ŽIVOT

- růst
- rozmnožování
- vývoj a diferenciace
- dráždivost
- pohyb

Látková přeměna - intermediální metabolismus

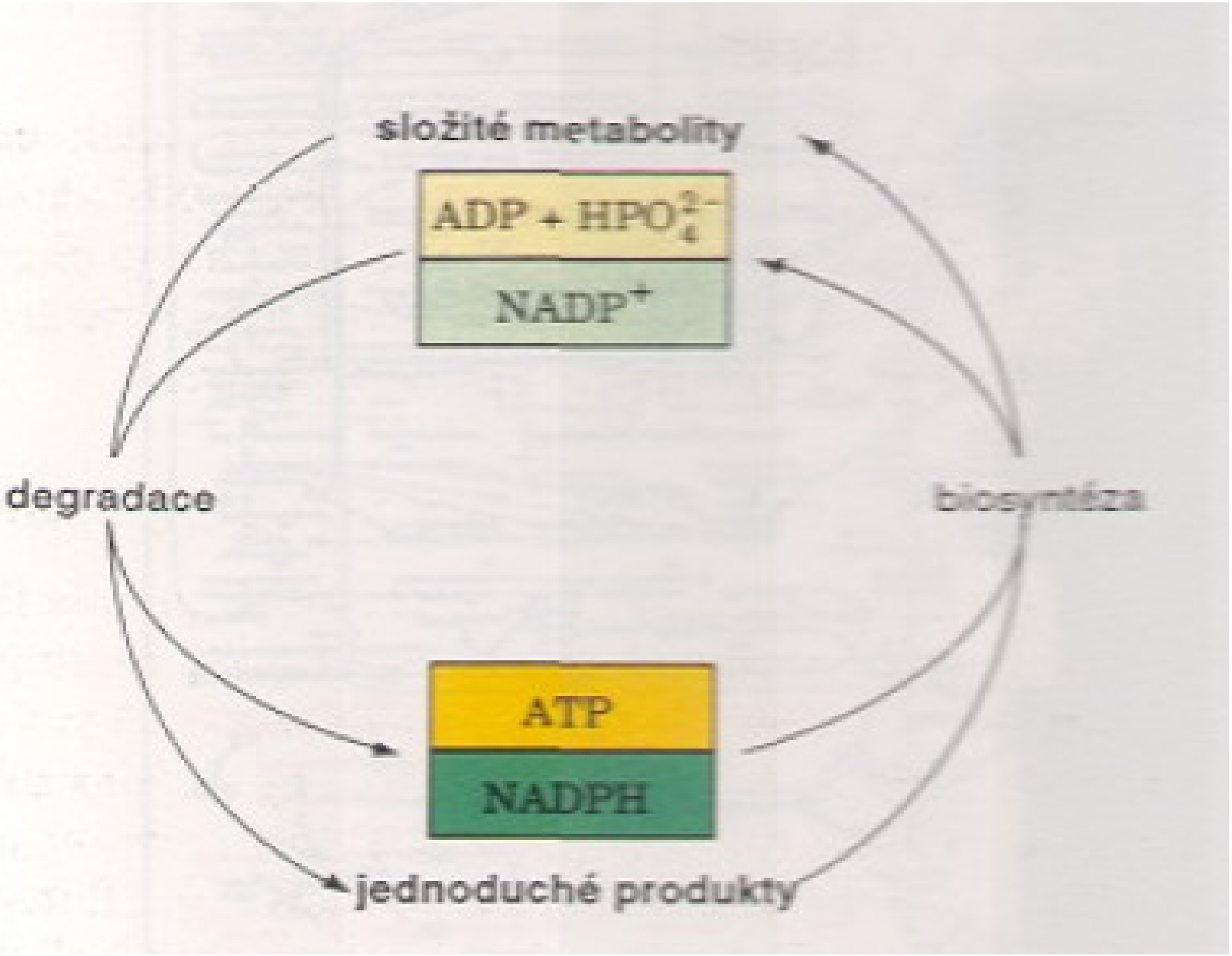
Funkce - zajišťování energie

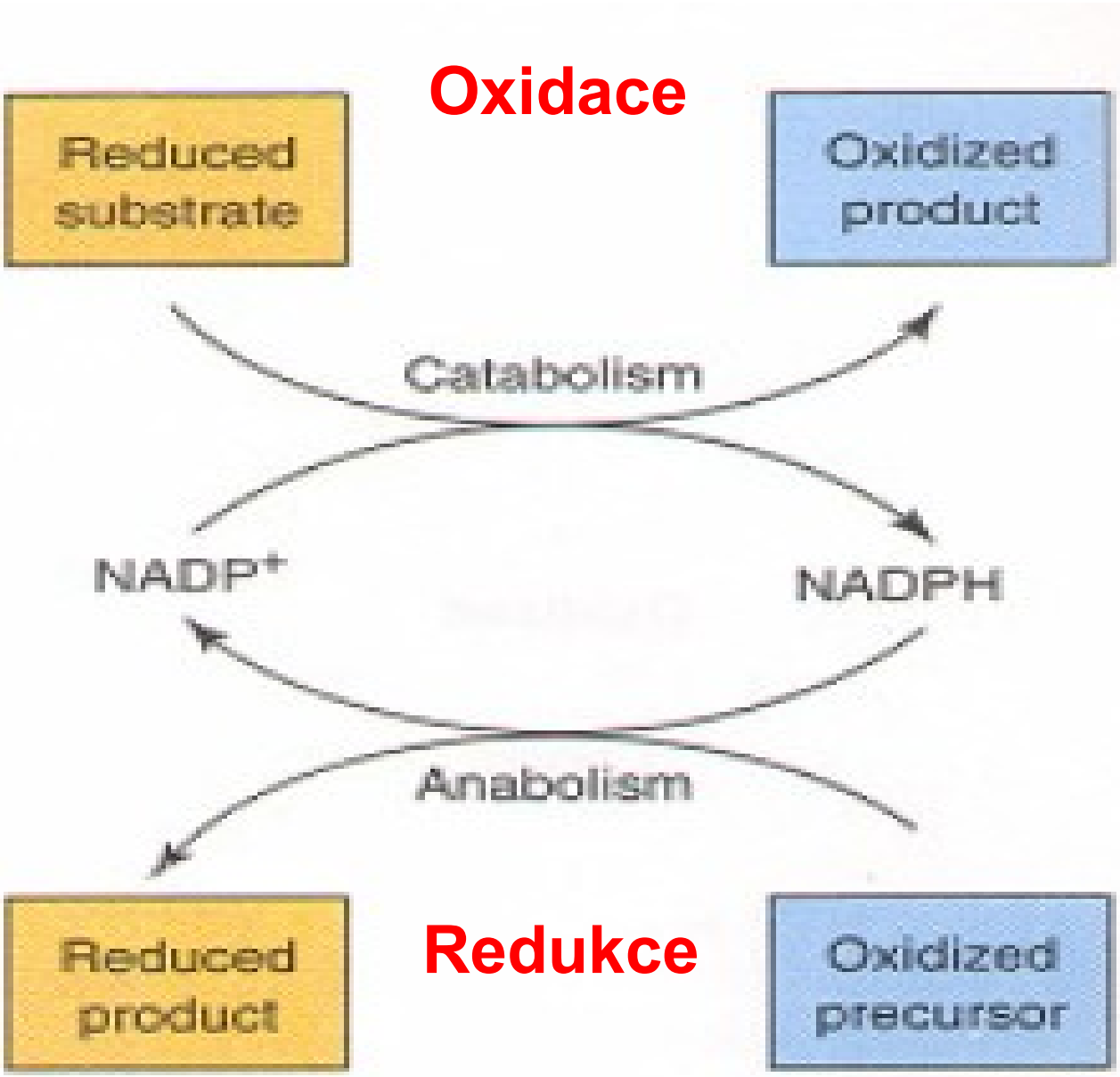
- zajišťování stavebního materiálu

Procesy - rozkladné - katabolické - disimilační

- biosyntetické - anabolické - asimilační

- amfibolické - obojí


složité metabolity
ADP + HPO_4^{2-}
$NADP^+$
degradace
biosyntéza
ATP
NADPH
jednoduché produkty


Oxidace
Reduced substrate
Oxidized product
Catabolism
NADP+
NADPH
Anabolism
Reduced product
Redukce
Oxidized precursor

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

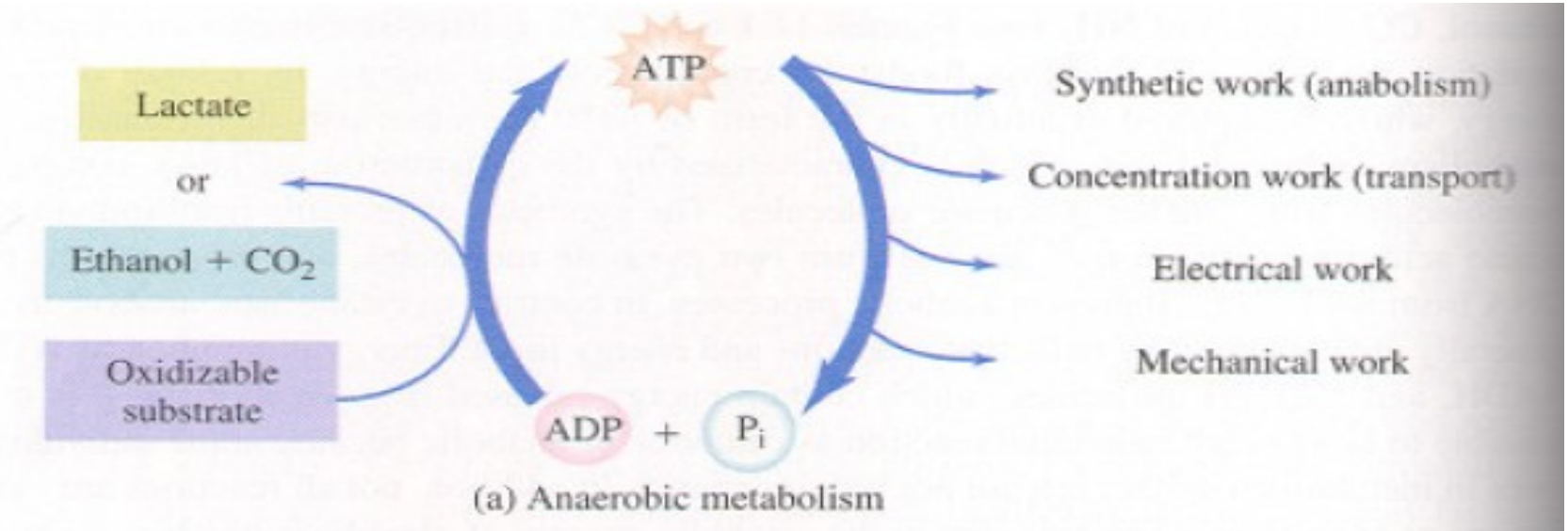
litotrofy - anorganické látky

D. Podle konečného akceptoru elektronů

aeroby - O_2

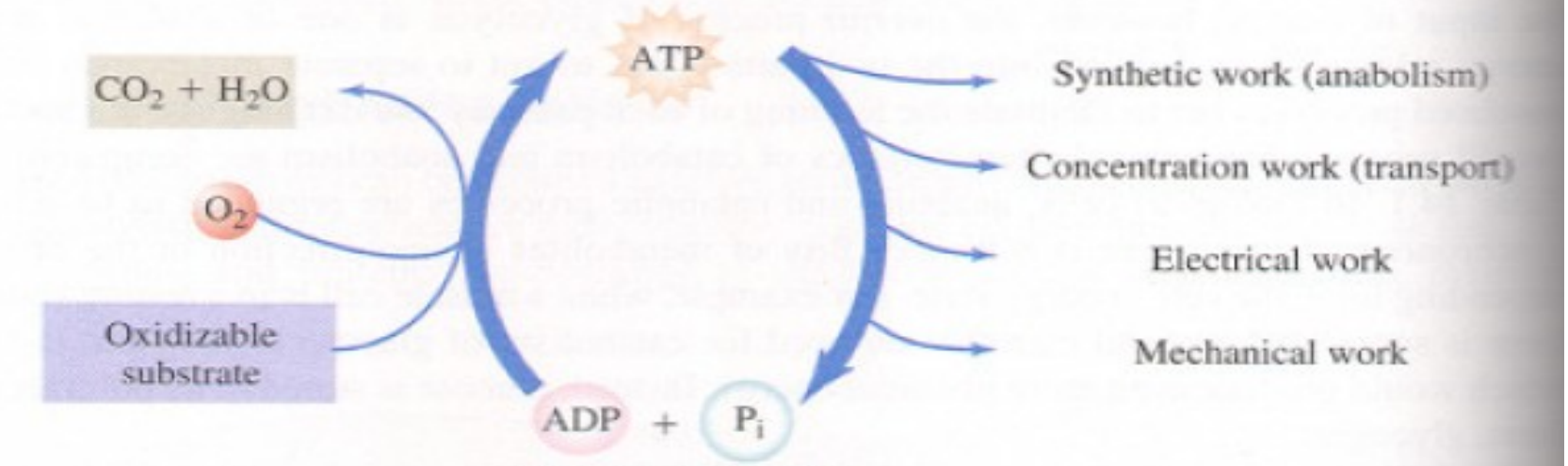
anaeroby - NO_3^-, SO_4^{2-}

fermentace - elektrony jsou předávány na jiné organické látky



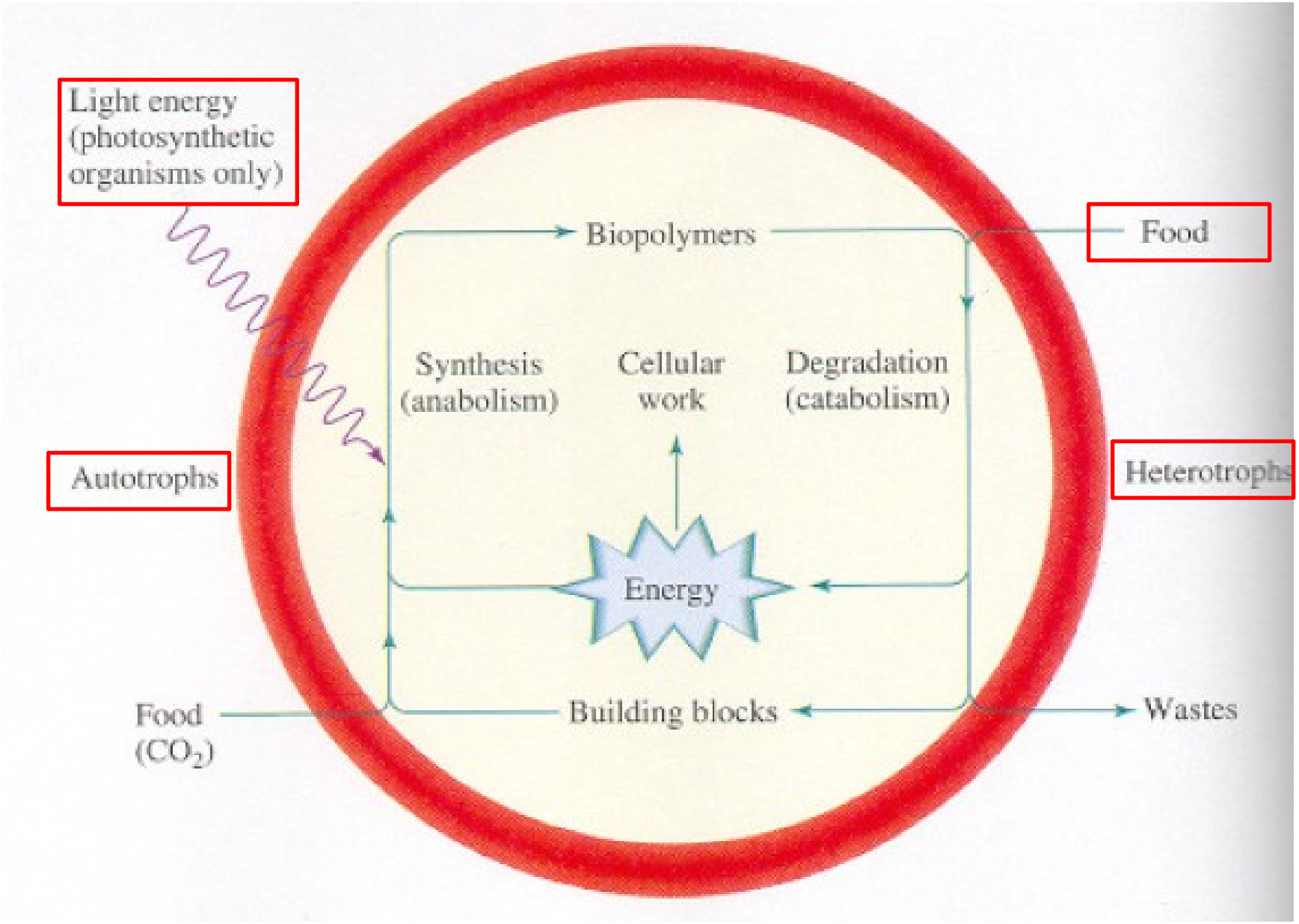
(a) Anaerobic metabolism

Fermentace



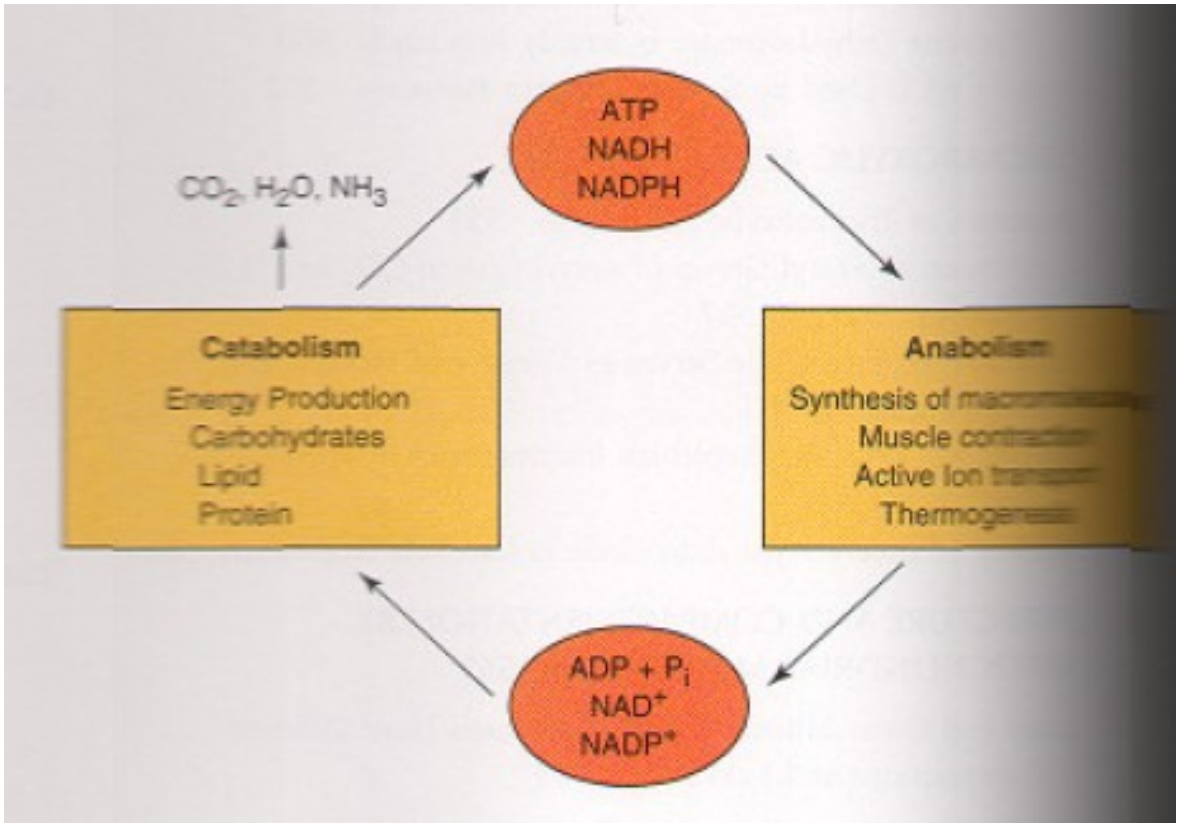
(b) Aerobic metabolism

Respirace


Light energy
(photosynthetic
organisms only)
Biopolymers
Food
Synthesis
(anabolism)
Cellular
work
Degradation
(catabolism)
Autotrophs
Heterotrophs
Energy
Food
(CO_2)
Building blocks
Wastes

Metabolismus

H. KREBS - tři fáze metabolismu



Katabolismus - degradační fáze metabolismu - konvergentní

Funkce - produkce energie

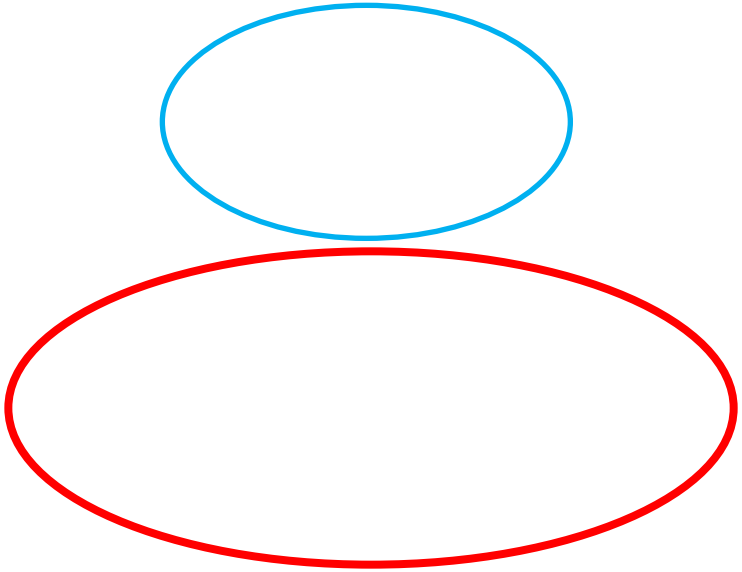
- poskytuje prekurzory
- poskytuje NADPH

1. Fáze - složité molekuly štěpeny na stavební jednotky **0 % energie**
2. Fáze - stavební jednotky převedeny na C_1 a C_2 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

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

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

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

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

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

$\Delta G < 0$ - reakce exergonické

$\Delta G > 0$ - reakce endergonické

Spřažení reakcí

$$A + B \leftrightarrow C + D \qquad \Delta G_1 \geq 0$$

$$D + E \leftrightarrow F + G \qquad \Delta G_2 < 0$$

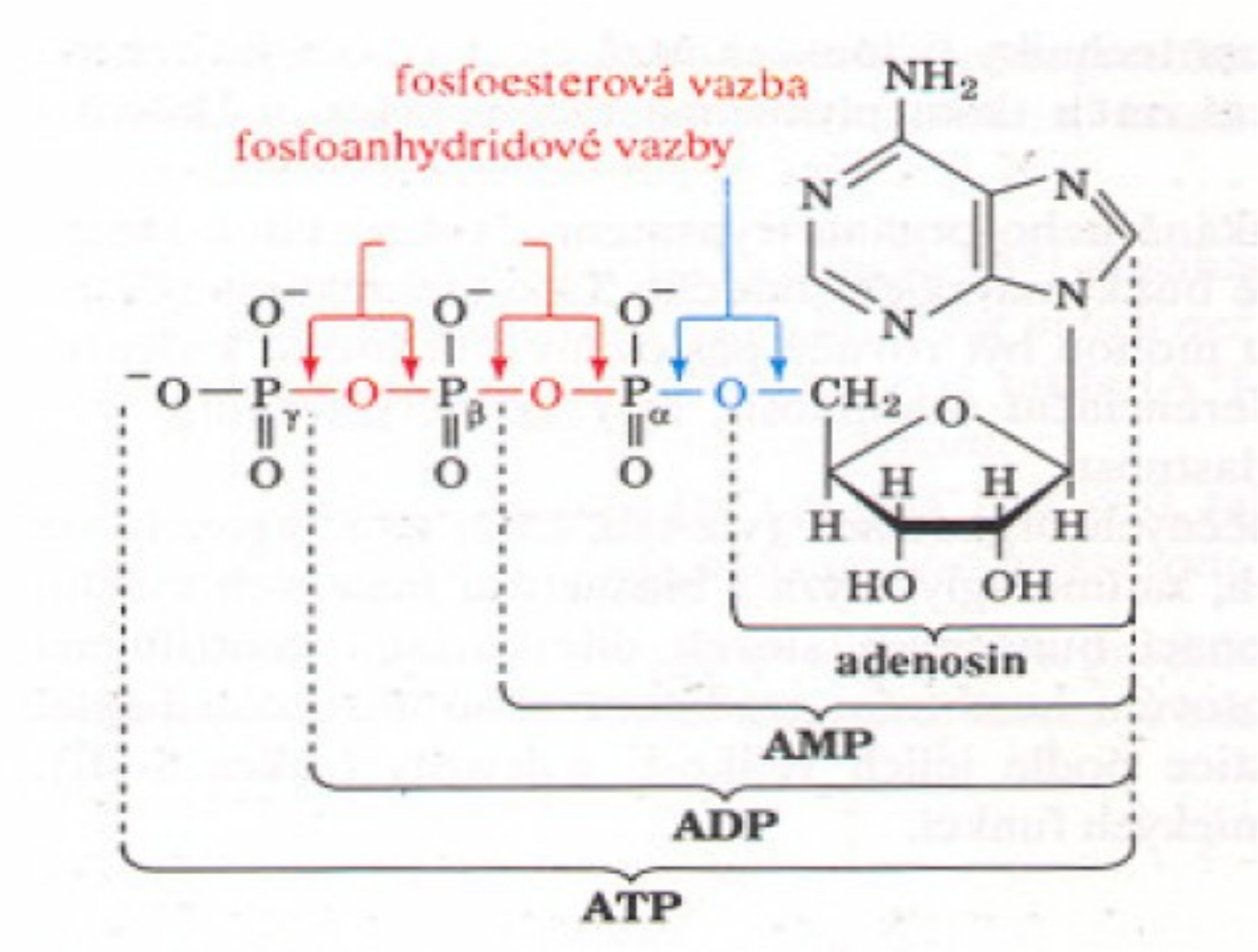
$$\Delta G = \Delta G_2 + \Delta G_2$$

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

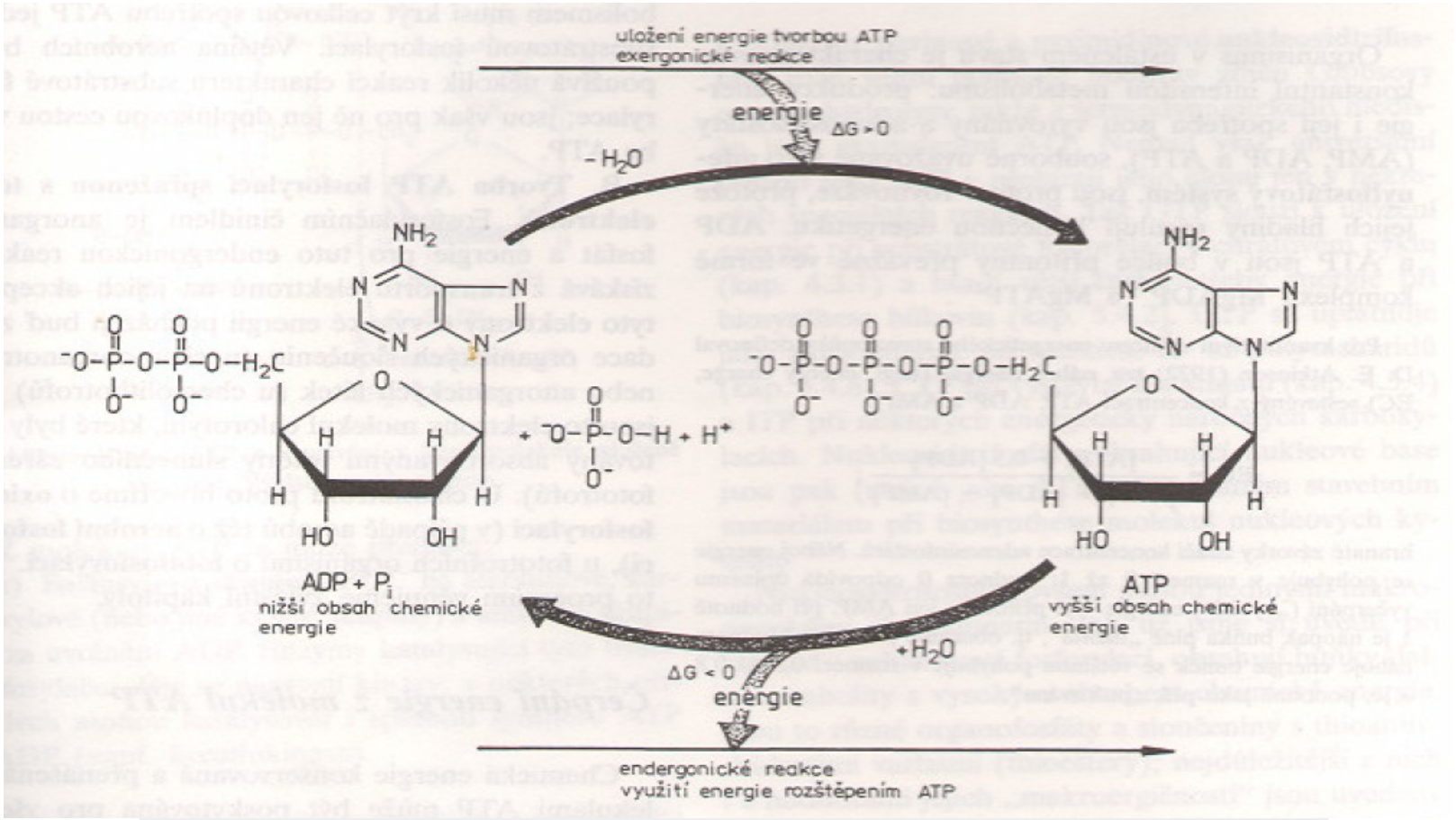


$$ATP + H_2O \rightarrow ADP + P_i + H^+ \qquad \Delta G = -33\ kJ/mol$$

$$ATP + 2H_2O \rightarrow AMP + 2P_i + 2H^+ \qquad \Delta G = -66\ kJ/mol$$

ATP - univerzální přenašeč energie

LIPMANN a KALCKAR 1941



Tvorba ATP

1. *Substrátová fosforylace*

$$M\text{-}P + ADP \rightarrow M + ATP$$

$$M\text{-}X + P_i + ADP \rightarrow M + X + ATP$$

2. *Fosforylace spřažena s tokem elektronů*

- oxidační fosforylace
- fotofosforylace

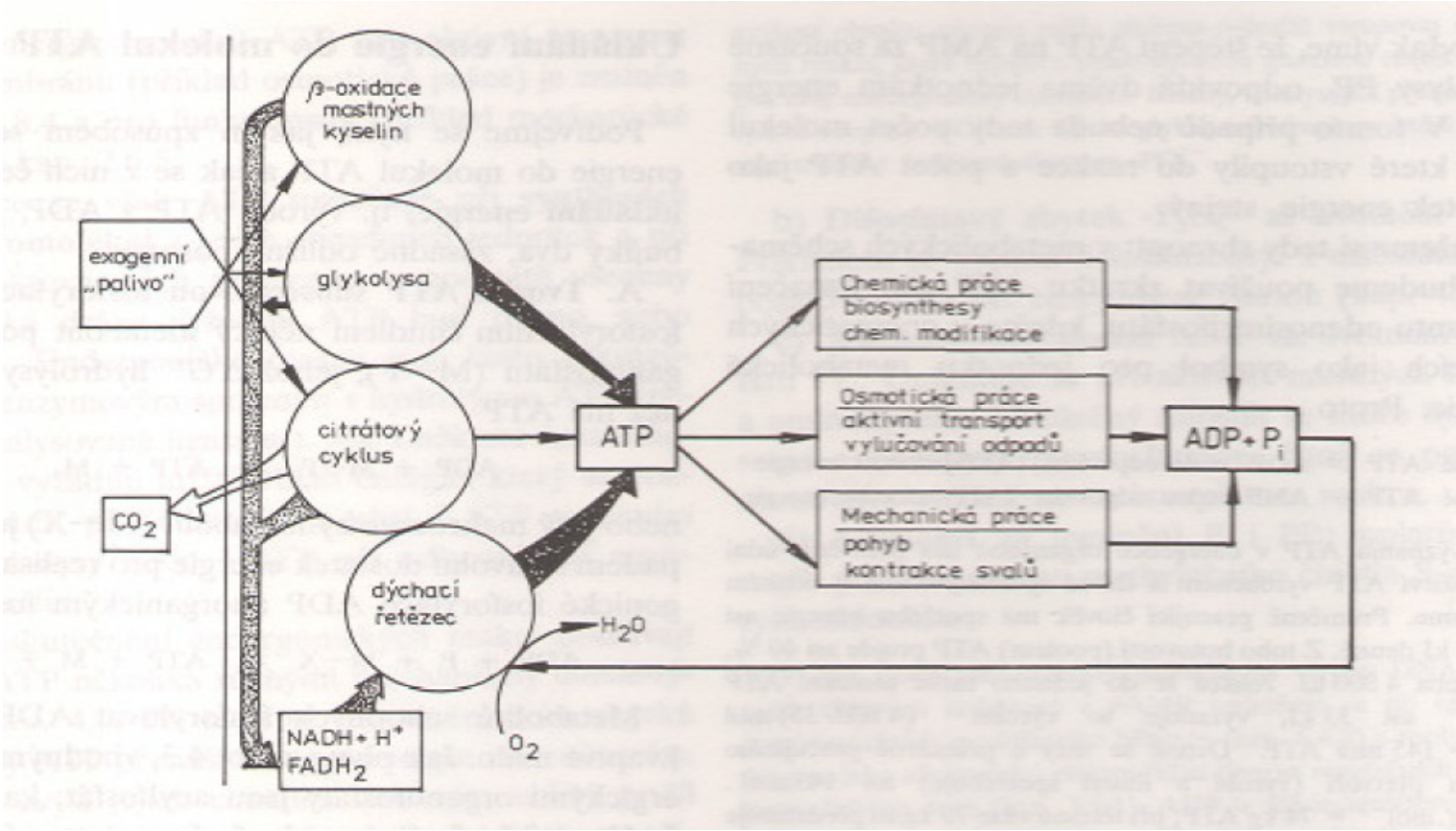
3. *Adenylátkinasovou reakcí*

$$ATP + AMP \rightarrow ADP$$

Spotřeba ATP

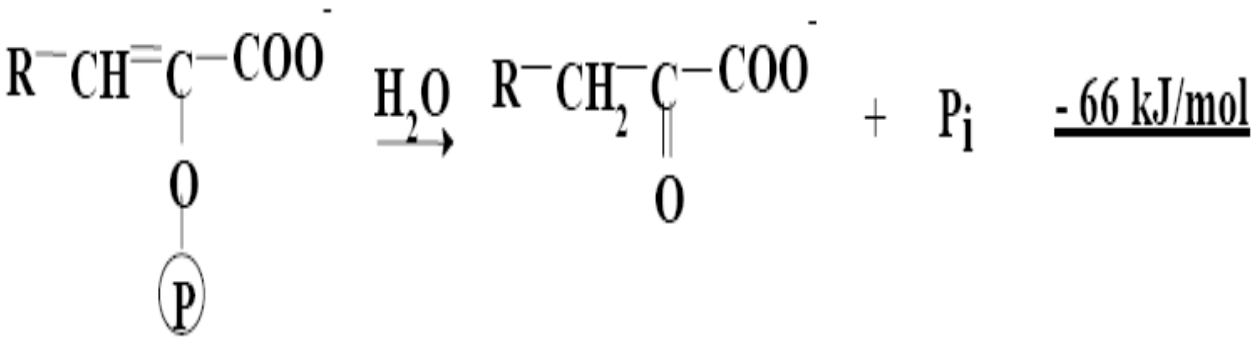
- **Biosyntetické reakce**
- **Počáteční stádia odbourávání živi**
- **Fyziologické procesy**
- **Vzájemné přeměny nukleotidů**

$$ATP + NDP \rightarrow ADP + NTP$$



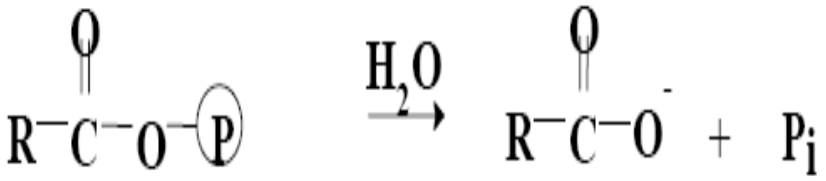
Další makroergické sloučeniny

ENOYLFOSFÁTY



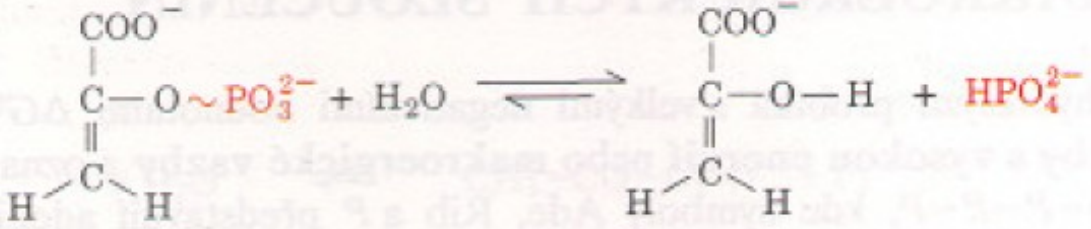
- 66 kJ/mol

ACYLFOSFÁTY



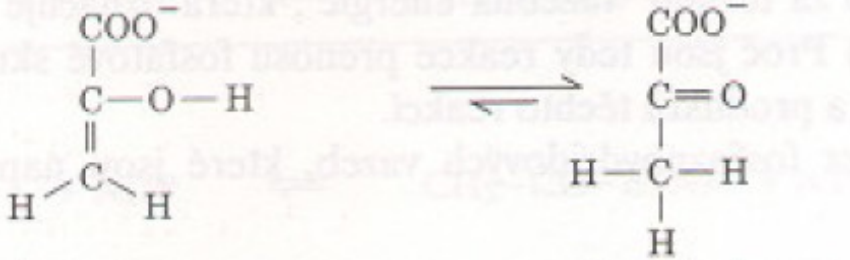
-(40-50) kJ/mol

hydrolýza

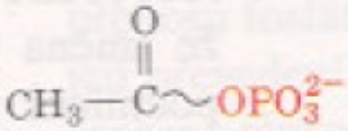


fosfoenolpyruvát

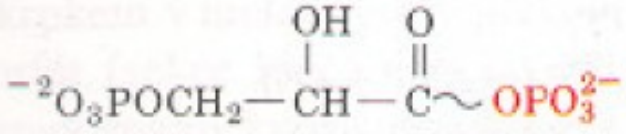
tautomerace



pyruvát (enol-forma) pyruvát (keto-forma)

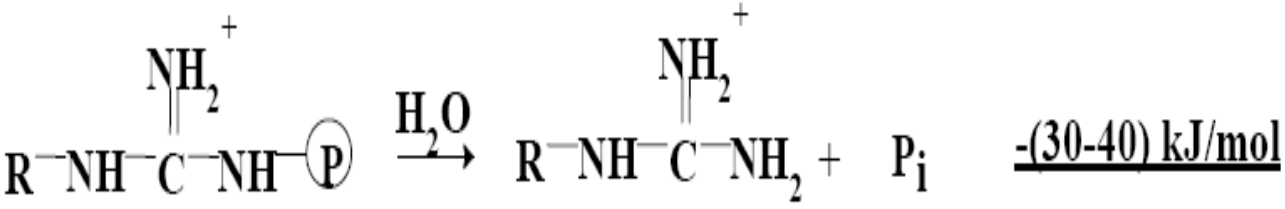


acetylfosfát



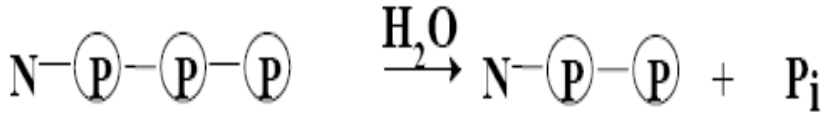
1,3-bisfosfoglycerát

GUANIDIUMFOSFÁTY

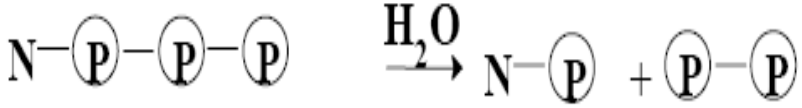


-(30-40) kJ/mol

NUKLEOTIDY

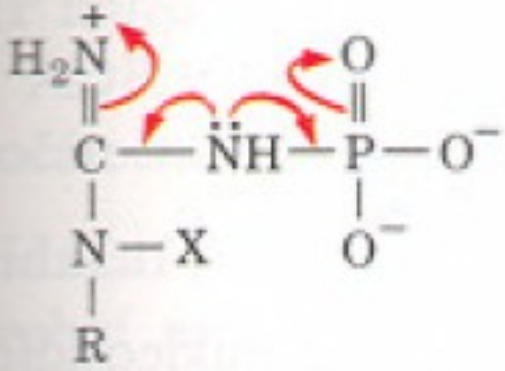


- 33 kJ/mol

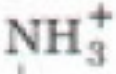


- 33 kJ/mol

- 33 kJ/mol

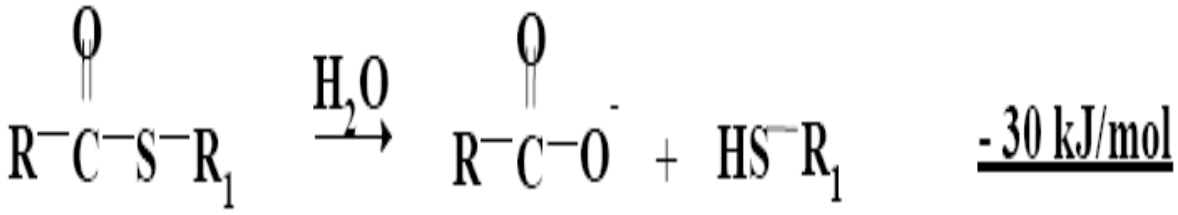


$R = CH_2-CO_2^-$; $X = CH_3$ fosfokreatin **obratlovci**



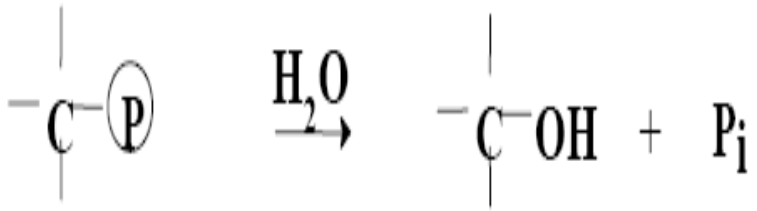
$R = CH_2-CH_2-CH_2-CH(NH_3^+)-CO_2^-$; $X = H$ fosfoarginin **bezobratli**

ACYLTHIOESTERY

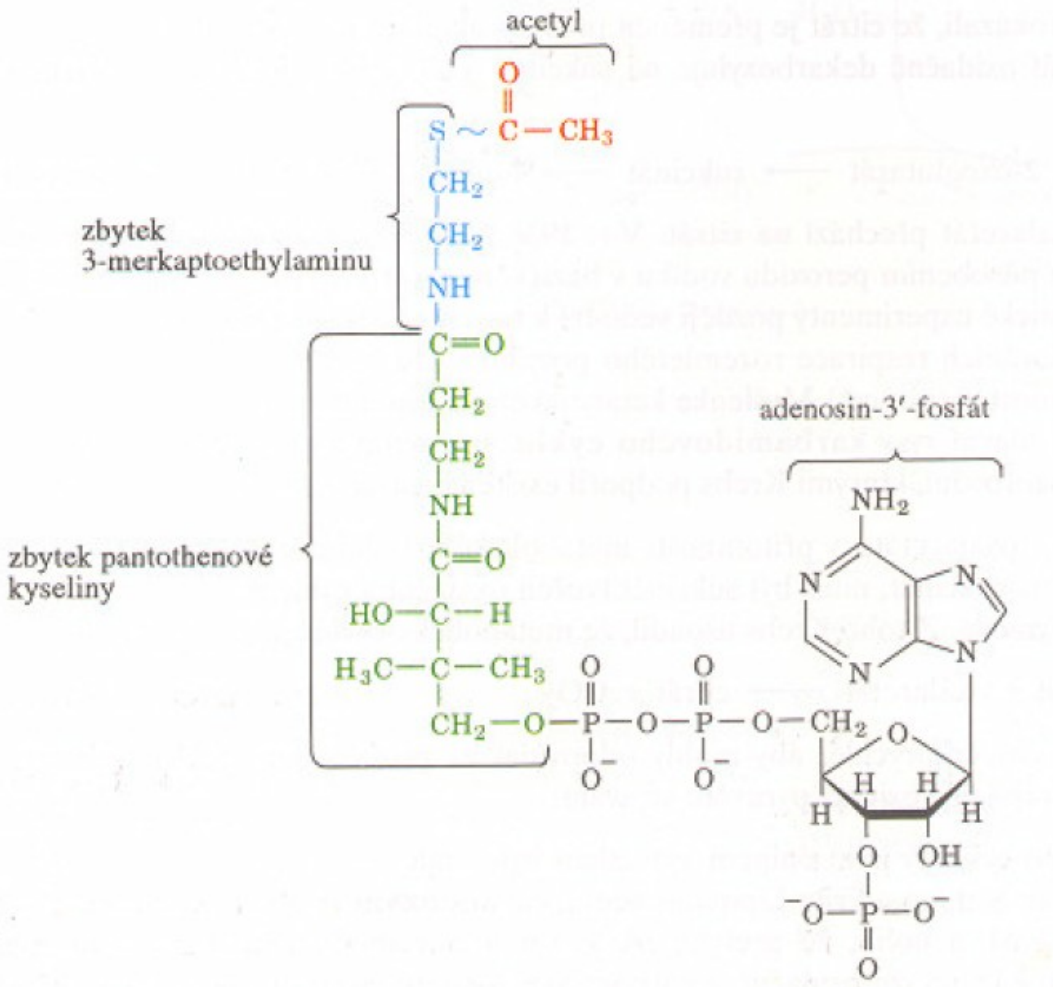


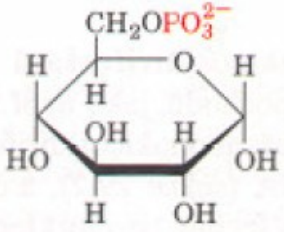
- 30 kJ/mol

FOSFOMONOESTERY

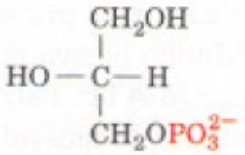


-(10 - 20) kJ/mol





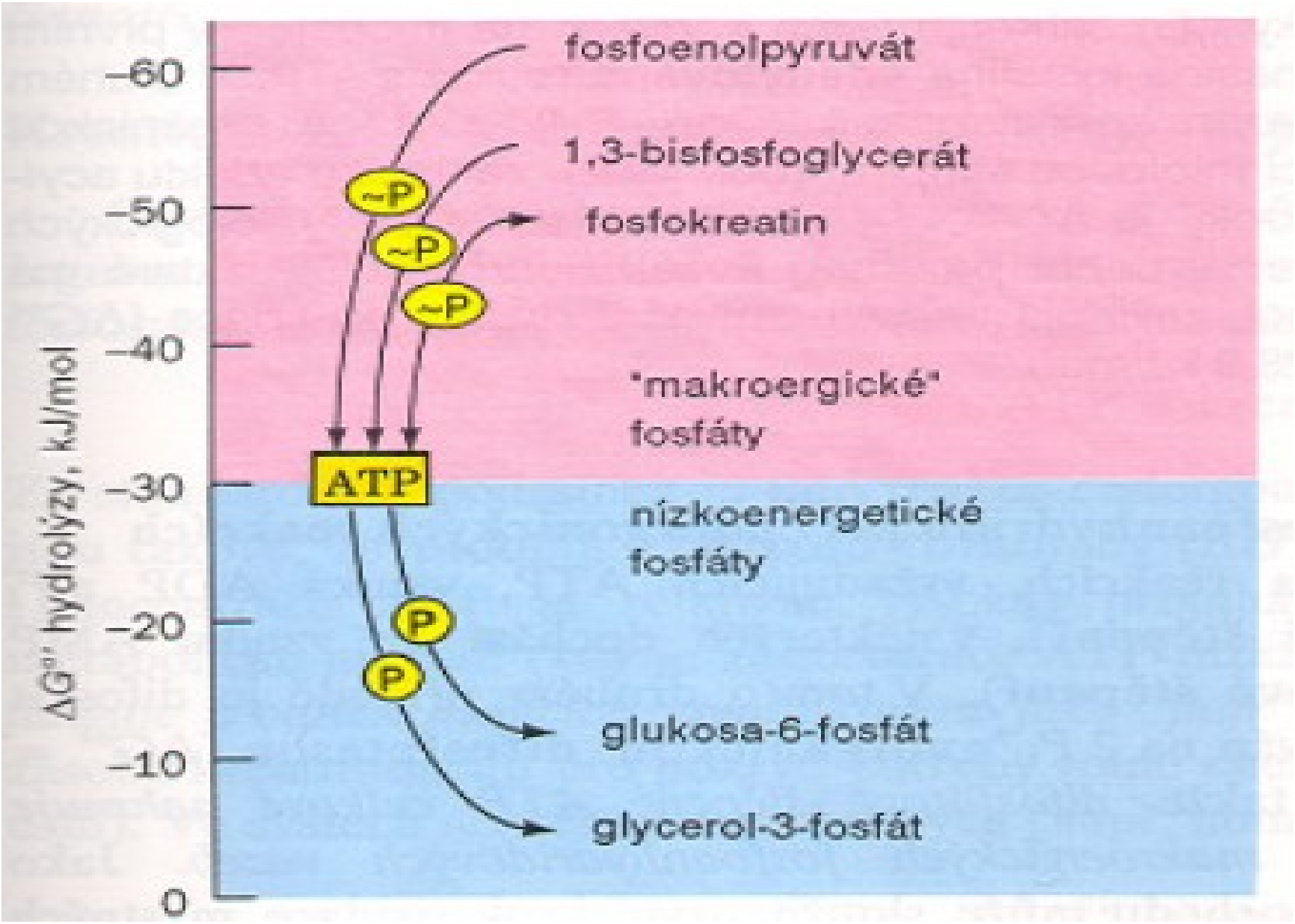
α-D-glukosa-6-fosfát



L-glycerol-3-fosfát

Phosphorylated Compounds	$\Delta G^{\circ\prime}$ (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	Lowest

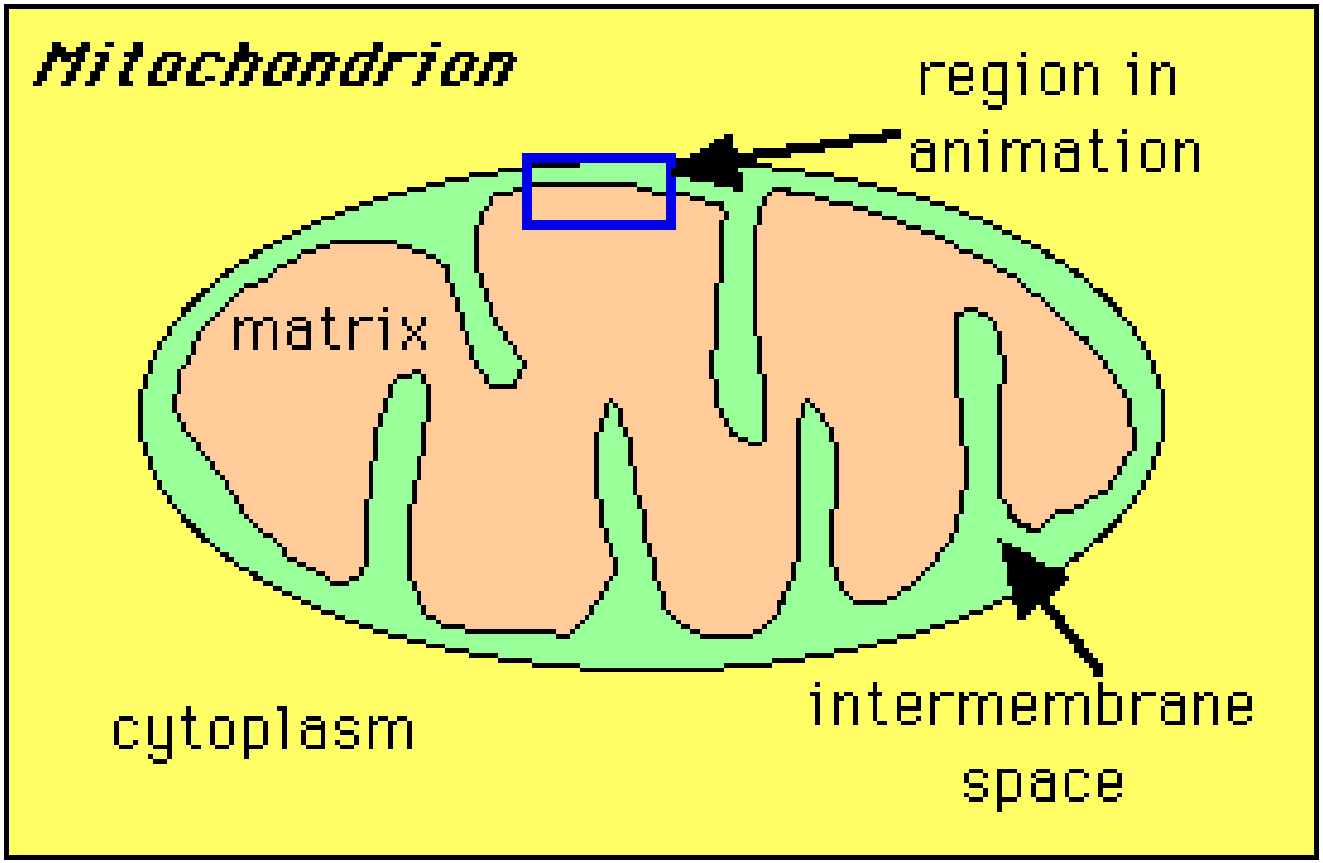
[a]These values are for hydrolysis reactions (the transfer potential of the phosphoryl group to H_2O).


fosfoenolpyruvát
1,3-bisfosfoglycerát
fosfokreatin
~P
~P
~P
"makroergické"
fosfáty
ATP
nízkoenergetické
fosfáty
P
P
glukosa-6-fosfát
glycerol-3-fosfát
ΔG°' hydrolýzy, kJ/mol
−60
−50
−40
−30
−20
−10
0

