

# METABOLISMUS

## ŽIVOT

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

## Látková přeměna - intermediální metabolismus

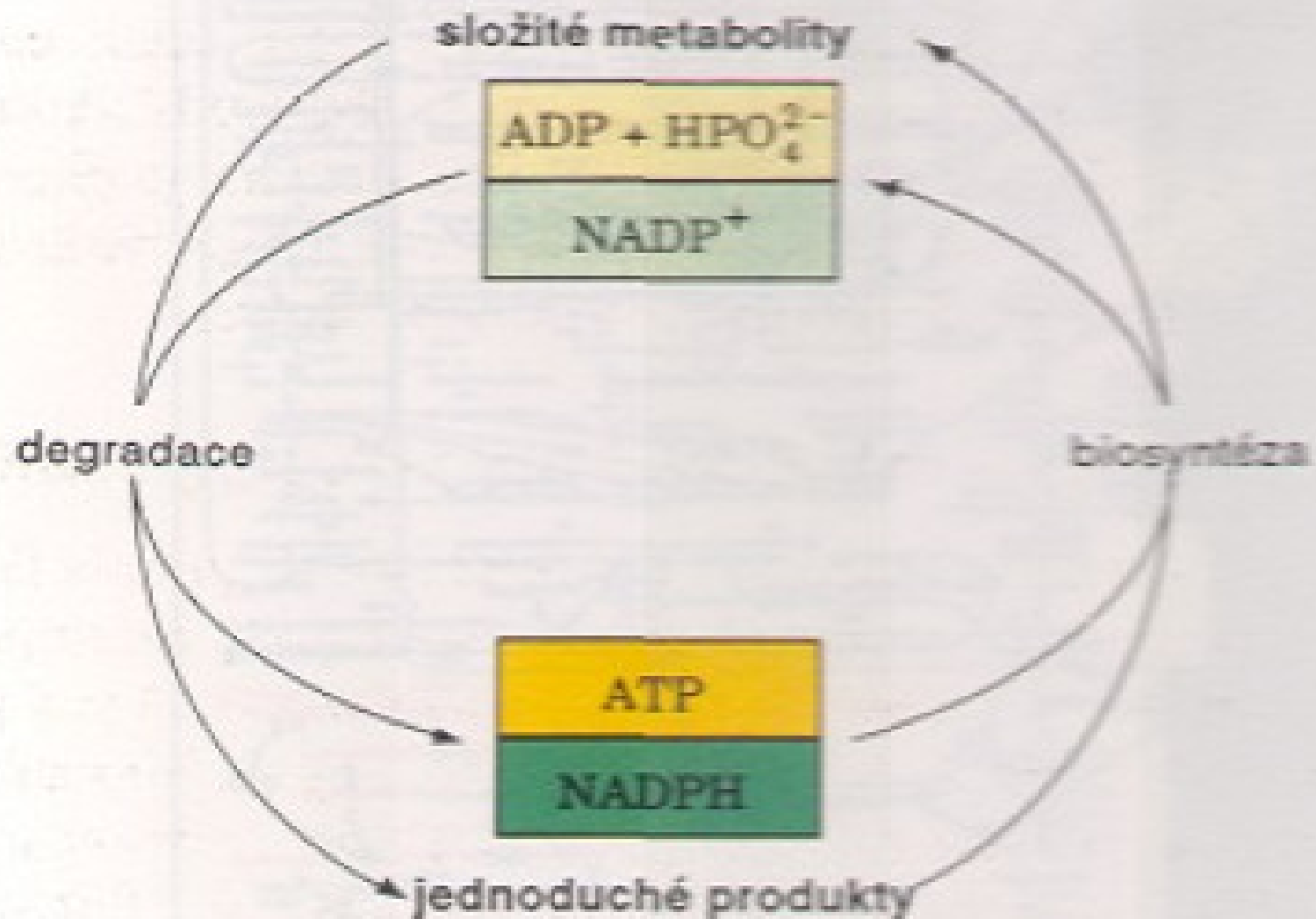
Funkce - zajišťování energie

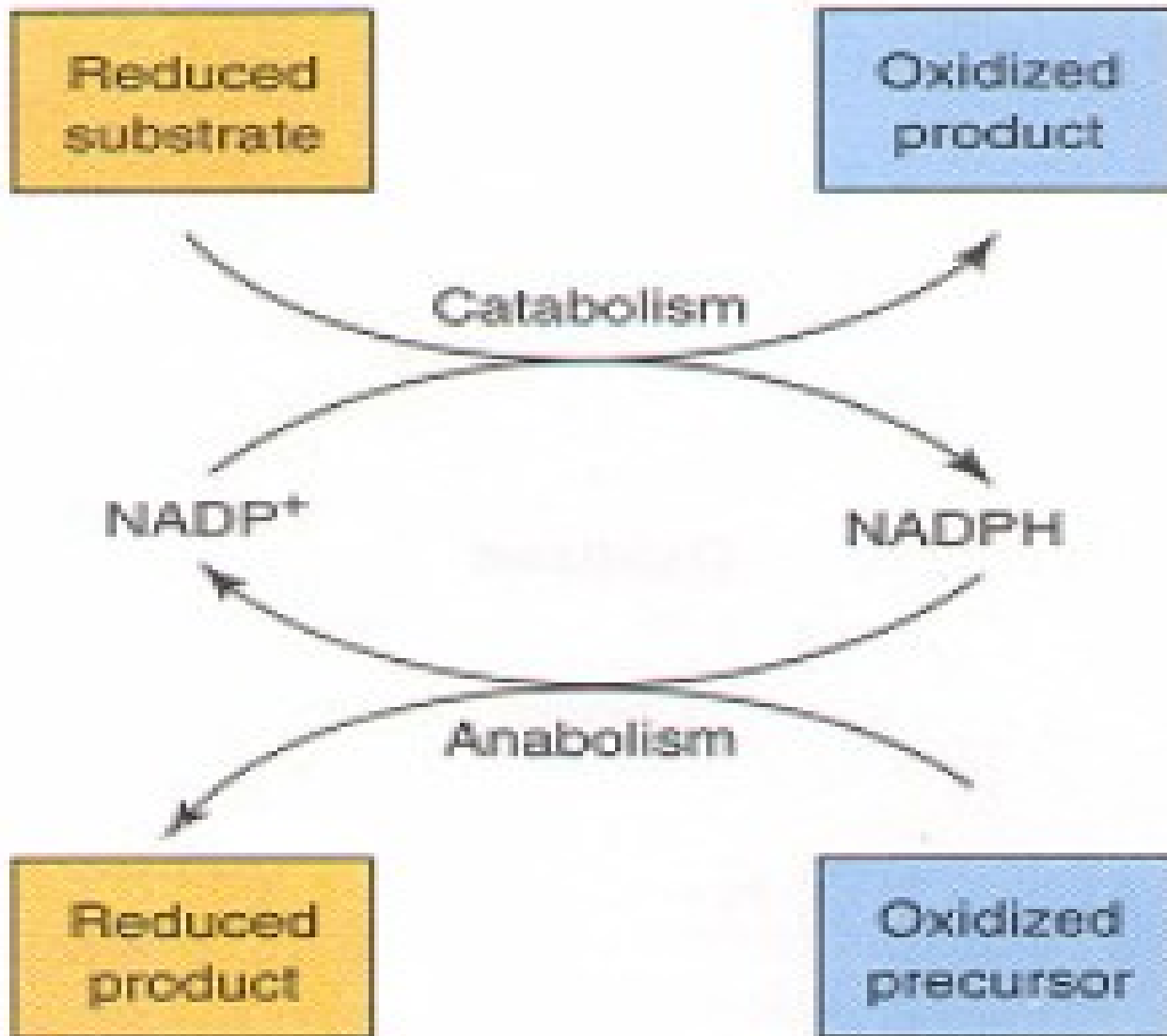
- zajišťování stavebního materiálu

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

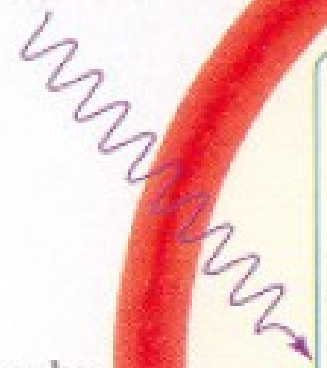
### D. Podle konečného akceptoru elektronů

aeroby -  $O_2$

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

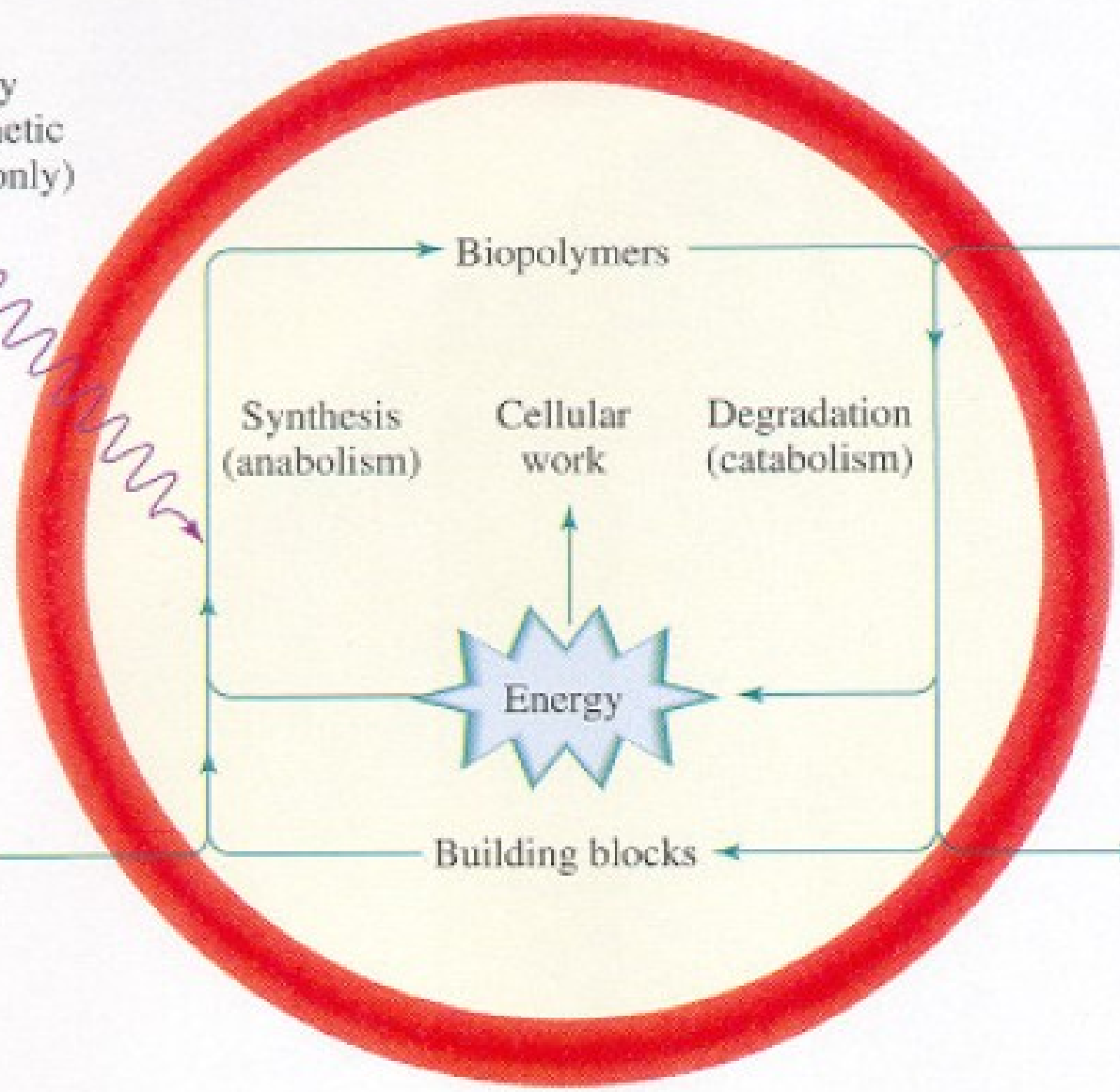
fermentace - elektrony jsou předávány na jiné organické látky

Light energy  
(photosynthetic  
organisms only)



Autotrophs

Food  
(CO<sub>2</sub>)



Biopolymers

Synthesis  
(anabolism)

Cellular  
work

Degradation  
(catabolism)

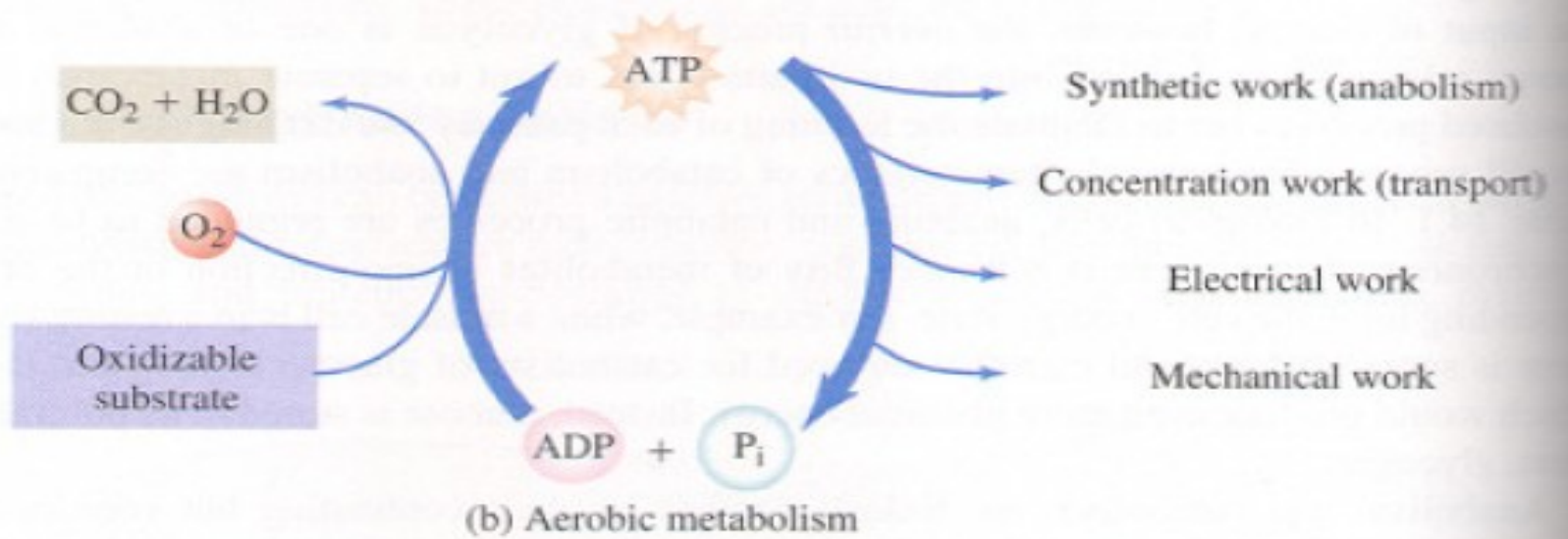
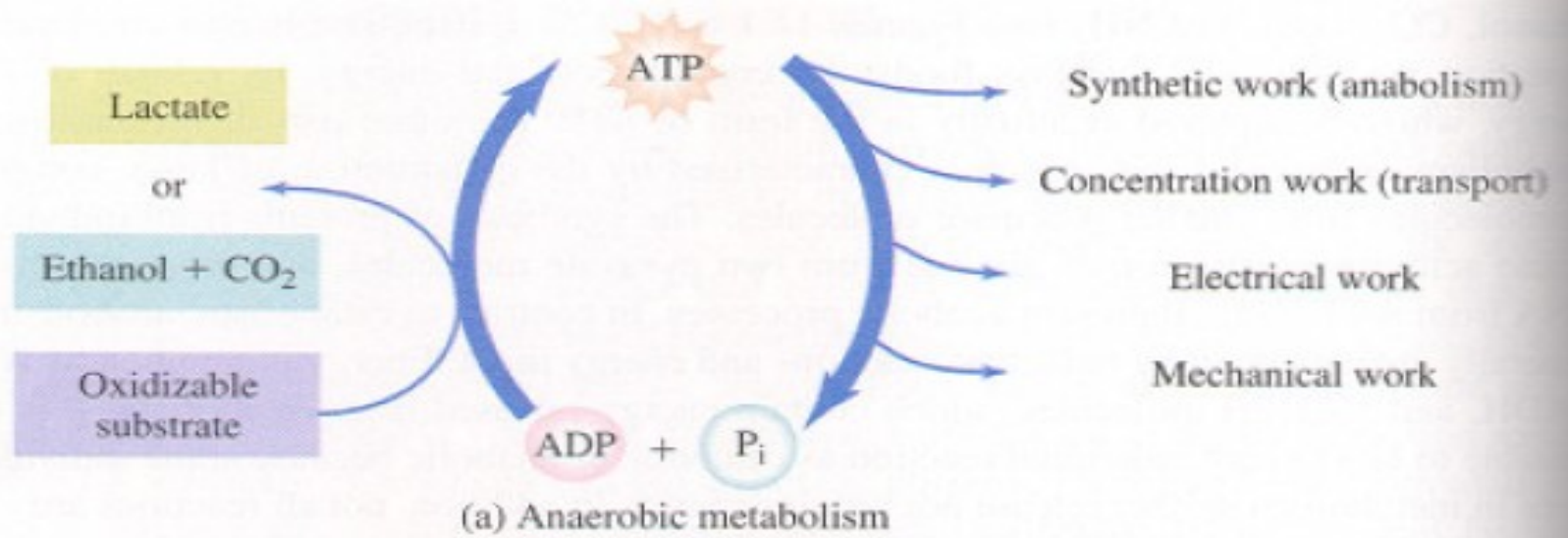
Energy

Building blocks

Food

Heterotrophs

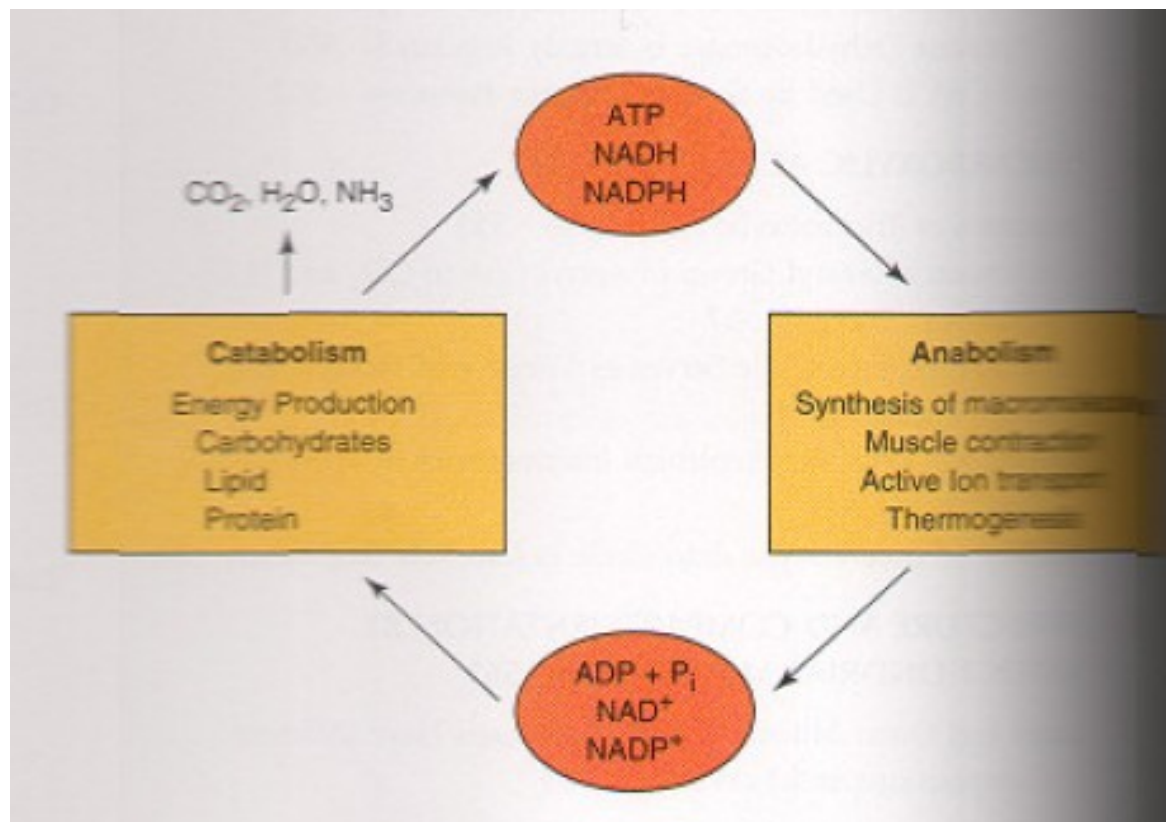
Wastes





# Metabolismus

## H. KREBS - tři fáze metabolismu



## *Katabolismus* - degradační fáze metabolismu - konvergentní

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

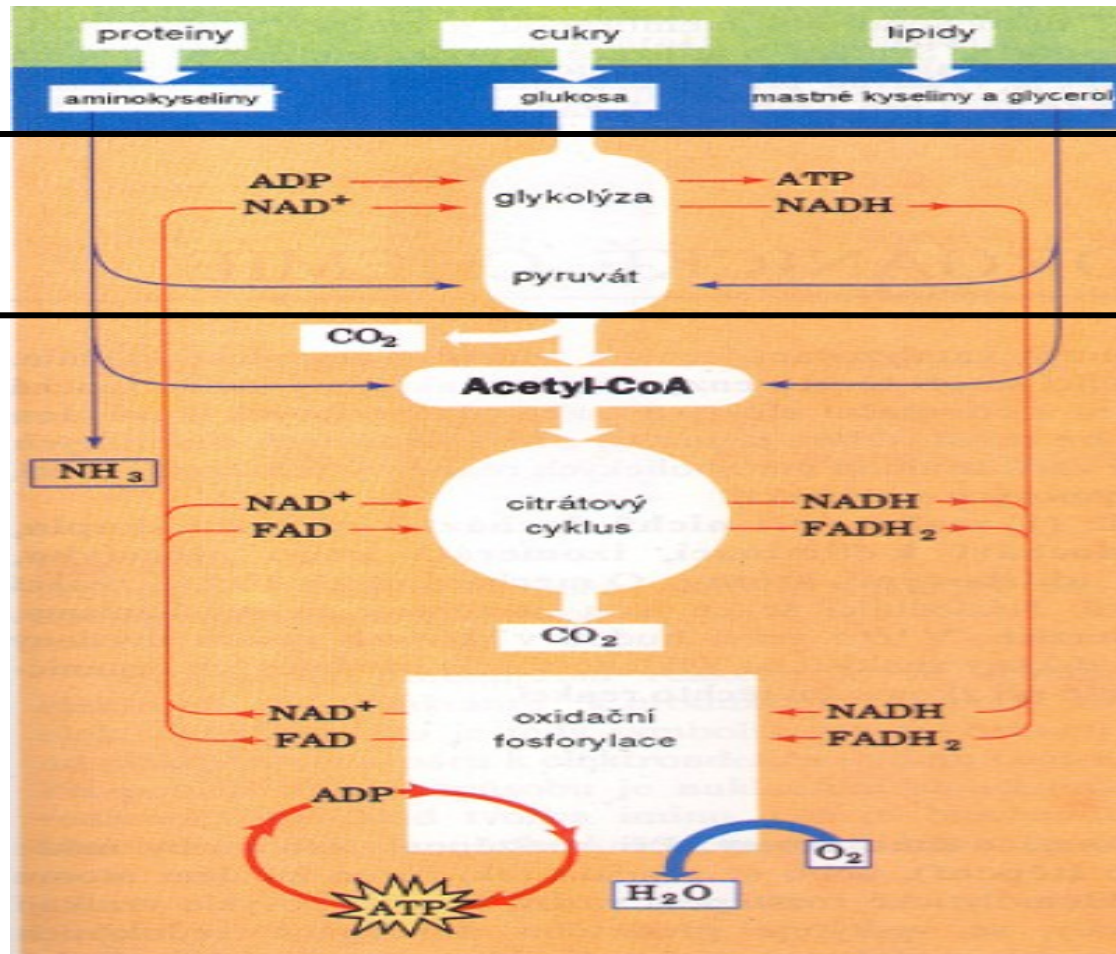
1. Fáze - složité molekuly štěpeny na stavební jednotky
2. Fáze - stavební jednotky převedeny na C<sub>1</sub> a C<sub>2</sub> látky
3. Fáze - citrátový cyklus + dýchací řetězec

# Katabolismus

I.fáze

II.fáze

III.fáze



*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

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

$$\Delta G^{\circ} = -RT \ln K$$

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

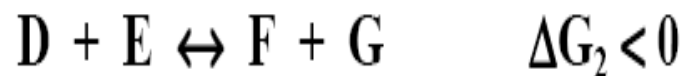
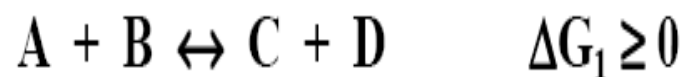
$$\Delta G^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ}$$

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

$\Delta G < 0$  - reakce exergonické

$\Delta G > 0$  - reakce endergonické

### Spřažení reakcí



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

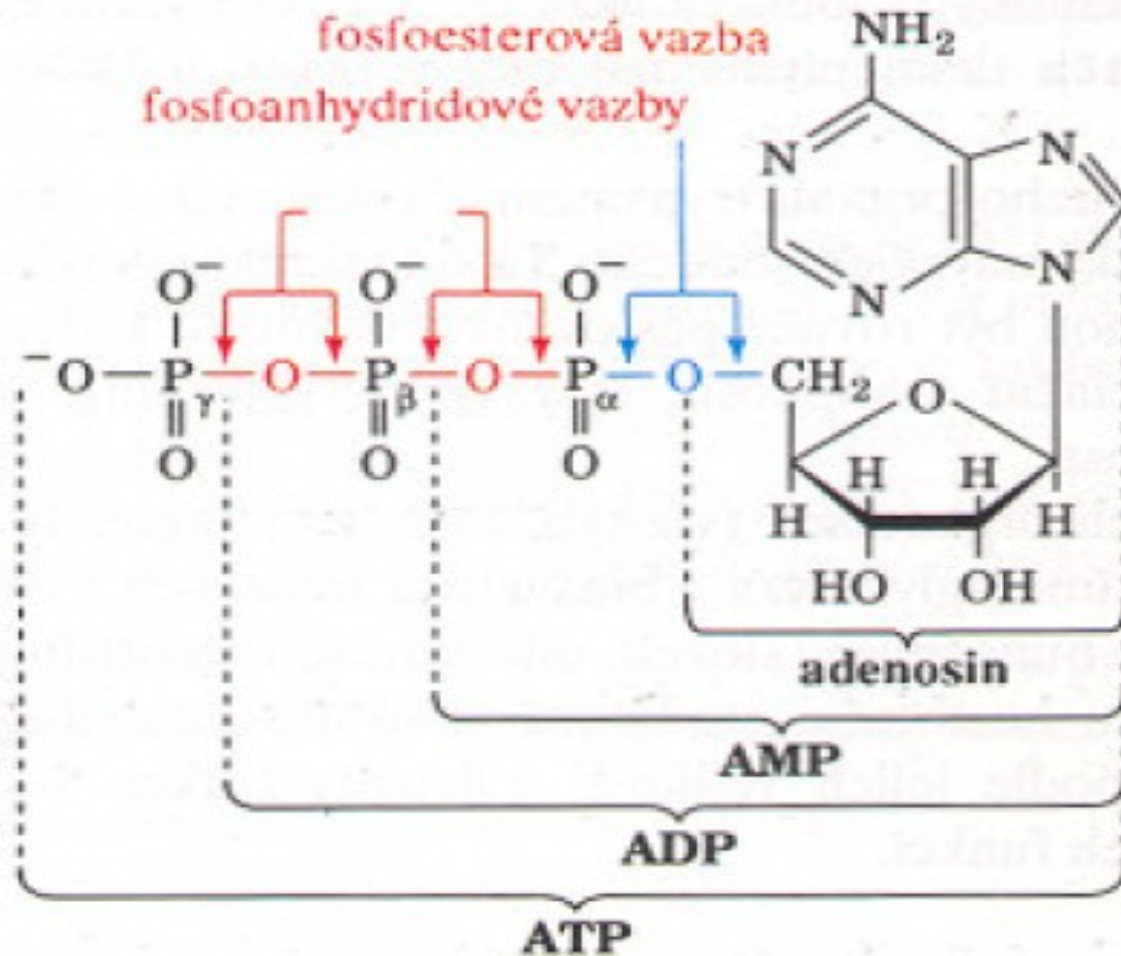


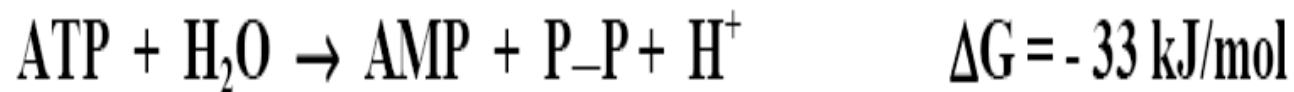
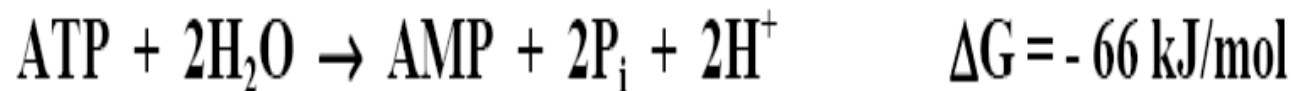
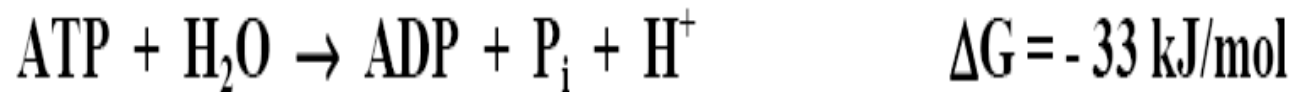
## Makroergické sloučeniny - makroergická vazba

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

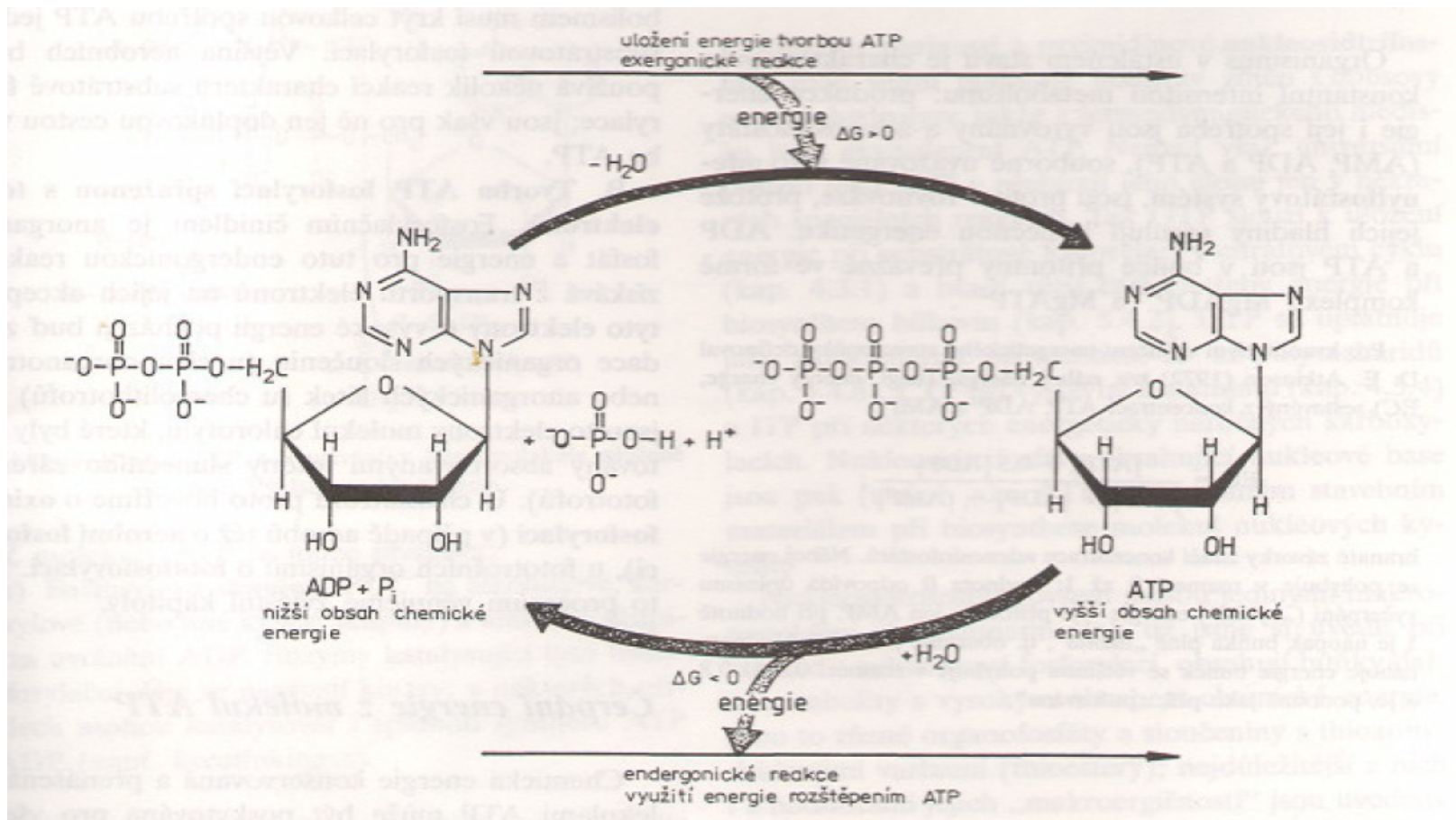
LIPMANN a KALCKAR 1941





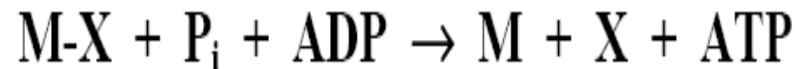
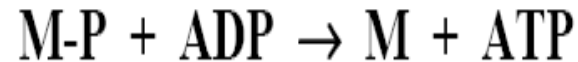
# ATP - univerzální přenašeč energie

LIPMANN a KALCKAR 1941



## Tvorba ATP

### 1. *Substrátová fosforylace*



### 2. *Fosforylace spřažena s tokem elektronů*

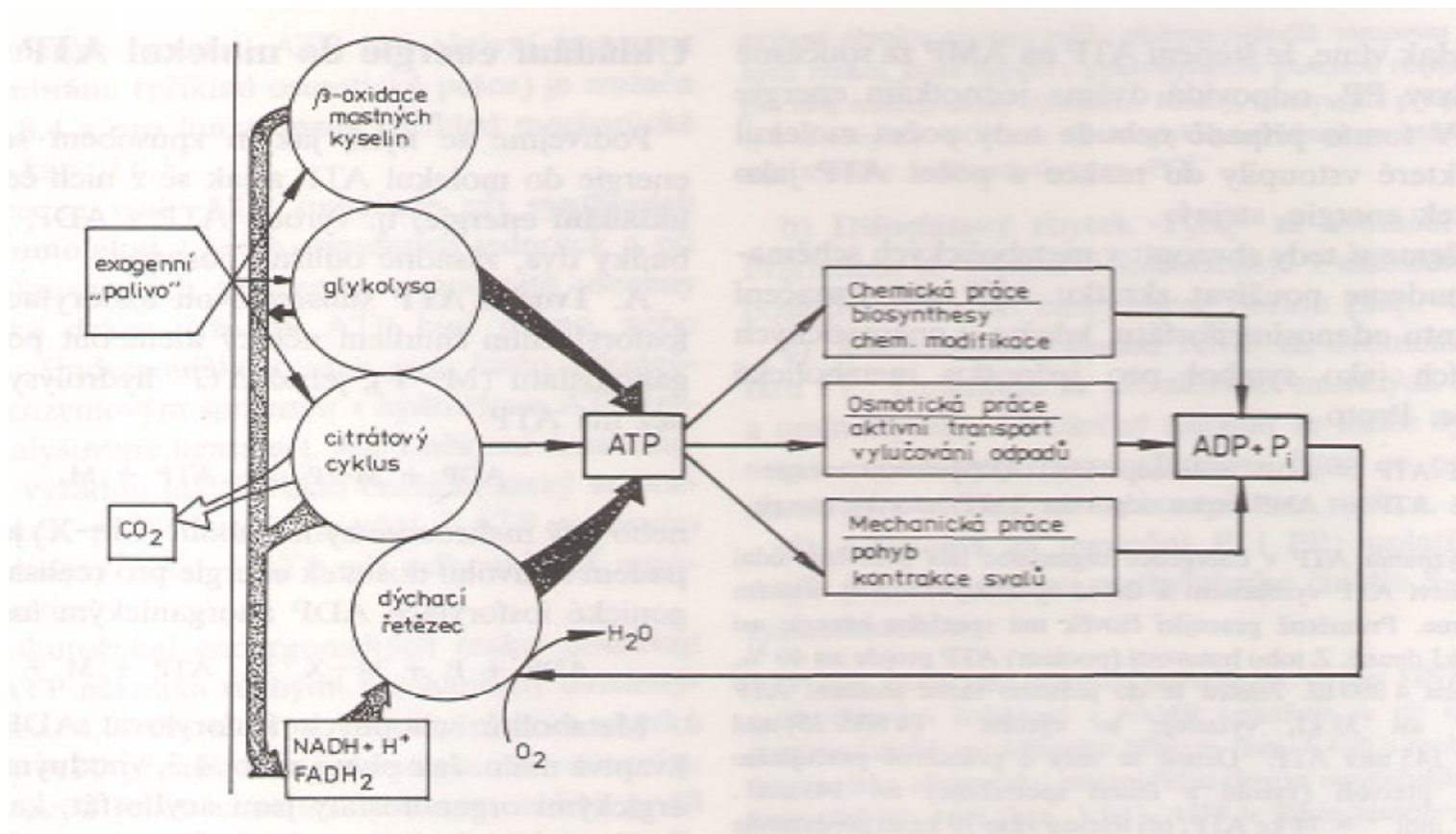
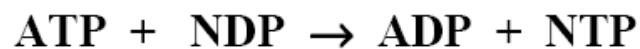
- oxidační fosforylace
- fotofosforylace

### 3. *Adenylátkinasovou reakcí*



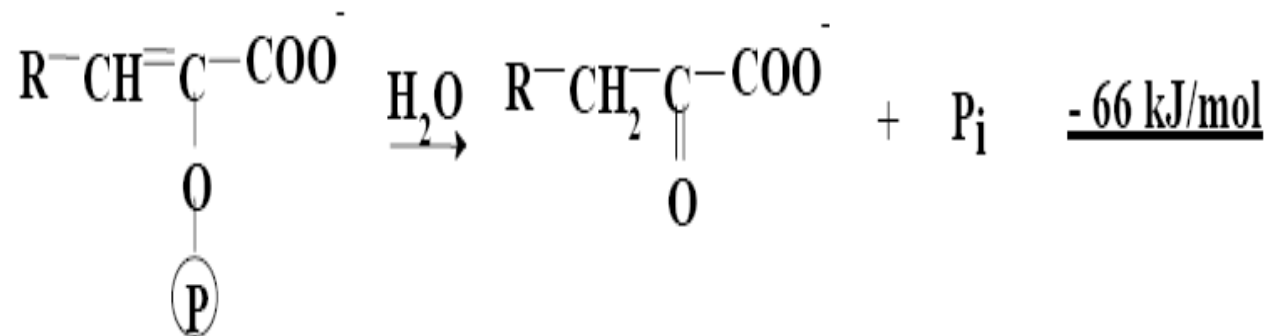
## Spotřeba ATP

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

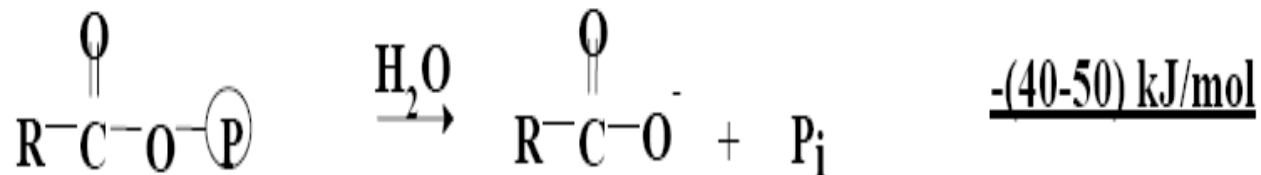


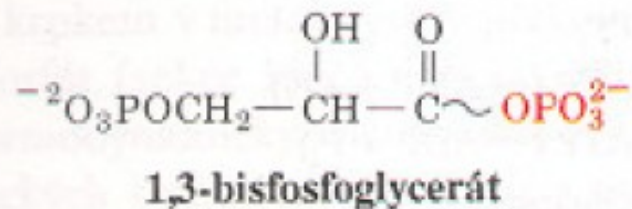
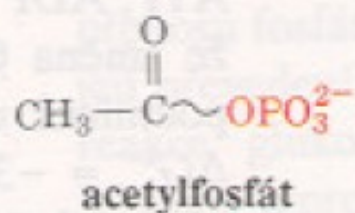
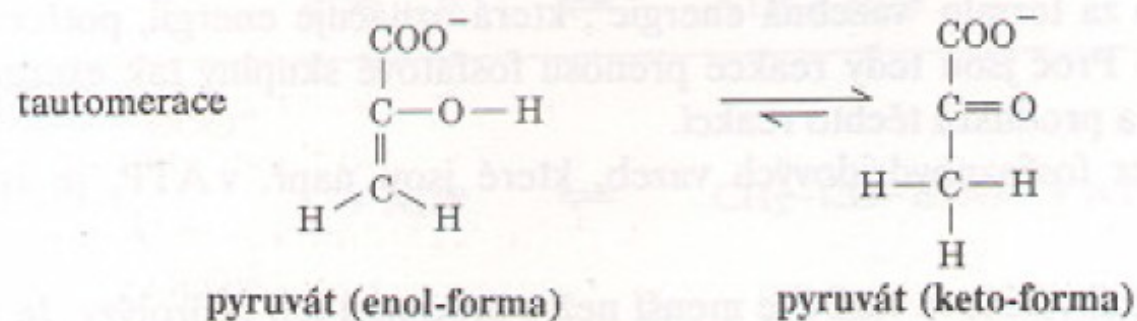
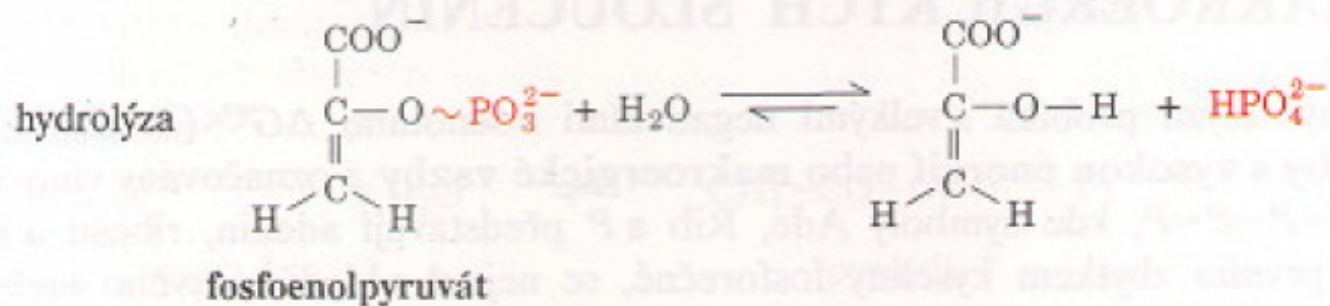
## Další makroergické sloučeniny

