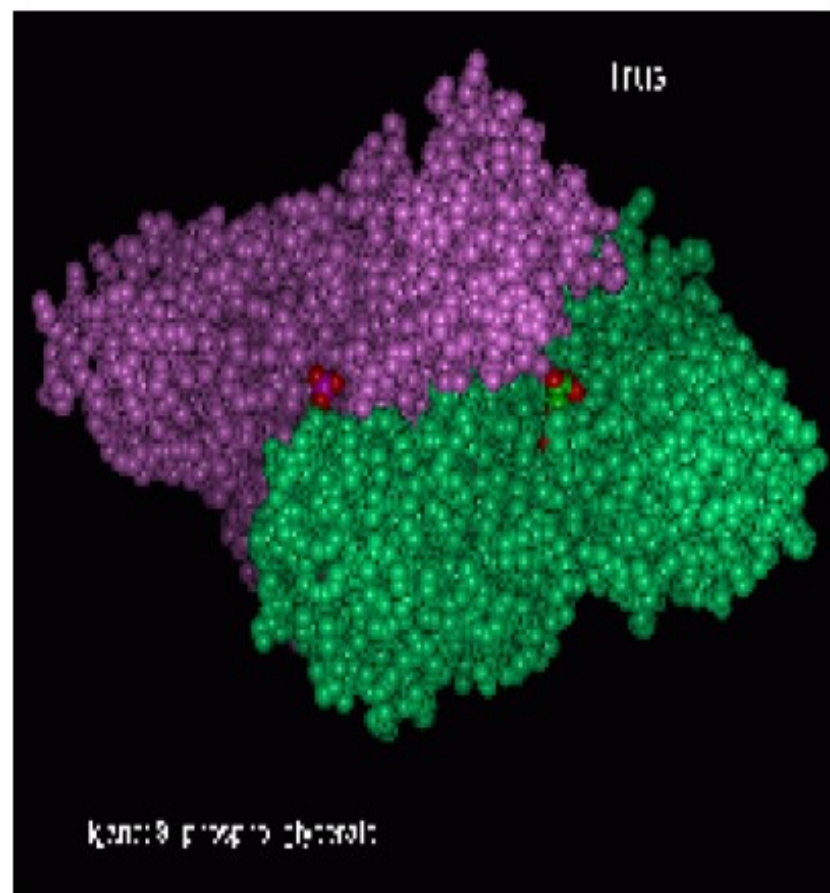


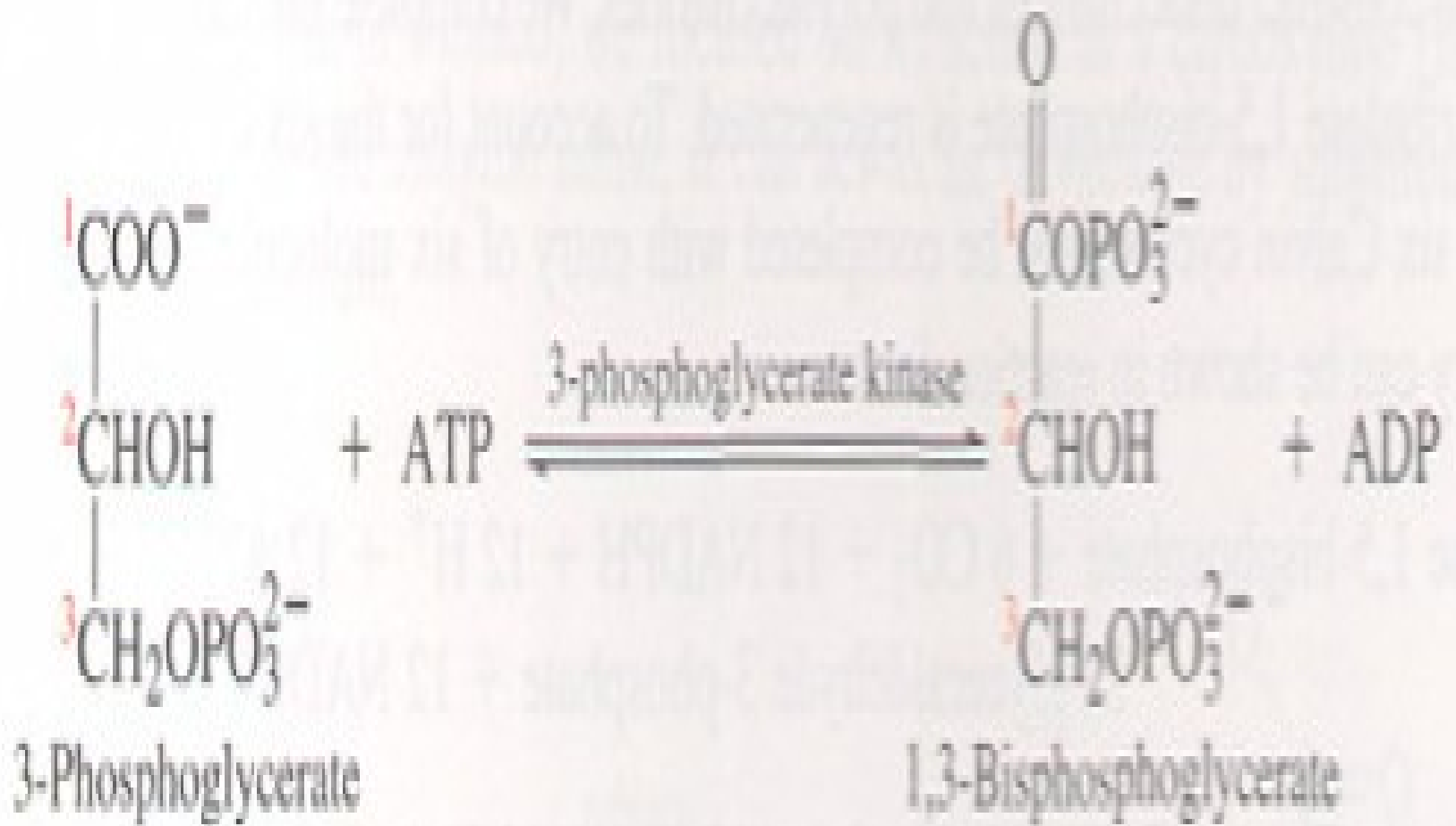