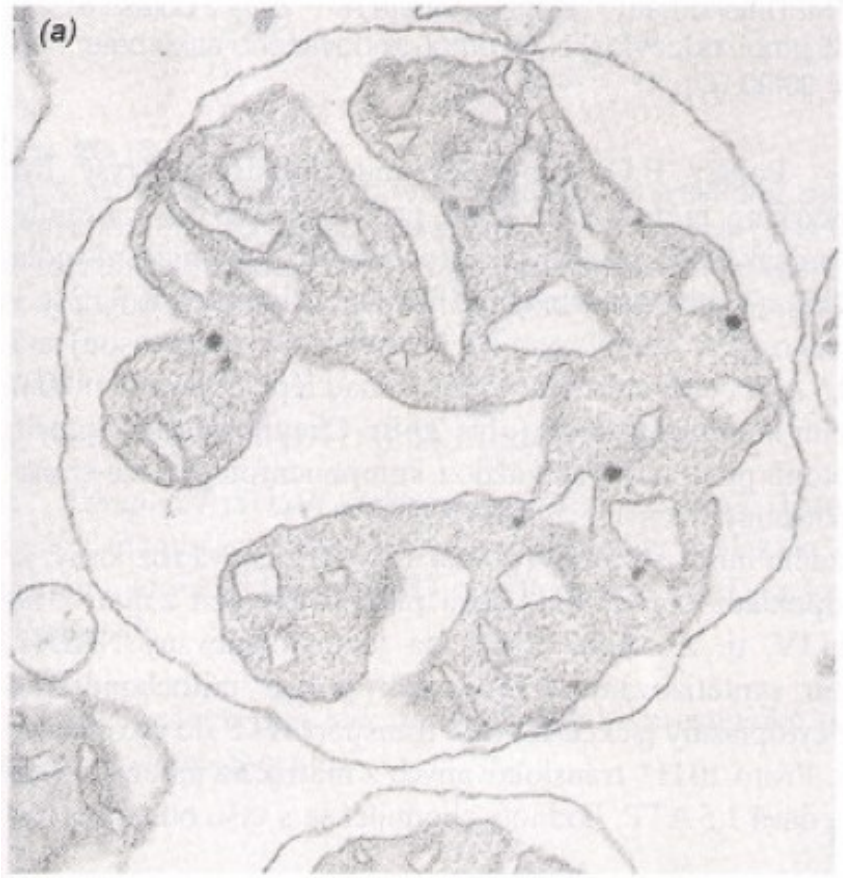
DÝCHACÍ ŘETĚZEC A OXIDAČNÍ FOSFORYLACE

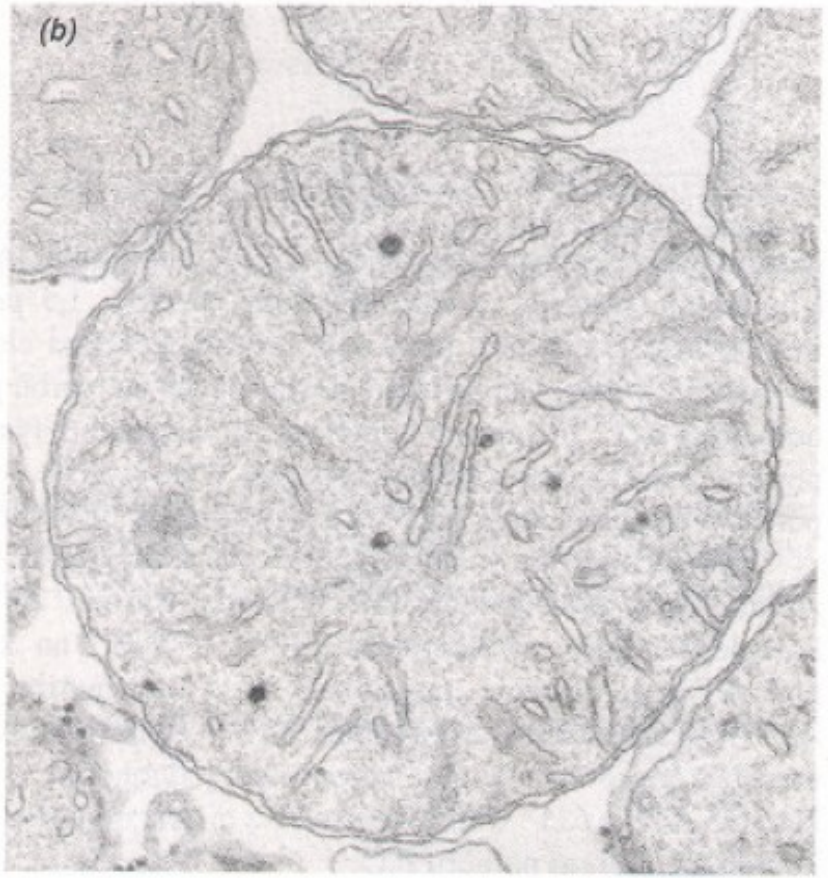
Mitochondrie

Lokalizace

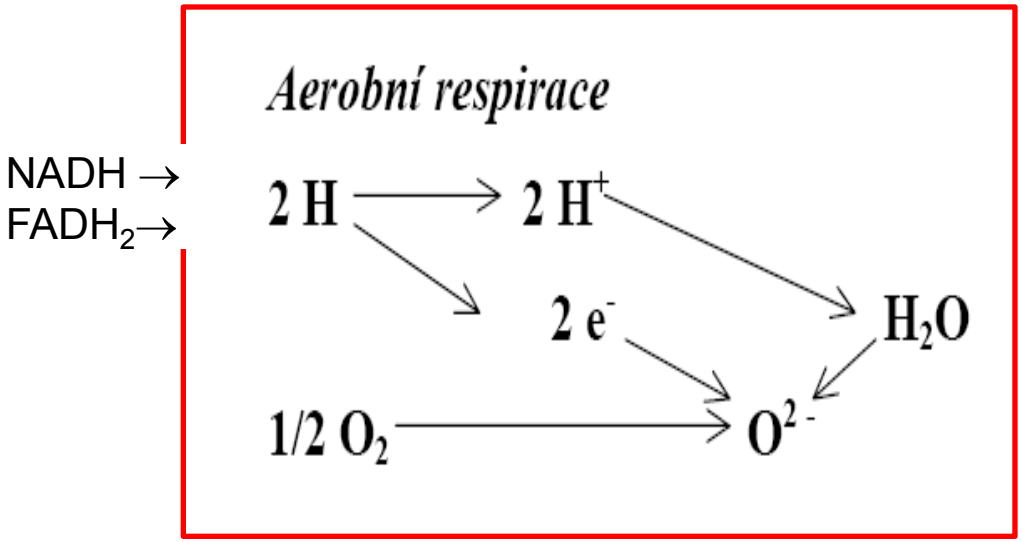

Mitochondrion
region in animation
matrix
cytoplasm
intermembrane space

Mitochondrie





DÝCHACÍ ŘETĚZEC A OXIDAČNÍ FOSFORYLACE

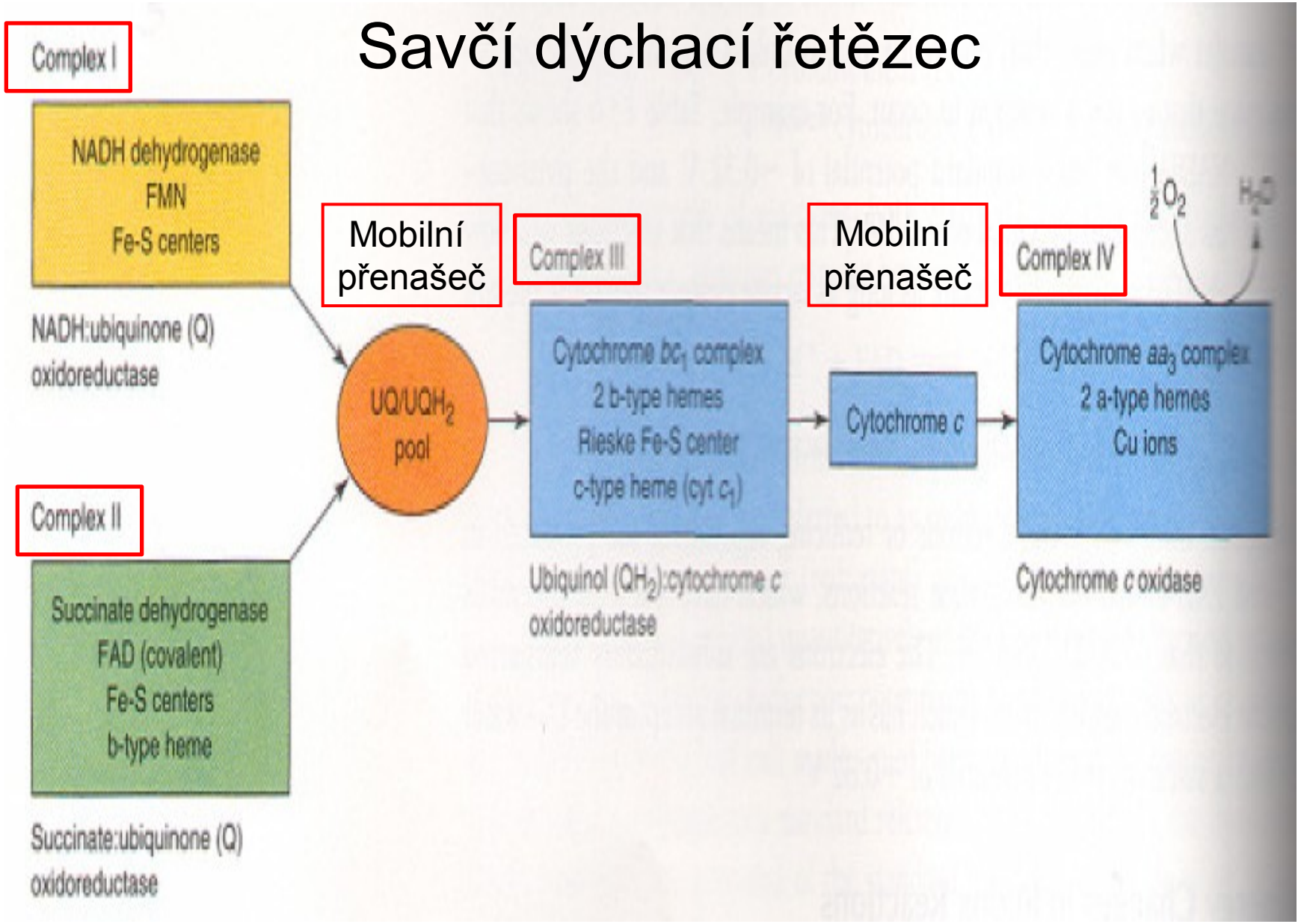


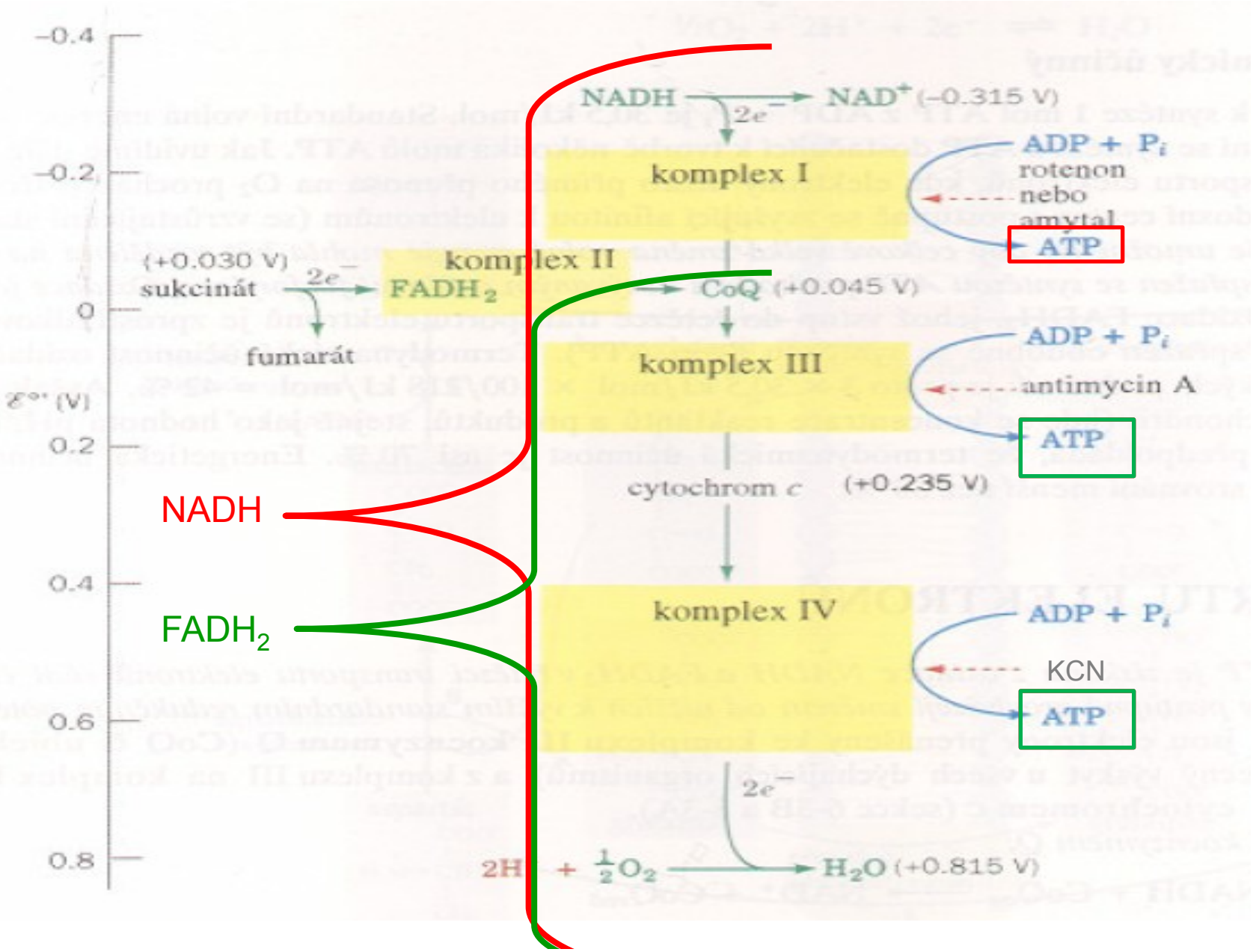
Živočichové
Rostliny
Některé bakterie

$$2H_2 + O_2 \rightarrow 2H_2O$$

45 %

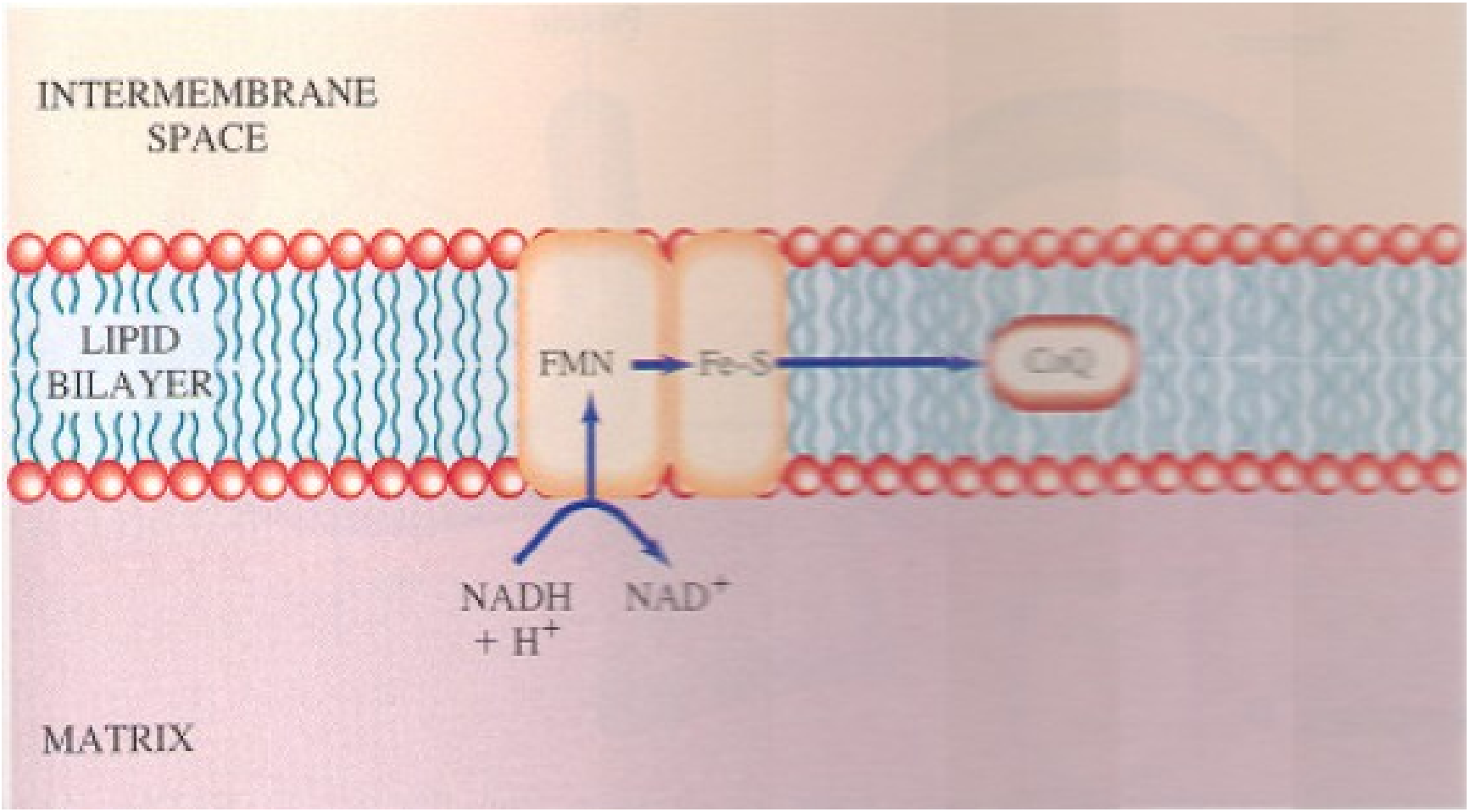
Savčí dýchací řetězec



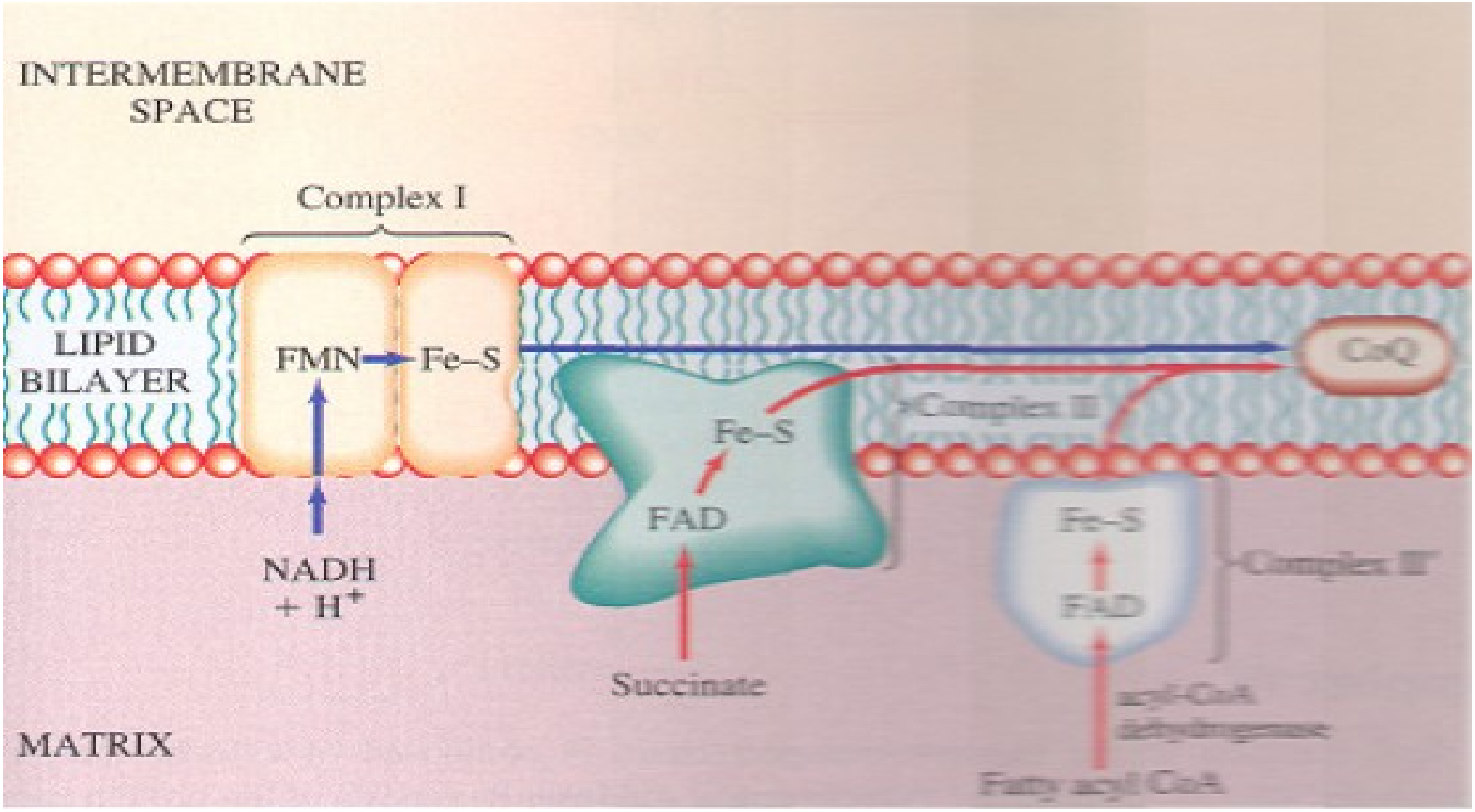


$\Delta G = -nF\Delta E^o$ $\Delta E^o = E_2{}^o - E_1{}^o$ — $0,18\,V \sim +35\,kJ/mol$

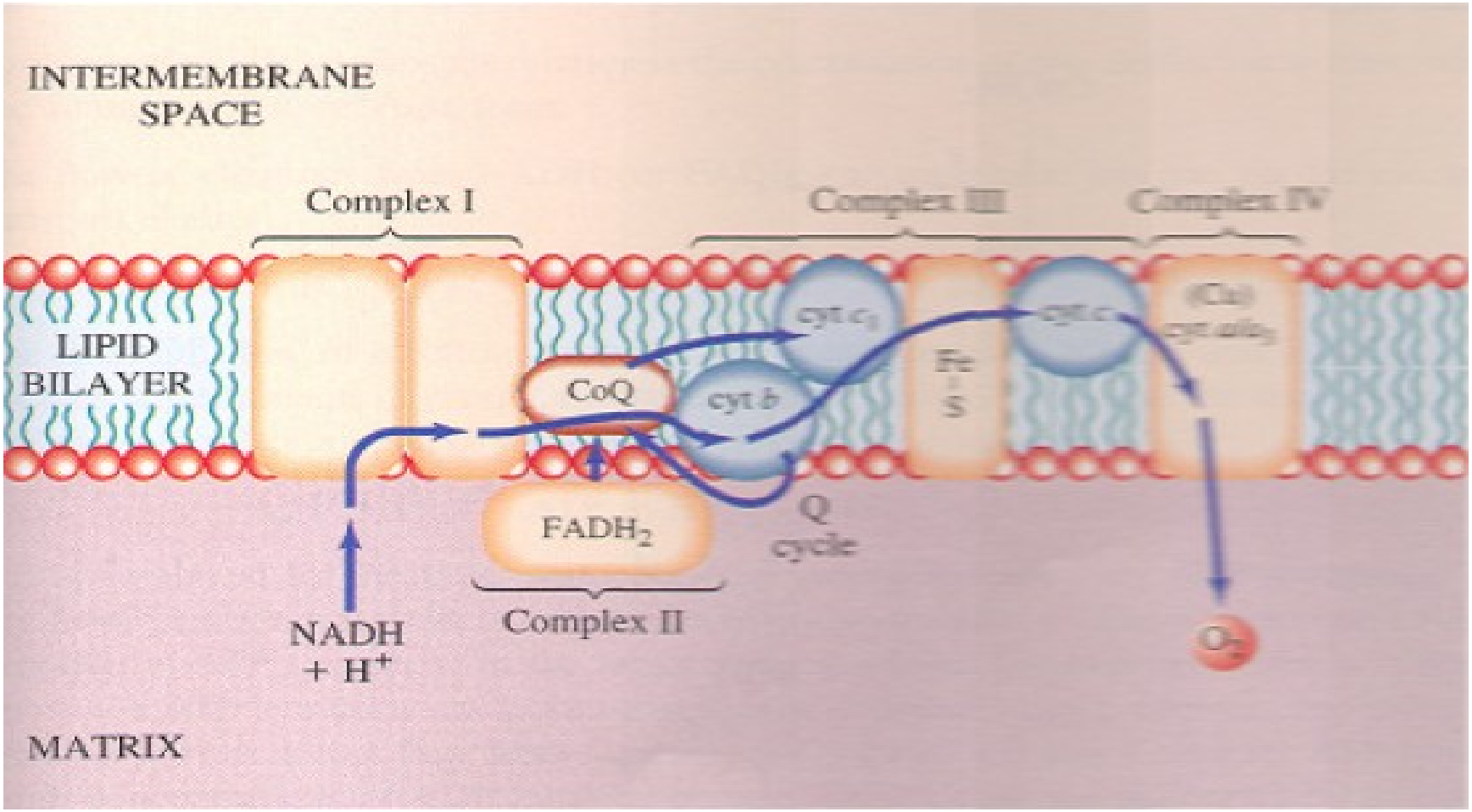
Komplex I


INTERMEMBRANE
SPACE
LIPID
BILAYER
FMN
Fe-S
CoQ
NADH
+ H+
NAD+
MATRIX

Komplex II

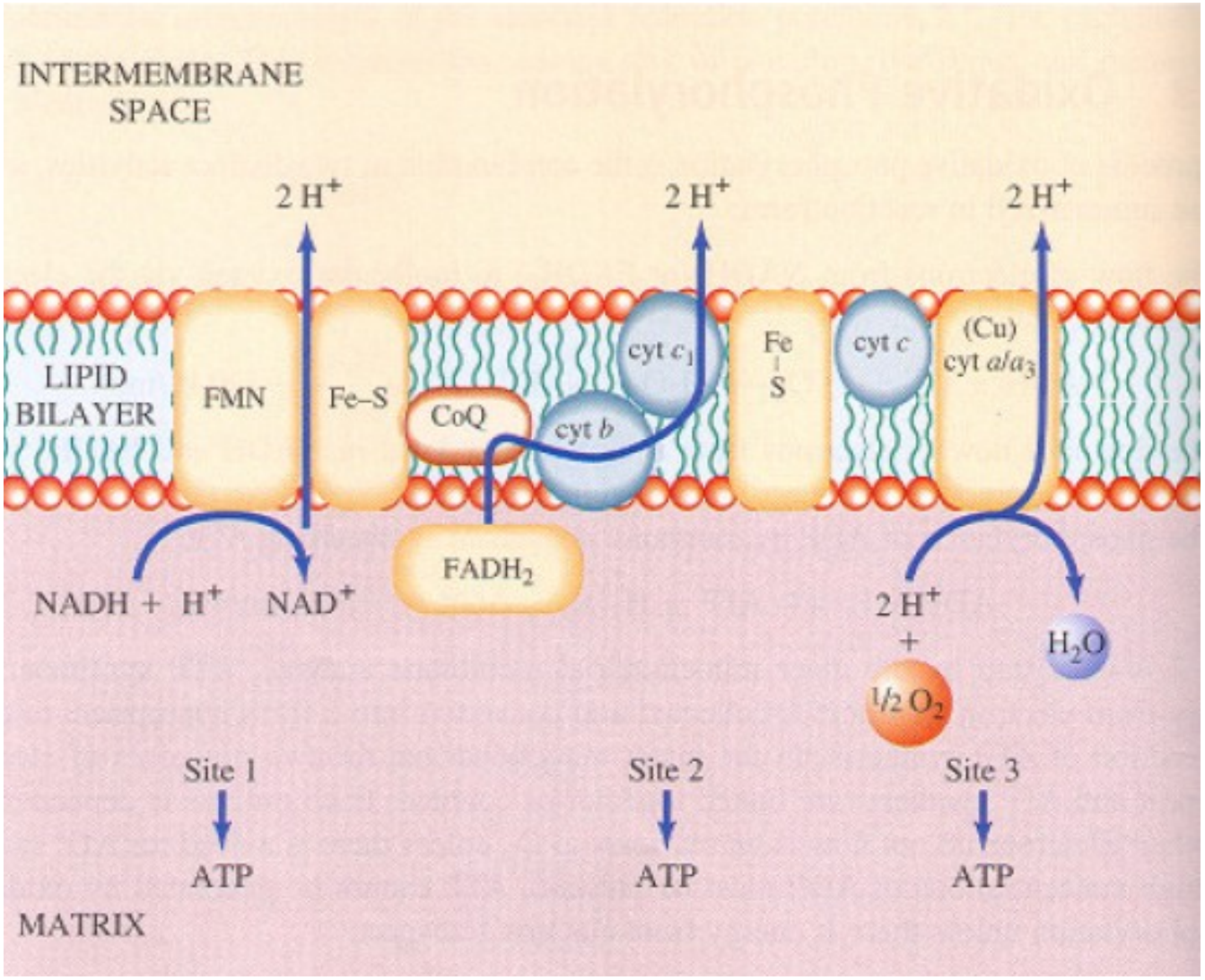

INTERMEMBRANE SPACE
Complex I
LIPID BILAYER
FMN
Fe–S
NADH + H+
Fe–S
FAD
Succinate
CoQ
Fe–S
FAD
MATRIX

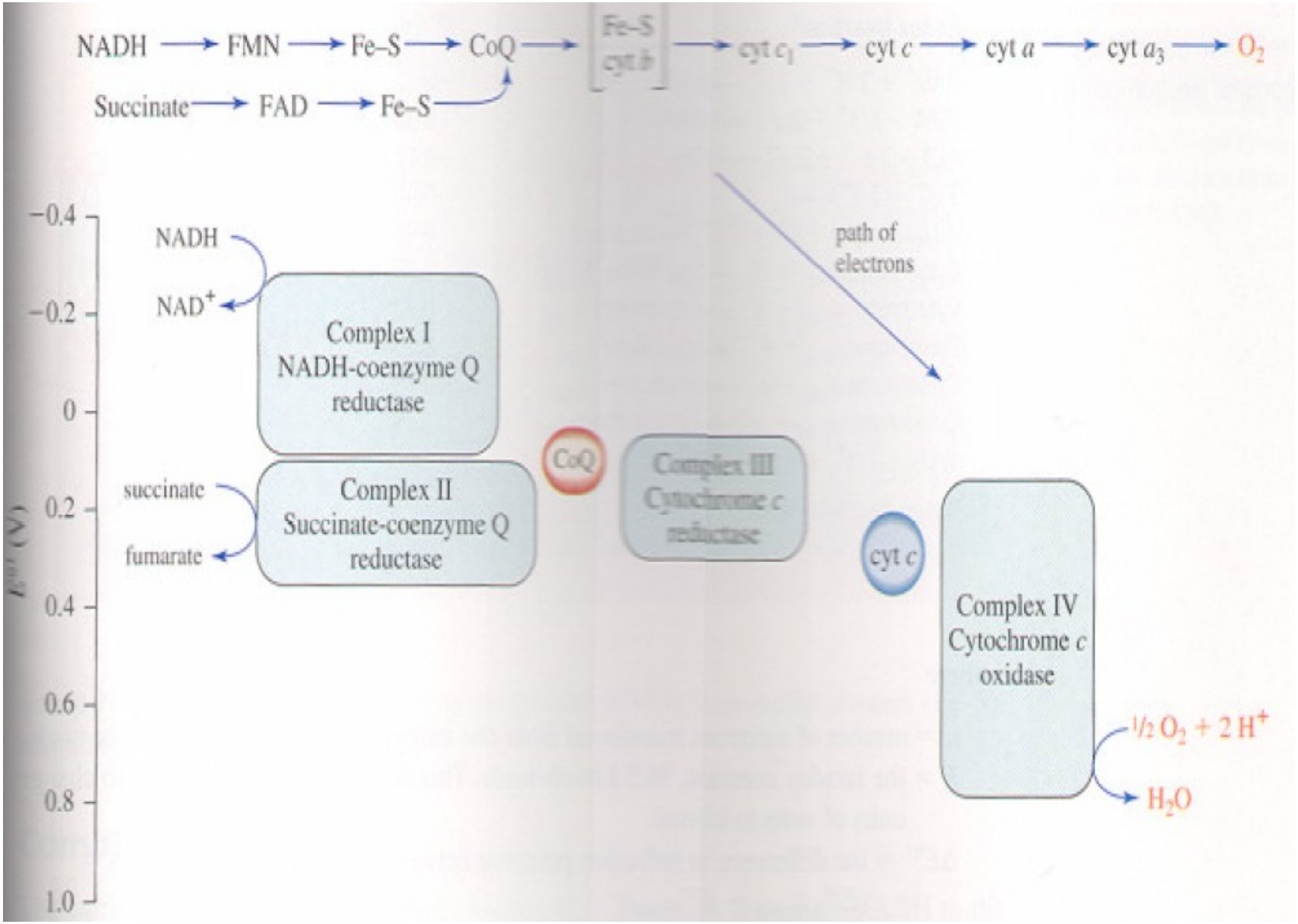
Komplex III a IV



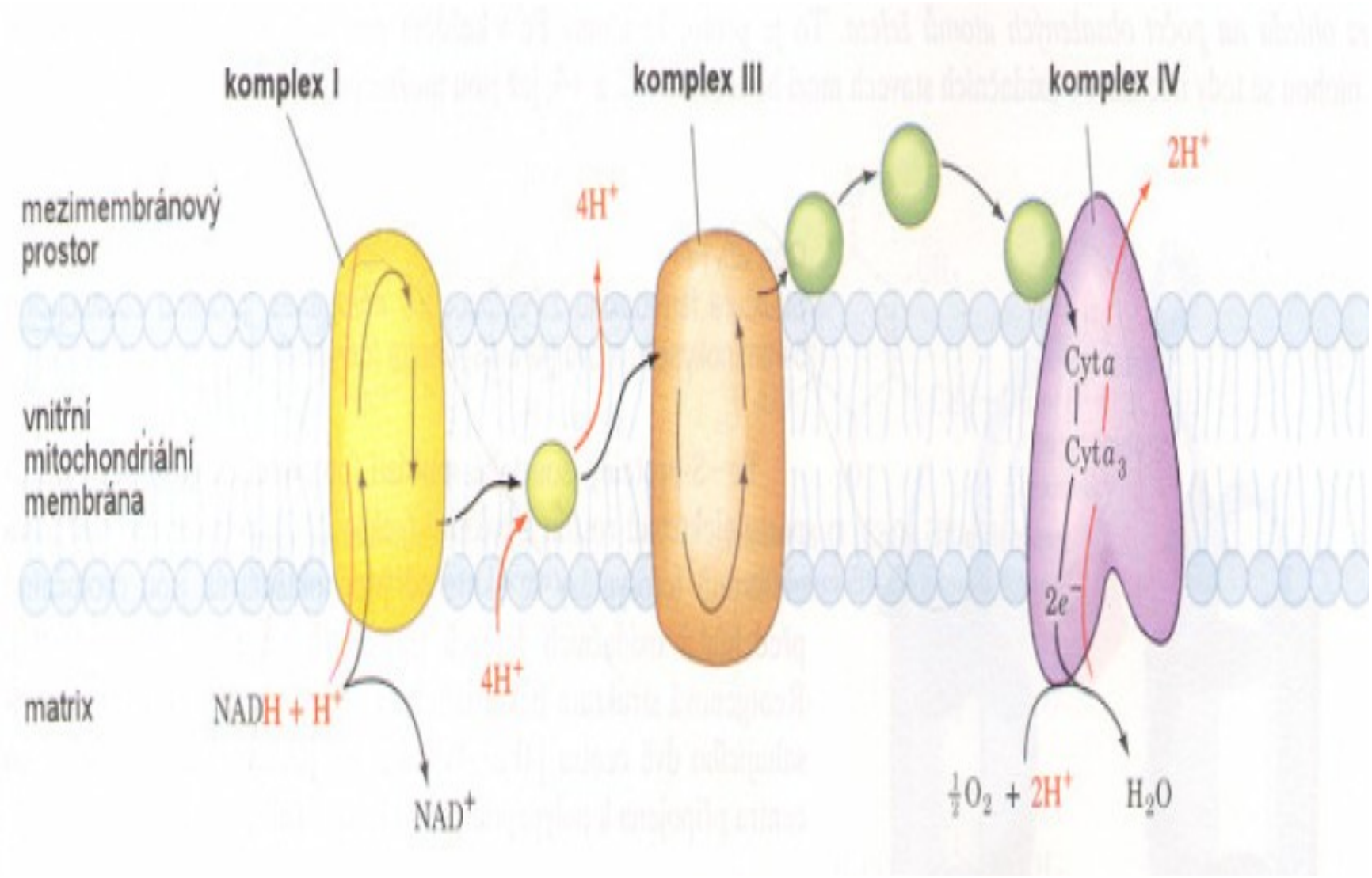
Chemiosmotická teorie

Mitchell 1961

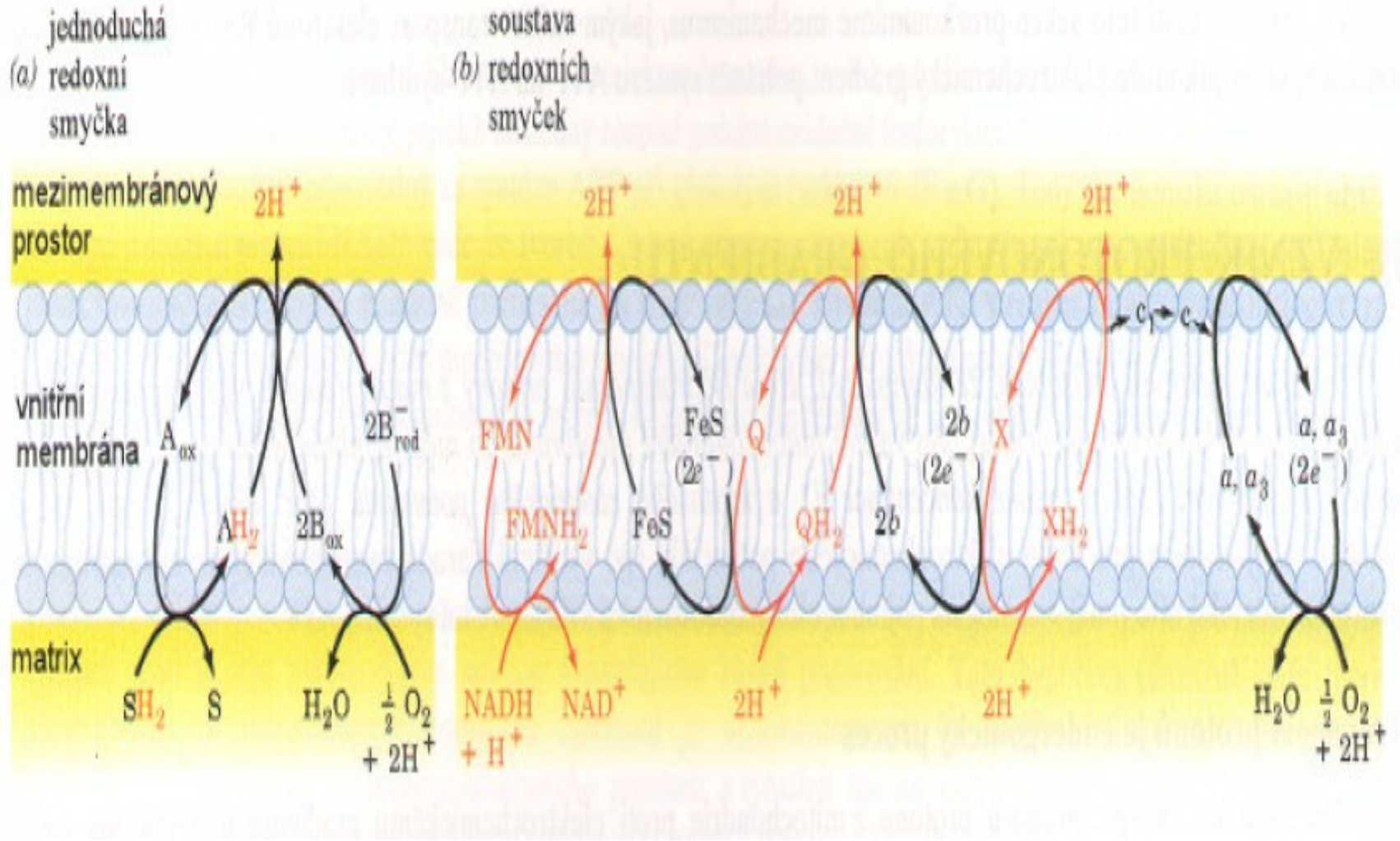



NADH → FMN → Fe–S → CoQ → Fe–S cyt b → cyt c_1 → cyt c → cyt a → cyt a_3 → O_2
Succinate → FAD → Fe–S
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1.0
NADH
NAD^+
Complex I
NADH-coenzyme Q
reductase
succinate
fumarate
Complex II
Succinate-coenzyme Q
reductase
CoQ
Complex III
Cytochrome c
reductase
cyt c
Complex IV
Cytochrome c
oxidase
path of
electrons
$\frac{1}{2} O_2 + 2 H^+$
H_2O

Složky DŘ prostorově orientované



Střídání přenosů e^- a H^+ a jen e^-



PH gradient + diference v elektrickém potenciálu

↓

PROTONMOTIVNÍ SÍLA

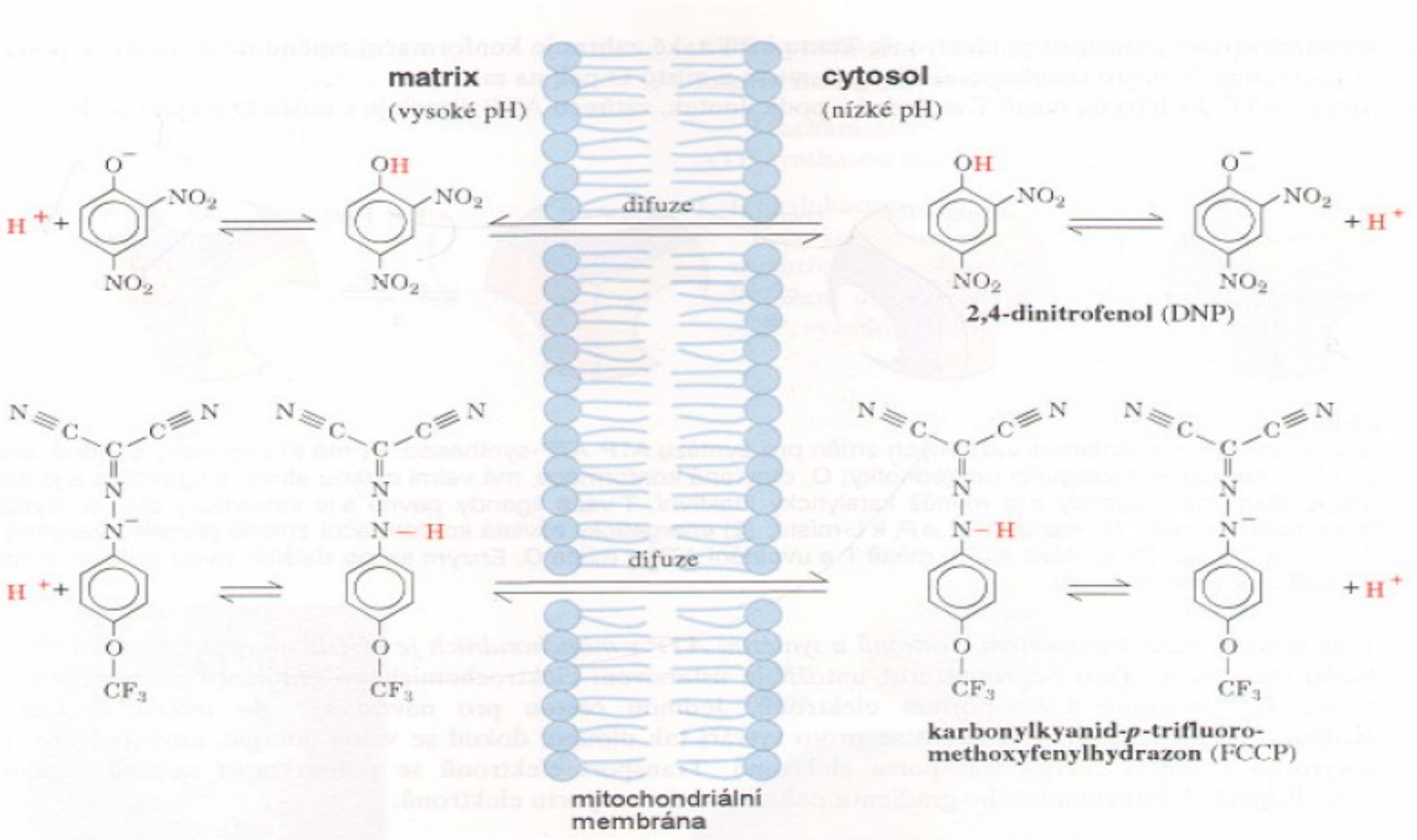
↓

Synthesa ATP

Potvrzení Mitchellovy teorie

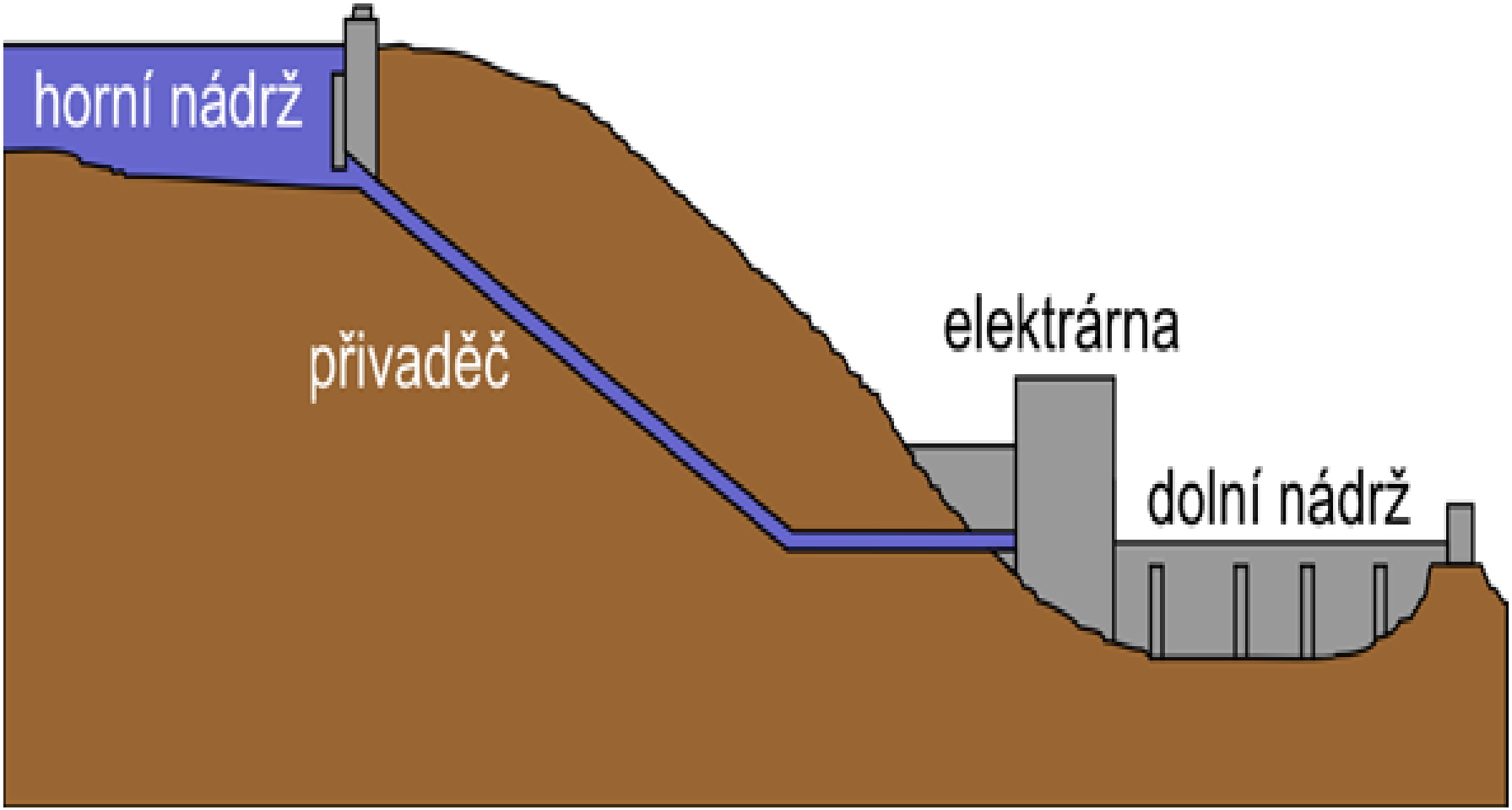
- Umělé snížení pH vně mitochondrie – sythesa ATP
- Látky inhibující tok elektronů brány fosforylaci
- Látky rušící pH gradient odpojují fosforylaci od toku elektronů

Rozpojovače

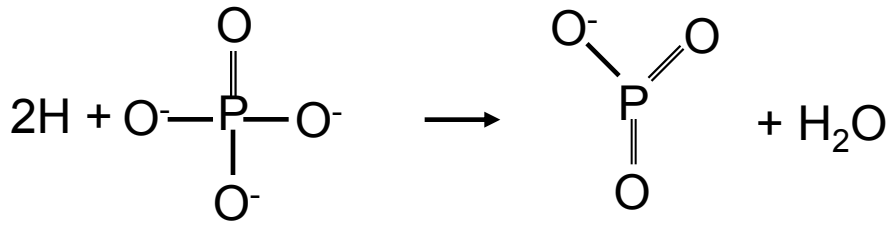


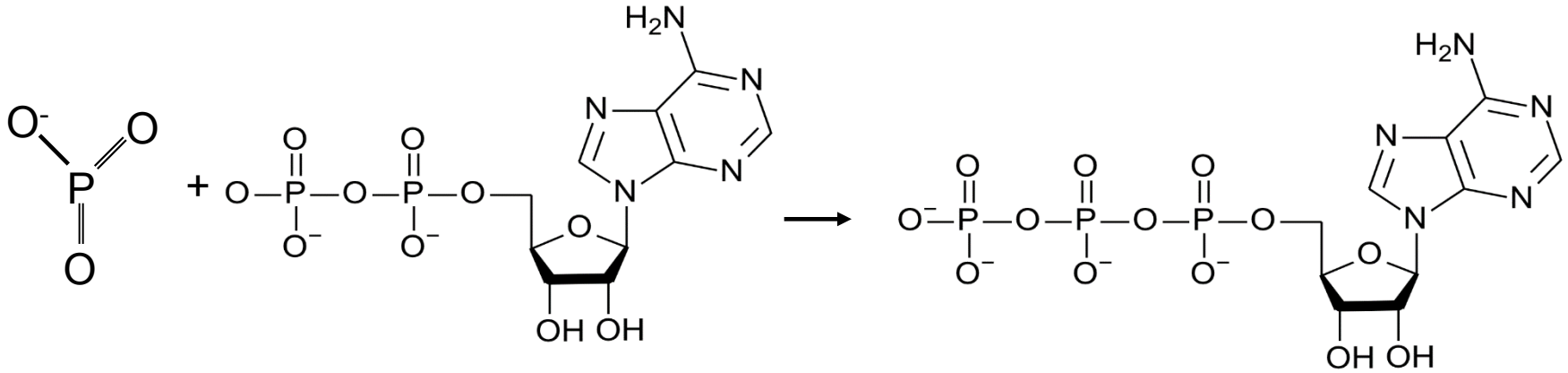
ATPasa

Schéma přečerpávací vodní elektrárny

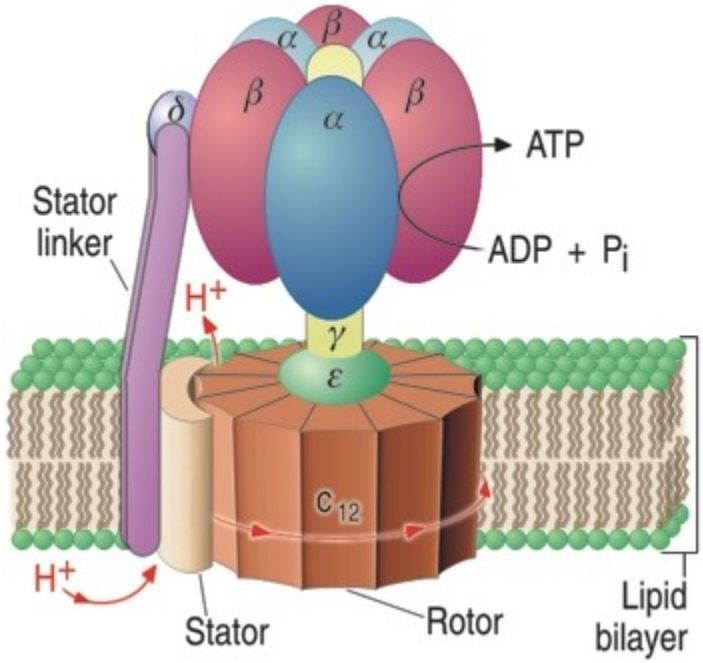


Přímé spřažení reaktivní meziprodukty

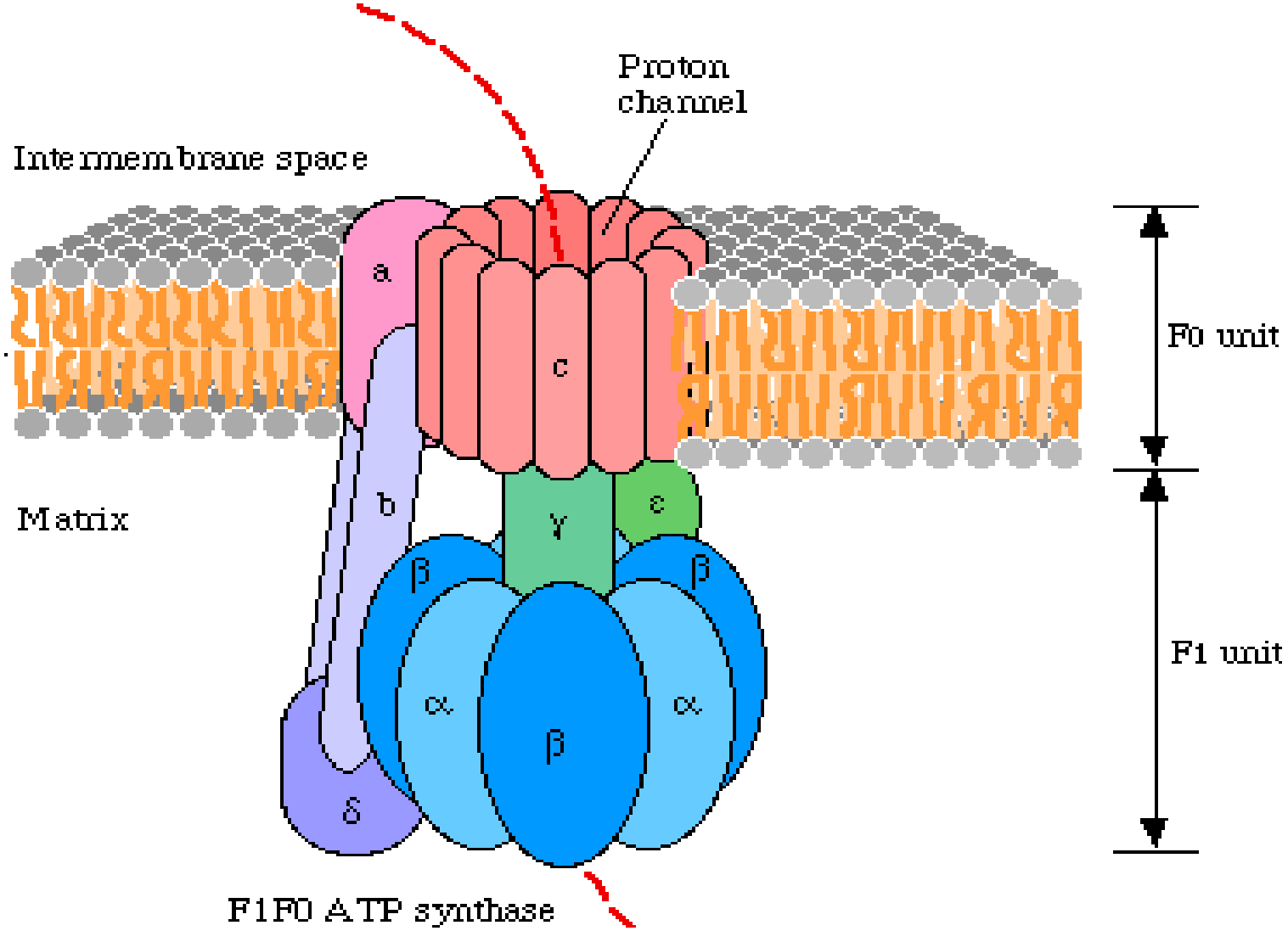


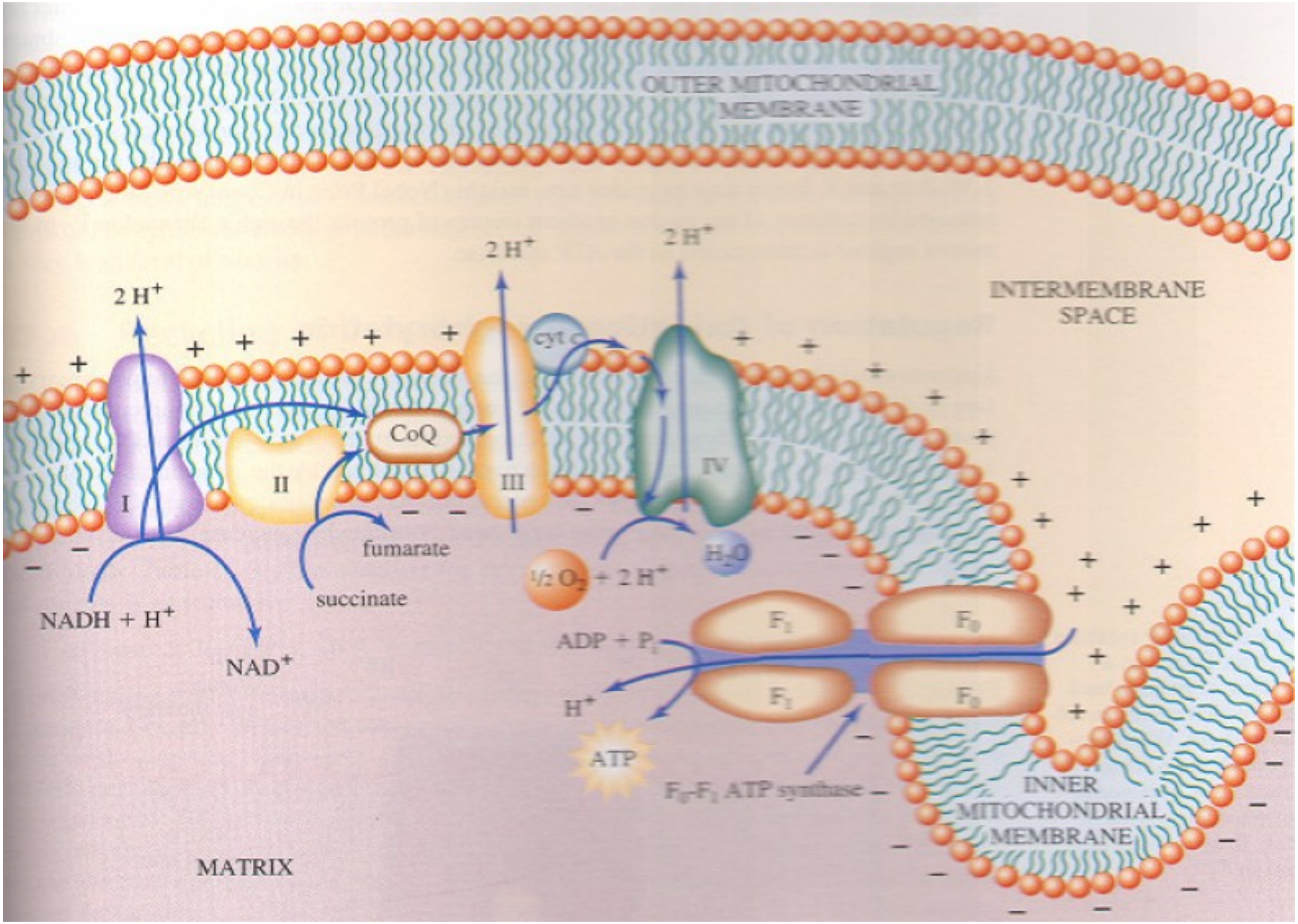


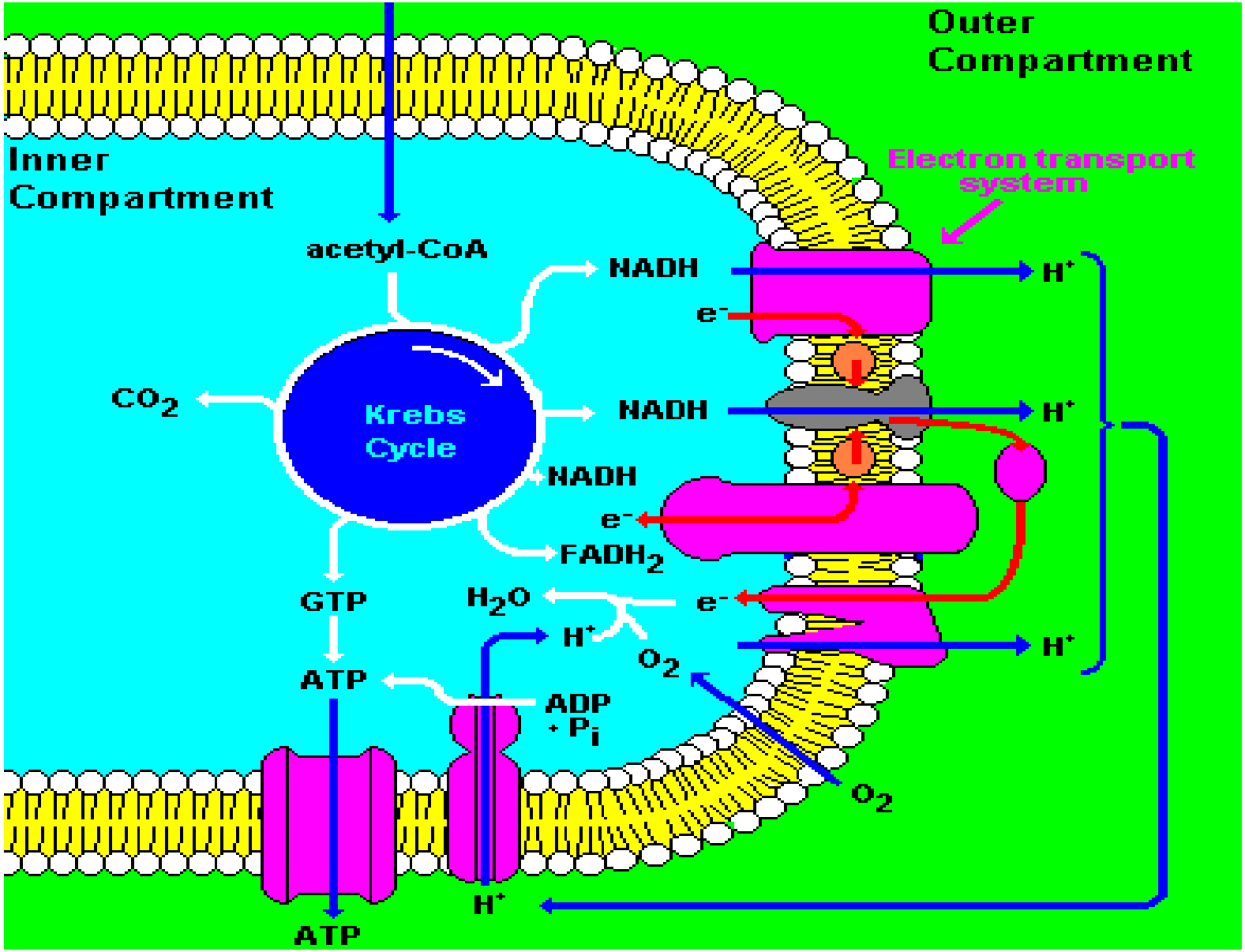
Přímé spřažení reorganizace ATPasy



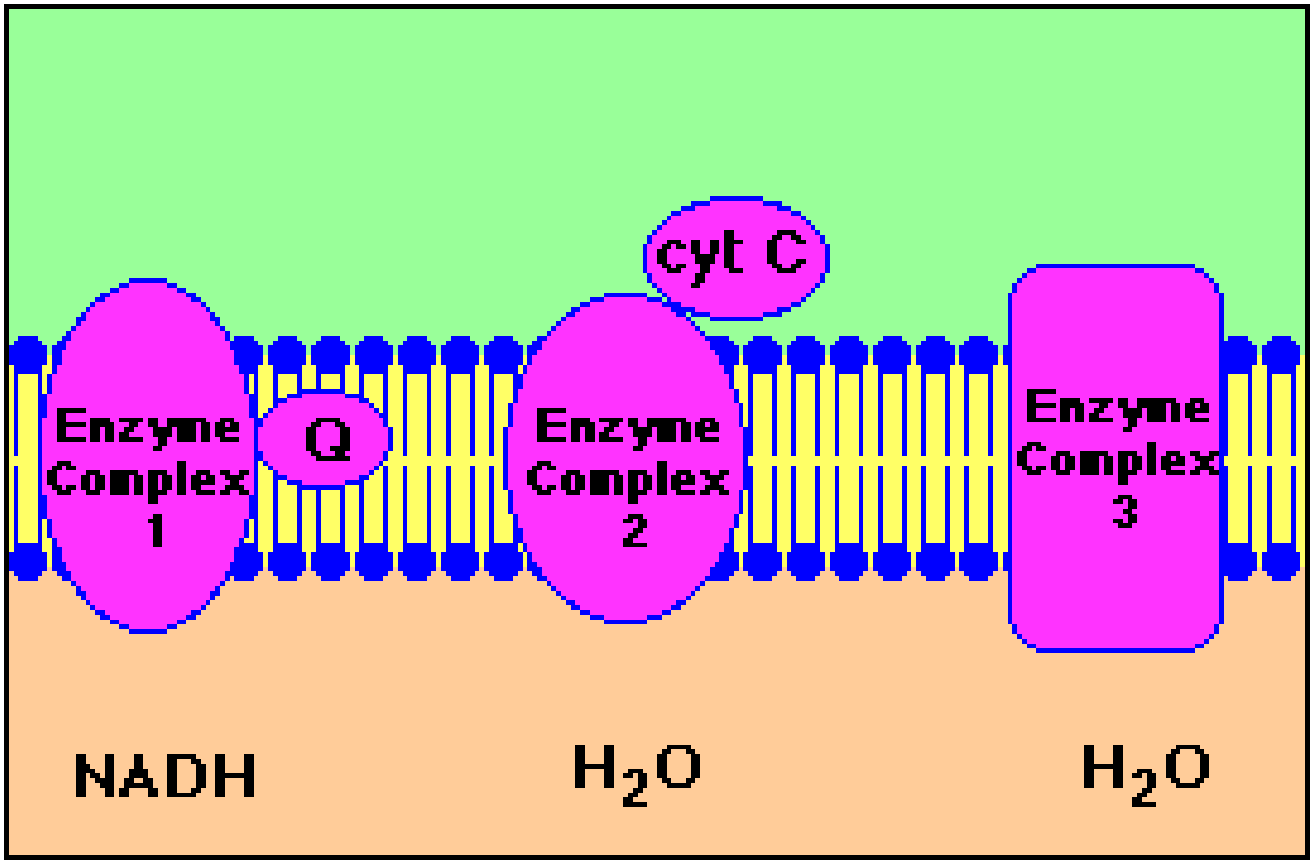
ATPasa


Proton
channel
Intermembrane space
a
c
b
γ
ε
Matrix
β
β
α
β
α
δ
F0 unit
F1 unit
F1F0 ATP synthase

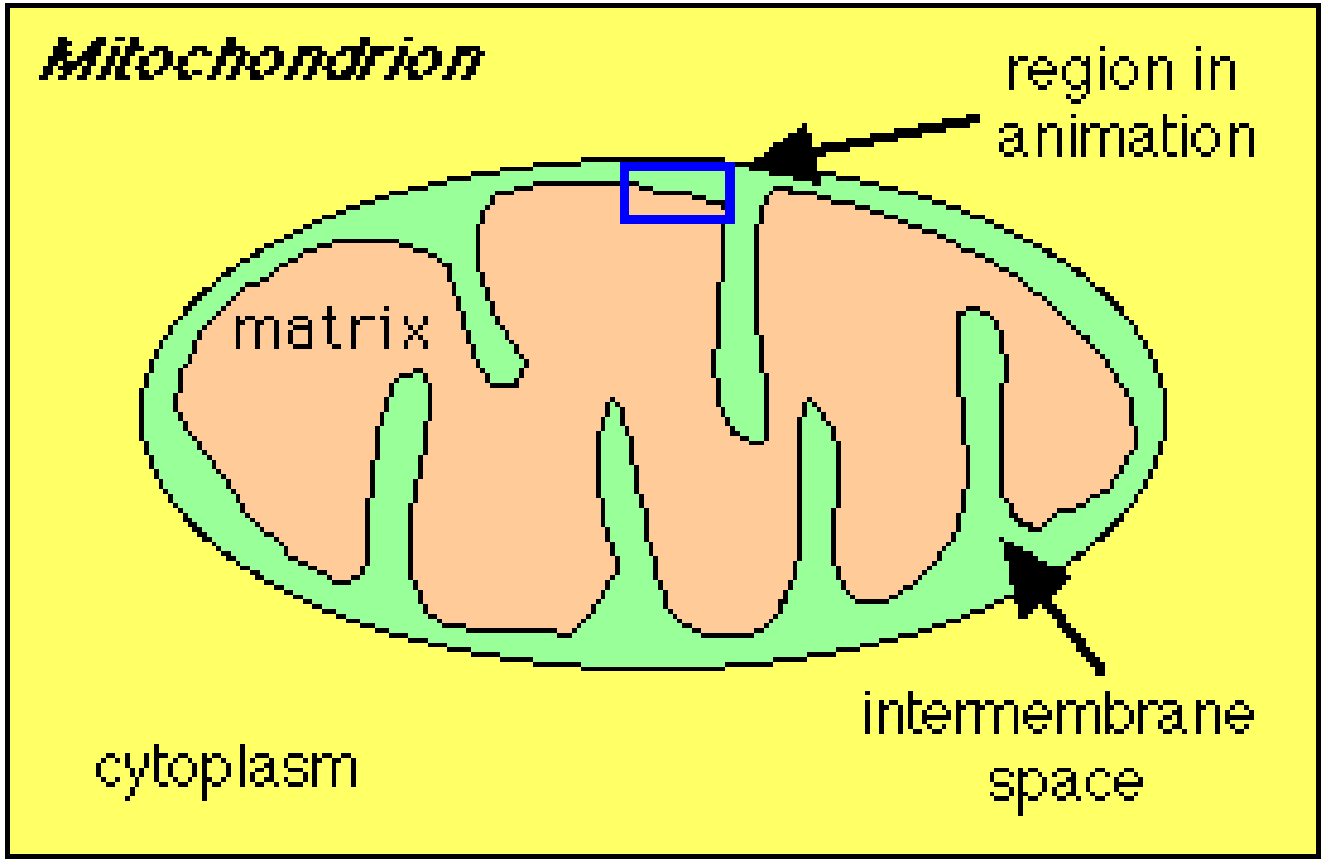

OUTER MITOCHONDRIAL MEMBRANE
INTERMEMBRANE SPACE
2 H+
2 H+
2 H+
I
II
III
IV
CoQ
cyt c
fumarate
succinate
NADH + H+
NAD+
½ O2 + 2 H+
H2O
ADP + Pi
H+
ATP
F0-F1 ATP synthase
F1
F0
F1
F0
MATRIX
INNER MITOCHONDRIAL MEMBRANE