### ENOYLFOSFÁTY



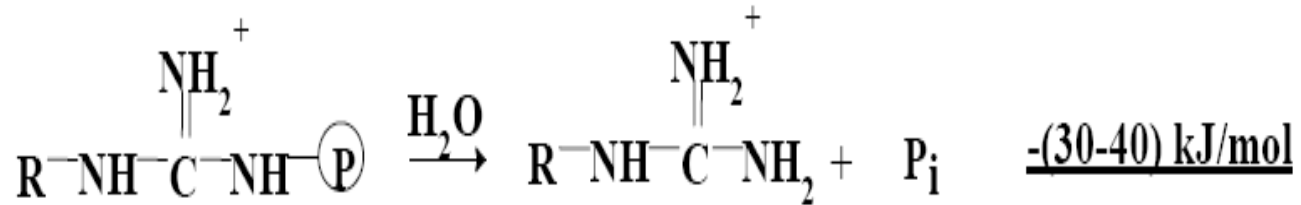
### ACYLFOSFÁTY



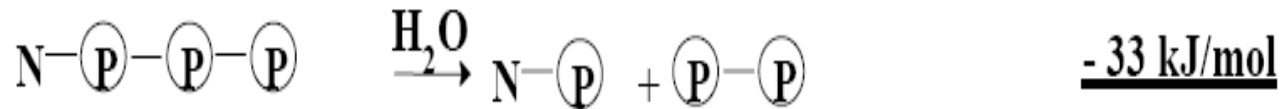
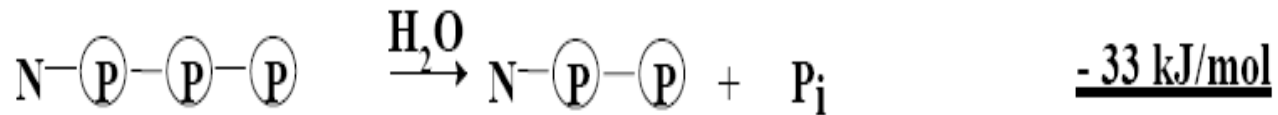


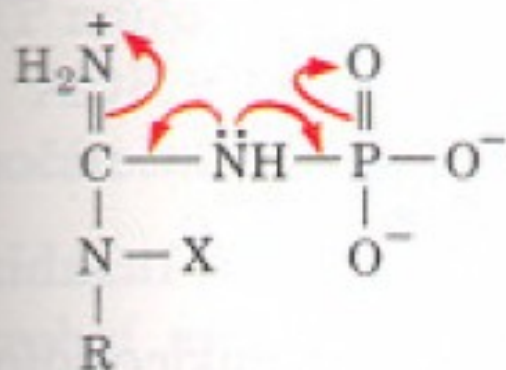


## GUANIDIUMFOSFÁTY



## NUKLEOTIDY

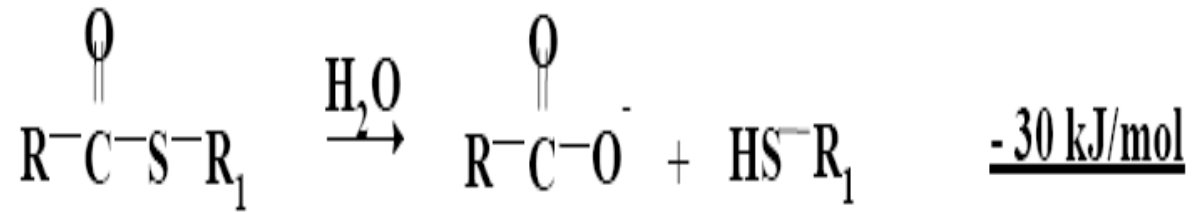




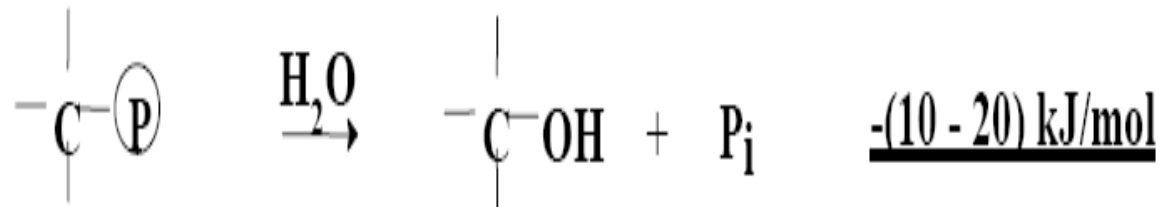
$\text{R} = \text{CH}_2 - \text{CO}_2^-$  ;  $\text{X} = \text{CH}_3$       fosfokreatin

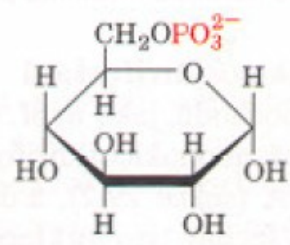
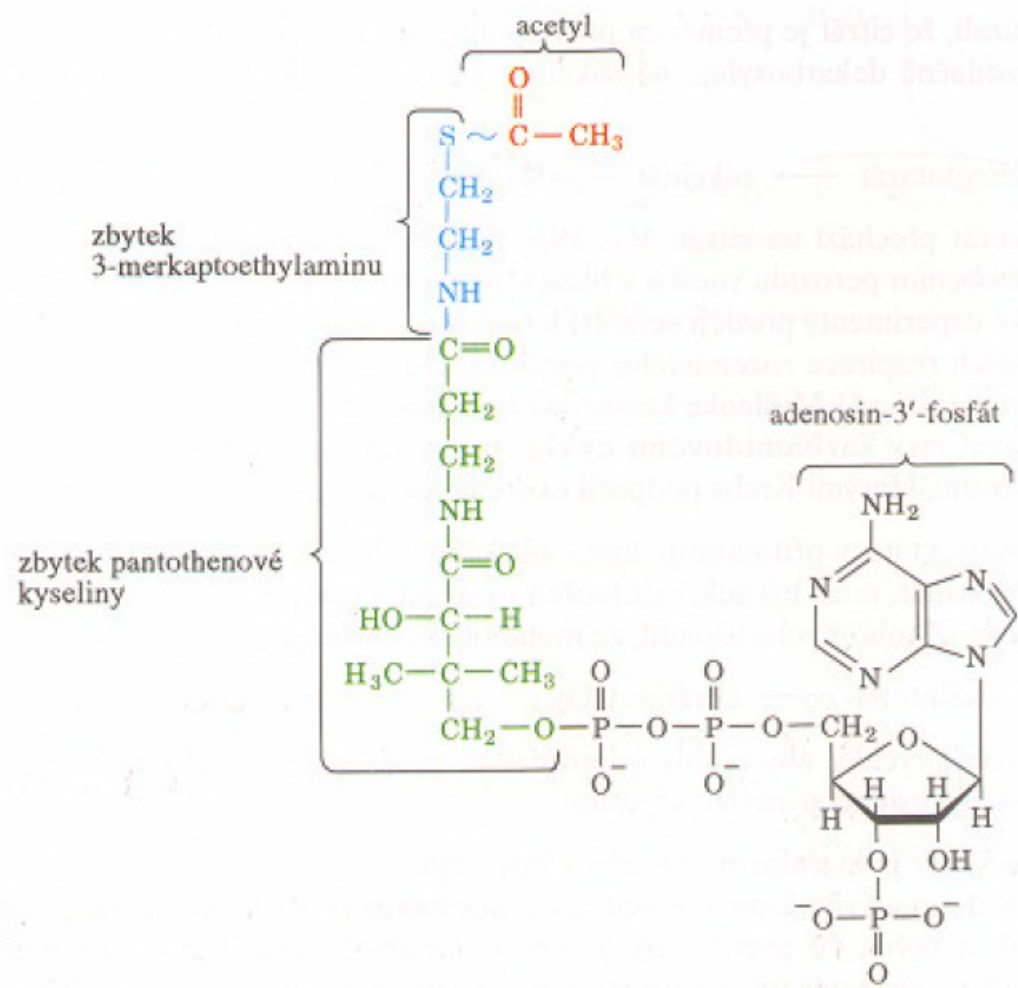
$\text{R} = \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \overset{\text{NH}_3^+}{\text{CH}} - \text{CO}_2^-$  ;  $\text{X} = \text{H}$       fosfoarginin

## ACYLTHIOESTERY

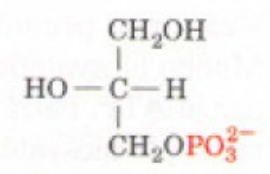


## FOSFOMONOESTERY






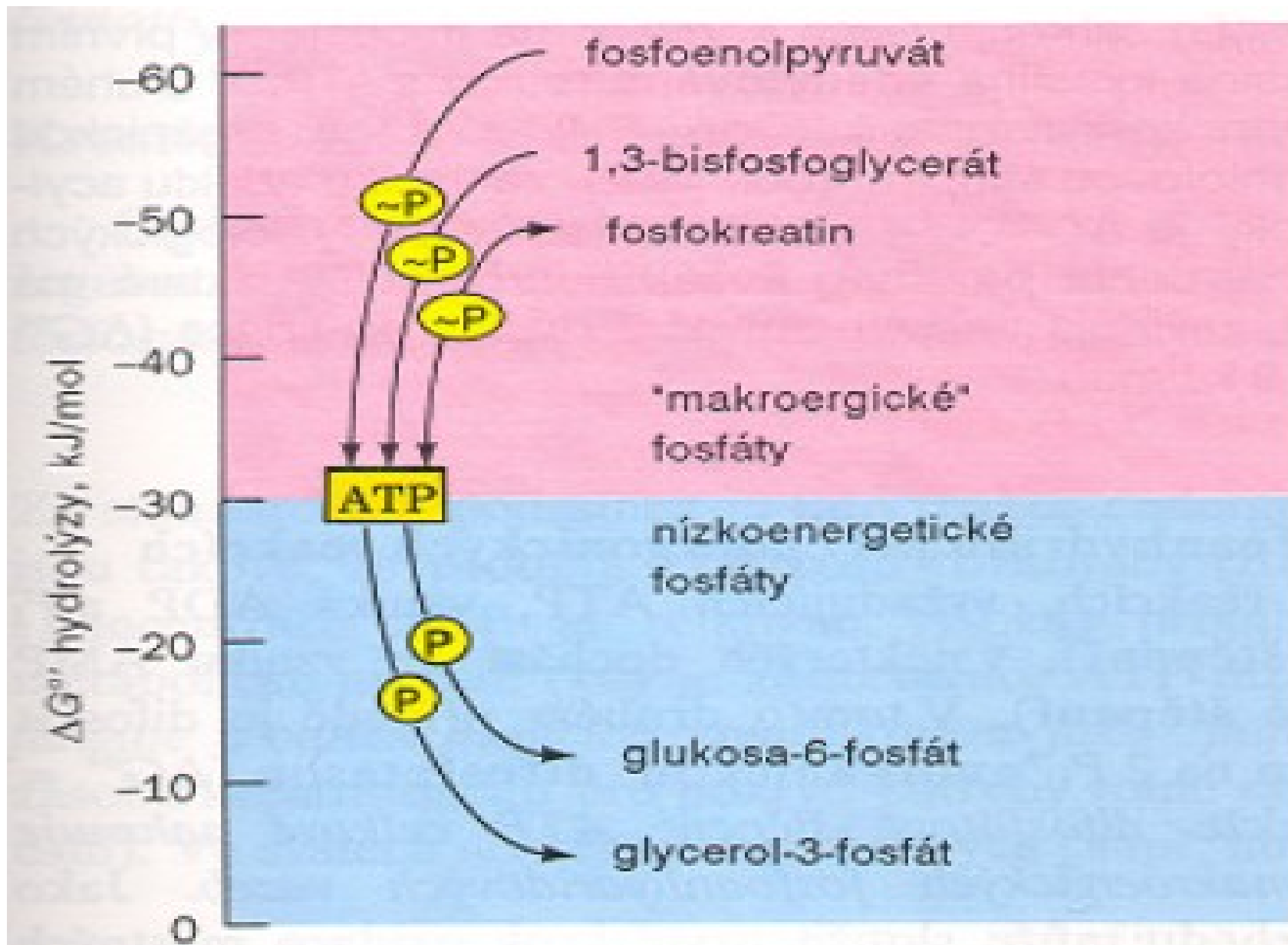
$\alpha$ -D-glukosa-6-fosfát



L-glycerol-3-fosfát

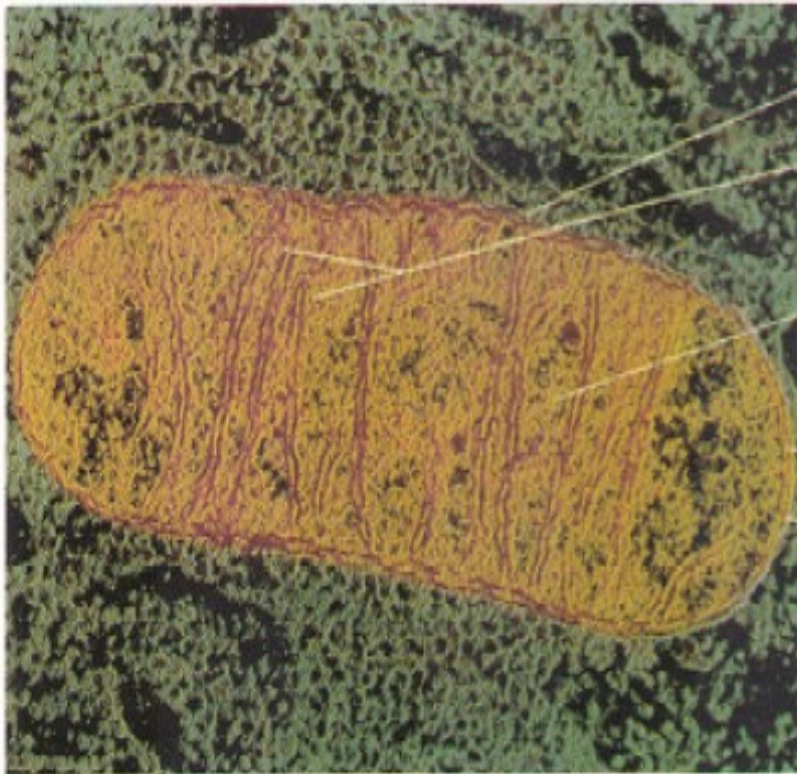
Phosphorylated Compounds	$\Delta G'$ (kJ/mol) <sup>a</sup>	Phosphoryl Group Transfer Potential
Phosphoenolpyruvate	- 61.9	Highest
1,3-Biphosphoglycerate	- 49.3	
Phosphocreatine	- 43.0	
ATP	- 30.5	
ADP	- 30.5	
Glucose 1-phosphate	- 20.9	
Glucose 6-phosphate	- 13.8	
Glycerol 1-phosphate	- 9.2	

<sup>a</sup>These values are for hydrolysis reactions (the transfer potential of the phosphoryl group to H<sub>2</sub>O).

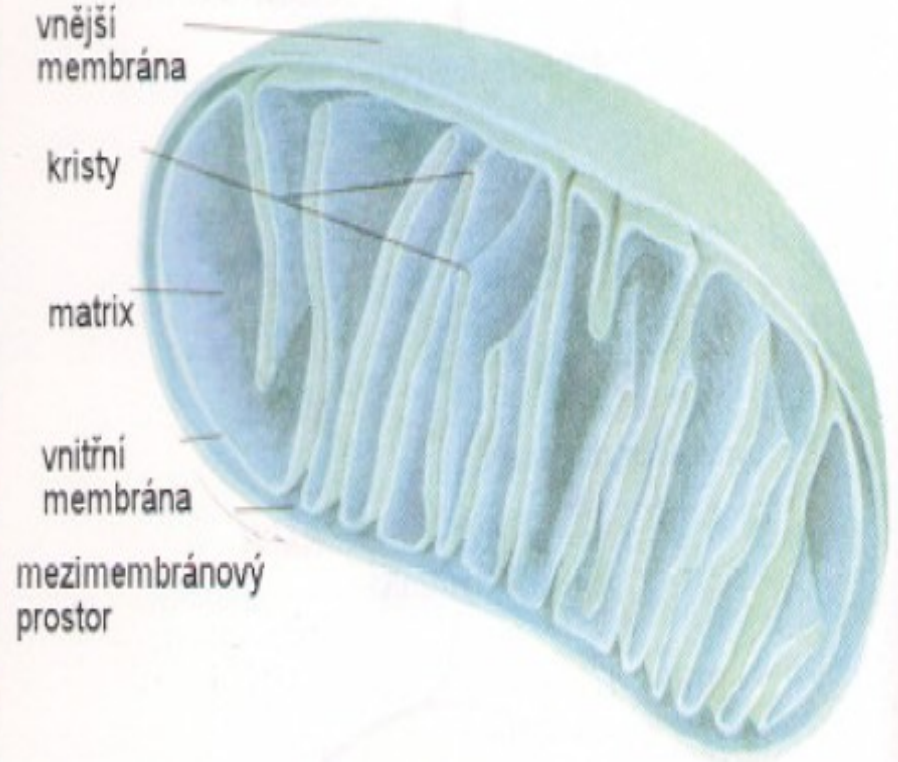




# Mitochondrie



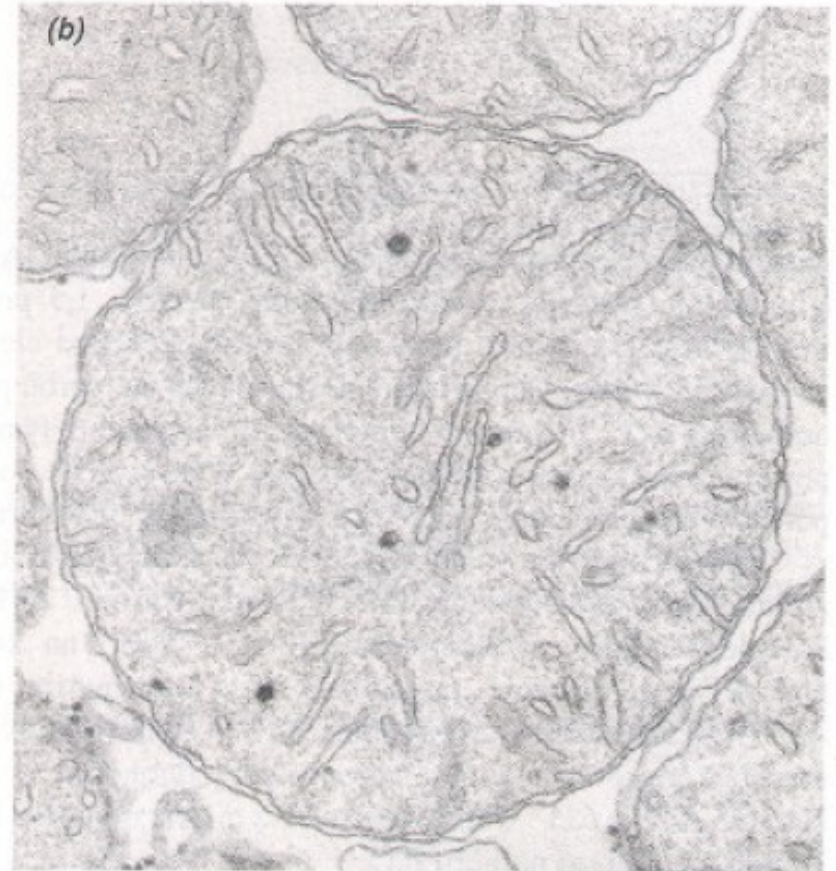
(a)

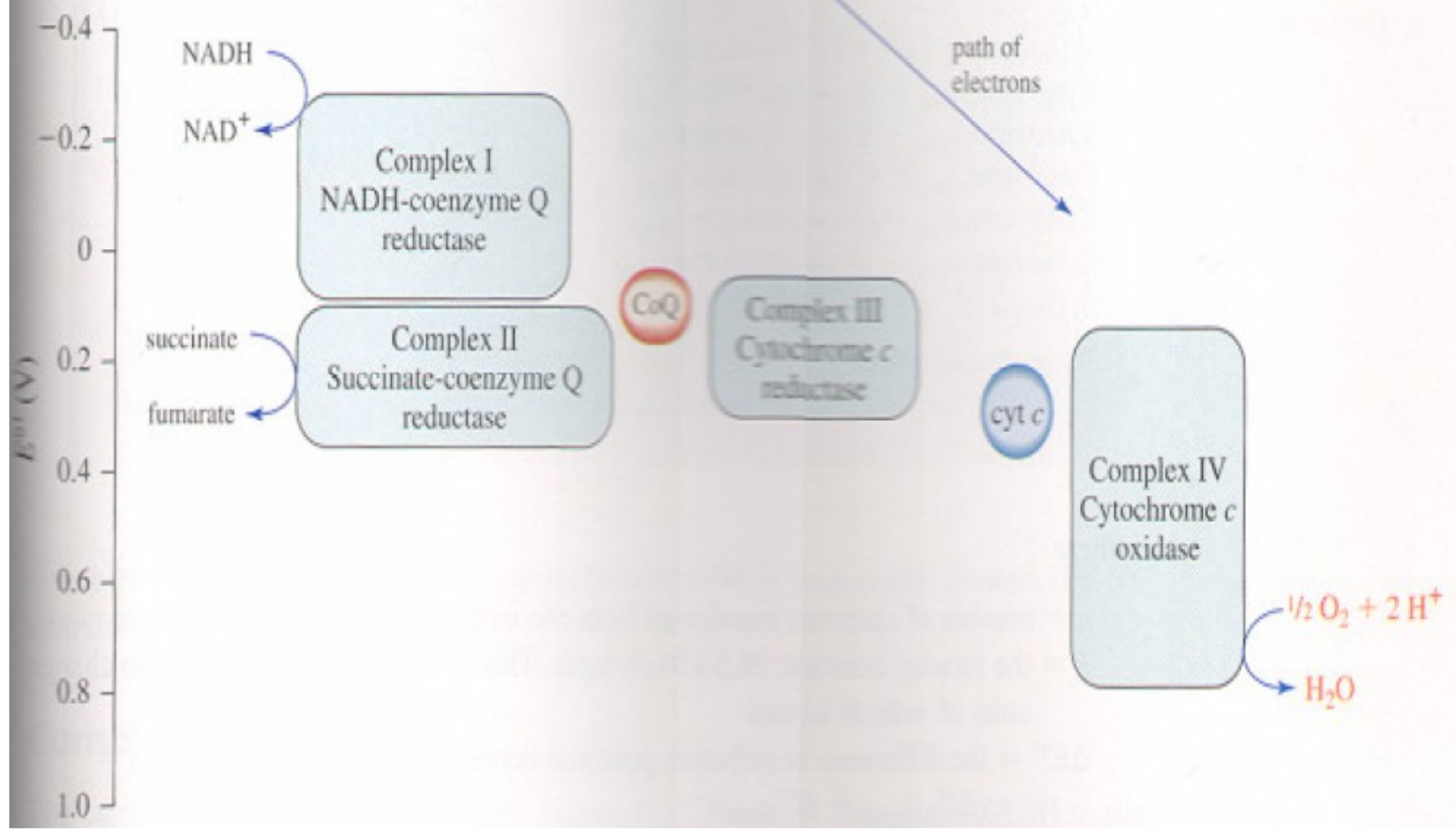
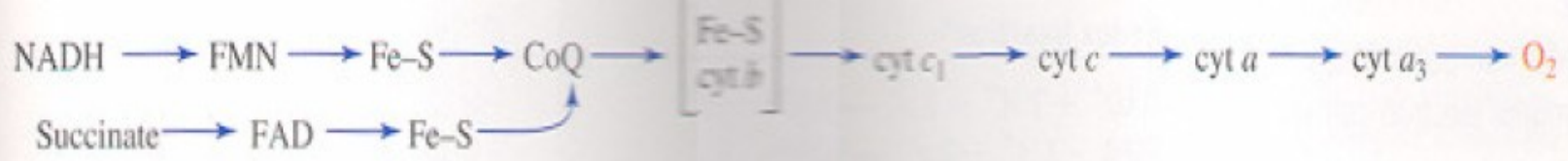


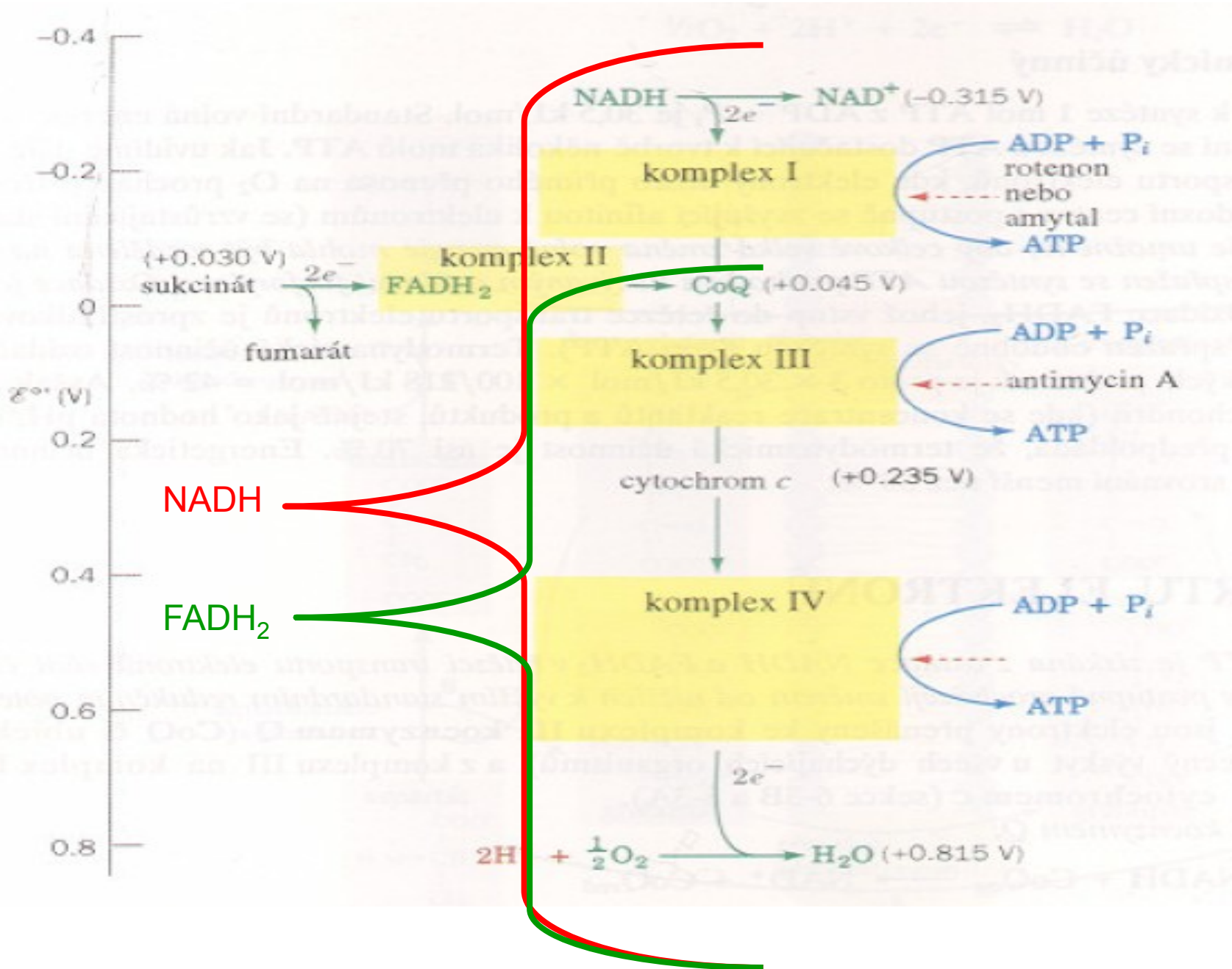
(b)



# Mitochondrie





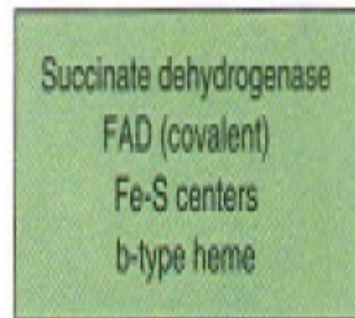


Complex I



NADH:ubiquinone (Q)  
oxidoreductase

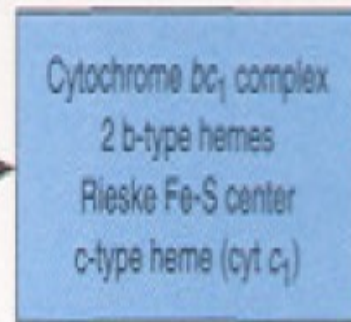
Complex II



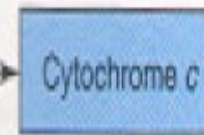
Succinate:ubiquinone (Q)  
oxidoreductase



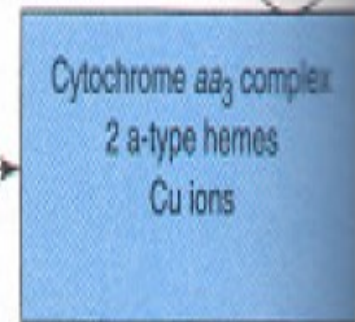
Complex III



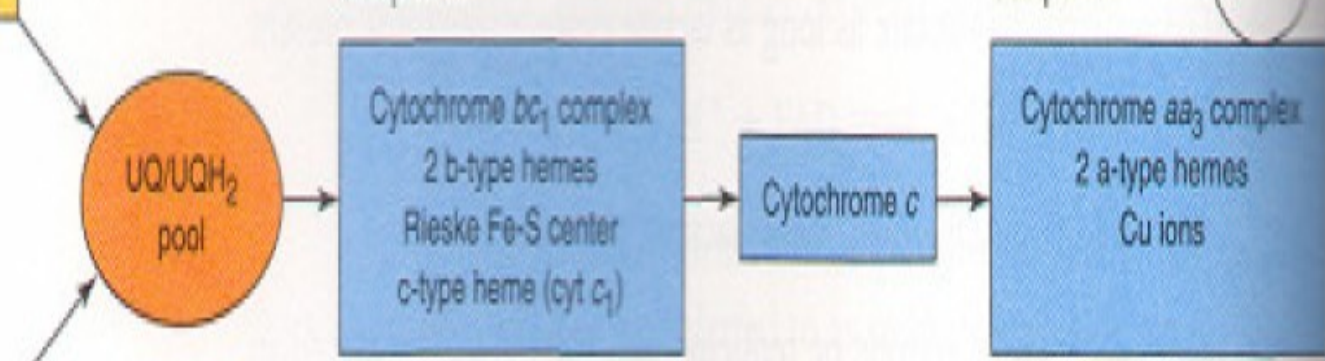
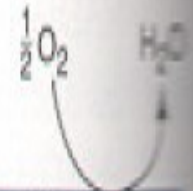
Ubiquinol (QH<sub>2</sub>):cytochrome c  
oxidoreductase