Rubisco



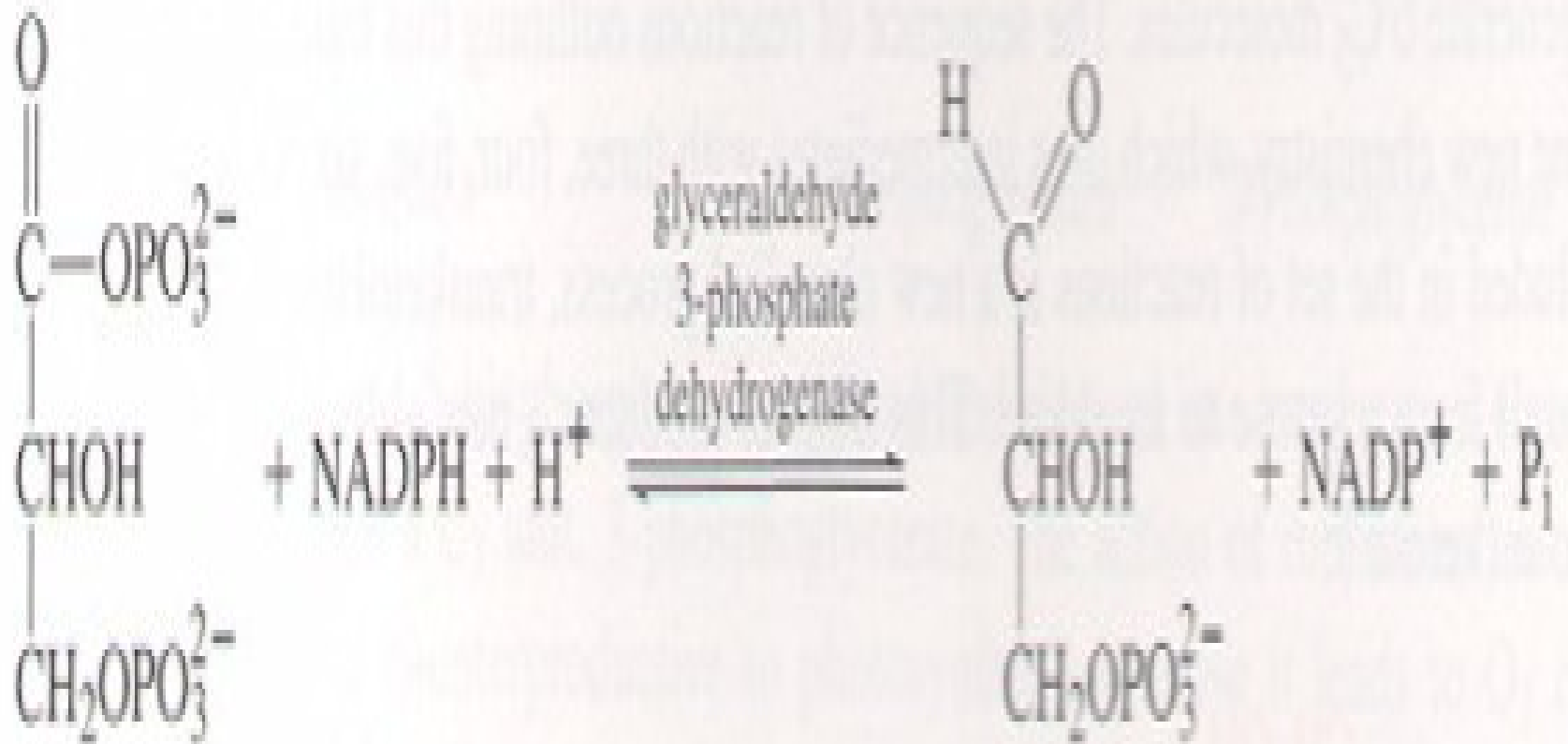
RUBISCO

2 podjednotky (1 katalytická)