Outer Compartment
Inner Compartment
Electron transport system
acetyl-CoA
NADH
H+
e-
CO2
Krebs Cycle
NADH
H+
NADH
e-
FADH2
GTP
H2O
e-
H+
H+
O2
ATP
ADP + Pi
O2
H+
ATP

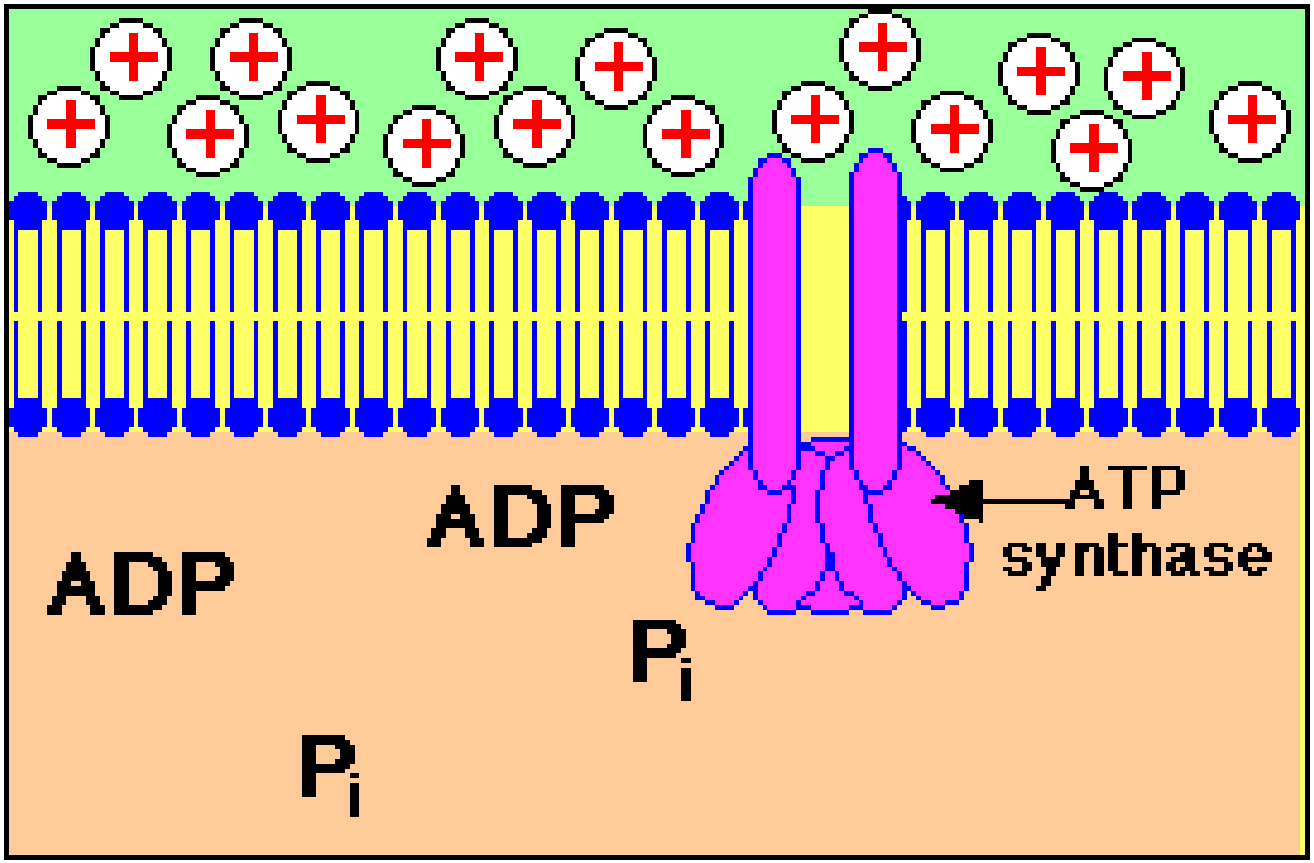
Transport elektronů



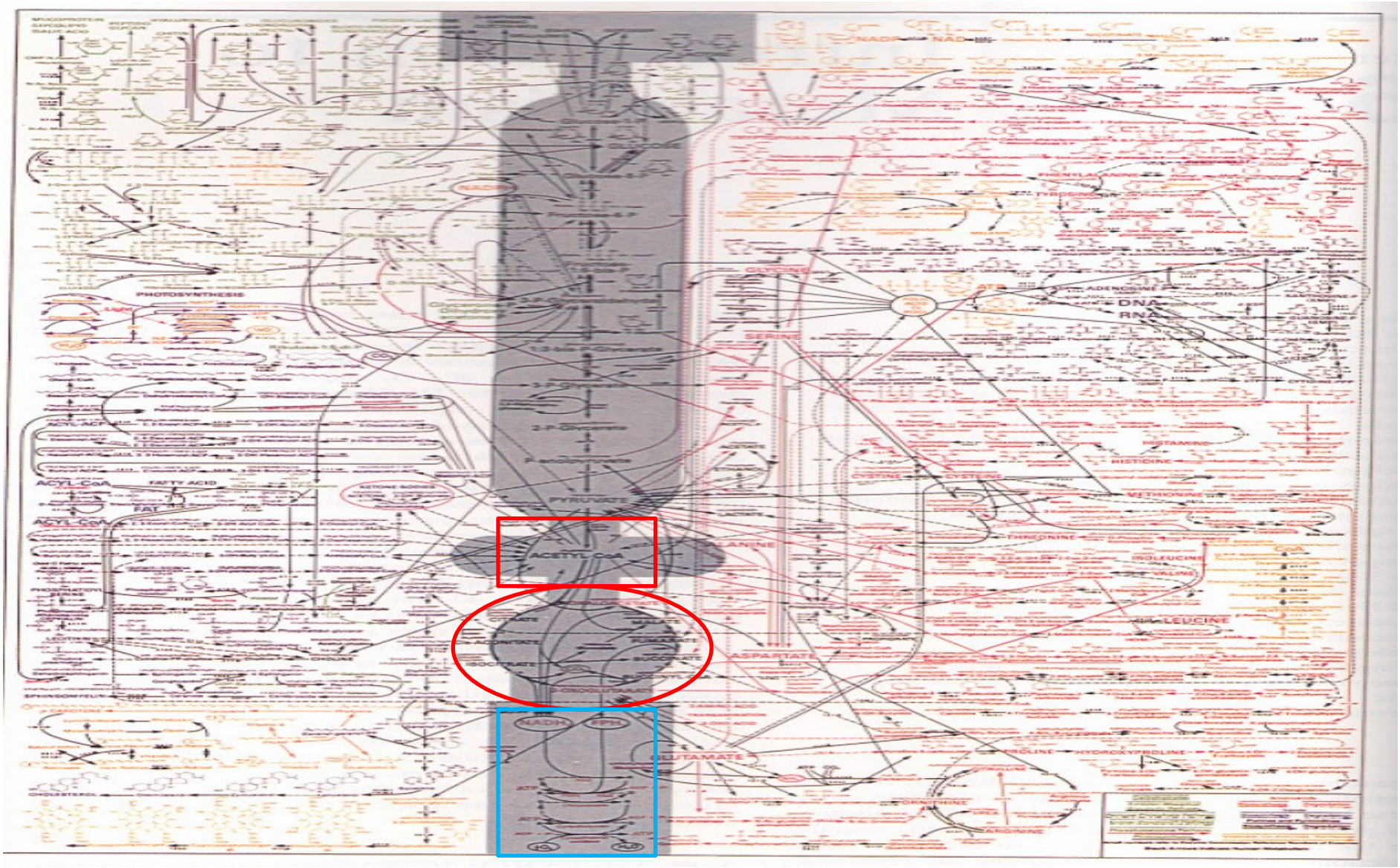
Lokalizace


Mitochondrion
region in animation
matrix
intermembrane space
cytoplasm

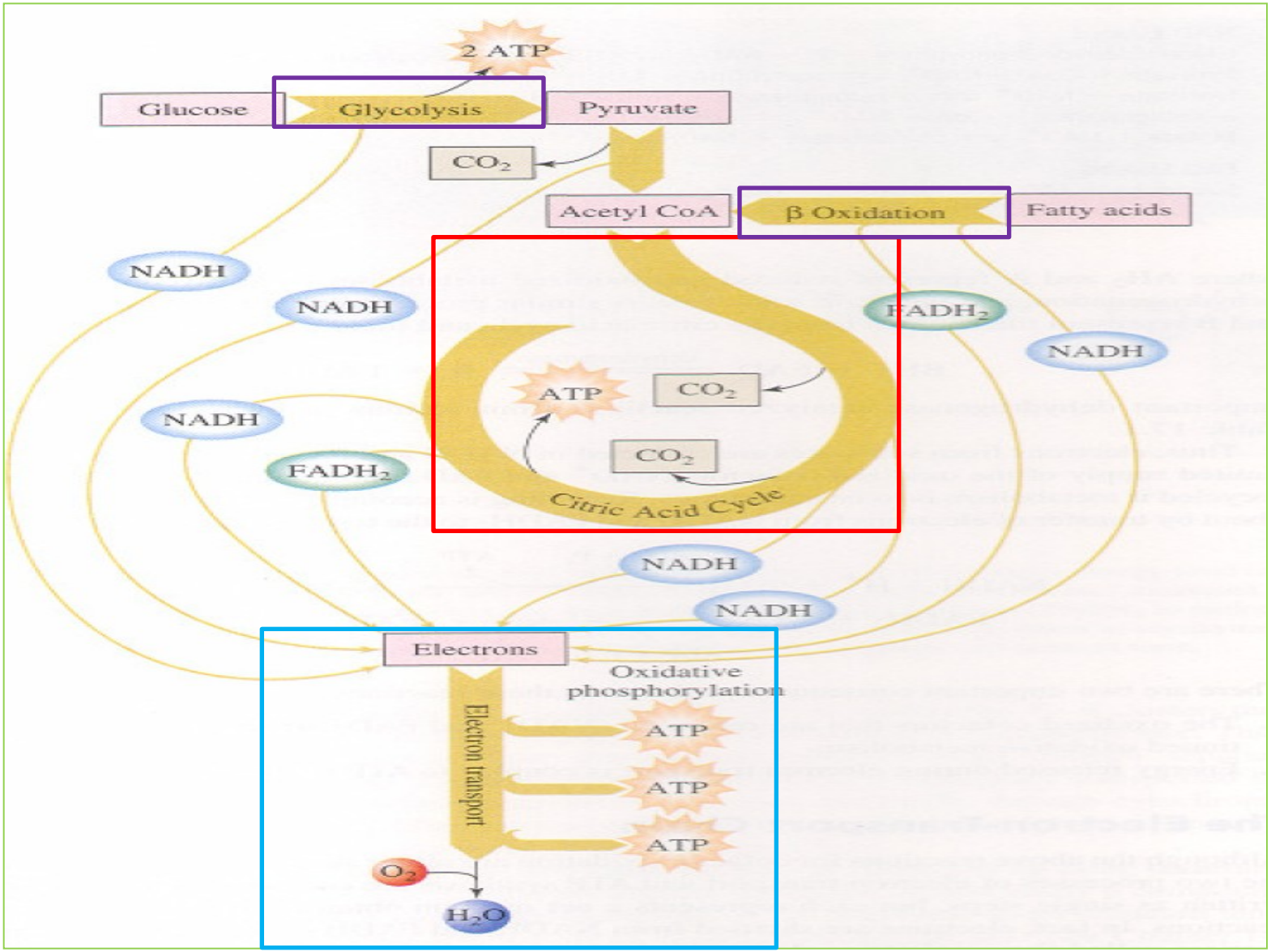
ATPasa



Metabolické dráhy

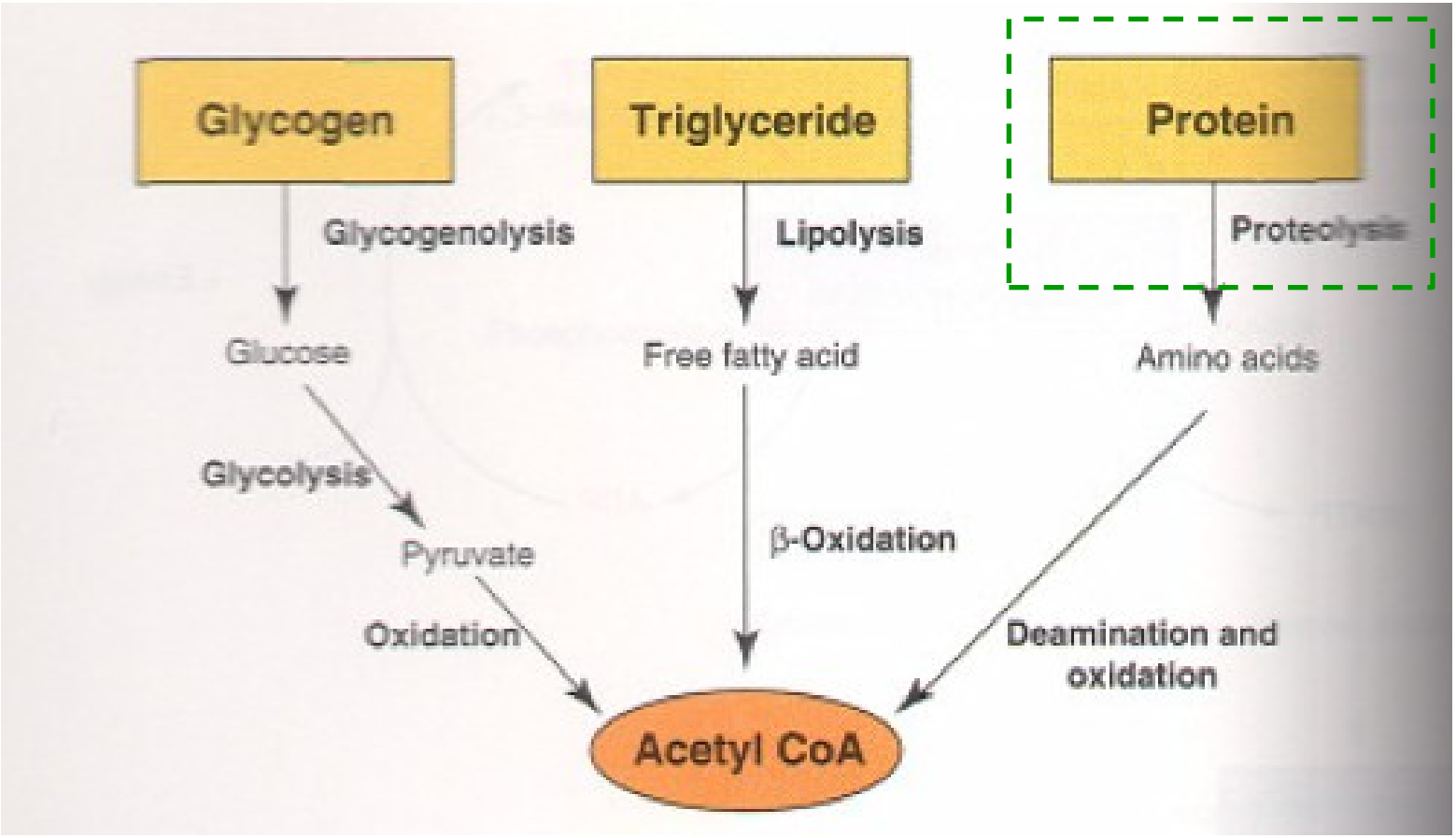


Metabolické dráhy



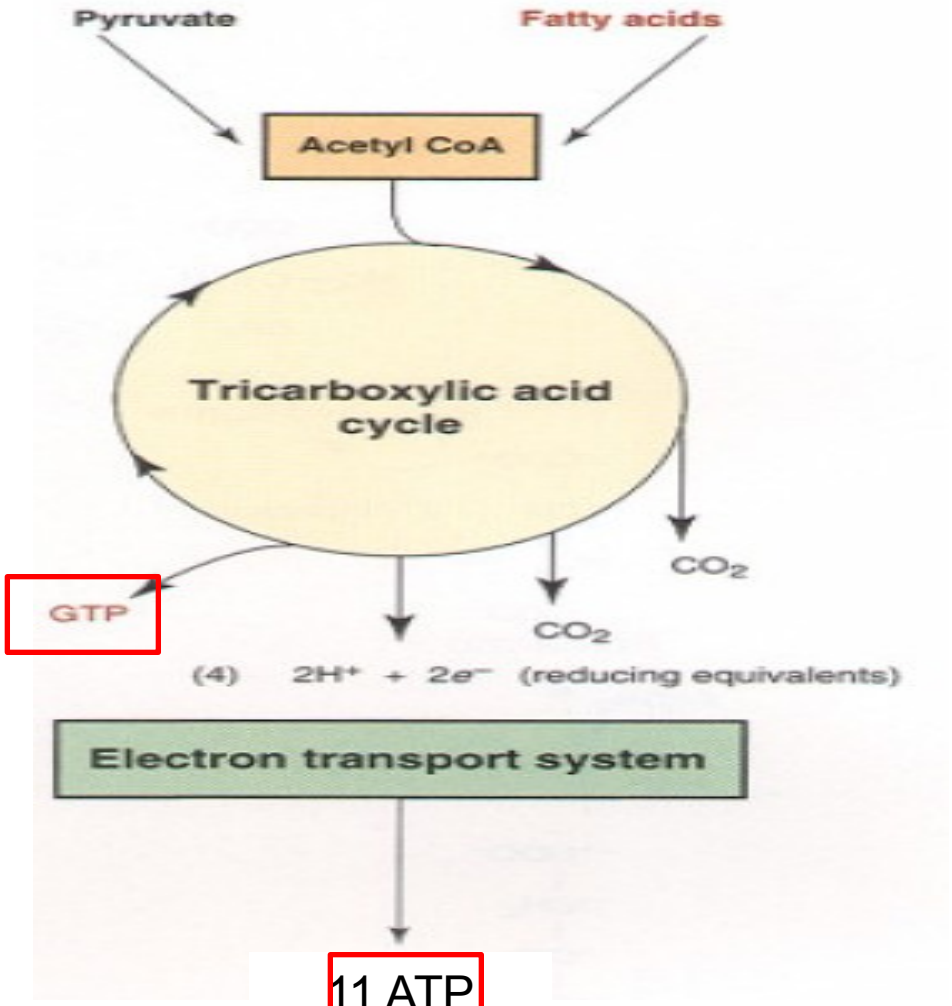
CITRÁTOVÝ CYKLUS

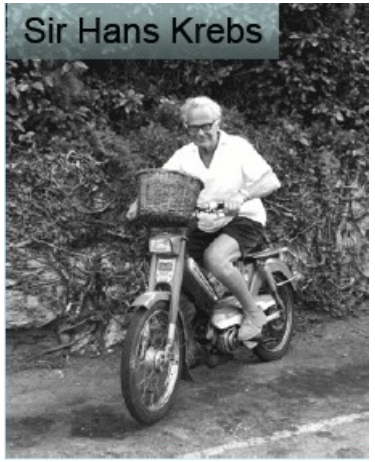
H.Krebs (1937) - Krebsův cyklus, cyklus trikarboxylových kyselin



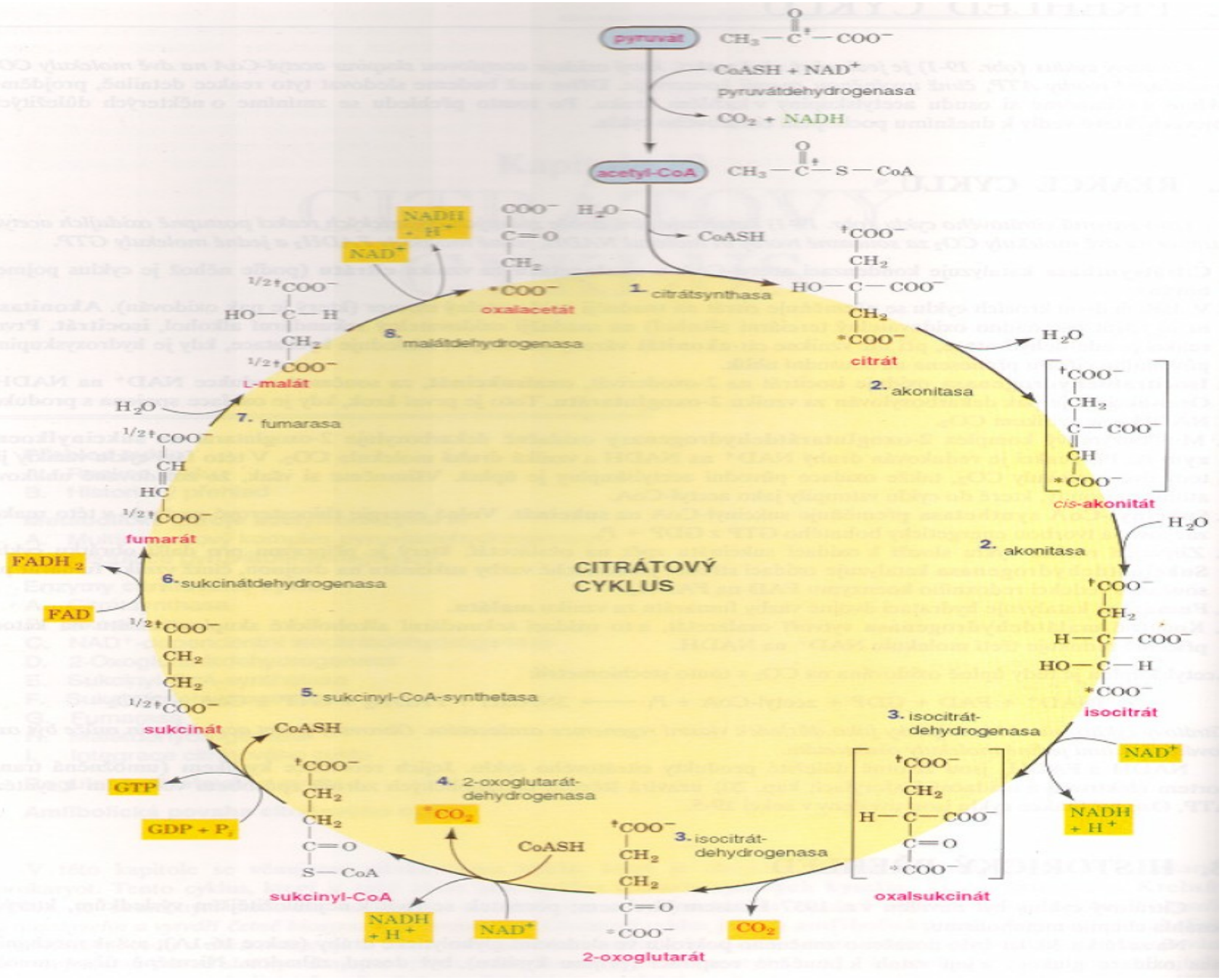
CITRÁTOVÝ CYKLUS

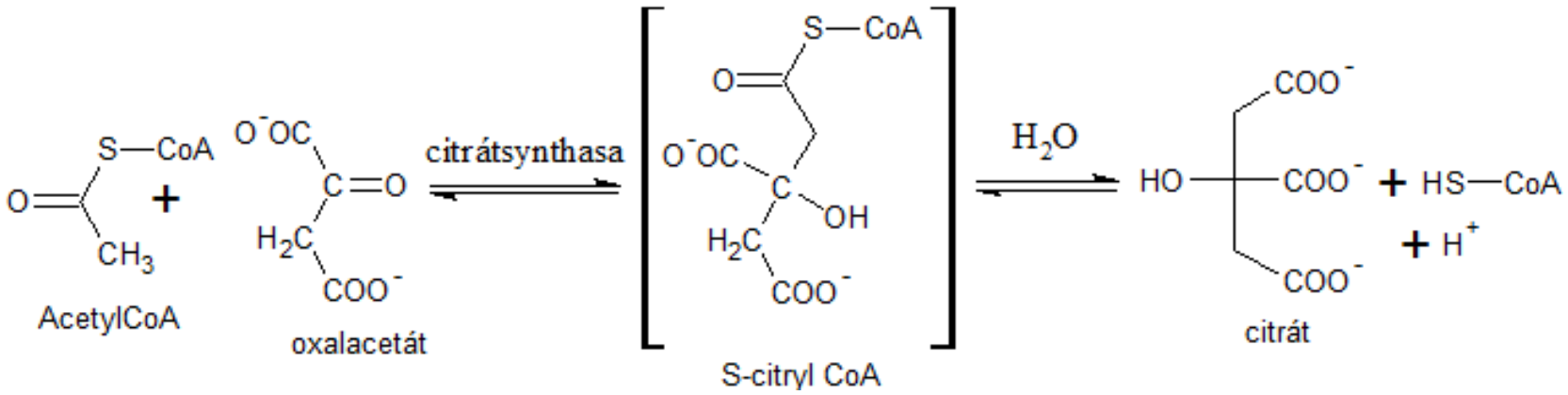
H.Krebs (1937) - Krebsův cyklus, cyklus trikarboxylových kyselin

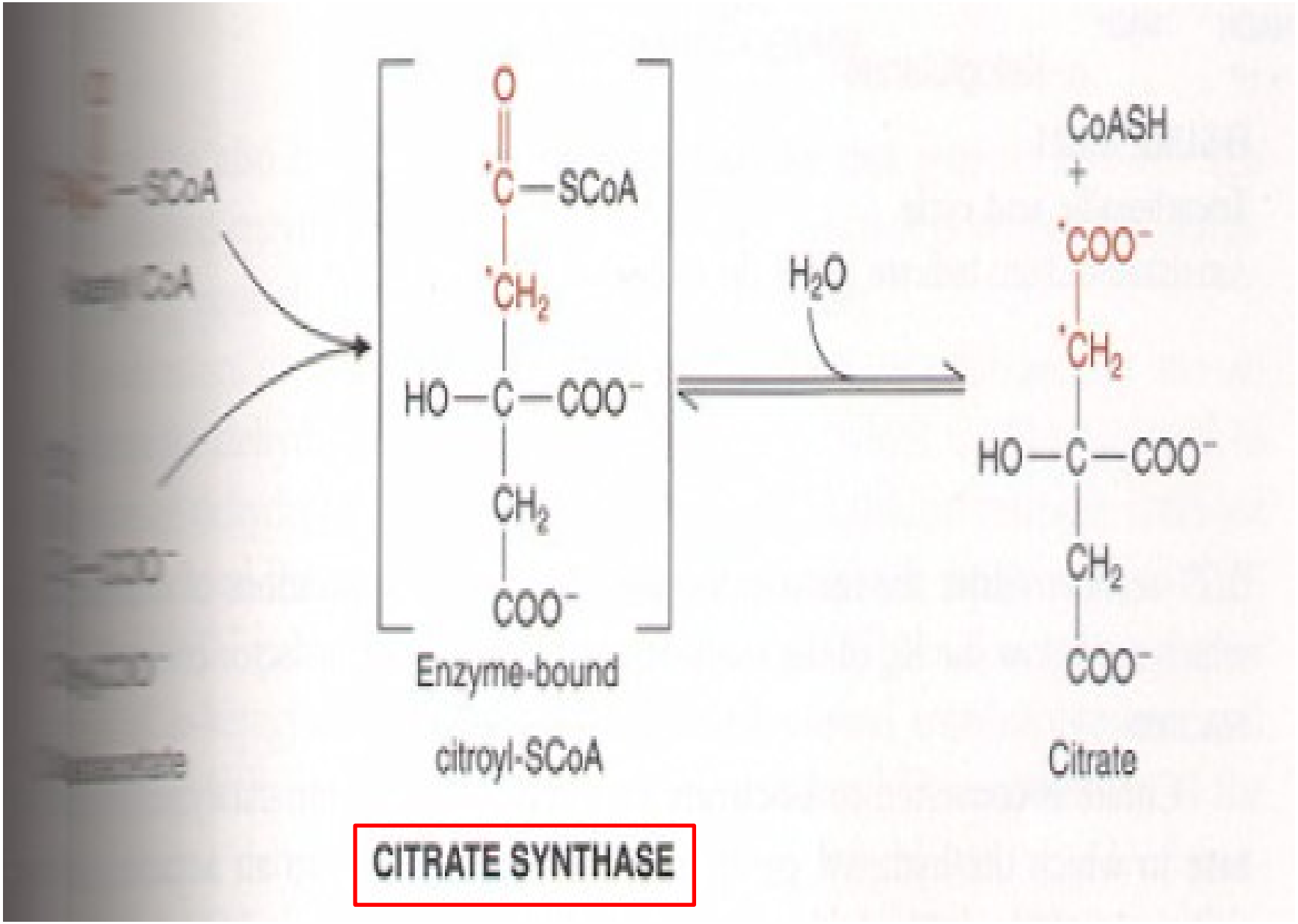




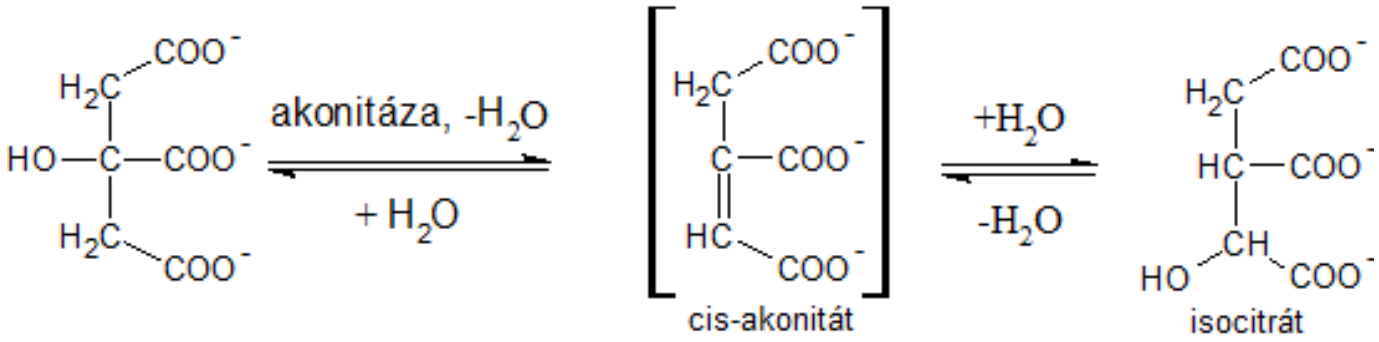
1953 NC

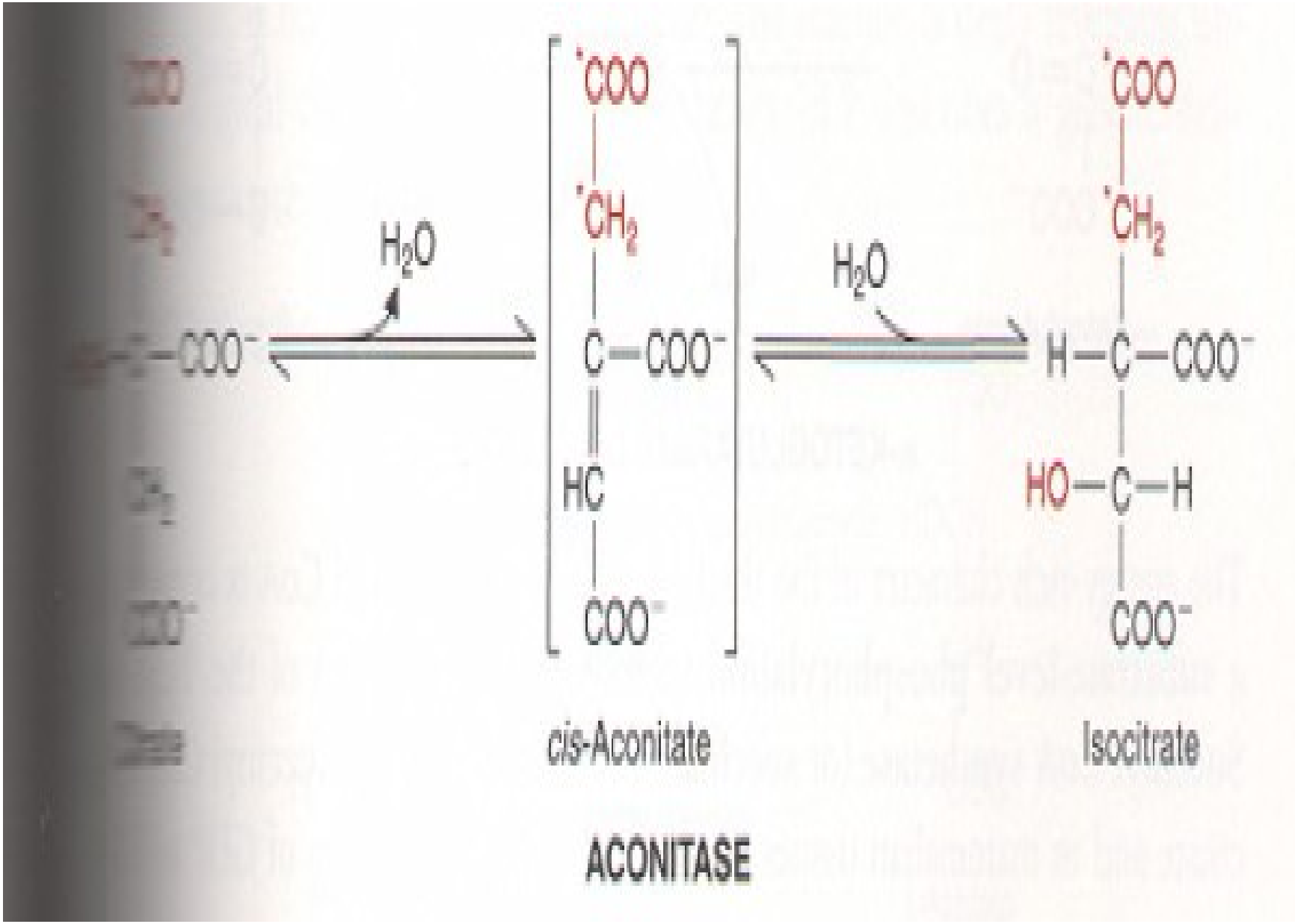

pyruvát
CoASH + NAD+
pyruvátdehydrogenasa
CO2 + NADH
acetyl-CoA
CoASH
1. citrátsynthasa
oxalacetát
citrát
2. akonitasa
cis-akonitát
2. akonitasa
isocitrát
3. isocitrát-dehydrogenasa
NADH + H+
oxalsukcinát
CO2
3. isocitrát-dehydrogenasa
2-oxoglutarát
4. 2-oxoglutarát-dehydrogenasa
CO2
CoASH
sukcinyl-CoA
5. sukcinyl-CoA-synthetasa
GTP
GDP + P
sukcinát
6. sukcinátdehydrogenasa
FADH2
FAD
fumarát
7. fumarasa
L-malát
8. malátdehydrogenasa
NADH + H+
NAD+
CITRÁTOVÝ CYKLUS

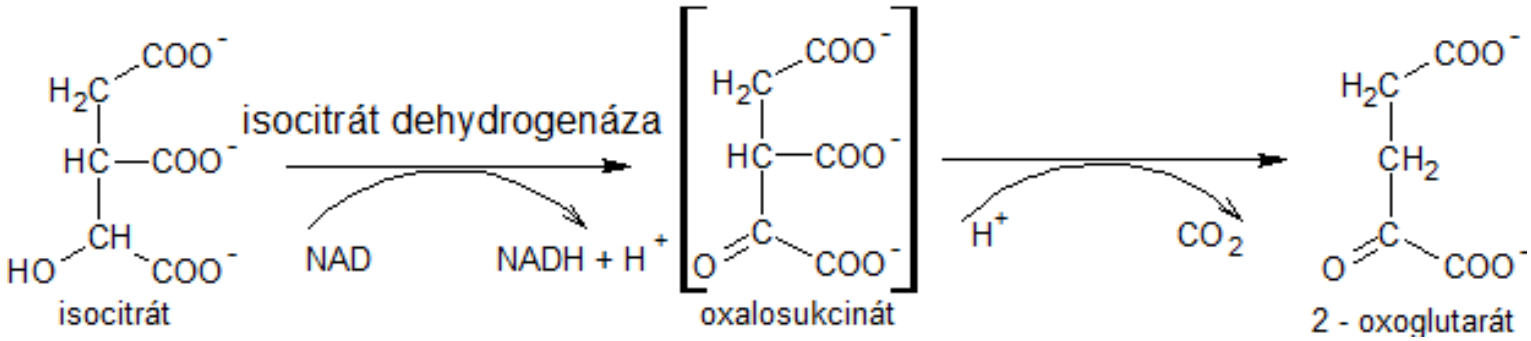

S—CoA
O
CH3
AcetylCoA
O-OC
C=O
H2C
COO-
oxalacetát
citrátsynthasa
S—CoA
O
O-OC
C
OH
H2C
COO-
S-citryl CoA
H2O
COO-
HO
COO-
COO-
citrát
HS—CoA
H+

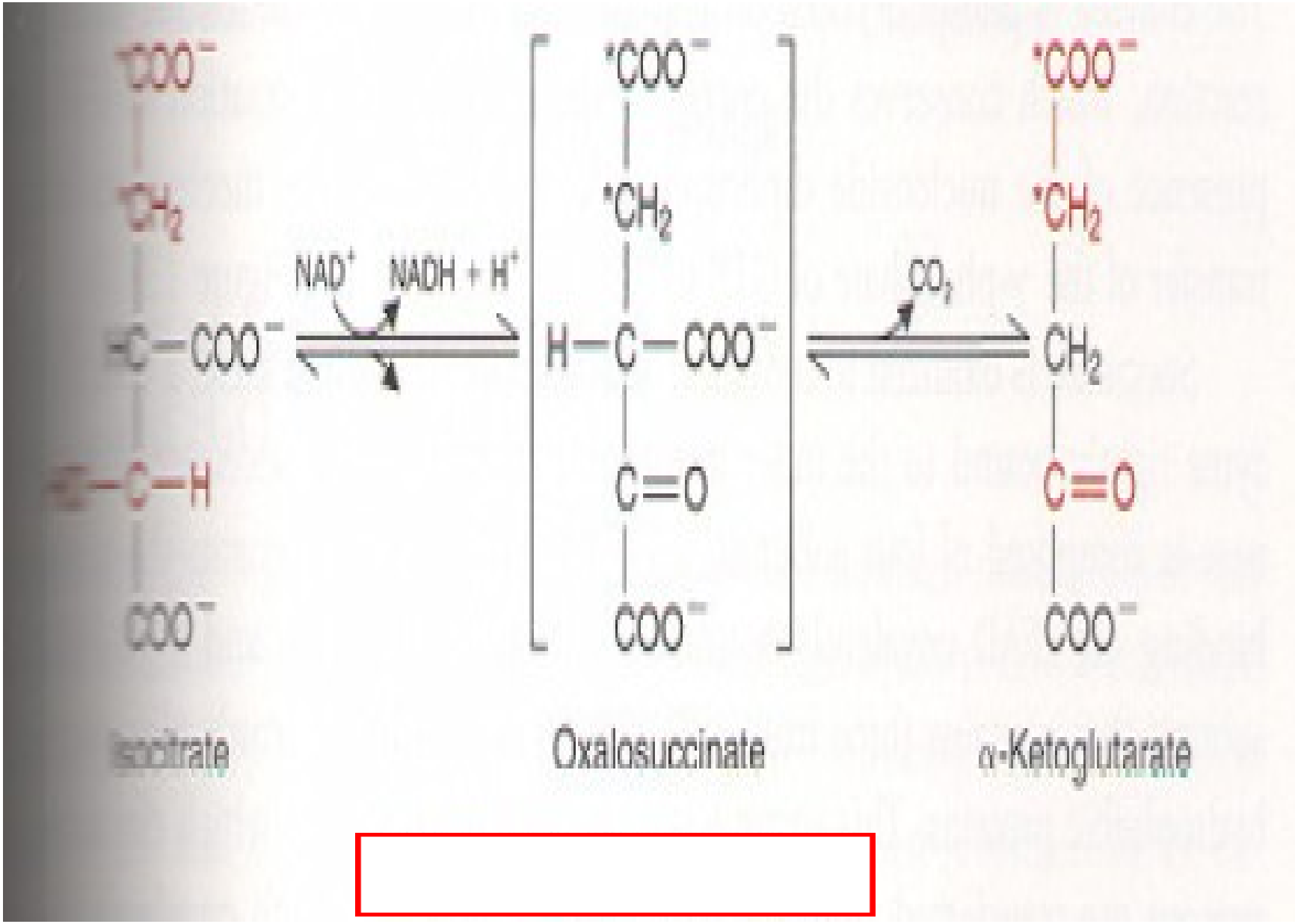


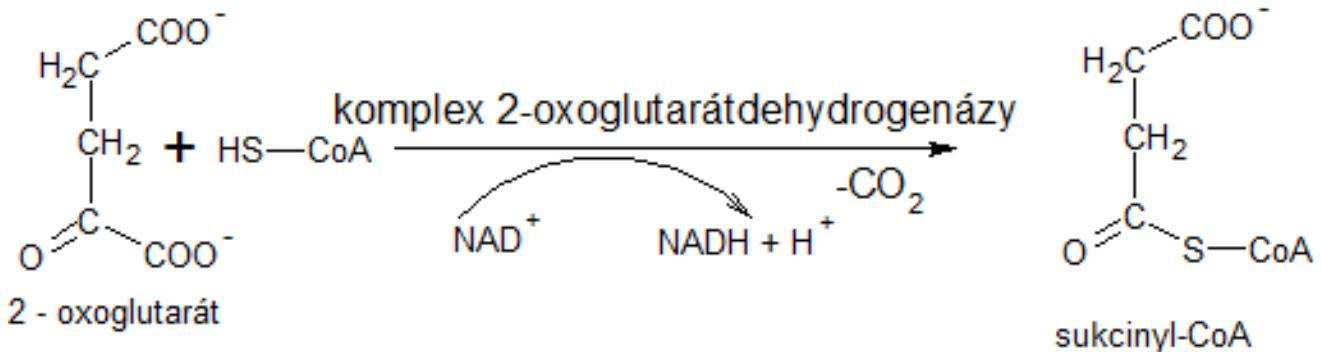
CITRATE SYNTHASE


akonitáza, -H2O
+ H2O
cis-akonitát
+H2O
-H2O
isocitrát


H2O
H2O
cis-Aconitate
Isocitrate
ACONITASE

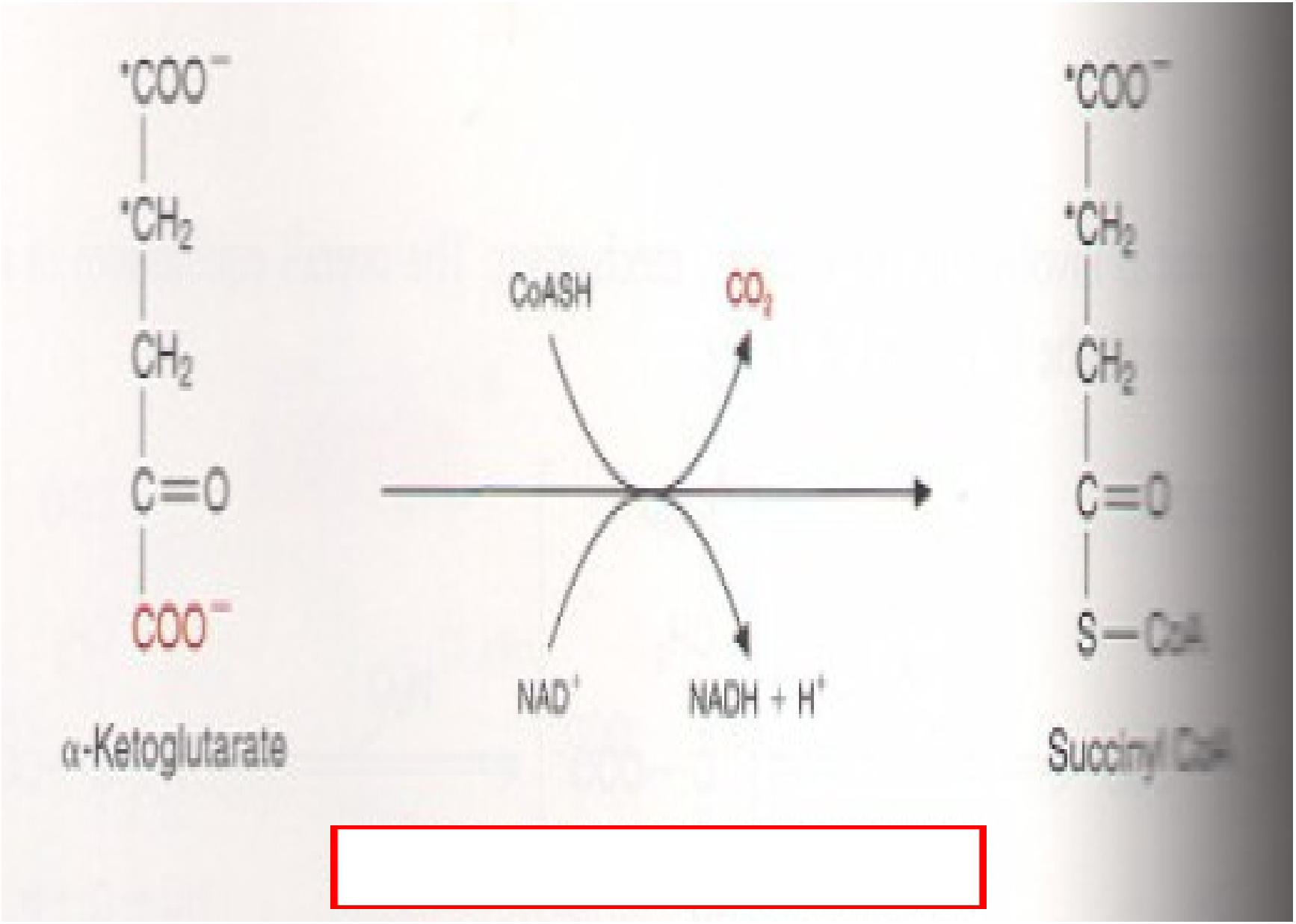

isocitrát dehydrogenáza
NAD
NADH + H+
H+
CO2
isocitrát
oxalosukcinát
2 - oxoglutarát


NAD+
NADH + H+
CO2
Isocitrate
Oxalosuccinate
α-Ketoglutarate

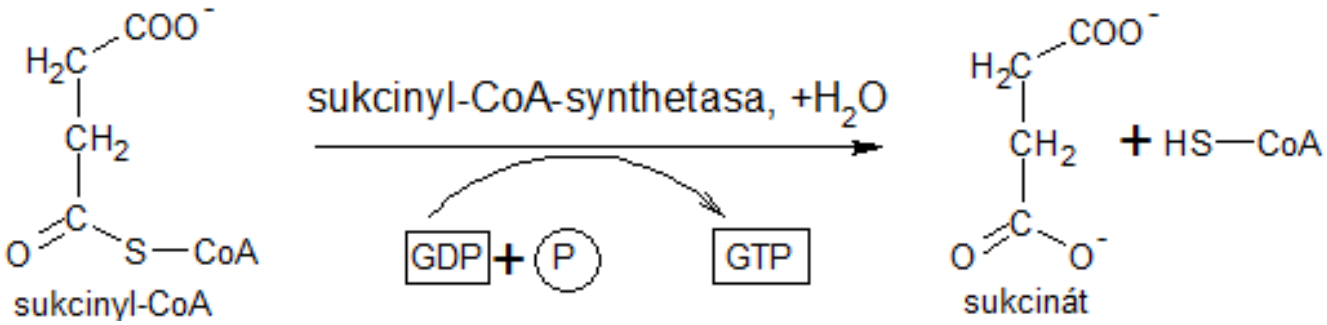


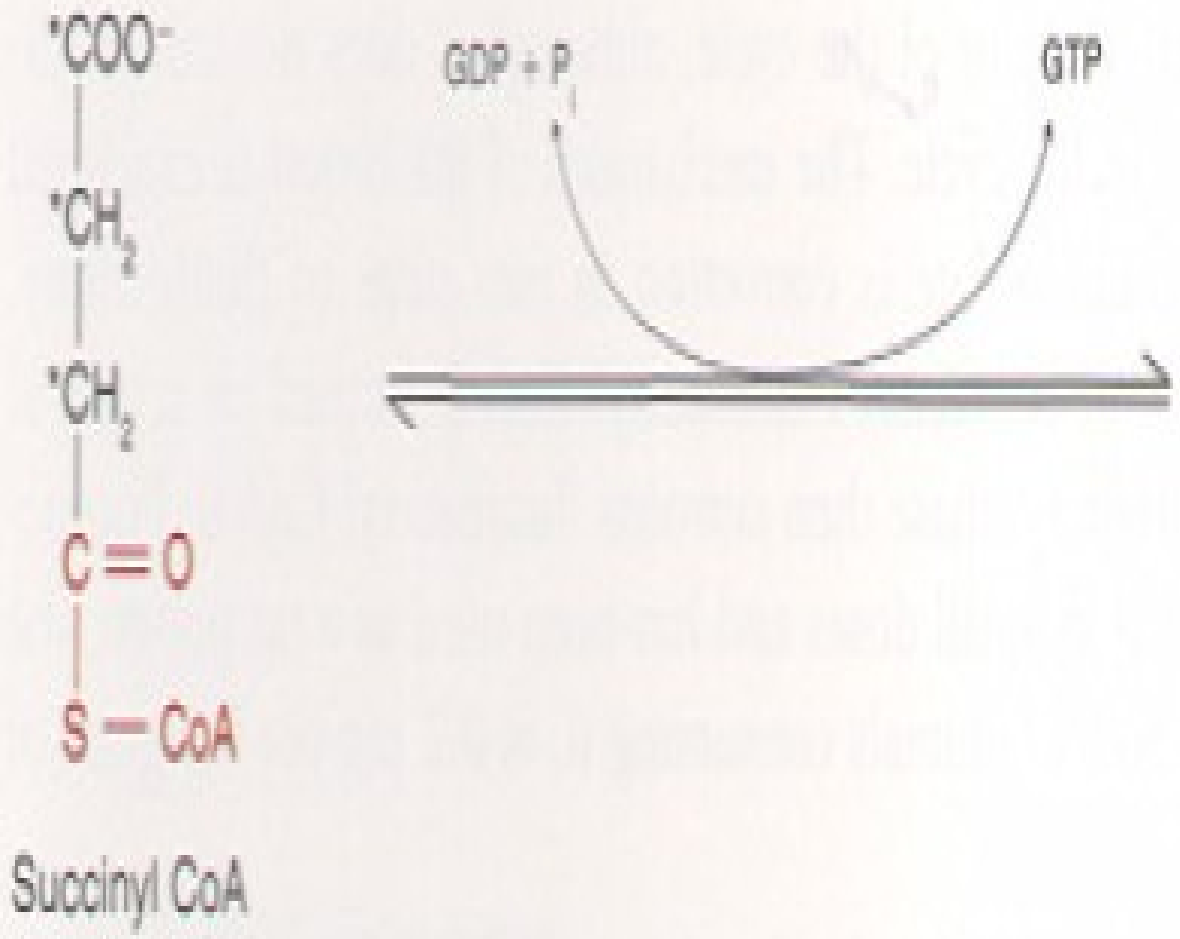
2 - oxoglutarát

sukcinyl-CoA

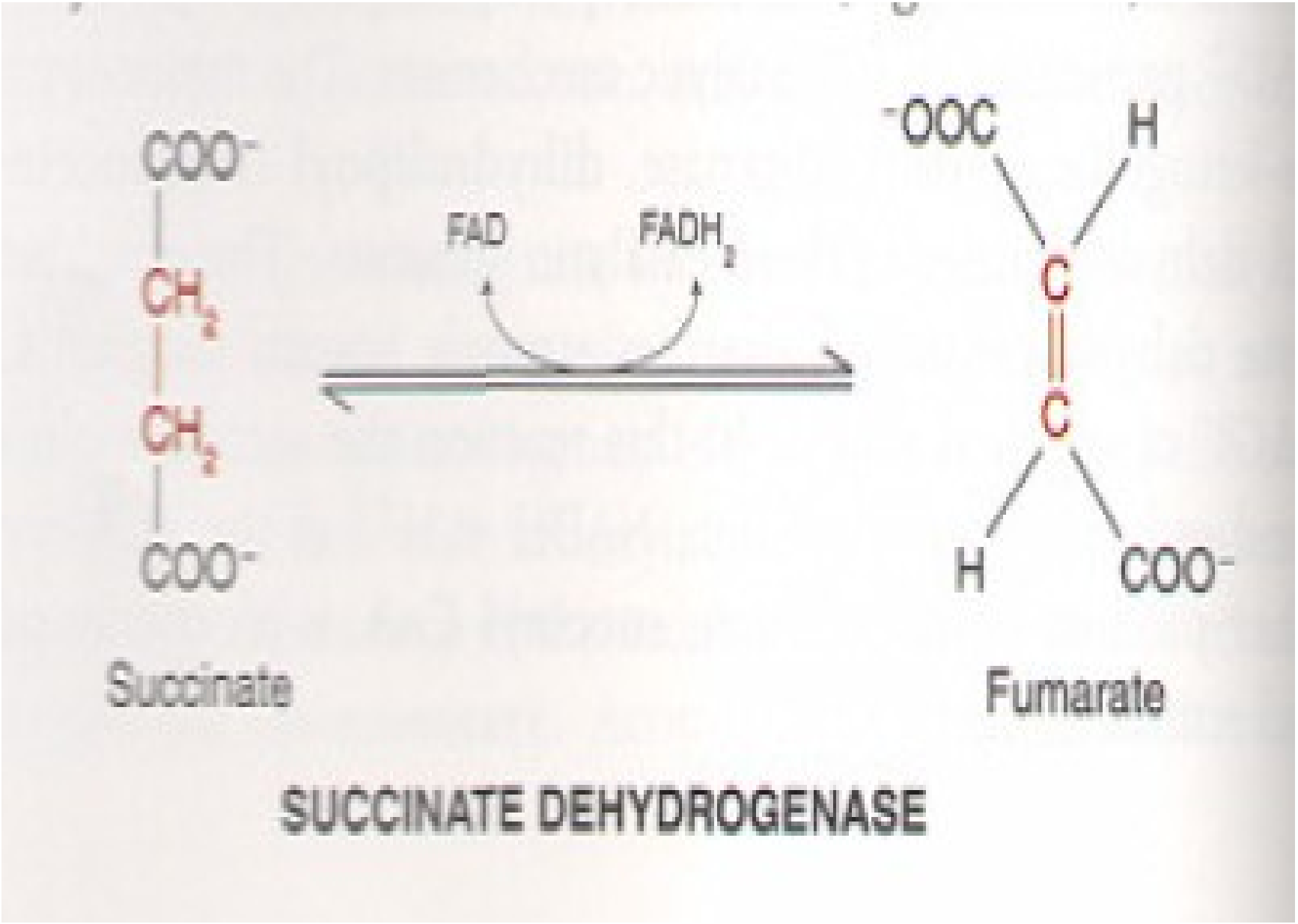


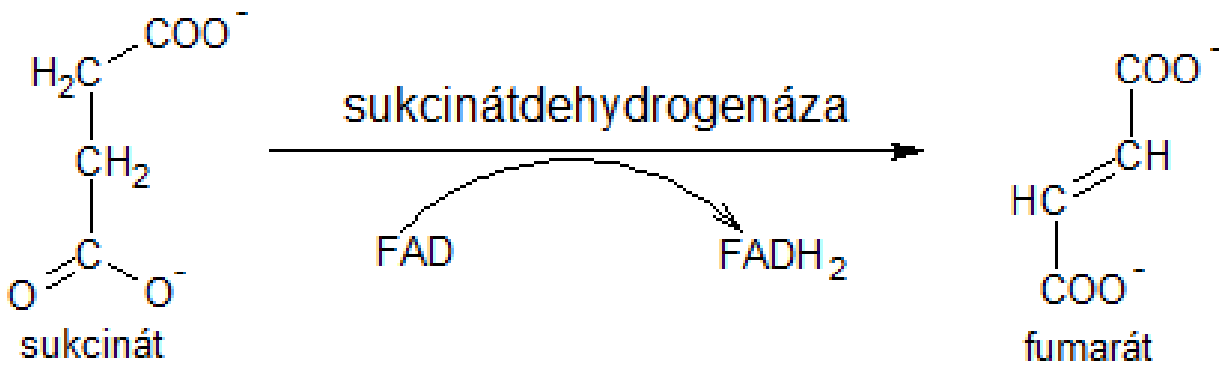
3 enzymy + 5 kofaktorů

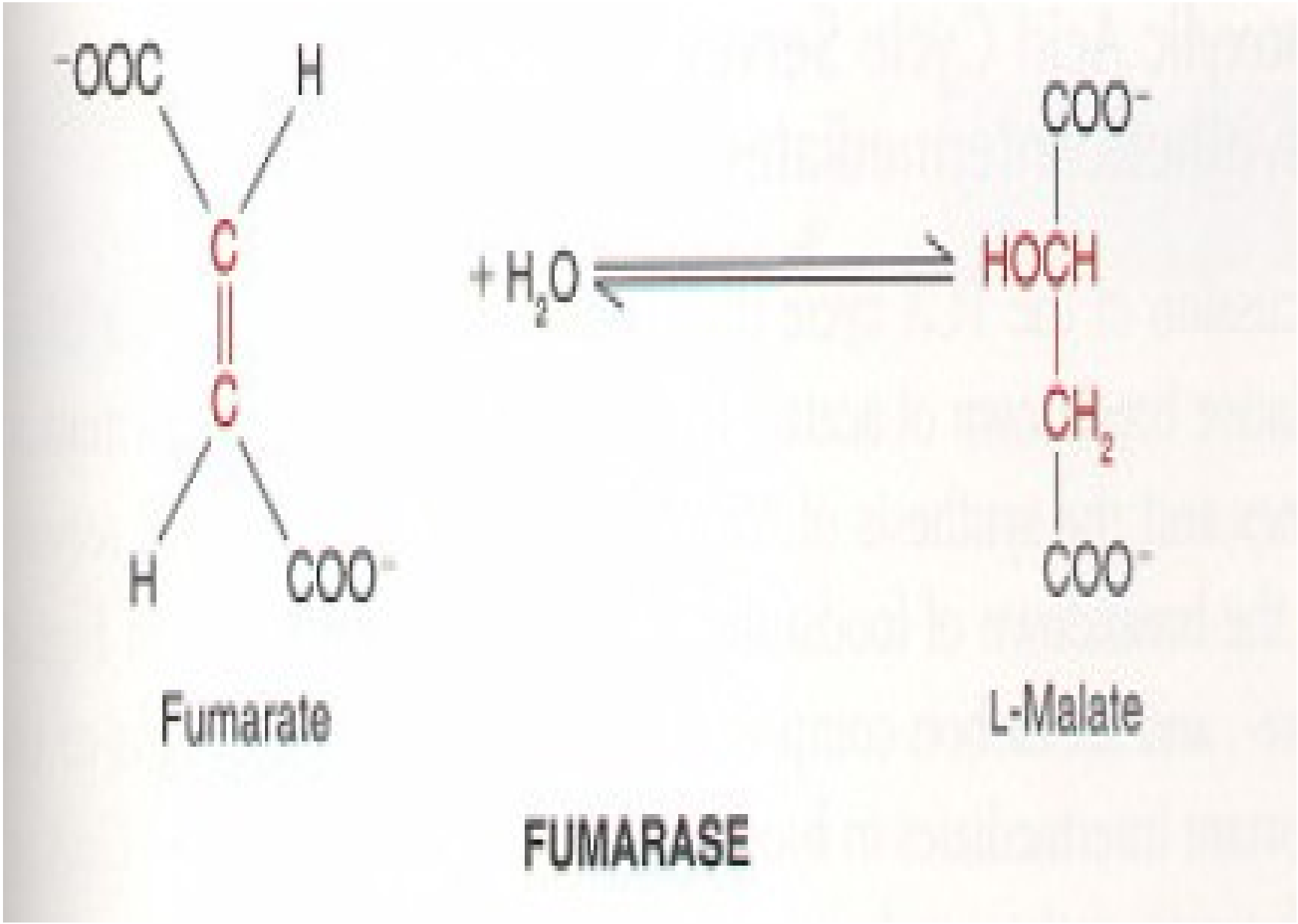

COO-
H2C
CH2
C
O
S—CoA
sukcinyl-CoA
sukcinyl-CoA-synthetasa, +H2O
GDP
+
P
GTP
COO-
H2C
CH2
C
O
O-
+ HS—CoA
sukcinát