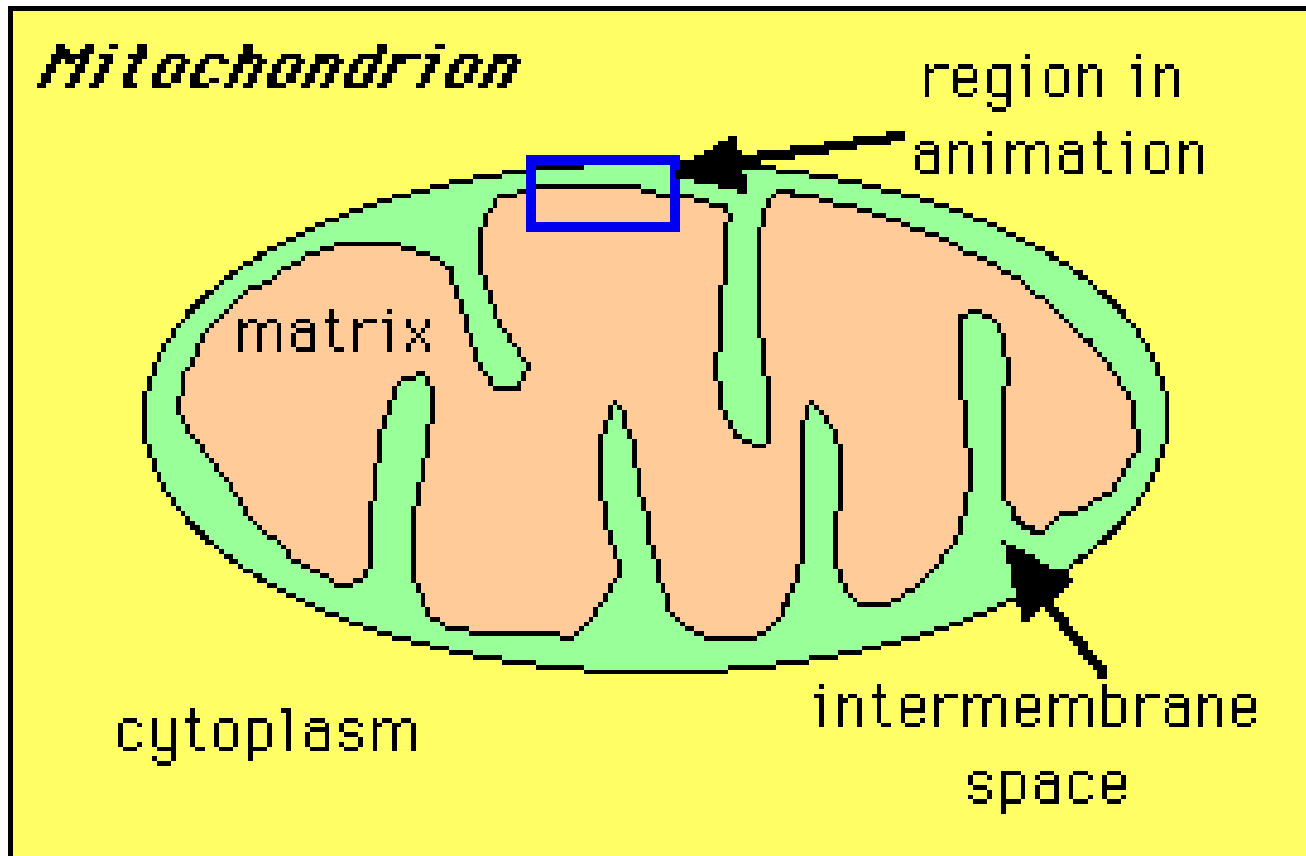
Complex IV



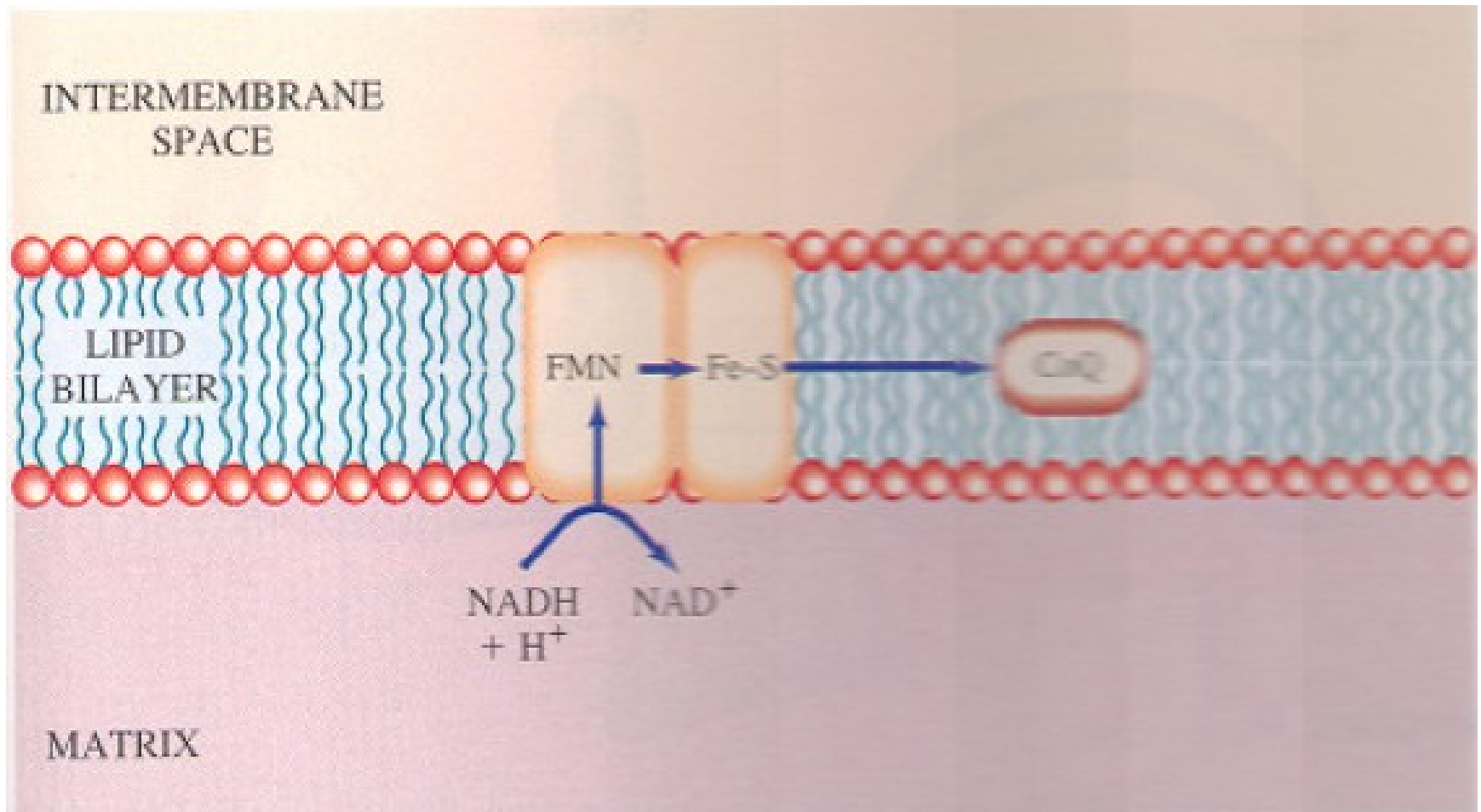
Cytochrome c oxidase



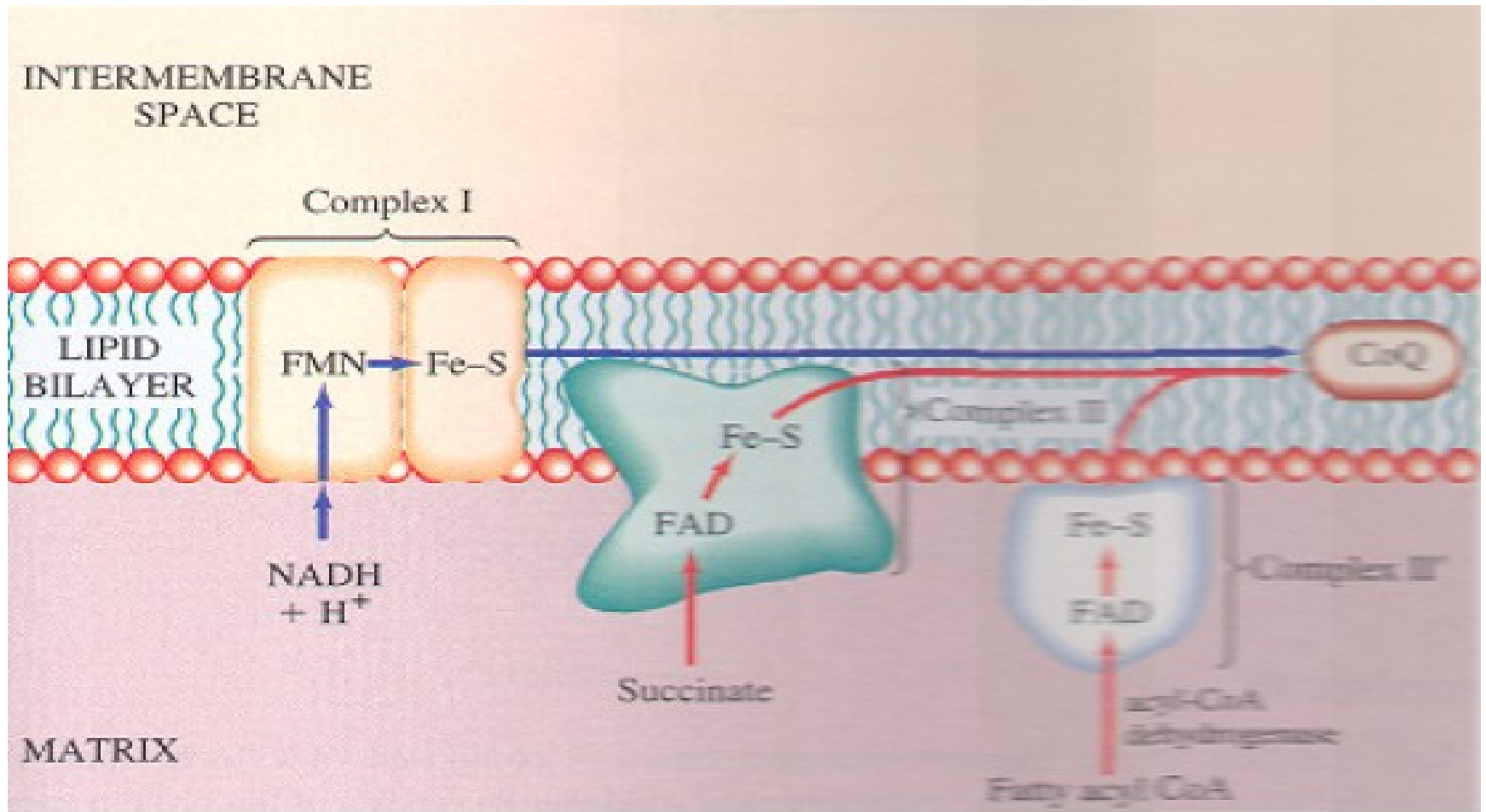
# Lokalizace



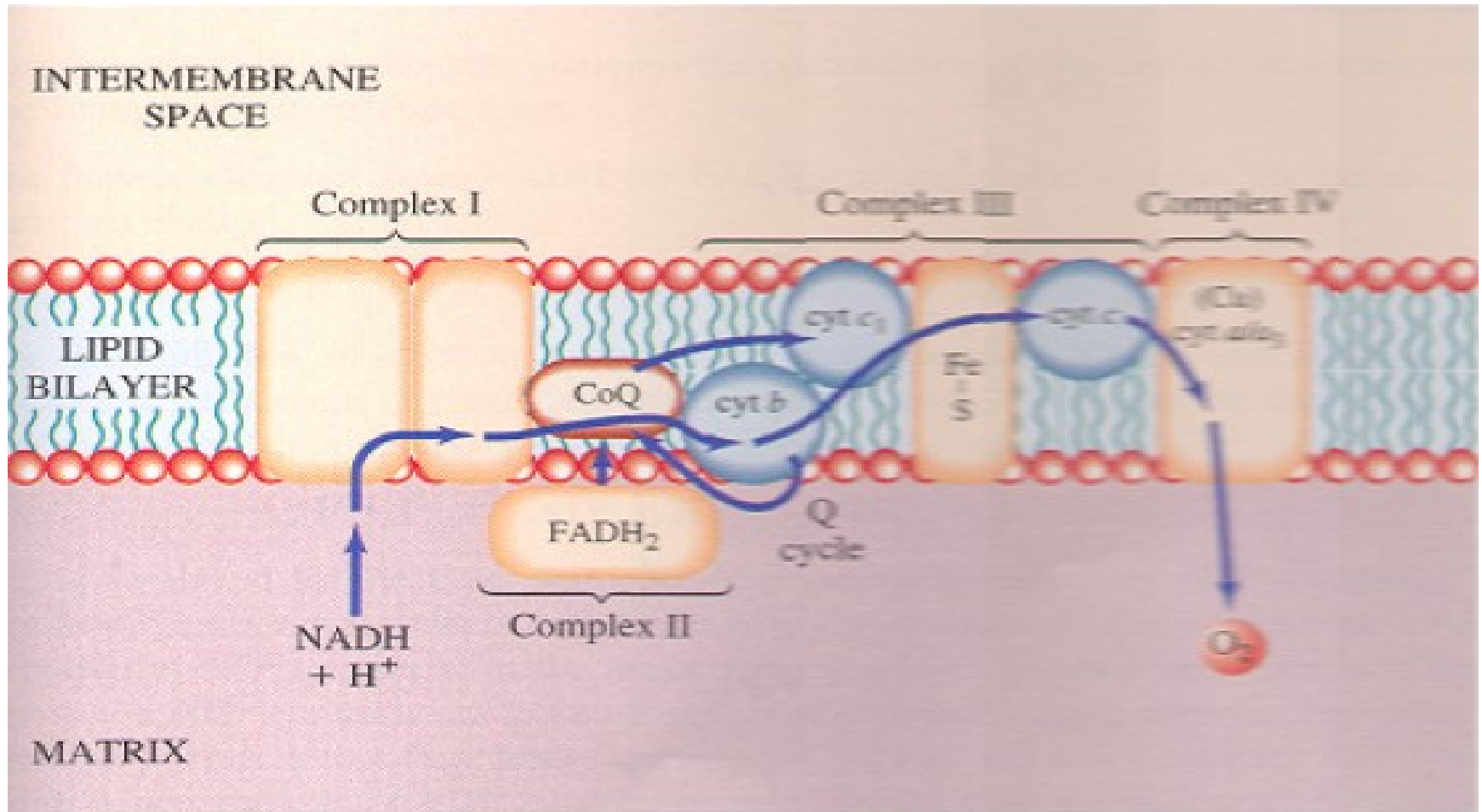
# Komplex I



# Komplex II



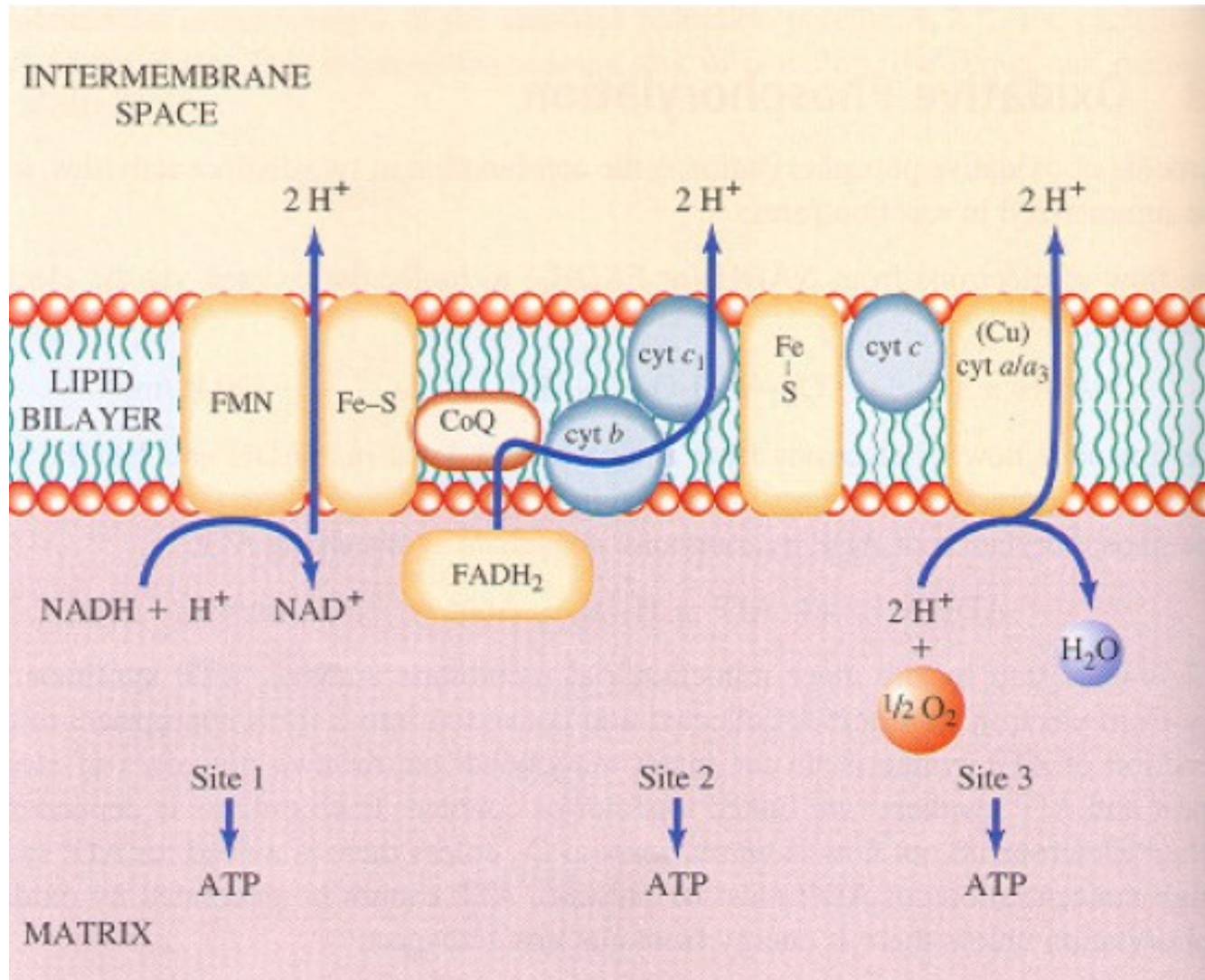
# Komplex III a IV

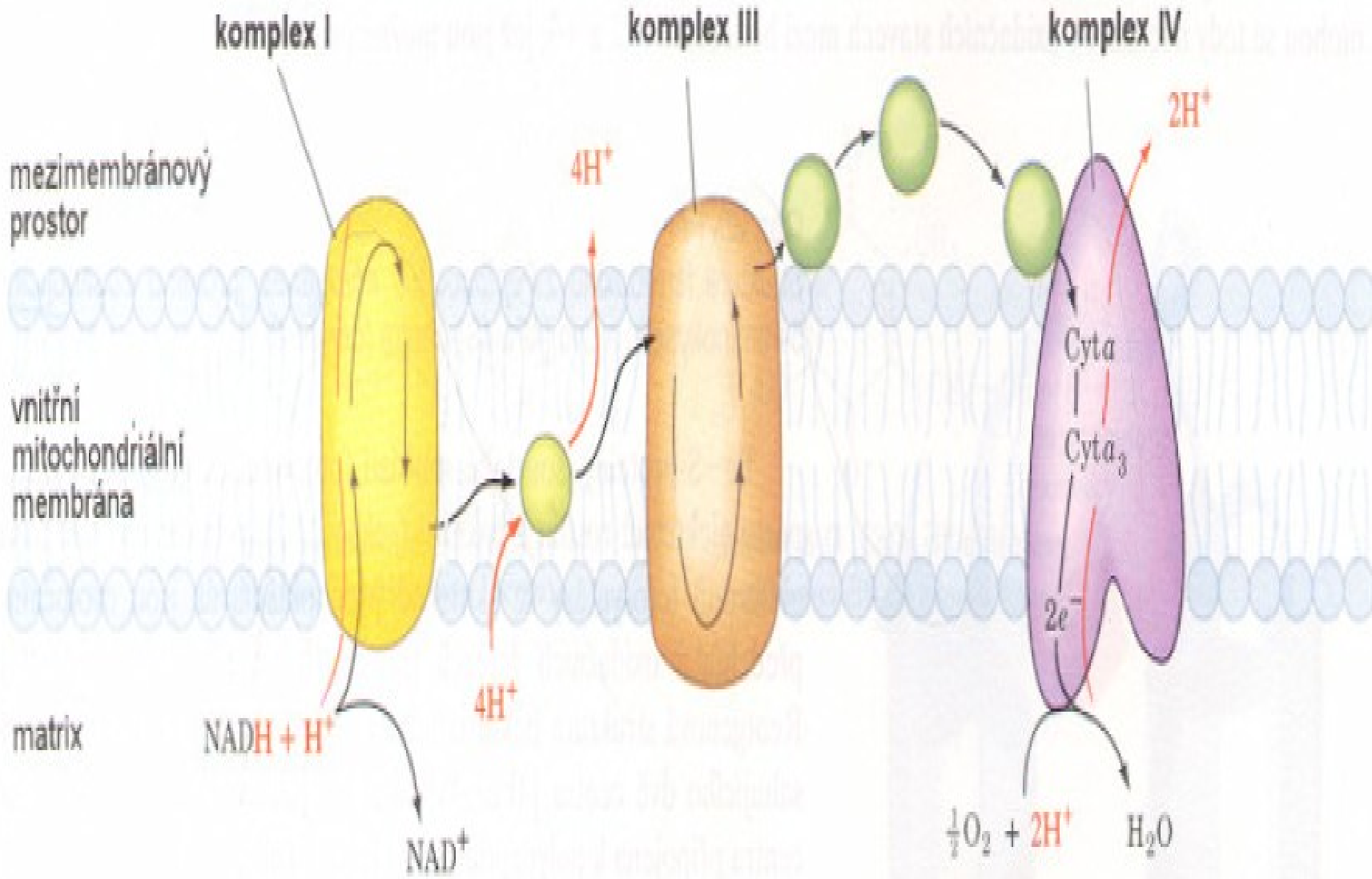




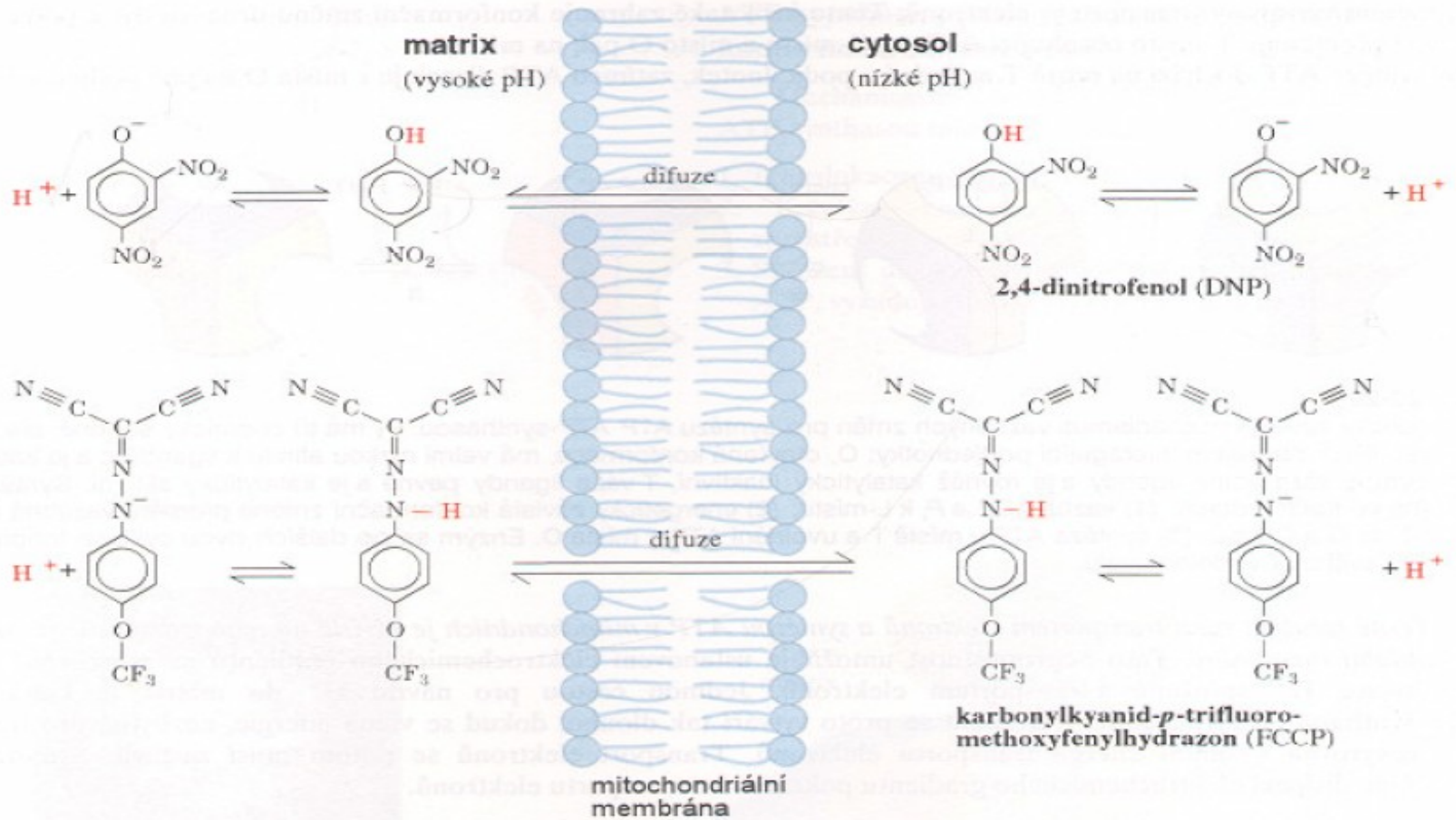
# Chemiosmotická teorie

## Mitchell 1961

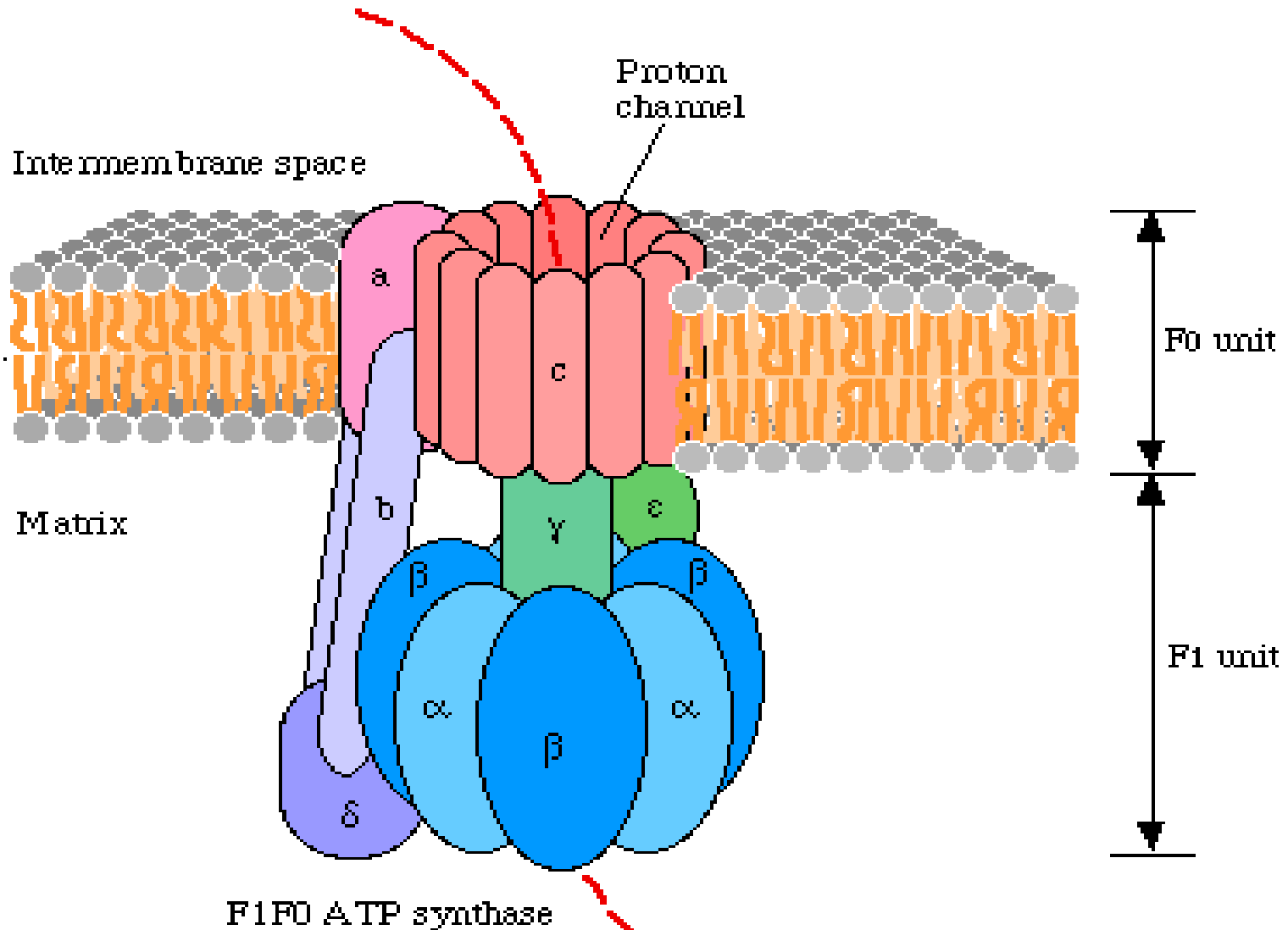


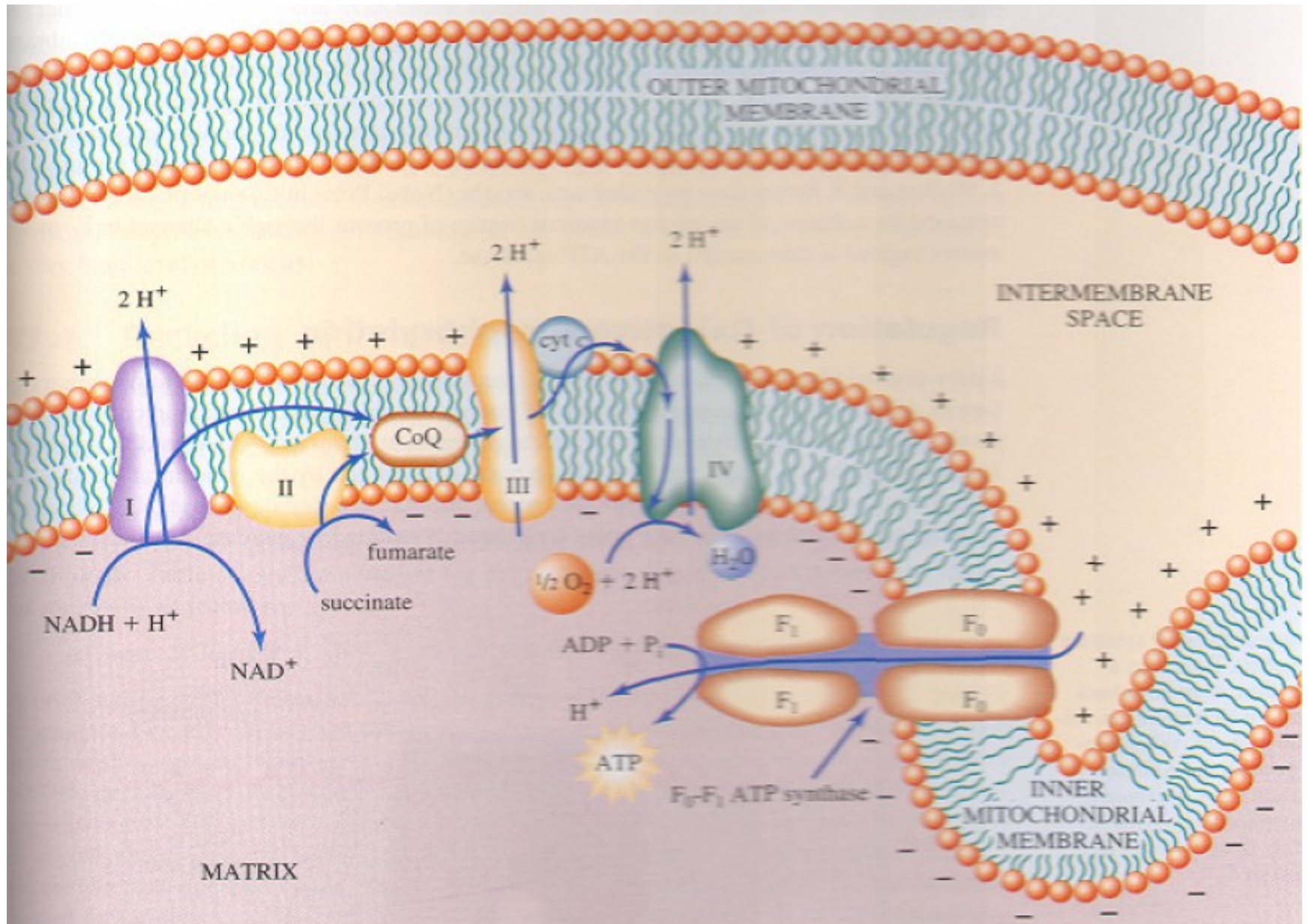


# Rozpojovače



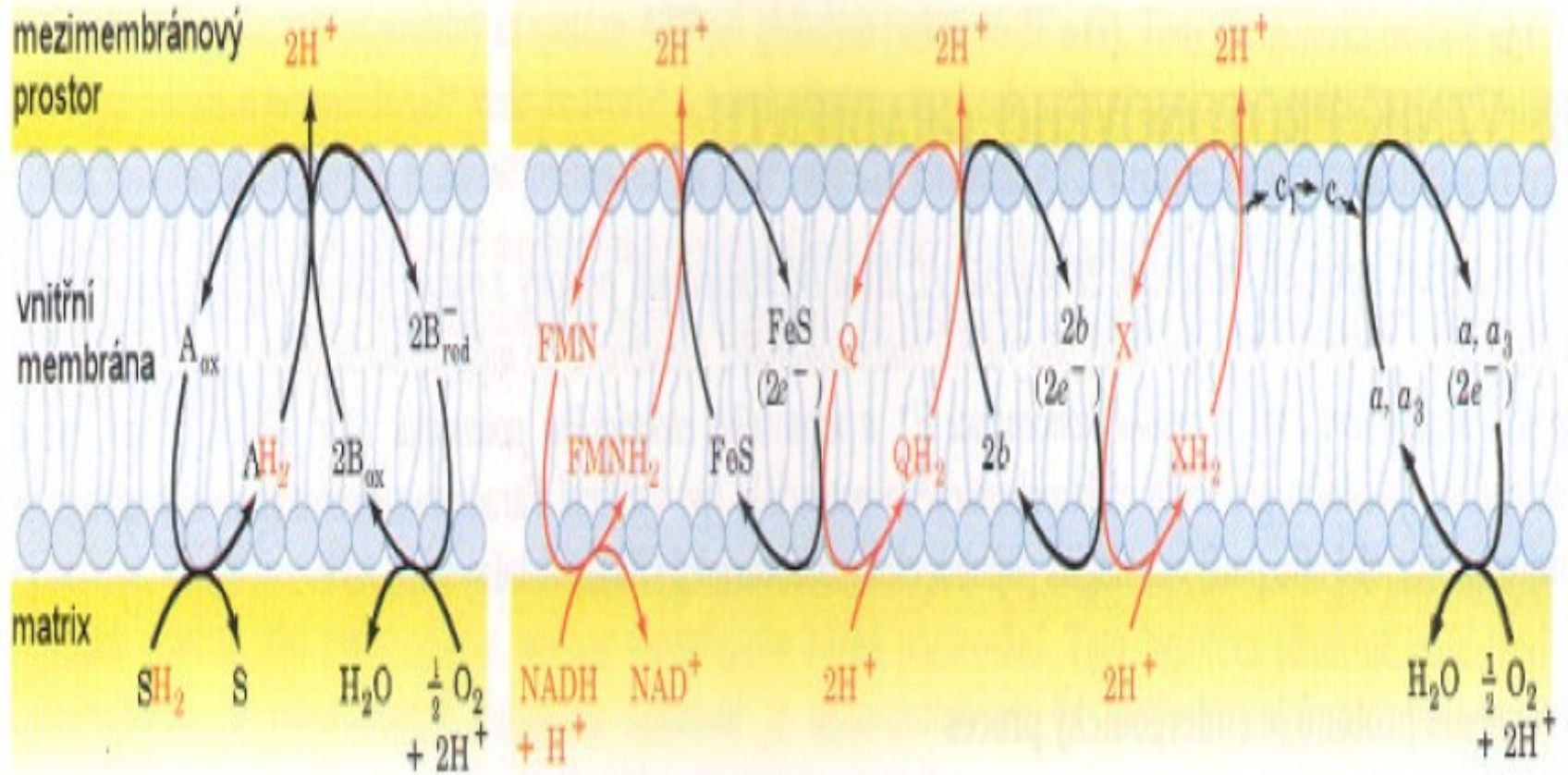
# ATPase

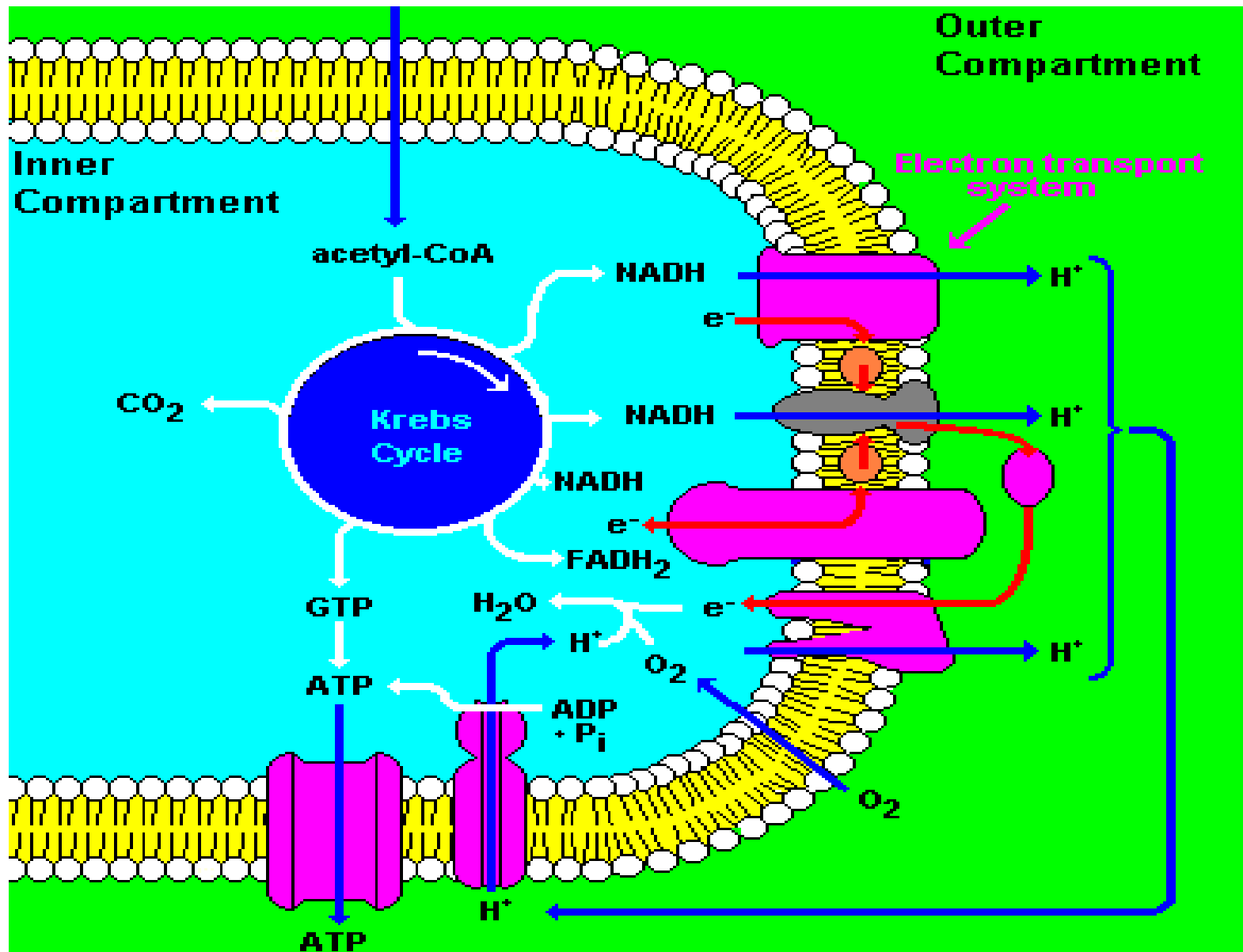




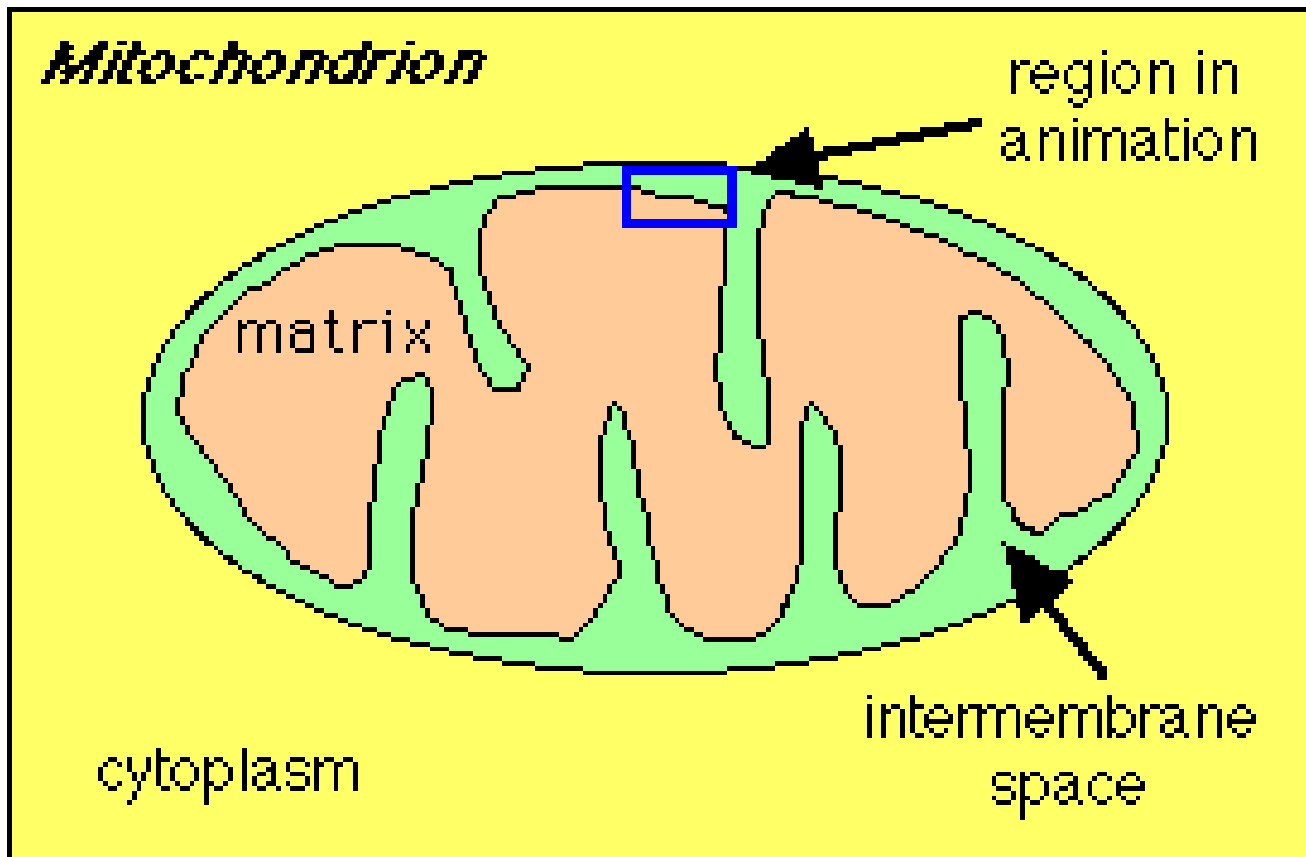
jednoduchá  
(a) redoxní  
smyčka

soustava  
(b) redoxních  
smyček



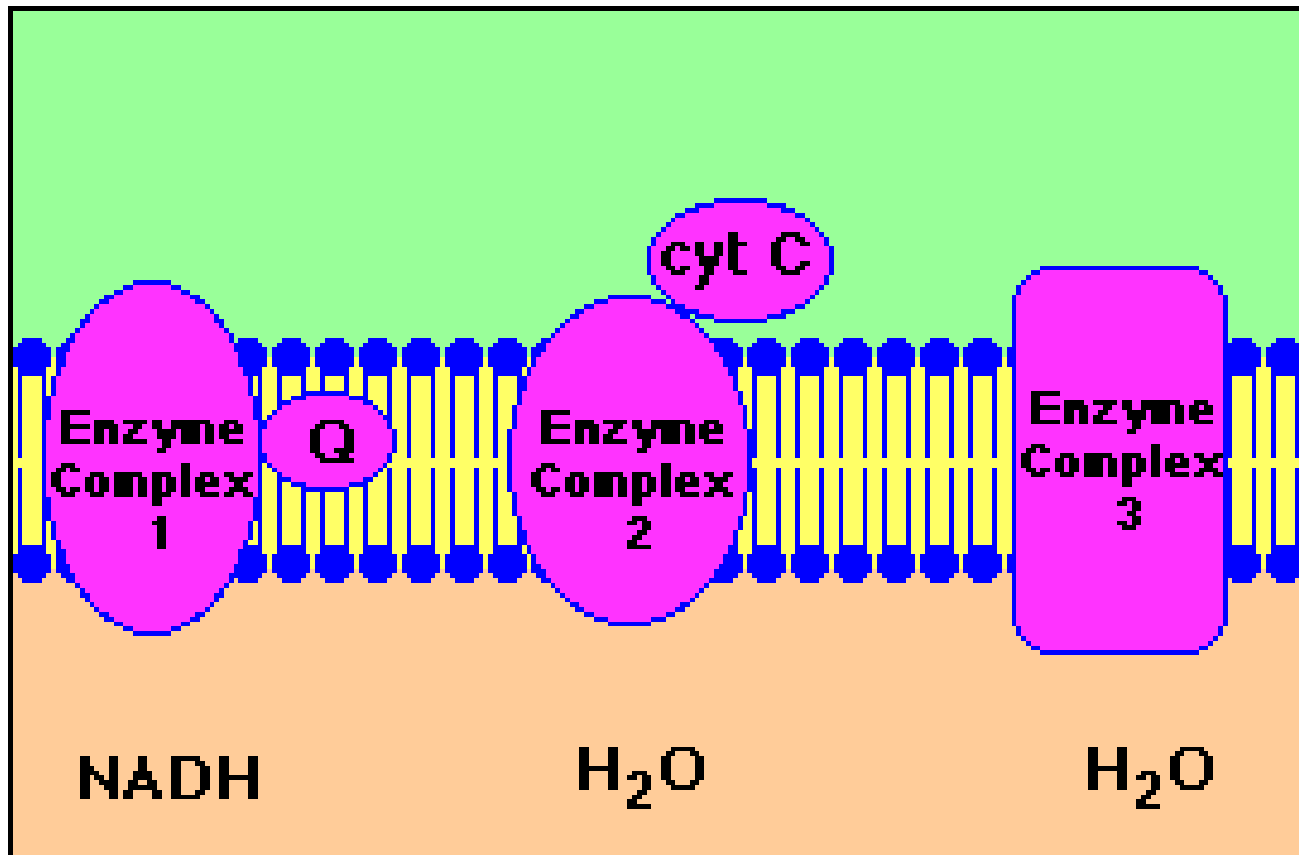


# Lokalizace

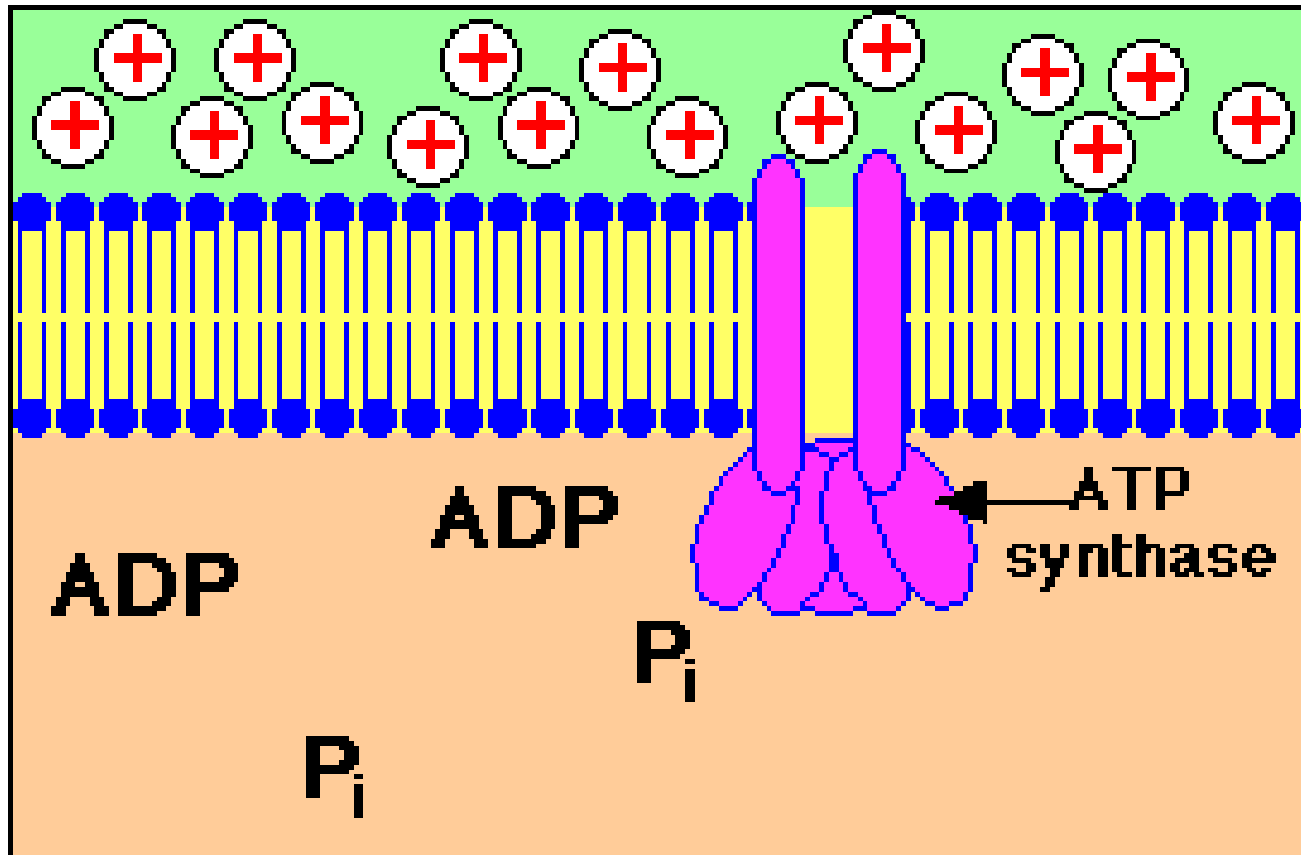




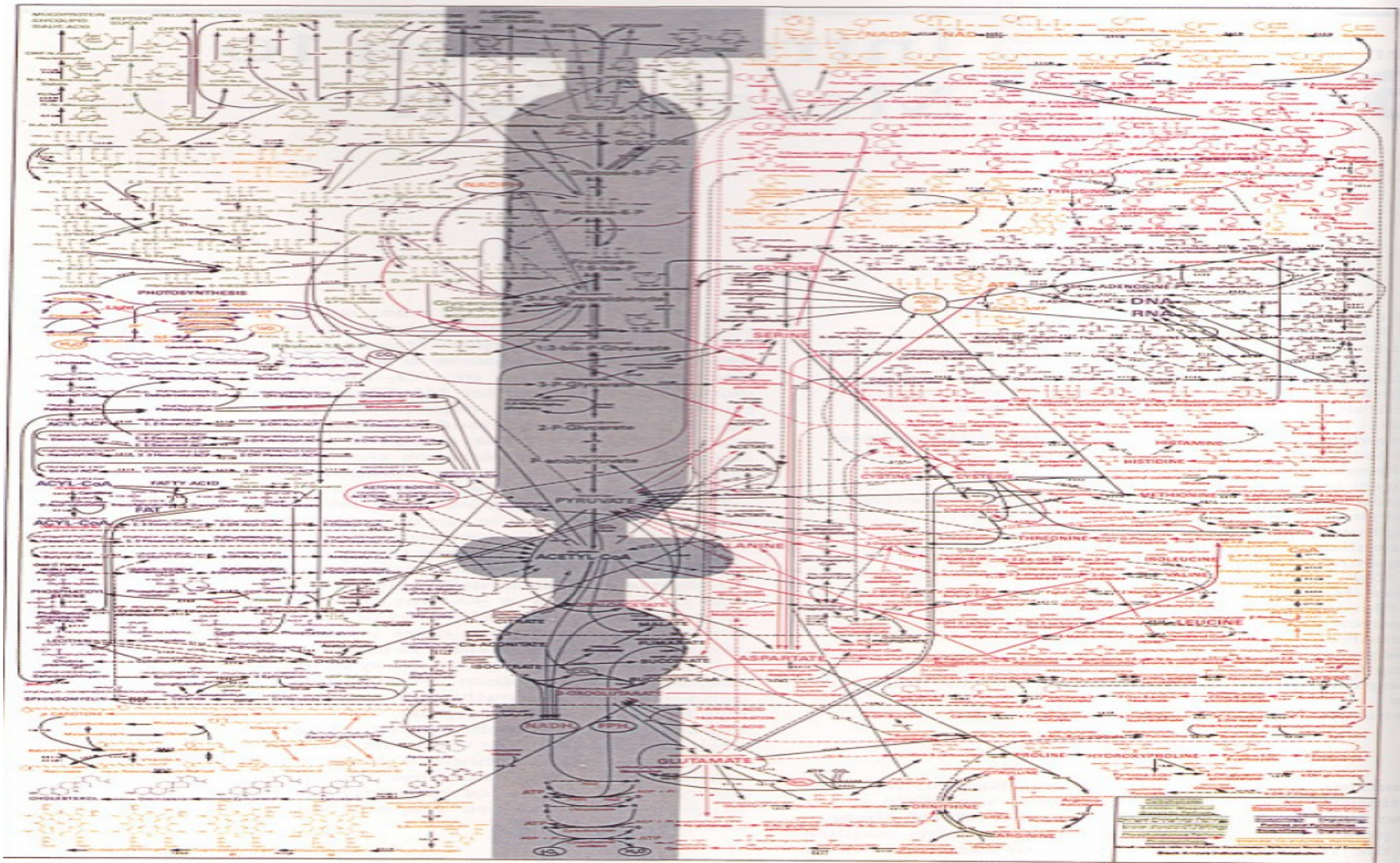
# Transport elektronů



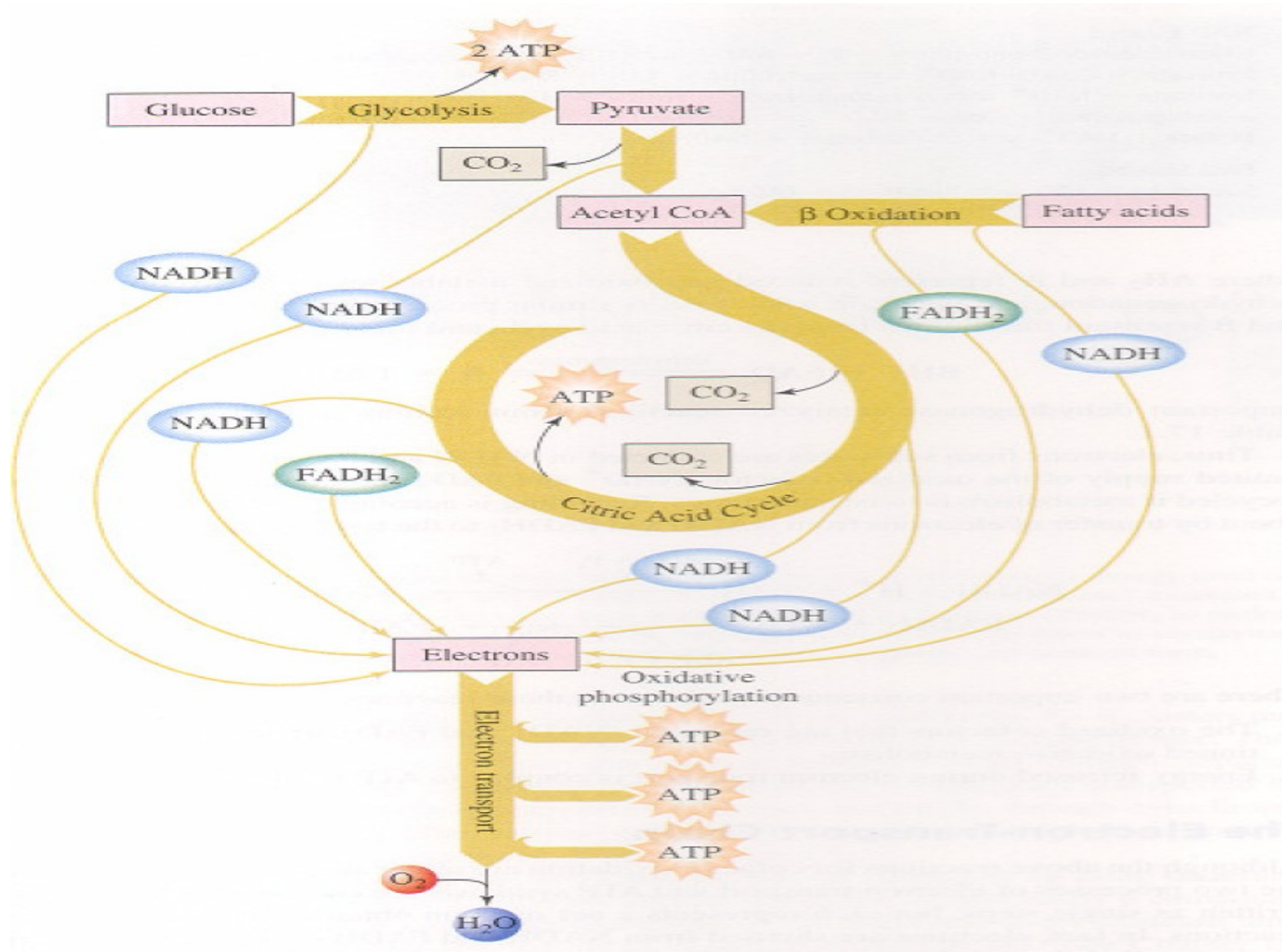
# ATPase



# Metabolické dráhy

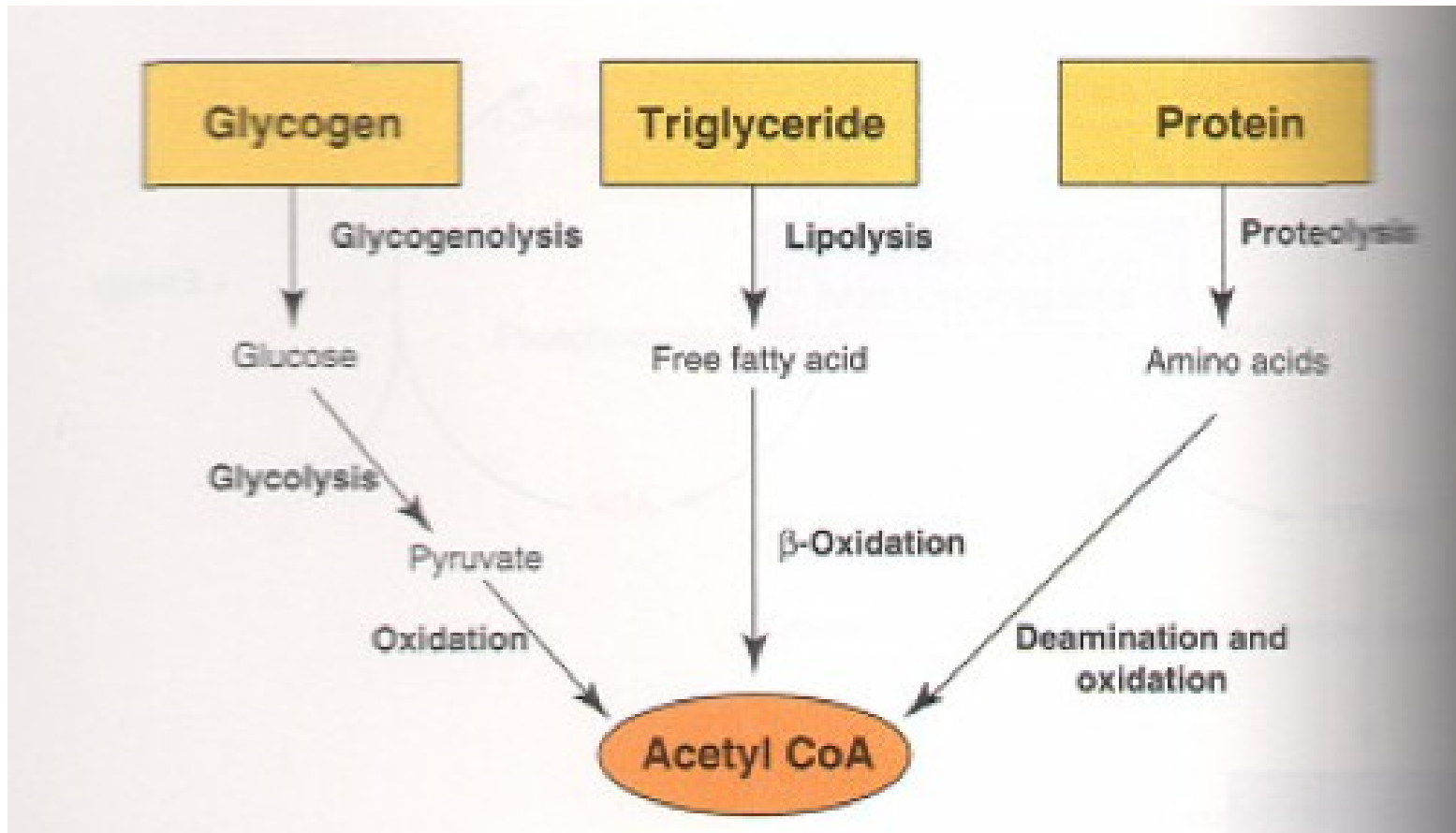


# Metabolické dráhy



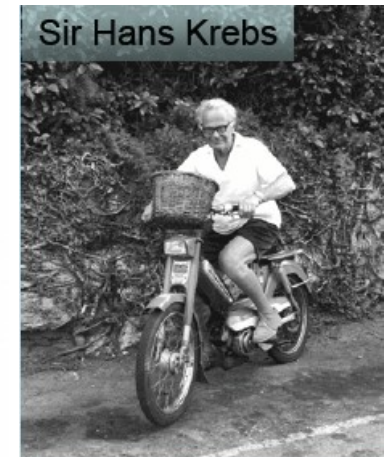
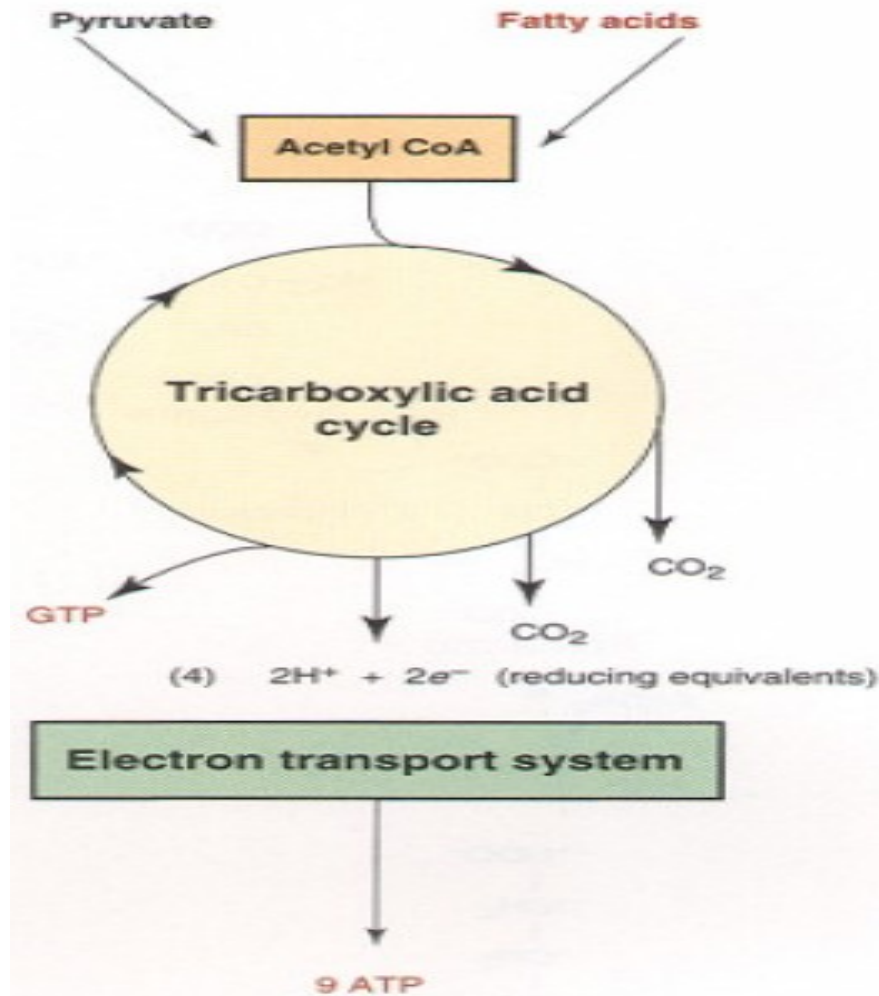
# CITRÁTOVÝ CYKLUS

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