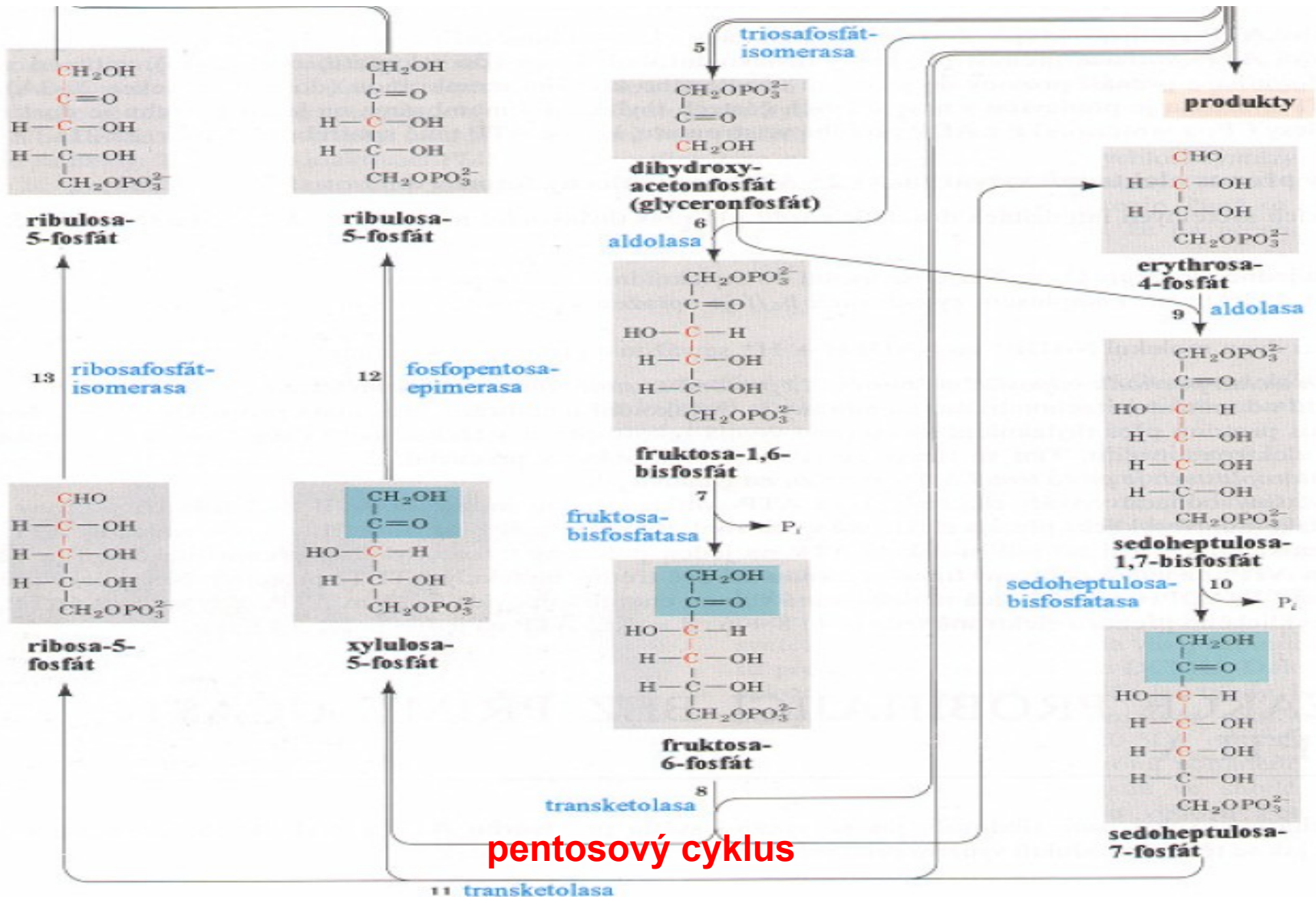


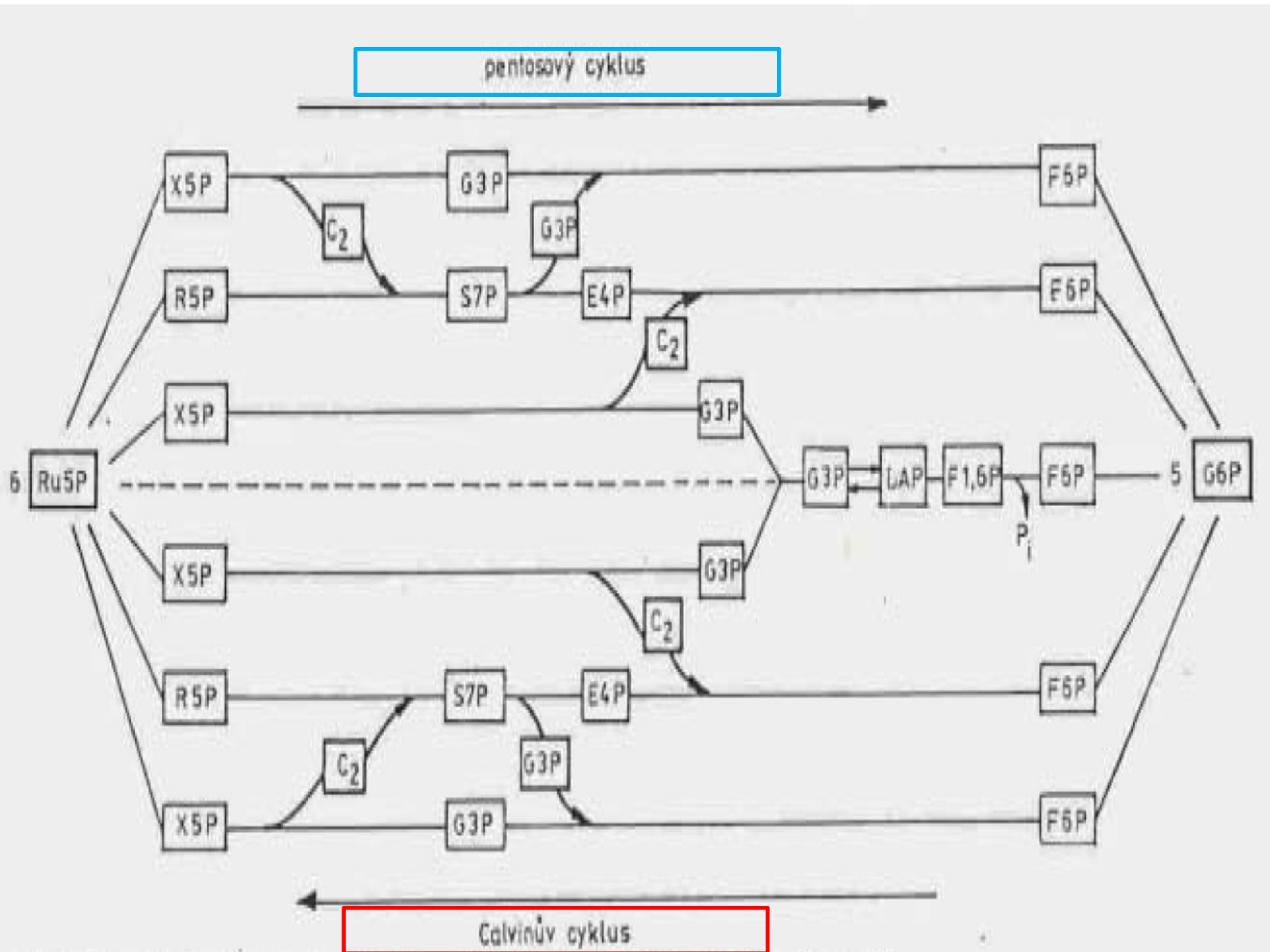
glykolysa