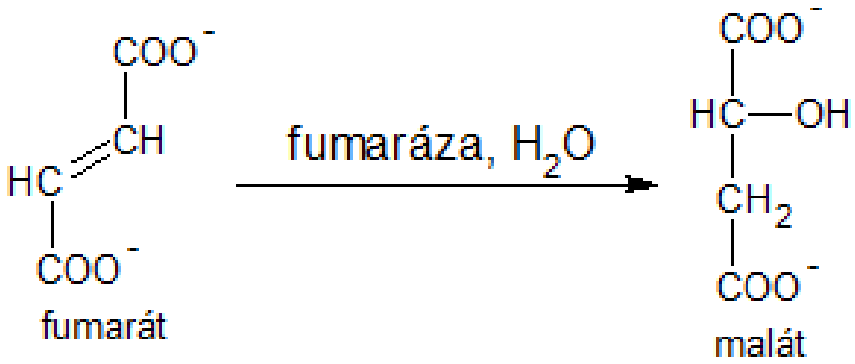


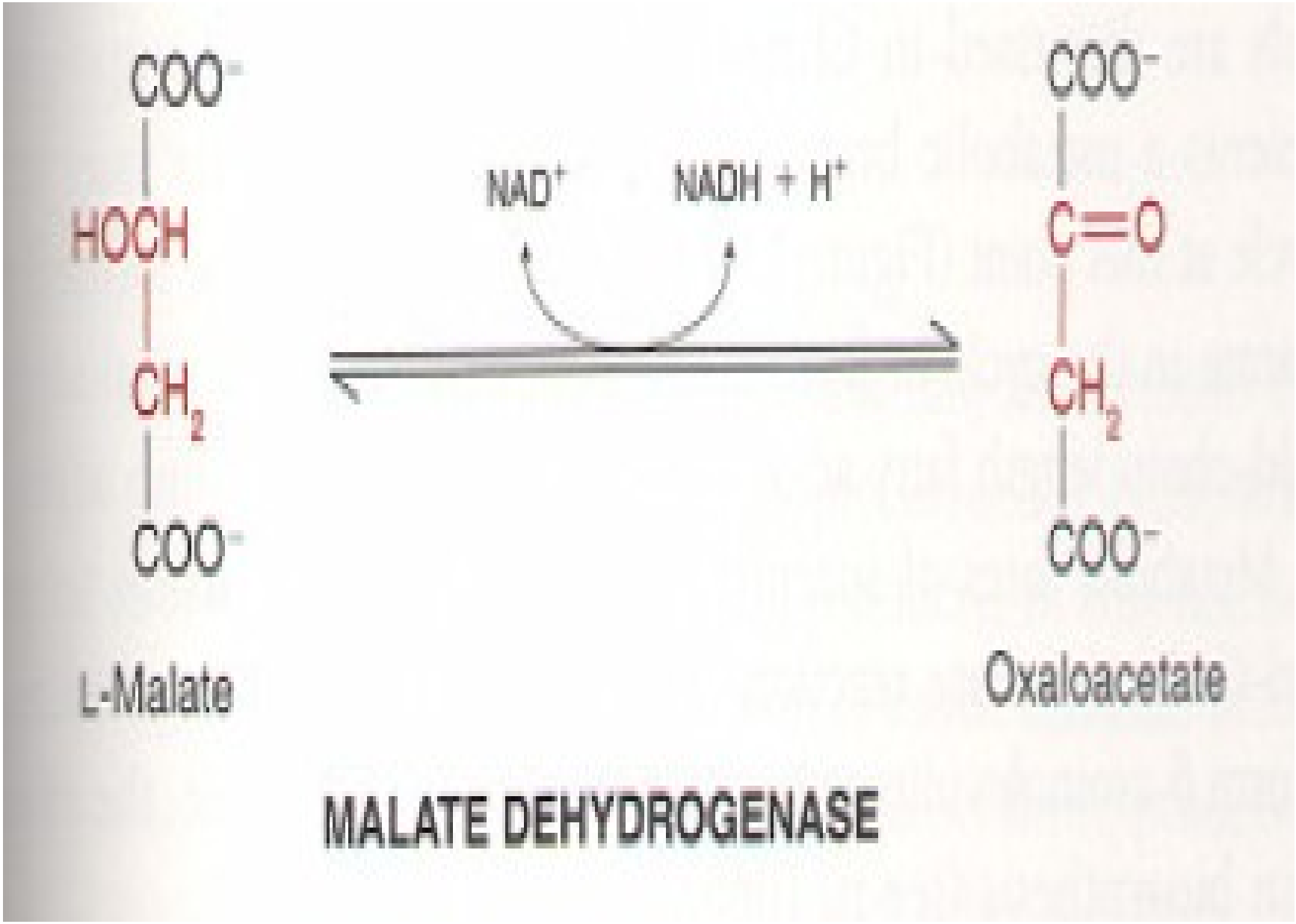
SUCCINYL CoA SYNTHETASE

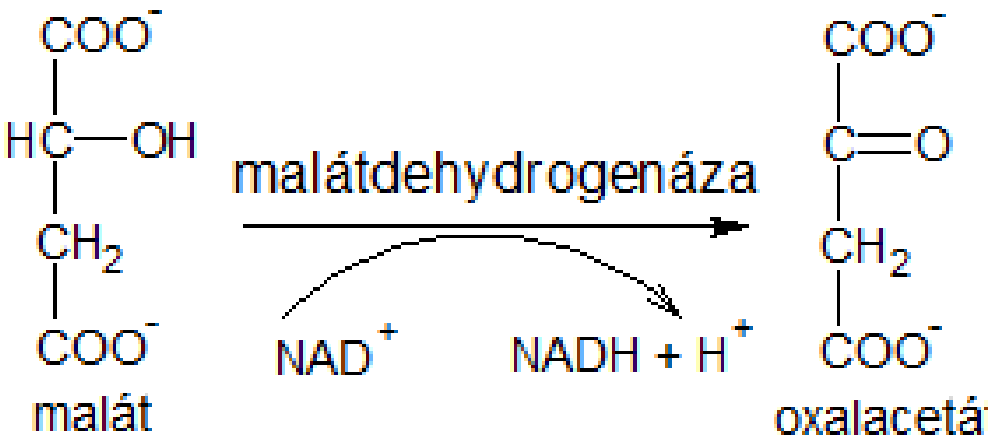

COO⁻
CH₂
CH₂
COO⁻
FAD
FADH₂
⁻OOC
H
C
C
H
COO⁻
Succinate
Fumarate
SUCCINATE DEHYDROGENASE

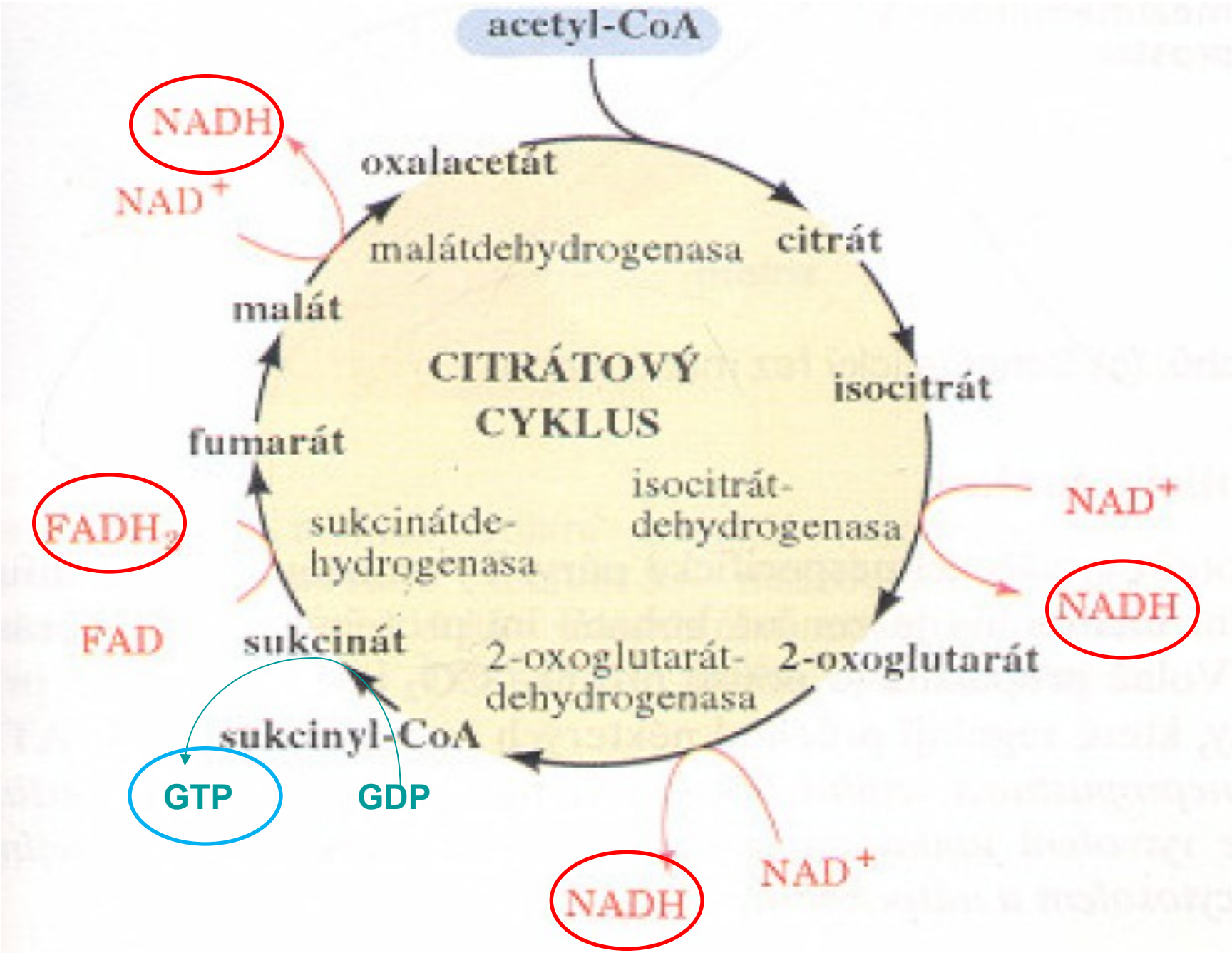

COO-
H2C
CH2
C
O
O-
sukcinát
sukcinátdehydrogenáza
FAD
FADH2
COO-
CH
HC
COO-
fumarát


⁻OOC
H
C
C
H
COO⁻
Fumarate
+ H₂O
COO⁻
HOCH
CH₂
COO⁻
L-Malate
FUMARASE


COO⁻
CH
HC
COO⁻
fumarát
fumaráza, H2O
COO⁻
HC—OH
CH2
COO⁻
malát


COO⁻
HOCH
CH₂
COO⁻
L-Malate
NAD⁺
NADH + H⁺
COO⁻
C=O
CH₂
COO⁻
Oxaloacetate
MALATE DEHYDROGENASE


COO-
HC—OH
CH2
COO-
malát
malátdehydrogenáza
NAD+
NADH + H+
COO-
C=O
CH2
COO-
oxalacetá


acetyl-CoA
NADH
NAD+
oxalacetát
malátdehydrogenasa
citrát
malát
CITRÁTOVÝ CYKLUS
isocitrát
fumarát
isocitrát-dehydrogenasa
NAD+
FADH2
sukcinátde-hydrogenasa
NADH
FAD
sukcinát
2-oxoglutarát-dehydrogenasa
2-oxoglutarát
sukcinyl-CoA
GTP
GDP
NADH
NAD+

Bilance cyklu :

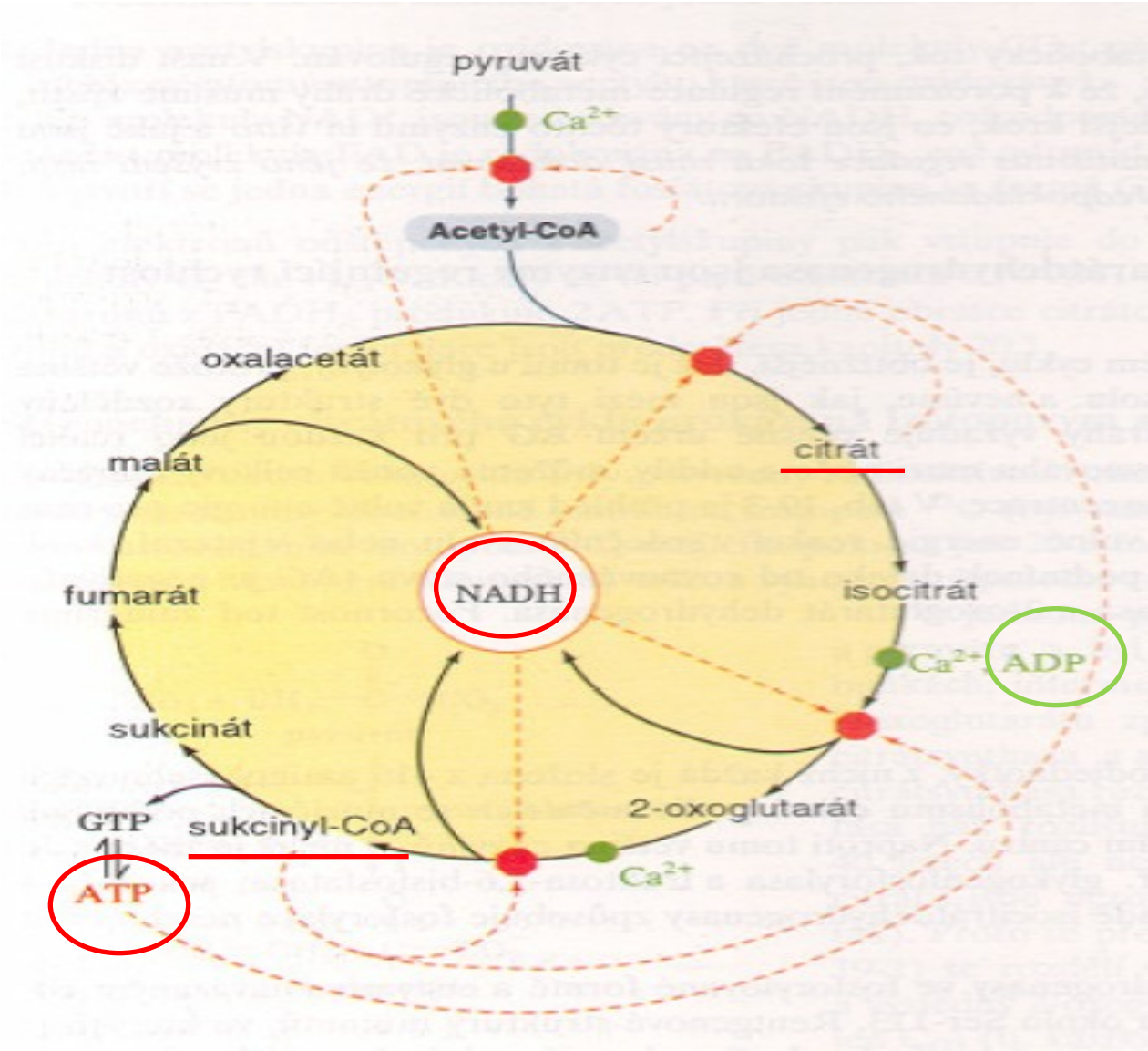
$$\text{Acetyl-CoA} + 3\,NAD^+ + FAD + GDP + Pi + 3\,H_2O$$

$$\rightarrow$$

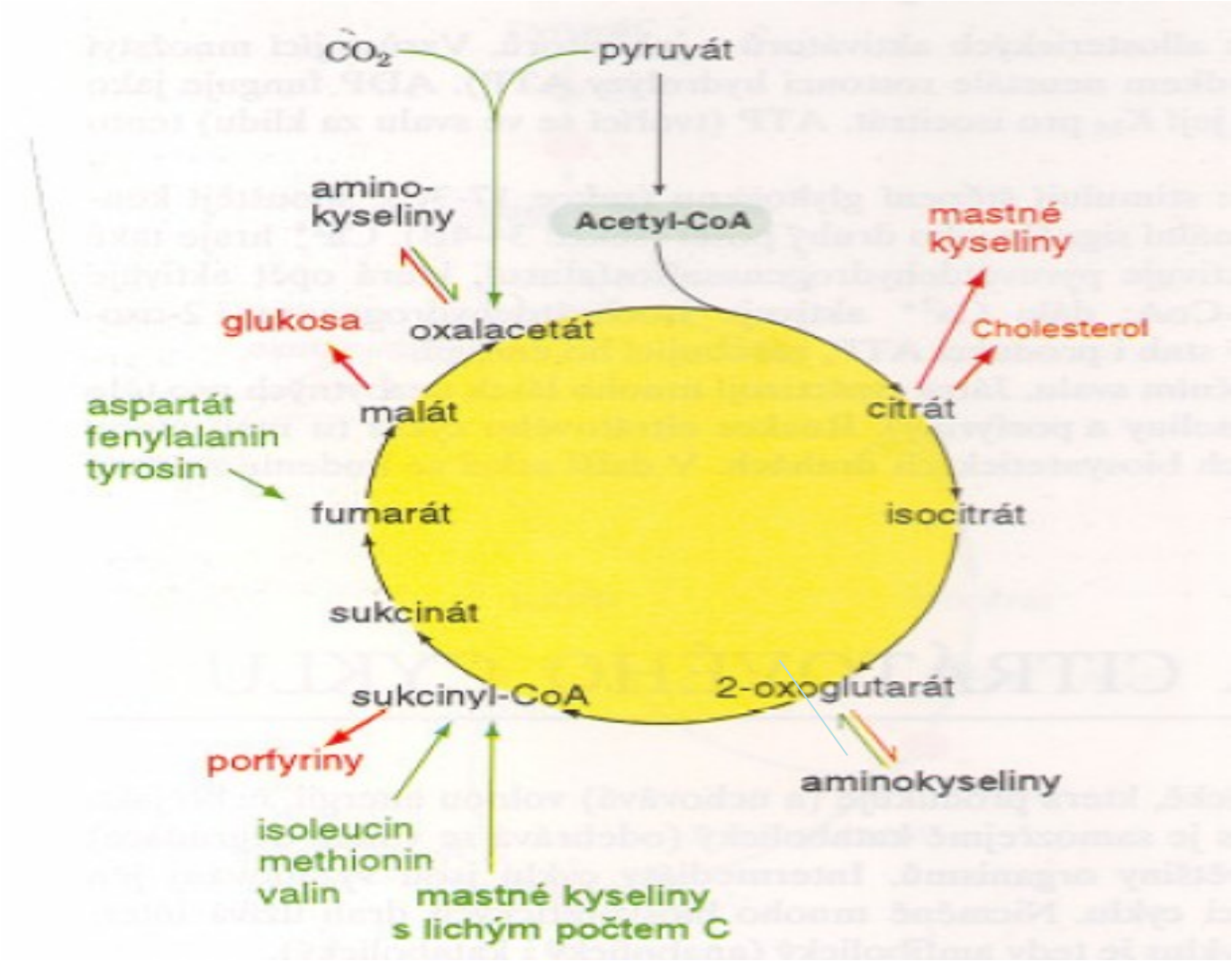
$$3\,NADH + 3\,H^+ + FADH2 + GTP + CoA + 2\,CO_2$$

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

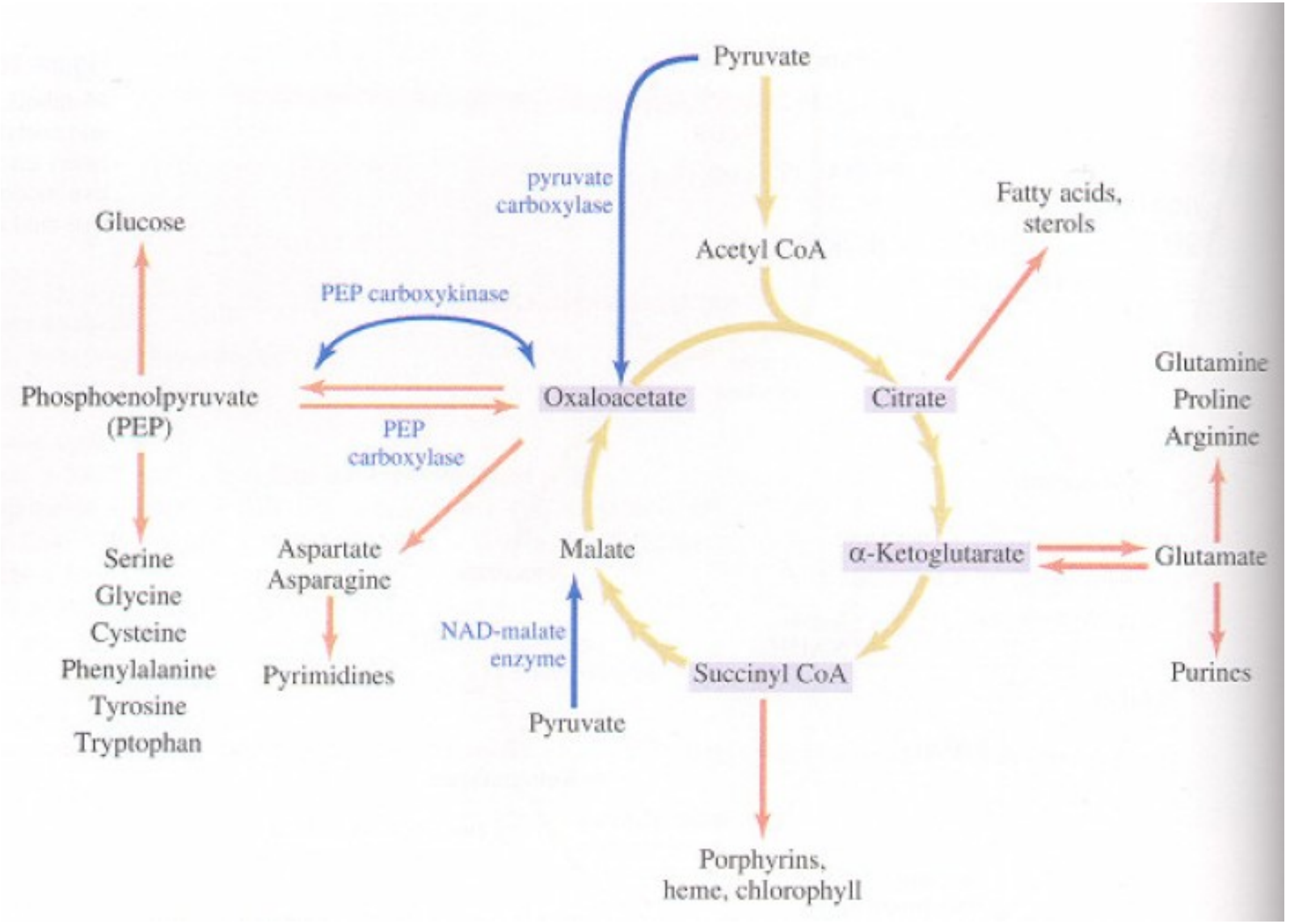
Regulace


pyruvát
Ca2+
Acetyl-CoA
oxalacetát
malát
citrát
fumarát
NADH
isocitrát
Ca2+
ADP
sukcinát
2-oxoglutarát
GTP
sukcinyl-CoA
Ca2+
ATP

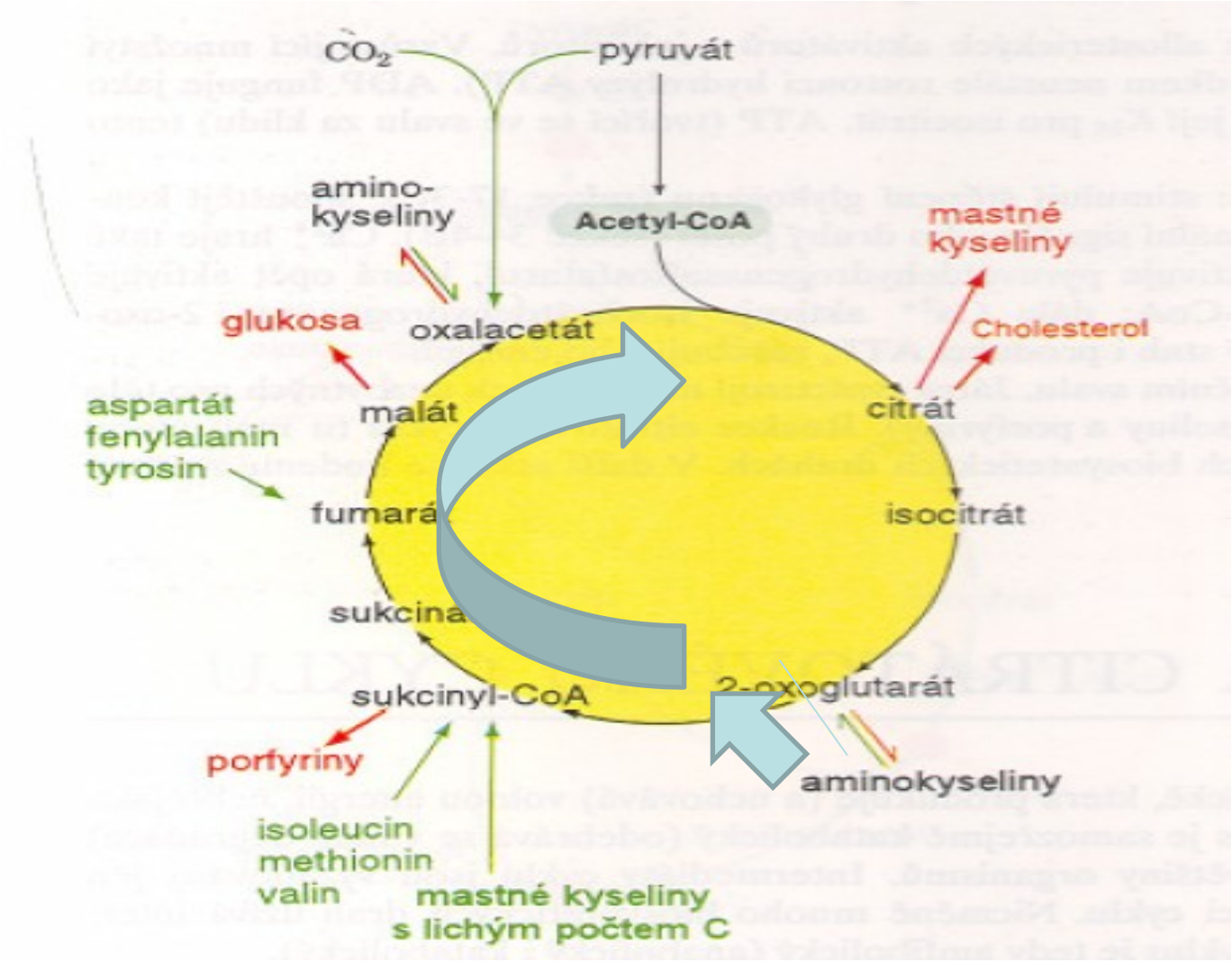
Odbourávání jiných živin



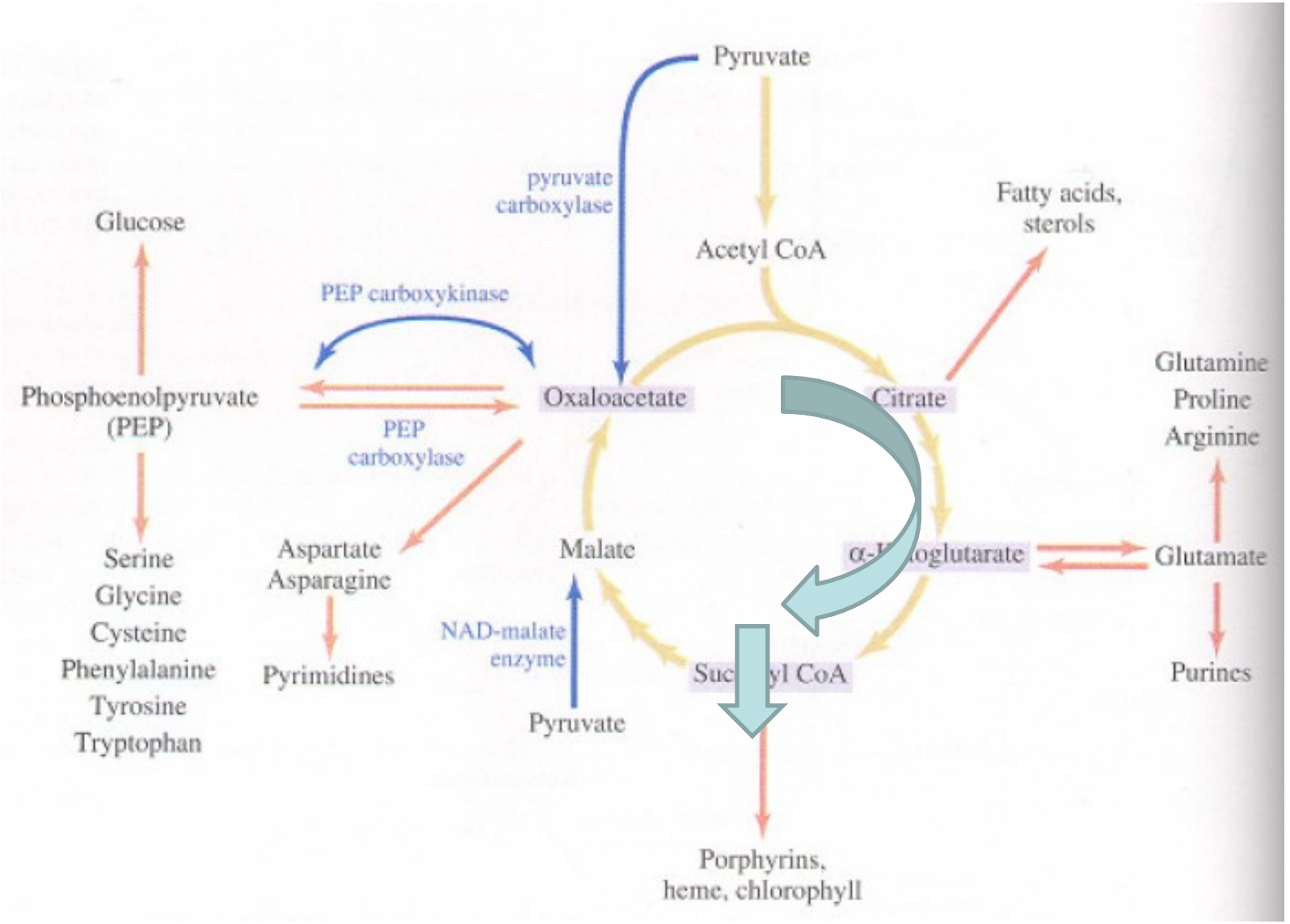
Amfibolická povaha cyklu



Odbourávání jiných živin



Amfibolická povaha cyklu



Anaplerotické reakce

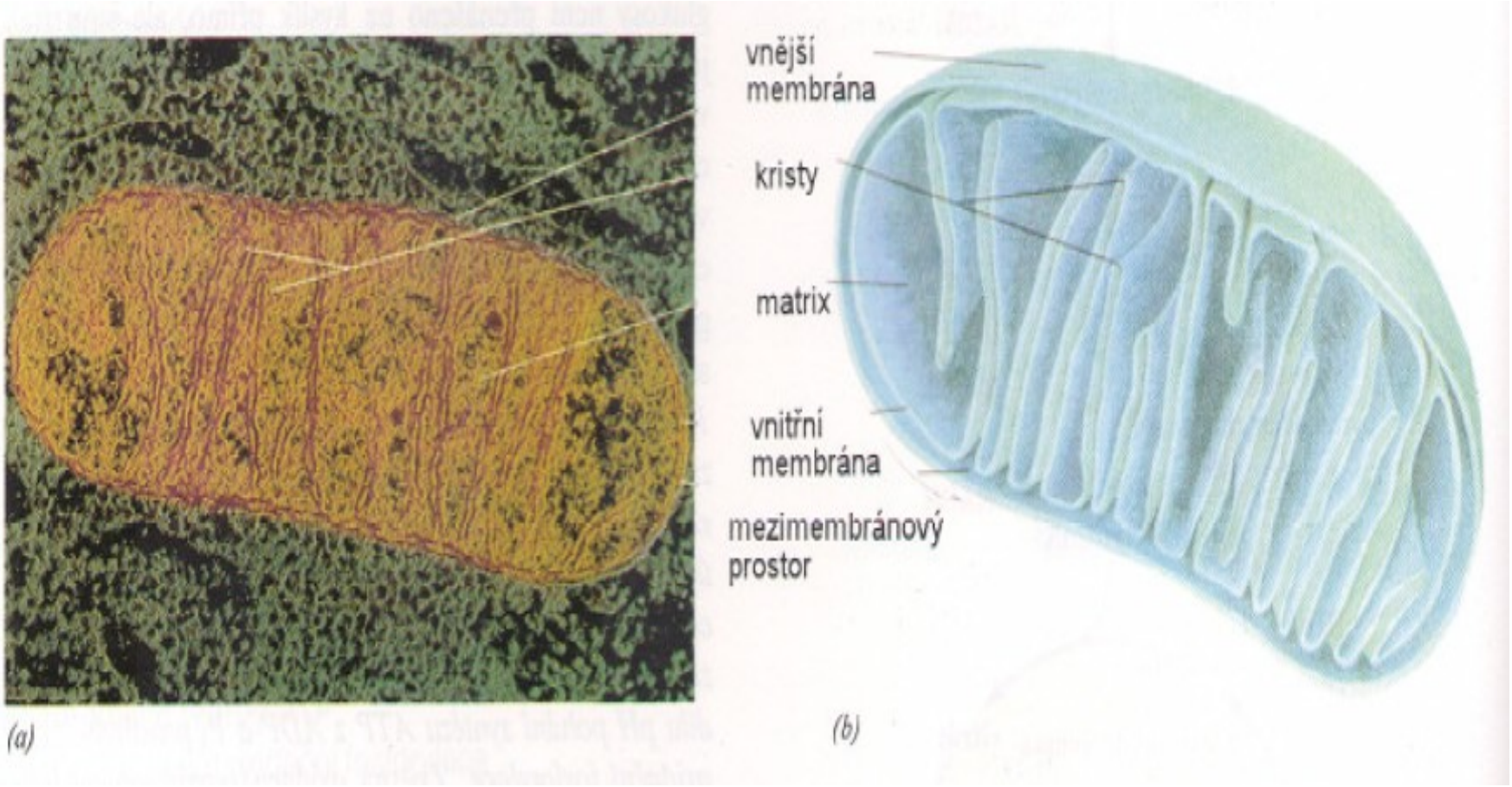
Table 16.5

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

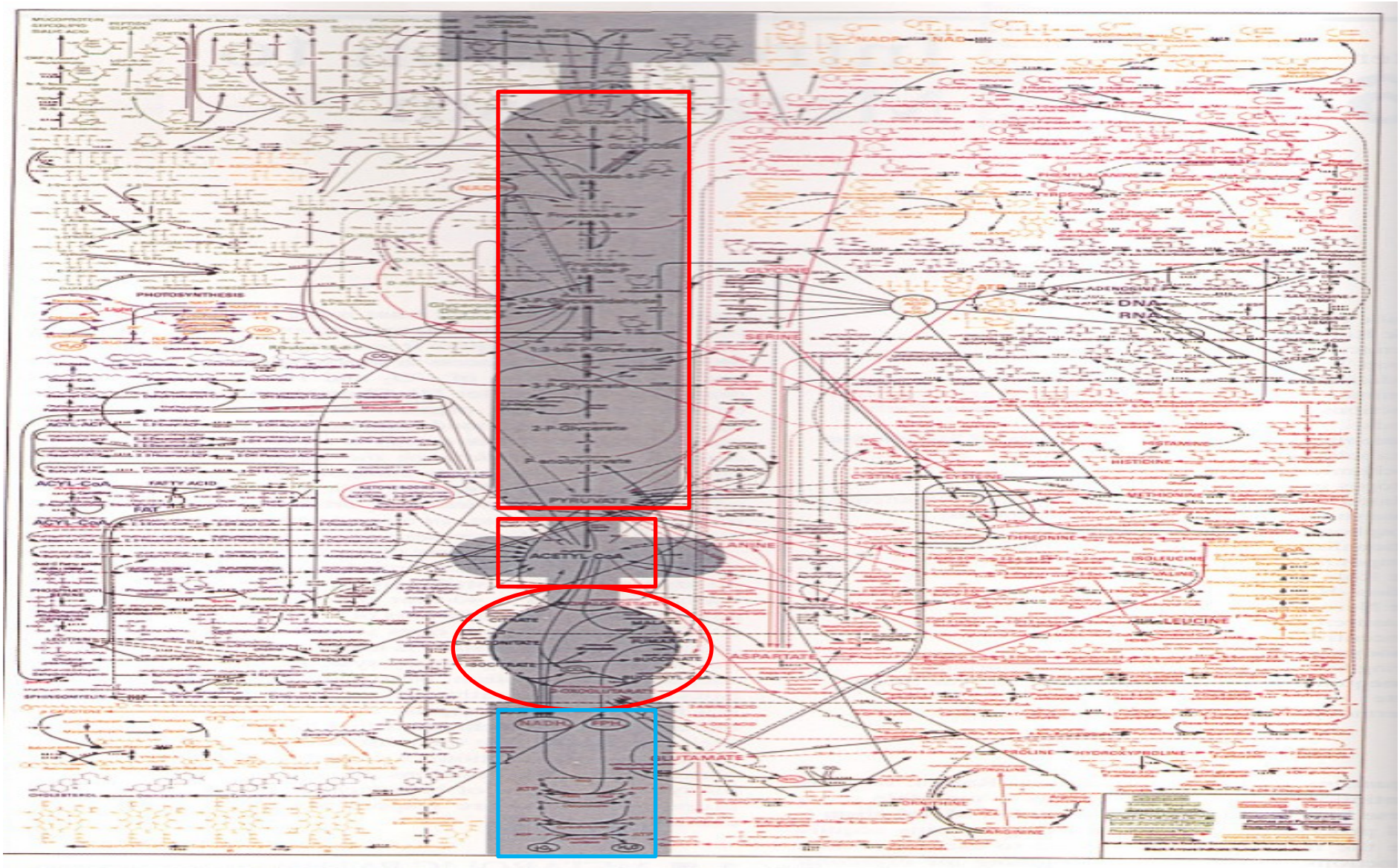
Enzyme	Reaction	Comments
Pyruvate carboxylase	Pyruvate + CO_2 + ATP + H_2O $\rightleftharpoons$ oxaloacetate + ADP + P_i	Also the starting point for gluconeogenesis
PEP carboxykinase	Phosphoenolpyruvate + CO_2 + GDP $\rightleftharpoons$ oxaloacetate + GTP	The reverse reaction is important in gluconeogenesis
PEP carboxylase	Phosphoenolpyruvate + CO_2 $\rightleftharpoons$ oxaloacetate + P_i	Found in higher plants and bacteria
NAD–malate enzyme	Pyruvate + CO_2 + NADH + H^+ $\rightleftharpoons$ malate + NAD^+	Found in plants and microorganisms

Table 16-5 Concepts in Biochemistry, 3/e

Lokalizace citrátového cyklu



Metabolické dráhy



METABOLISMUS SACHARIDŮ

Štěpení oligosacharidů a polysacharidů

A. Štěpení sacharidů při trávení potravy

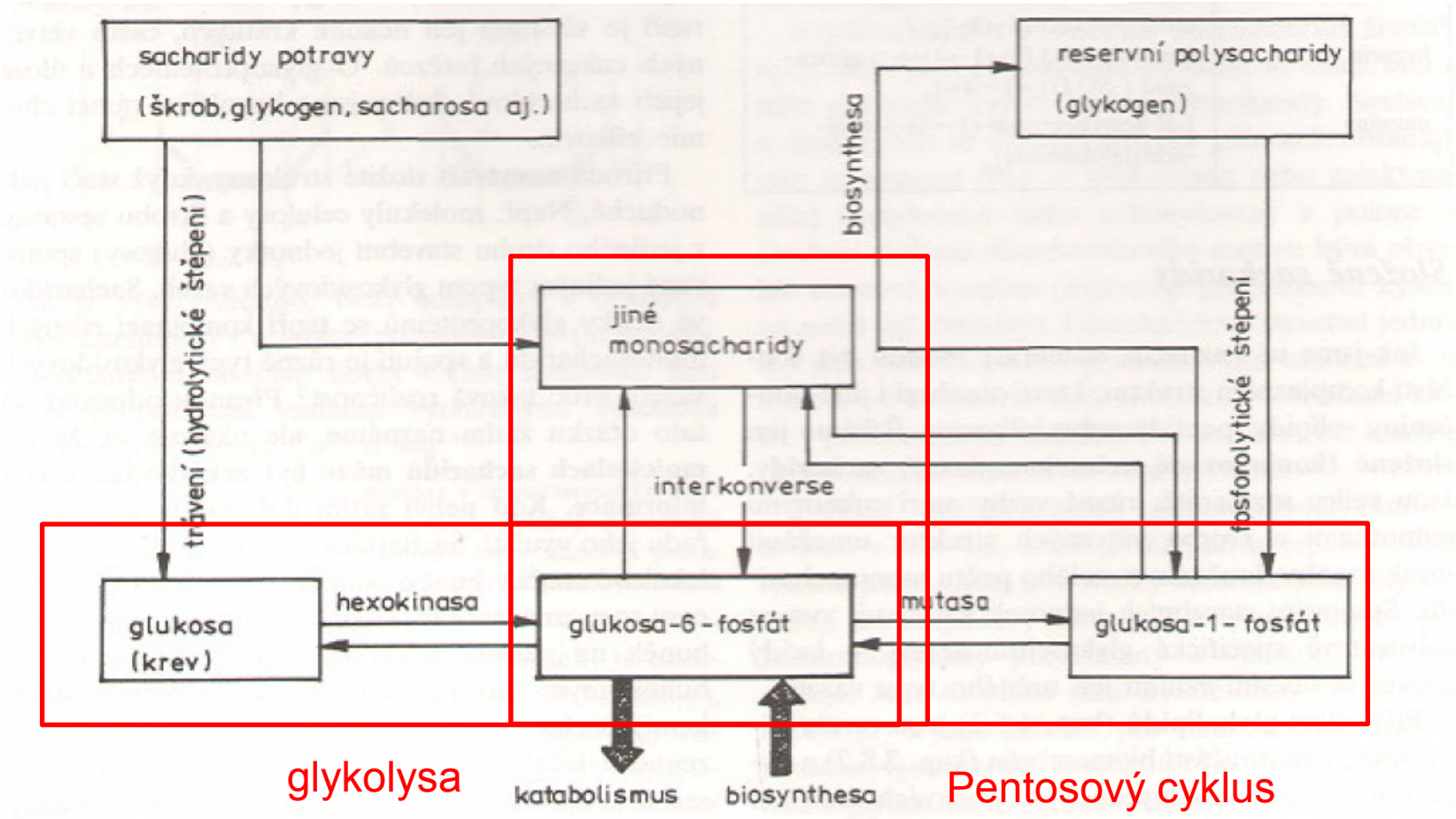
α – amylasa	sliny, pankreas	škrob	Dextriny, maltosa, glukosa
amyloglukosidasa	střeva	glykogen	maltosa
maltasa	"	maltosa	glukosa
laktasa	"	laktosa	glukosa, galaktosa
sacharasa	"	sacharosa	glukosa fruktosa
celulasy	houby, bakterie	celulosa	glukosa

B. Štěpení rezervních polysacharidů

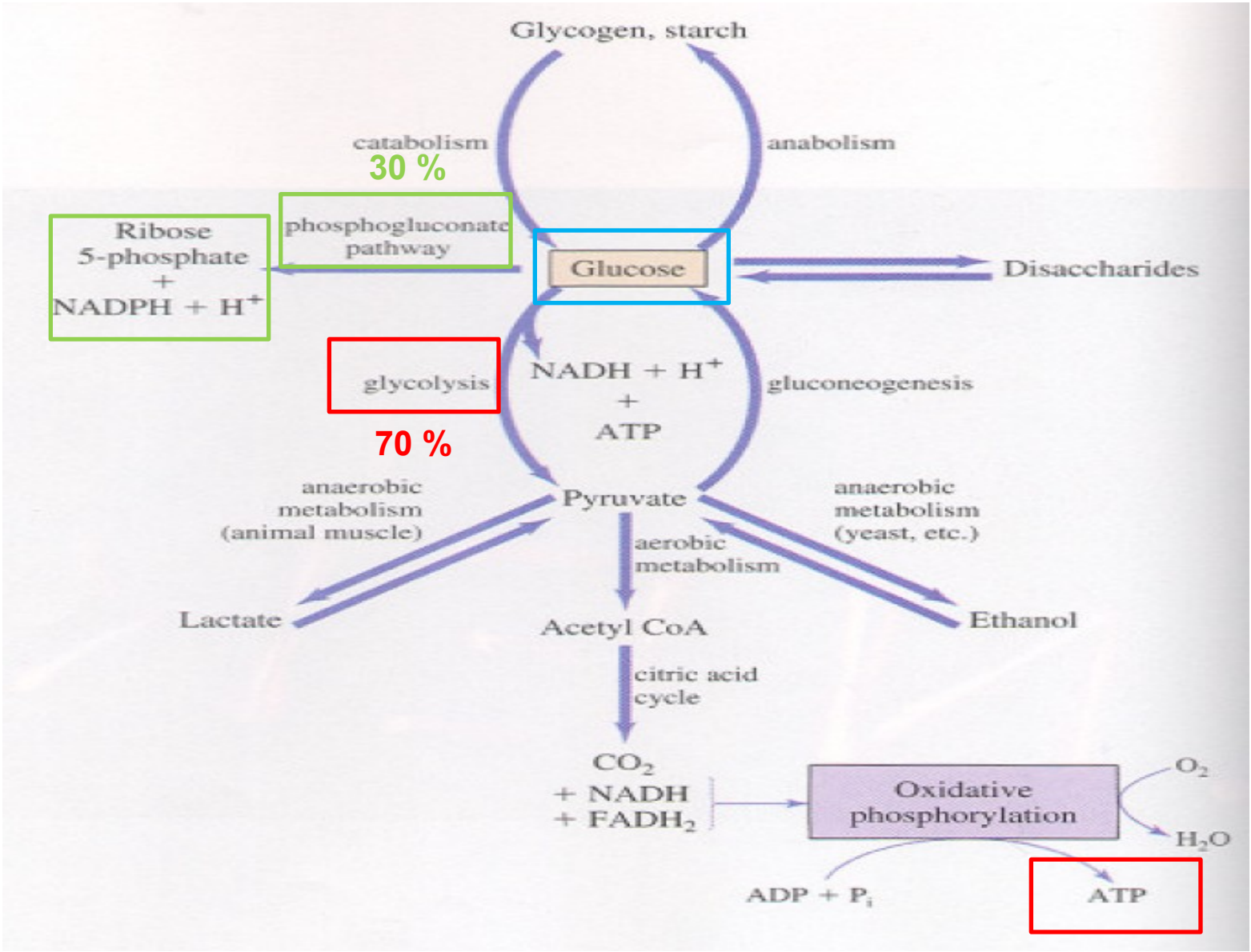
fosforylasa	**játra**	**glykogen**	**glukosa-1-P**
β – amylasa	**rostliny**	**škrob**	**maltosa**

Glukosa-6-fosfát - klíčový metabolit

P



METABOLISMUS SACHARIDŮ



GLYKOLÝZA

$$C_6H_{12}O_6 \rightarrow 2\,CH_3COCOOH + 4[H]$$

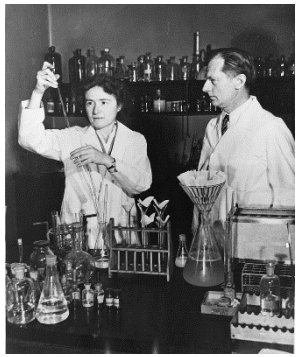
Historie : - 19. stol. Paster - kvasinky

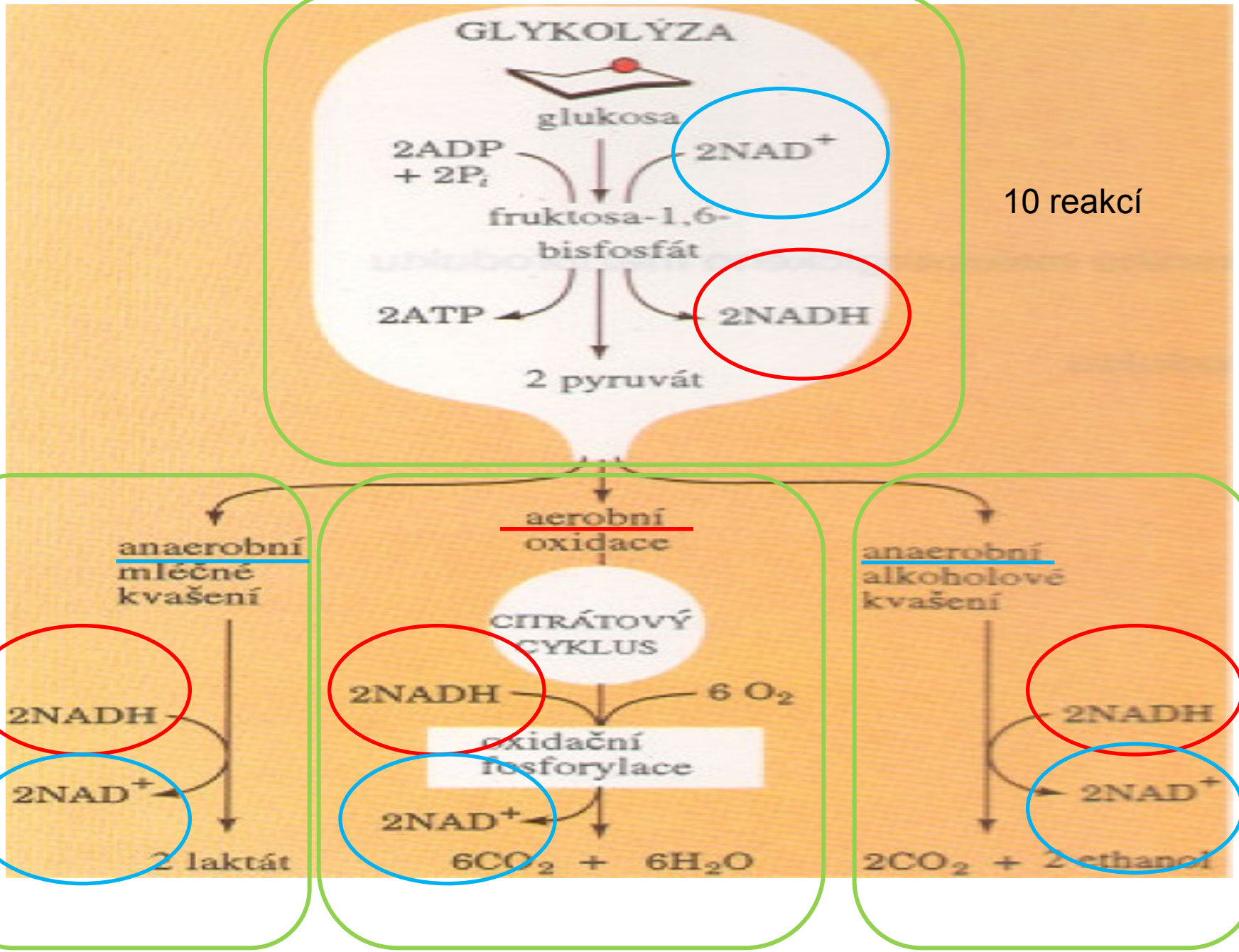
Buchner - kvasniční extrakt

- 1905 - 1910 Harden, Young

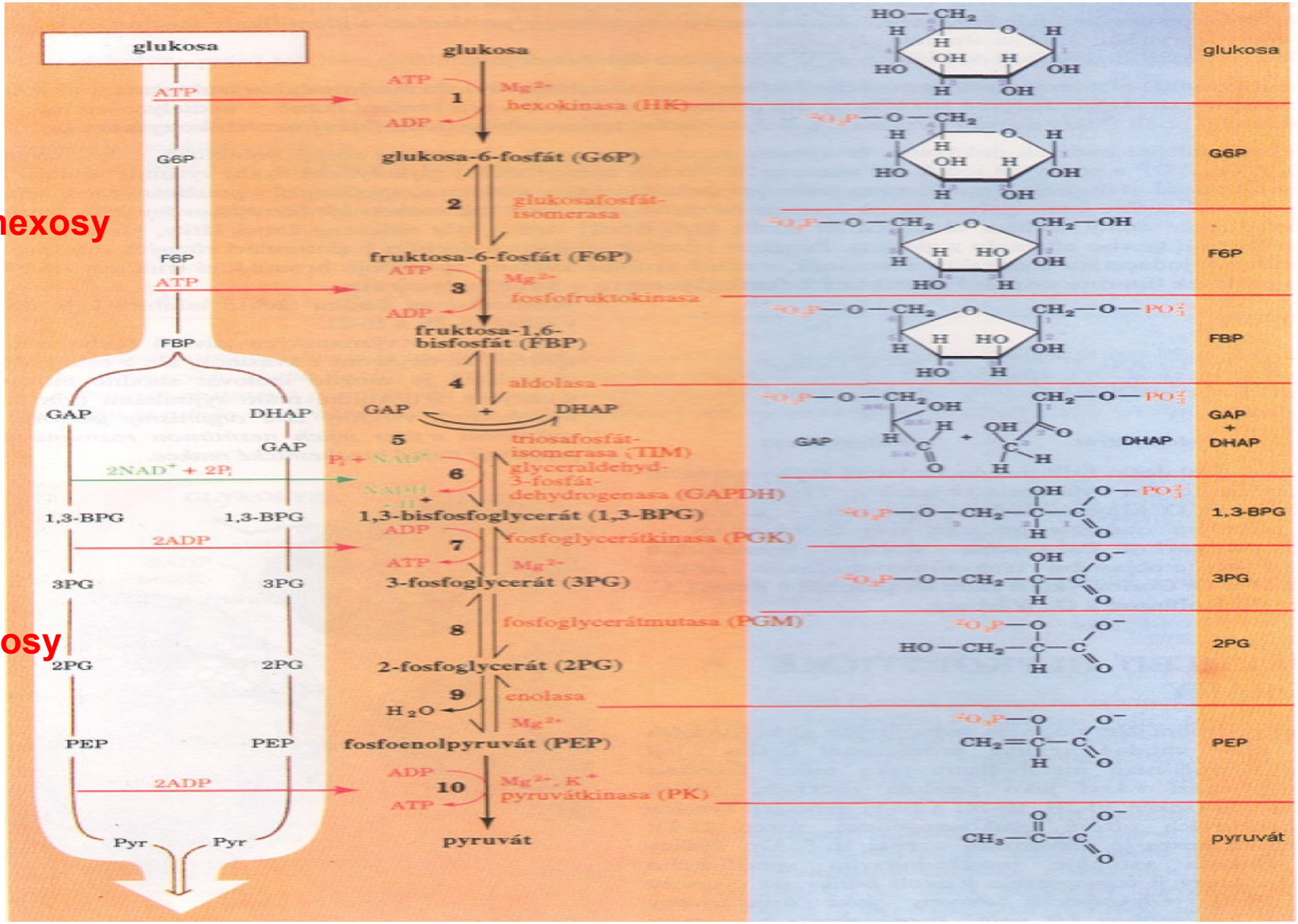
- 1940 Embden, Meyerhof, Parnas

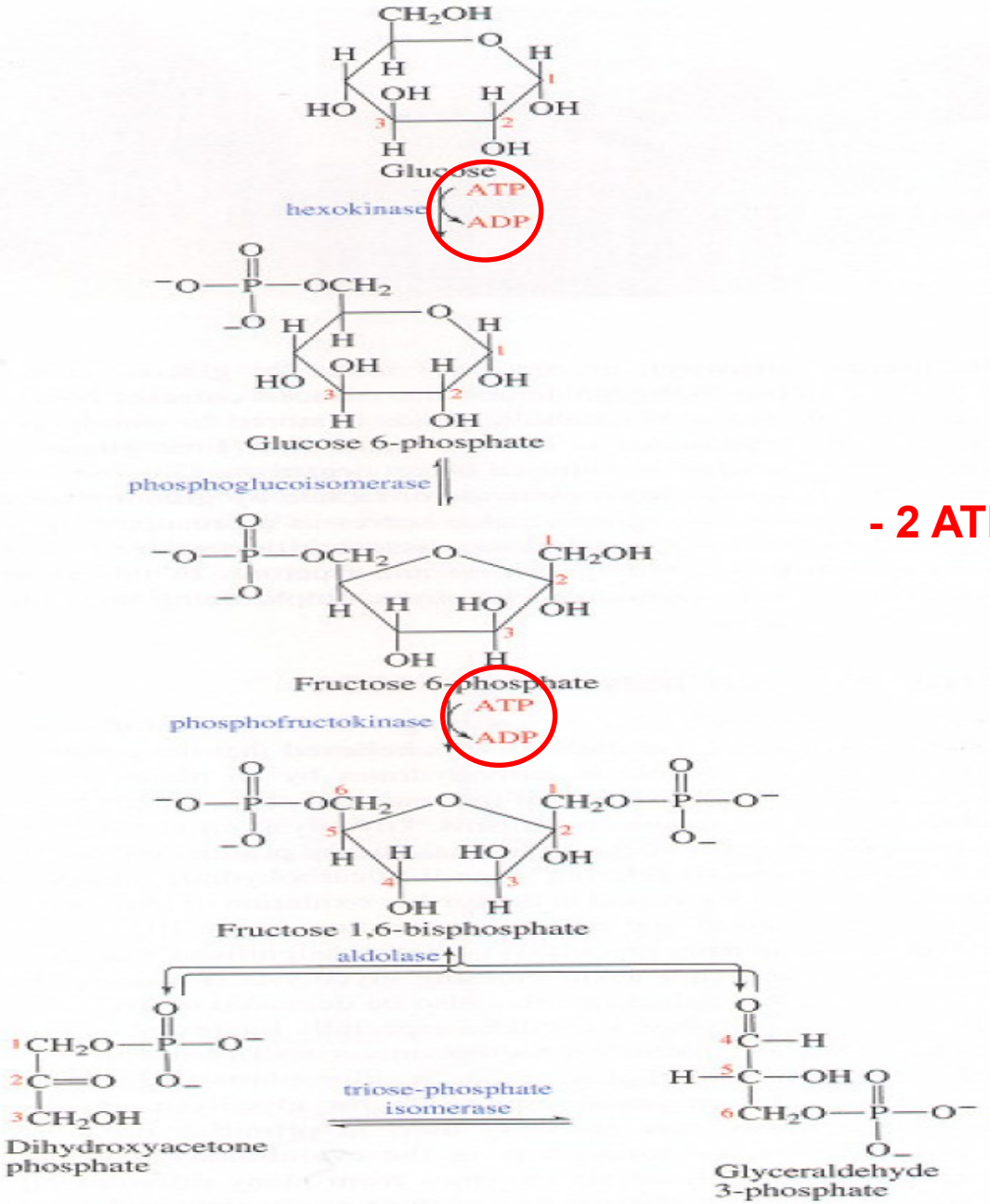
Manželé Corriovi




GLYKOLÝZA
glukosa
2ADP
+ 2P$_i$
2NAD$^+$
fruktosa-1,6-
bisfosfát
2ATP
2NADH
2 pyruvát
anaerobní
mléčné
kvašení
2NADH
2NAD$^+$
2 laktát
aerobní
oxidace
CITRÁTOVÝ
CYKLUS
2NADH
6 O$_2$
oxidační
fosforylace
2NAD$^+$
6CO$_2$ + 6H$_2$O
anaerobní
alkoholové
kvašení
2NADH
2NAD$^+$
2CO$_2$ + 2 ethanol

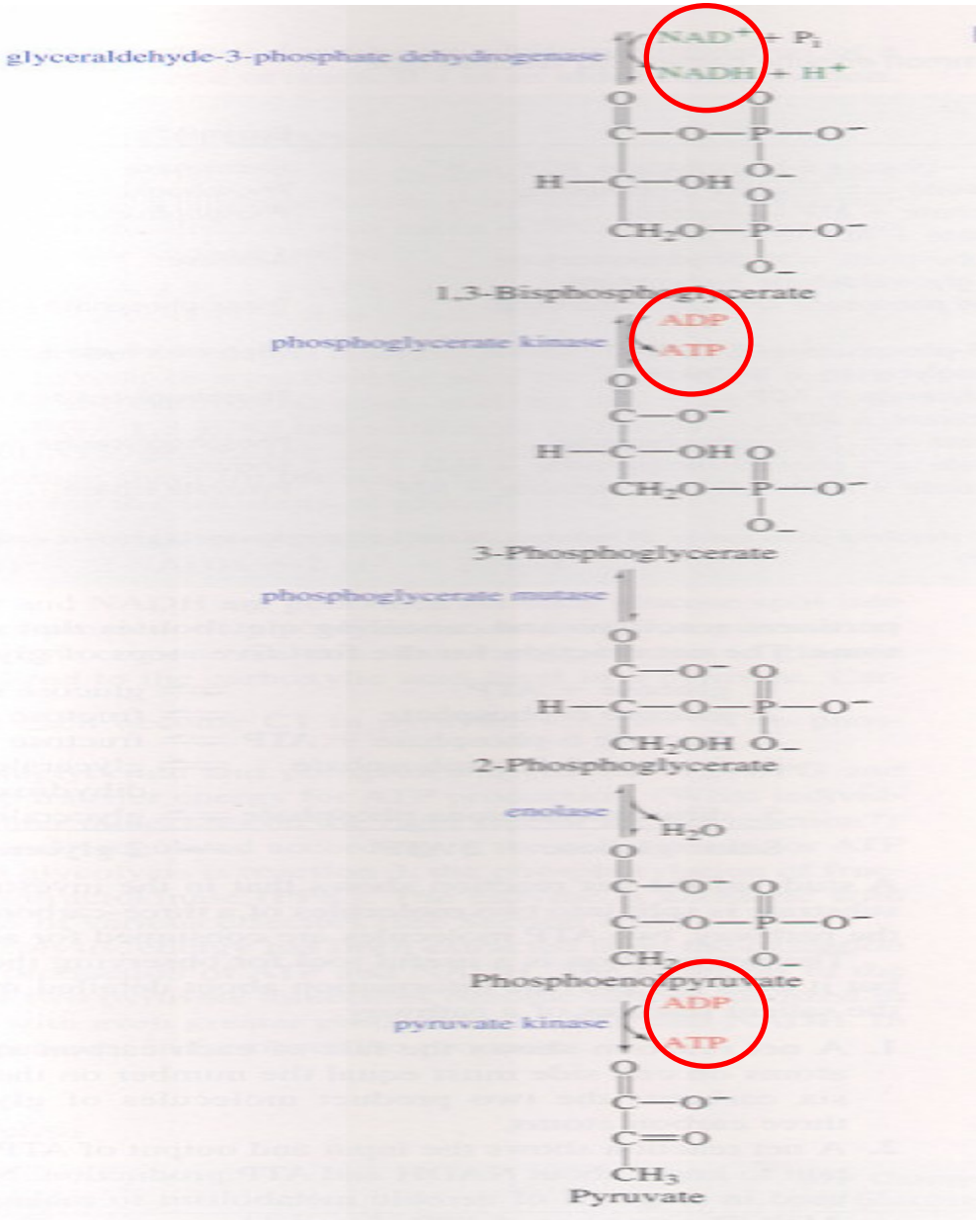
10 reakcí


hexosy
triosy
glukosa
ATP
G6P
F6P
ATP
FBP
GAP
DHAP
GAP
2NAD+ + 2Pi
1,3-BPG
1,3-BPG
2ADP
3PG
3PG
2PG
2PG
PEP
PEP
2ADP
Pyr
Pyr
glukosa
ATP
1
Mg2+
hexokinasa (HK)
ADP
glukosa-6-fosfát (G6P)
2
glukosafosfát-isomerasa
fruktosa-6-fosfát (F6P)
ATP
3
Mg2+
fosfofruktokinasa
ADP
fruktosa-1,6-bisfosfát (FBP)
4
aldolasa
GAP
+
DHAP
5
triosafosfát-isomerasa (TIM)
Pi + NAD+
6
glyceraldehyd-3-fosfát-dehydrogenasa (GAPDH)
NADH + H+
1,3-bisfosfoglycerát (1,3-BPG)
ADP
7
fosfoglycerátkinasa (PGK)
ATP
Mg2+
3-fosfoglycerát (3PG)
8
fosfoglycerátmutasa (PGM)
2-fosfoglycerát (2PG)
9
H2O
enolasa
Mg2+
fosfoenolpyruvát (PEP)
ADP
10
Mg2+, K+
pyruvátkinasa (PK)
ATP
pyruvát
glukosa
G6P
F6P
FBP
GAP
+
DHAP
1,3-BPG
3PG
2PG
PEP
pyruvát