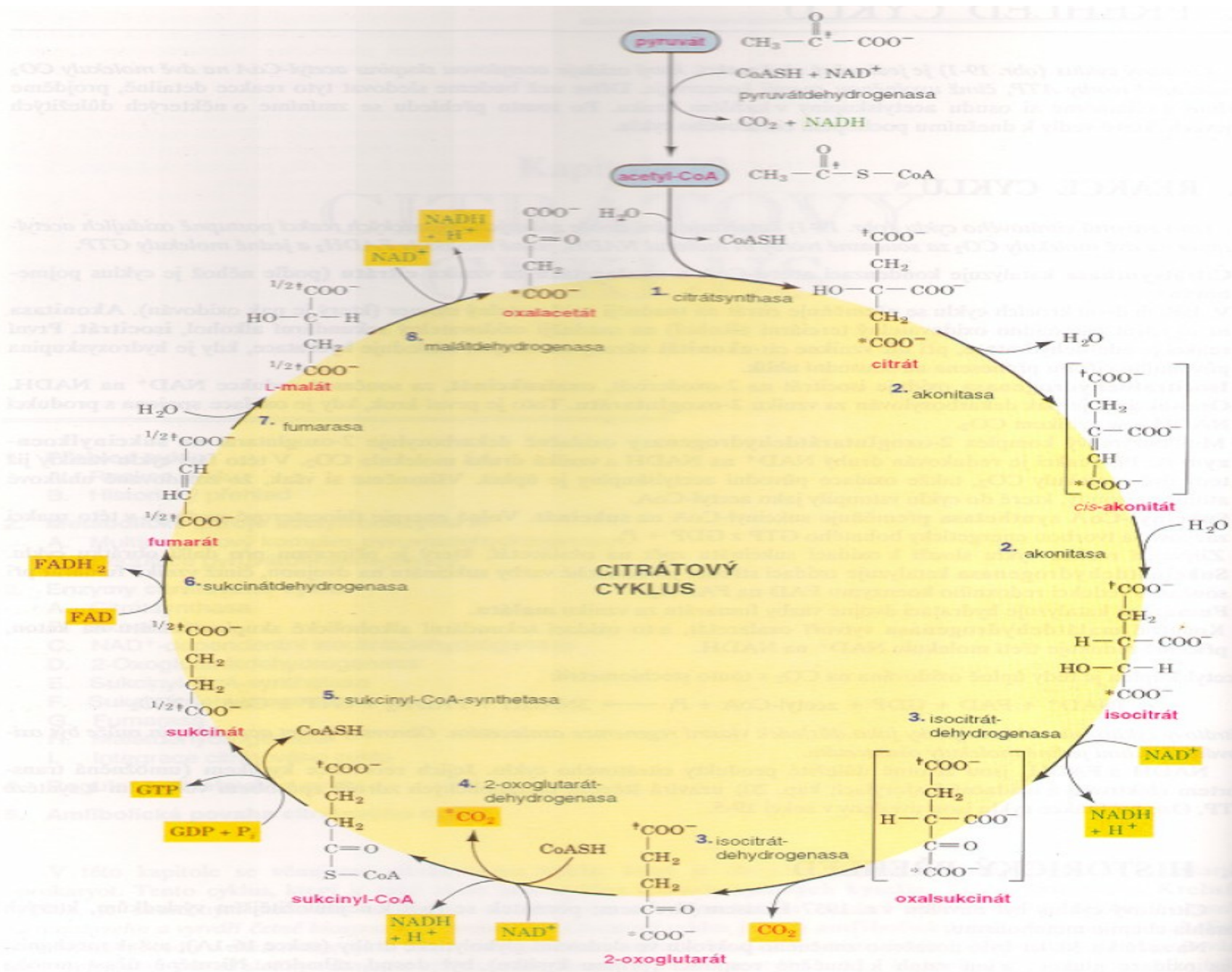


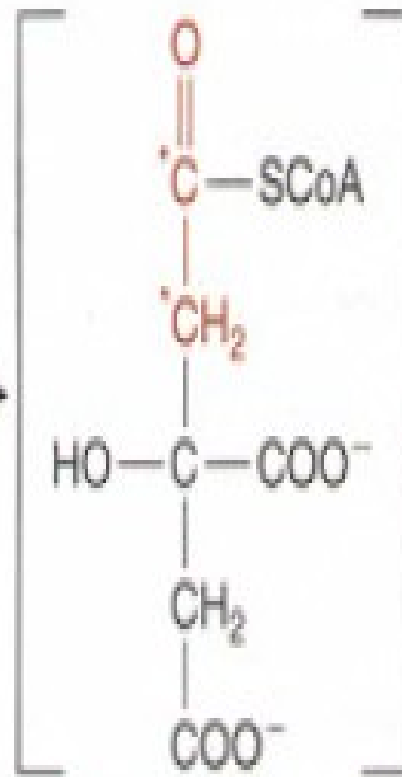
# CITRÁTOVÝ CYKLUS

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



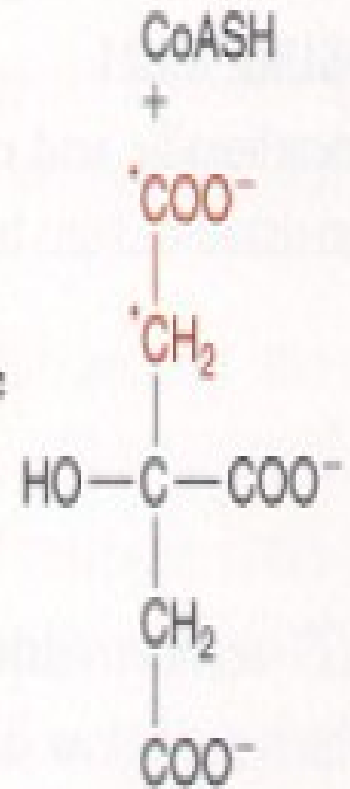
Sir Hans Krebs





Enzyme-bound

citroyl-SCoA



Citrate

### CITRATE SYNTHASE



100

150

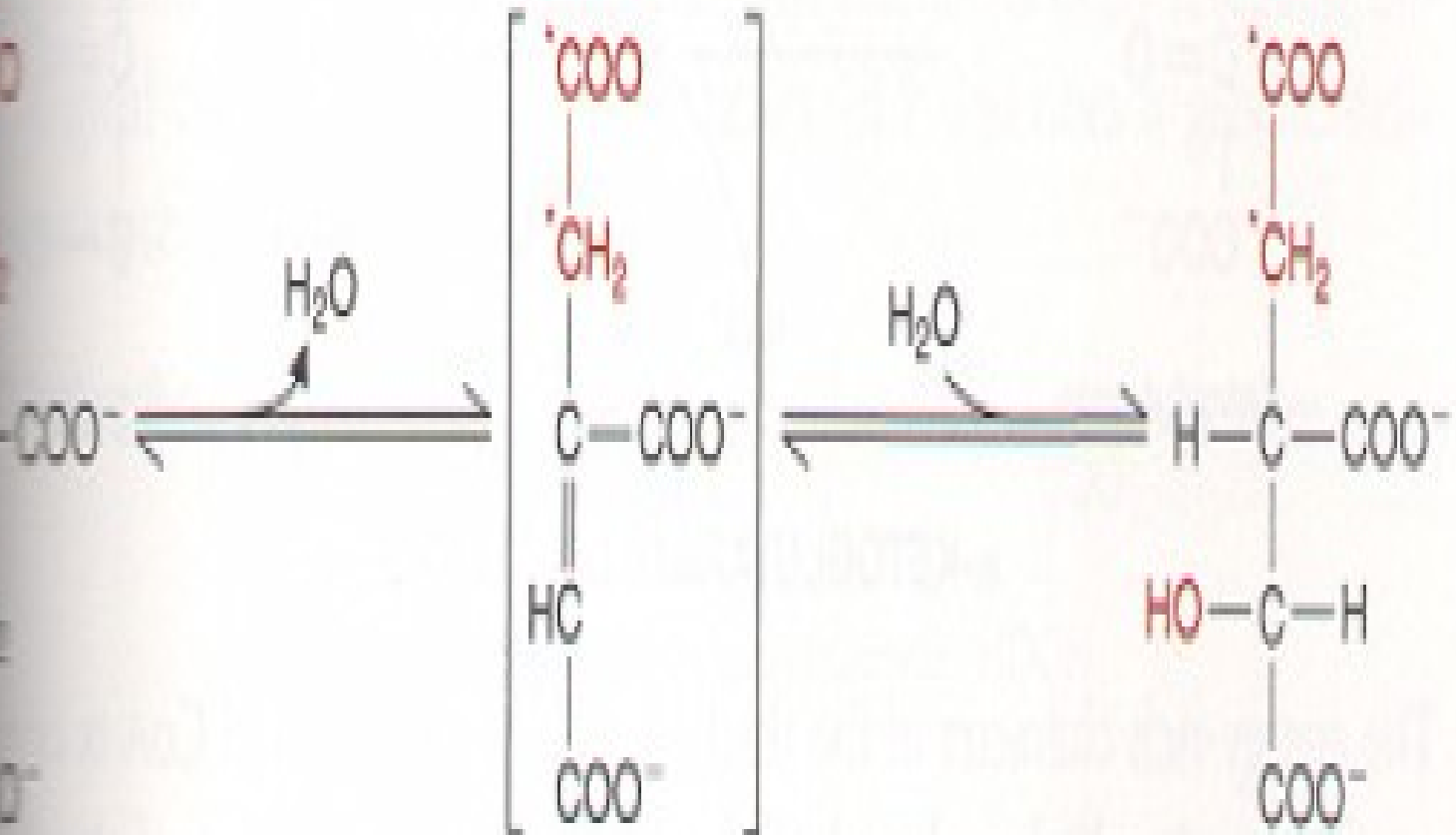
200

250

200

150

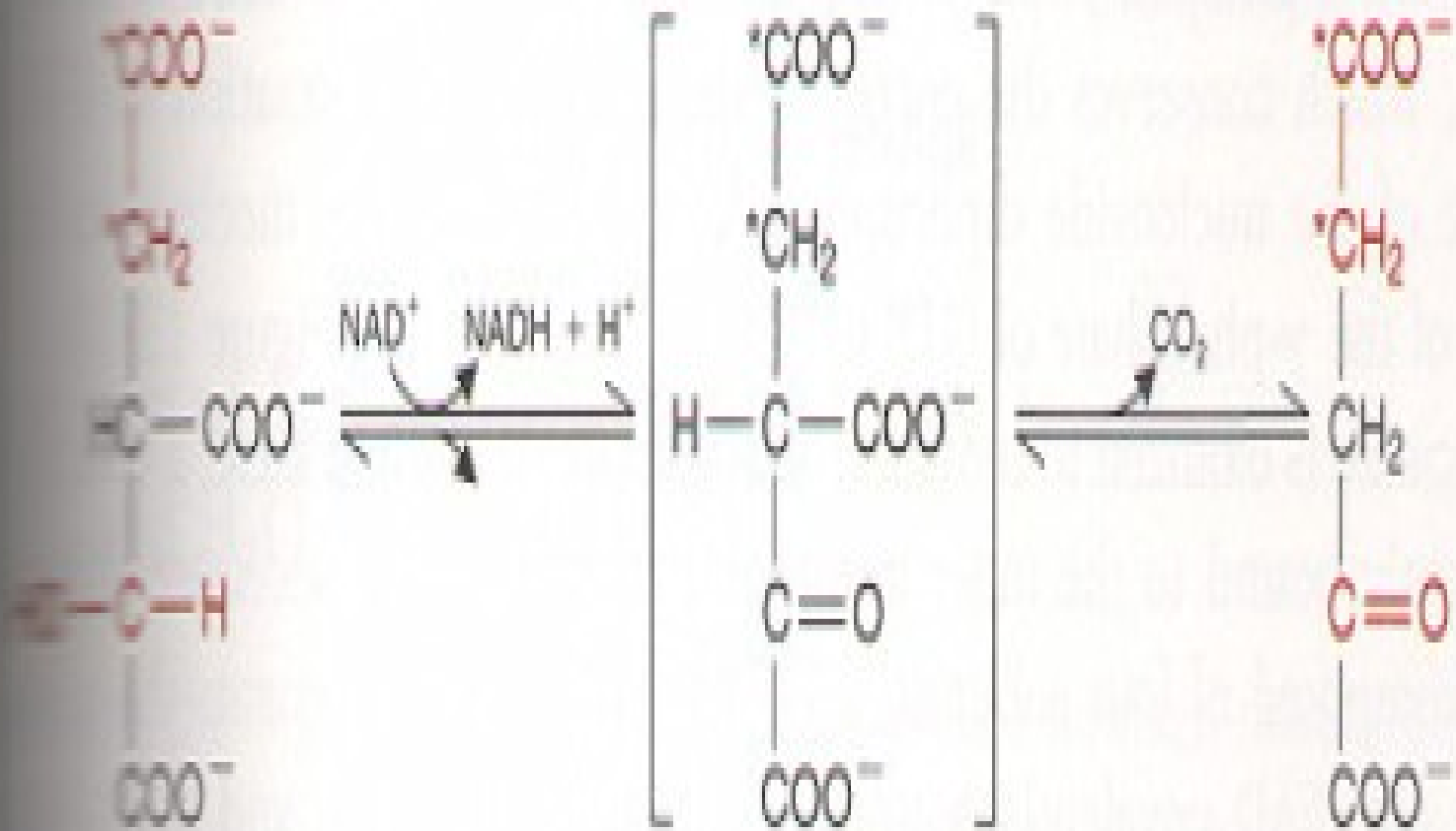
100



cis-Aconitate

Isocitrate

**ACONITASE**



isocitrate

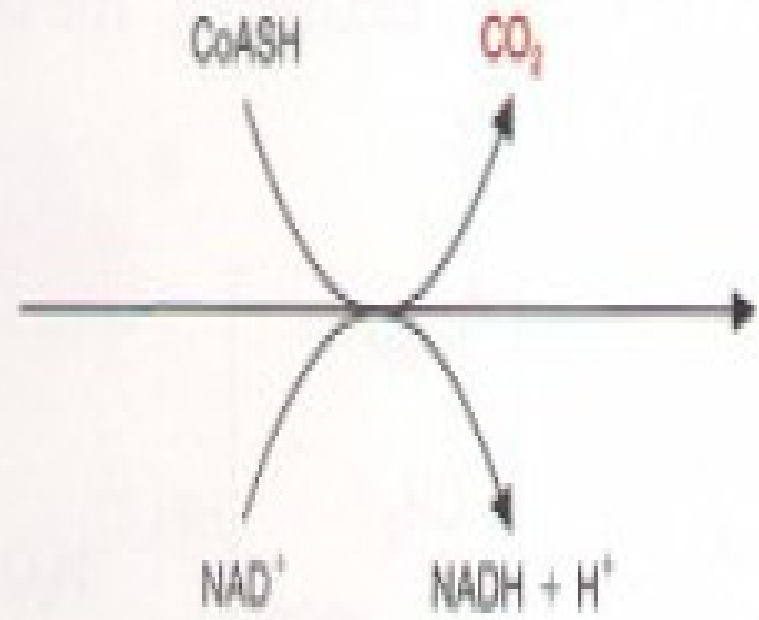
Oxalosuccinate

$\alpha$ -Ketoglutarate

## ISOCITRATE DEHYDROGENASE

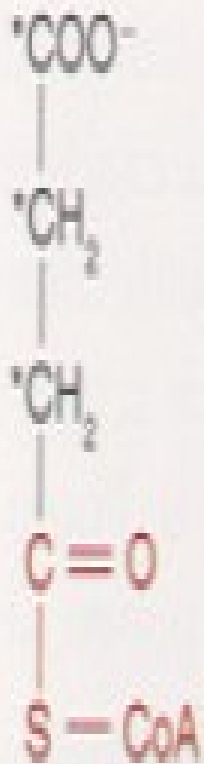


$\alpha$ -Ketoglutarate



Succinyl CoA

### $\alpha$ -KETOGLUTARATE DEHYDROGENASE

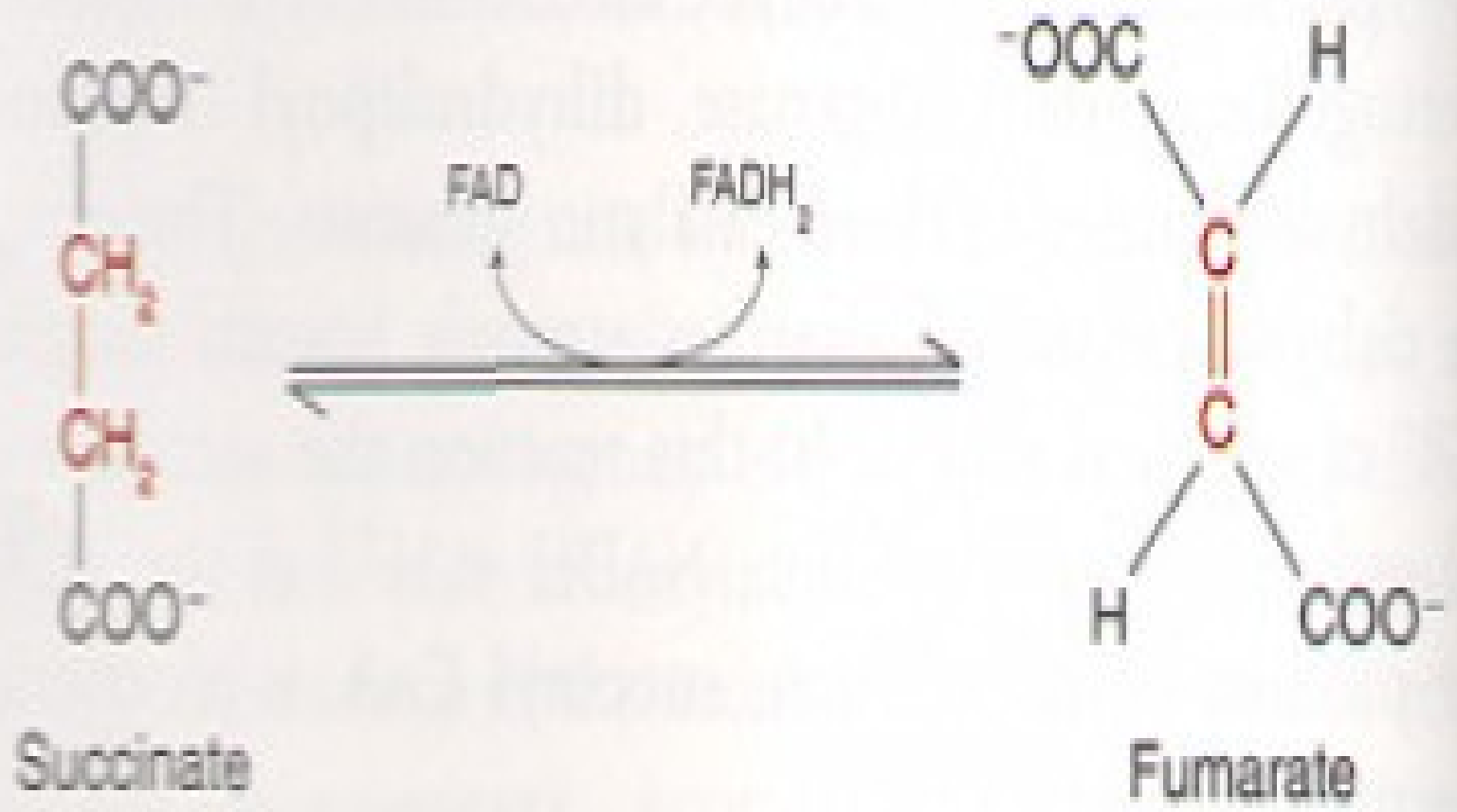


Succinyl CoA



Succinate

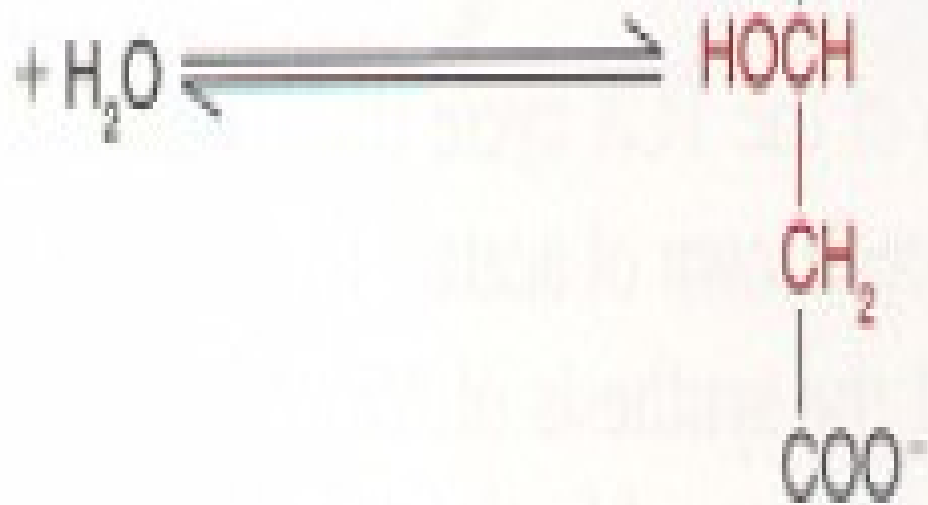
**SUCCINYL CoA SYNTHETASE**



**SUCCINATE DEHYDROGENASE**



Fumarate

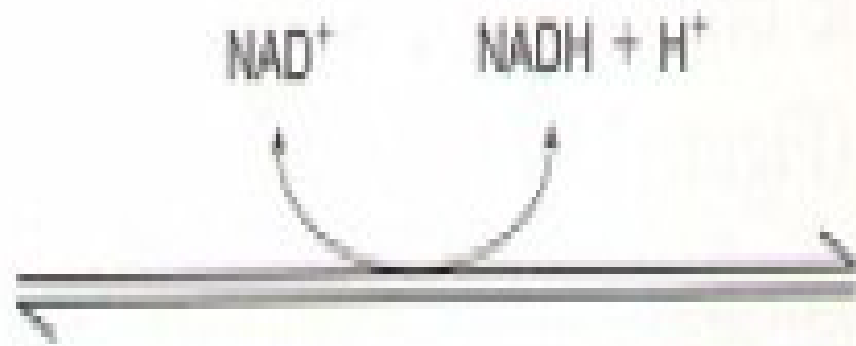


L-Malate

**FUMARASE**

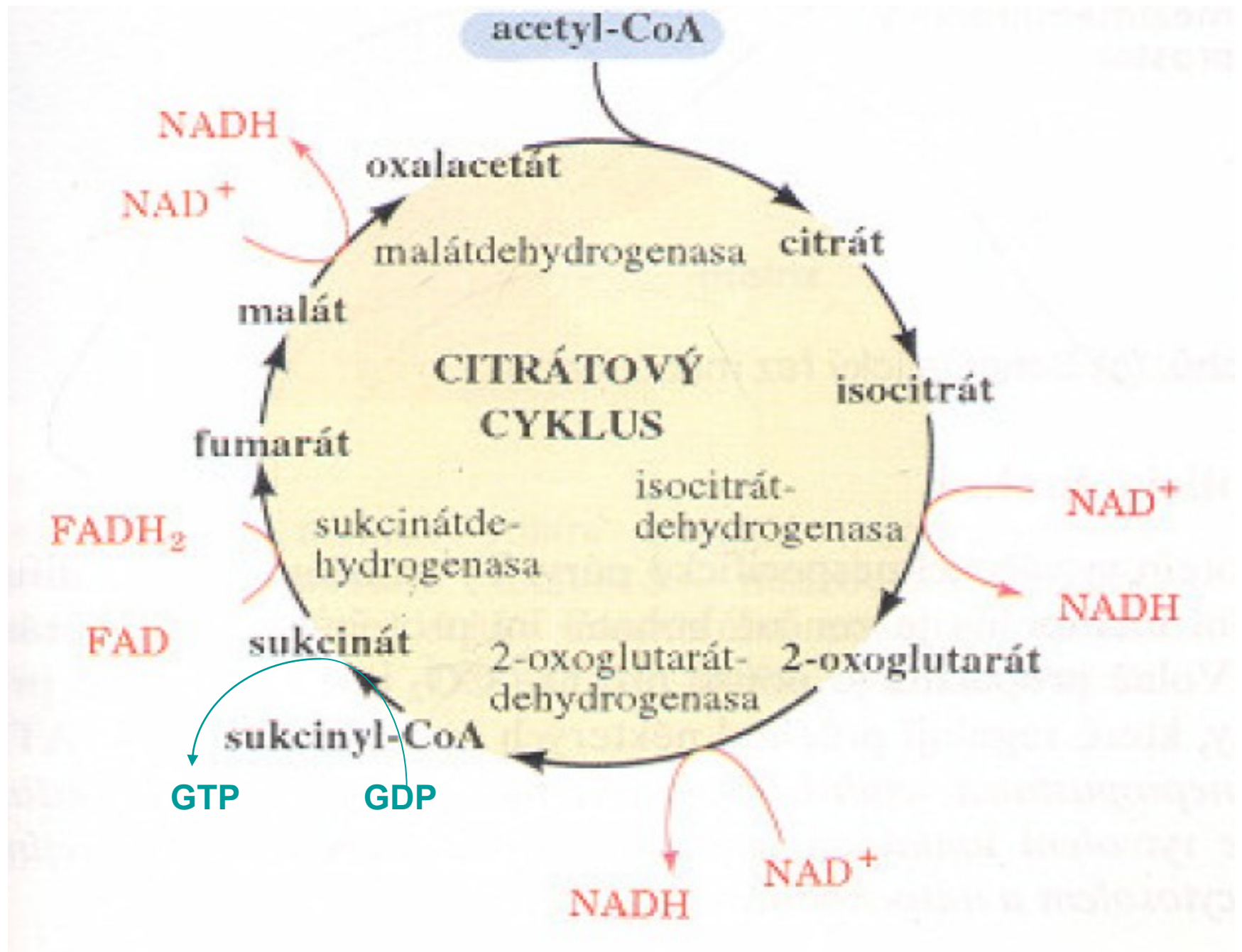


L-Malate



Oxaloacetate

### MALATE DEHYDROGENASE





Bilance cyklu :



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

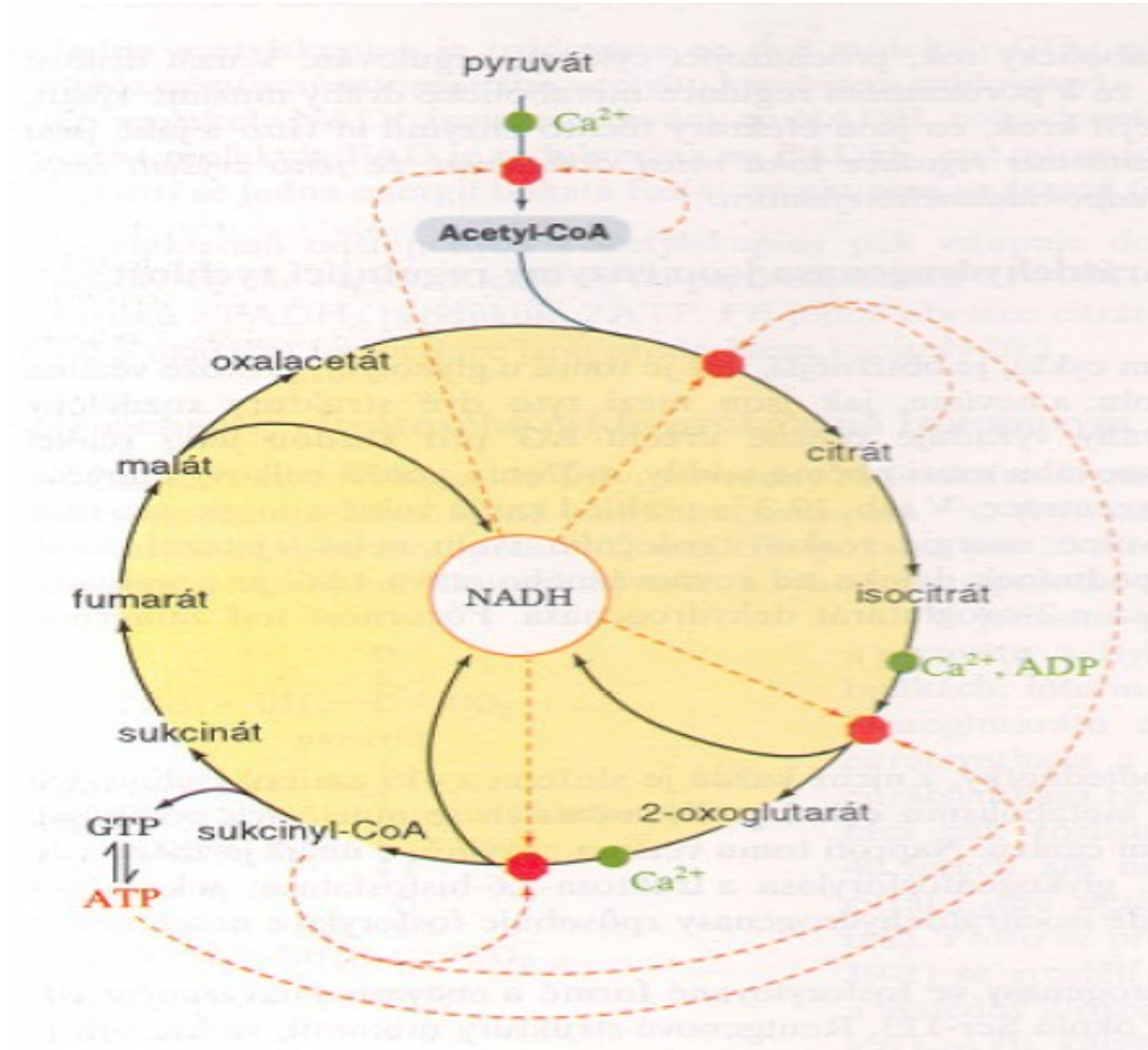
1 FADH <sub>2</sub>	1 x 2 ATP	2 ATP
---------------------	-----------	-------