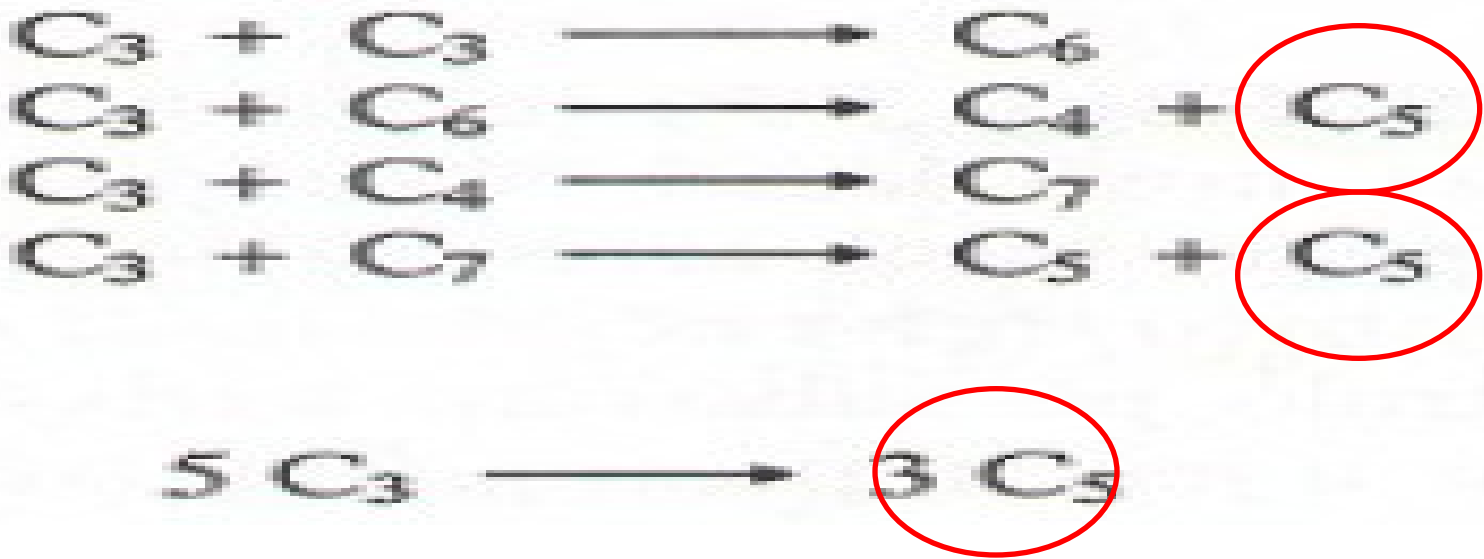
glykolysa

Calvinův cyklus





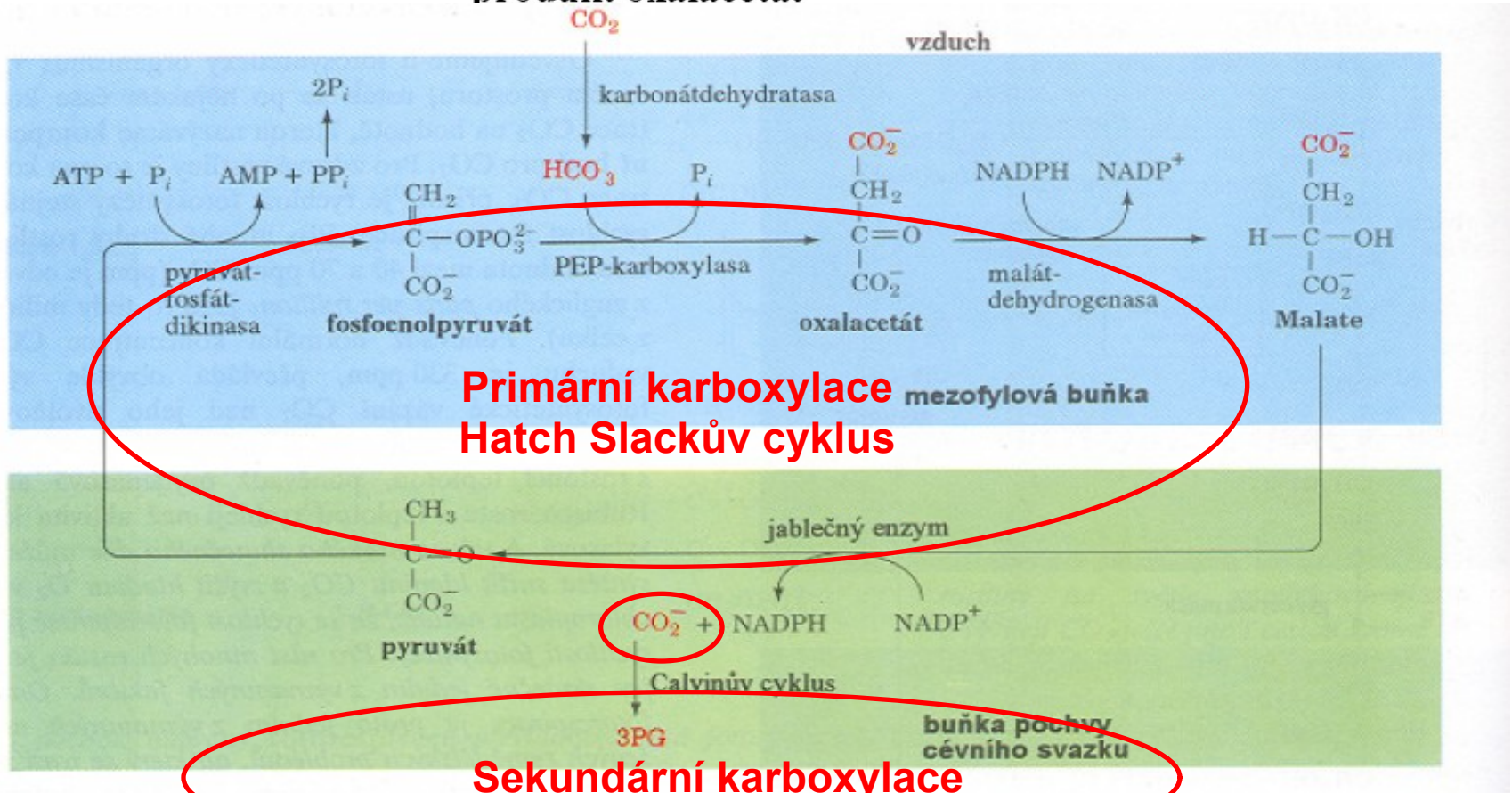
pentosový cyklus