Glucose
hexokinase
ATP
ADP
Glucose 6-phosphate
phosphoglucoisomerase
Fructose 6-phosphate
phosphofructokinase
ATP
ADP
Fructose 1,6-bisphosphate
aldolase
triose-phosphate isomerase
Dihydroxyacetone phosphate
Glyceraldehyde 3-phosphate

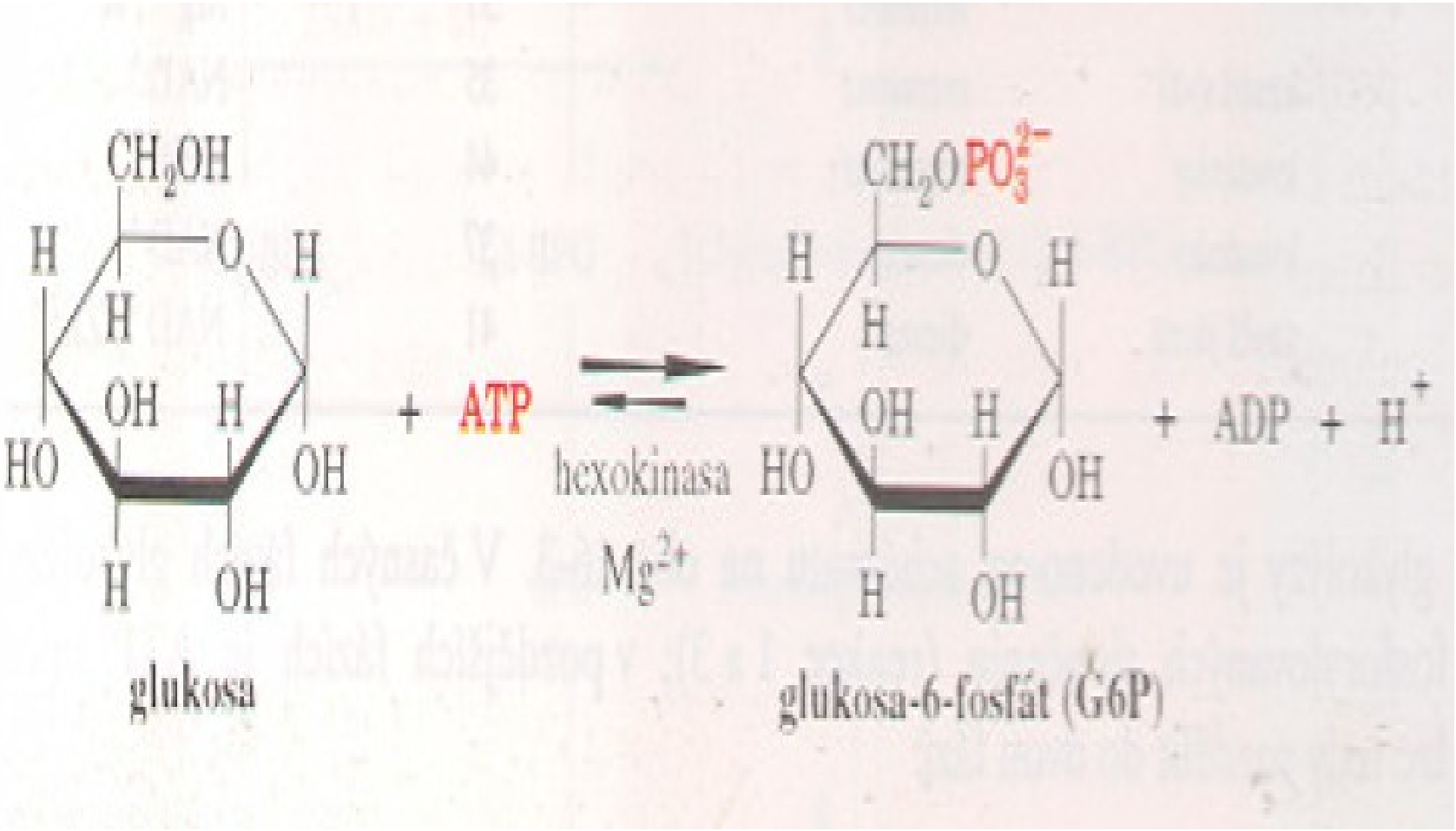
- 2 ATP

2 x

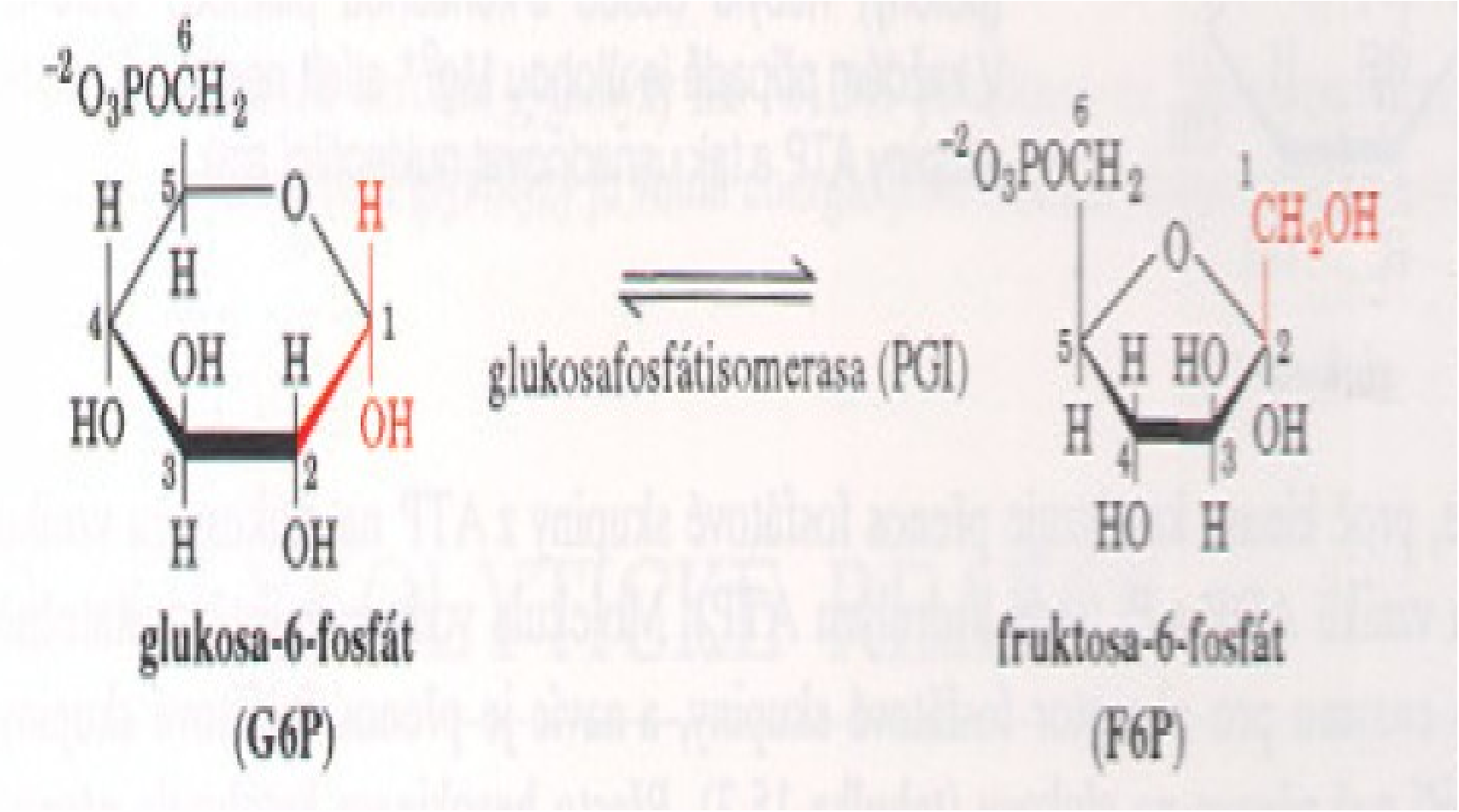


2 x (2ATP + NADH)

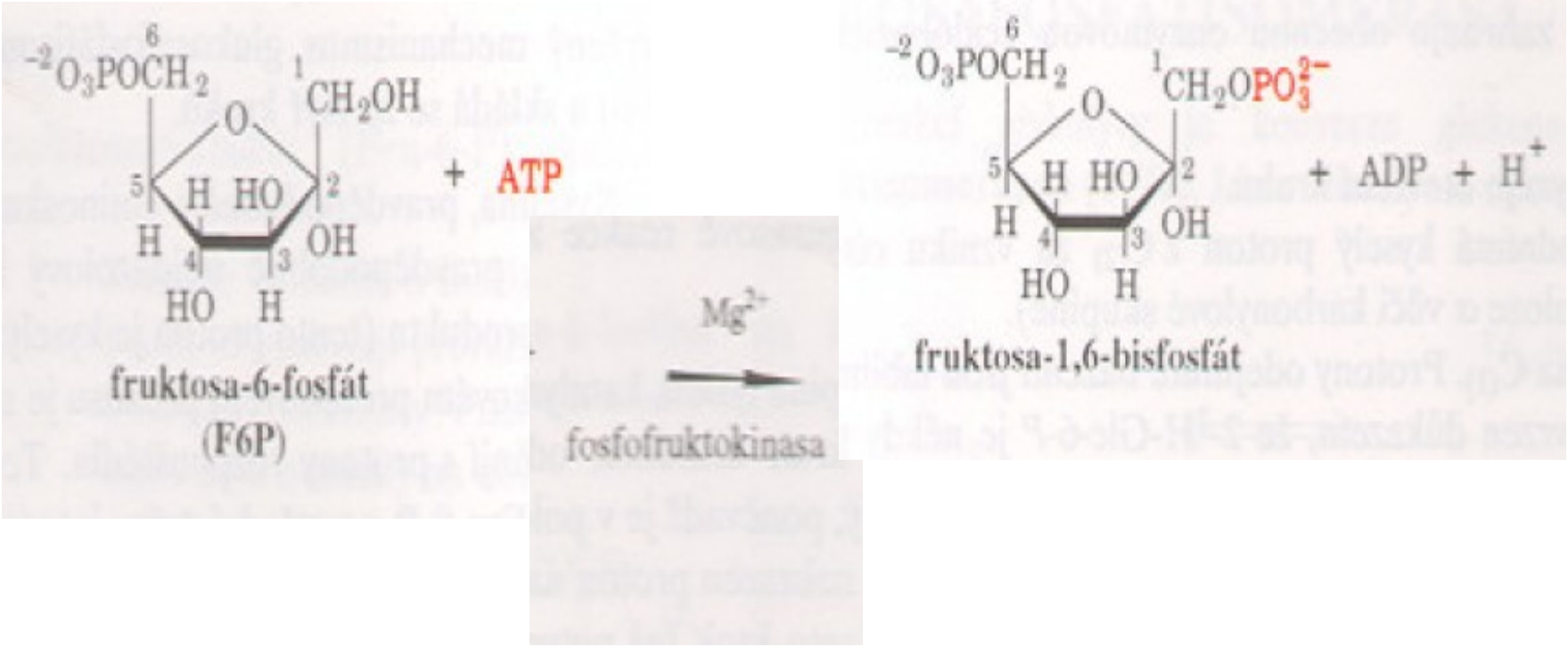
Hexokinasa - glukokinasa



Glukosafosfátisomerasa



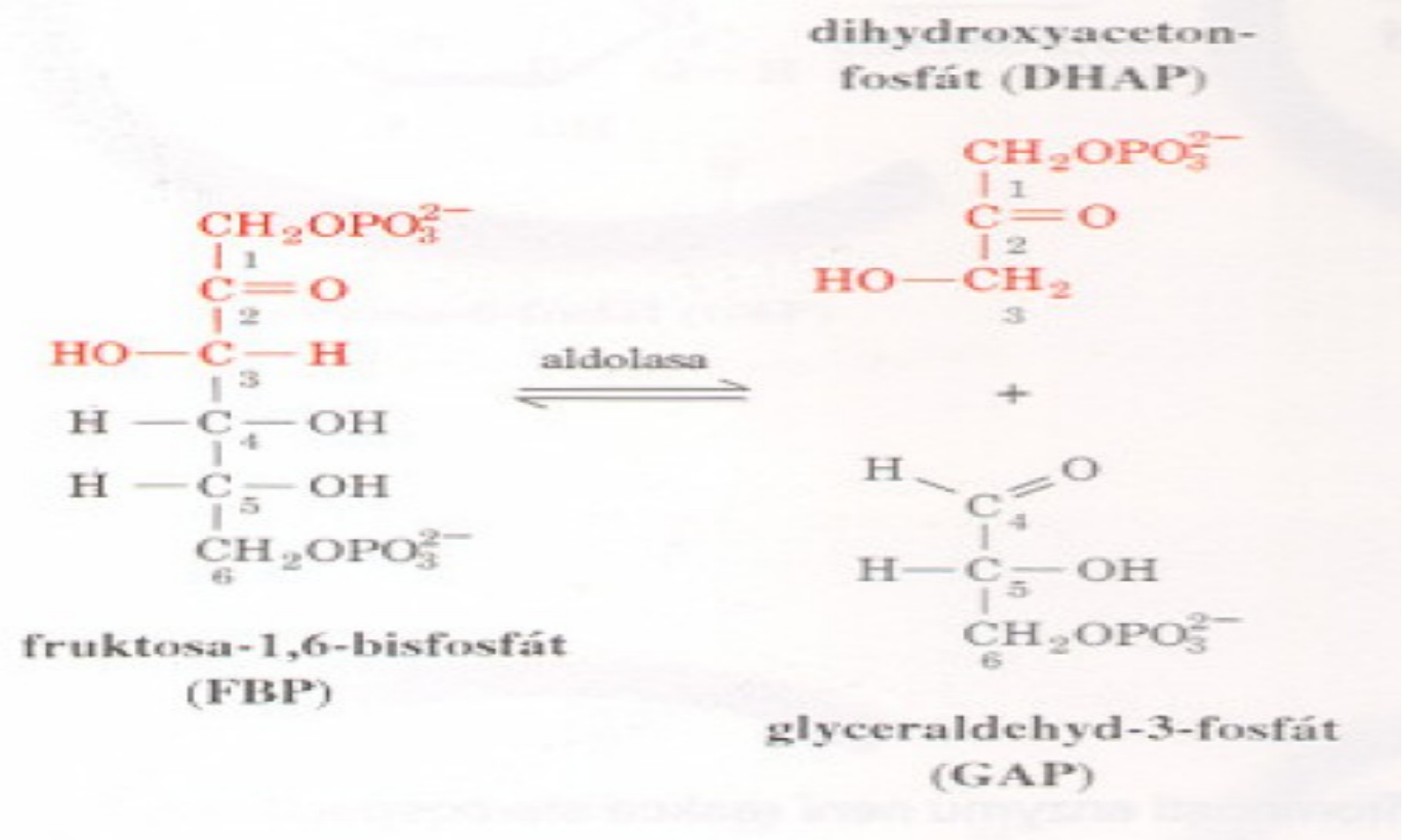
Fosfofruktokinasa



+ ADP, AMP

- ATP, citrát, fosfoenolpyruvát

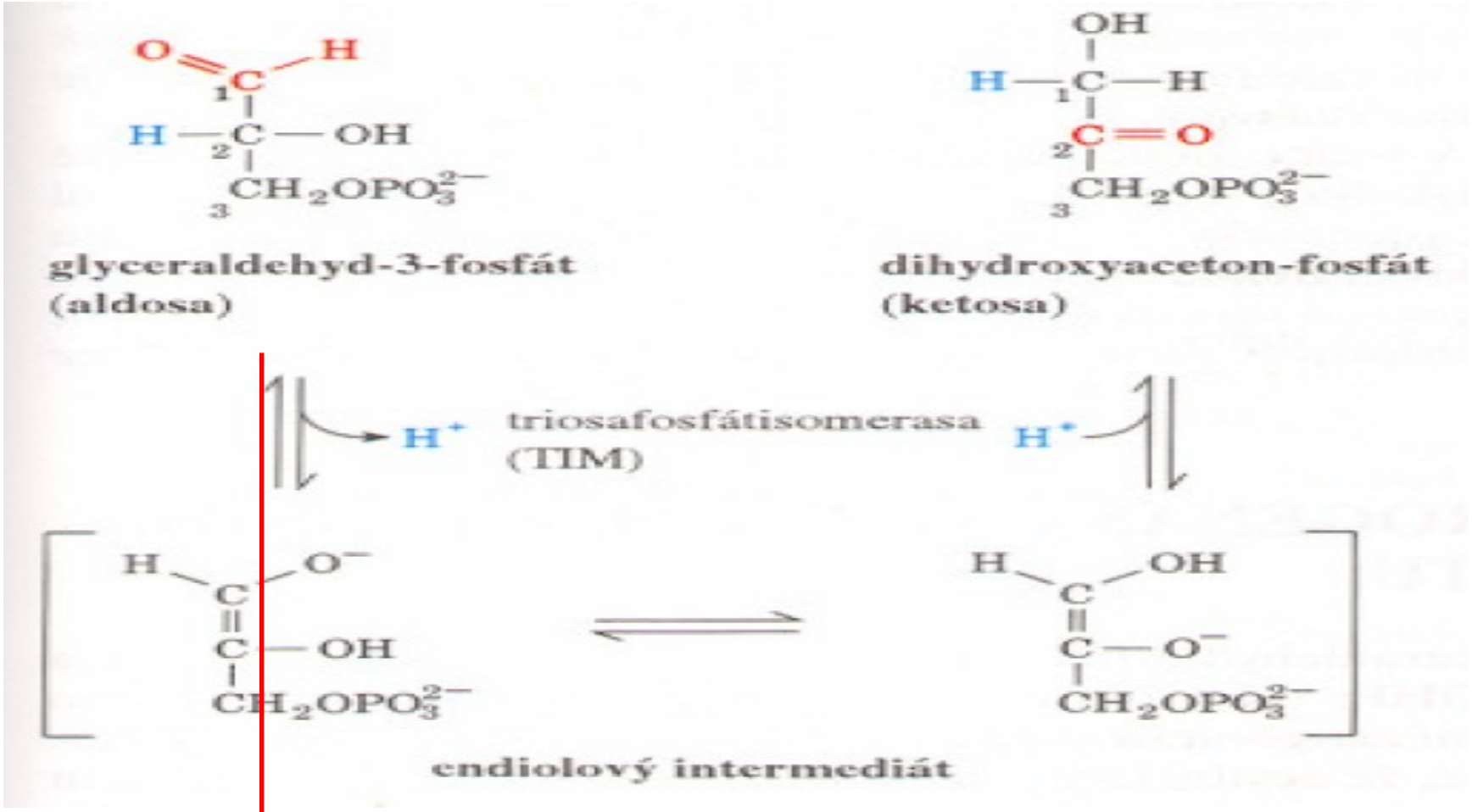
Aldolsa


dihydroxyaceton-
fosfát (DHAP)
aldolasa
fruktosa-1,6-bisfosfát
(FBP)
glyceraldehyd-3-fosfát
(GAP)

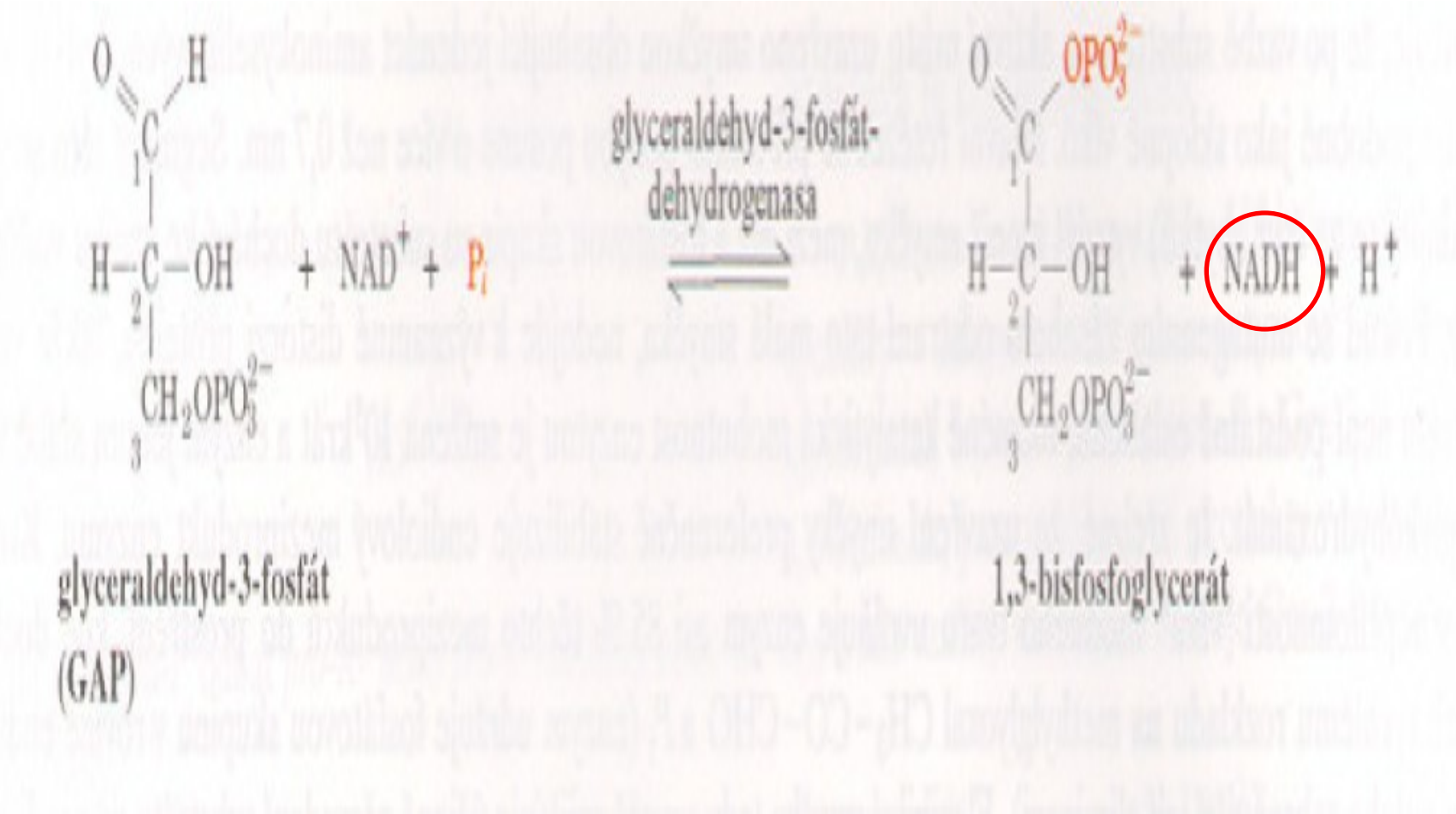
Triosafosfátisomerasa

4 %

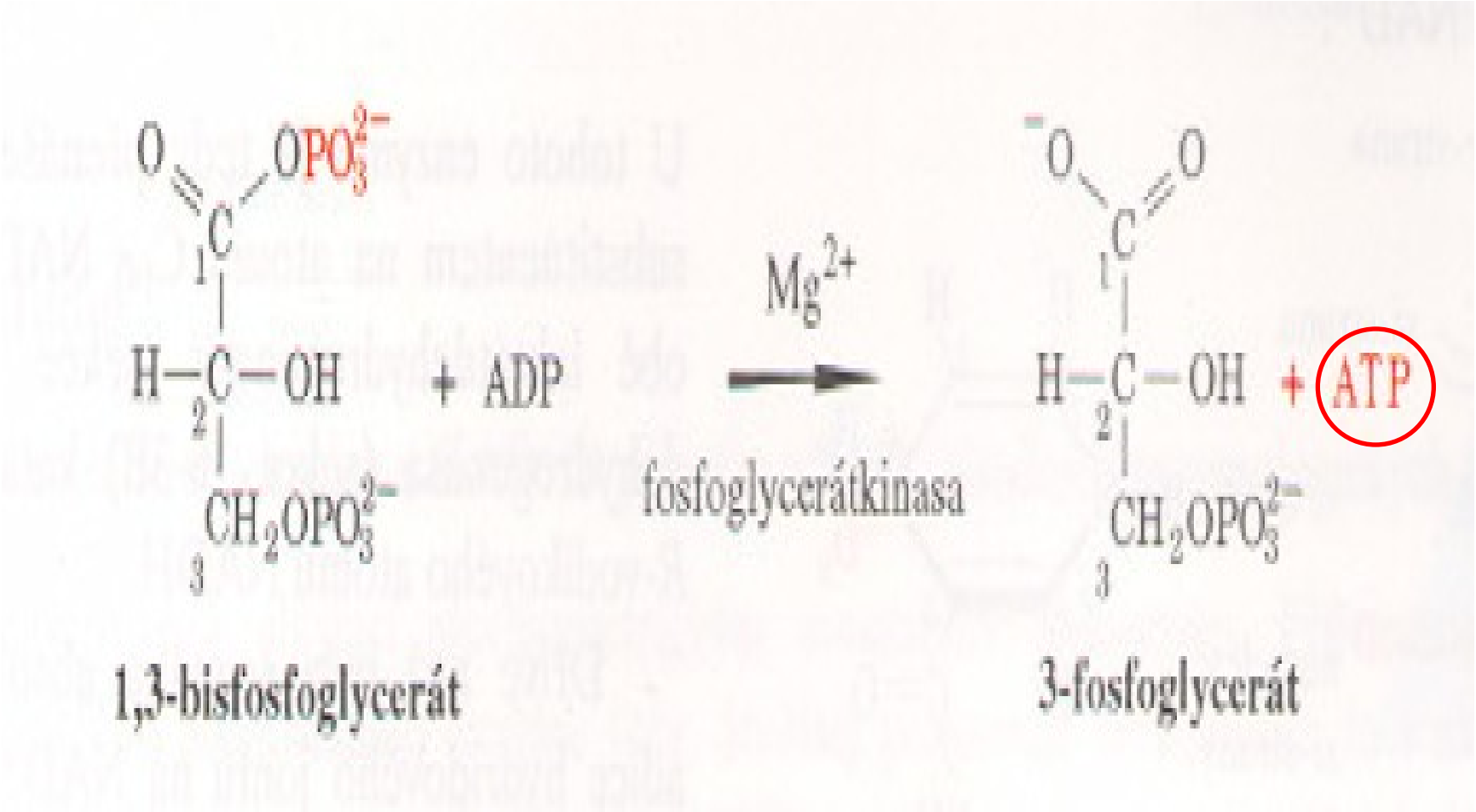
96 %



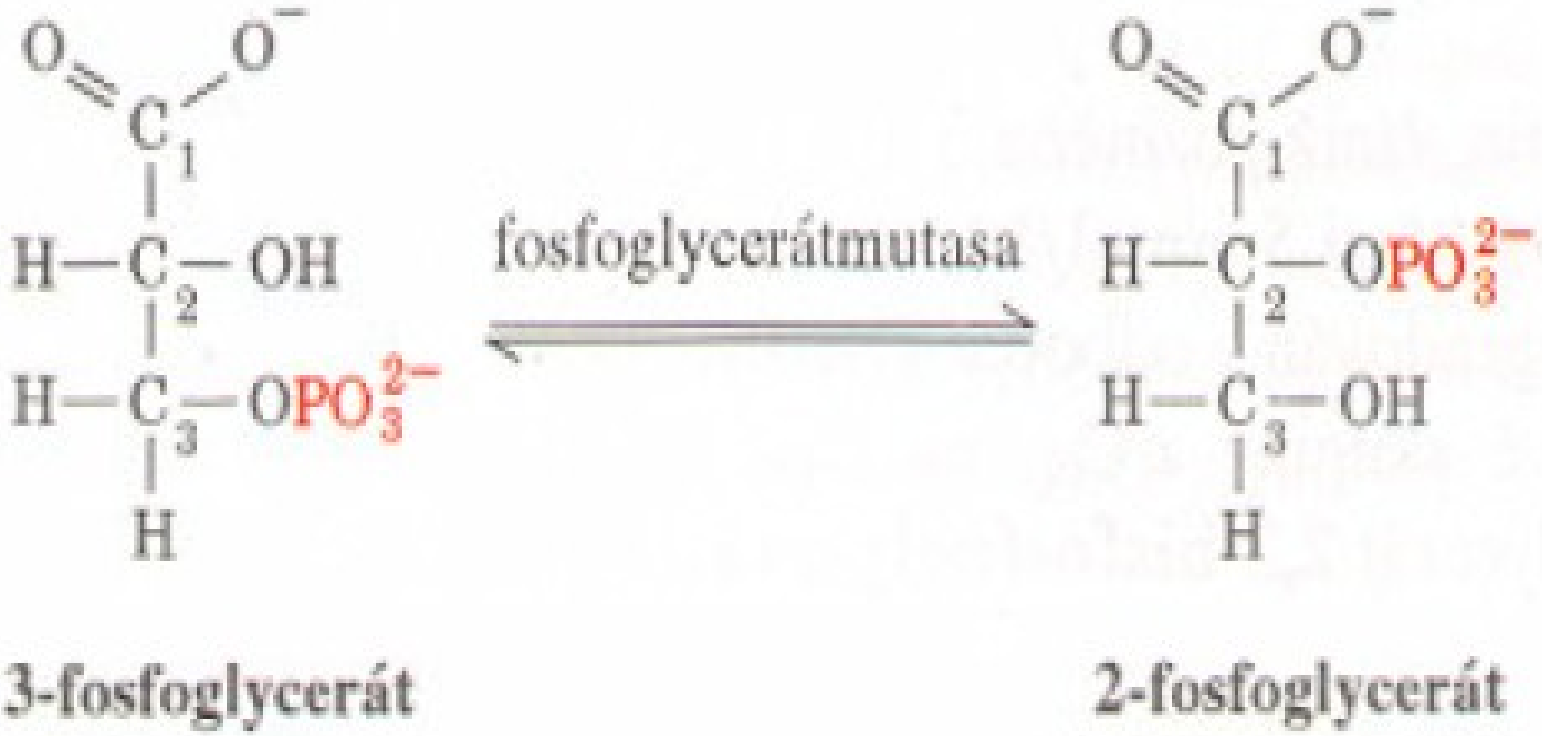
Glyceraldehyd-3-fosfát-dehydrogenasa



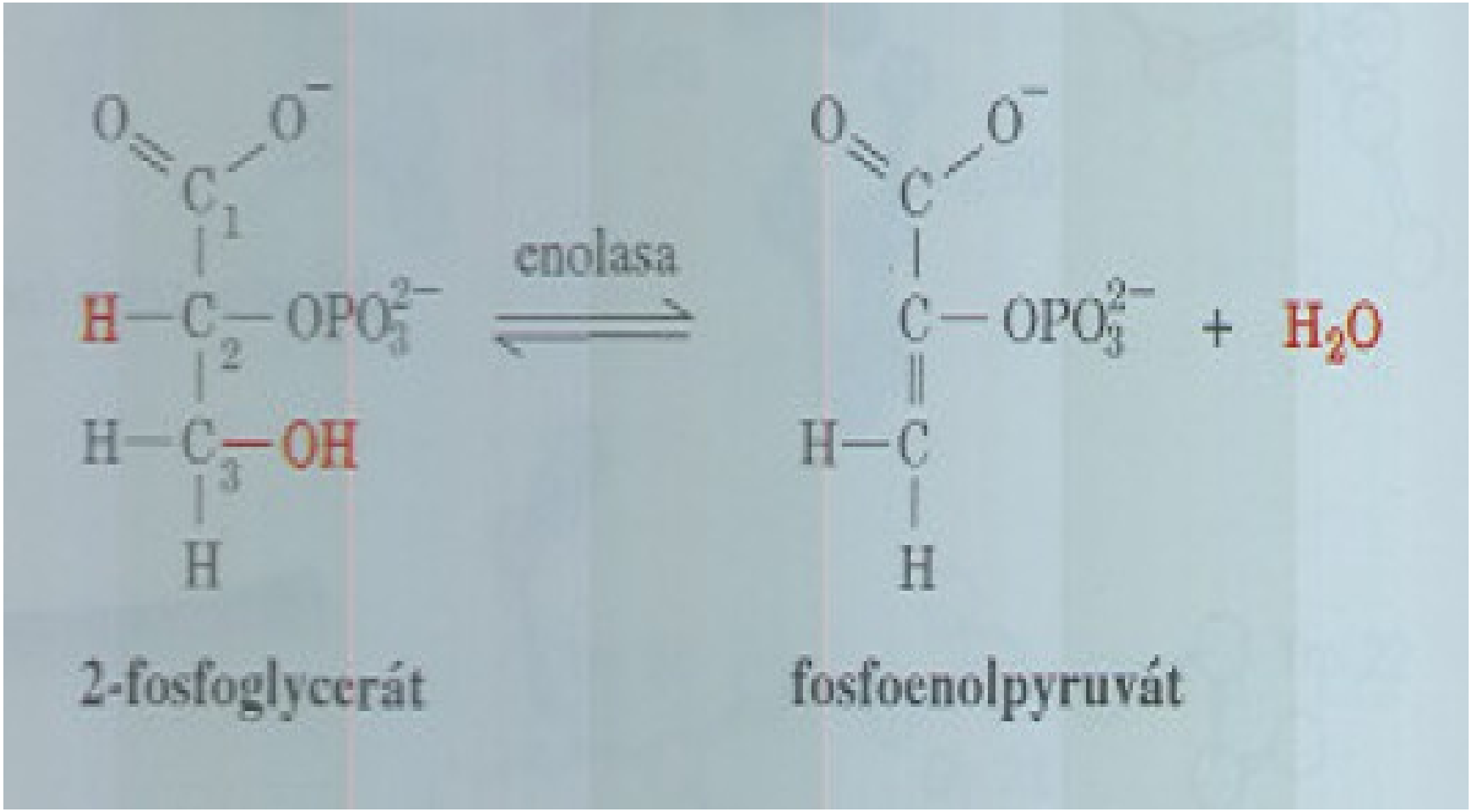
Fosfoglycerátkinasa



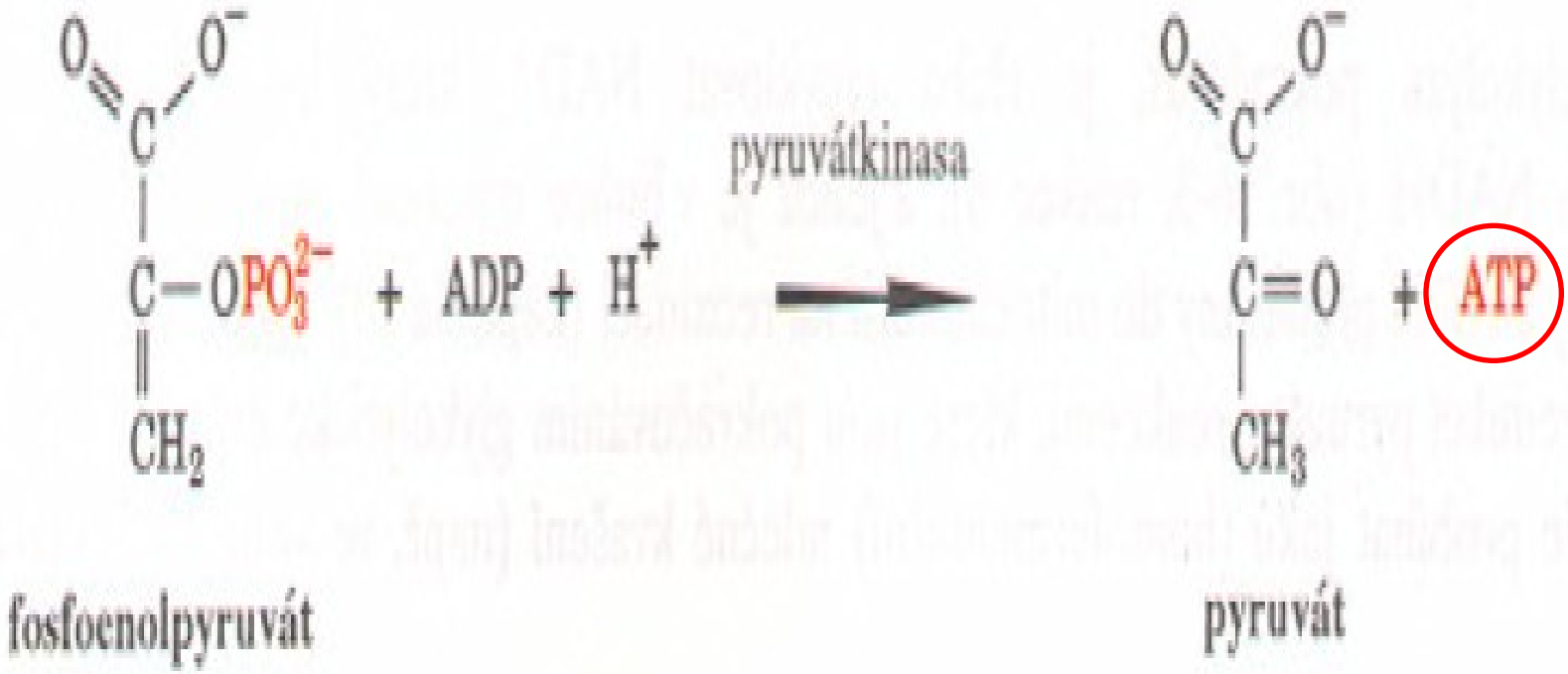
Fosfoglycerátmutasa



Enolasa



Pyruvátkinasa

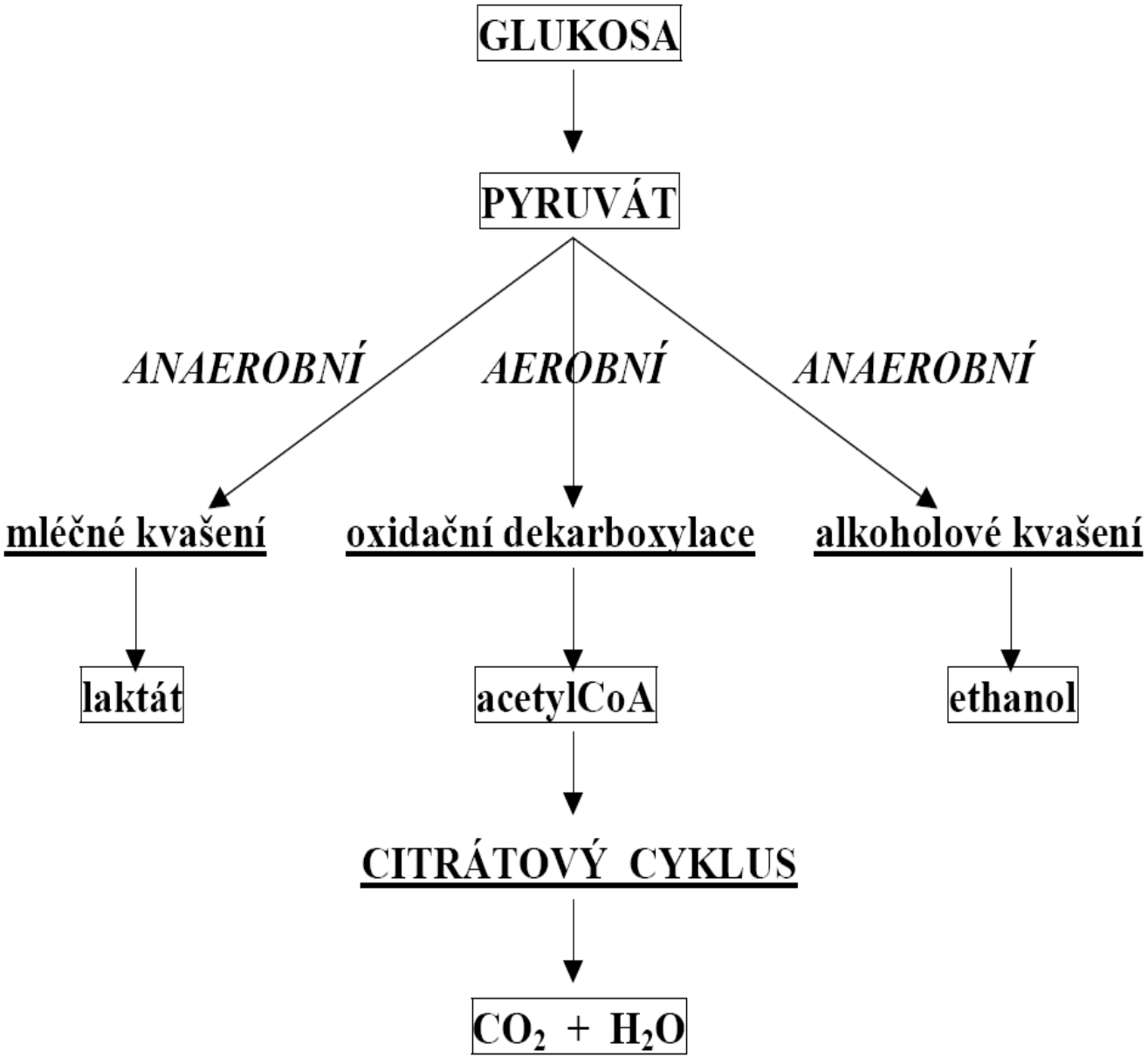


Bilance glykolýzy

$$\text{glukosa} + 2\,NAD^{+} + 2\,ADP + 2Pi$$

$$\rightarrow$$

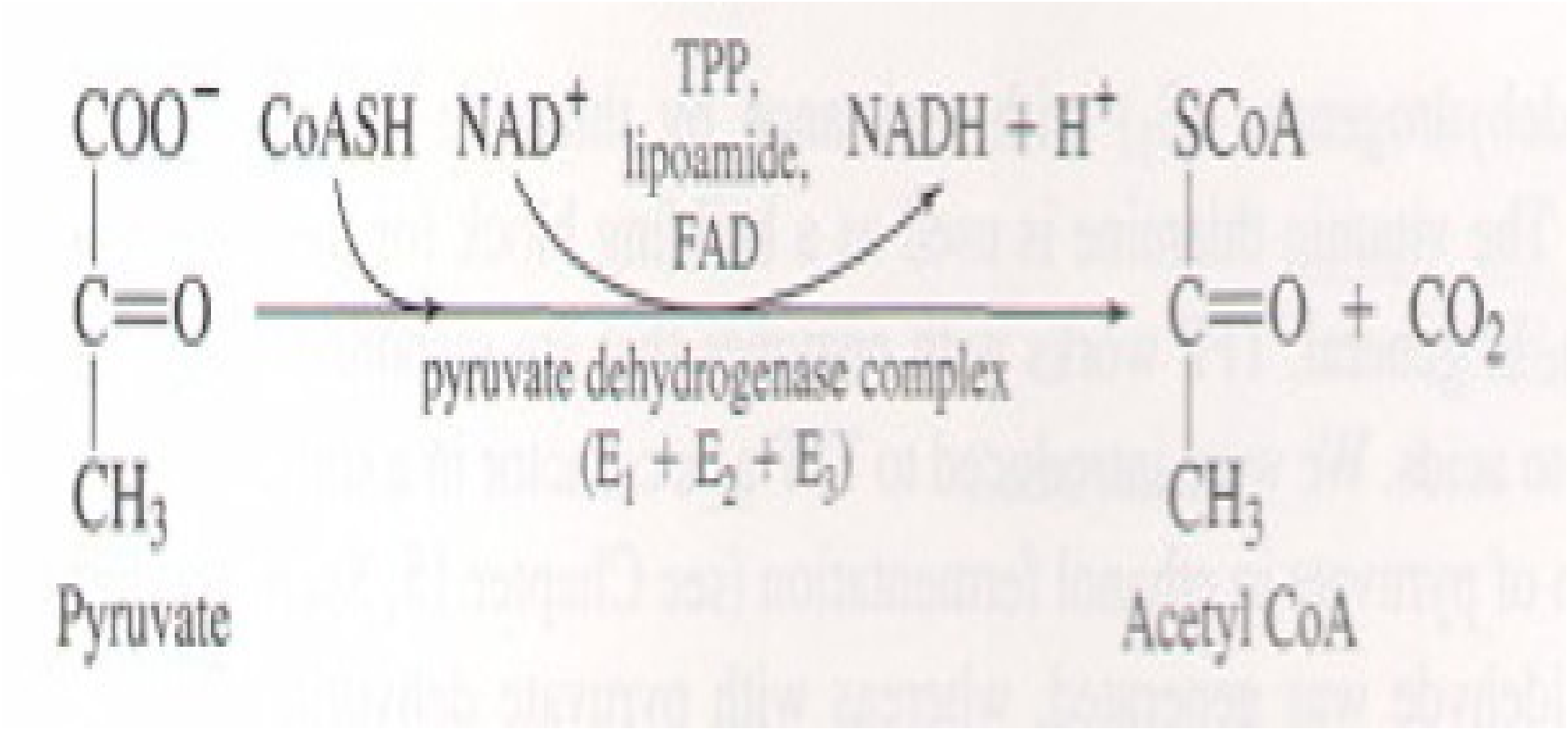
$$2\,\text{pyruvát} + 2\,ATP + 2\,NADH + 2\,H^{+} + 2\,H_2O$$


GLUKOSA
PYRUVÁT
ANAEROBNÍ
AEROBNÍ
ANAEROBNÍ
mléčné kvašení
oxidační dekarboxylace
alkoholové kvašení
laktát
acetylCoA
ethanol
CITRÁTOVÝ CYKLUS
CO2 + H2O

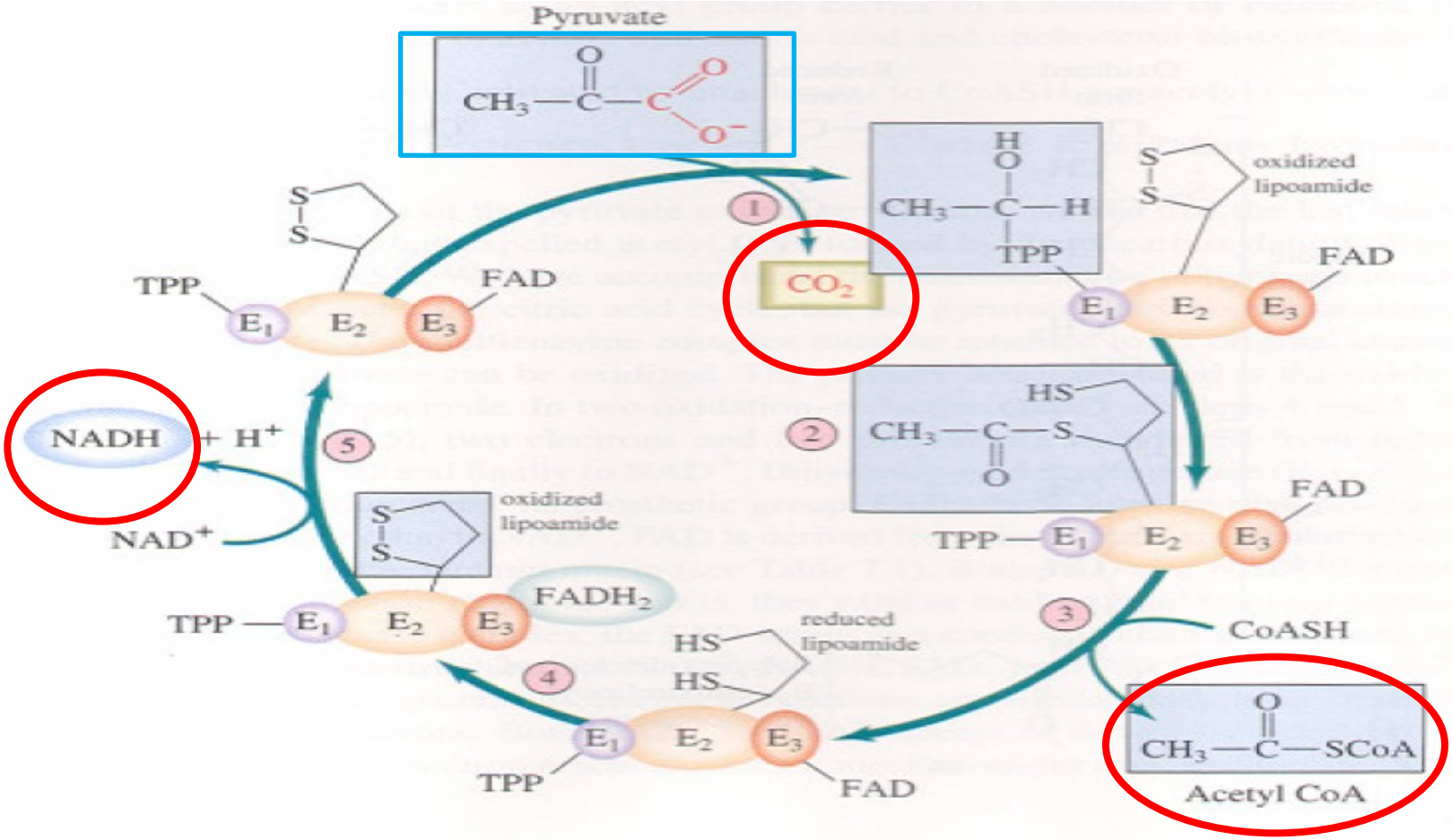
Aerobní odbourávání

Oxidační dekarboxylace :

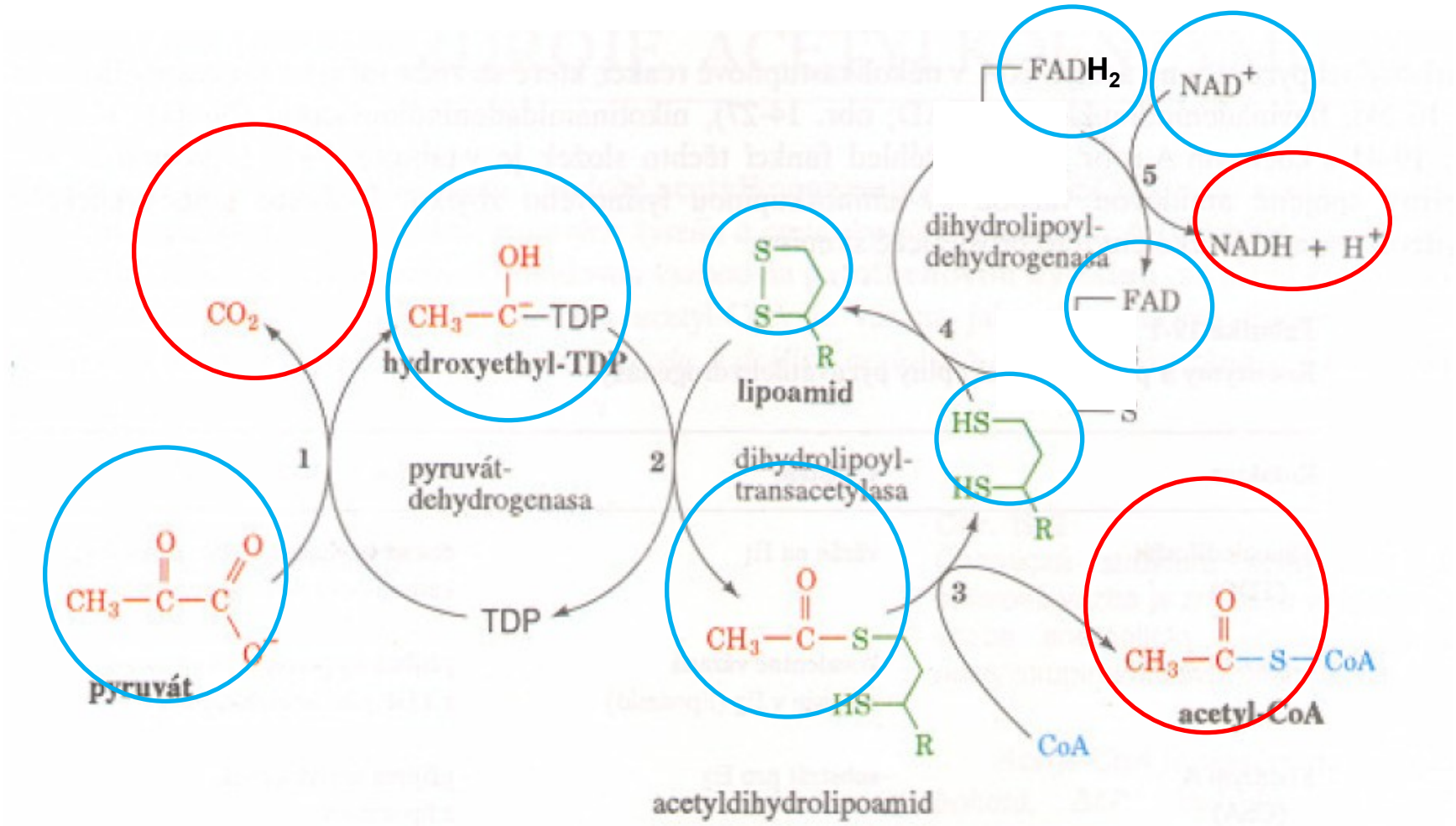
pyruvát + NAD^+ + CoA → acetylCoA + NADH + H^+ + CO_2



Pyruvátdehydrogenasa



Pyruvátdehydrogenasa



Aerobní odbourávání

Oxidační dekarboxylace :

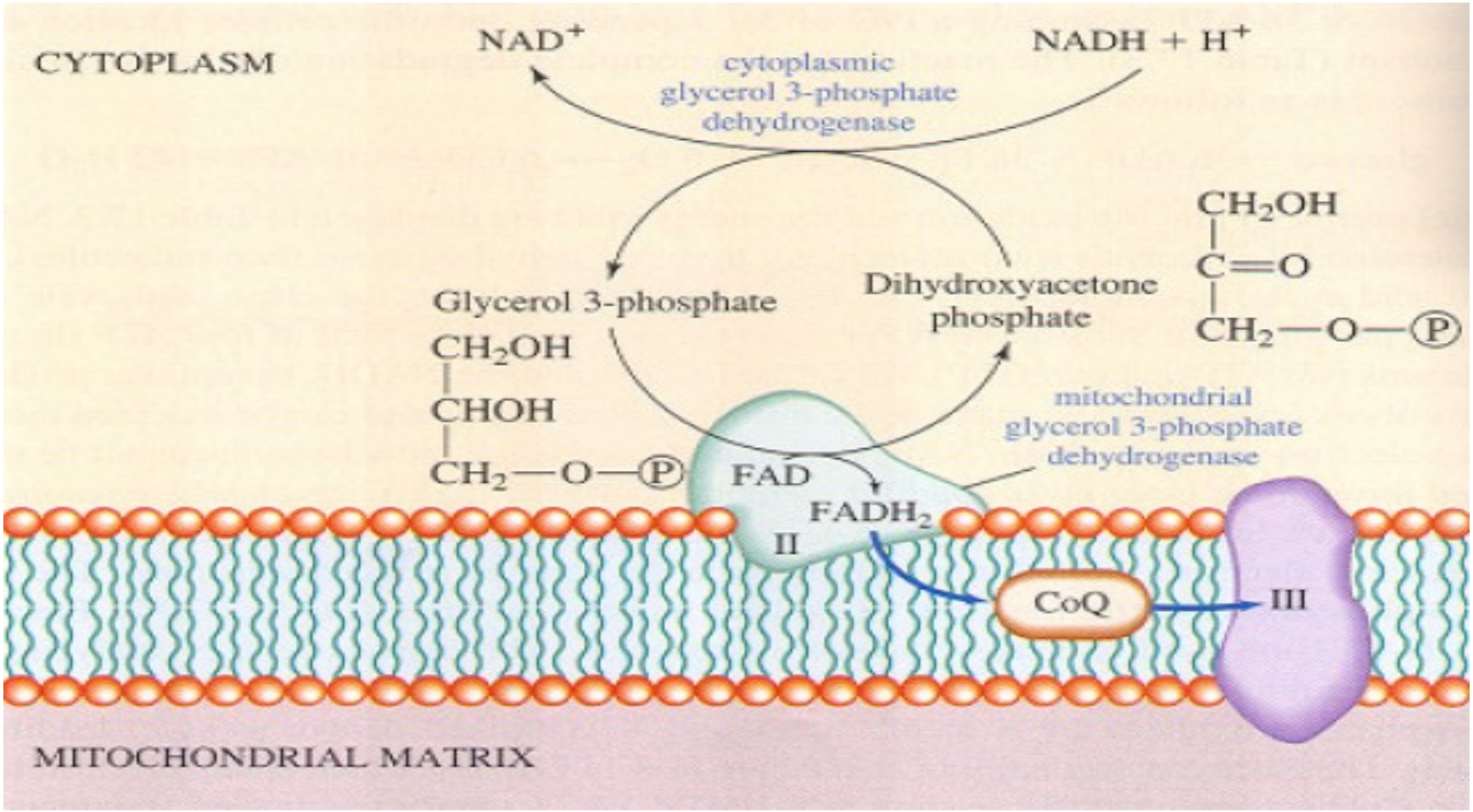
$$\text{pyruvát} + NAD^+ + CoA \rightarrow \text{acetylCoA} + NADH + H^+ + CO_2$$

Bilance aerobní glykolýzy :

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

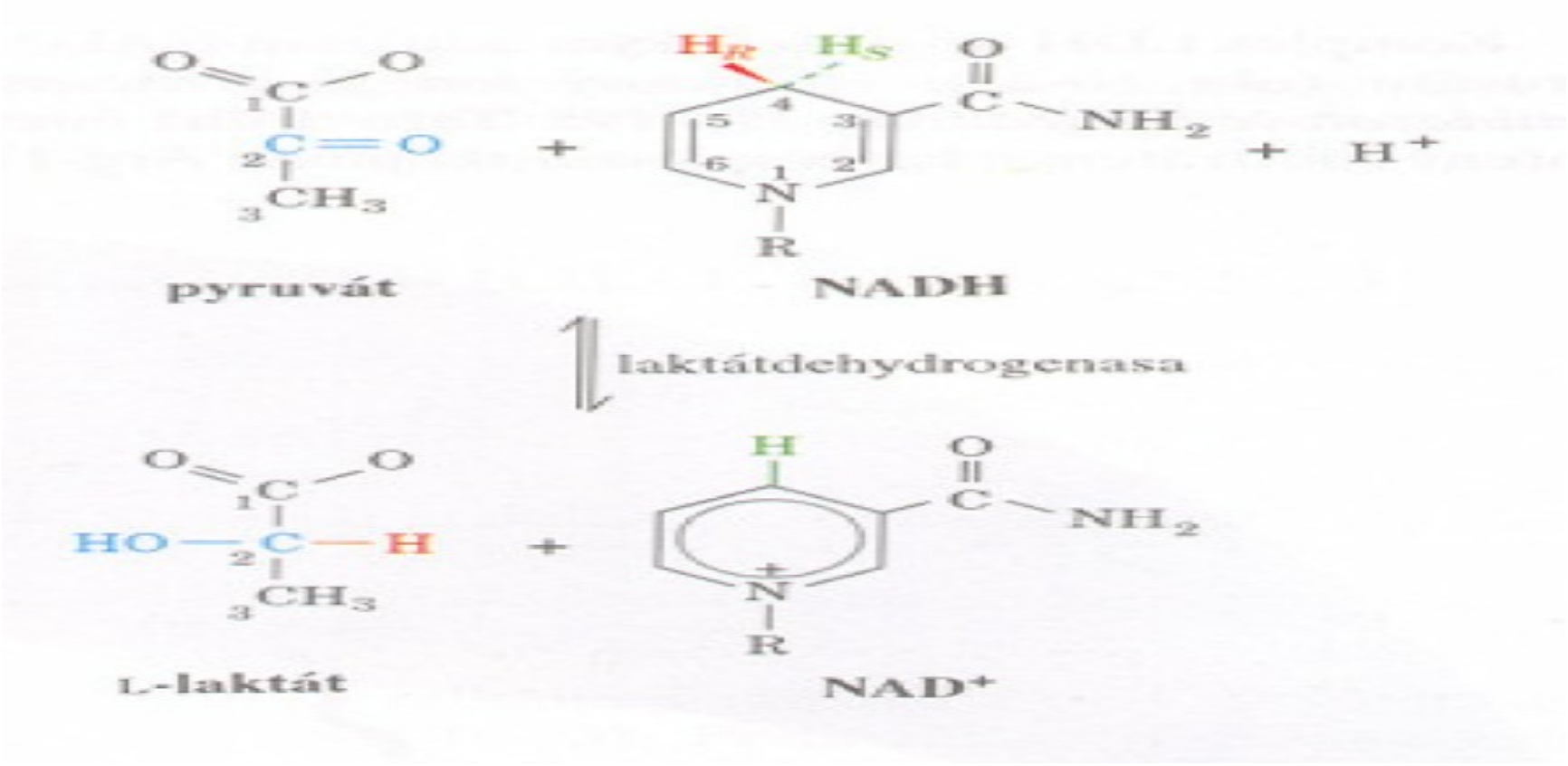
Glykolýza		1 ATP + 1 NADH	(4-1) ATP	CYT
Oxidační dekarboxylace		1 NADH	3 ATP	MIT
Citrátový cyklus	1 ATP	3 NAD + $FADH_2$	12 ATP	
CELKEM	18 ATP/ triosu tj.	36 ATP/ glukosu tj.	40 %	