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

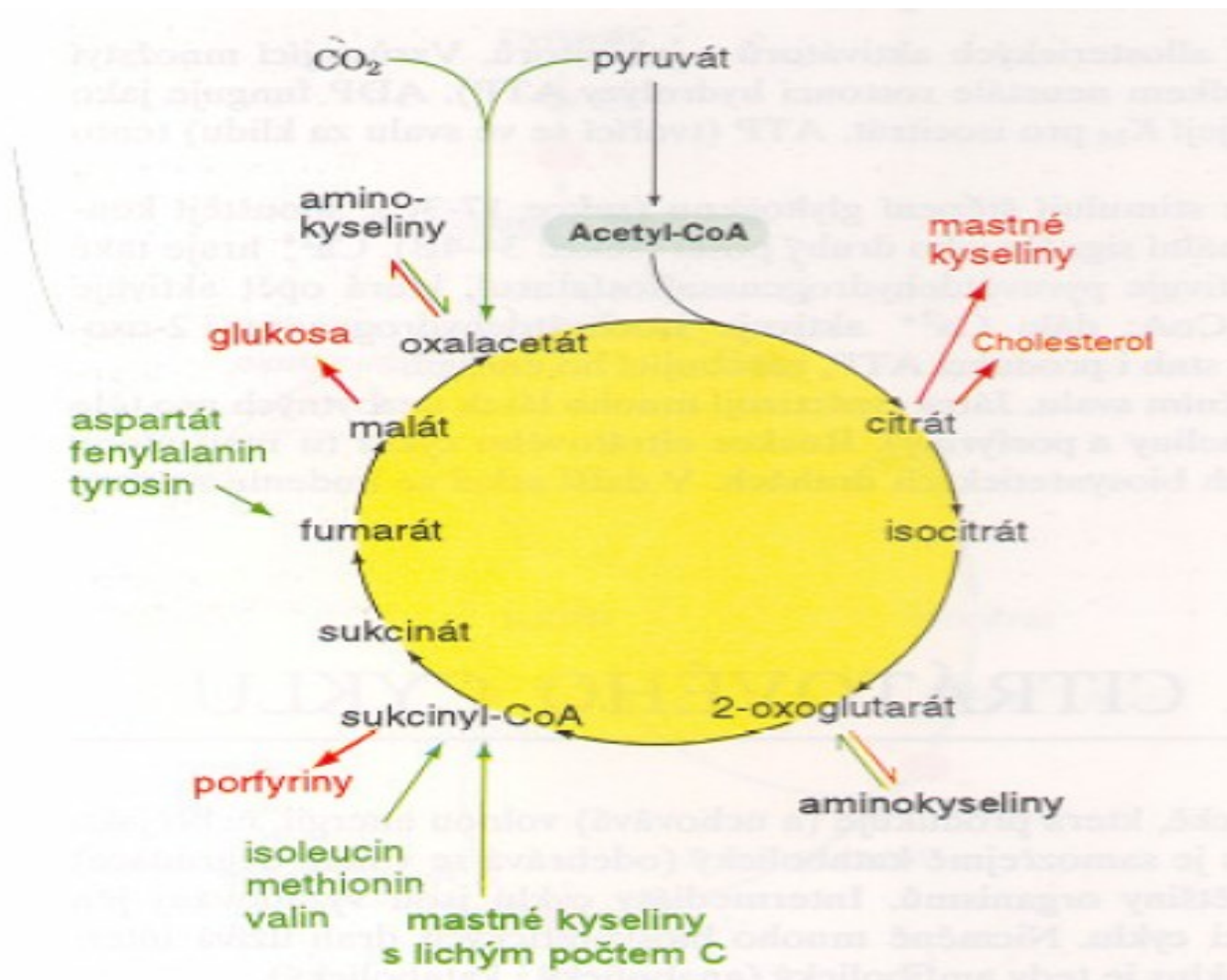
---

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

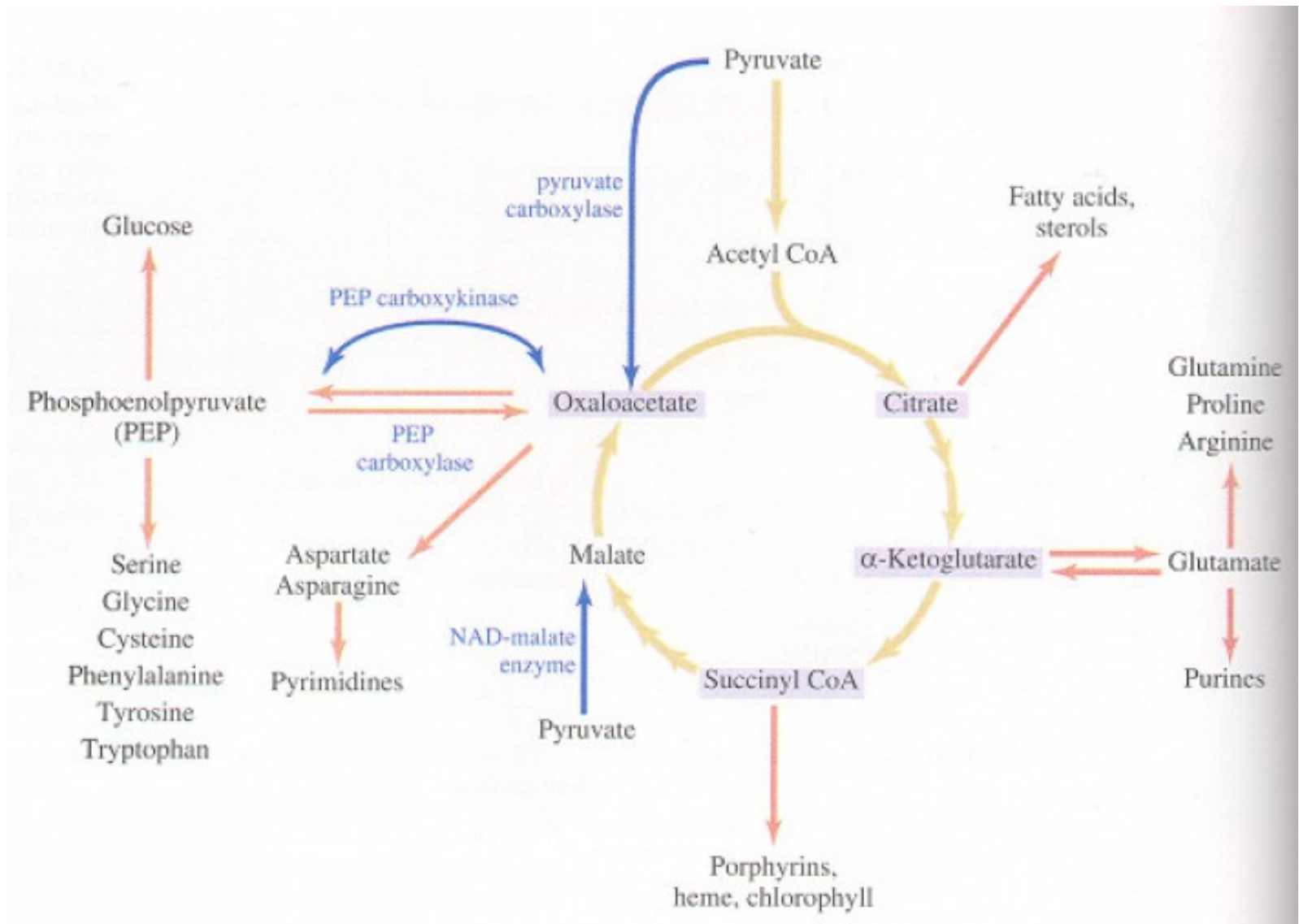
# Regulace



# Odbourávání jiných živin



# Amfibolická povaha cyklu



# METABOLISMUS SACHARIDŮ

## Štěpení oligosacharidů a polysacharidů

### *A. Štěpení sacharidů při trávení potravy*

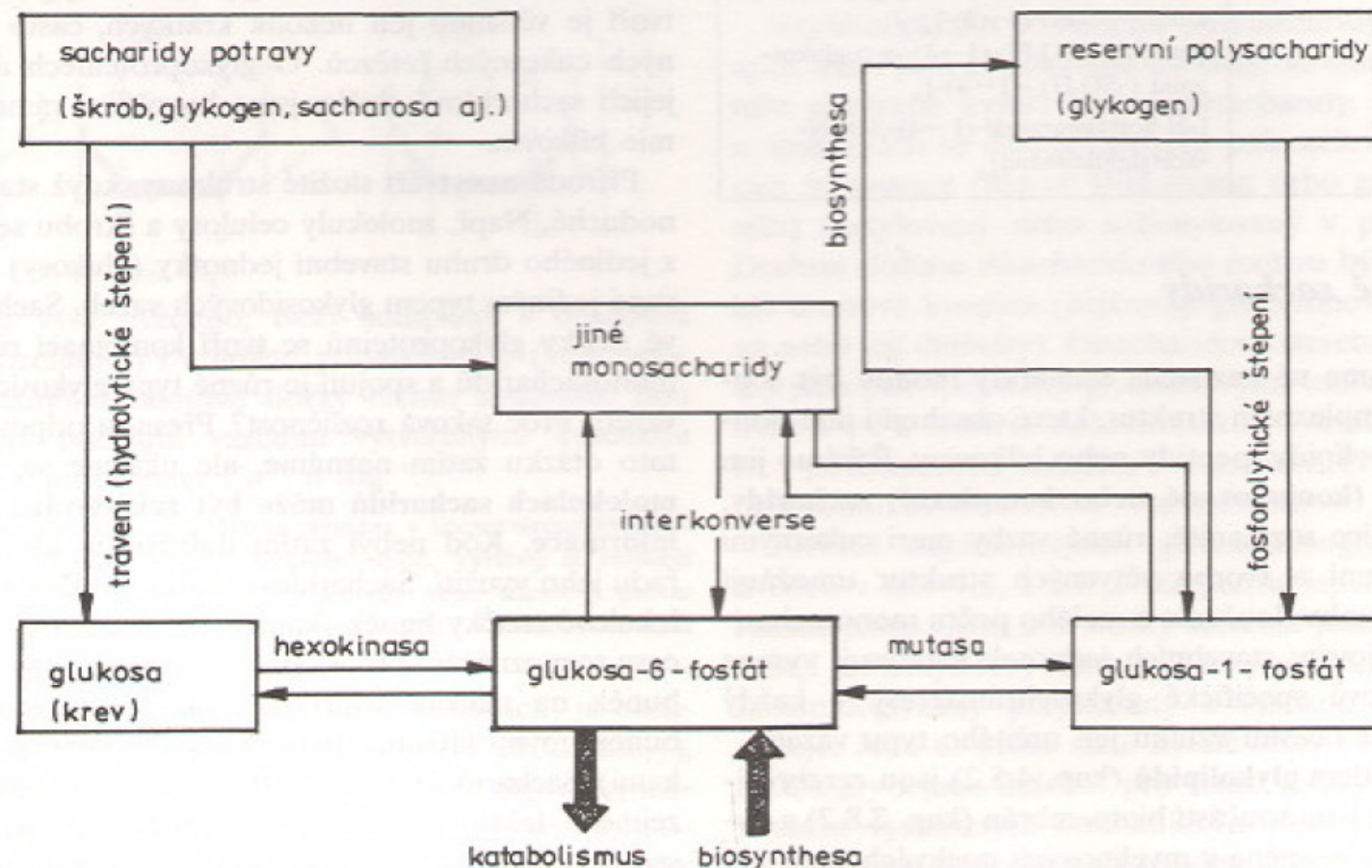
<b><math>\alpha</math> – amylasa</b>	<b>sliny, pankreas</b>	<b>škrob</b>	<b>Dextriny, maltosa, glukosa</b>
<b>amyloglikosidada</b>	<b>střeva</b>	<b>glykogen</b>	<b>maltosa</b>
<b>maltasa</b>	<b>"</b>	<b>maltosa</b>	<b>glukosa</b>
<b>laktasa</b>	<b>"</b>	<b>laktosa</b>	<b>glukosa, galaktosa</b>
<b>sacharasa</b>	<b>"</b>	<b>sacharosa</b>	<b>glukosa fruktosa</b>
<b>celulasy</b>	<b>houby, bakterie</b>	<b>celulosa</b>	<b>glukosa</b>

*B. Štěpení rezervních polysacharidů*

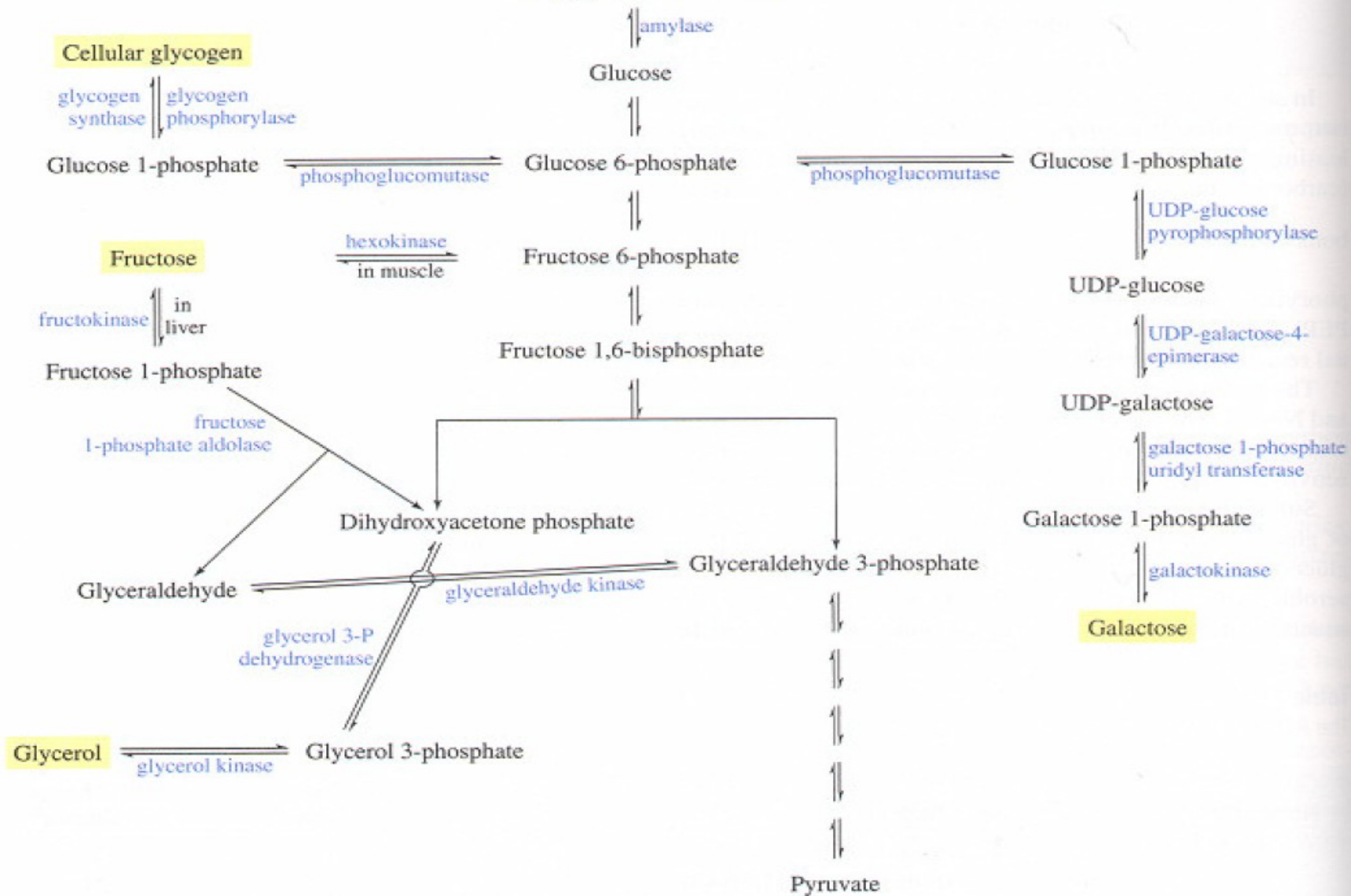
<b>fosforylasa</b>	<b>játra</b>	<b>glykogen</b>	<b>glukosa-1-P</b>
<b><math>\beta</math> – amylasa</b>	<b>rostliny</b>	<b>škrob</b>	<b>maltosa</b>

## Glukosa-6-fosfát - klíčový metabolit

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

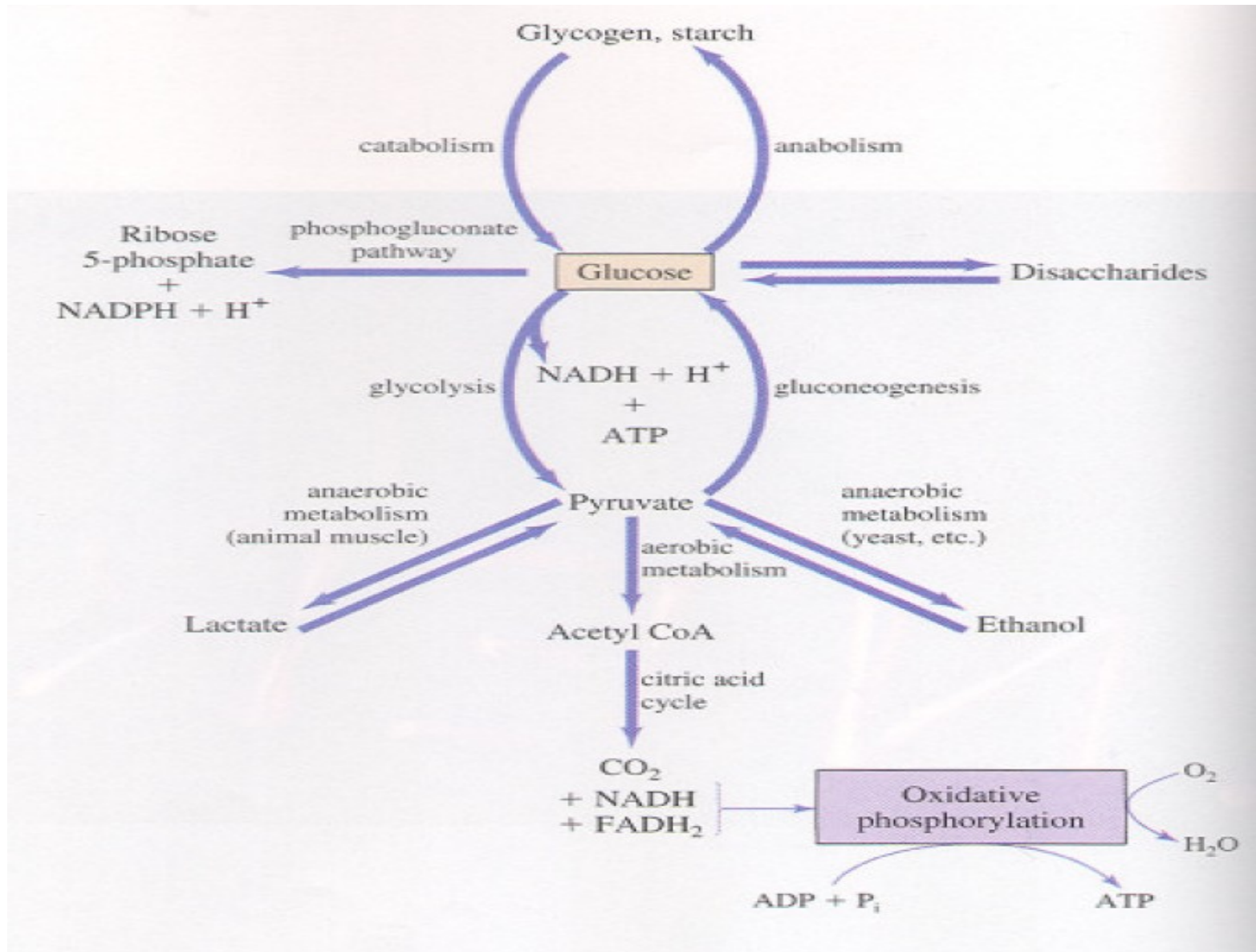


Dietary glycogen and starch

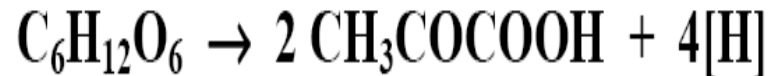




# METABOLISMUS SACHARIDŮ



# GLYKOLÝZA



*Historie :*

- 19. stol. Paster - kvasinky

Buchner - kvasniční extrakt

- 1905 - 1910 Harden, Young

- 1940 Embden, Meyerhof, Parnas

# GLYKOLÝZA



glukosa

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

$2\text{NAD}^+$

fruktosa-1,6-  
bisfosfát

$2\text{ATP}$

$2\text{NADH}$

2 pyruvát

anaerobní  
mléčné  
kvašení

aerobní  
oxidace

anaerobní  
alkoholové  
kvašení

CITRÁTOVÝ  
CYKLUS

$2\text{NADH}$

$2\text{NADH}$

$6\text{O}_2$

$2\text{NADH}$

$2\text{NAD}^+$

$2\text{NAD}^+$

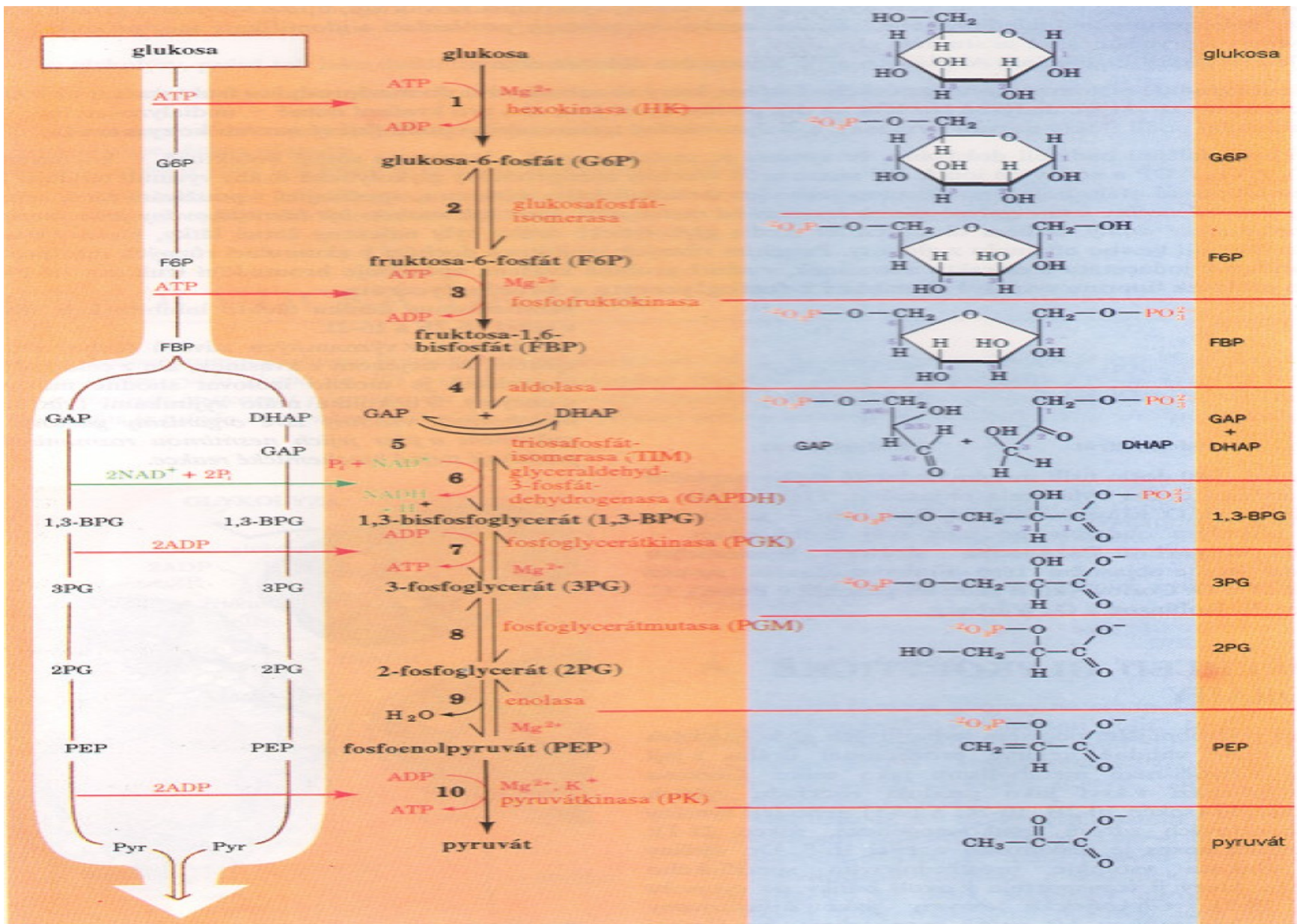
$2\text{NAD}^+$

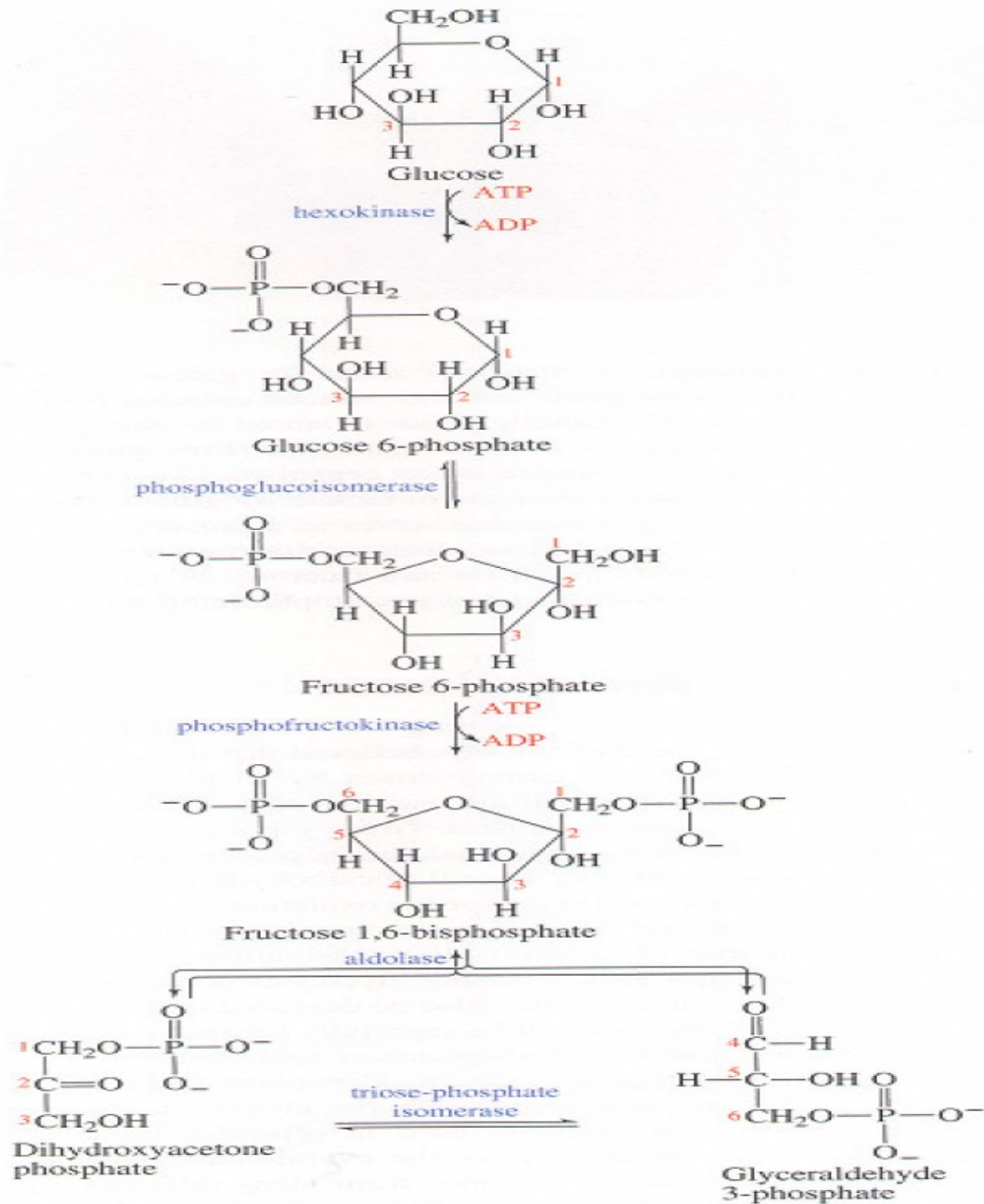
oxidační  
fosforylace

2 laktát

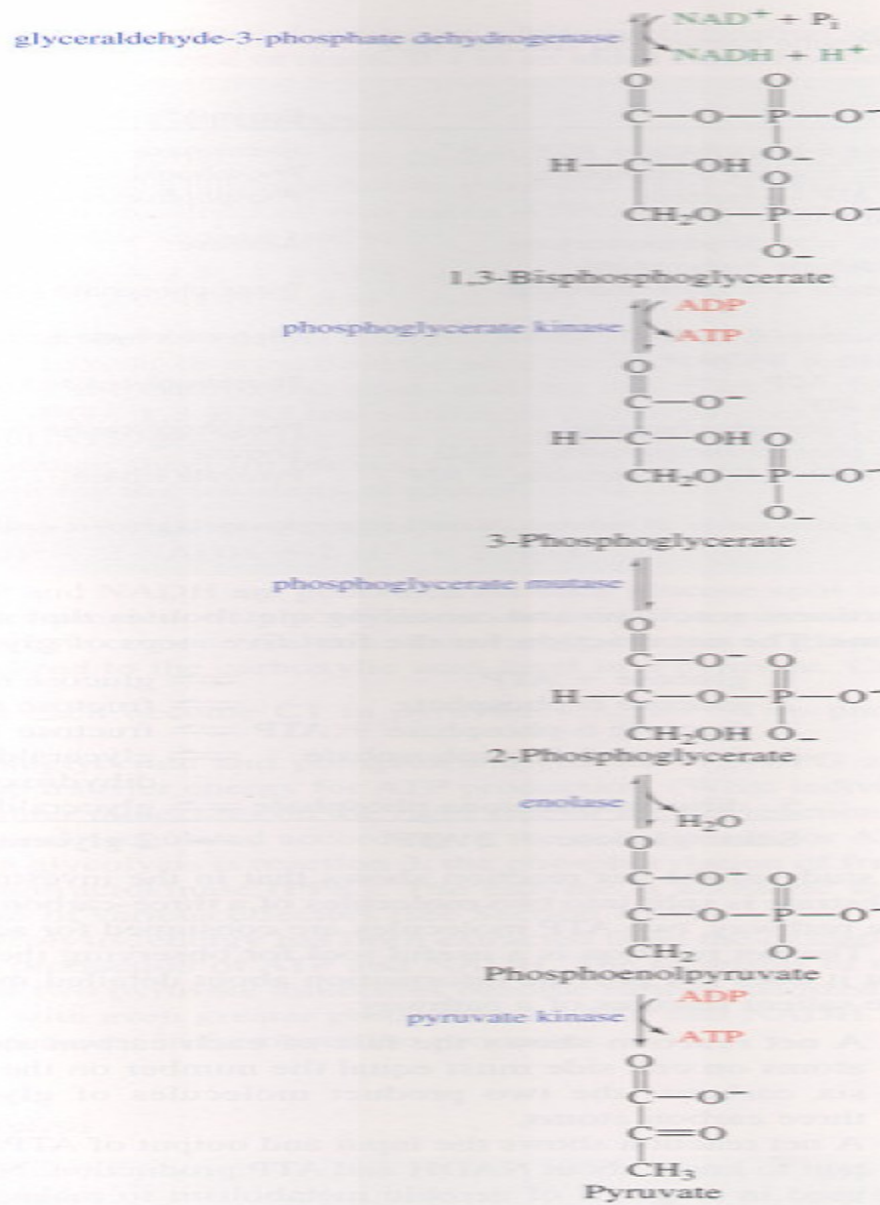
$6\text{CO}_2 + 6\text{H}_2\text{O}$

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

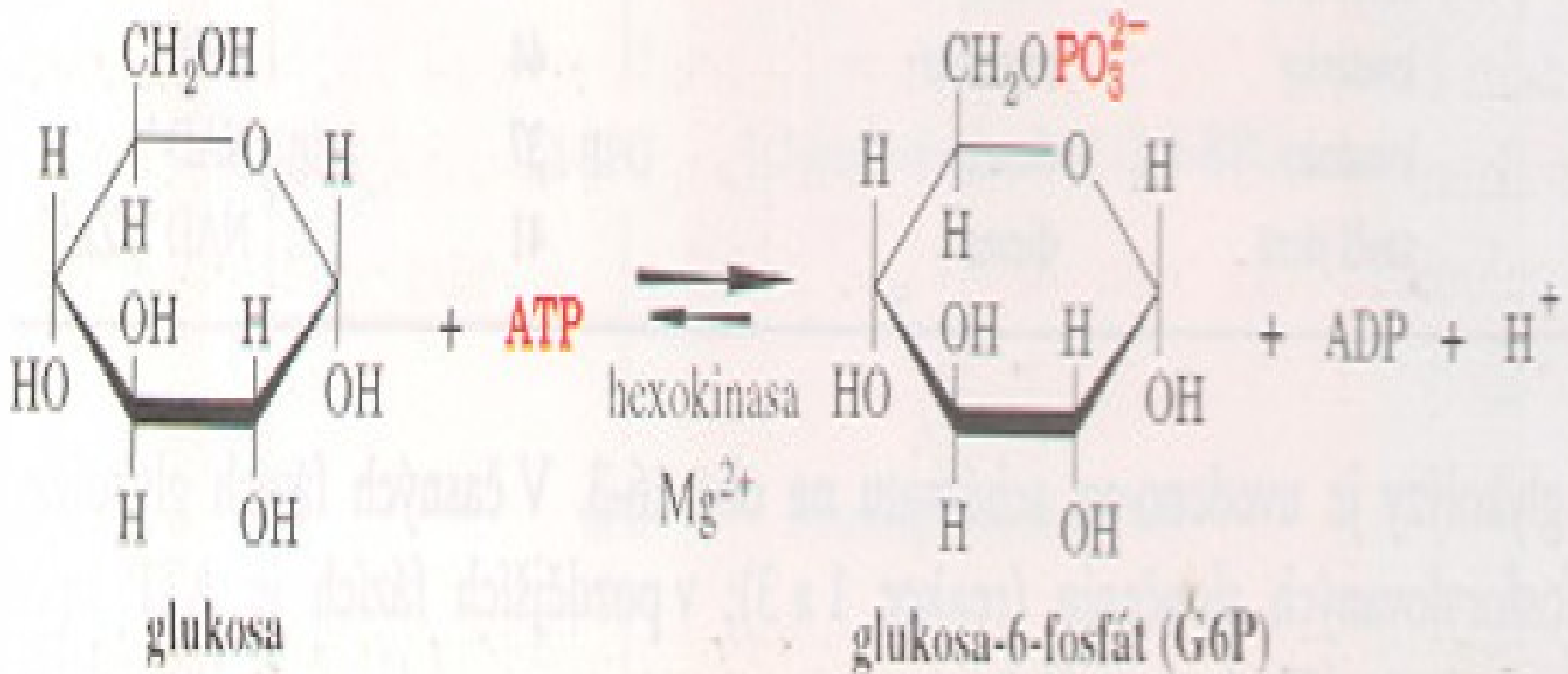




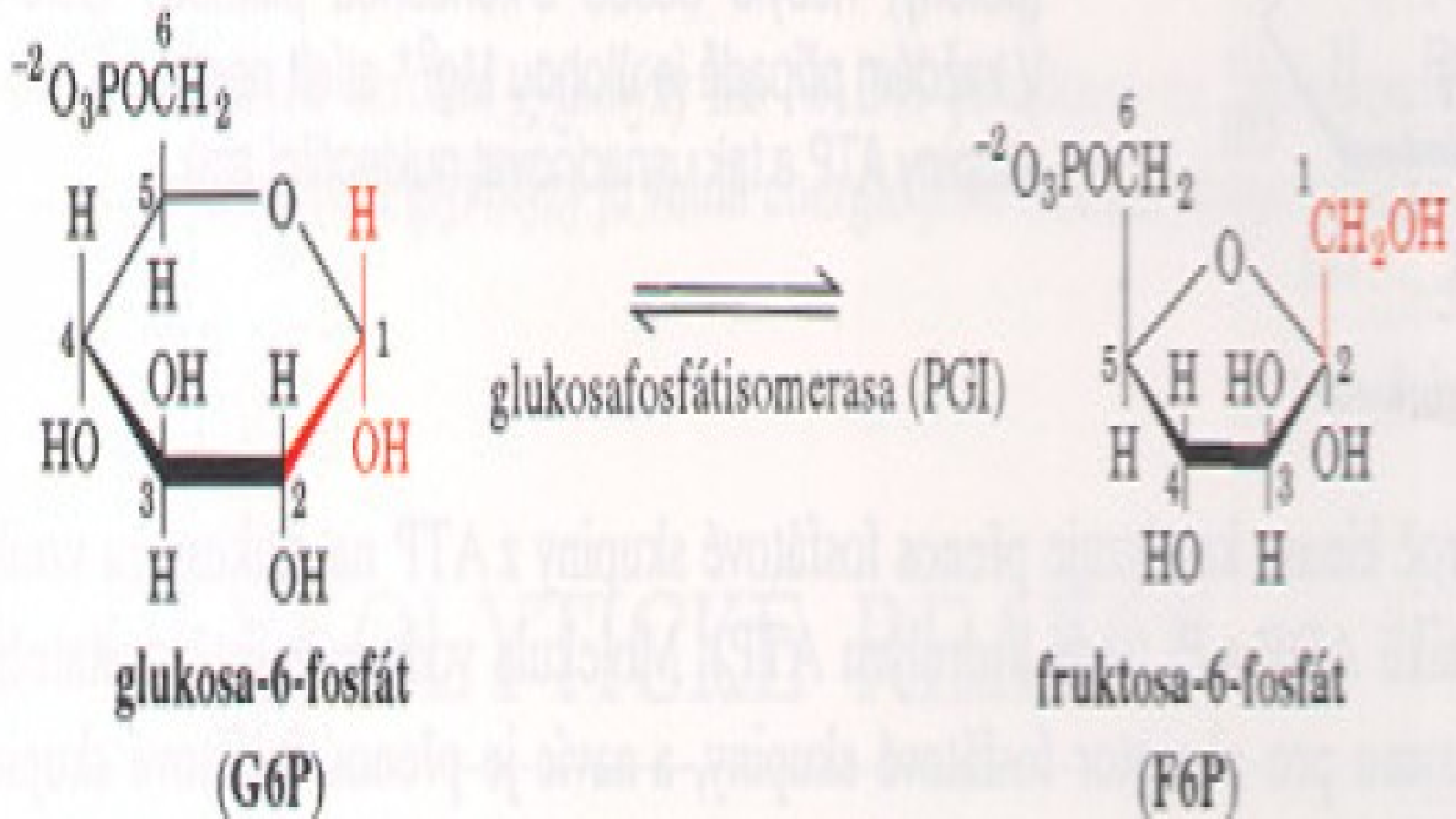
2 x



# Hexokinasa -glukokinasa

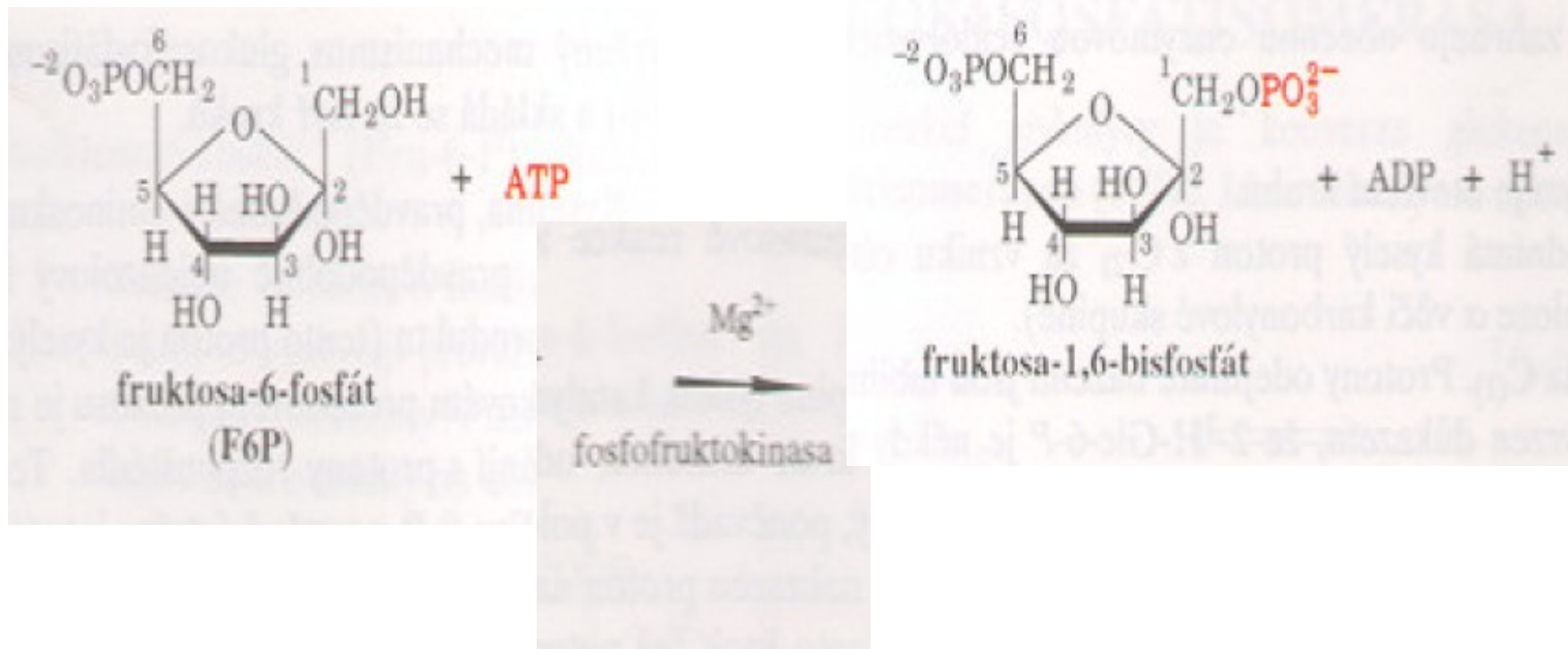


# Glukosafosfátisomerasa

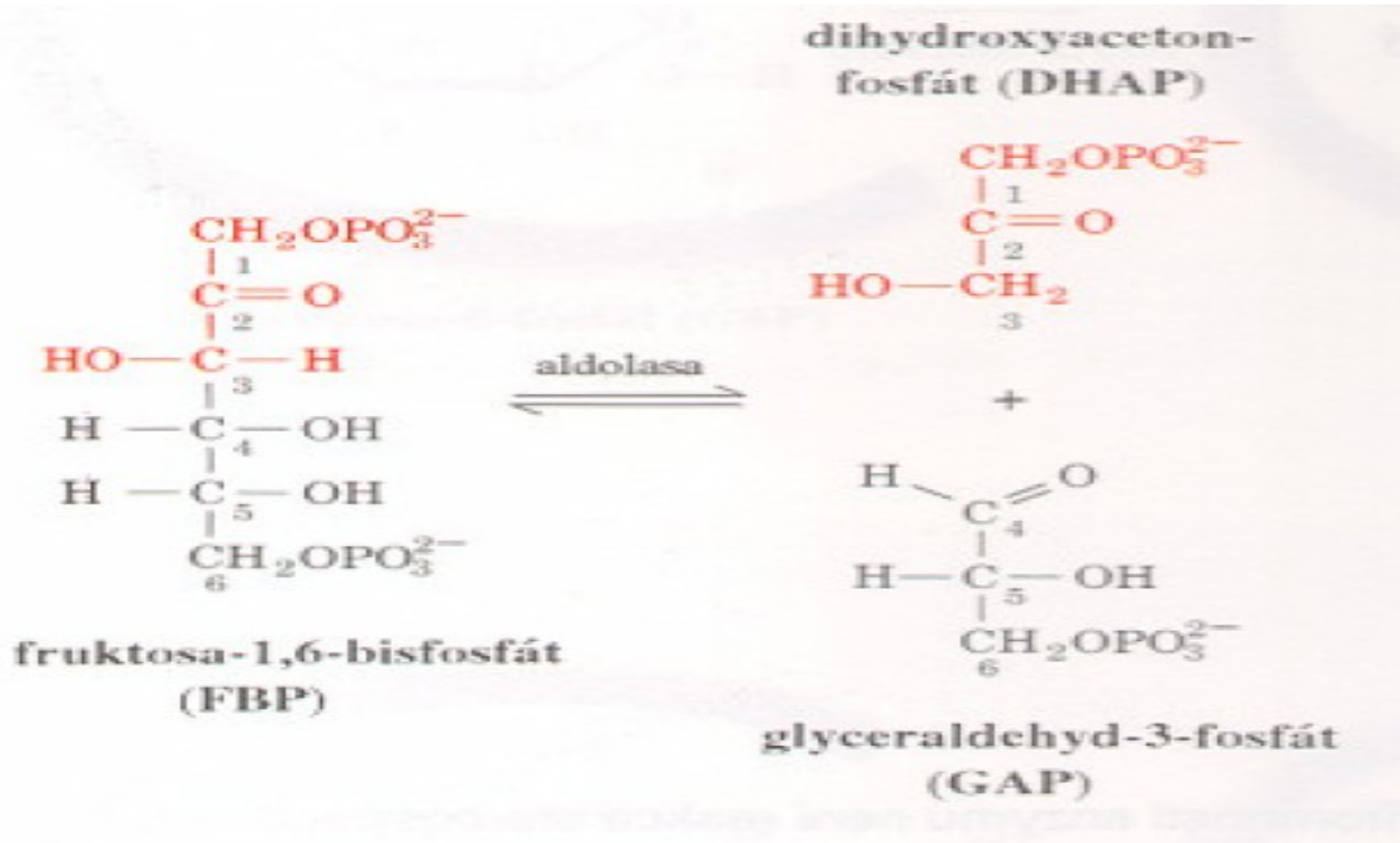




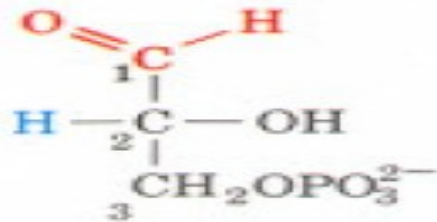
# Fosfofruktokinasa



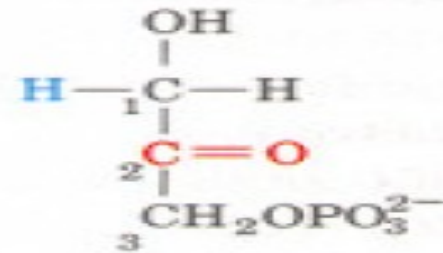
# Aldolsa



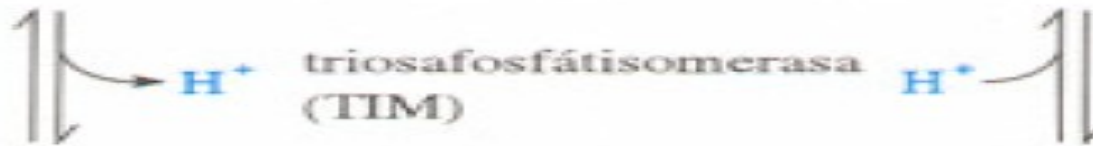
# Triosafosfátisomerasa



glyceraldehyd-3-fosfát  
(aldosa)