pentosový cyklus

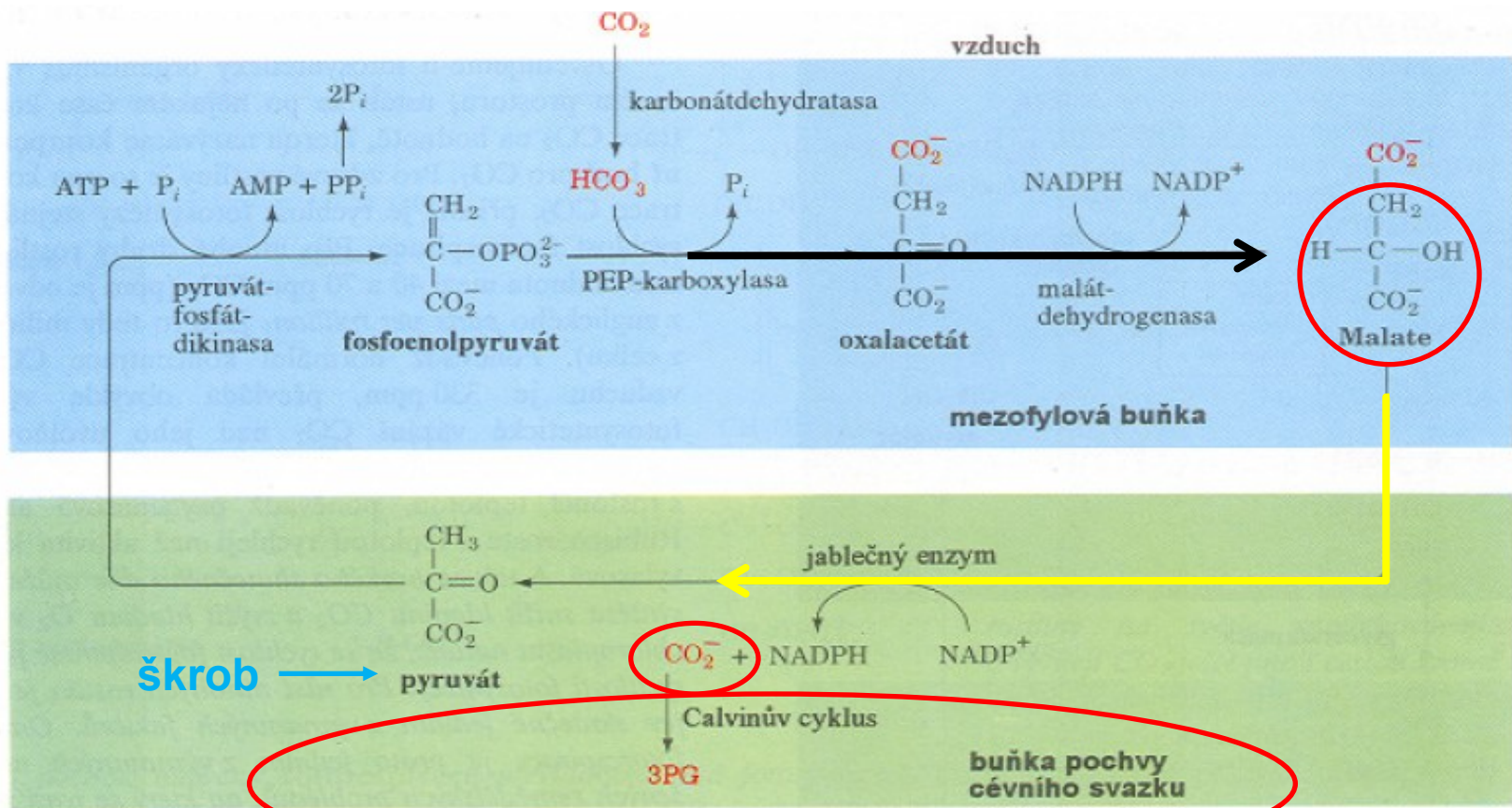
C₄ rostliny

- rychlerostoucí tropické rostliny
- akceptor CO₂ fosfoenolpyruvát
- produkt oxalacetát



Primární karboxylace
Hatch Slackův cyklus

Sekundární karboxylace
Calvinův cyklus



- CAM rostliny** - tučnolisté
- příjem CO₂ probíhá v noci

Fotorespirace