G-3-P DH člunek

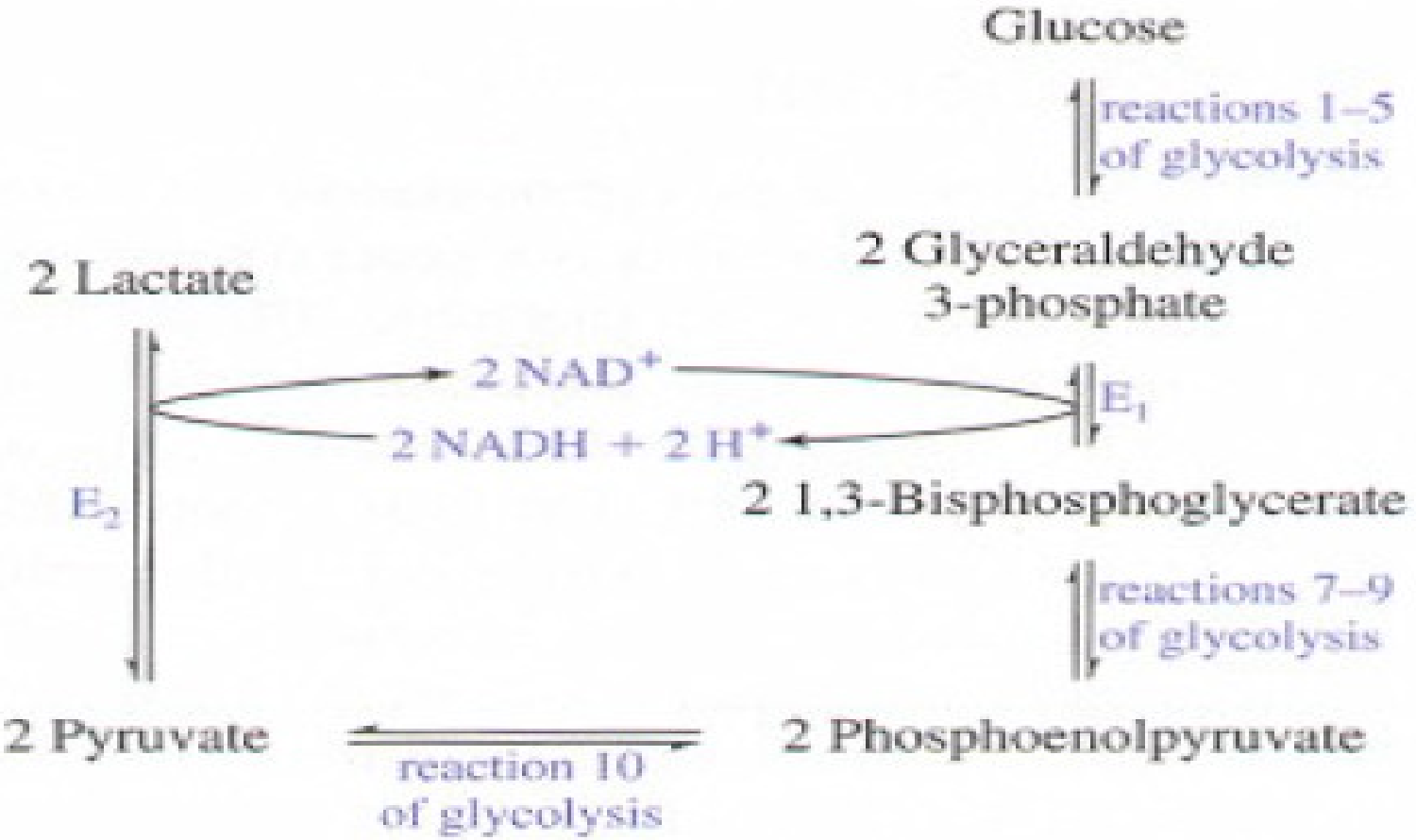


Mléčné kvašení

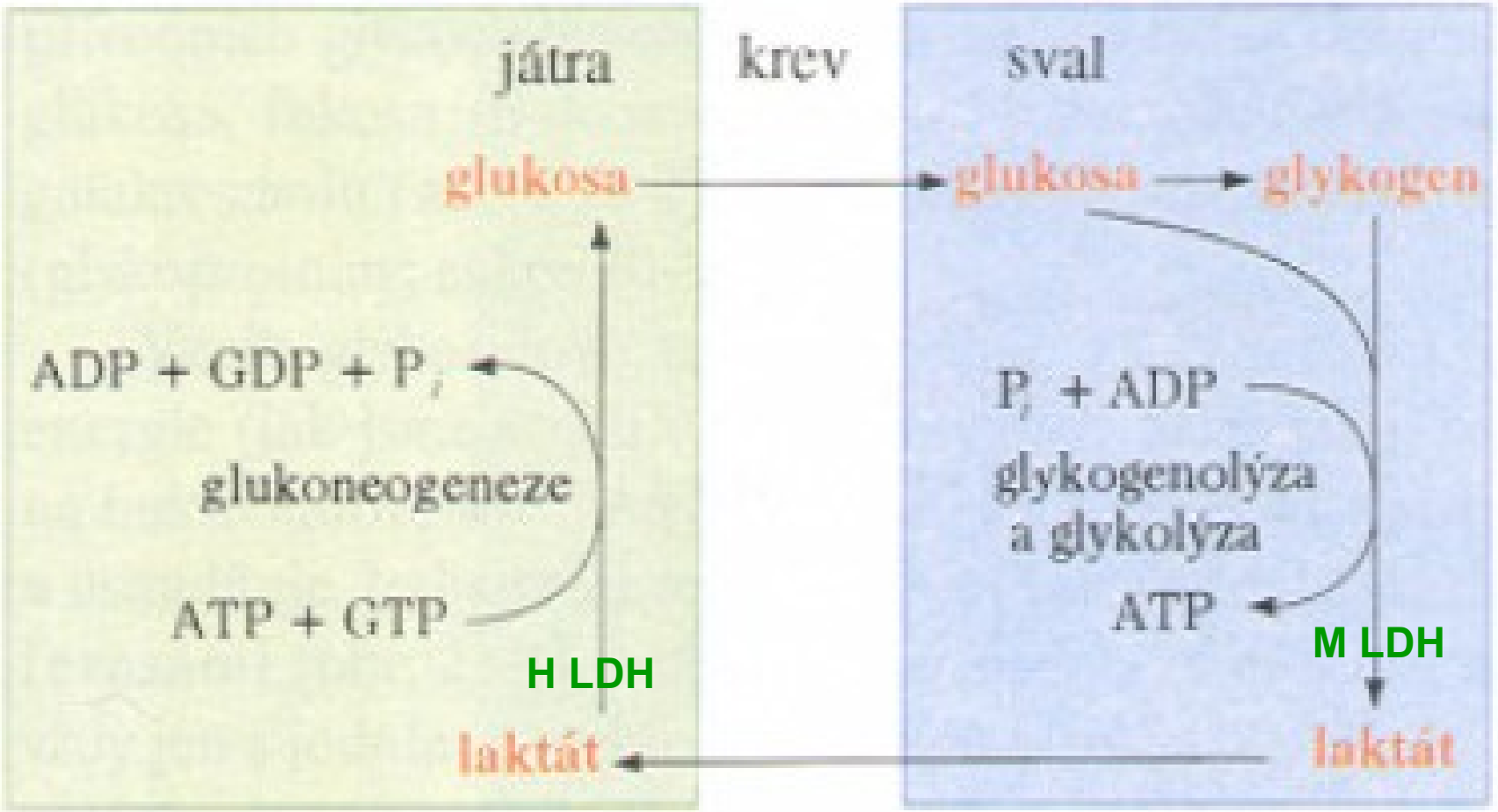
pyruvát + NADH + H^+ → laktát + NAD^+



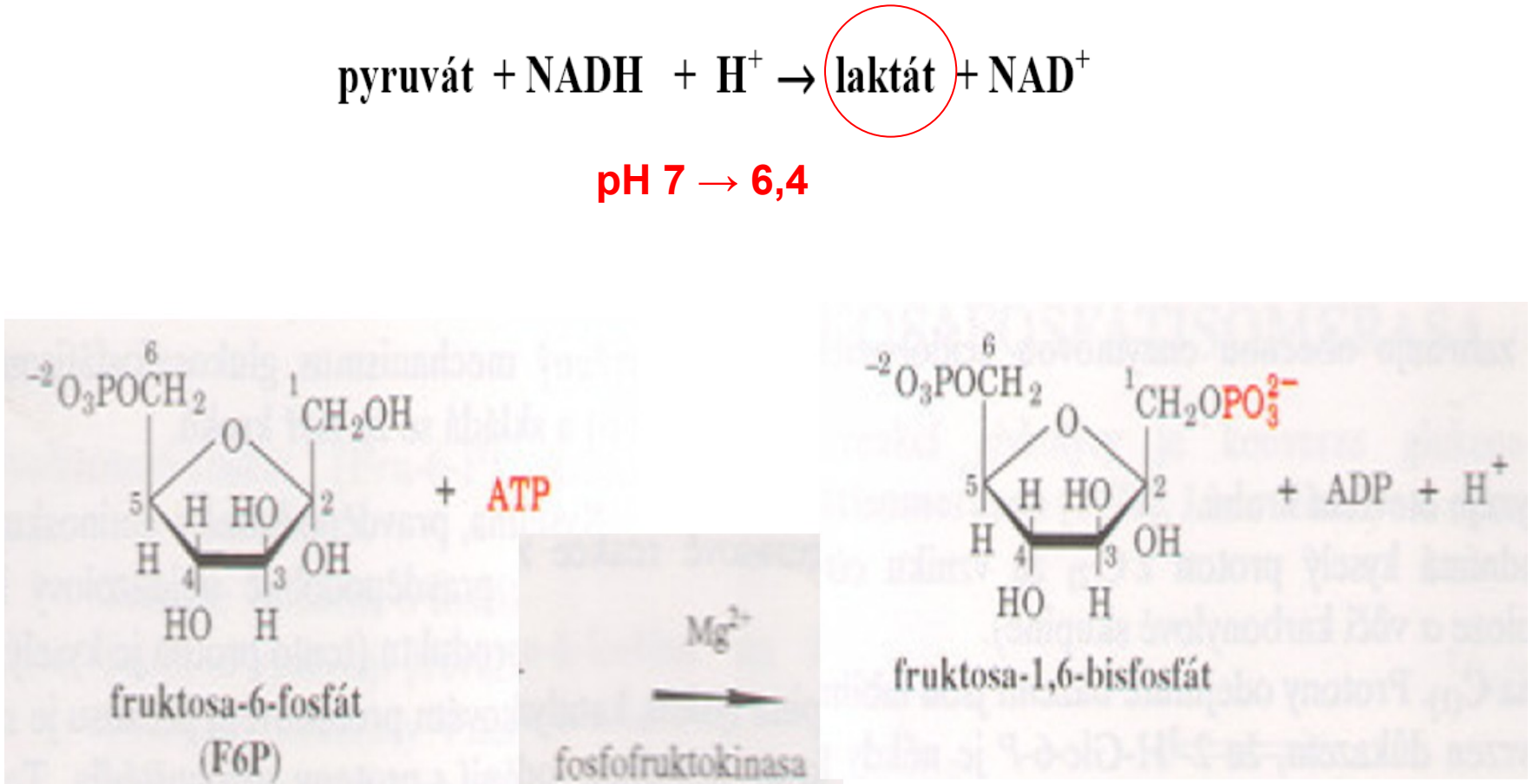
Mléčné kvašení



Coriho cyklus



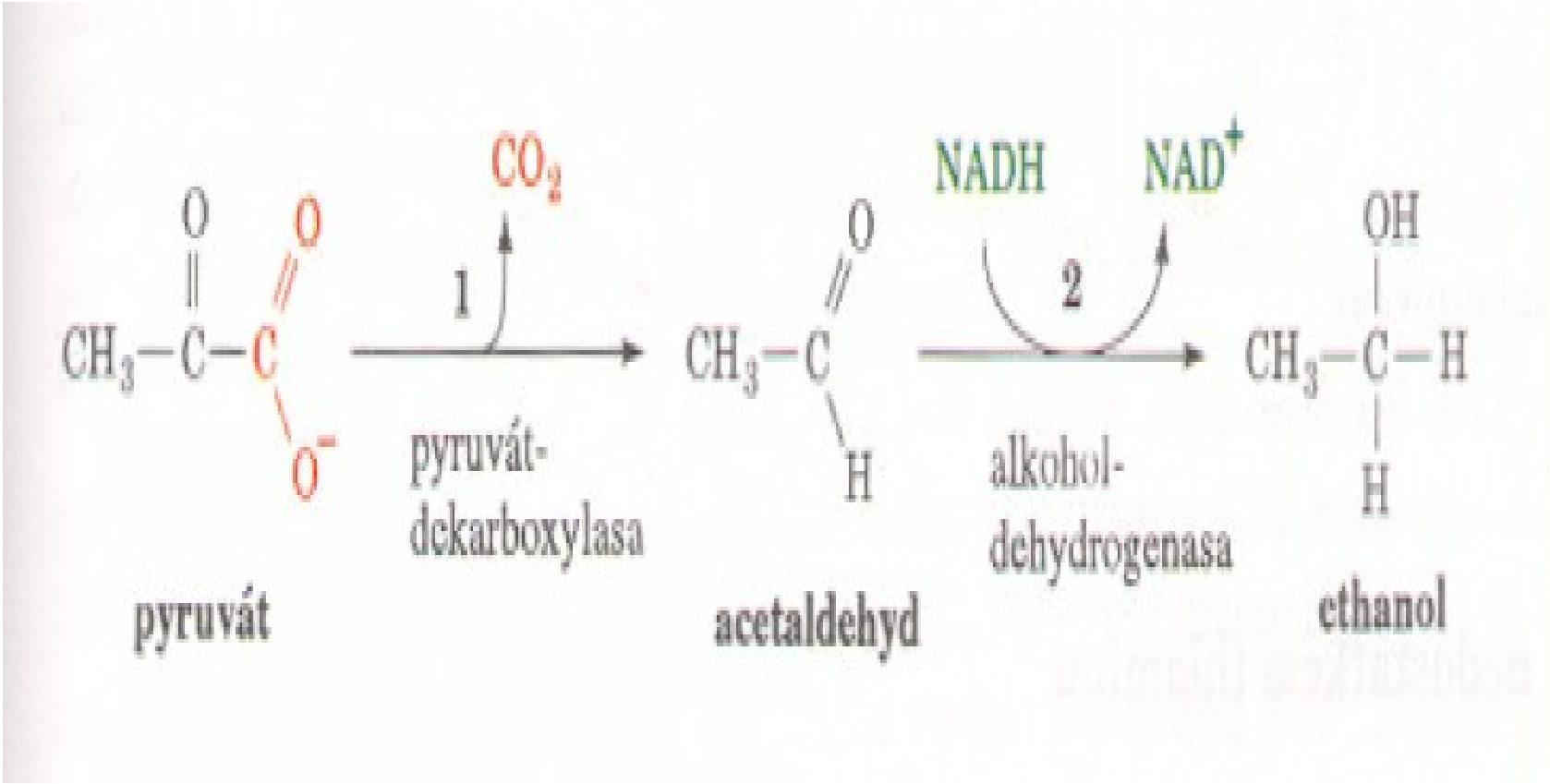
Mléčné kvašení



Alkoholové kvašení

Pyruvát → acetaldehyd + CO_2

Acetaldehyd + NADH + H^+ → ethanol + NAD^+



Alkoholové kvašení

$$\text{Pyruvát} \rightarrow \text{acetaldehyd} + CO_2$$

$$\text{Acetaldehyd} + NADH + H^+ \rightarrow \text{ethanol} + NAD^+$$

Bilance alkoholového kvašení :

$$C_6H_{12}O_6 + 2\ ADP + 2\ Pi \rightarrow 2\ \text{ethanol} + 2\ ATP + 2\ CO_2$$

Glykolýza	1 ATP +	1 NADH
Alkoholové kvašení	-	1 NADH

CELKEM	1 ATP/ triosu tj.	2 ATP/ glukosu tj.	2 %

Další druhy kvašení

Substrátová fosforylace

- **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

NAD^+ versus $NADP^+$

Rozdíl :

- Využití:

NAD^+ energetická

$NADP^+$ biosyntetická

- Lokalizace

NAD^+ mitochondrie

$NADP^+$ cytosol

NAD(P) transhydrogenasa

$$NAD^+ + NADPH \leftrightarrow NADH + NADP^+$$

NAD^+ versus $NADP^+$

Rozdíl :

- Využití:

NAD^+	energetická	glykolysa
$NADP^+$	biosyntetická	pentosový cyklus

- Lokalizace

NAD^+	mitochondrie
$NADP^+$	cytosol

Pentosový cyklus

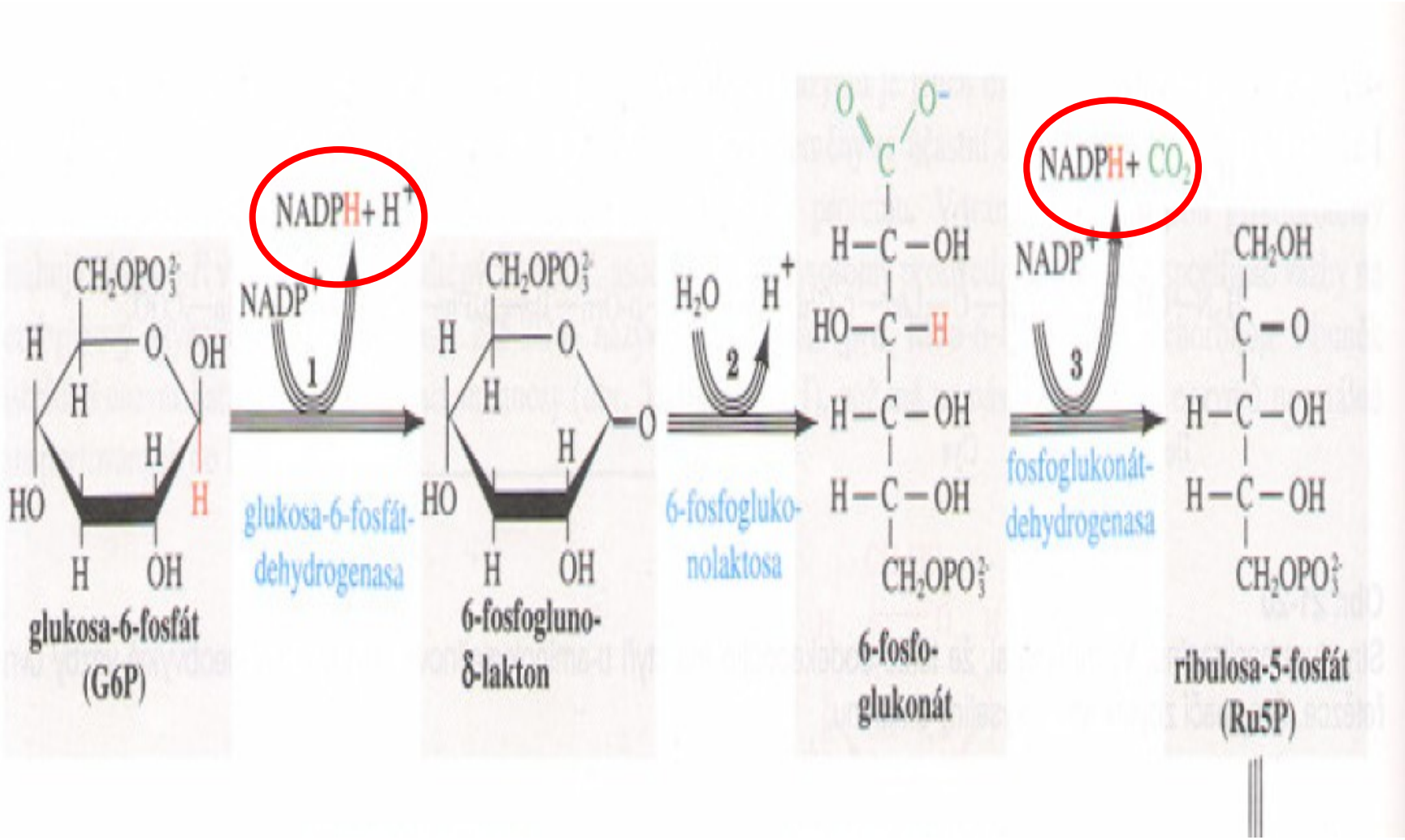
- Zdroj NADPH u heterotrofů (fotosyntesa u autotrofů)
- NADPH + ribosa-5-P
- Živočichové, rostliny, mikroorganismy
- 20 - 30 % glukosy

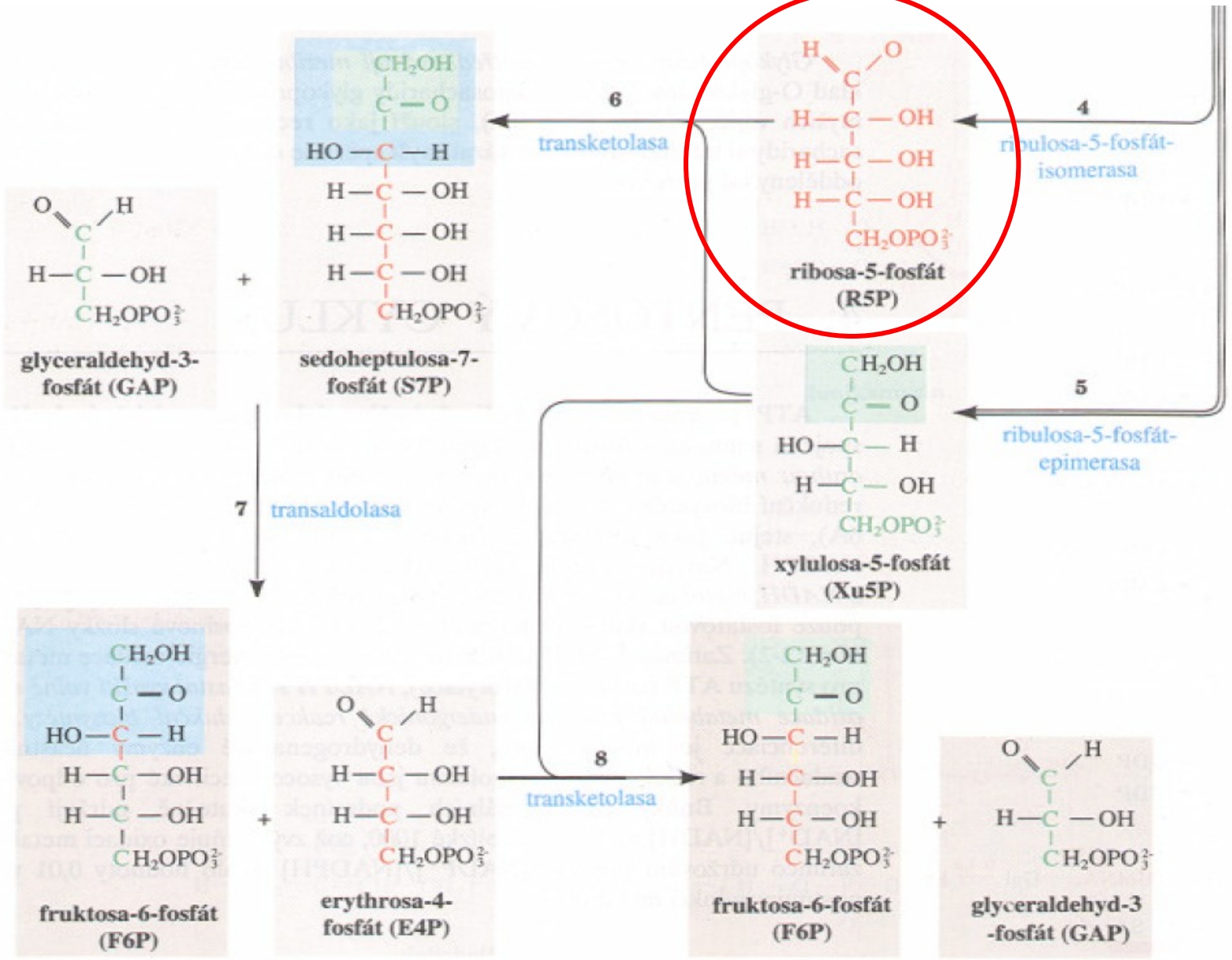
Pentosový cyklus

Dvě fáze :

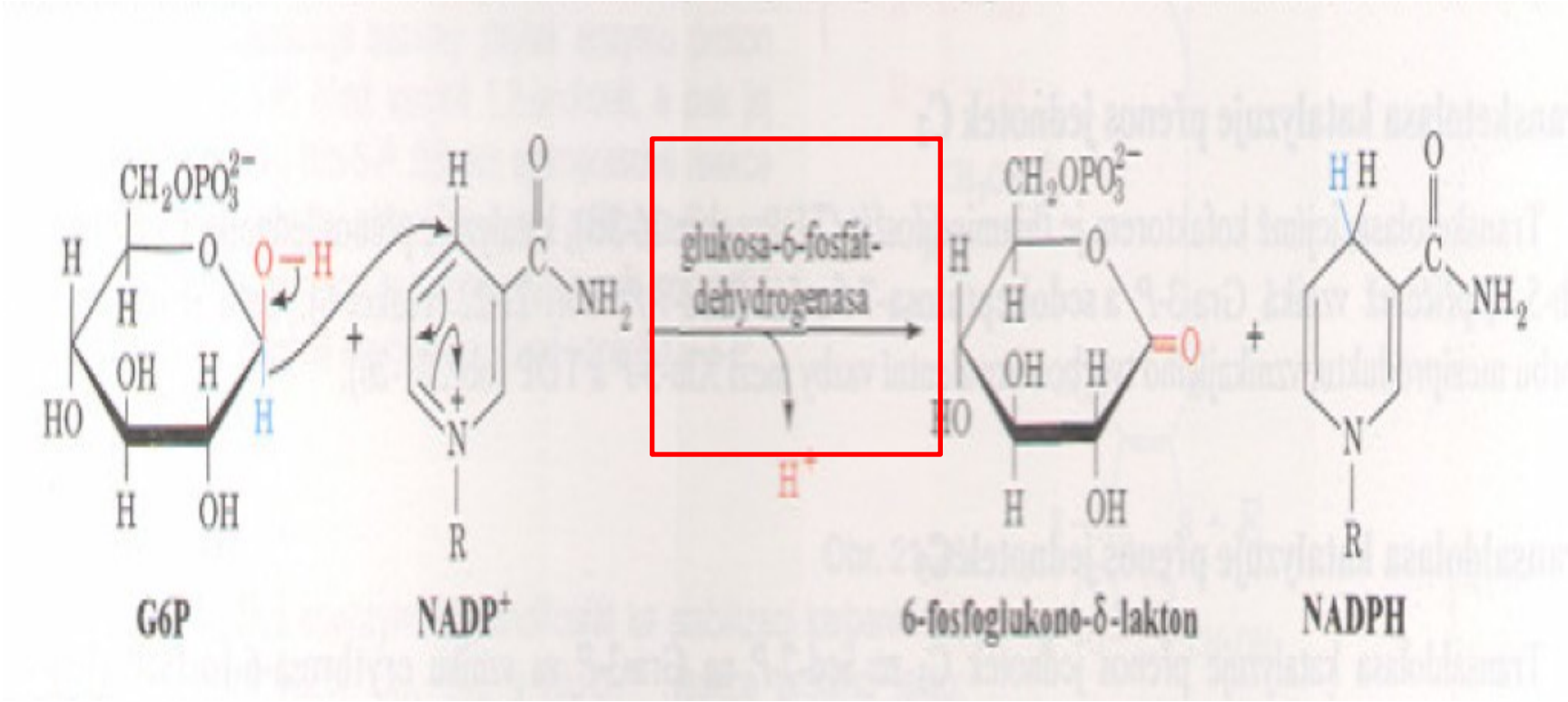
- Oxidační – NADPH + CO_2
- Regenerační – regenerace hexosy z pentosy

Pentosový cyklus



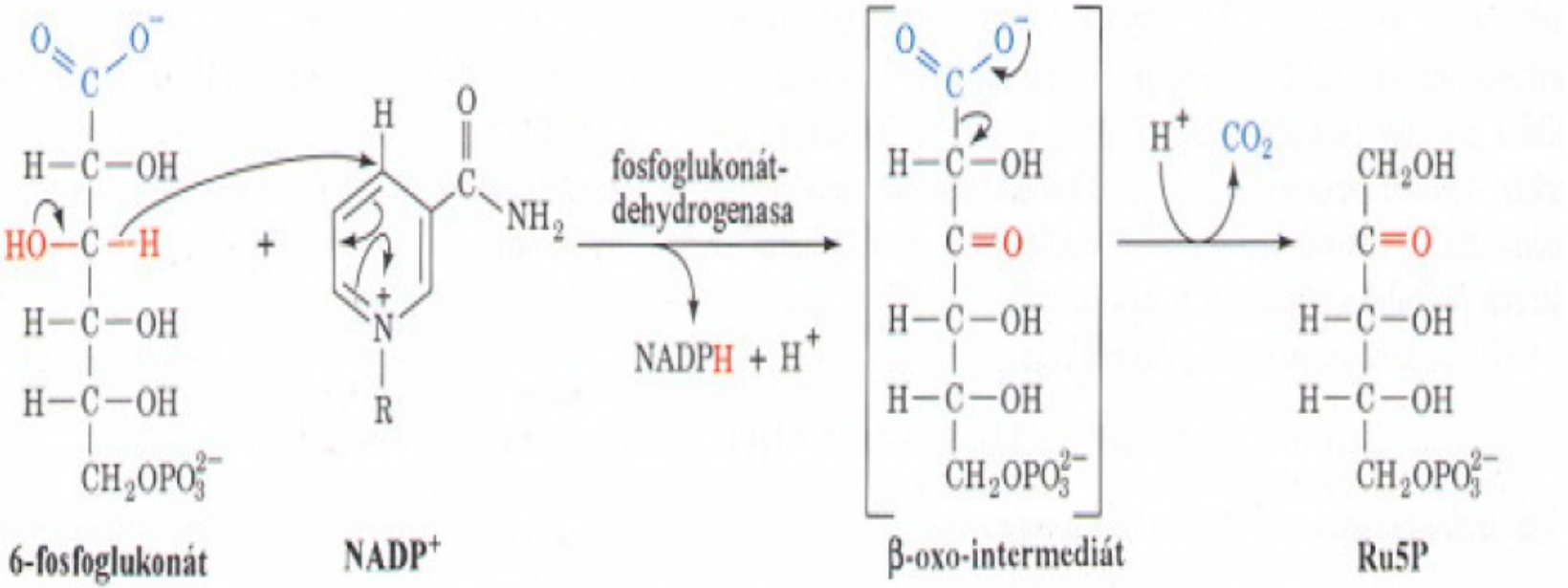

ribosa-5-fosfát (R5P)
6
transketolasa
4
ribulosa-5-fosfát-izomerasa
5
ribulosa-5-fosfát-epimerasa
xylulosa-5-fosfát (Xu5P)
glyceraldehyd-3-fosfát (GAP)
sedoheptulosa-7-fosfát (S7P)
7
transaldolasa
fruktosa-6-fosfát (F6P)
erythrosa-4-fosfát (E4P)
8
transketolasa
fruktosa-6-fosfát (F6P)
glyceraldehyd-3-fosfát (GAP)

Oxidační fáze

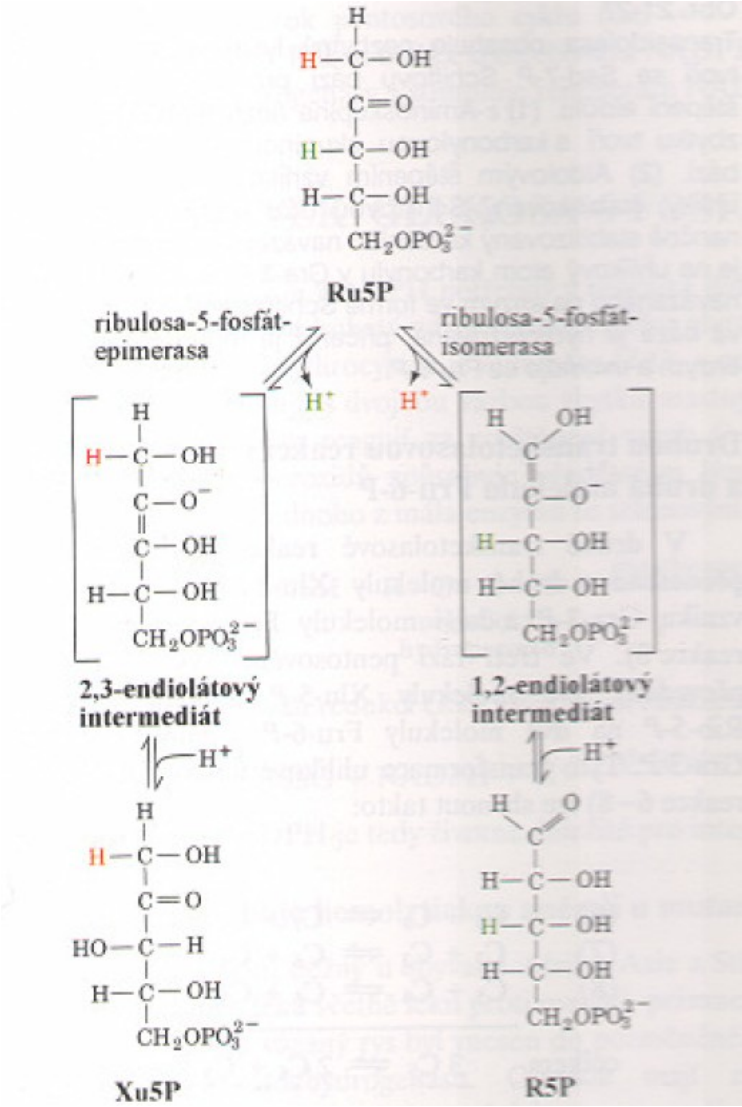


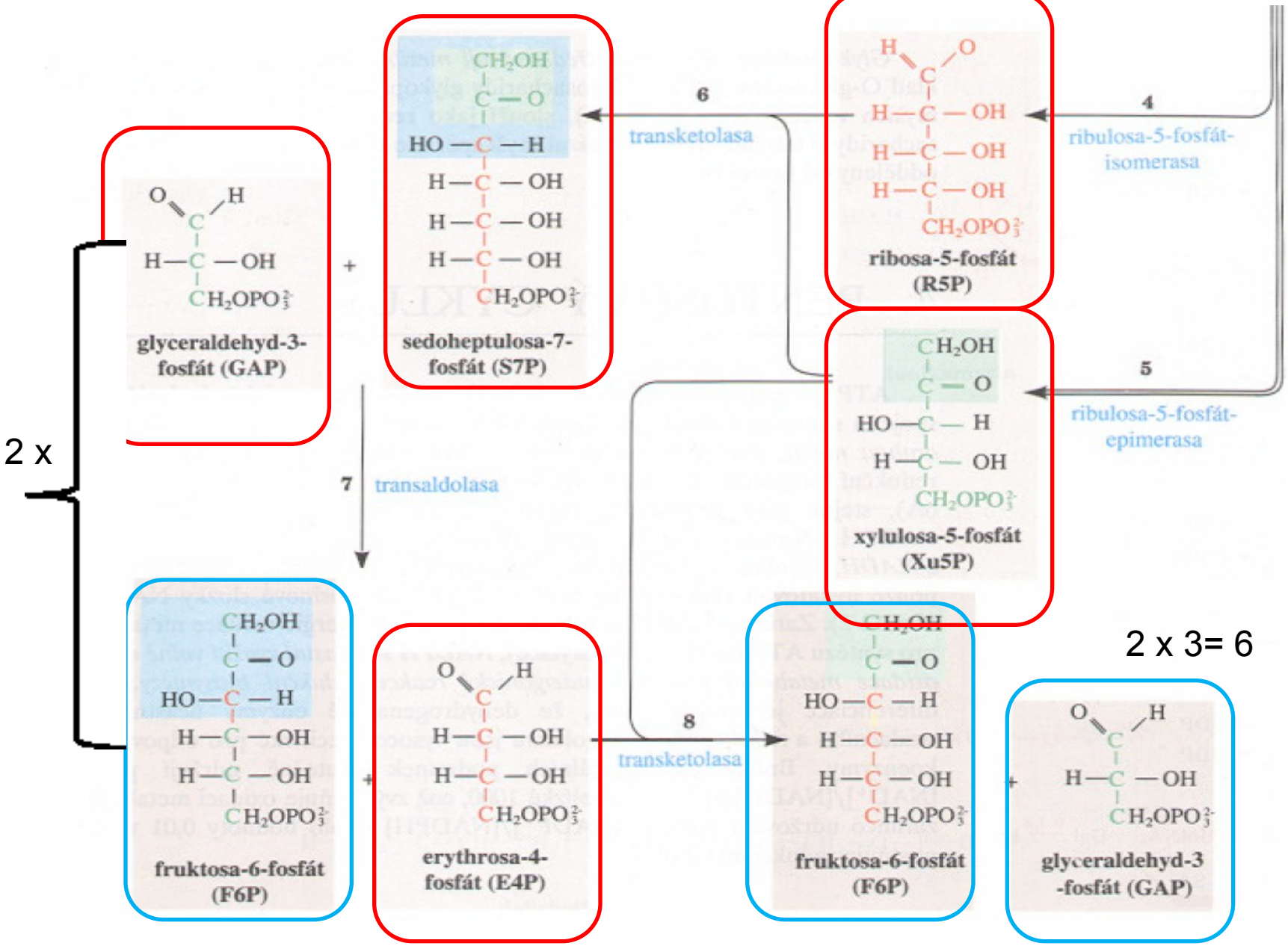
+ $NADP^+$

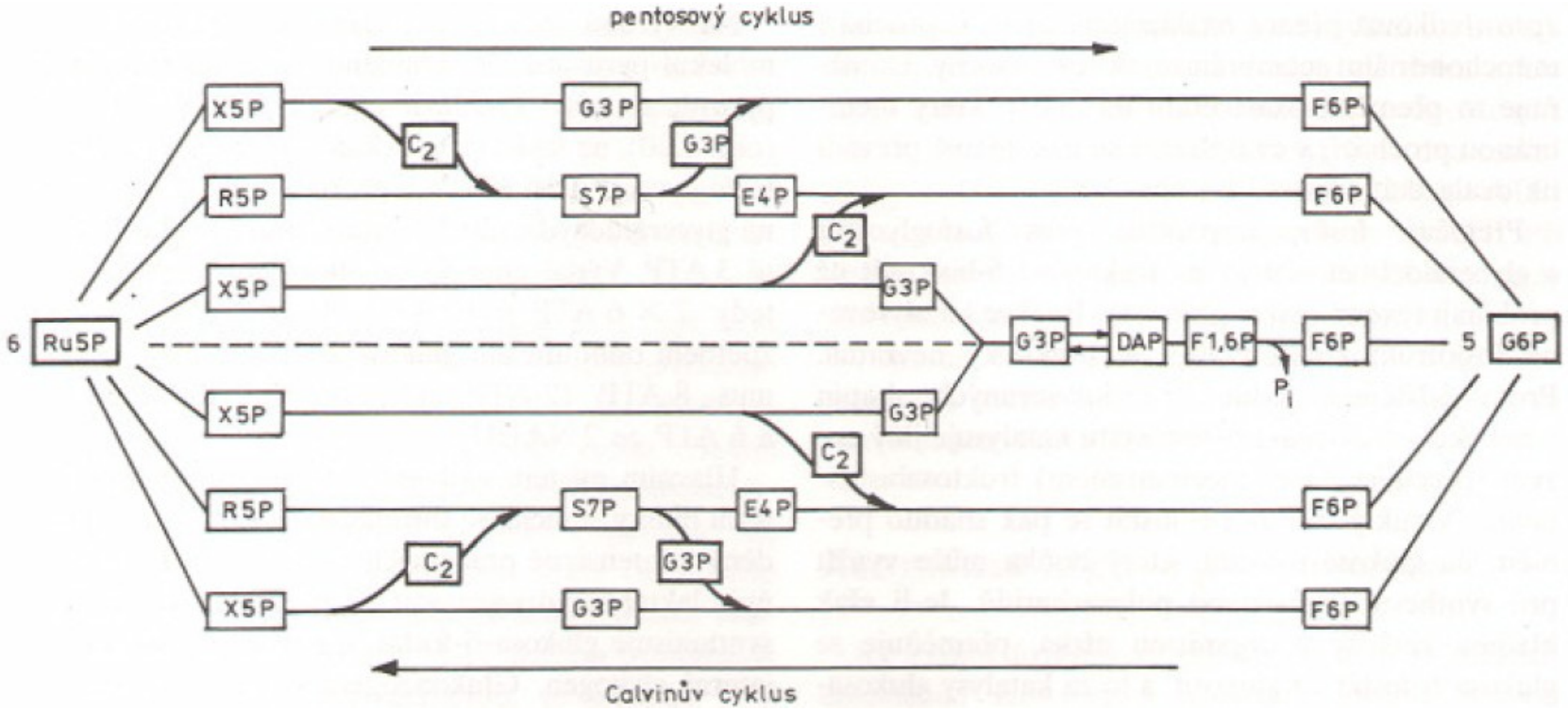
- NADPH

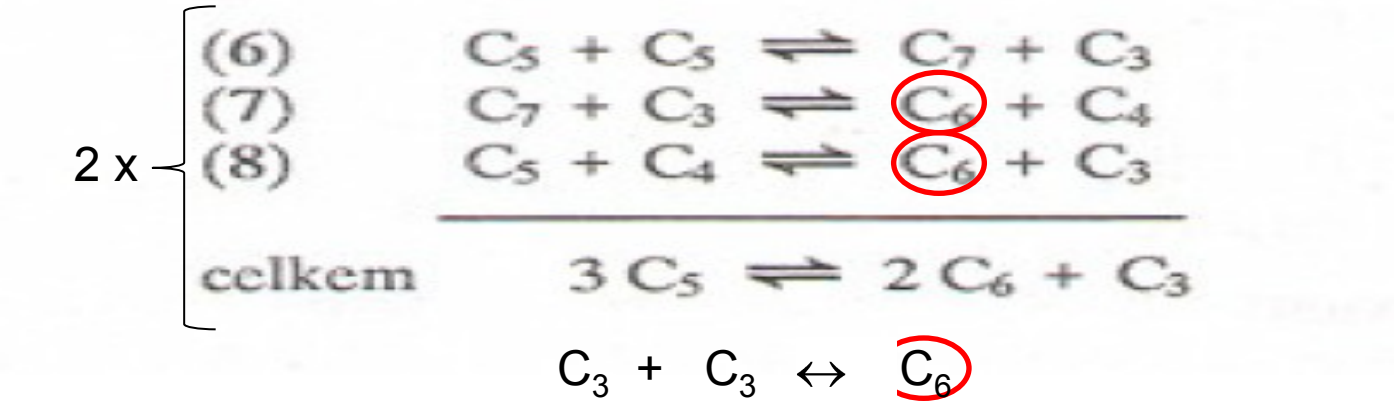

fosfoglukonát-
dehydrogenasa
NADPH + H+
H+
CO2
6-fosfoglukonát
NADP+
β-oxo-intermediát
Ru5P

Regenerační fáze




2 x
glyceraldehyd-3-fosfát (GAP)
+
sedoheptulosa-7-fosfát (S7P)
6
transketolasa
ribosa-5-fosfát (R5P)
4
ribulosa-5-fosfát-isomerasa
5
ribulosa-5-fosfát-epimerasa
xylulosa-5-fosfát (Xu5P)
7
transaldolasa
fruktosa-6-fosfát (F6P)
+
erythrosa-4-fosfát (E4P)
8
transketolasa
fruktosa-6-fosfát (F6P)
+
glyceraldehyd-3-fosfát (GAP)
2 x 3= 6


pentosový cyklus
X5P
G3P
F6P
C2
G3P
R5P
S7P
E4P
F6P
C2
X5P
G3P
6 Ru5P
G3P
DAP
F1,6P
F6P
5 G6P
Pi
X5P
G3P
C2
R5P
S7P
E4P
F6P
C2
G3P
X5P
G3P
F6P
Calvinův cyklus



$C_3 + C_3 \leftrightarrow C_6$

$$6\ \text{Glu-6-P} + 12\ NADP^{+} + 6\ H_2O$$

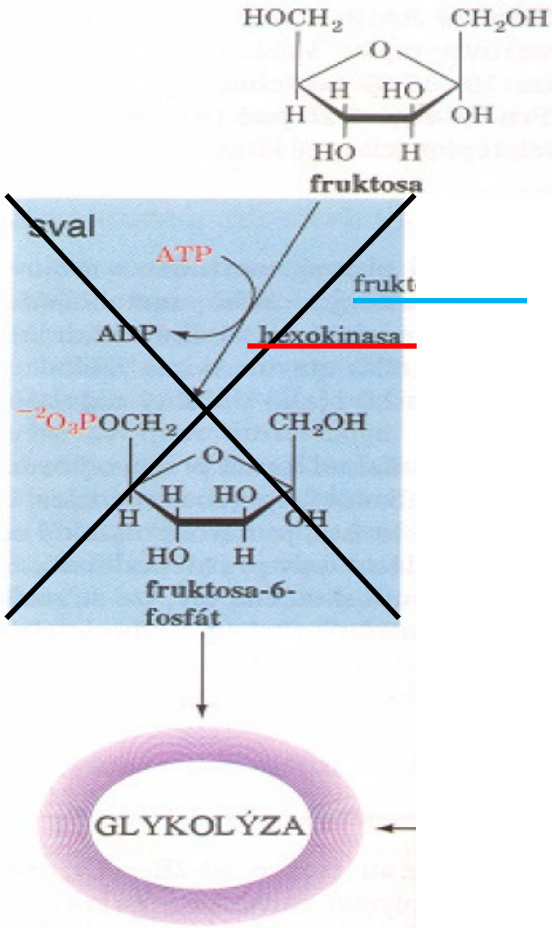
$$\rightarrow$$

$$5\ \text{Glu-6-P} + 6\ CO_2 + 12\ NADPH + 12\ H^{+} + Pi$$

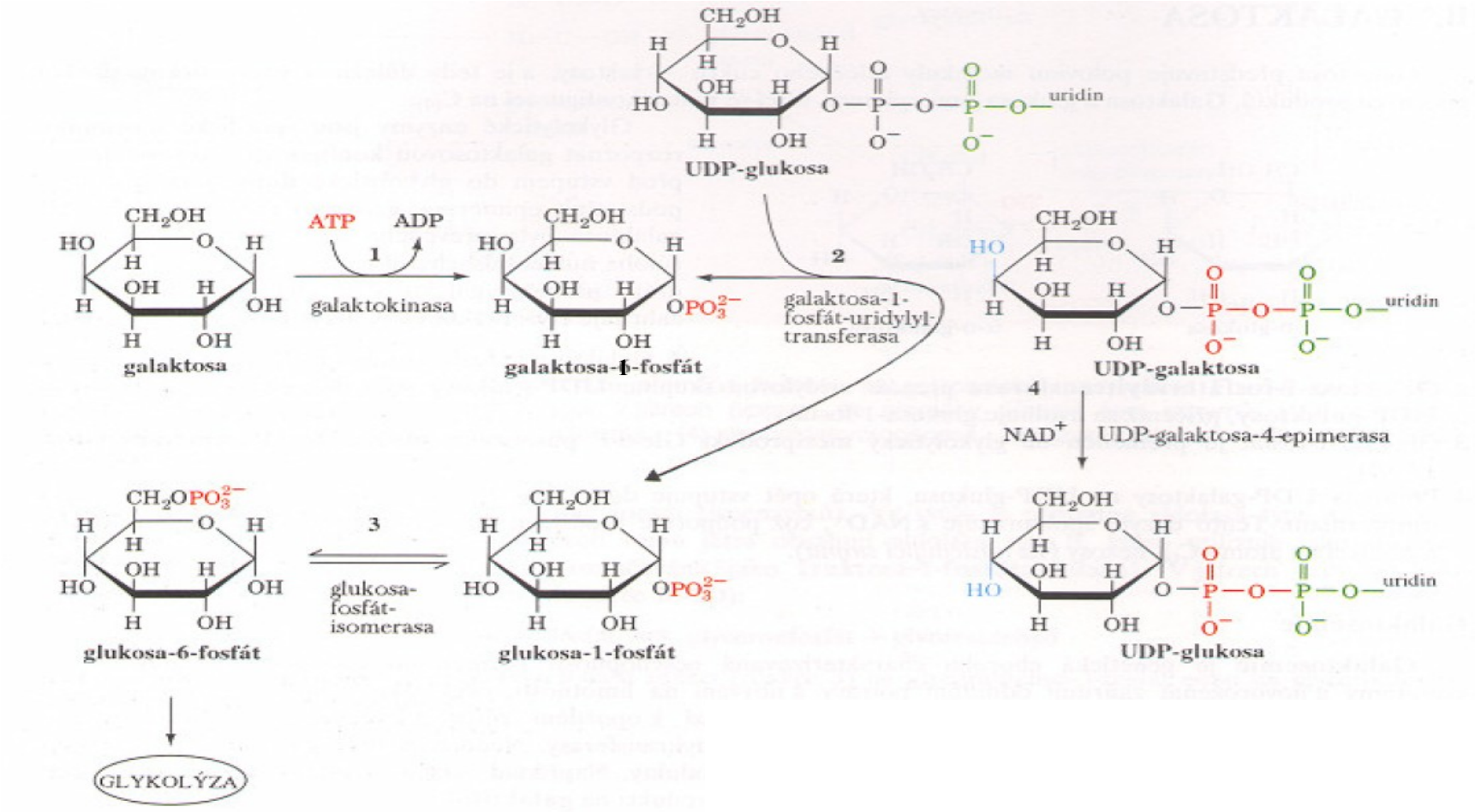
glykolýza	-	36 ATP
pentosový cyklus	-	36 ATP

CYT

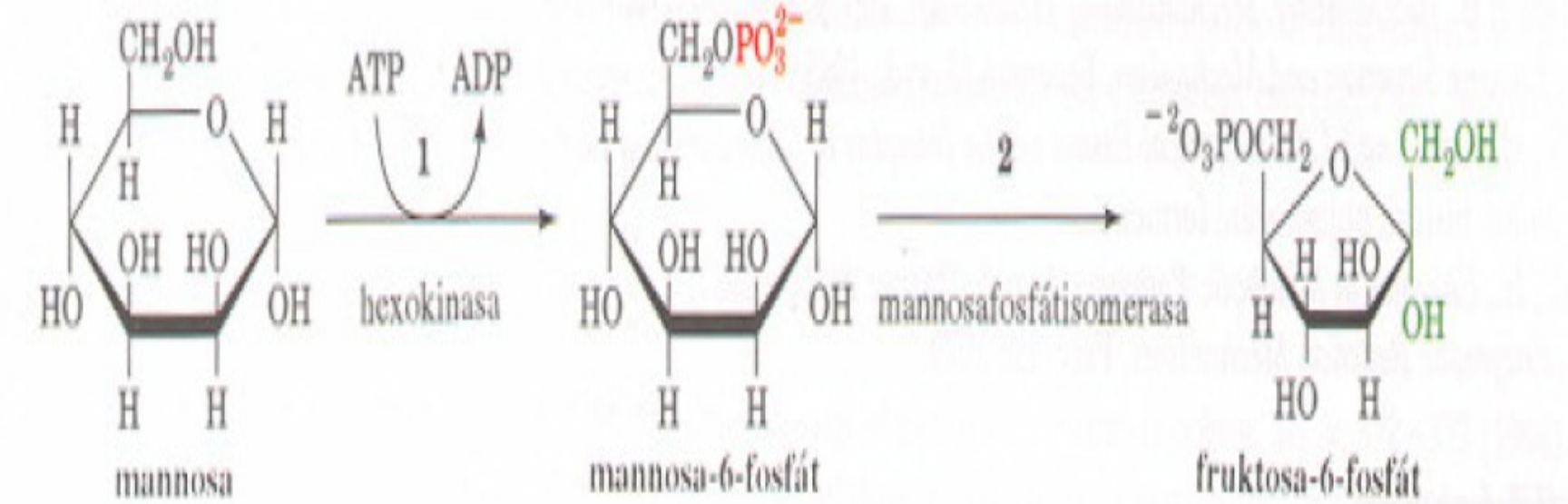
Fruktosa


HOCH2
CH2OH
O
H
HO
H
OH
HO
H
fruktosa
sval
ATP
frukt
ADP
hexokinasa
−2O3POCH2
CH2OH
O
H
HO
H
OH
HO
H
fruktosa-6-fosfát
GLYKOLÝZA

Galaktosa


UDP-glukosa
galaktosa
ATP
ADP
1
galaktokinasa
galaktosa-1-fosfát
2
galaktosa-1-fosfát-uridylyl-transferasa
UDP-galaktosa
4
NAD+
UDP-galaktosa-4-epimerasa
glukosa-6-fosfát
3
glukosa-fosfát-isomerasa
glukosa-1-fosfát
UDP-glukosa
GLYKOLÝZA

Manosa


CH2OH
H
O
H
H
OH HO
HO
OH
H H
mannosa
ATP
ADP
1
hexokinasa
CH2OPO3 2−
mannosa-6-fosfát
2
mannosafosfátisomerasa
−2O3POCH2
CH2OH
fruktosa-6-fosfát

Glykogen

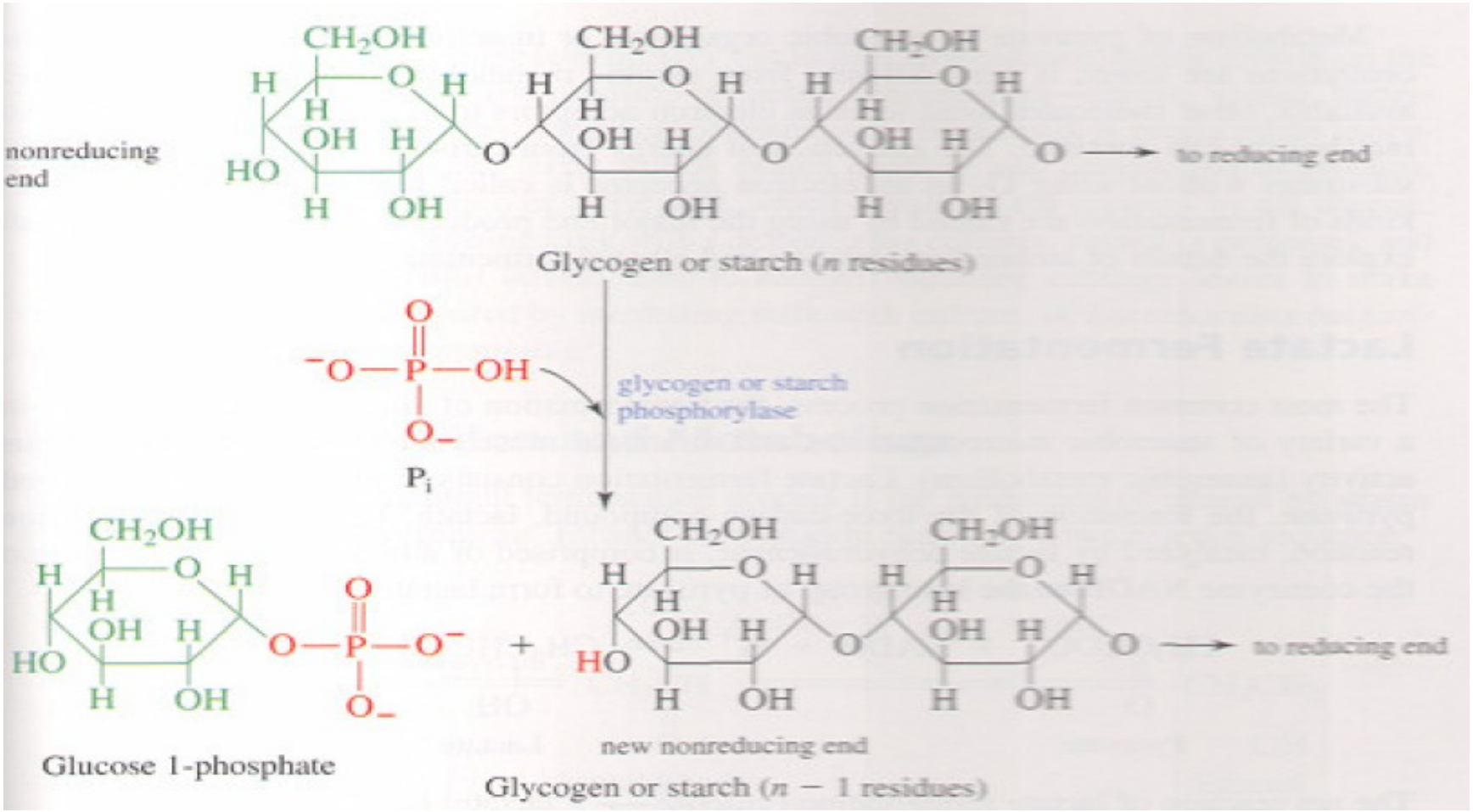
Hydrolytic cleavage catalyzed by amylase: Trávící

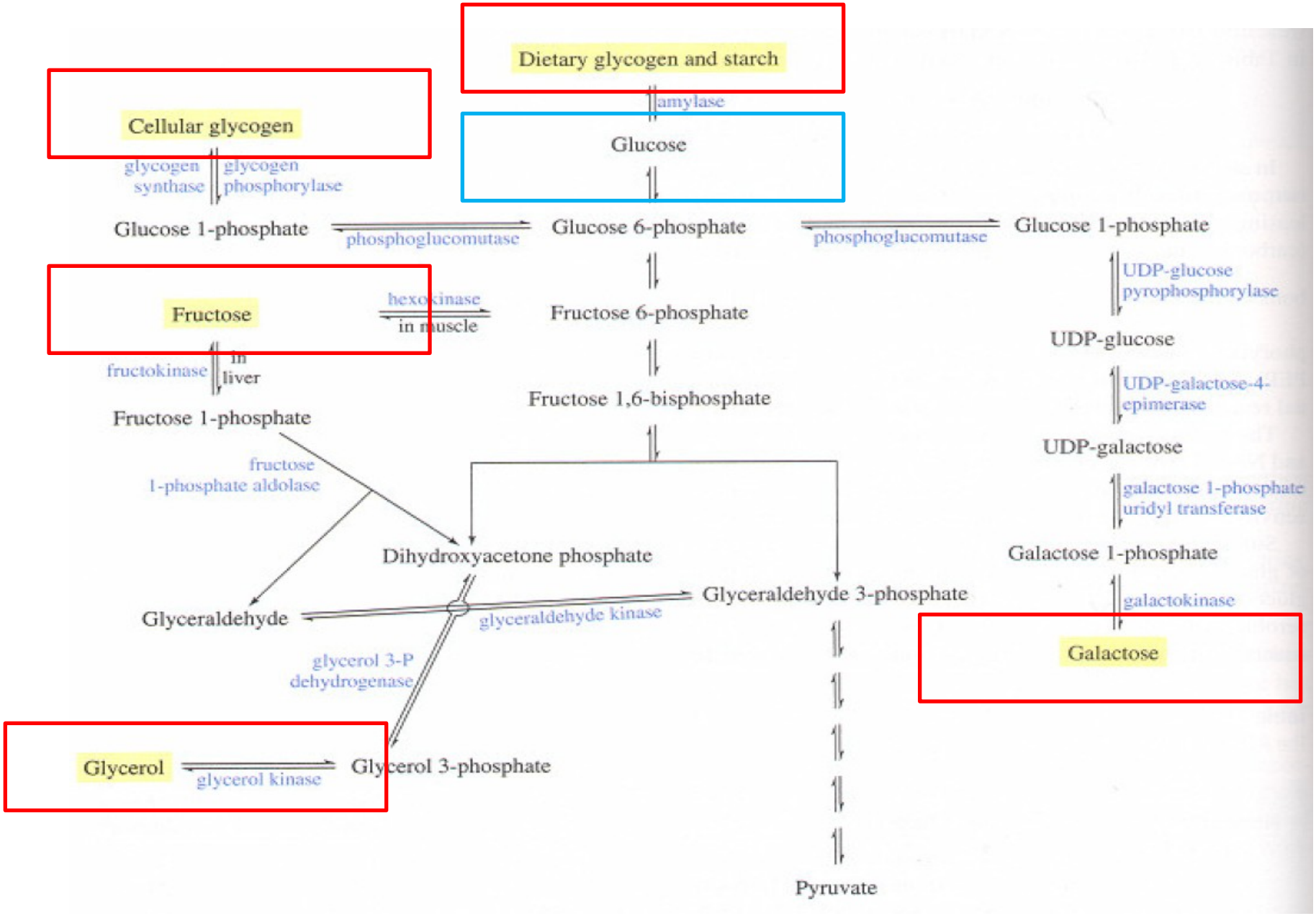
$$(\text{glucose})_n + H_2O \rightleftharpoons \text{glucose} \xrightleftharpoons{ATP} \text{glucose 6-phosphate}$$

Phosphorolytic cleavage catalyzed by phosphorylase: Tkáňový

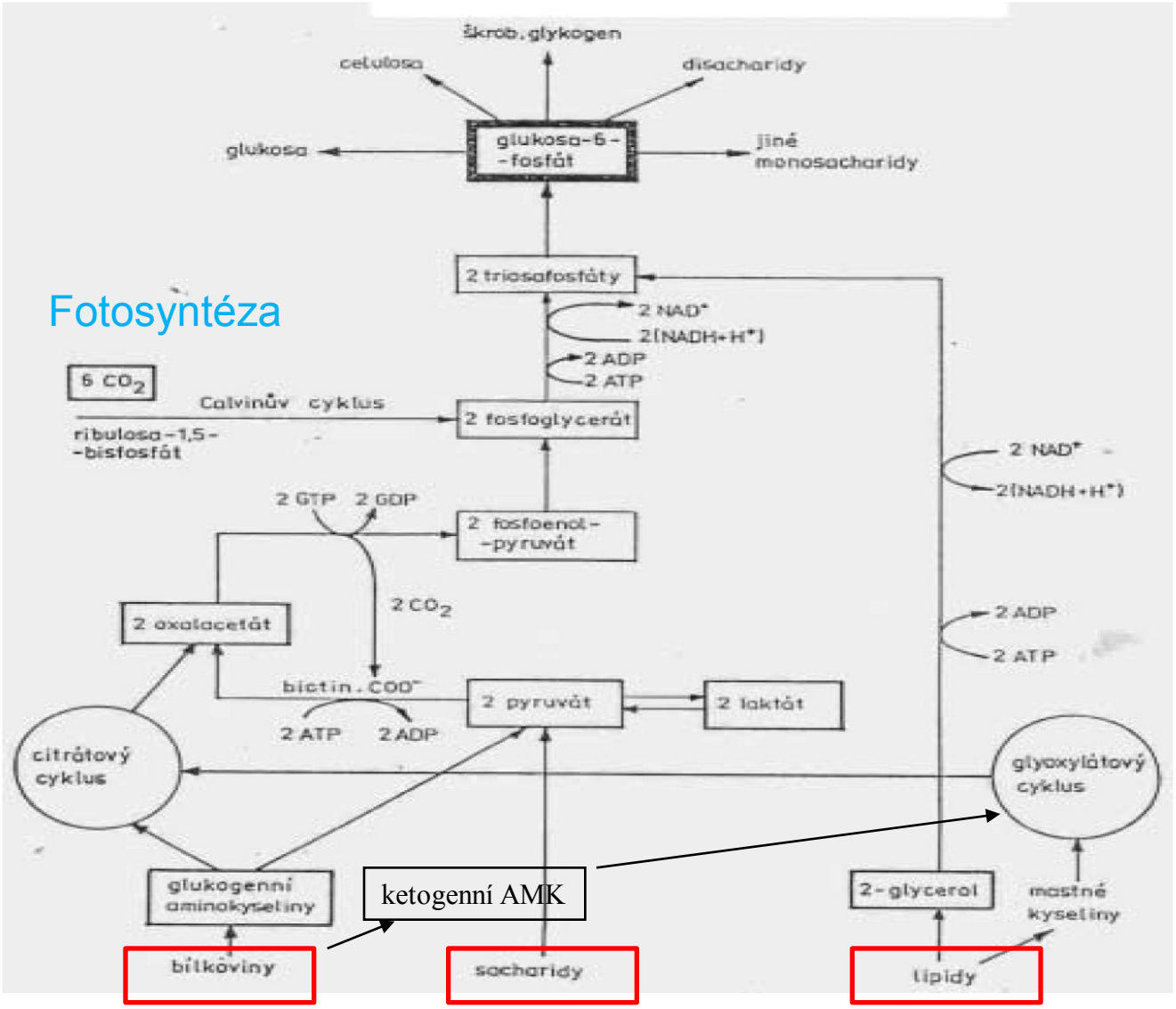
$$(\text{glucose})_n + P_i \rightleftharpoons \text{glucose 1-phosphate} \rightleftharpoons \text{glucose 6-phosphate}$$