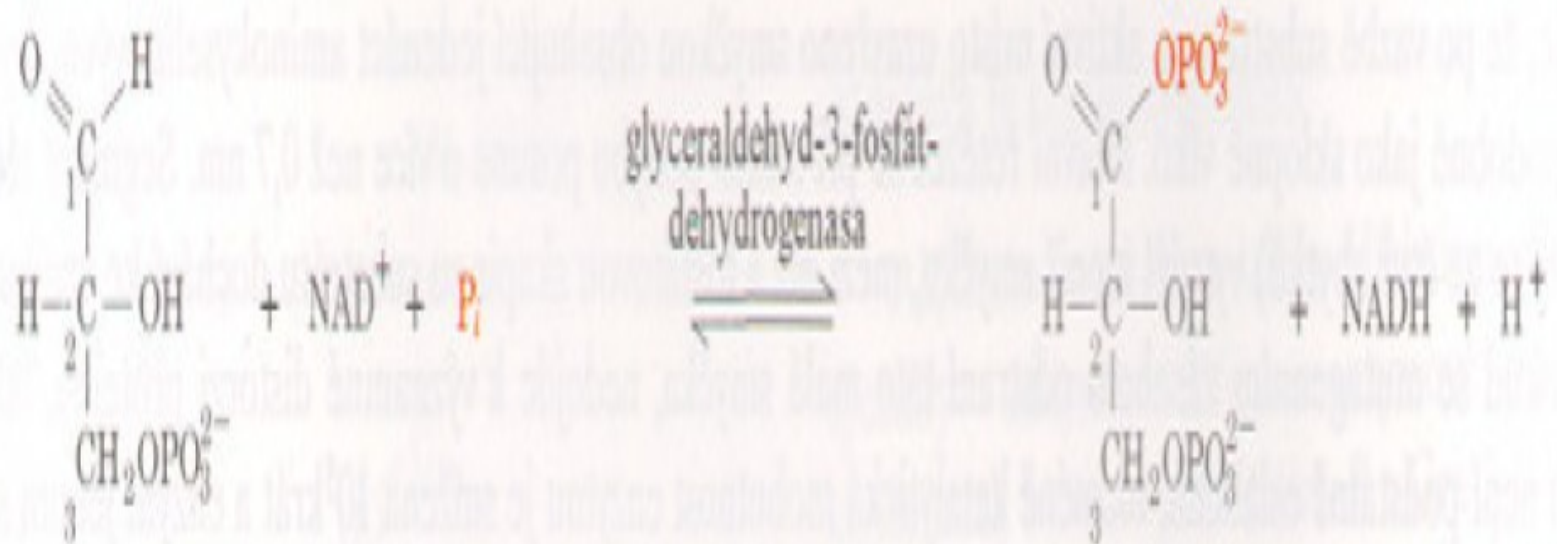


dihydroxyaceton-fosfát  
(ketosa)



endiolový intermediát

# Glyceraldehyd-3-fosfát-dehydrogenasa

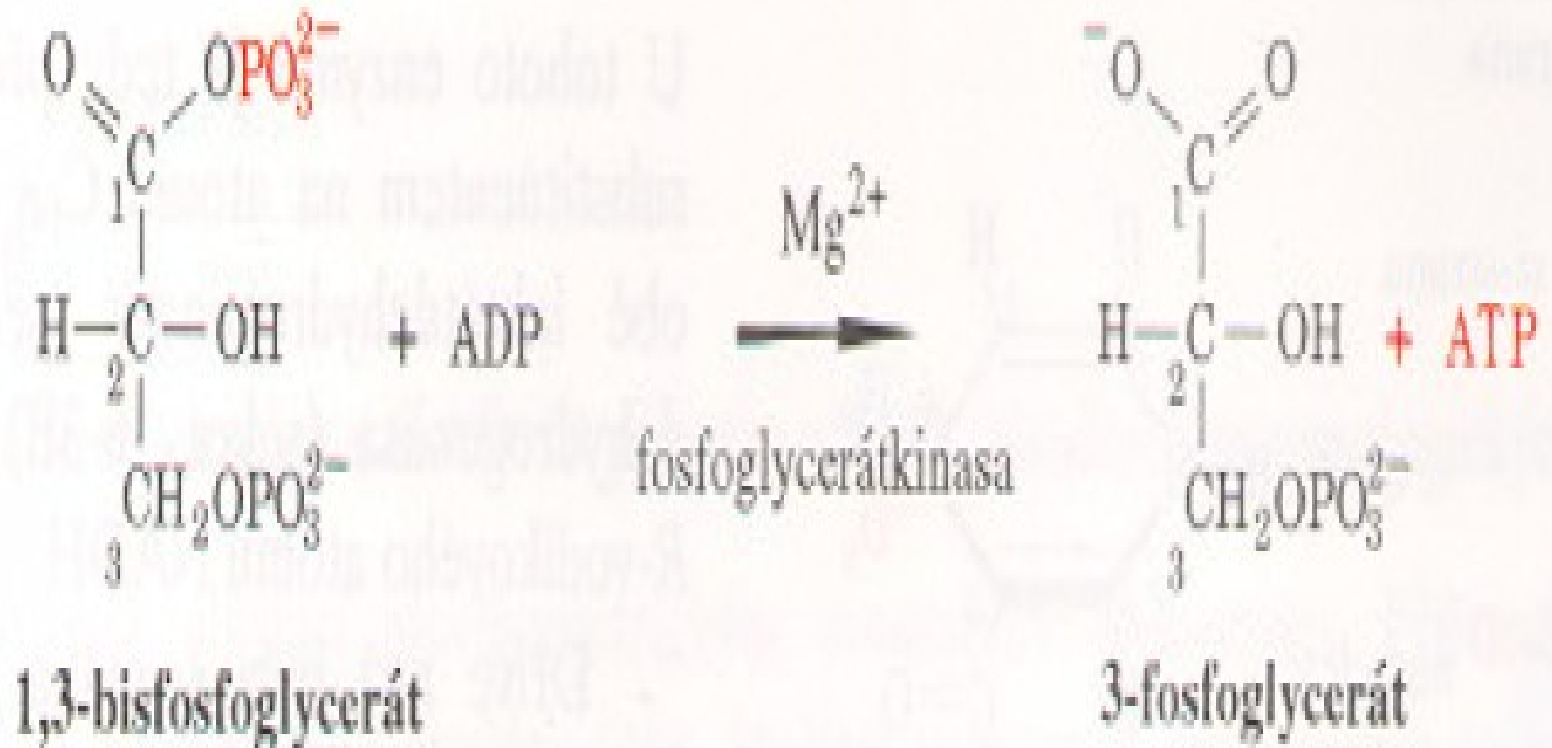


glyceraldehyd-3-fosfát

(GAP)

1,3-bisfosfoglycerát

# Fosfoglycerátkinasa



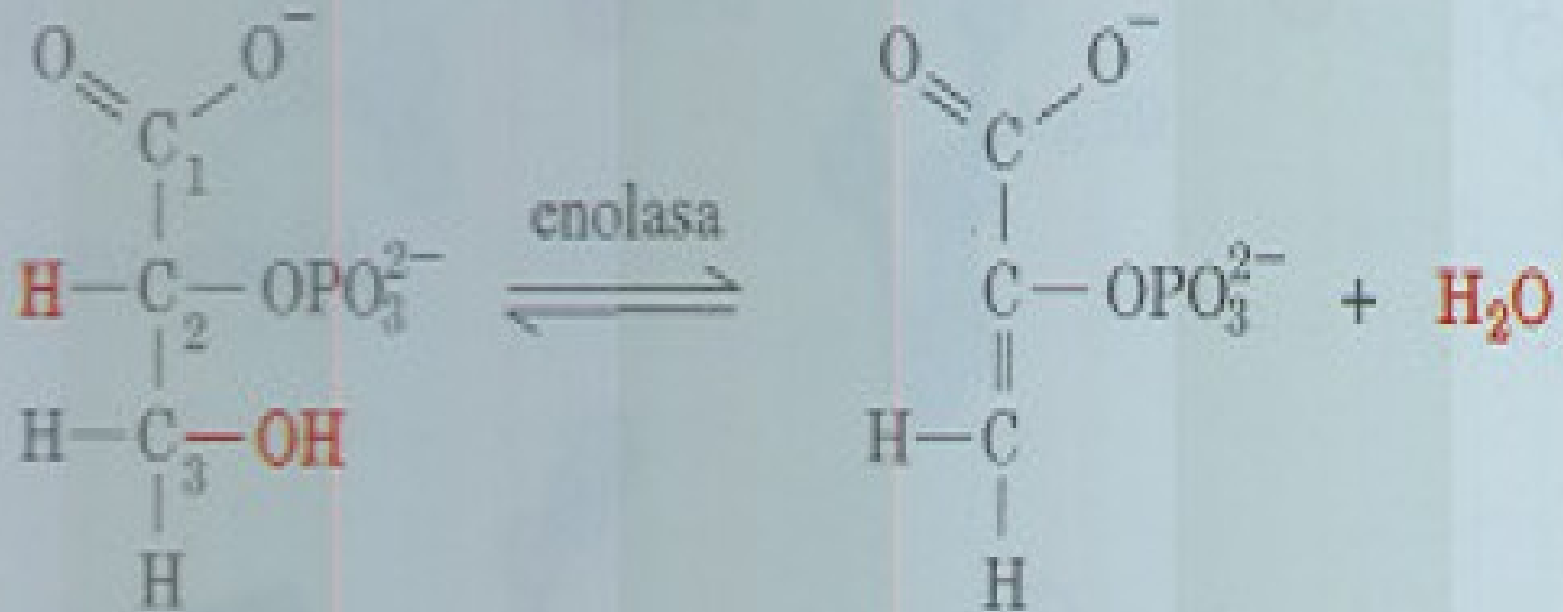
# Fosfoglycerátmutasa



3-fosfoglycerát

2-fosfoglycerát

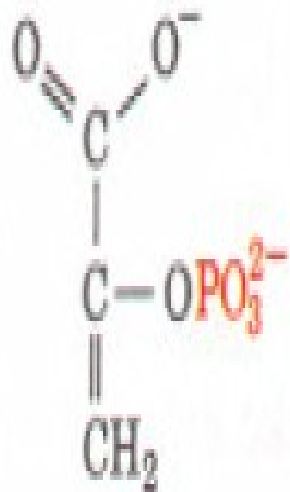
# Enolasa



2-fosfoglycerát

fosfoenolpyruvát

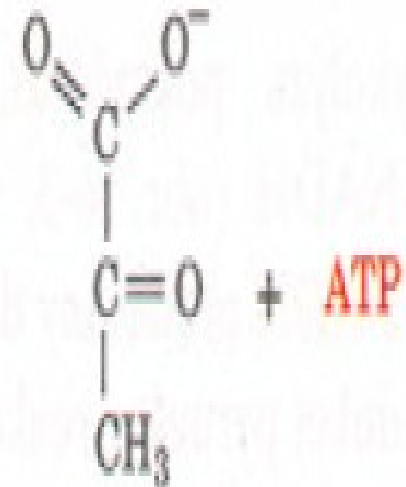
# Pyruvátkinasa



fosfoenolpyruvát



pyruvátkinasa



pyruvát

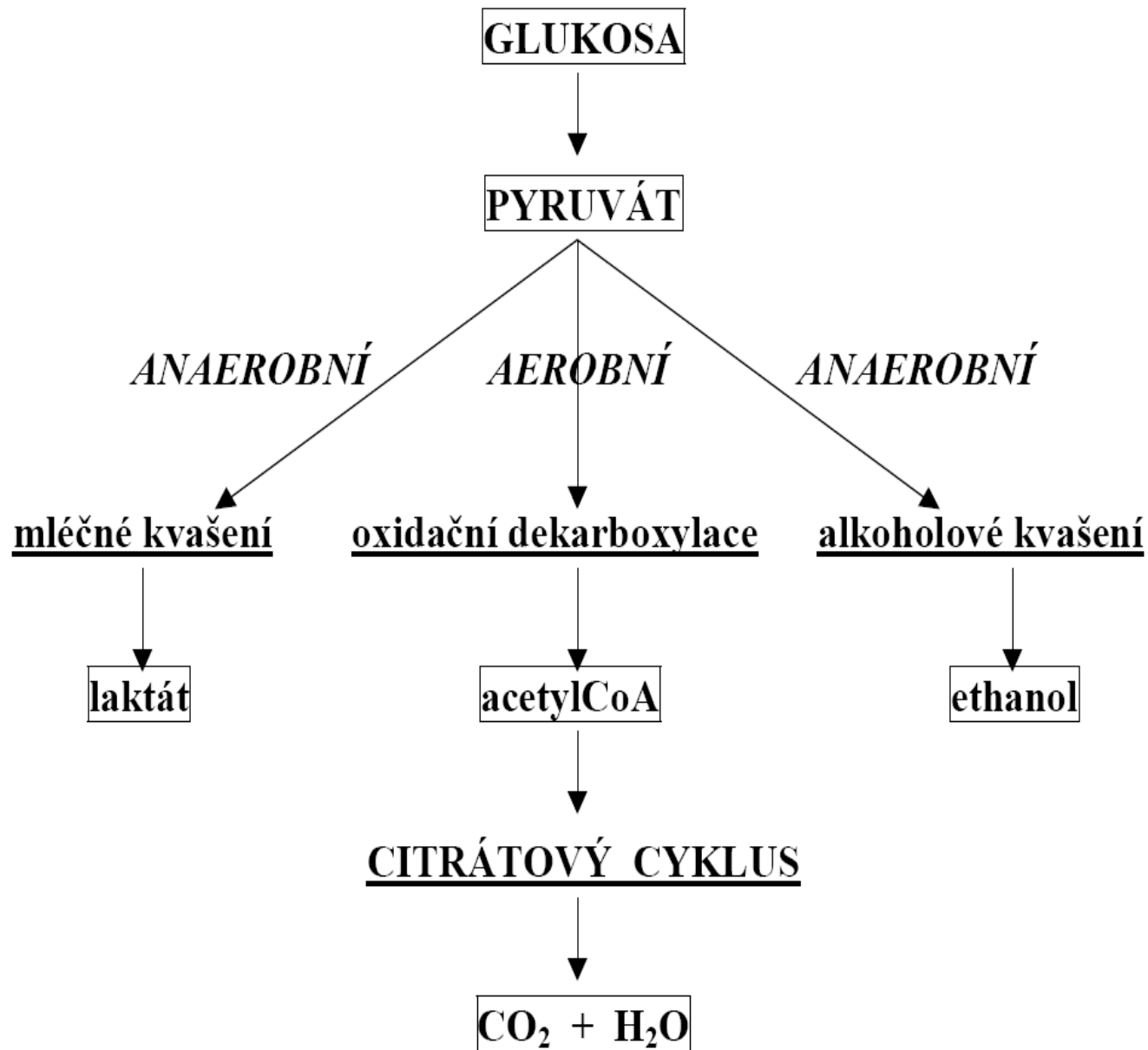


## Bilance glykolýzy

**glukosa + 2 NAD<sup>+</sup> + 2 ADP + 2 Pi**

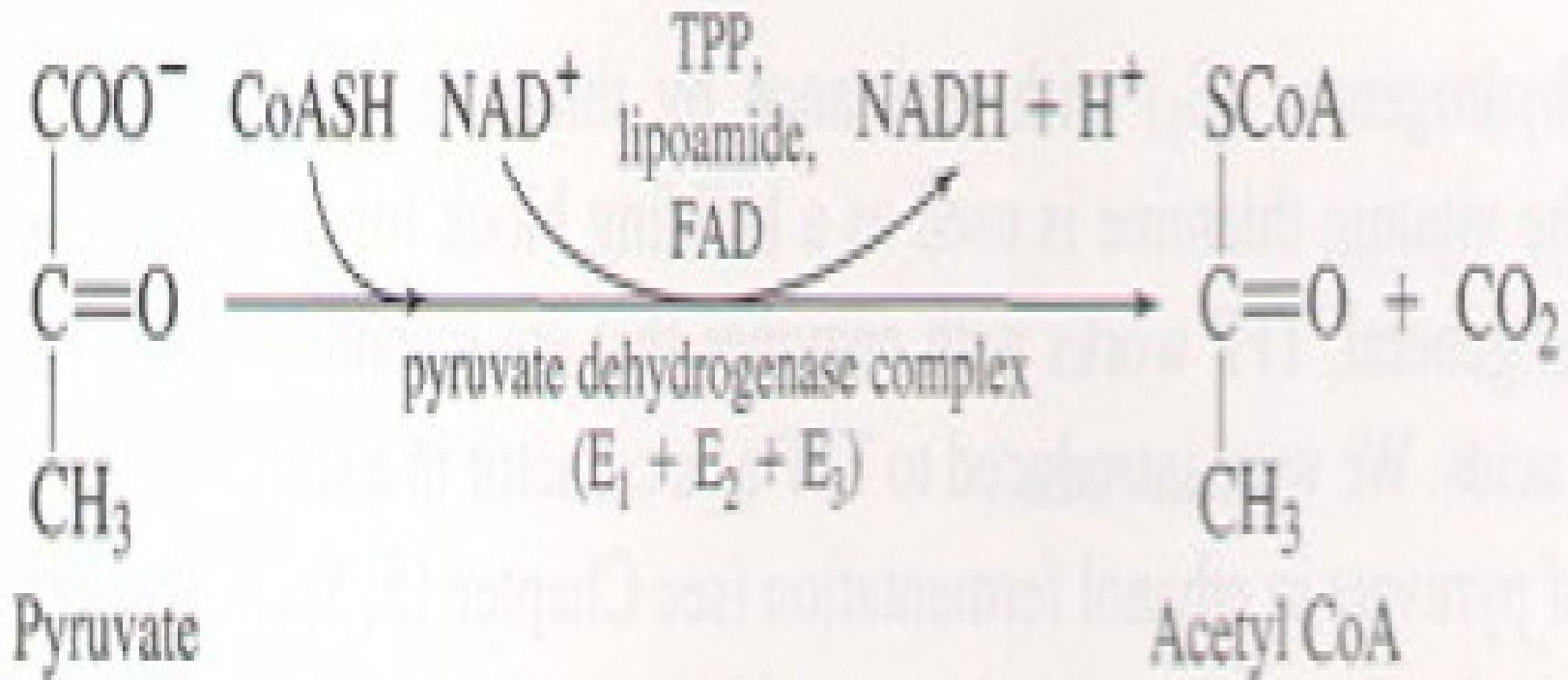
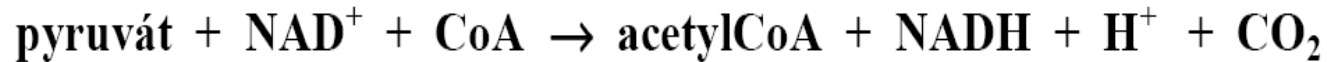
**→**

**2 pyruvát + 2 ATP + 2 NADH + 2 H<sup>+</sup> + 2 H<sub>2</sub>O**

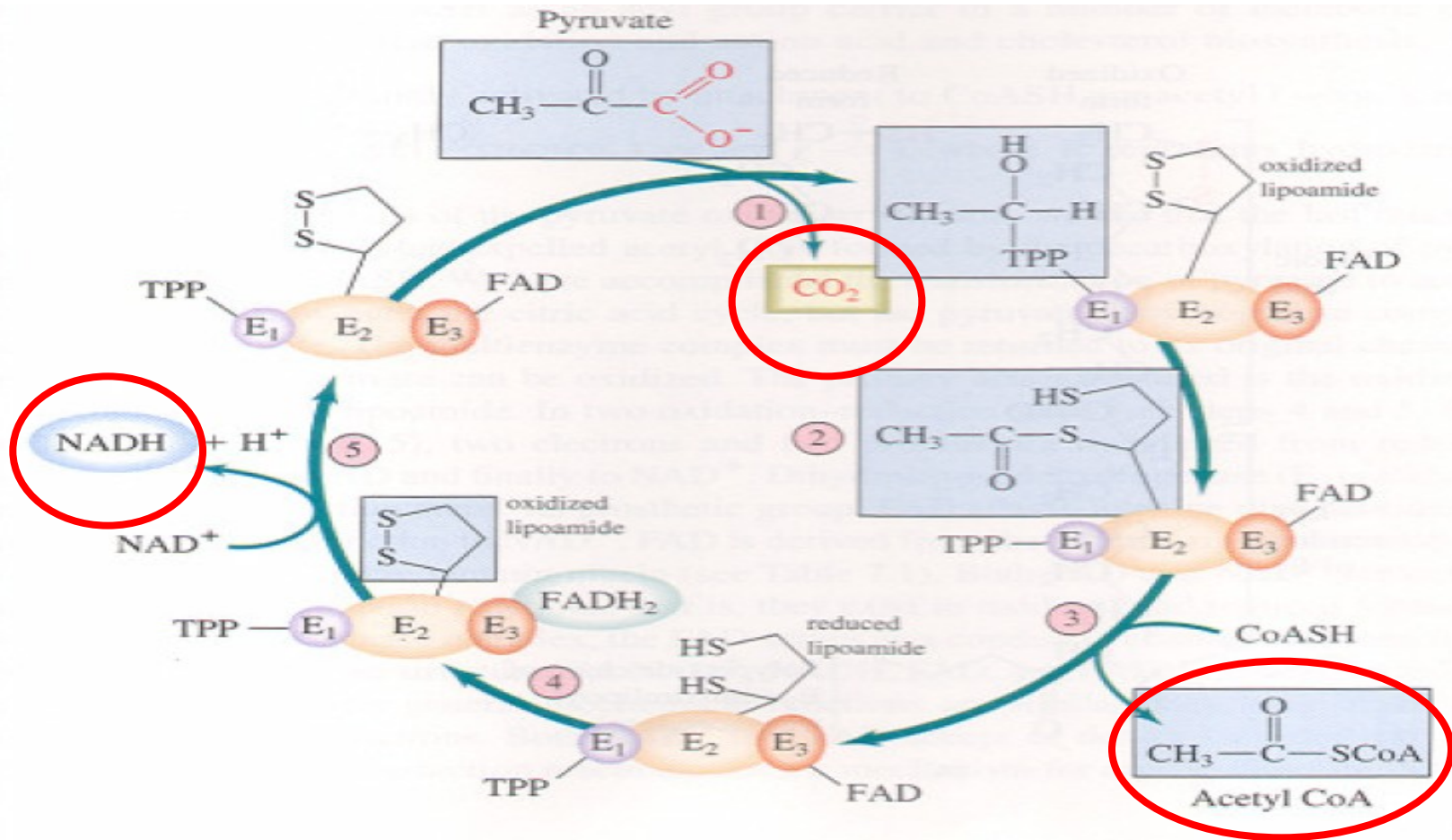


## Aerobní odbourávání

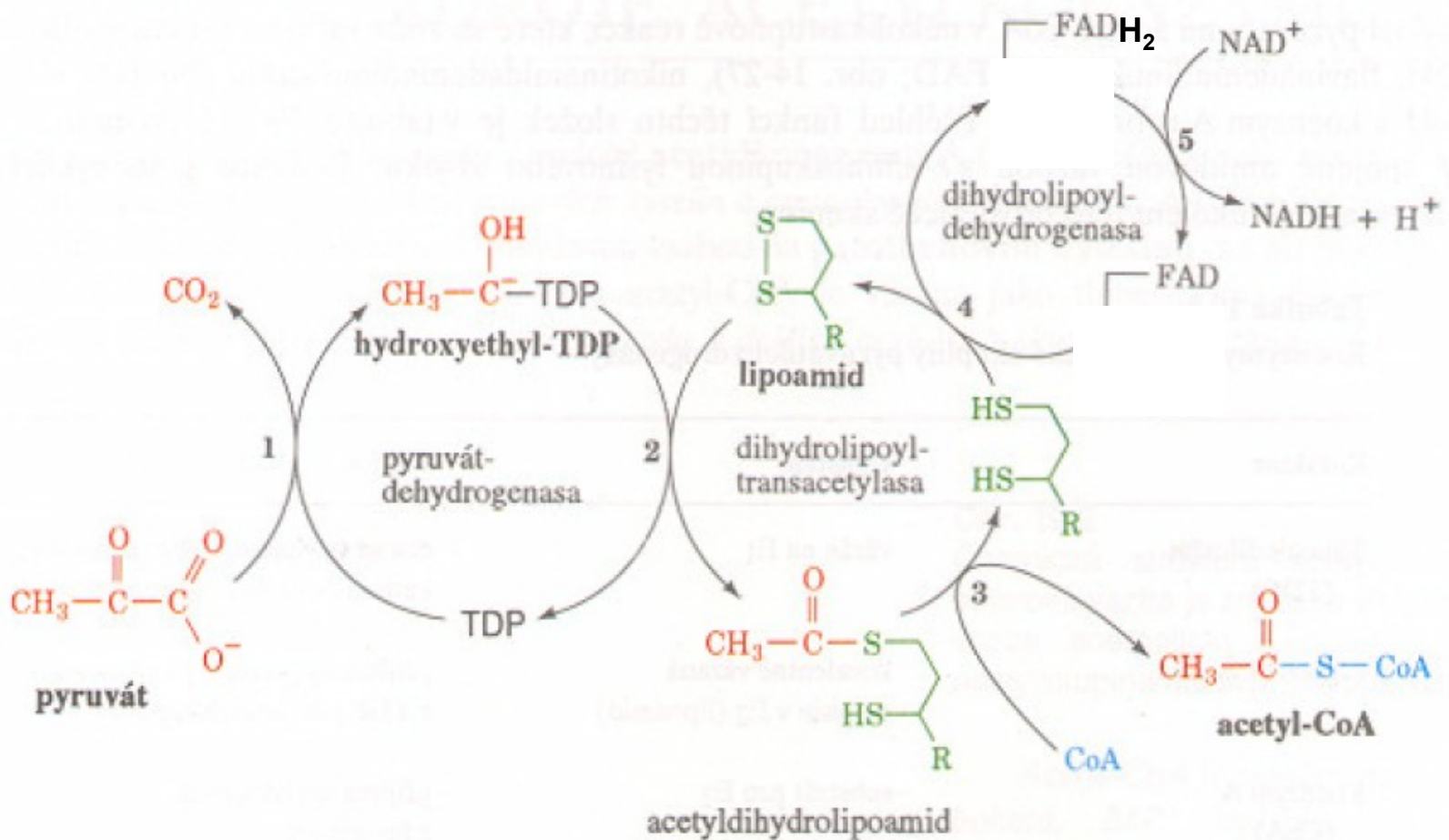
### Oxidační dekarboxylace :



# Pyruvátdehydrogenasa

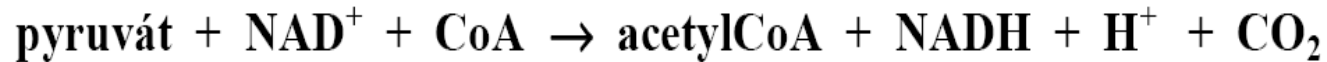


# Pyruvátdehydrogenasa

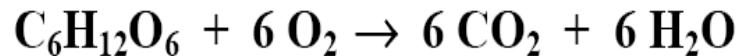


## Aerobní odbourávání

### Oxidační dekarboxylace :

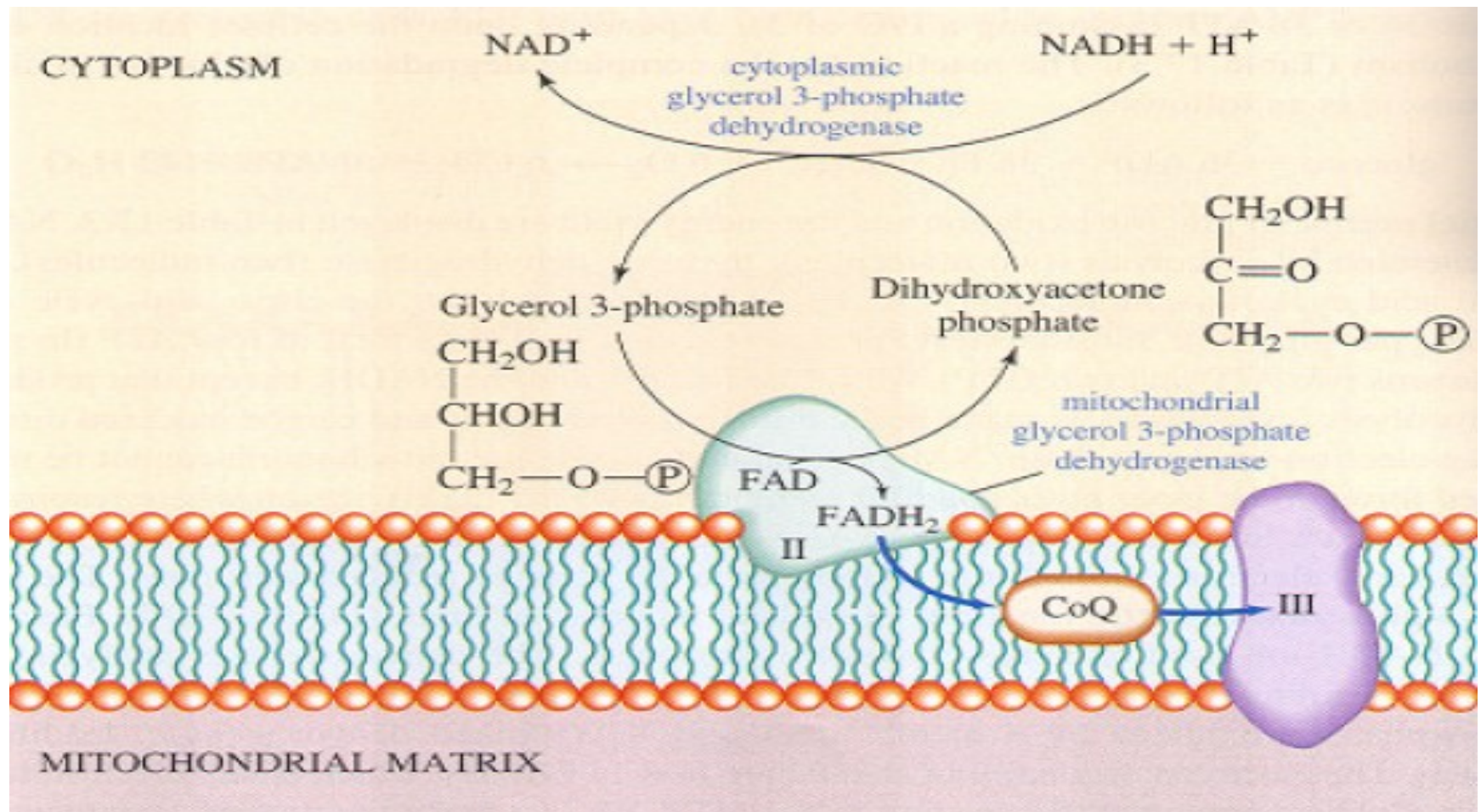


### Bilance aerobní glykolýzy :

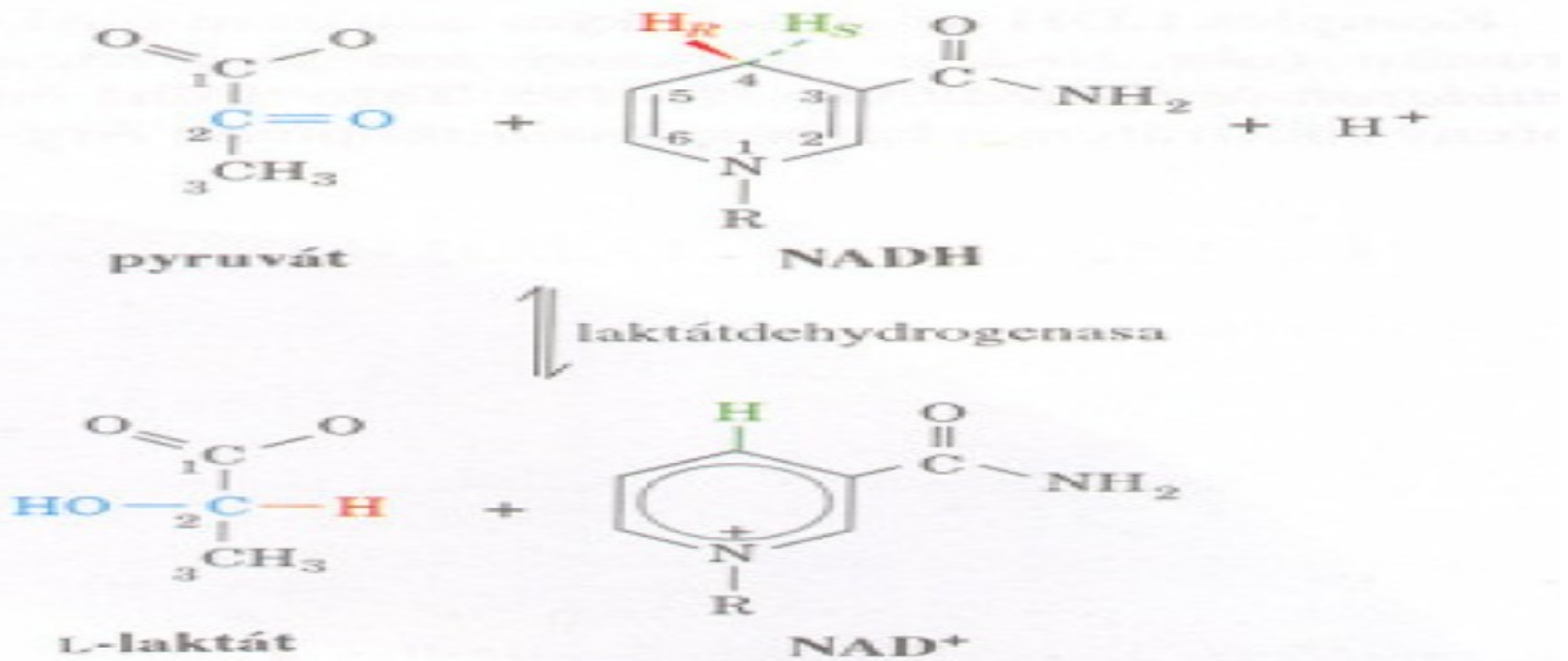
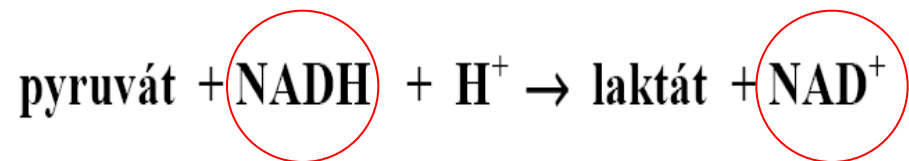


Glykolýza	1 ATP + 1 NADH	(4-1) ATP
Oxidační dekarboxylace	1 NADH	3 ATP
Citrátový cyklus	1 ATP 3 NAD + FADH <sub>2</sub>	12 ATP
<b>CELKEM</b>	<b>18 ATP/ triosu tj.</b>	<b>36 ATP/ glukosu tj. 40 %</b>

# G-3-P DH člunek

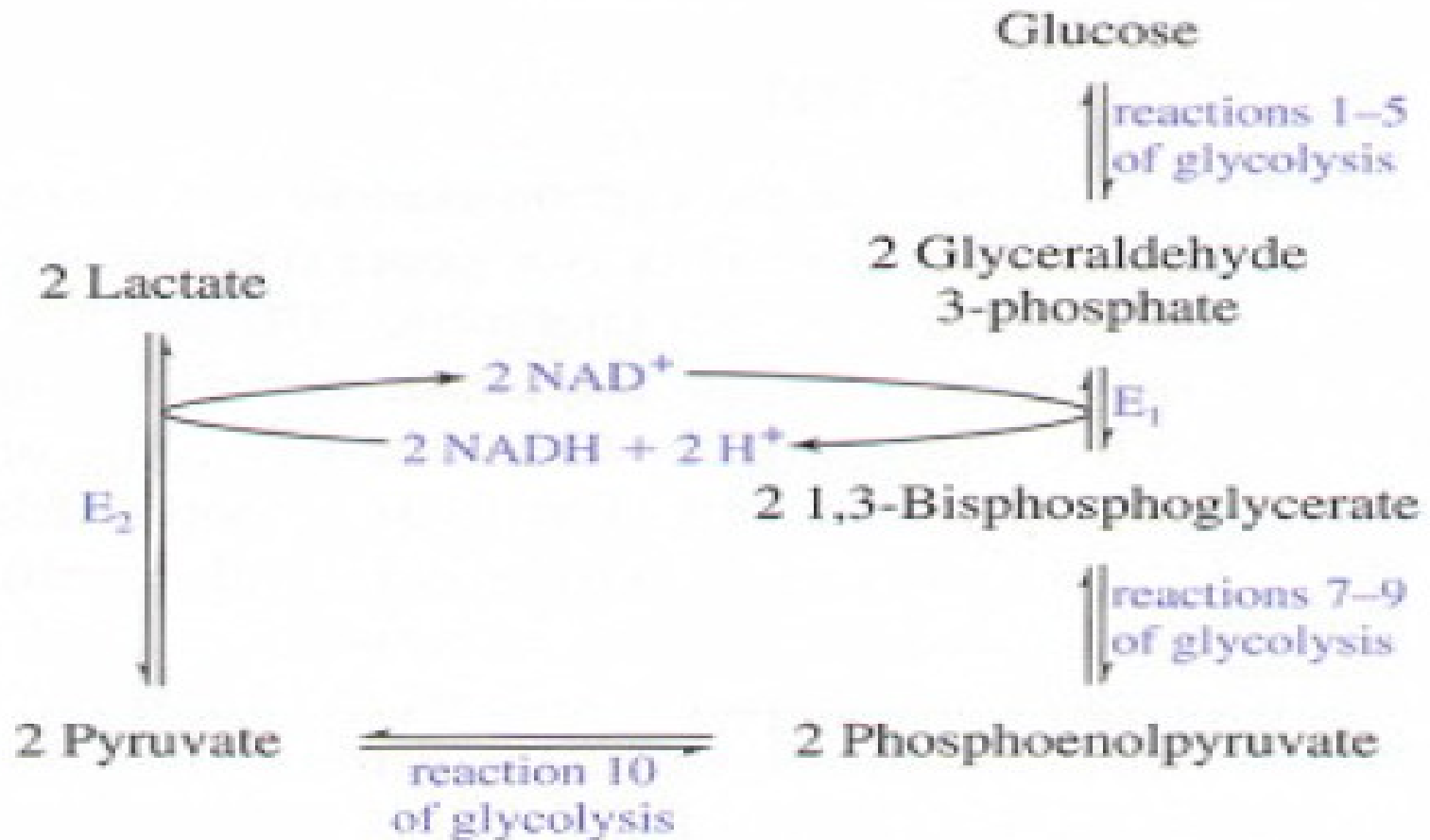


## Mléčné kvašení

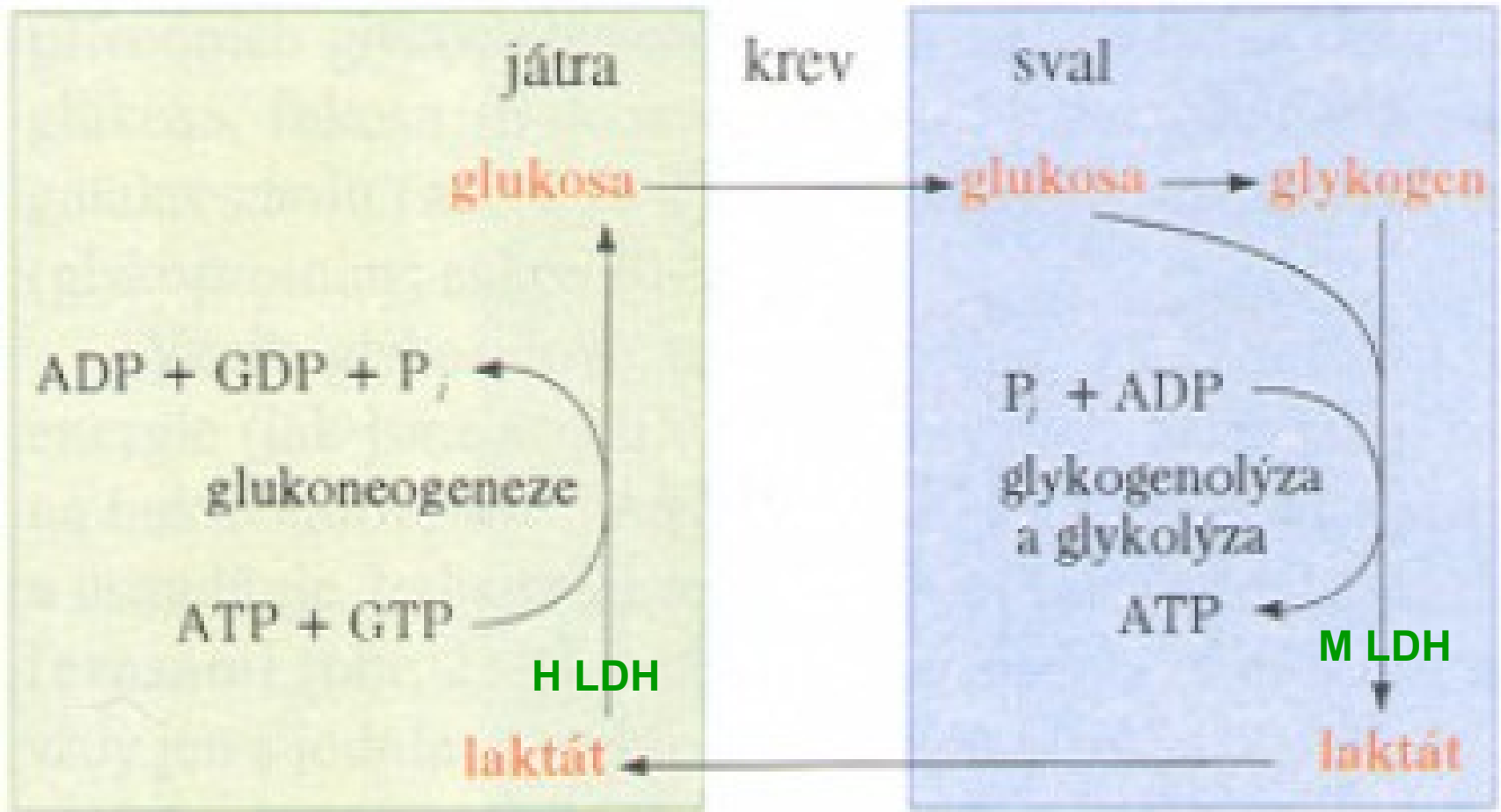




# Mléčné kvašení

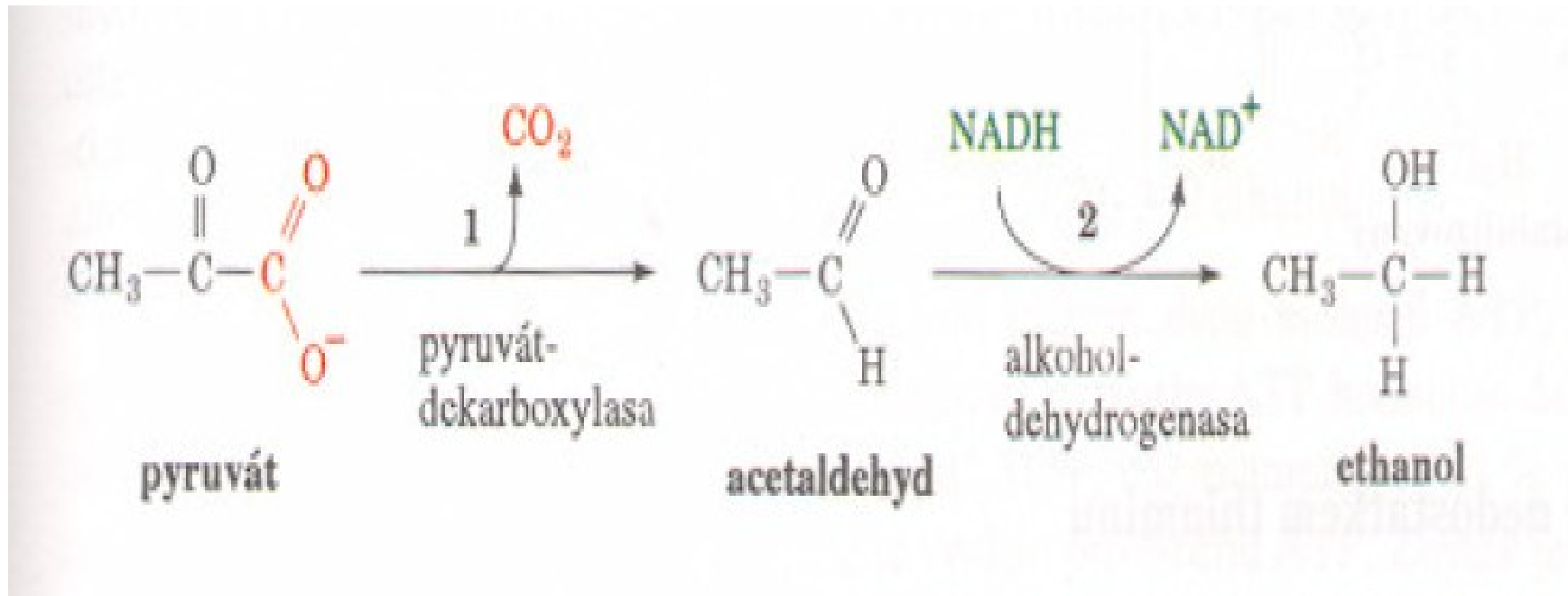
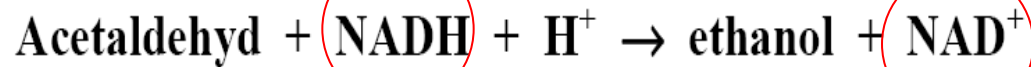


# Coriho cyklus





## Alkoholové kvašení

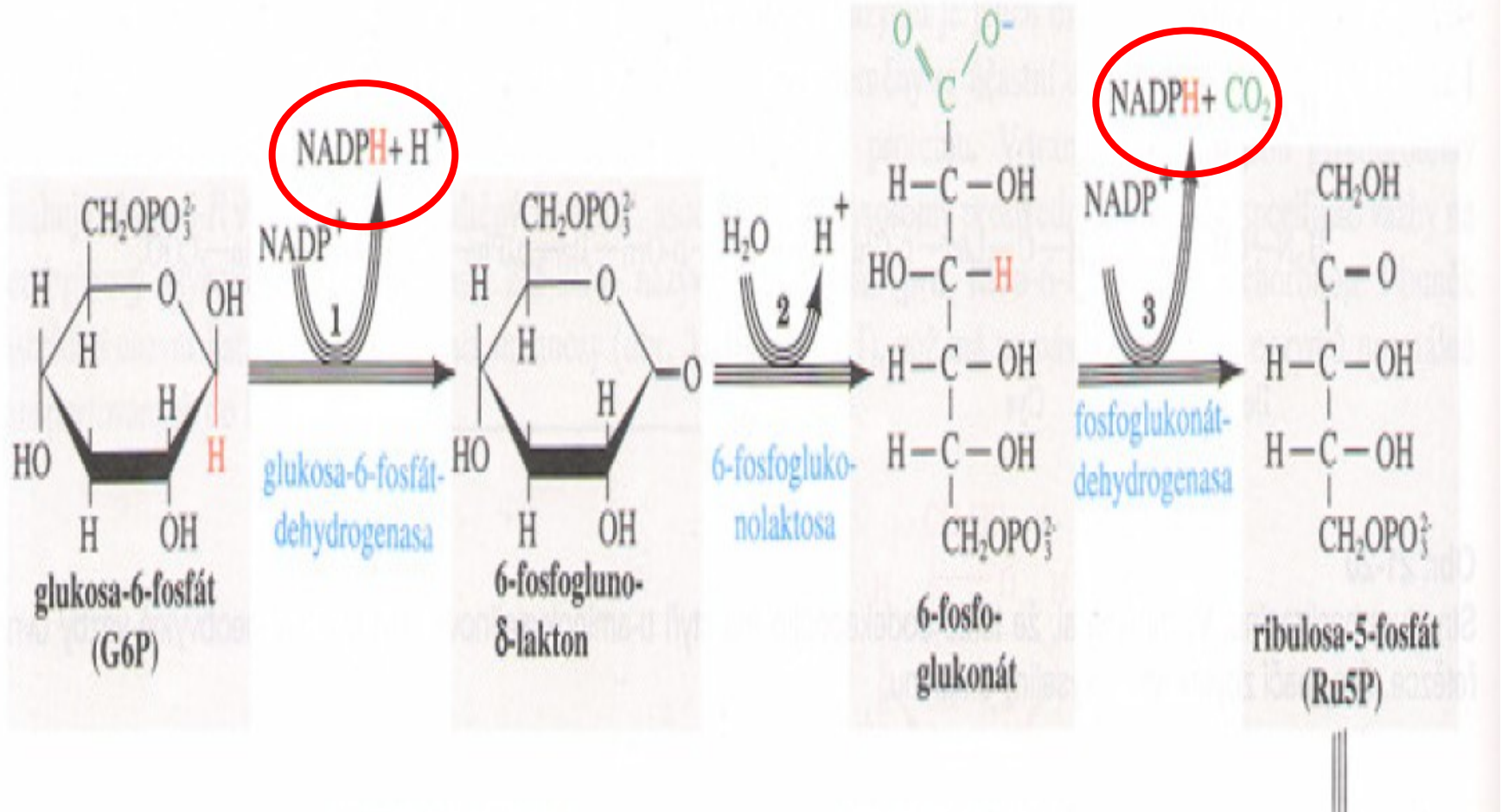


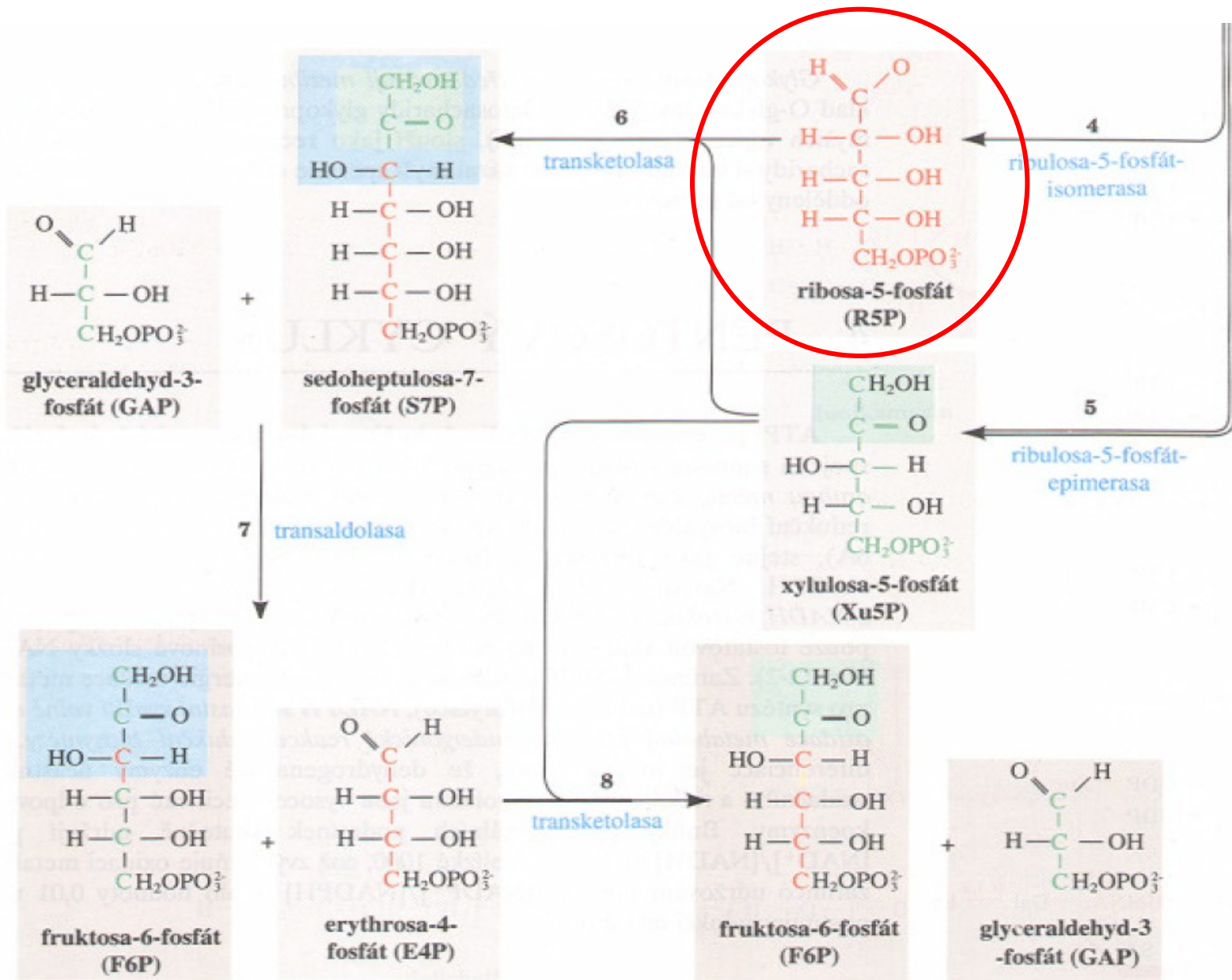


## Další druhy kvašení

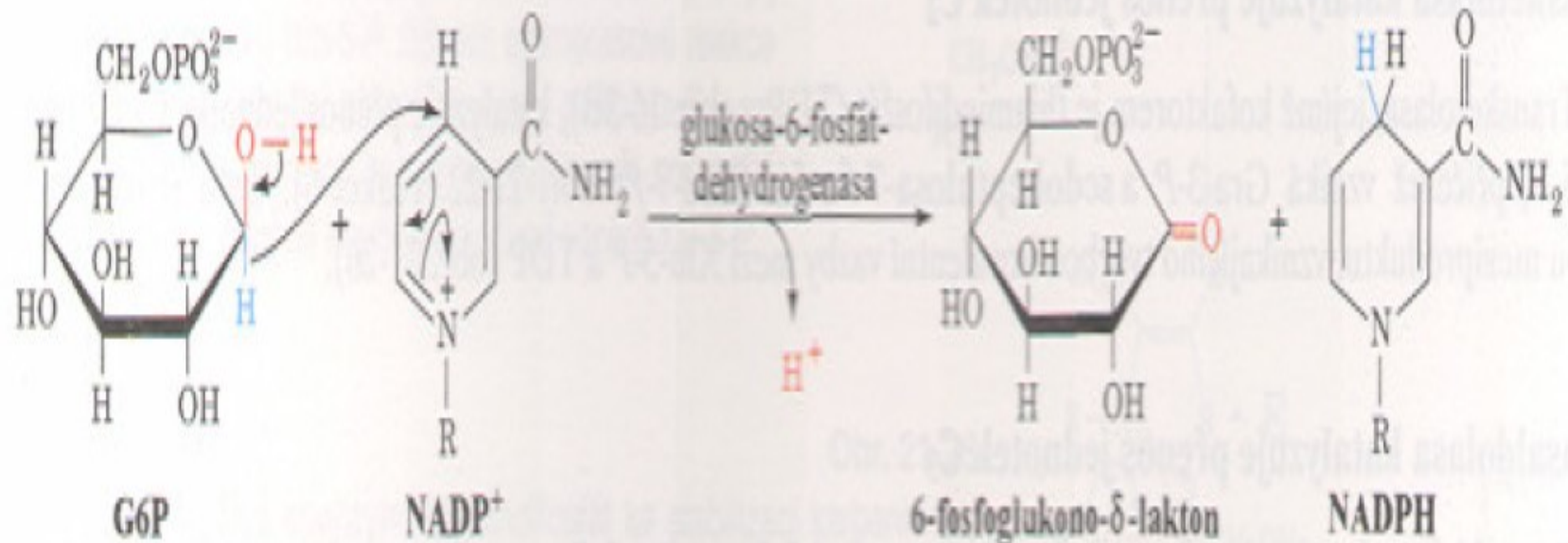
- Mléčné - *Lactobacterium*  
glukosa → laktát
- Propionové - *Propionibacterium*  
glukosa → k. propionová
- Máselné - *Clostridium*  
glukosa → k. máselnou
- Octové - *Acetobacter*  
glukosa → k. octová
- Citronové - *Aspergillus*  
glukosa → k. citronová

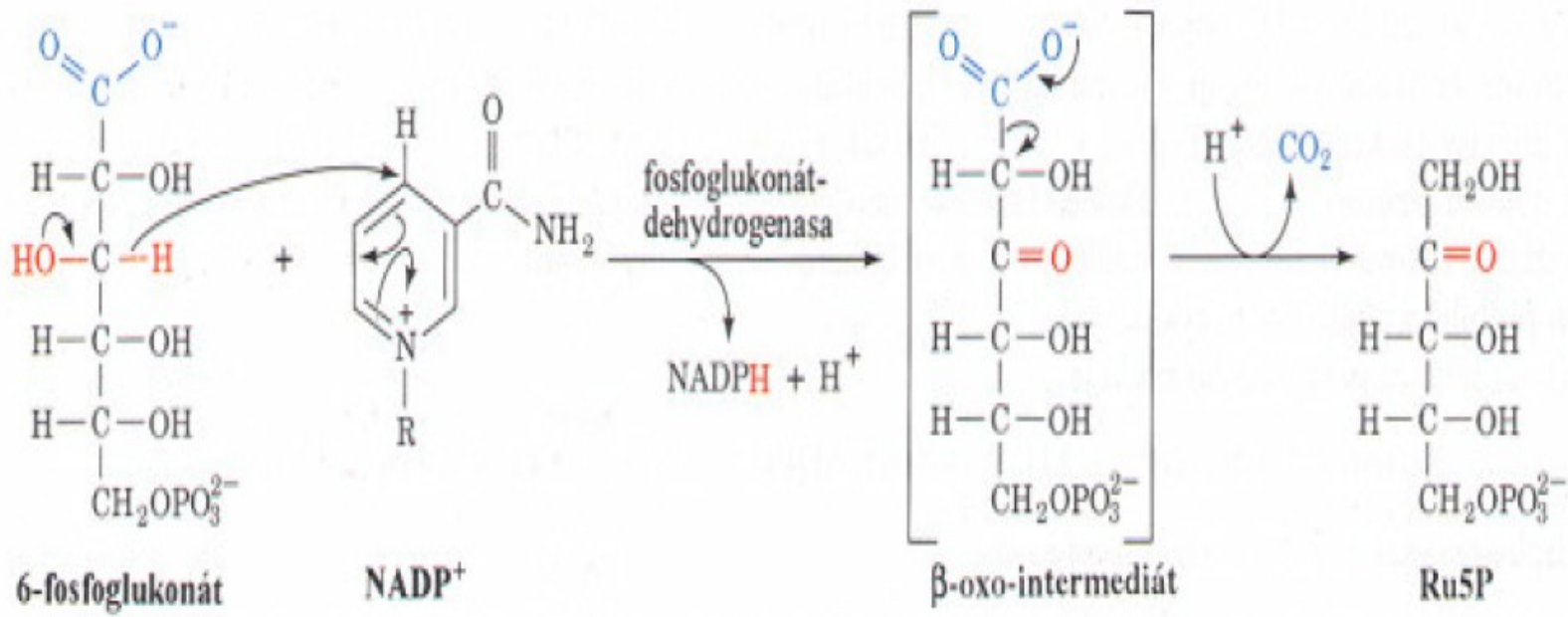
# Pentosový cyklus



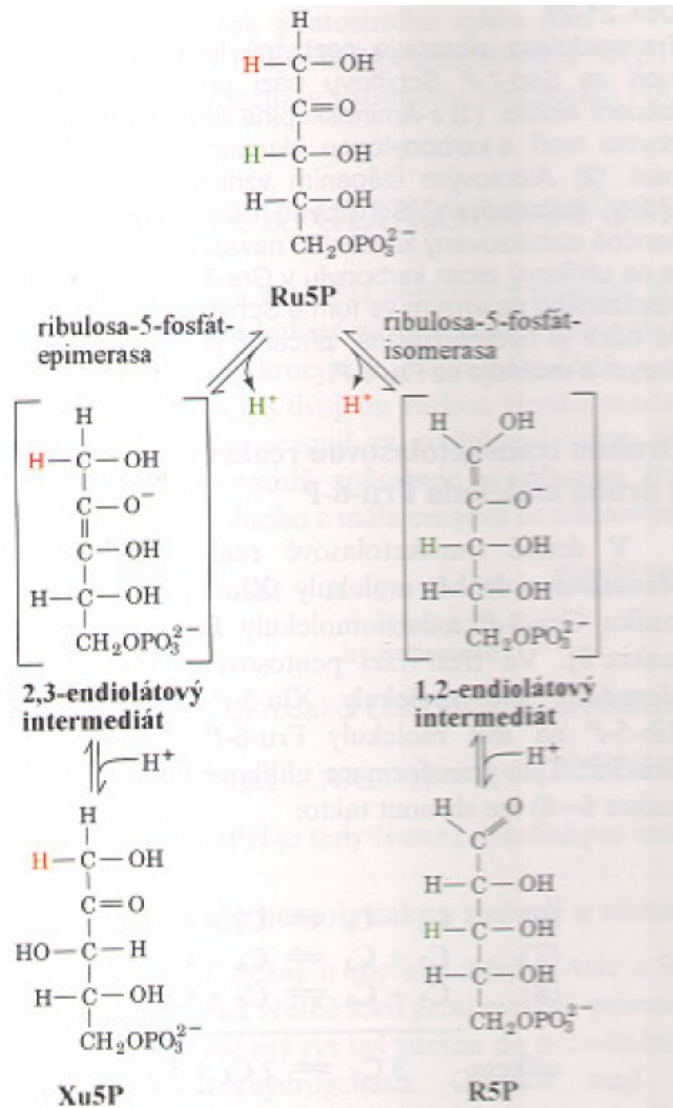


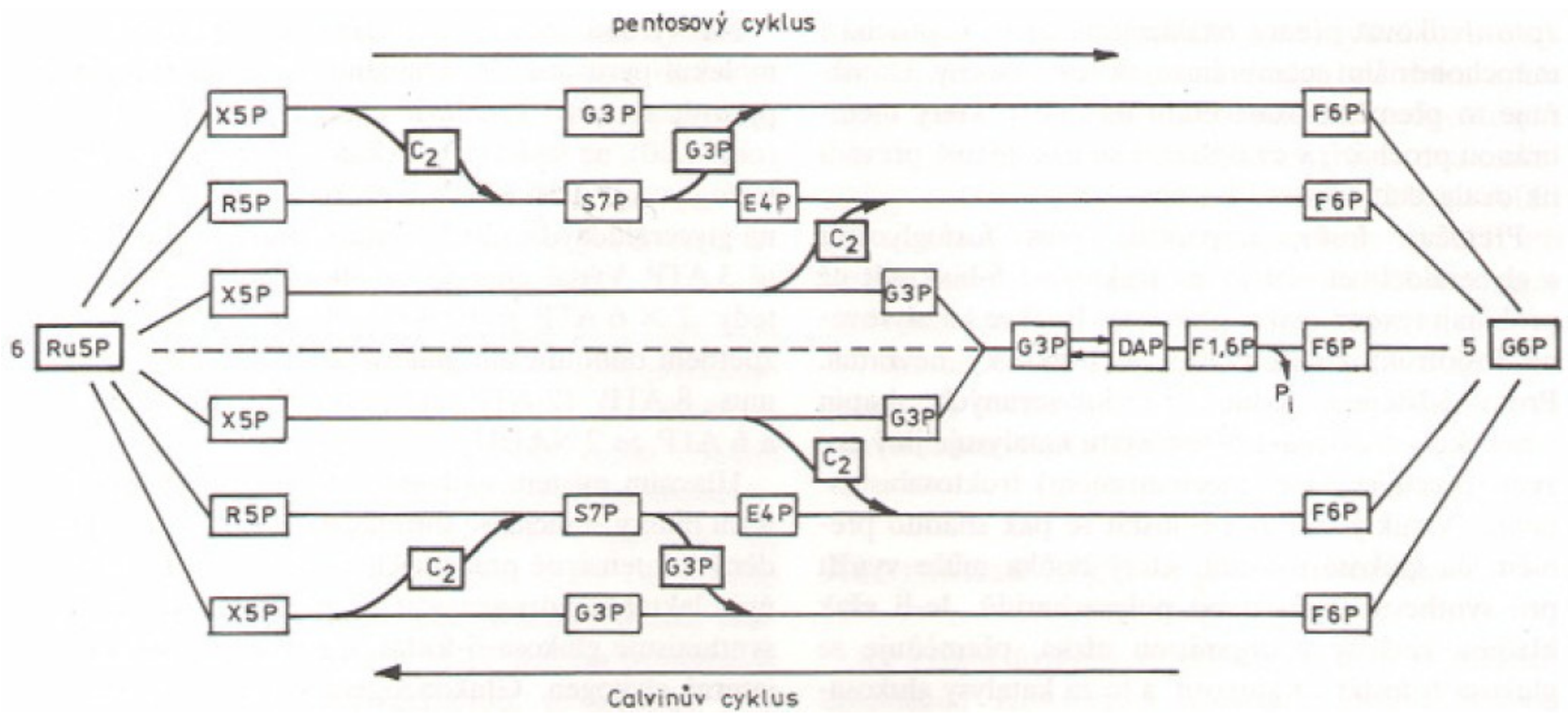






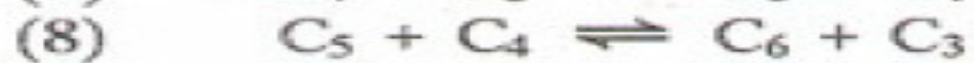
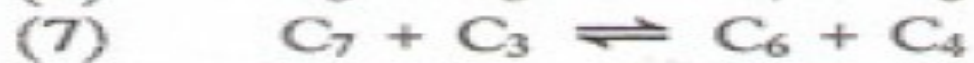
# Regenerační fáze

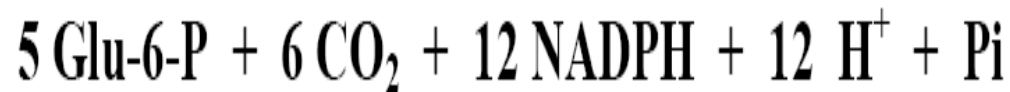




pentosový cyklus

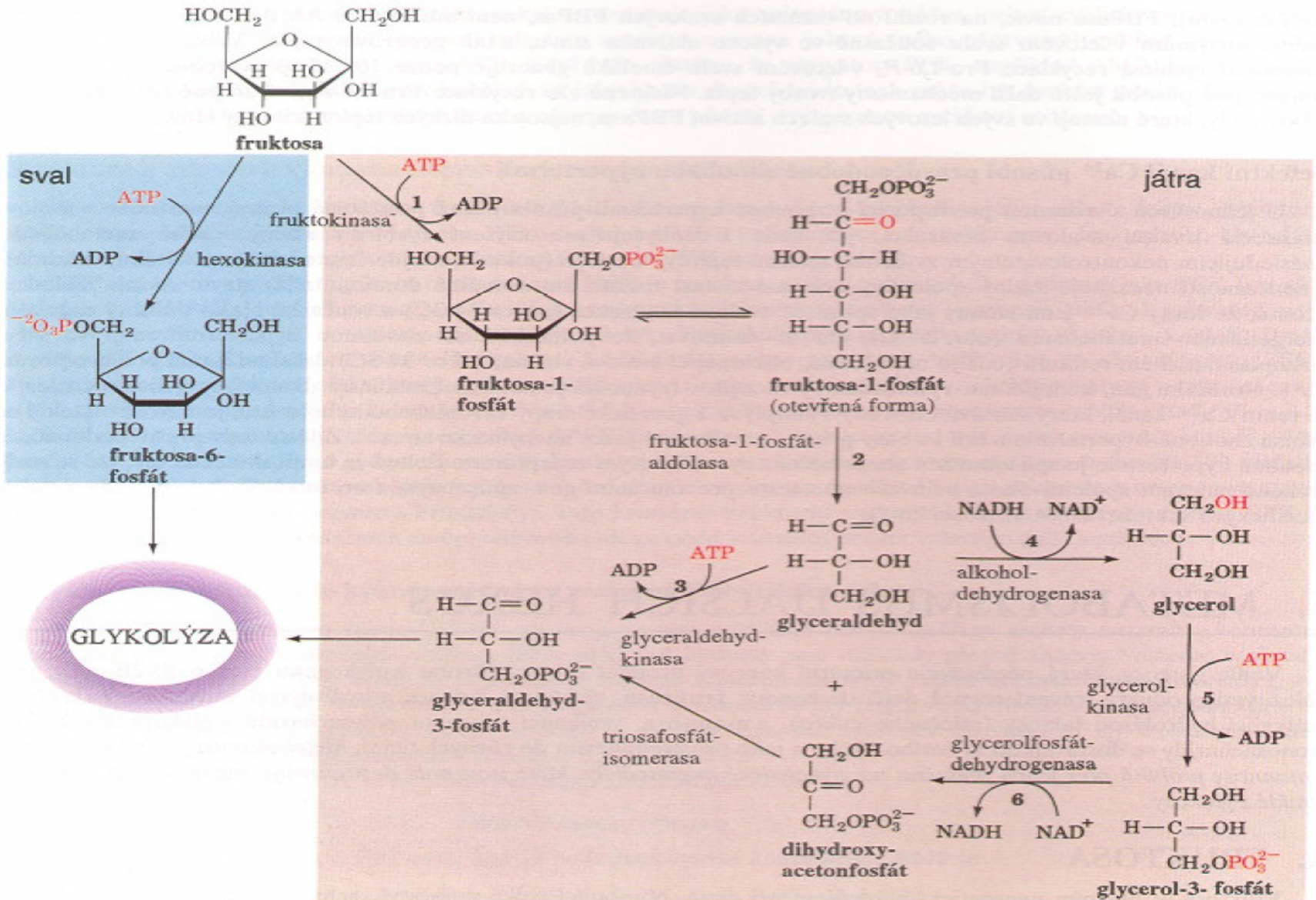
Calvinův cyklus



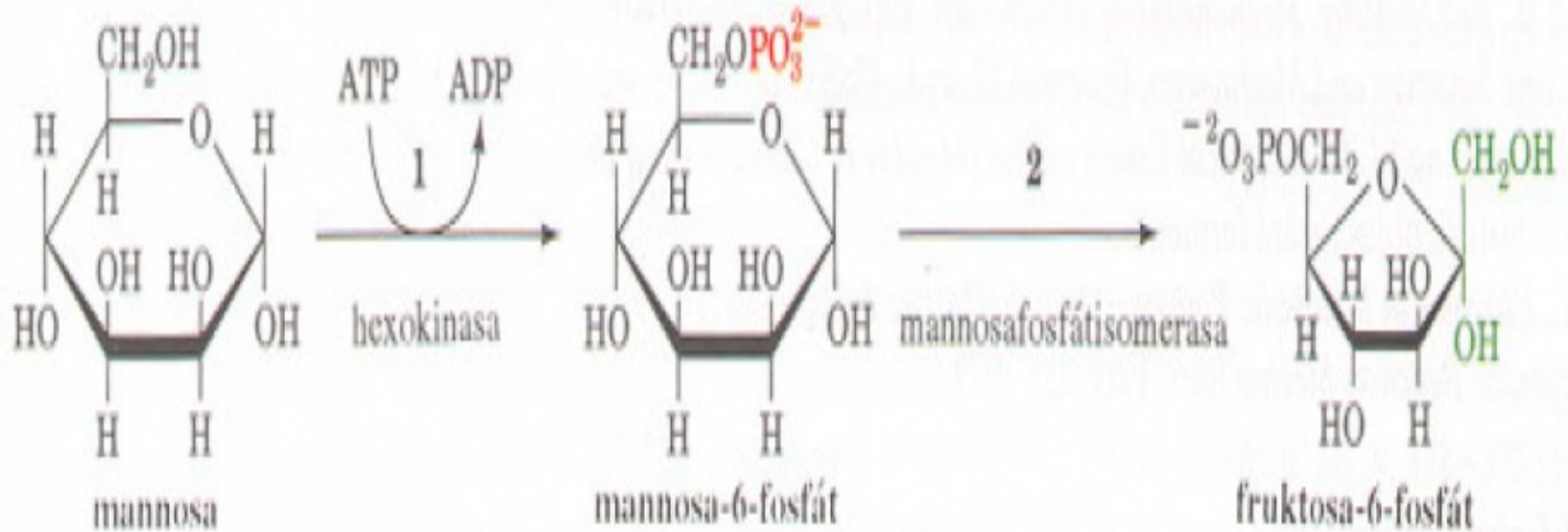


glykolýza	-	36 ATP
pentosový cyklus	-	36 ATP

# Fruktosa

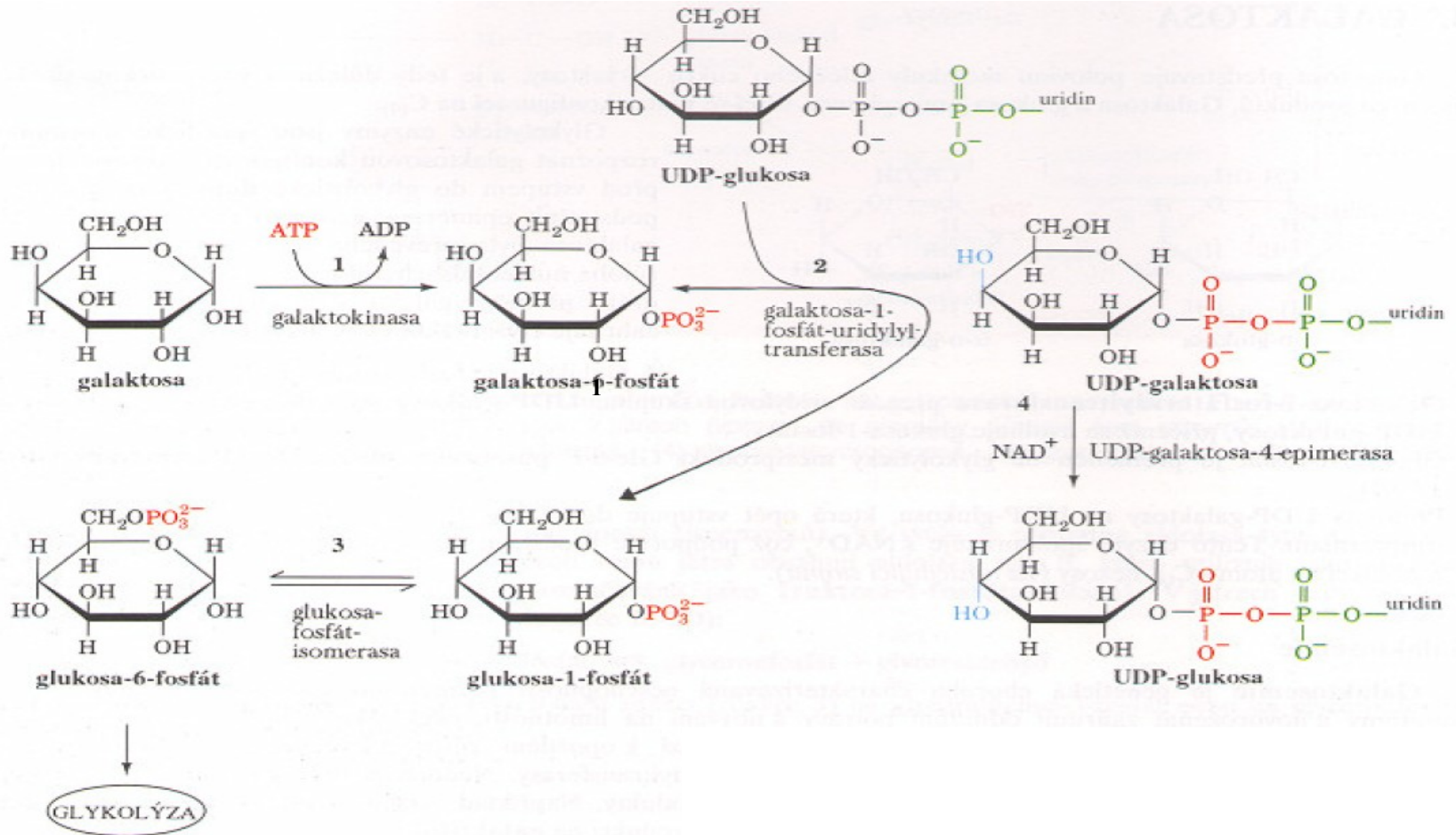


# Manosa



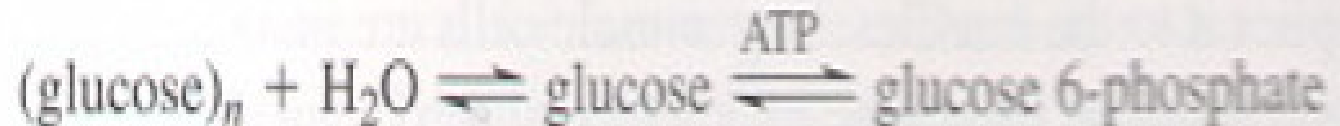


# Galaktosa



# Glykogen

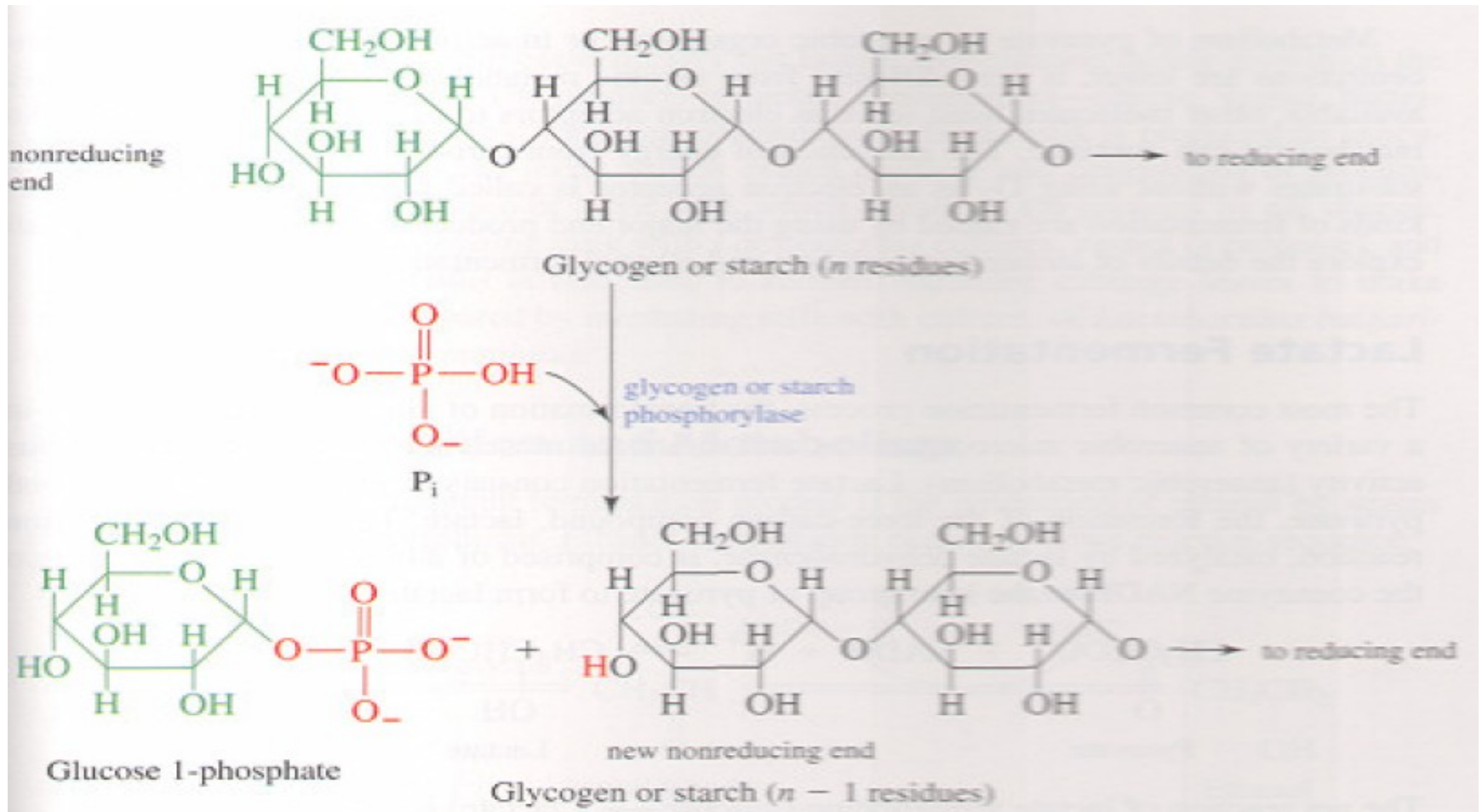
*Hydrolytic cleavage catalyzed by amylase:*