Glykogen


nonreducing end
to reducing end
Glycogen or starch (n residues)
glycogen or starch phosphorylase
Pi
Glucose 1-phosphate
new nonreducing end
Glycogen or starch (n − 1 residues)


Dietary glycogen and starch
amylase
Glucose
Cellular glycogen
glycogen synthase
glycogen phosphorylase
Glucose 1-phosphate
phosphoglucomutase
Glucose 6-phosphate
phosphoglucomutase
Glucose 1-phosphate
UDP-glucose pyrophosphorylase
UDP-glucose
Fructose
hexokinase in muscle
Fructose 6-phosphate
fructokinase in liver
Fructose 1-phosphate
Fructose 1,6-bisphosphate
UDP-galactose-4-epimerase
UDP-galactose
fructose 1-phosphate aldolase
galactose 1-phosphate uridyl transferase
Galactose 1-phosphate
Dihydroxyacetone phosphate
Glyceraldehyde 3-phosphate
galactokinase
Glyceraldehyde
glyceraldehyde kinase
Galactose
glycerol 3-P dehydrogenase
Glycerol
glycerol kinase
Glycerol 3-phosphate
Pyruvate

BIOSYNTÉZA SACHARIDŮ



Fotosyntéza

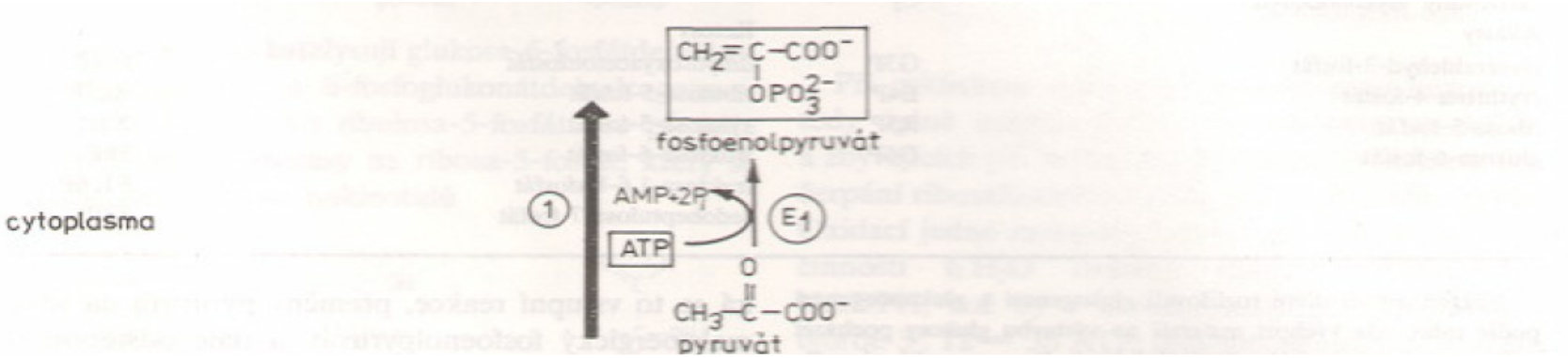
Glukoneogenese

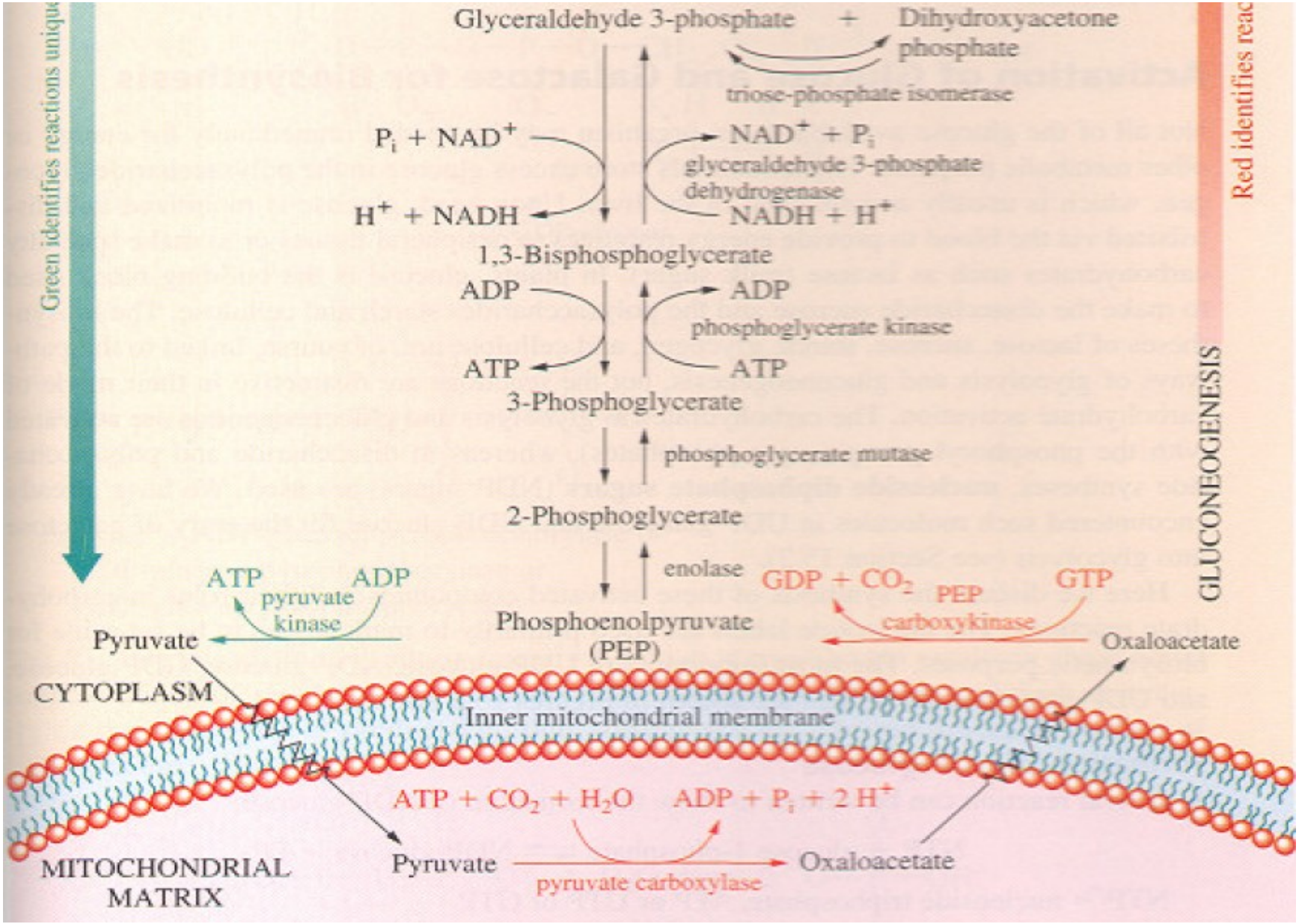
BIOSYNTÉZA SACHARIDŮ

- Glukoneogenese
- Fotosyntéza

Glukoneogenese

1. *Vznik fosfoenolpyruvátu*




Green identifies reactions uniqu
Red identifies reac
GLUCONEOGENESIS
Glyceraldehyde 3-phosphate
+
Dihydroxyacetone phosphate
triose-phosphate isomerase
$P_i + NAD^+$
$NAD^+ + P_i$
glyceraldehyde 3-phosphate dehydrogenase
$H^+ + NADH$
$NADH + H^+$
1,3-Bisphosphoglycerate
ADP
ADP
phosphoglycerate kinase
ATP
ATP
3-Phosphoglycerate
phosphoglycerate mutase
2-Phosphoglycerate
enolase
ATP
ADP
pyruvate kinase
$GDP + CO_2$
PEP carboxykinase
GTP
Pyruvate
Phosphoenolpyruvate (PEP)
Oxaloacetate
CYTOPLASM
Inner mitochondrial membrane
$ATP + CO_2 + H_2O$
$ADP + P_i + 2\,H^+$
MITOCHONDRIAL MATRIX
Pyruvate
pyruvate carboxylase
Oxaloacetate

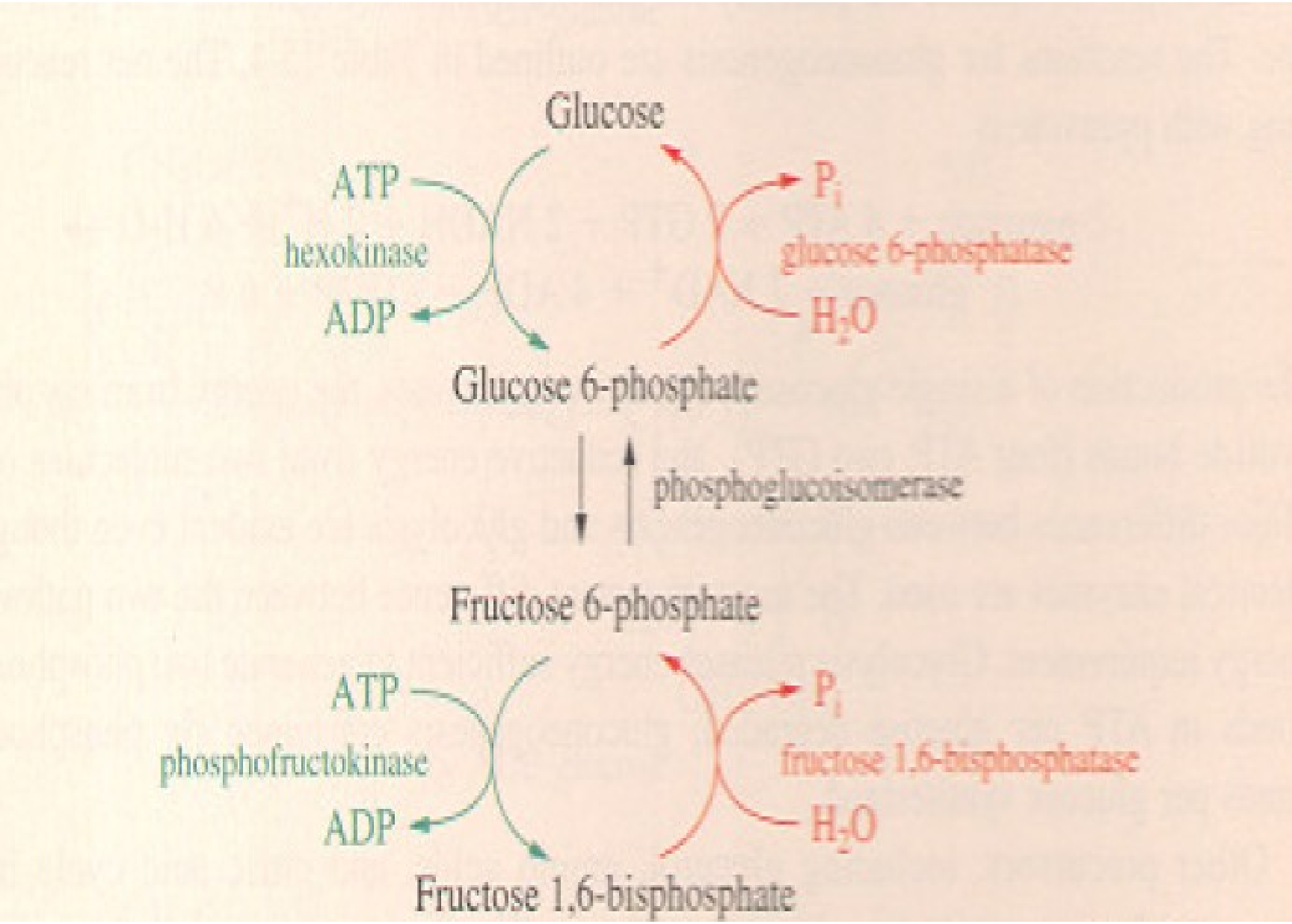
2. Hydrolytické reakce

A. fruktosabisfosfatasa

$$\text{fruktosa-1,6-bisfosfát} + H_2O \rightarrow \text{fruktosa-1-fosfát} + Pi$$

B. glukosafosfatasa

$$\text{glukosa-6-fosfát} + H_2O \rightarrow \text{glukosa} + Pi$$


Glucose
ATP
hexokinase
ADP
P_i
glucose 6-phosphatase
H_2O
Glucose 6-phosphate
phosphoglucoisomerase
Fructose 6-phosphate
ATP
phosphofructokinase
ADP
P_i
fructose 1,6-bisphosphatase
H_2O
Fructose 1,6-bisphosphate

Bilance glukoneogenese

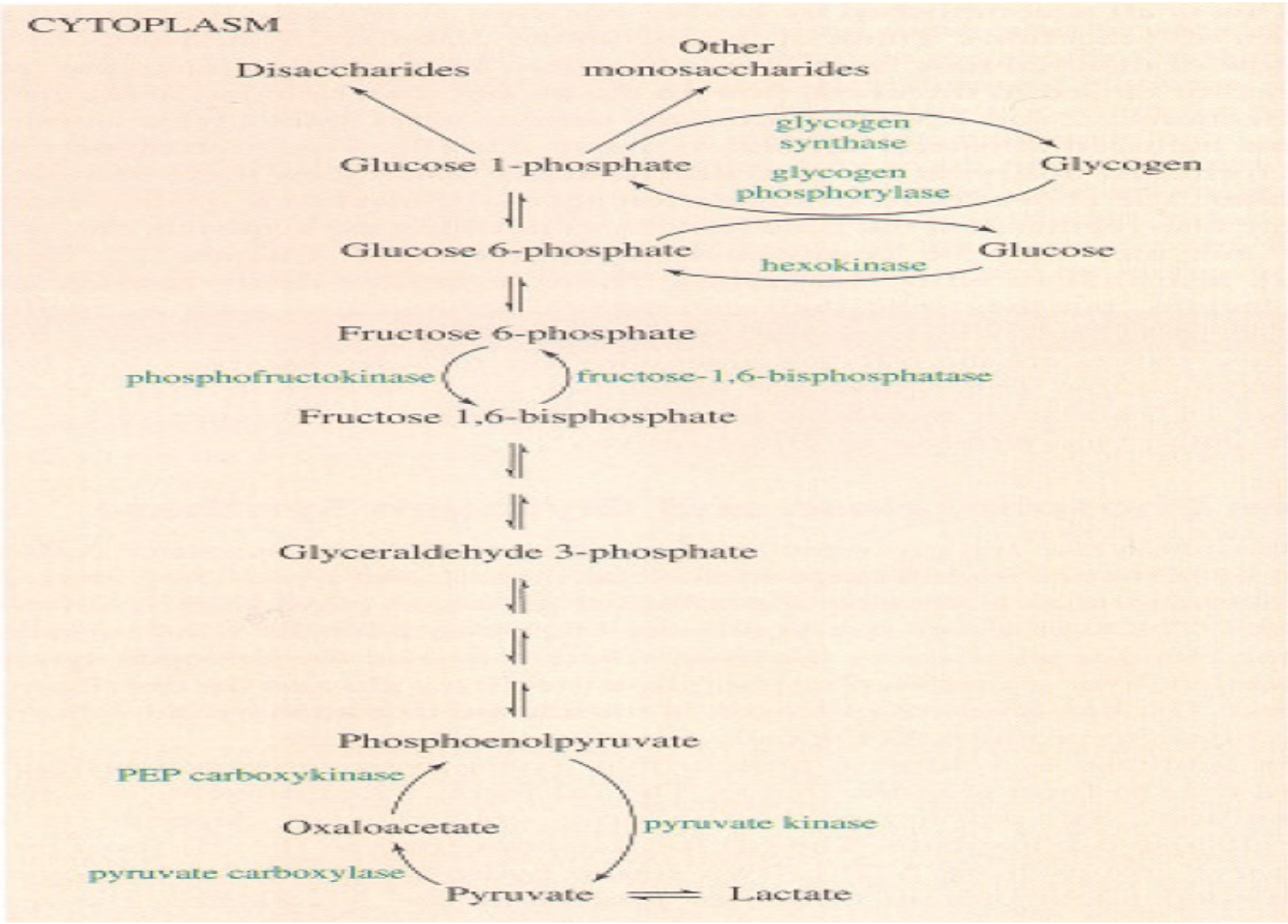
$$2\ \text{pyruvát} + 2\ \text{ATP} + 2\ \text{GTP} + 2\ \text{ATP} + 2\ \text{NADH} + 4\ H^{+} + 6\ H_2O$$

$$\rightarrow$$

$$\text{glukosa} + 4\ \text{ADP} + 2\ \text{GDP} + 2\ NAD^{+} + 6\ \text{Pi}$$

---

glykolysa (8 ATP) - glukoneogenese (12 ATP) = - 4 ATP


CYTOPLASM
Disaccharides
Other monosaccharides
Glucose 1-phosphate
glycogen synthase
glycogen phosphorylase
Glycogen
Glucose 6-phosphate
hexokinase
Glucose
Fructose 6-phosphate
phosphofructokinase
fructose-1,6-bisphosphatase
Fructose 1,6-bisphosphate
Glyceraldehyde 3-phosphate
Phosphoenolpyruvate
PEP carboxykinase
Oxaloacetate
pyruvate kinase
pyruvate carboxylase
Pyruvate
Lactate

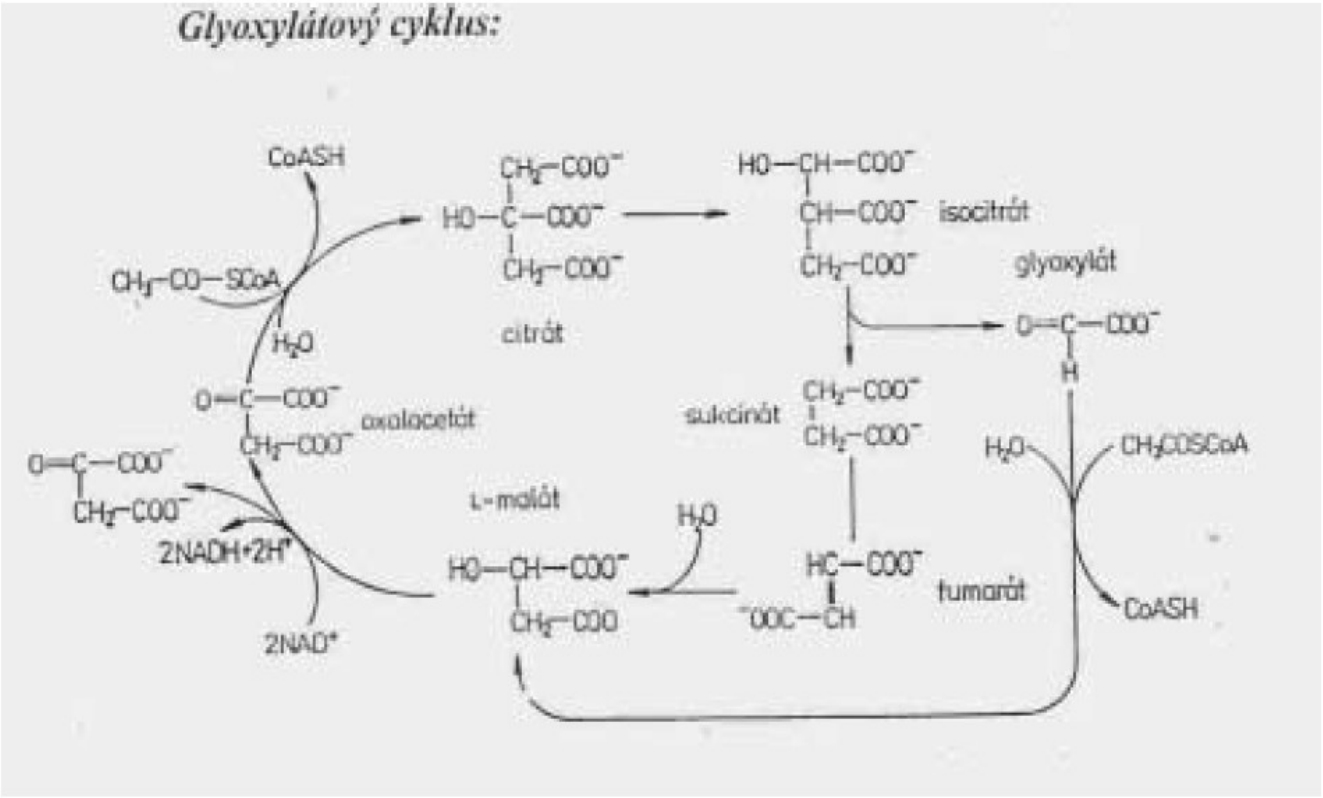
Biosyntéza glukosy z dalších prekurzorů

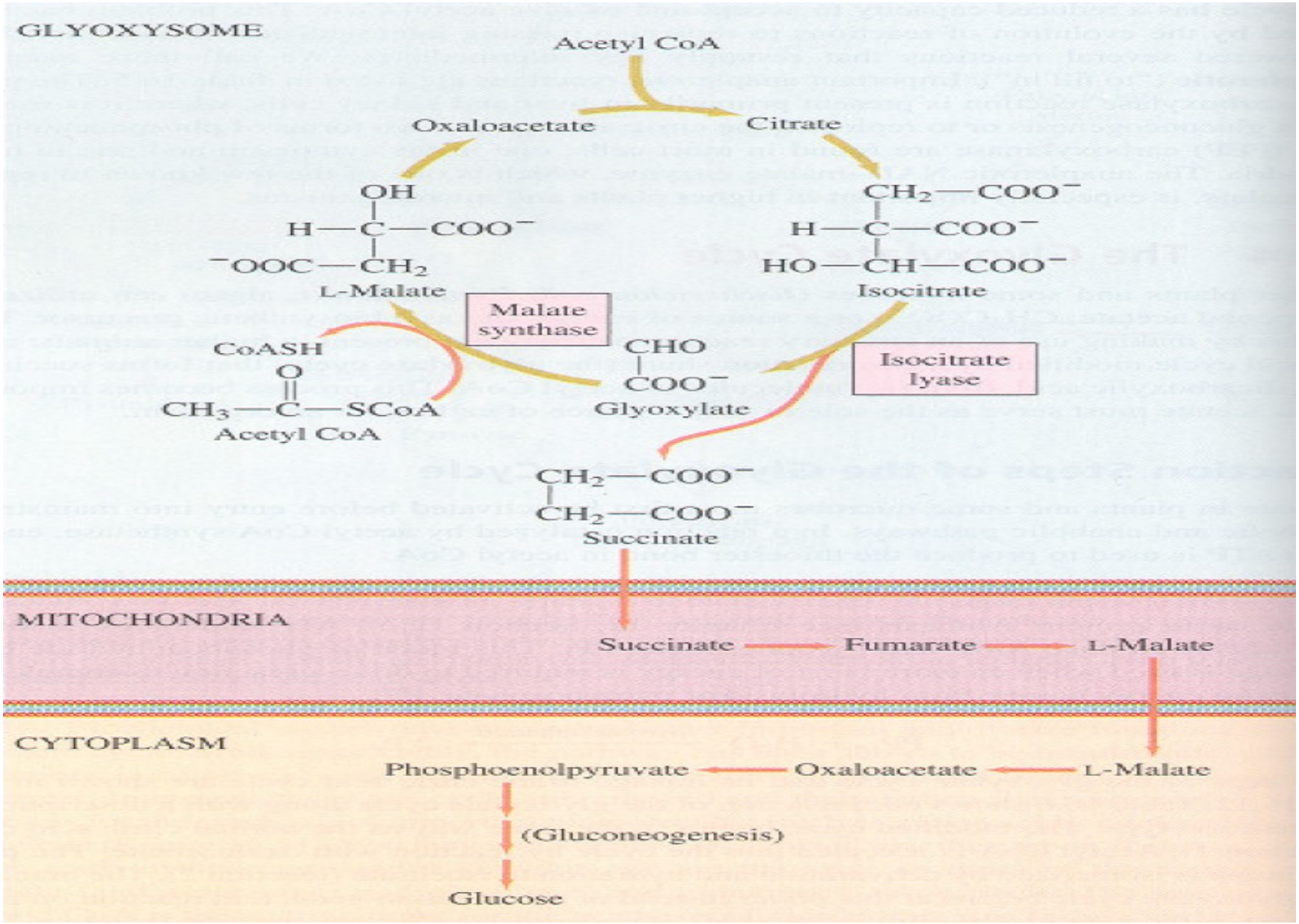
- **glukogenní aminokyseliny -pyruvát a meziprodukty citrátového cyklu**

Biosyntéza glukosy z dalších prekurzorů

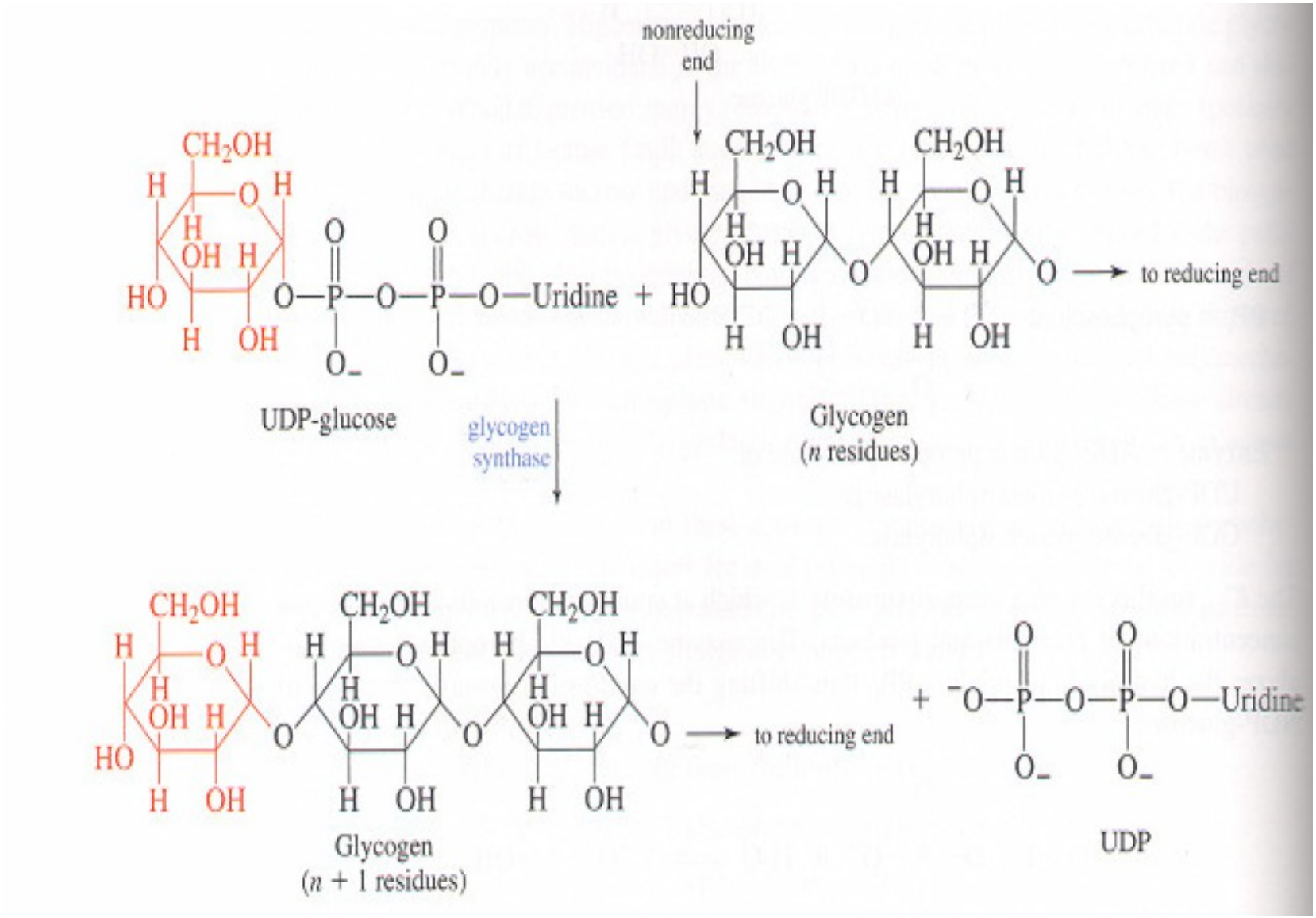
- **lipidy - glycerol a acetylCoA + ketogenní AMK**

  Glyoxylátový cyklus:




GLYOXYSOME
Acetyl CoA
Oxaloacetate
Citrate
L-Malate
Isocitrate
Malate synthase
Isocitrate lyase
CoASH
Acetyl CoA
Glyoxylate
Succinate
MITOCHONDRIA
Succinate
Fumarate
L-Malate
CYTOPLASM
Phosphoenolpyruvate
Oxaloacetate
L-Malate
(Gluconeogenesis)
Glucose

Biosyntéza oligo- a polysacharidů



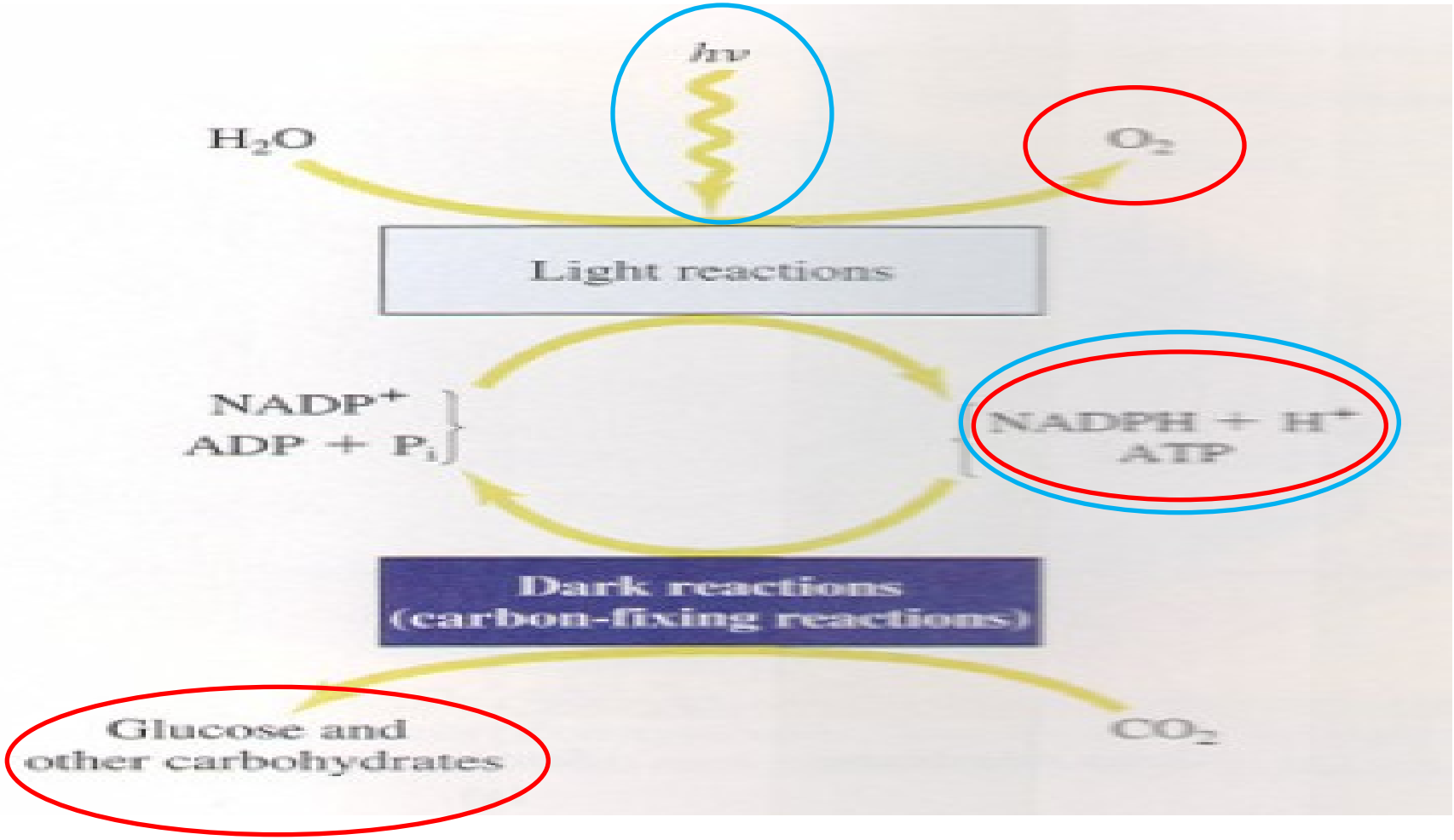
FOTOSYNTÉZA

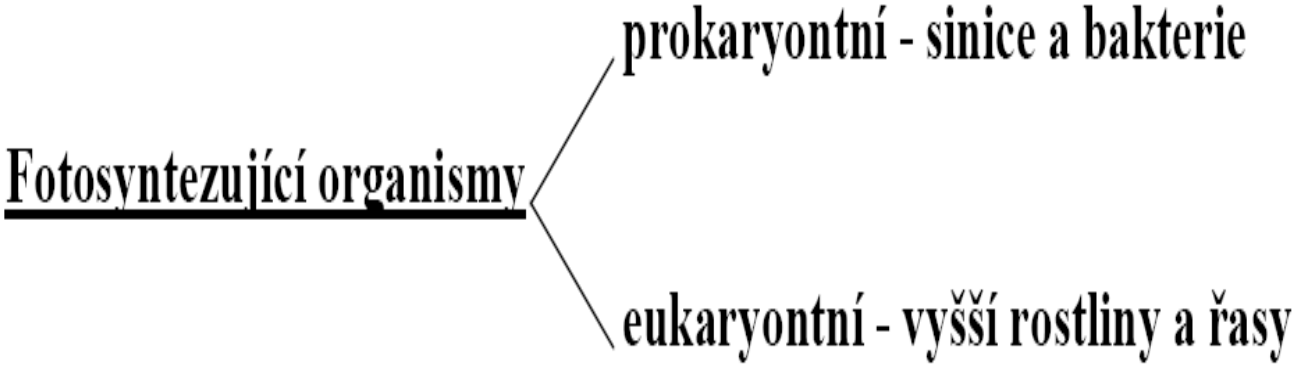
Význam :

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

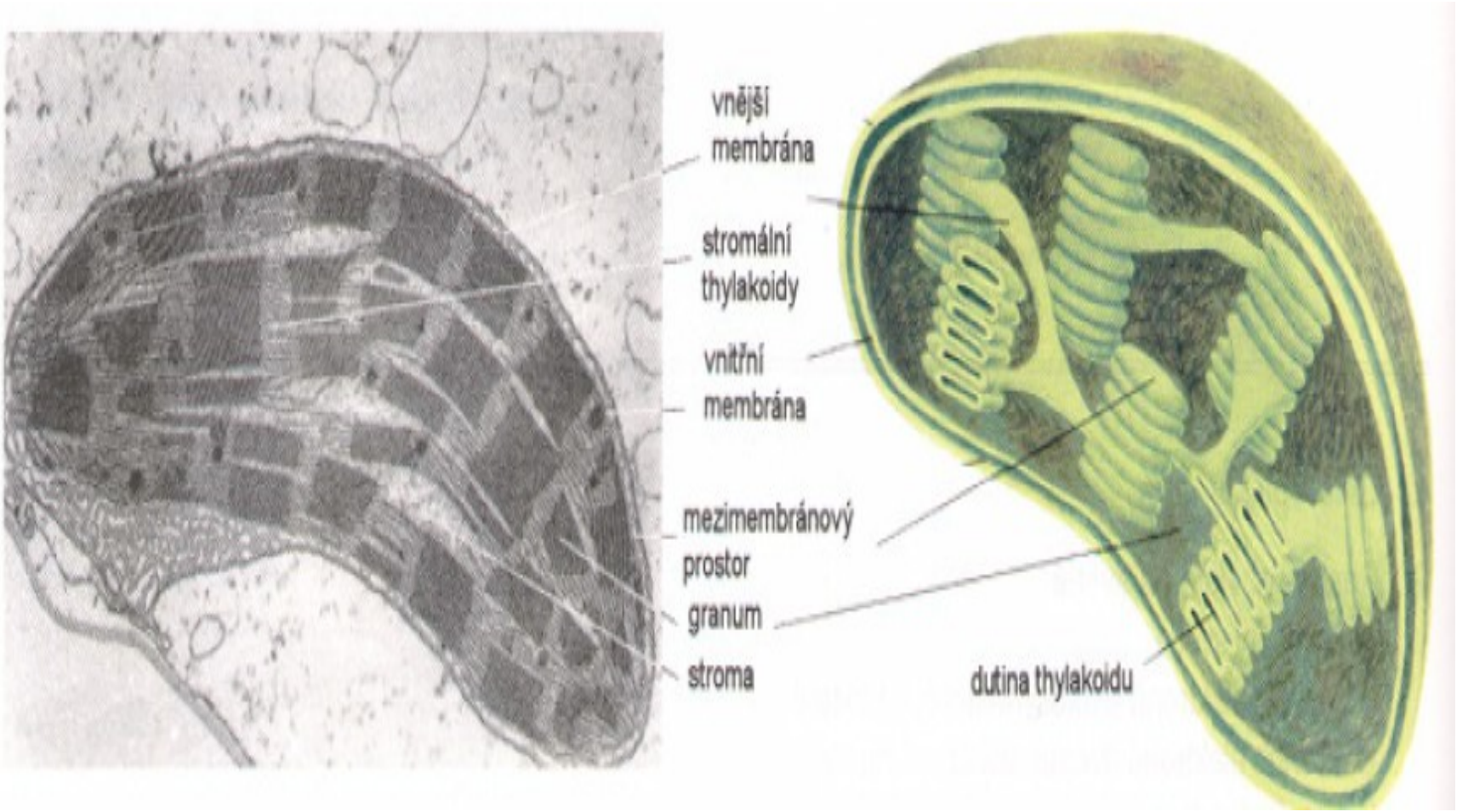
$$6\,CO_2 + 12\,H_2O \xrightarrow{h\nu} C_6H_{12}O_6 + 6\,H_2O + 6\,O_2$$

Světelná a temná fáze

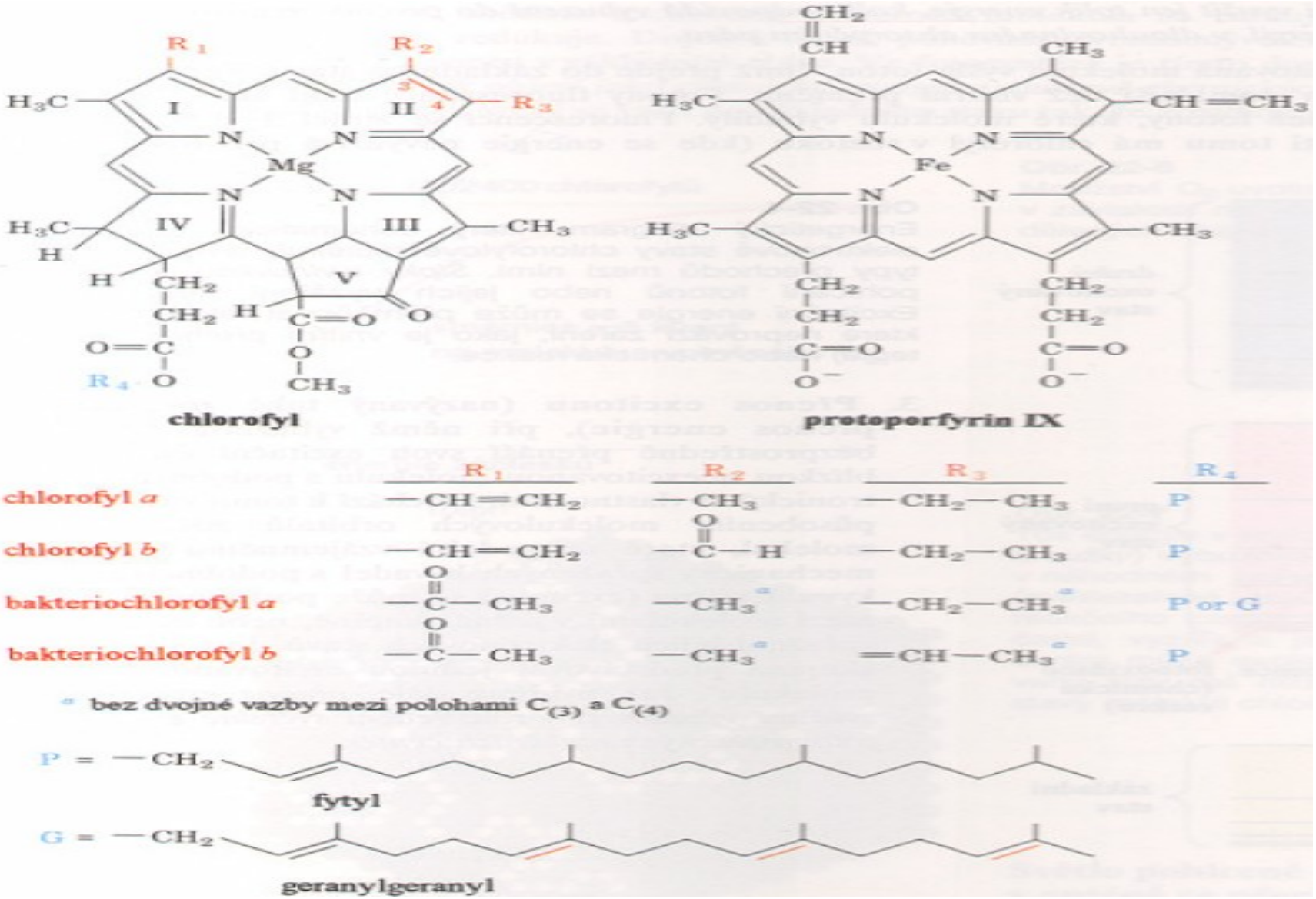



Fotosyntezující organismy
prokaryontní - sinice a bakterie
eukaryontní - vyšší rostliny a řasy

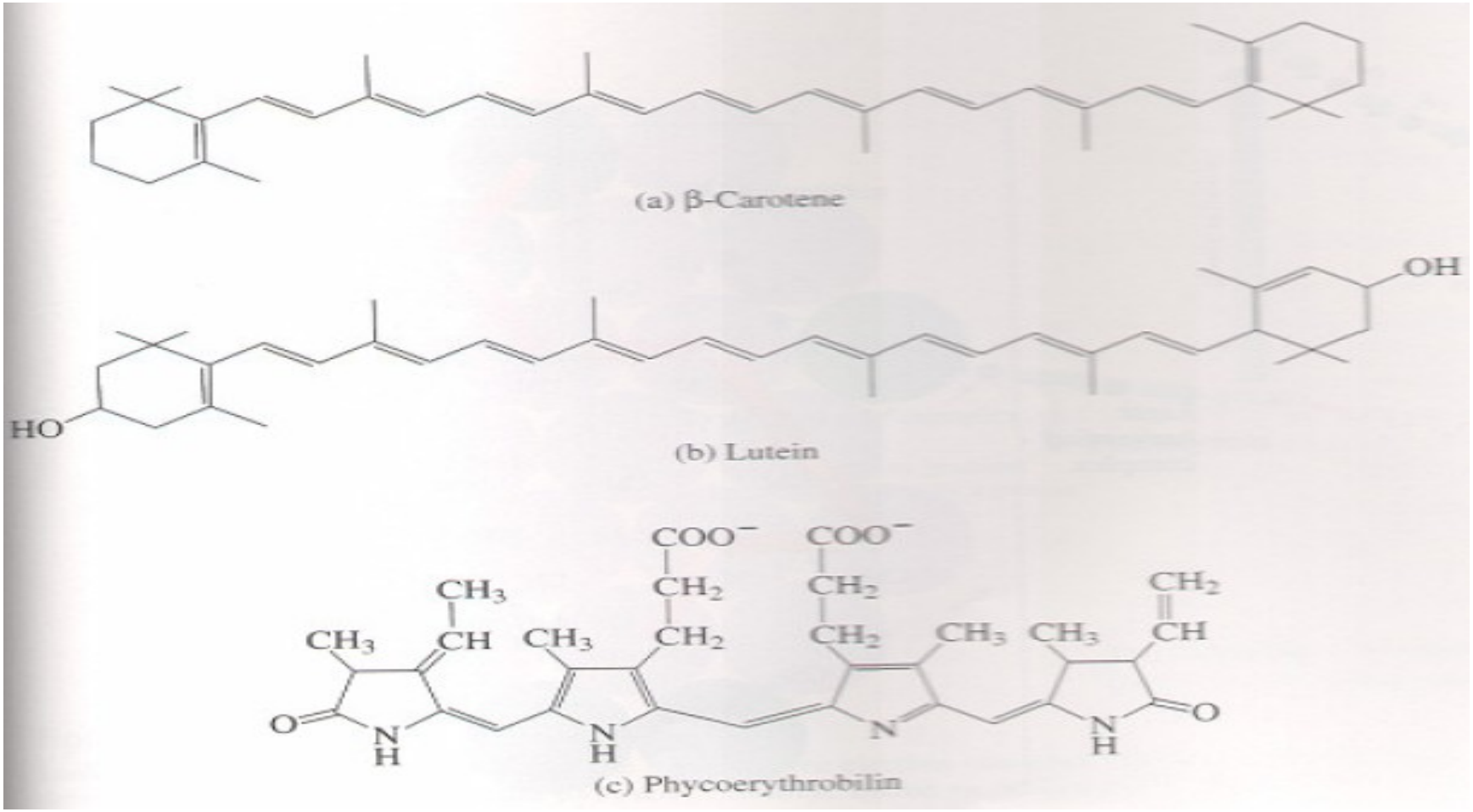
Chloroplast

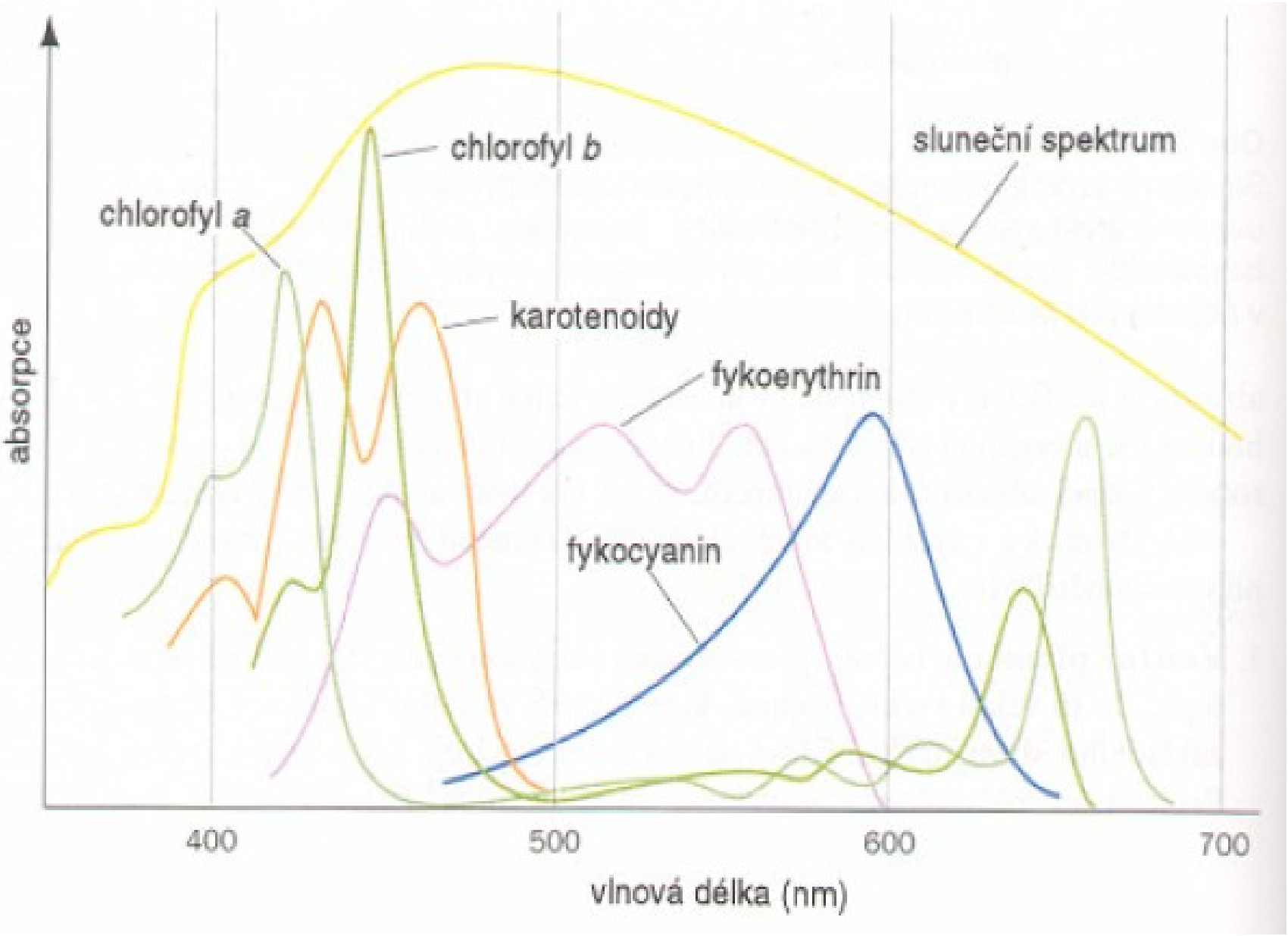


Chlorofyly


chlorofyl
protoporfyrin IX
chlorofyl a
chlorofyl b
bakteriochlorofyl a
bakteriochlorofyl b
R1
R2
R3
R4
P or G
a bez dvojné vazby mezi polohami C(3) a C(4)
P = —CH2
fytyl
G = —CH2
geranylgeranyl

Pomocná barviva

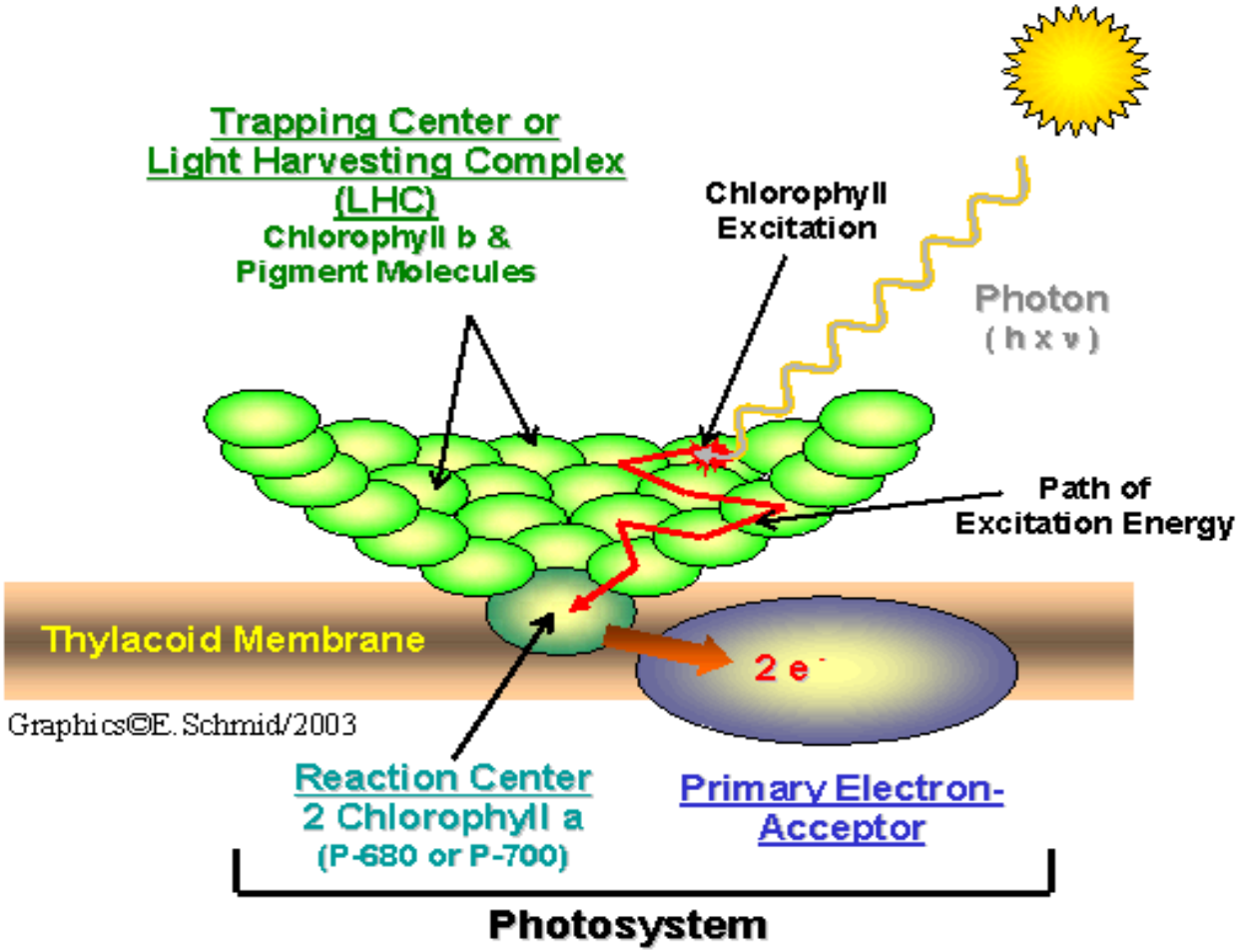



absorpce
chlorofyl a
chlorofyl b
karotenoidy
fykoerythrin
fykocyanin
sluneční spektrum
400
500
600
700
vlnová délka (nm)

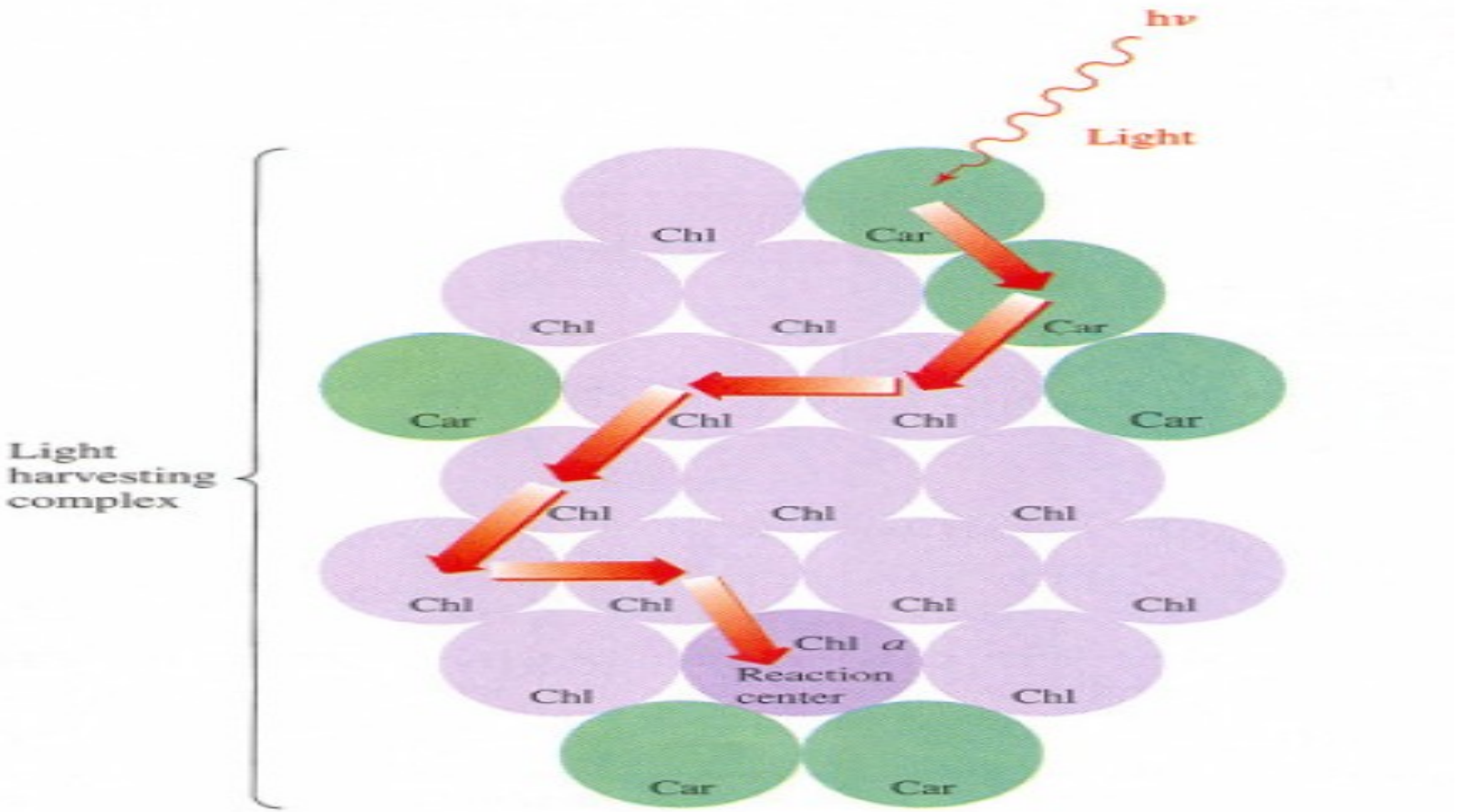
Světelná fáze

- proces zachycení záření
- cyklický tok elektronů - cyklická fotofosforylace → ATP
- necyklický tok elektronů - necyklická fotofosforylace → ATP, NADP
- fotolýza vody - $H_2O \rightarrow 2\,H^+ + 2\,e^- + {}^1/_2\,O_2$
- spřažení transportu elektronů se syntézou ATP

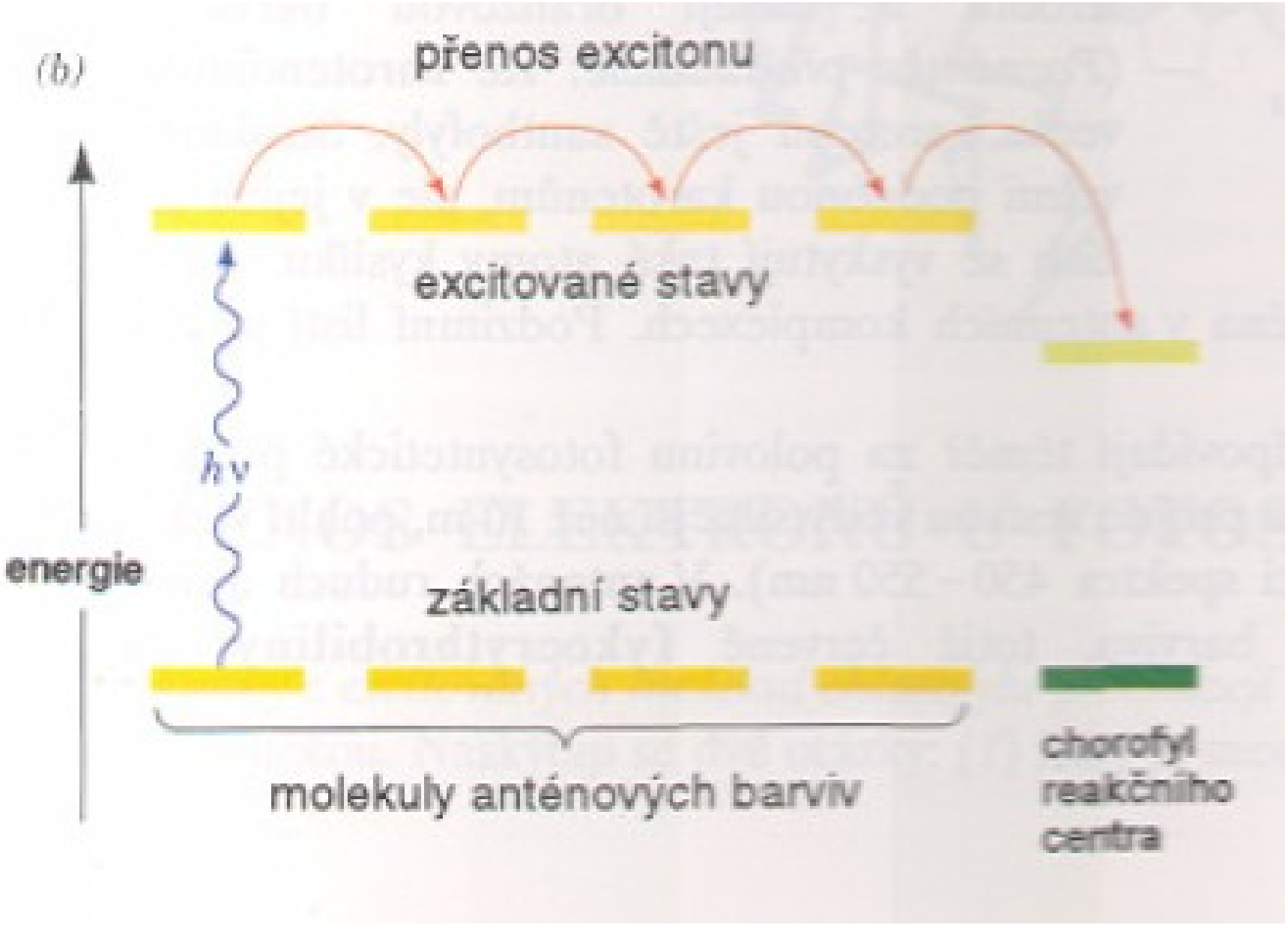
Proces zachycení záření light-harvesting complex



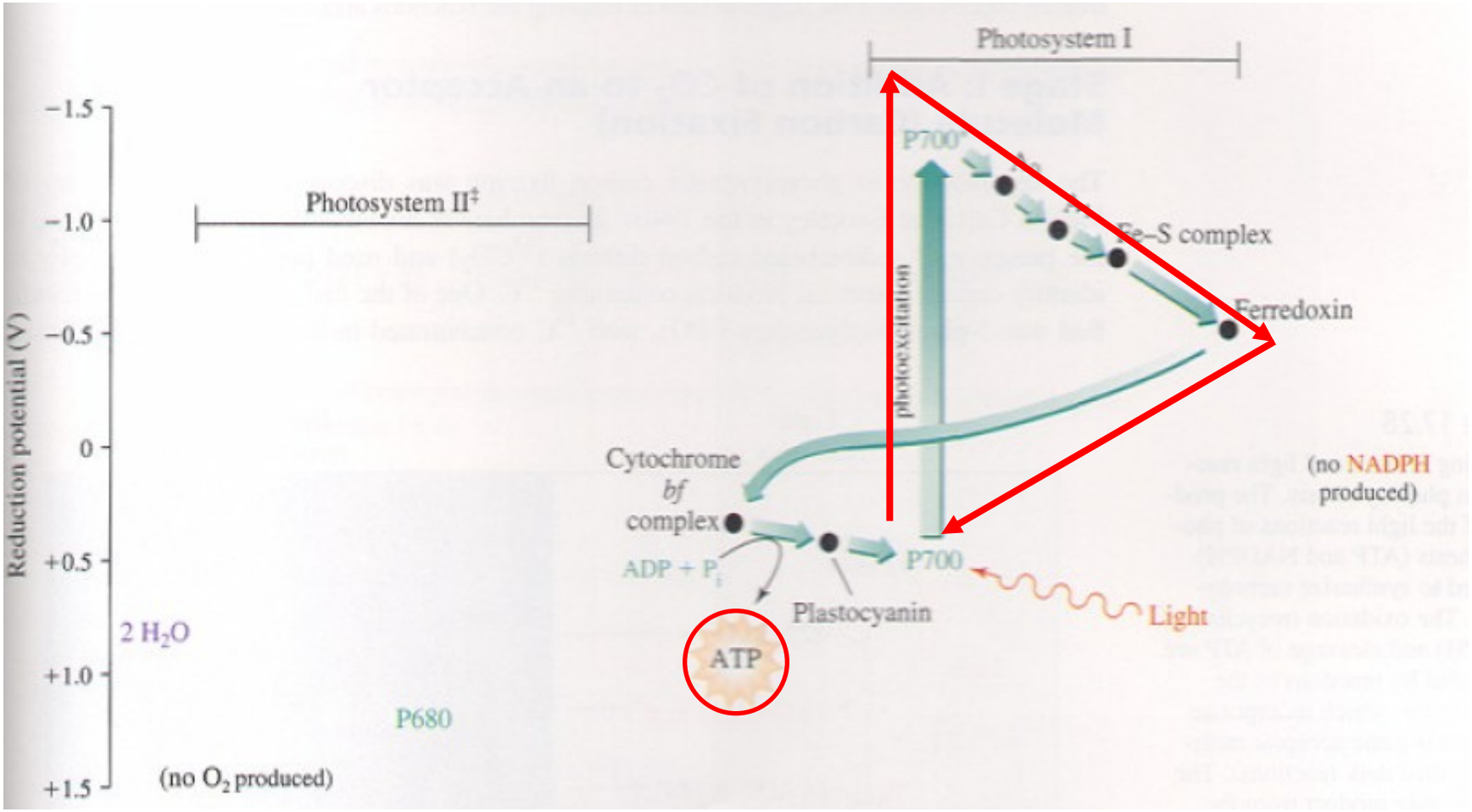
Proces zachycení záření kvantosomy



Anténní chlorofyl : chlorofyl reakčního centra (300 : 1)


(b)
přenos excitonu
excitované stavy
hν
energie
základní stavy
molekuly anténových barviv
chorofyl
reakčního
centra

Cyklický tok- produkce ATP



Necyklický tok- produkce NADPH

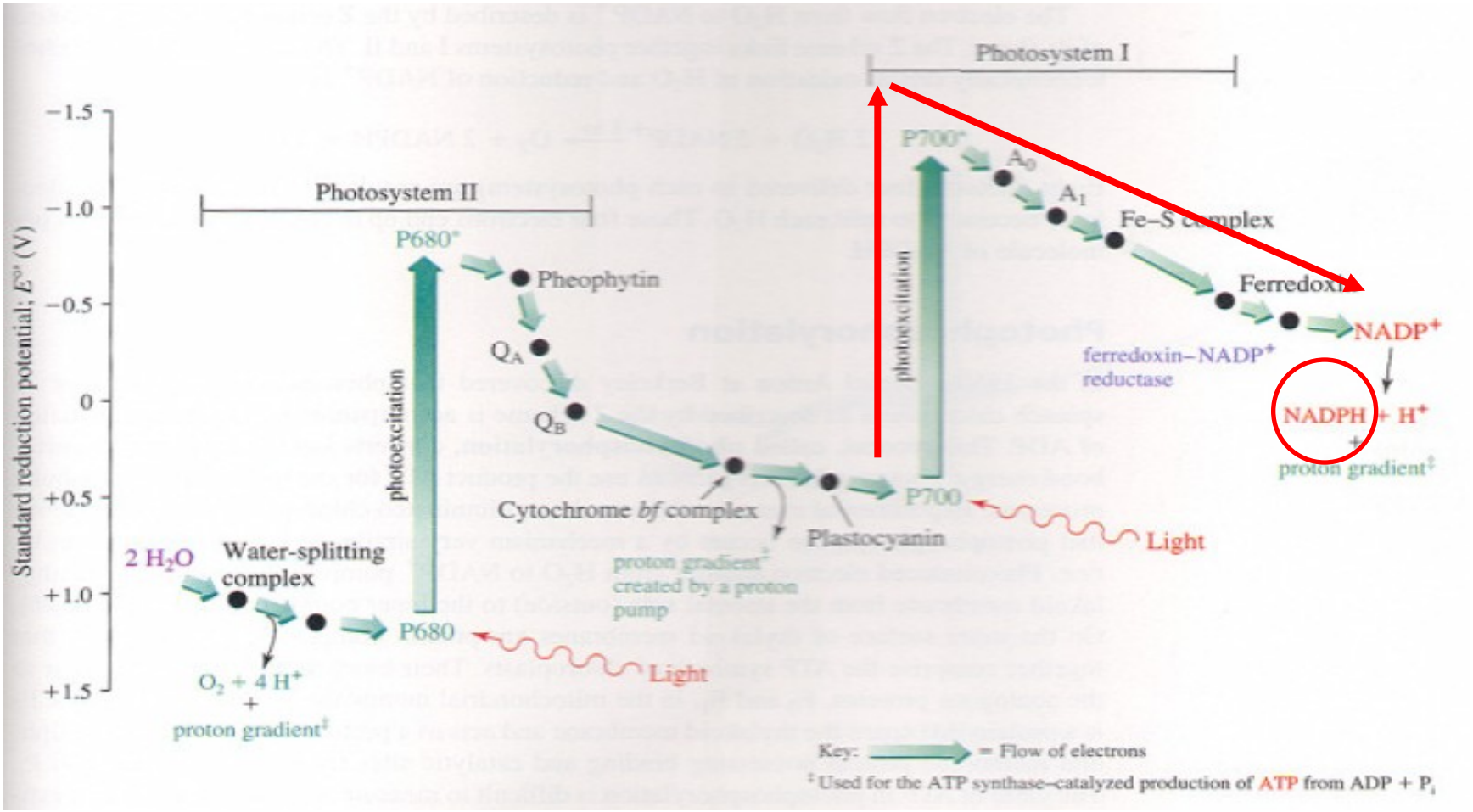
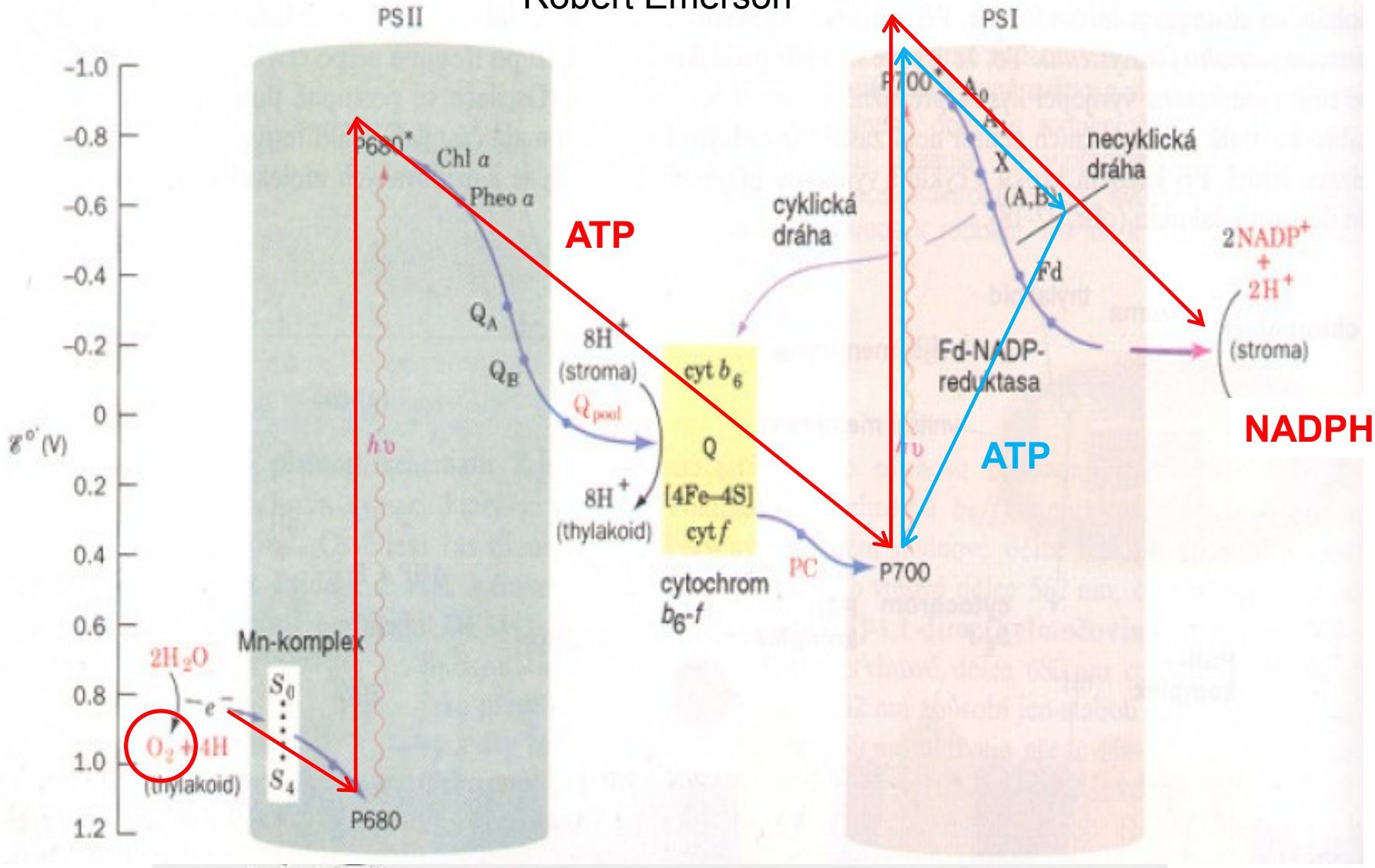
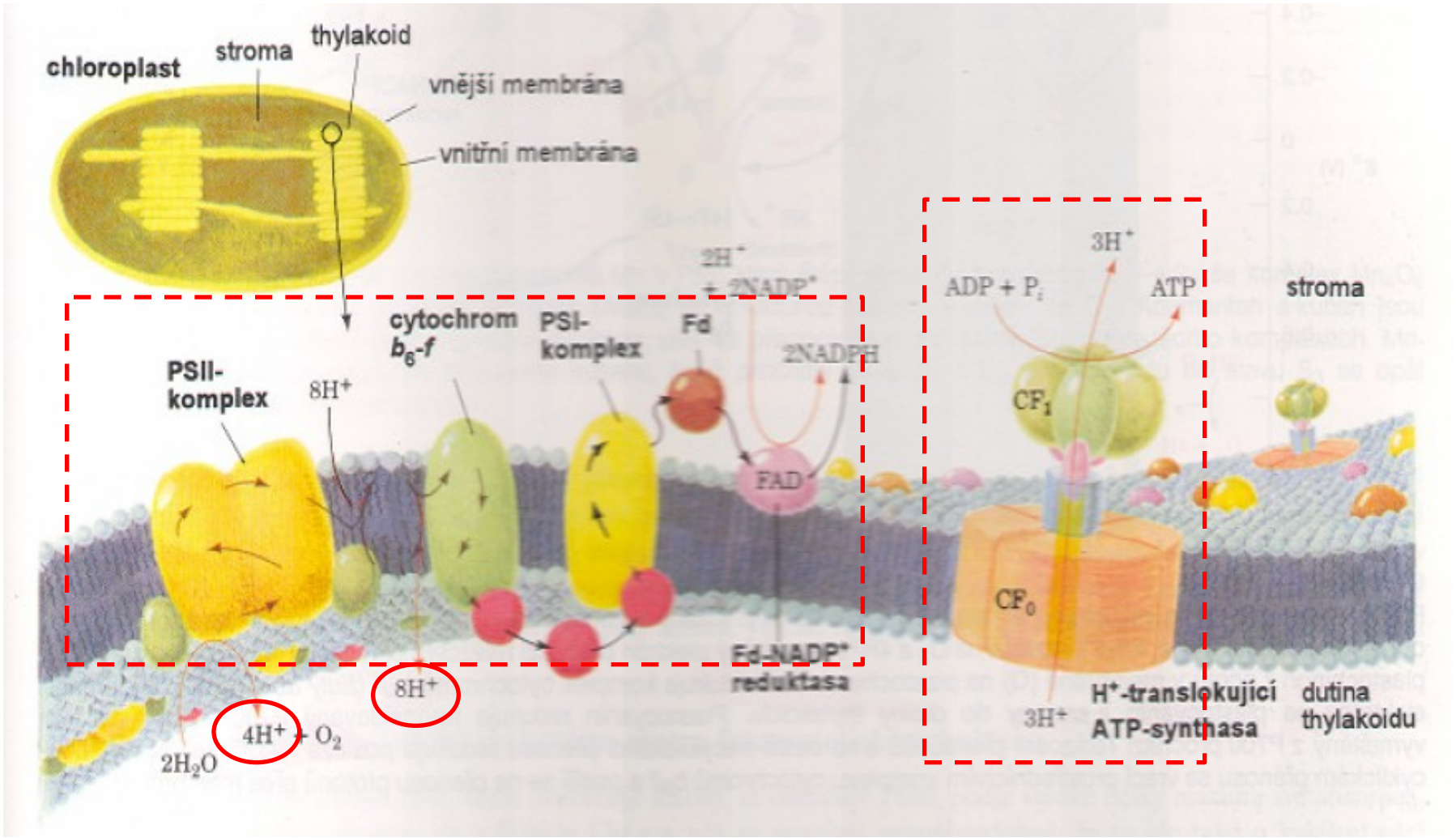


Schéma fotosystémů I a II

Robert Emerson

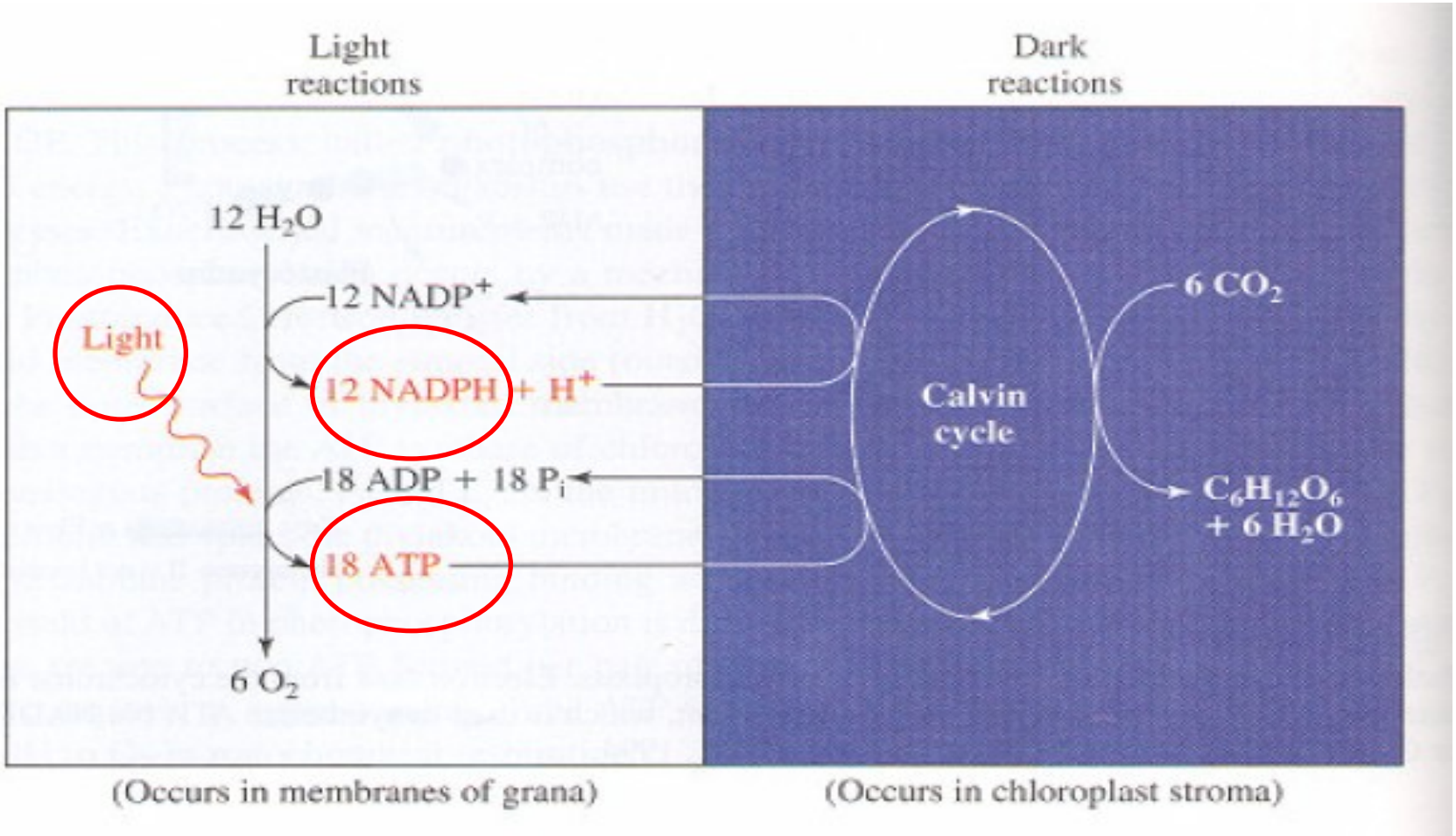


Spřažení toku elektronů a fotofosforylace



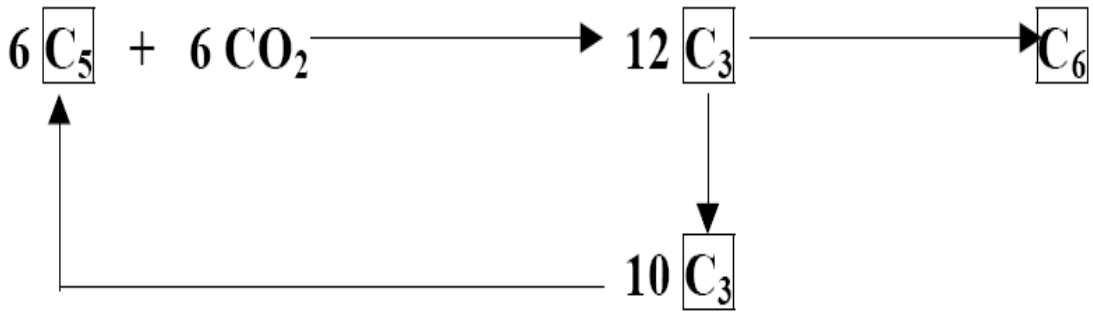
Chemisomotická teorie

Světelná a temná fáze



Temná fáze

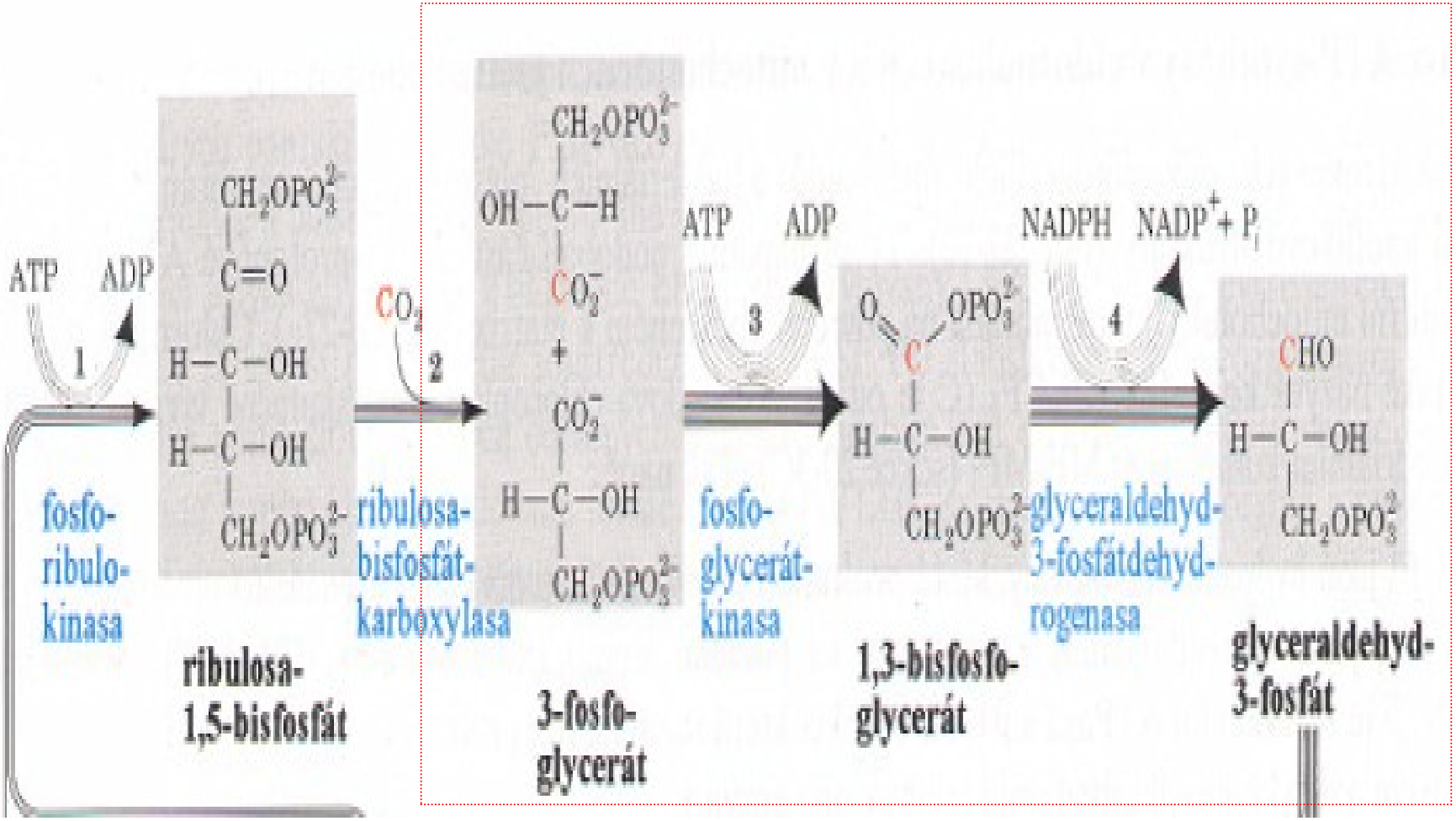
M.CALVIN



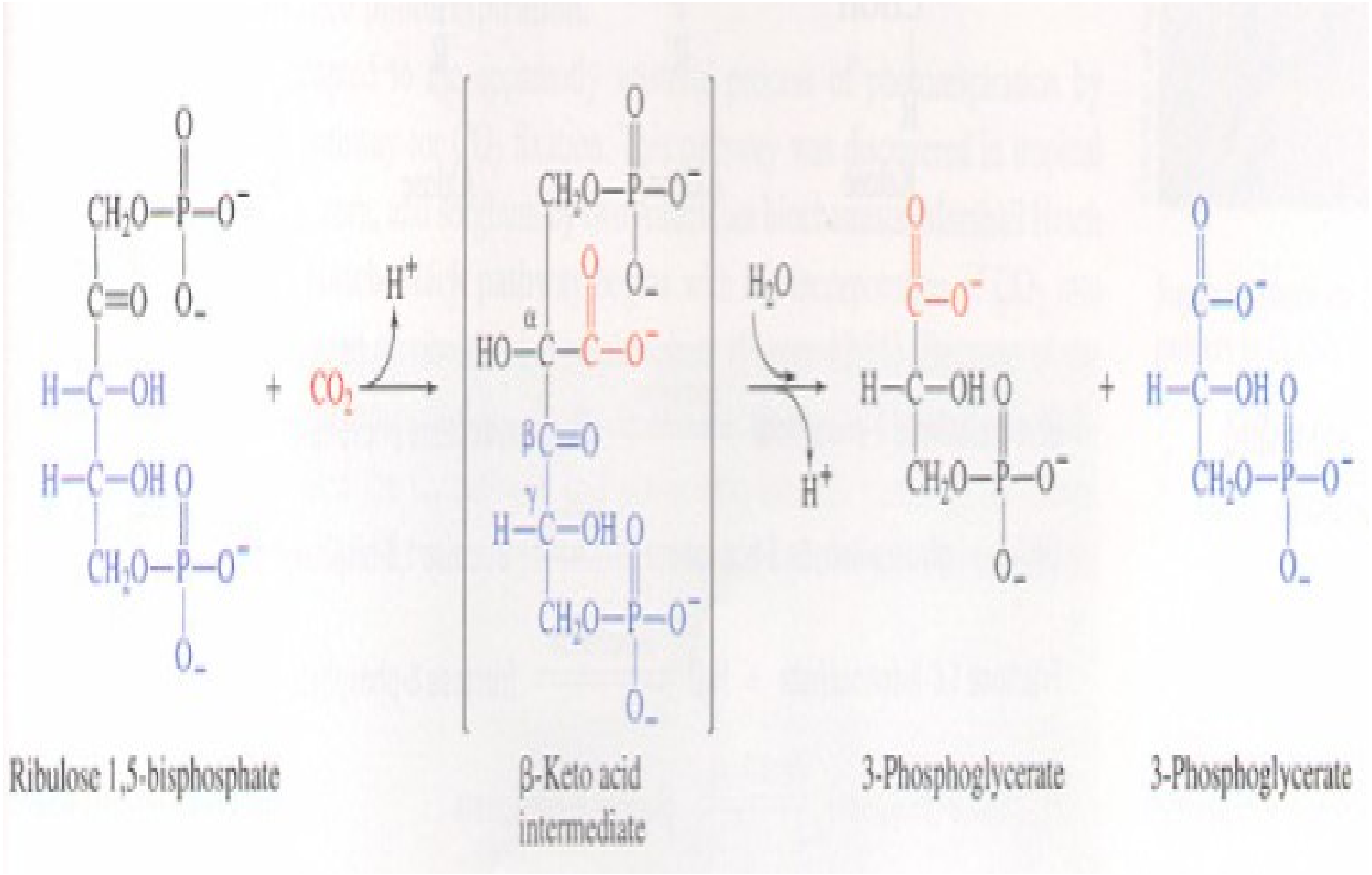
C3 rostliny

- většina rostlin a řas
- akceptor CO_2 ribulosa-5-P
- produkt 3-P-glycerát

Calvinův cyklus

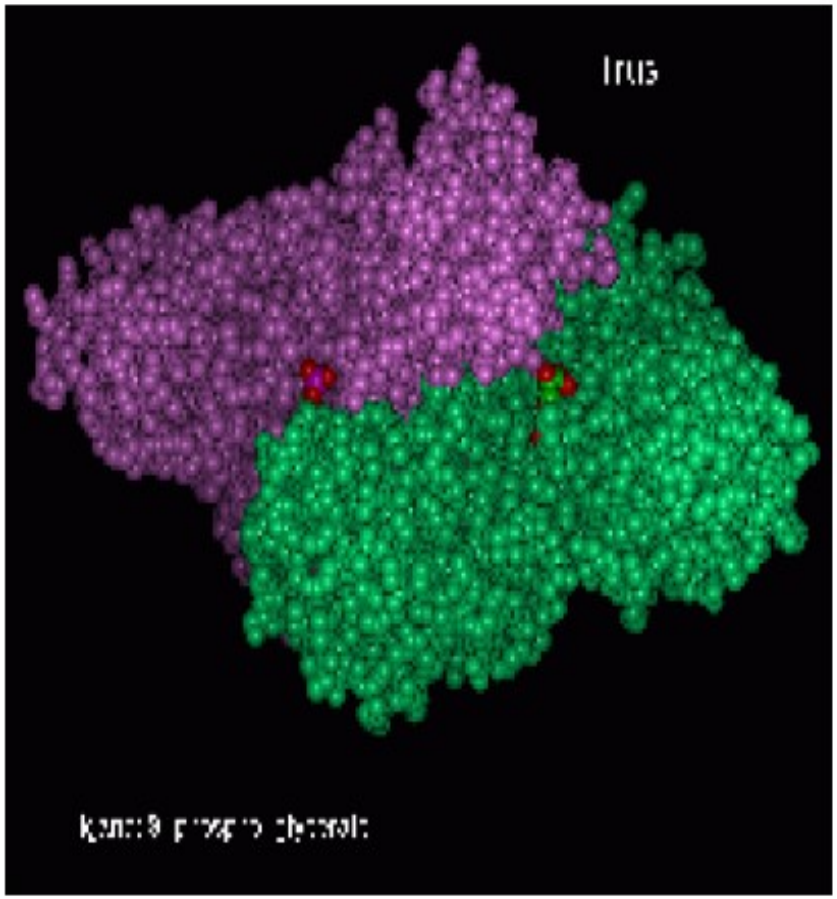


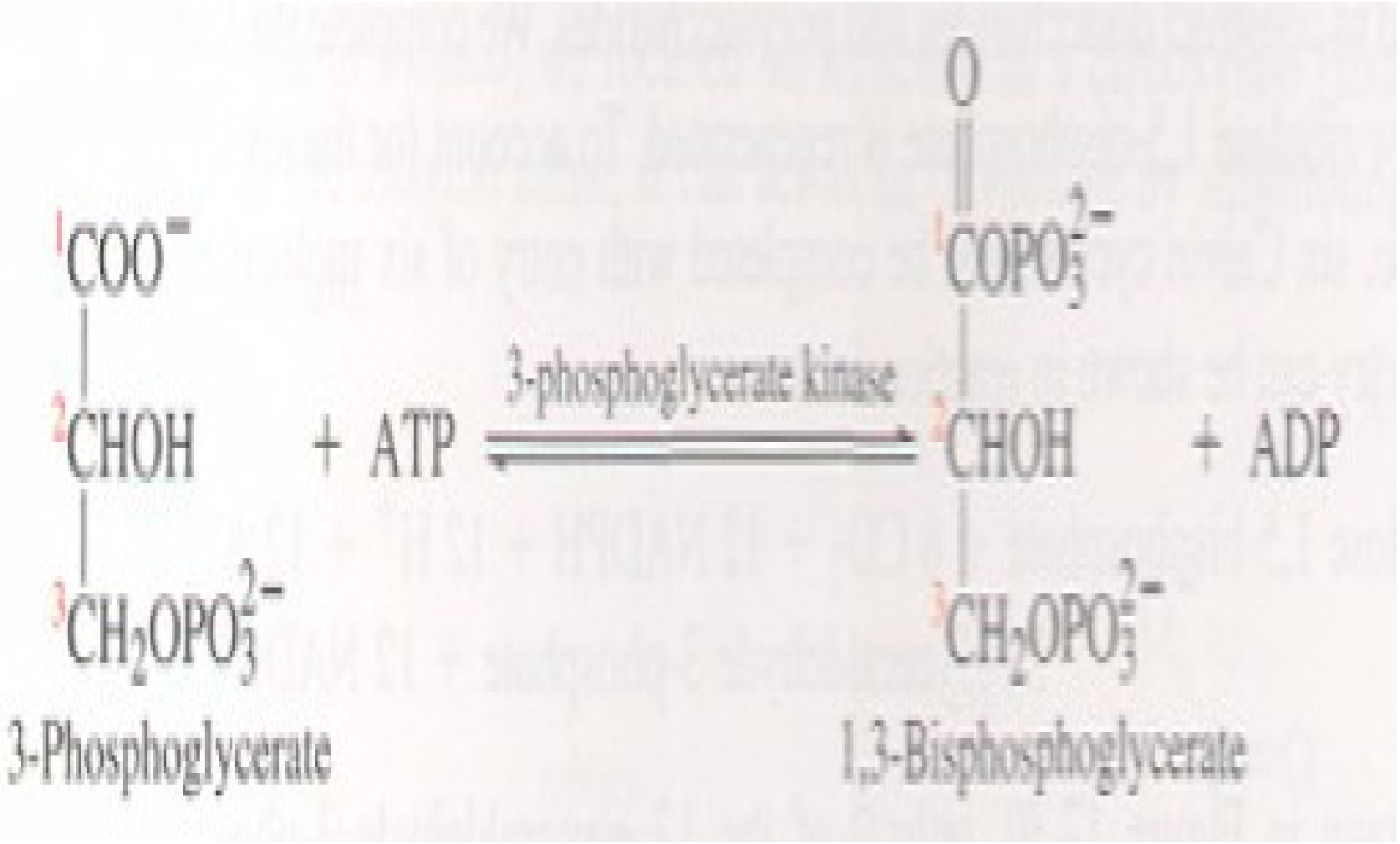
Rubisco


Ribulose 1,5-bisphosphate
β-Keto acid intermediate
3-Phosphoglycerate
3-Phosphoglycerate

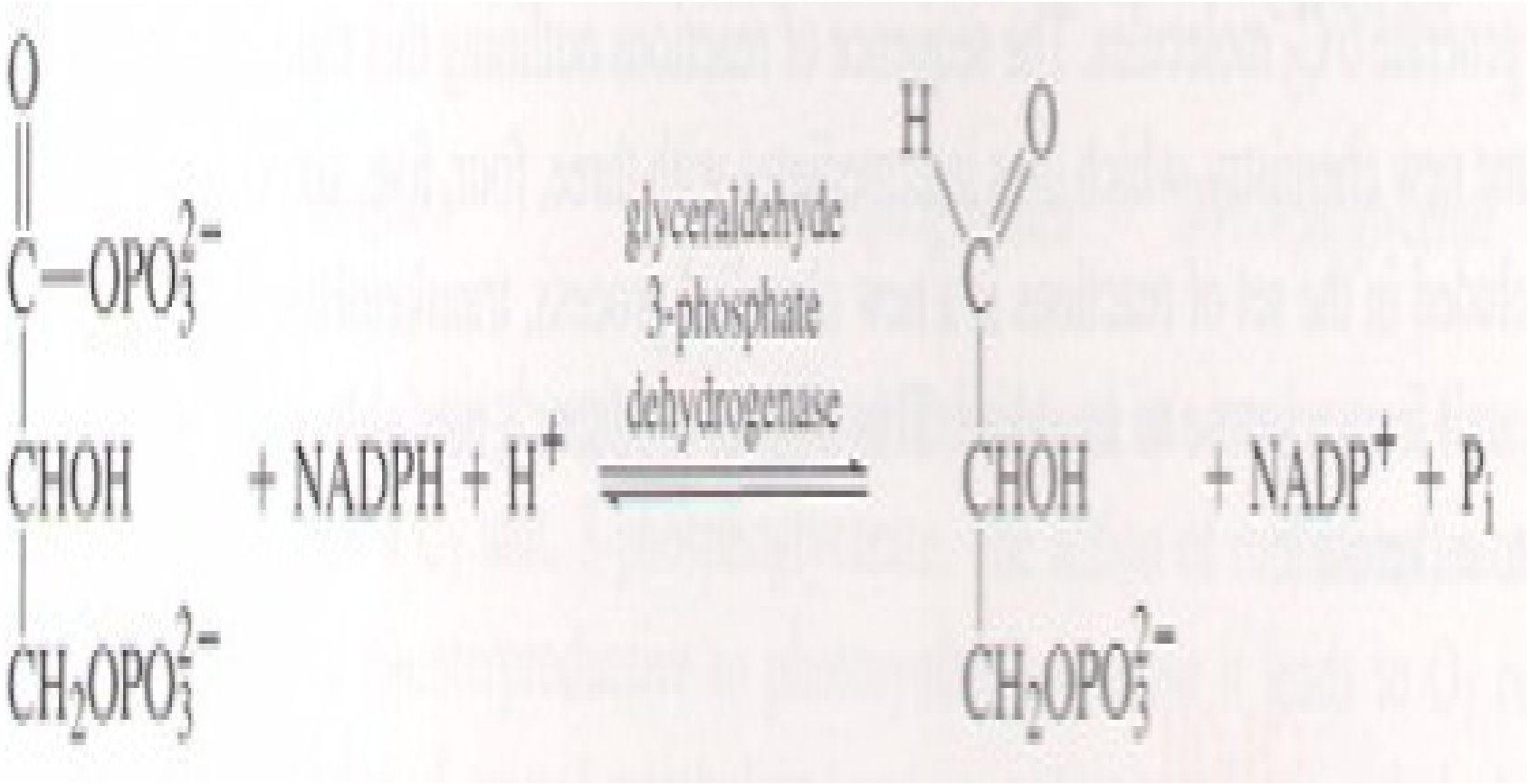
RUBISCO

2 podjednotky (1 katalytická)




COO⁻
CHOH
CH₂OPO₃²⁻
+ ATP
3-phosphoglycerate kinase
O
COPO₃²⁻
CHOH
CH₂OPO₃²⁻
+ ADP
3-Phosphoglycerate
1,3-Bisphosphoglycerate

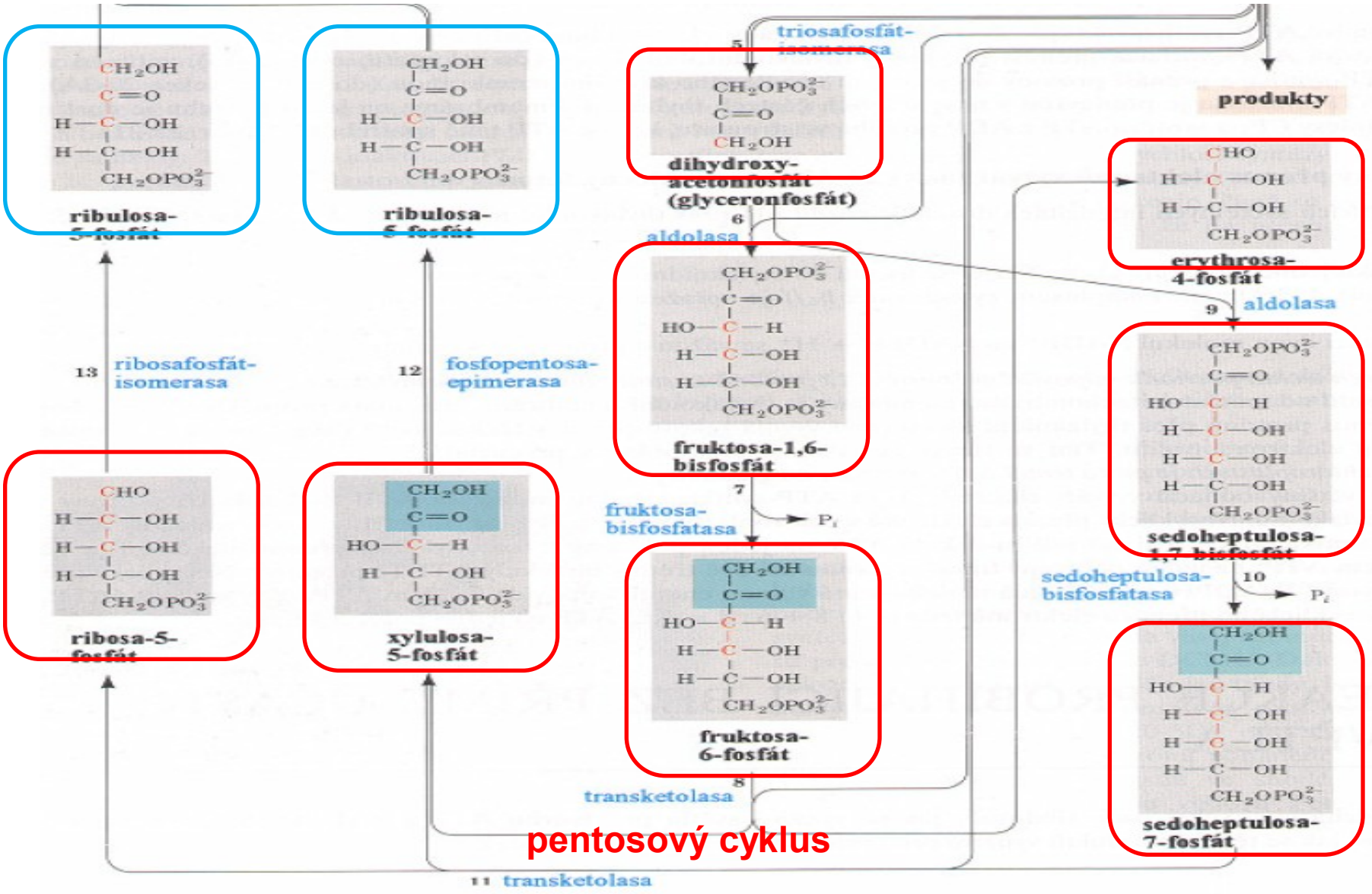
glykolysa

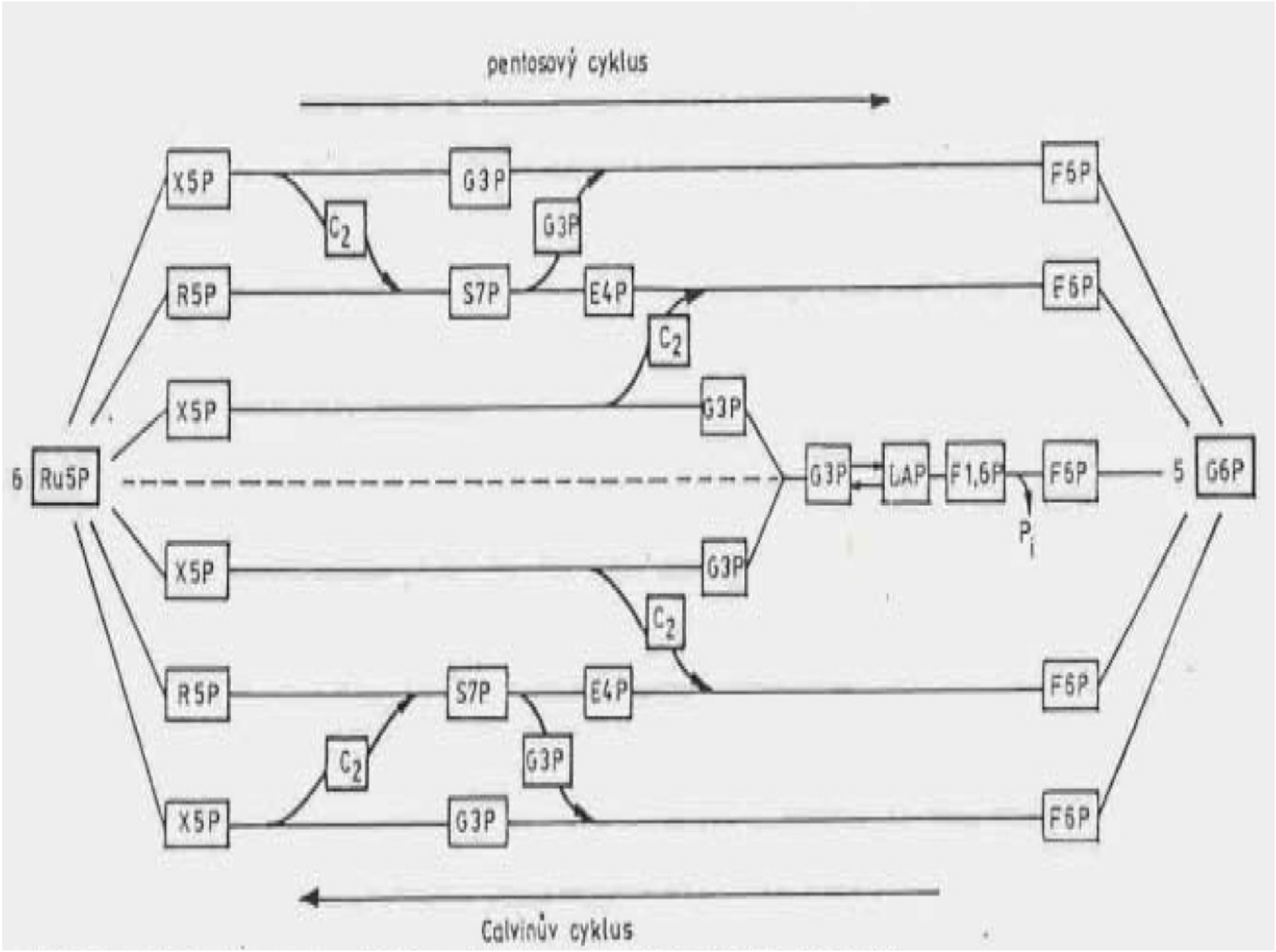


glykolysa

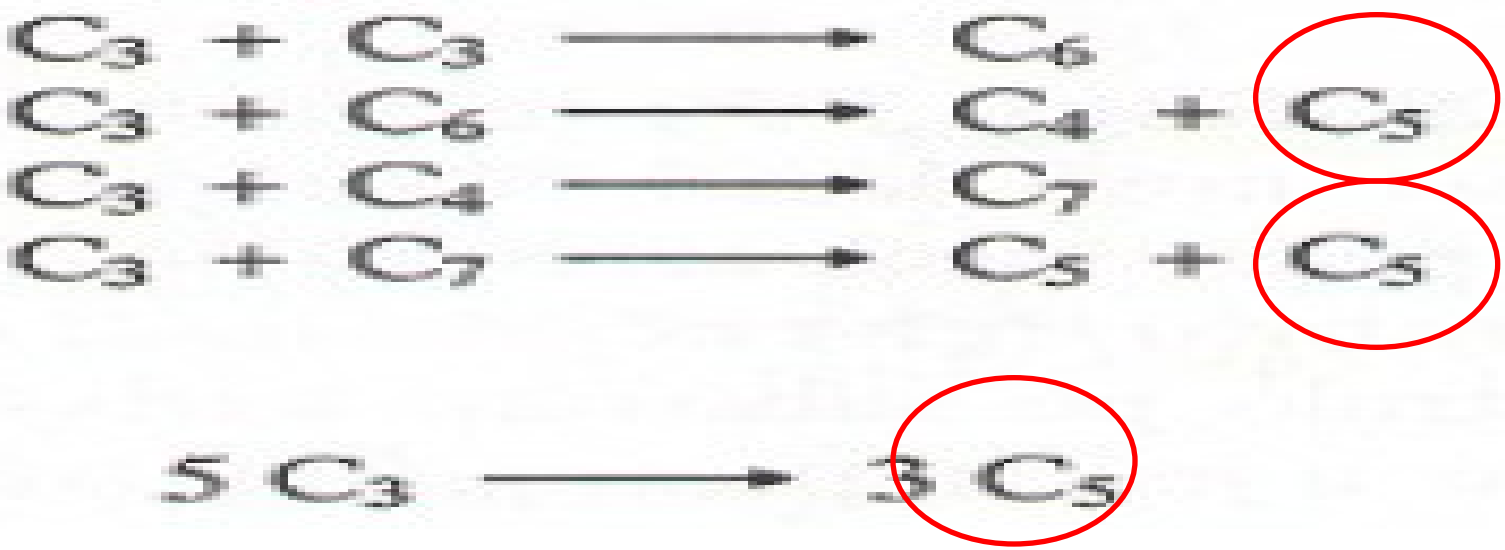
Calvinův cyklus

GA3P



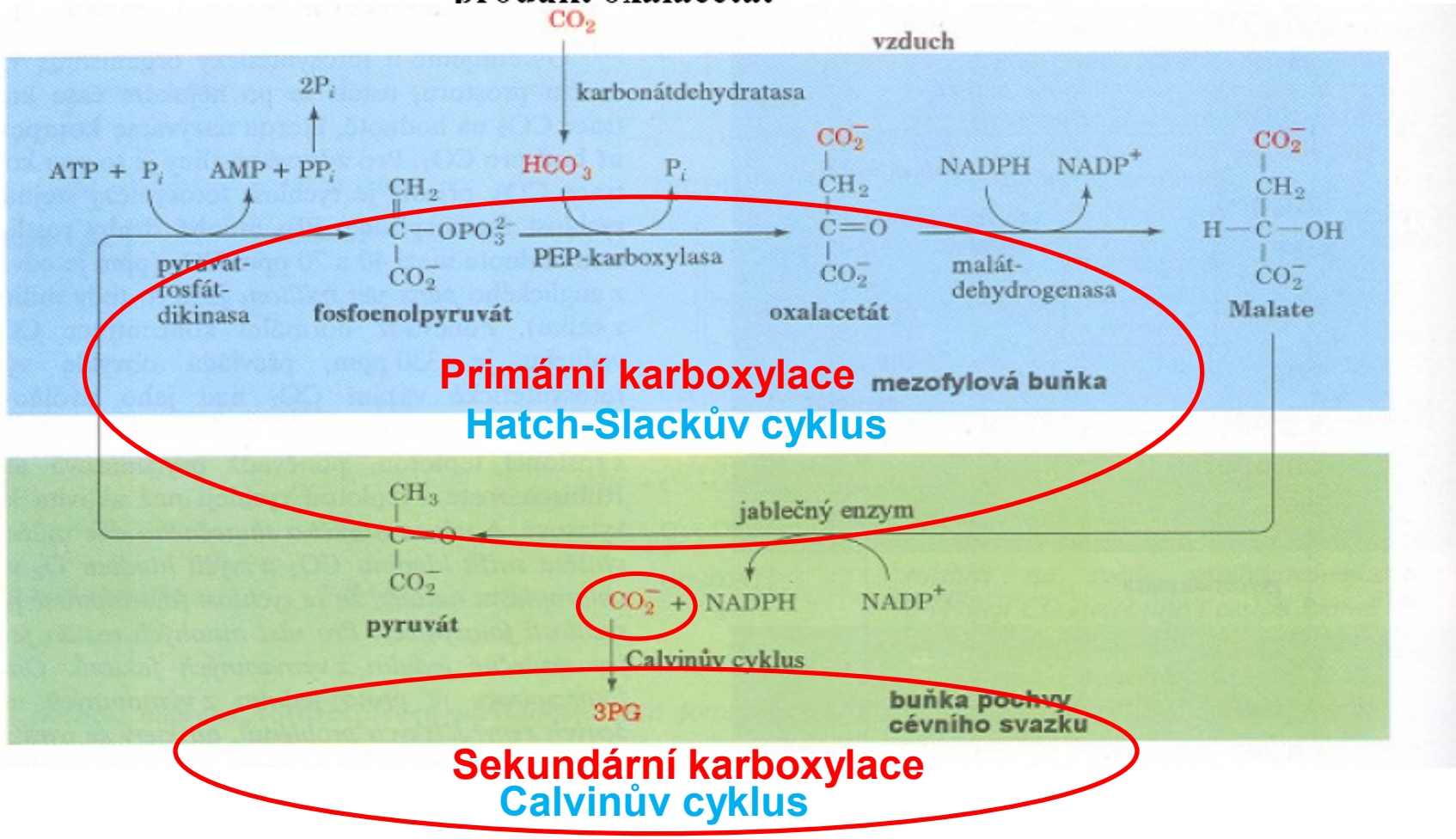


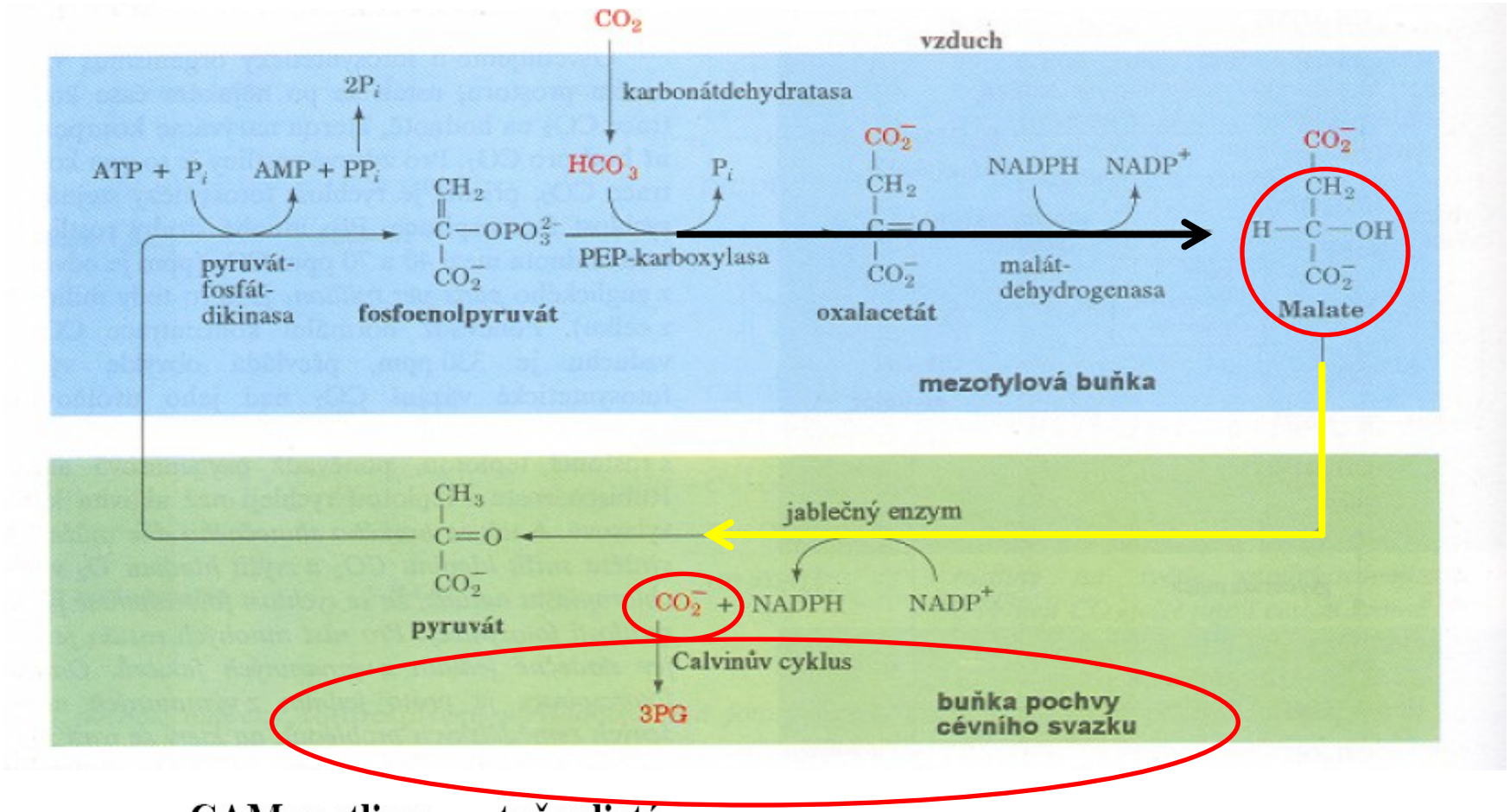
pentosový cyklus



pentosový cyklus

C_4 rostliny - rychlerostoucí tropické rostliny
- akceptor CO_2 fosfoenolpyruvát
- produkt oxalacetát

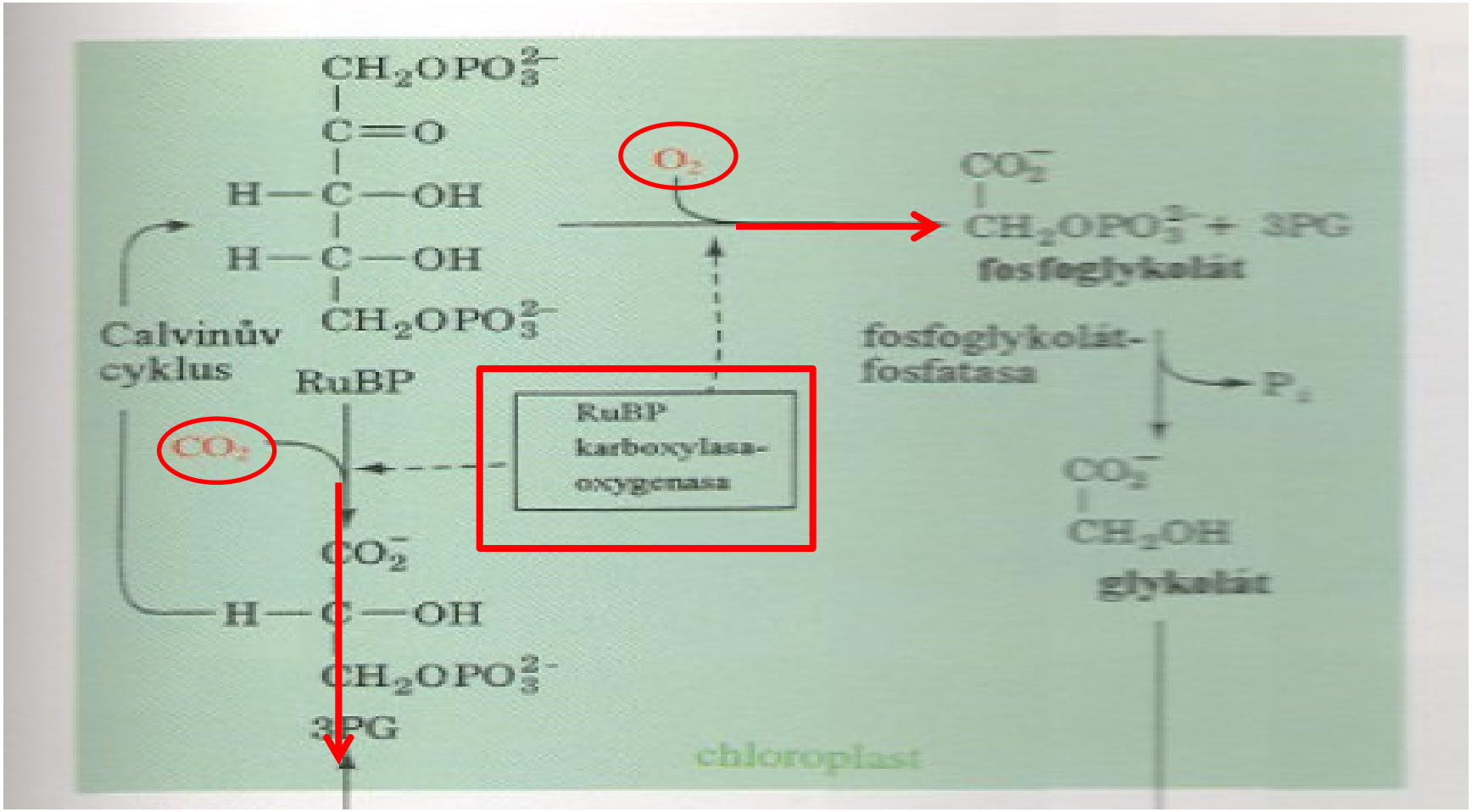


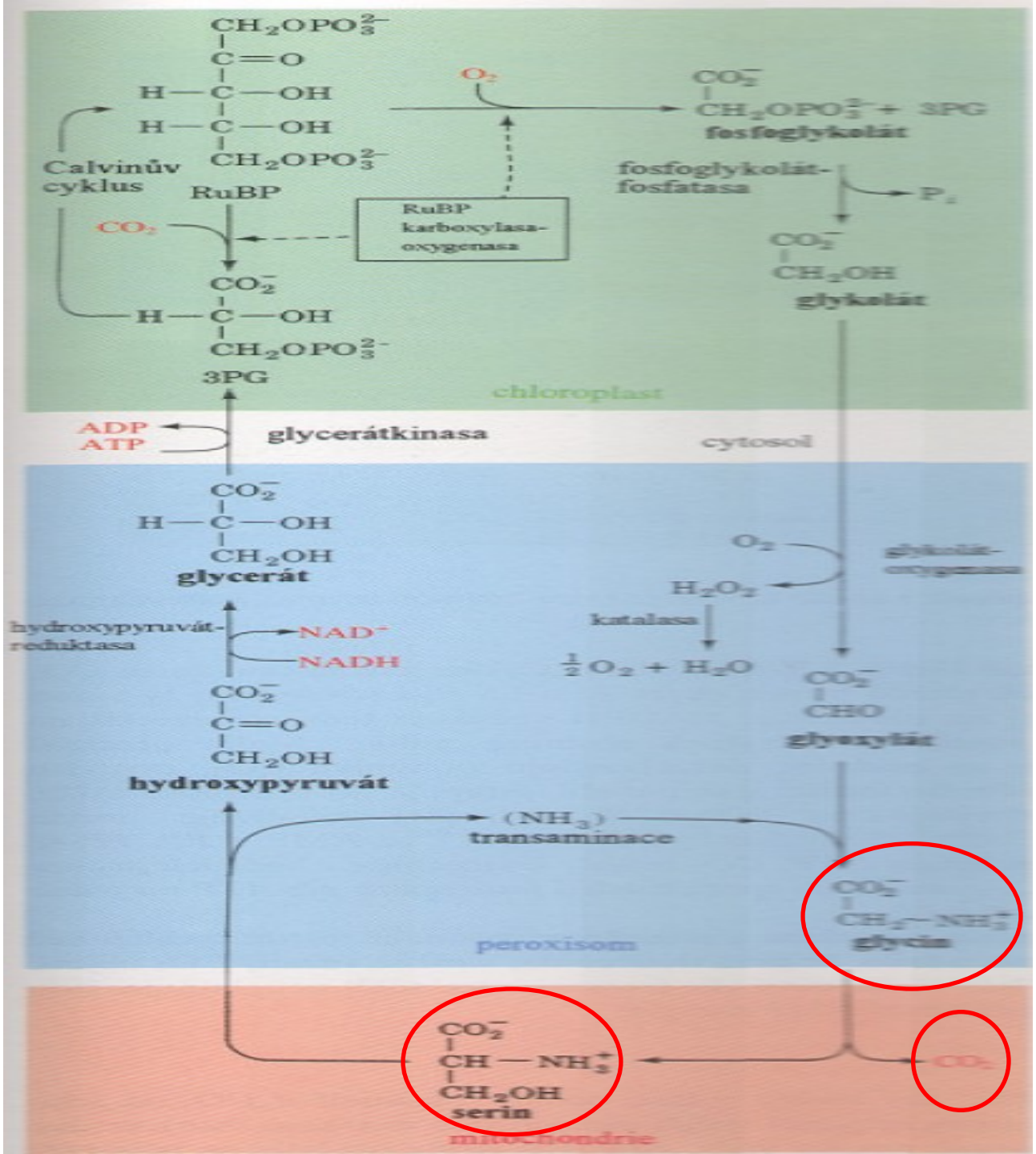


CAM rostliny - tučnolisté

- příjem CO_2 probíhá v noci

Fotorespirace




Calvinův cyklus
RuBP
RuBP karboxylasa-oxygenasa
fosfoglykolát
fosfoglykolát-fosfatasa
glykolát
3PG
chloroplast
ADP
ATP
glycerátkinasa
cytosol
glycerát
hydroxypyruvát-reduktasa
NAD+
NADH
hydroxypyruvát
katalasa
glykolát-oxygenasa
glyoxylát
(NH3)
transaminace
glycin
peroxisom
serin
mitochondrie

Fotorespirace

- fotorespirace evolučně zastaralá - způsobuje totiž ztráty substrátu a energie.

- fotorespirace je jakási „pojistka“, která chrání rostlinu před reakcemi přebytečného ATP a NADPH s kyslíkem a před vznikem volných radikálů.

- fotorespirace **zabraňuje poškození fotosyntetického aparátu** fotooxidačními reakcemi, které by mohly být způsobeny přeměnou pohlcené světelné energie **při nedostatečné koncentraci CO_2**.