*Phosphorolytic cleavage catalyzed by phosphorylase:*



# Glykogen

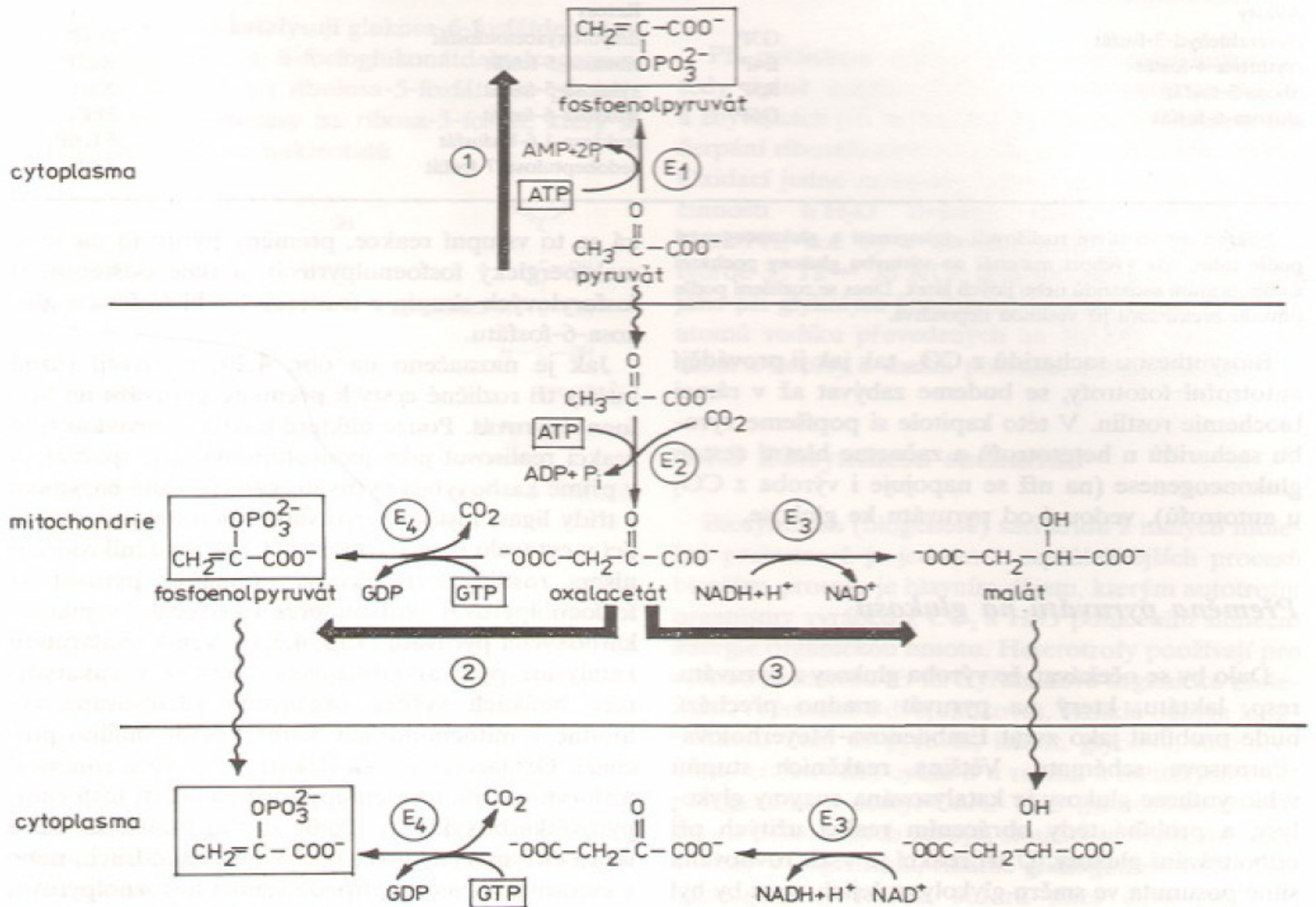


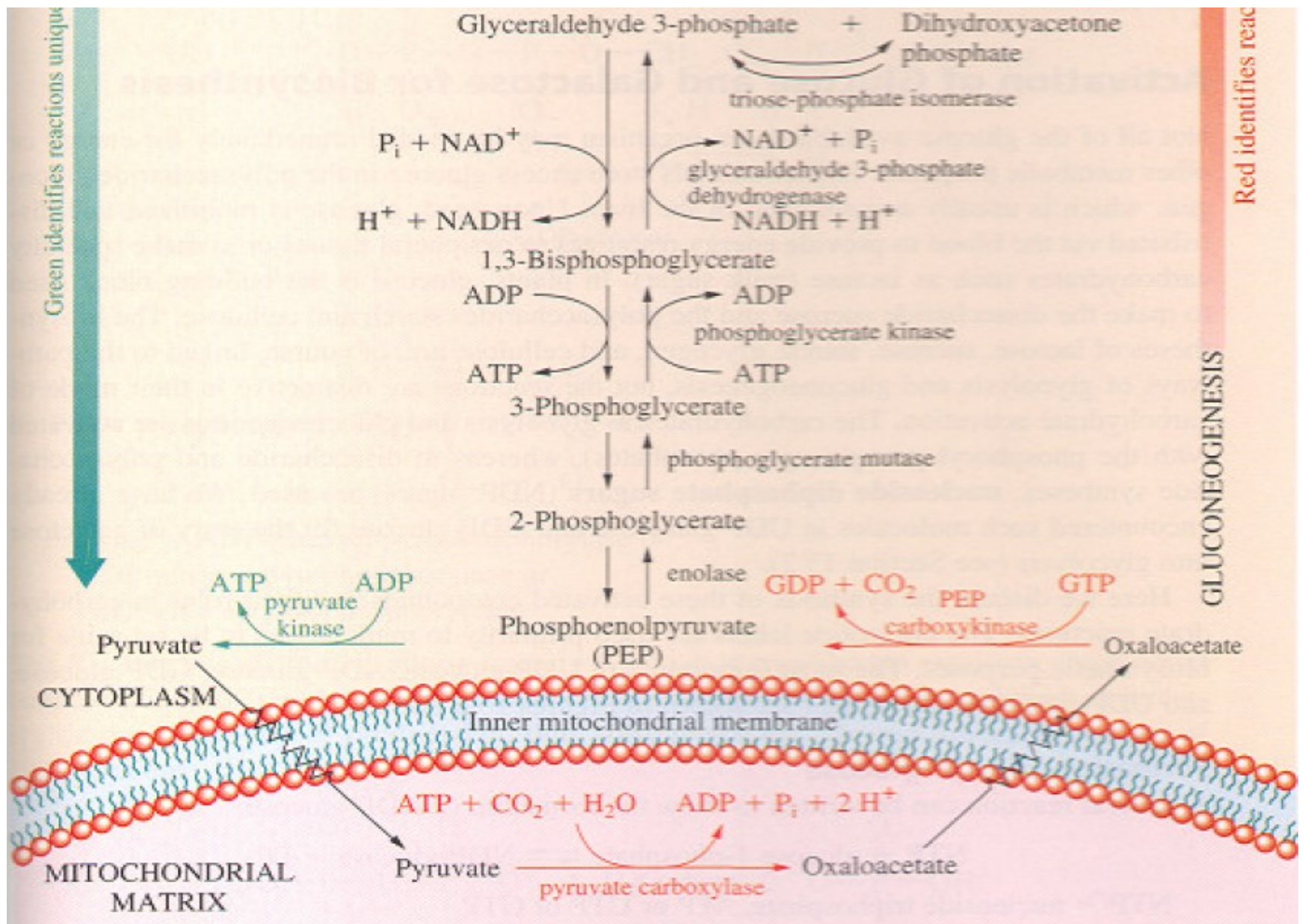
## BIOSYNTÉZA SACHARIDŮ

- Glukoneogenese
- Fotosyntéza

# Glukoneogeneze

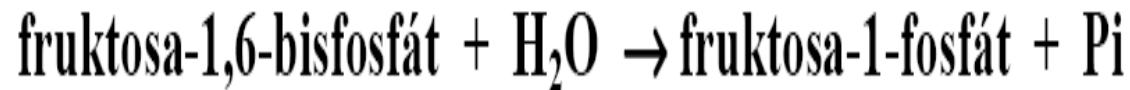
## 1. Vznik fosfoenolpyruvátu





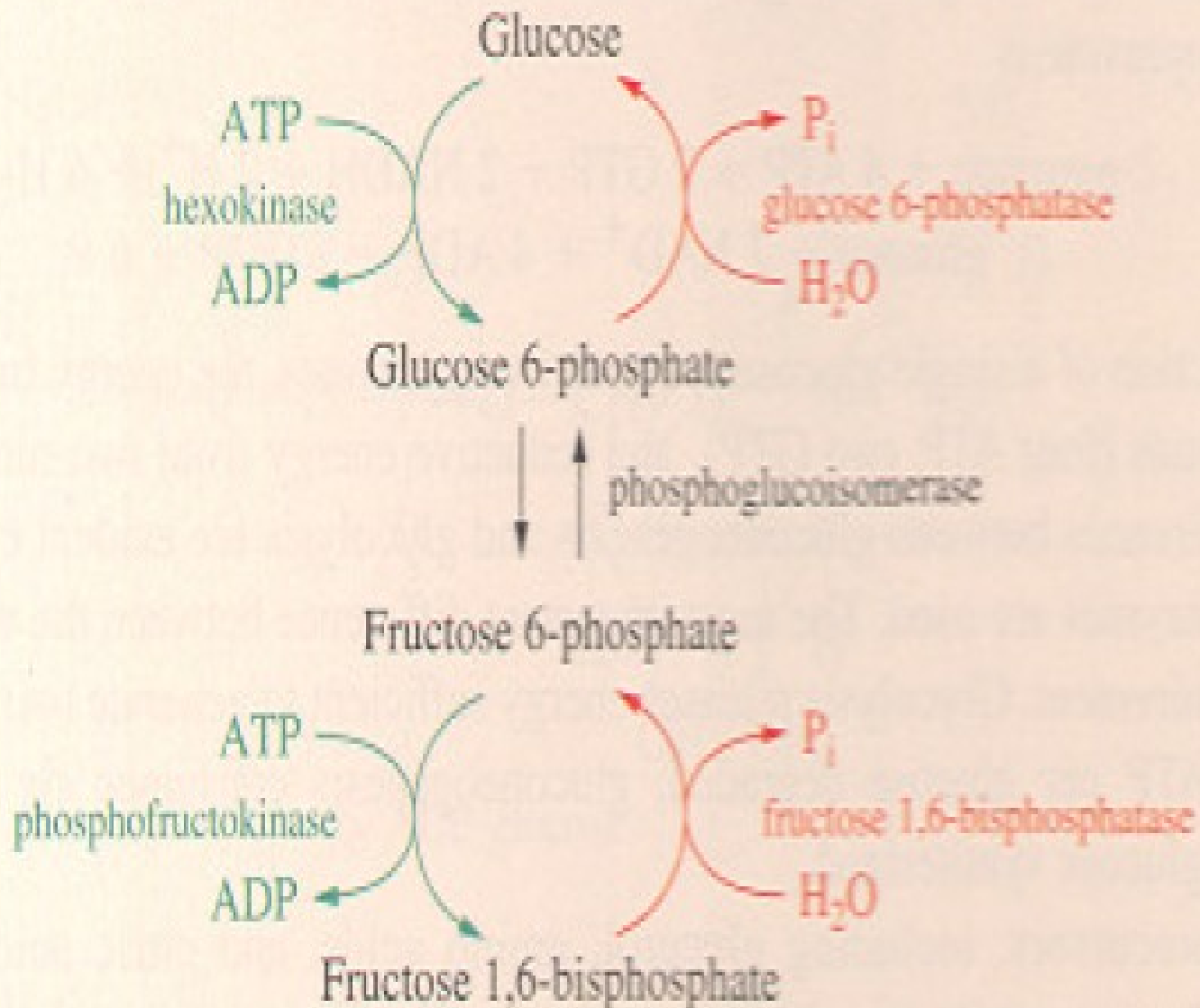
## 2. *Hydrolytické reakce*

### A. fruktosabisfosfatasa



### B. glukosafosfatasa







---

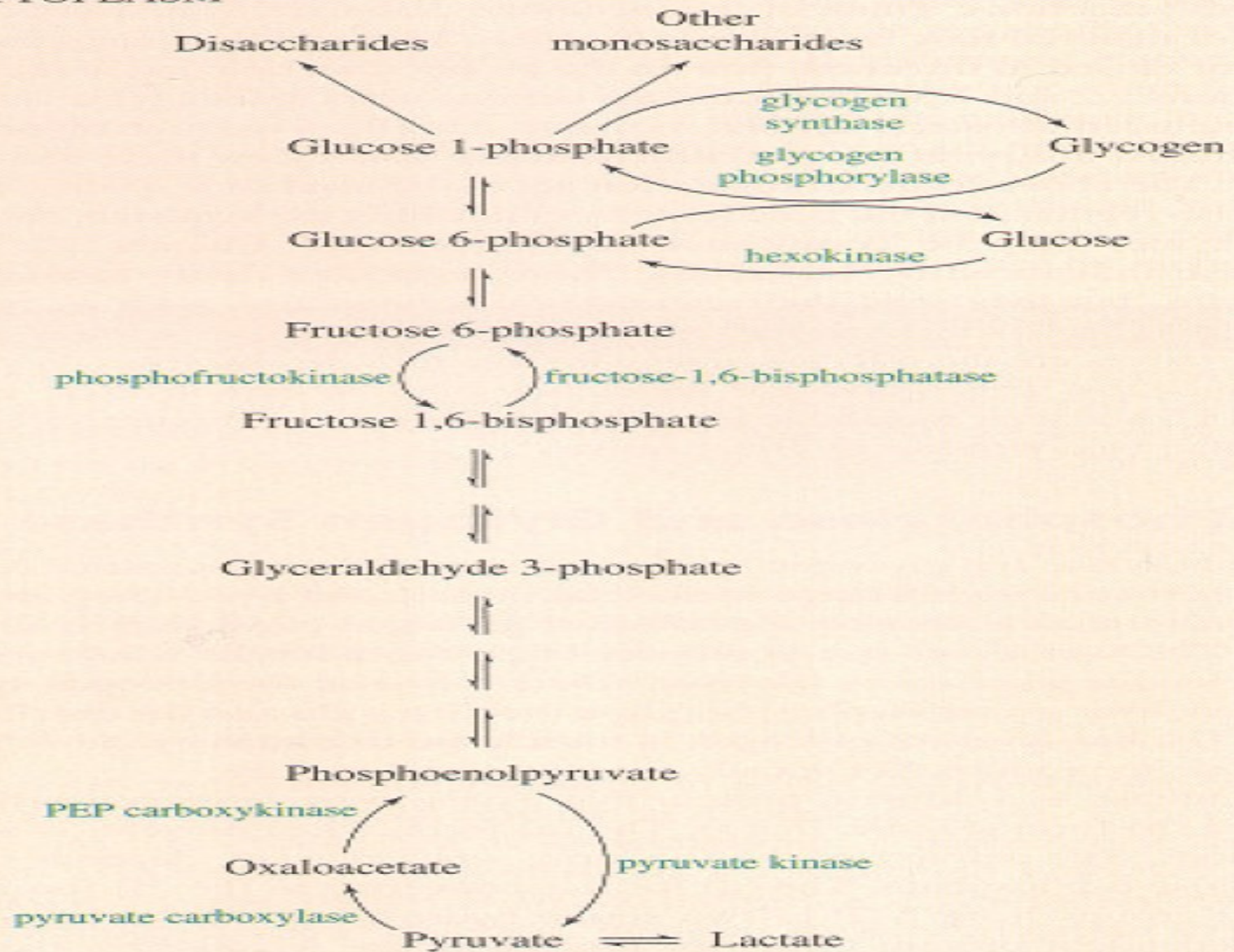
## Bilance glukoneogenese

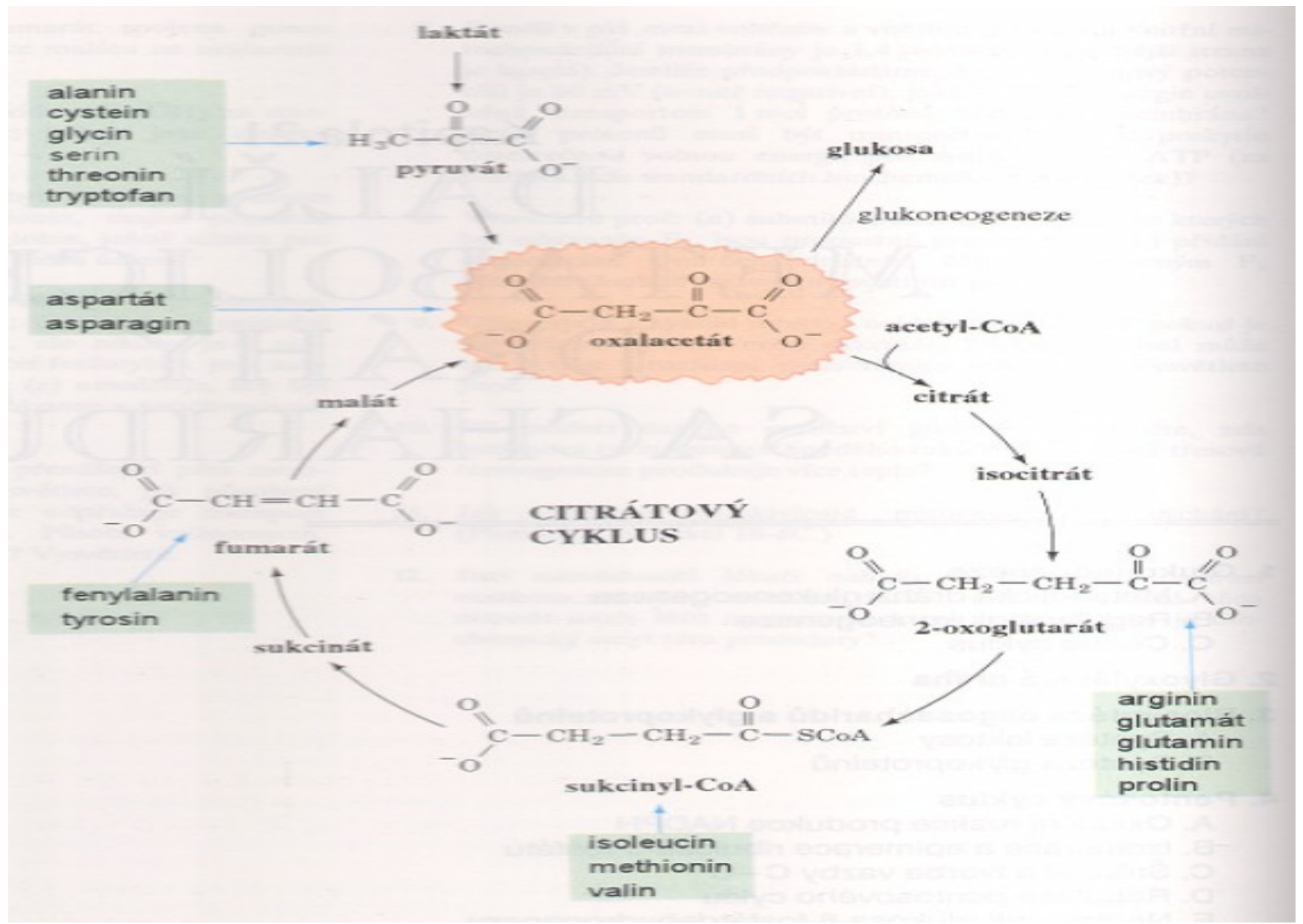


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$$\text{glykolysa (8 ATP) - glukoneogenese (12 ATP) = -4 ATP}$$

CYTOPLASM

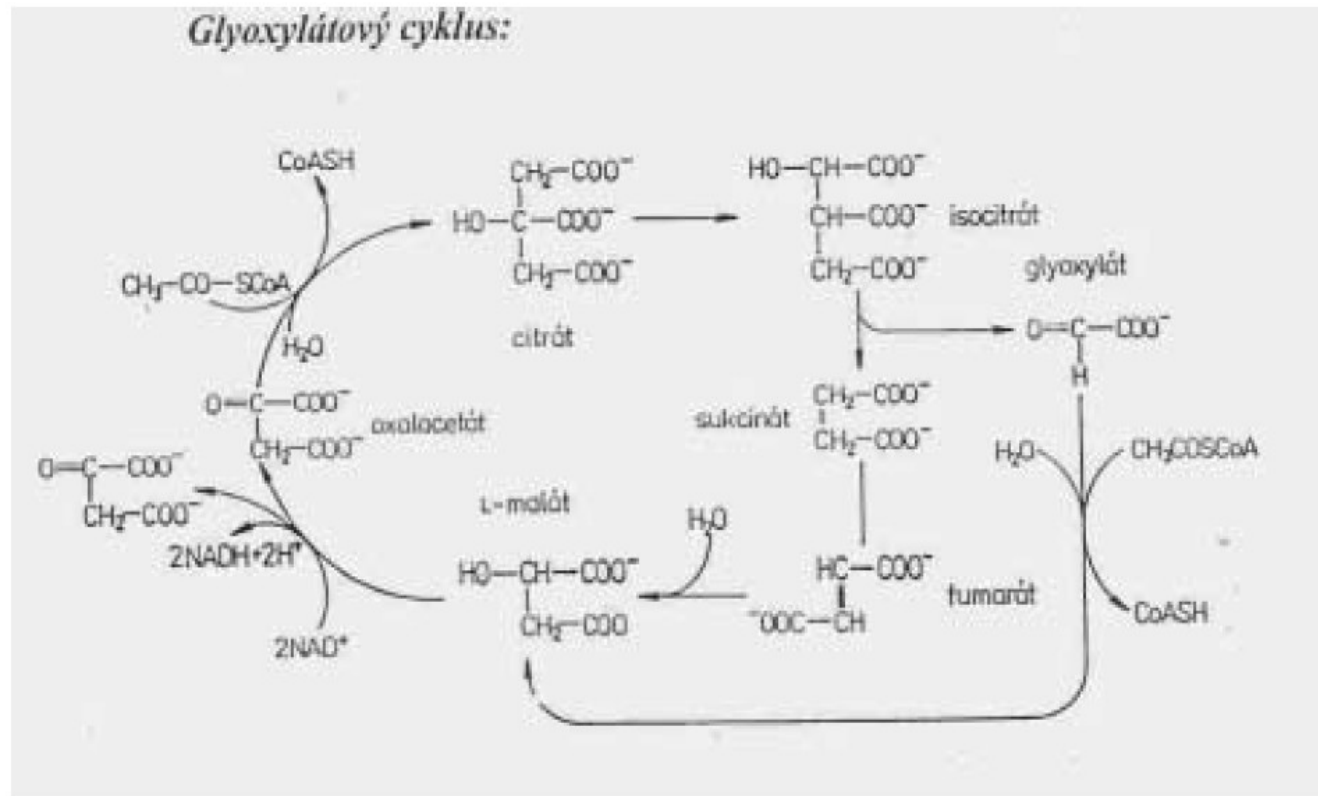




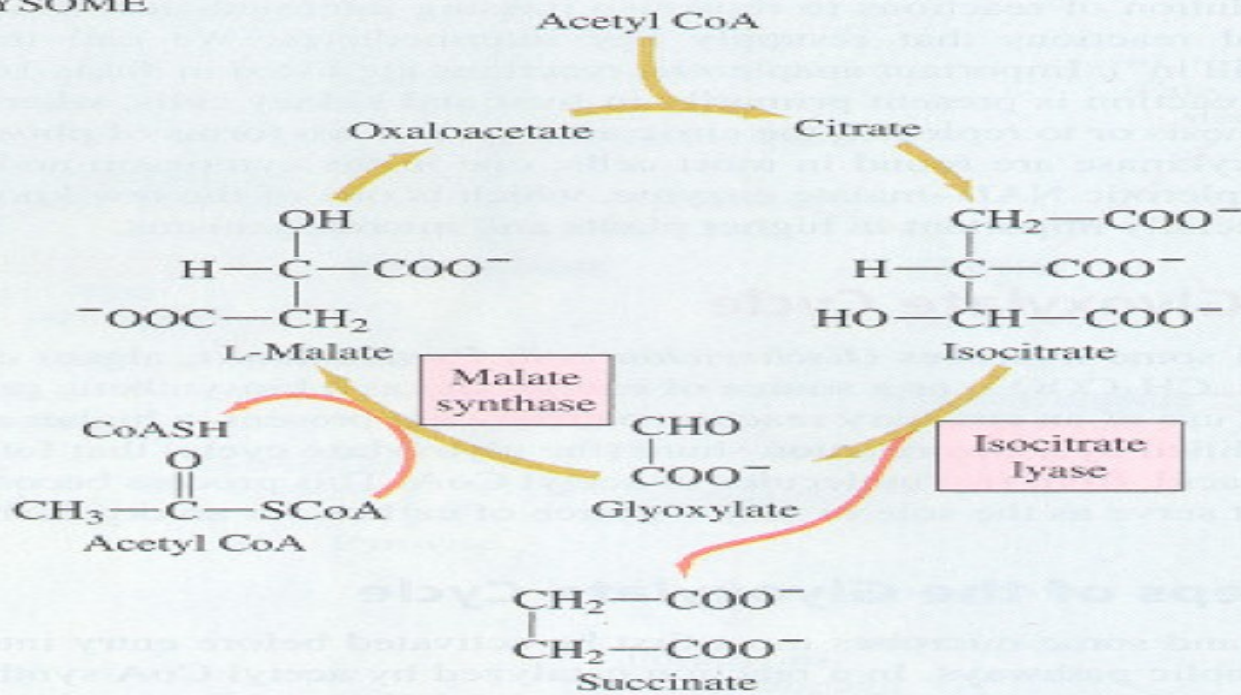
## Biosyntéza glukosy z dalších prekurzorů

- glukogenní aminokyseliny - pyruvát a meziproducty citrátového cyklu
- lipidy - glycerol a acetylCoA

### *Glyoxylátový cyklus:*



# GLYOXYSSOME



## MITOCHONDRIA

Succinate → Fumarate → L-Malate

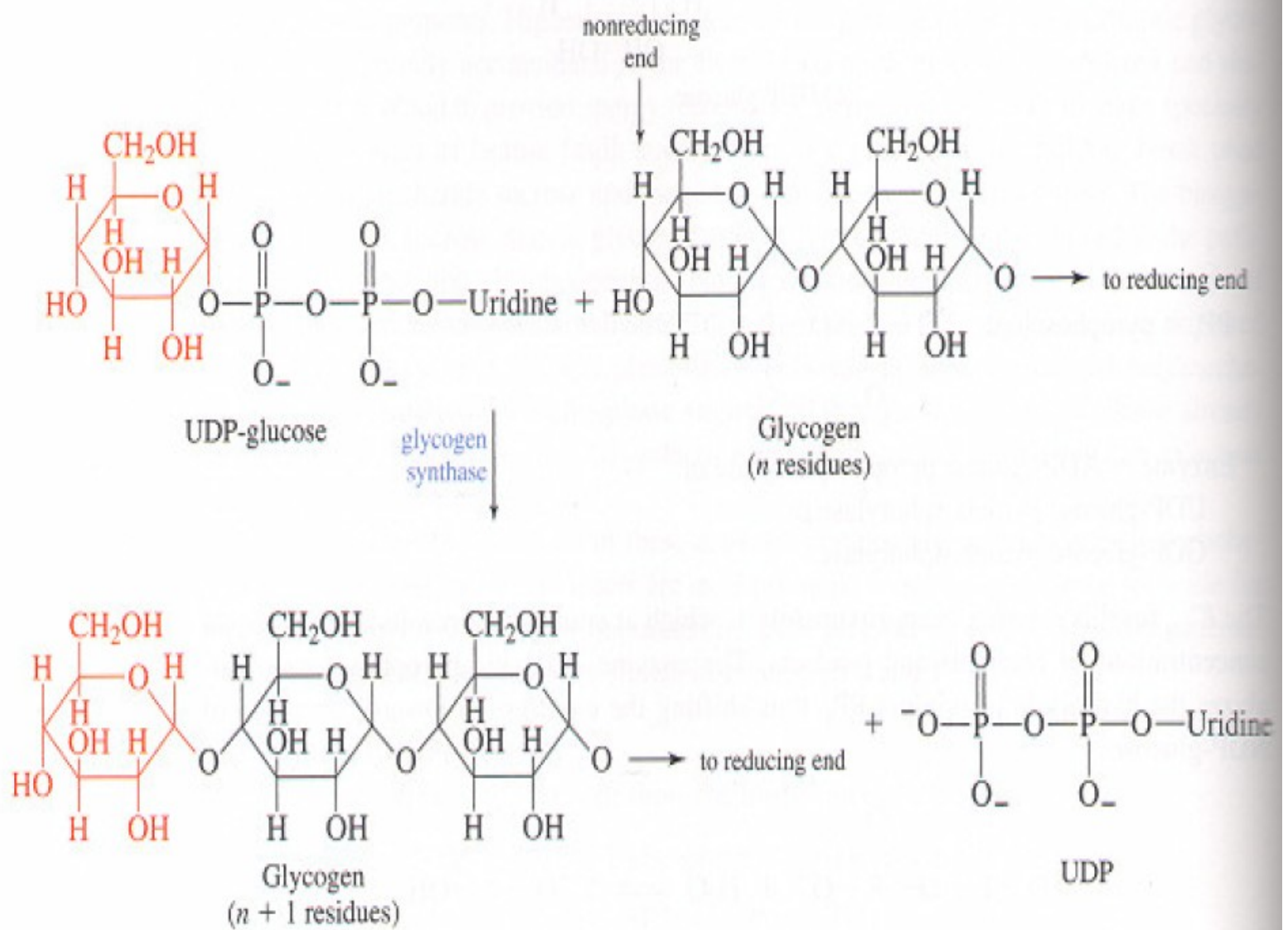
## CYTOPLASM

Phosphoenolpyruvate ← Oxaloacetate ← L-Malate

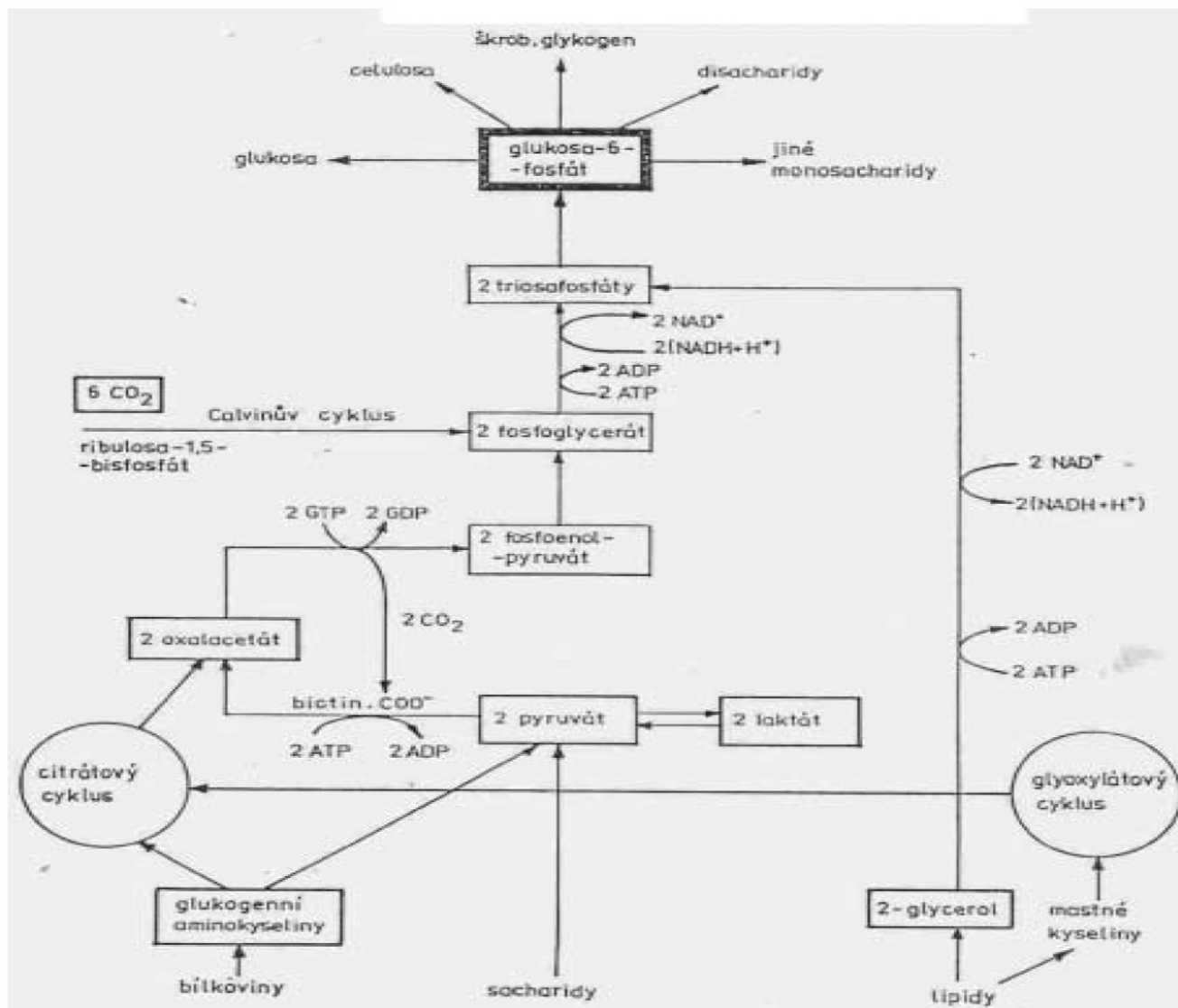
(Gluconeogenesis)

Glucose

# Biosyntéza oligo- a polysacharidů



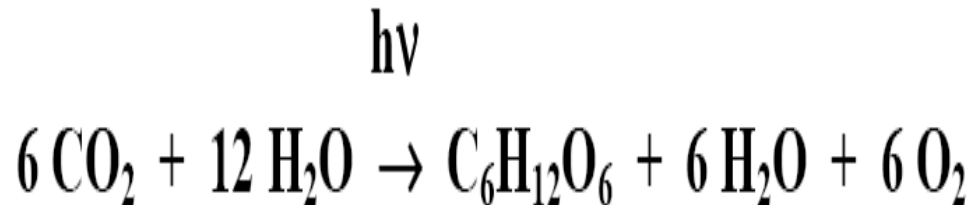
# BIOSYNTÉZA SACHARIDŮ



# FOTOSYNTÉZA

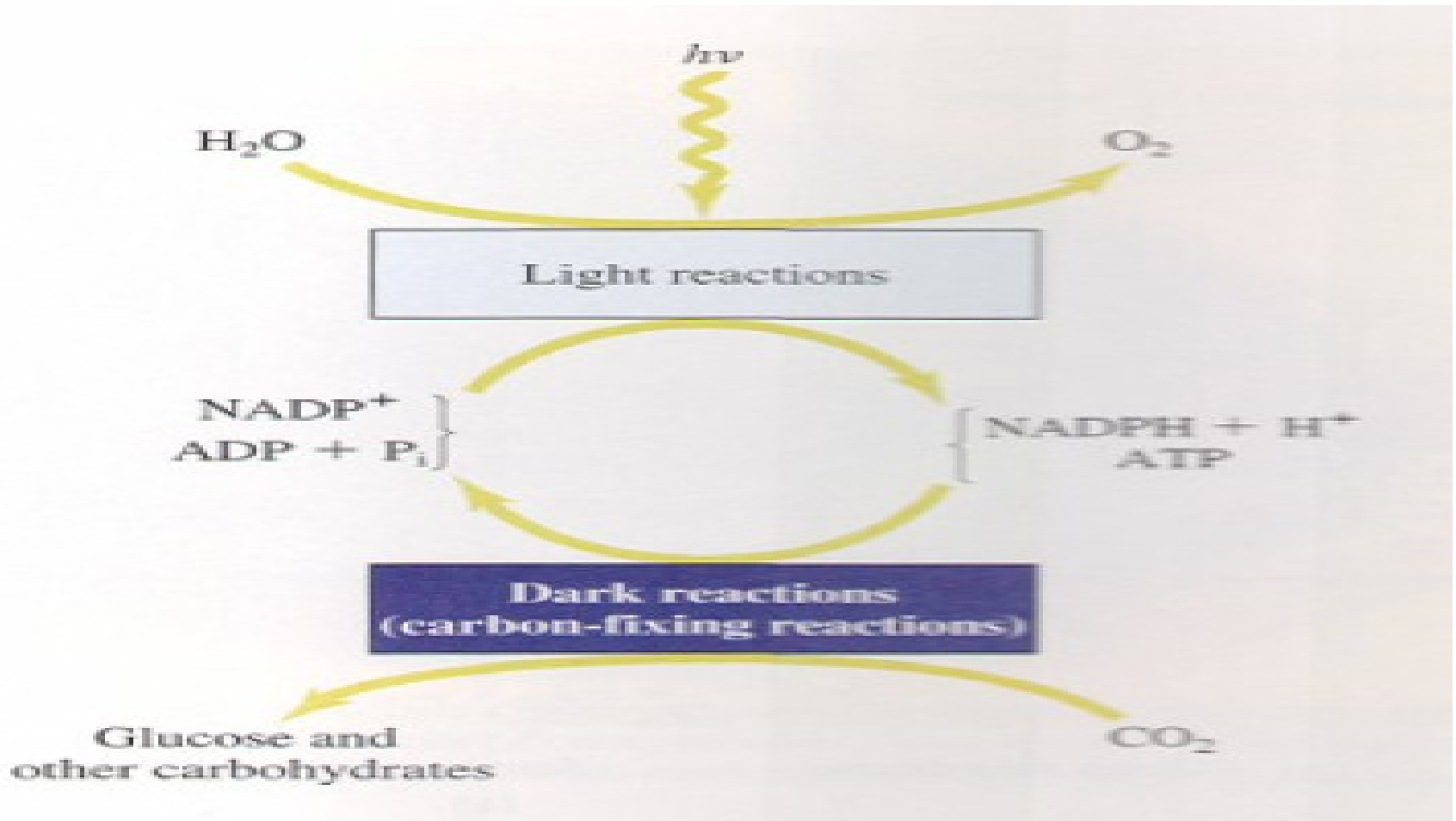
## Význam :

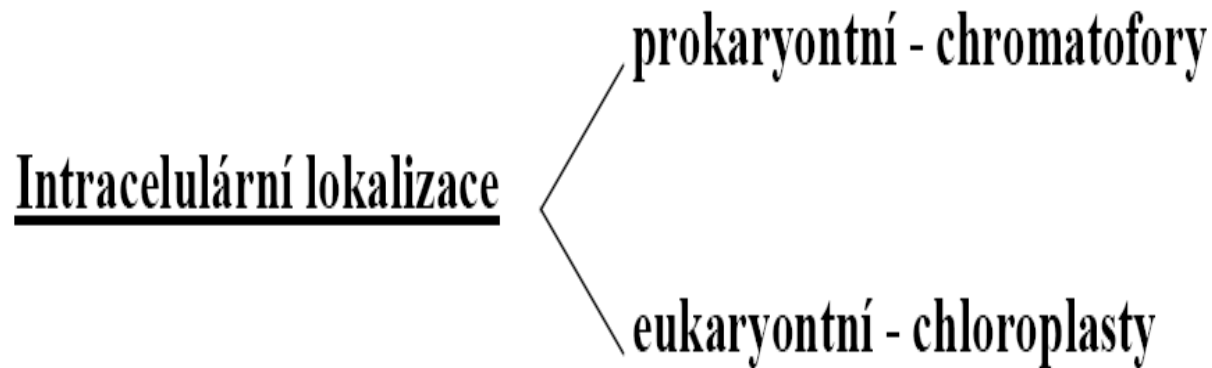
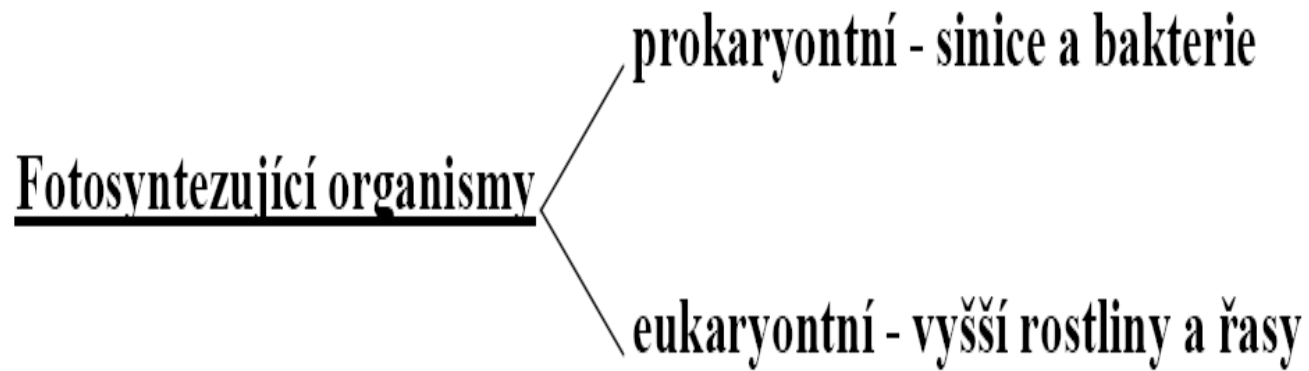
- zachycení sluneční energie a syntéza glukosy z  $\text{CO}_2$  a  $\text{H}_2\text{O}$
- produkce  $\text{O}_2$



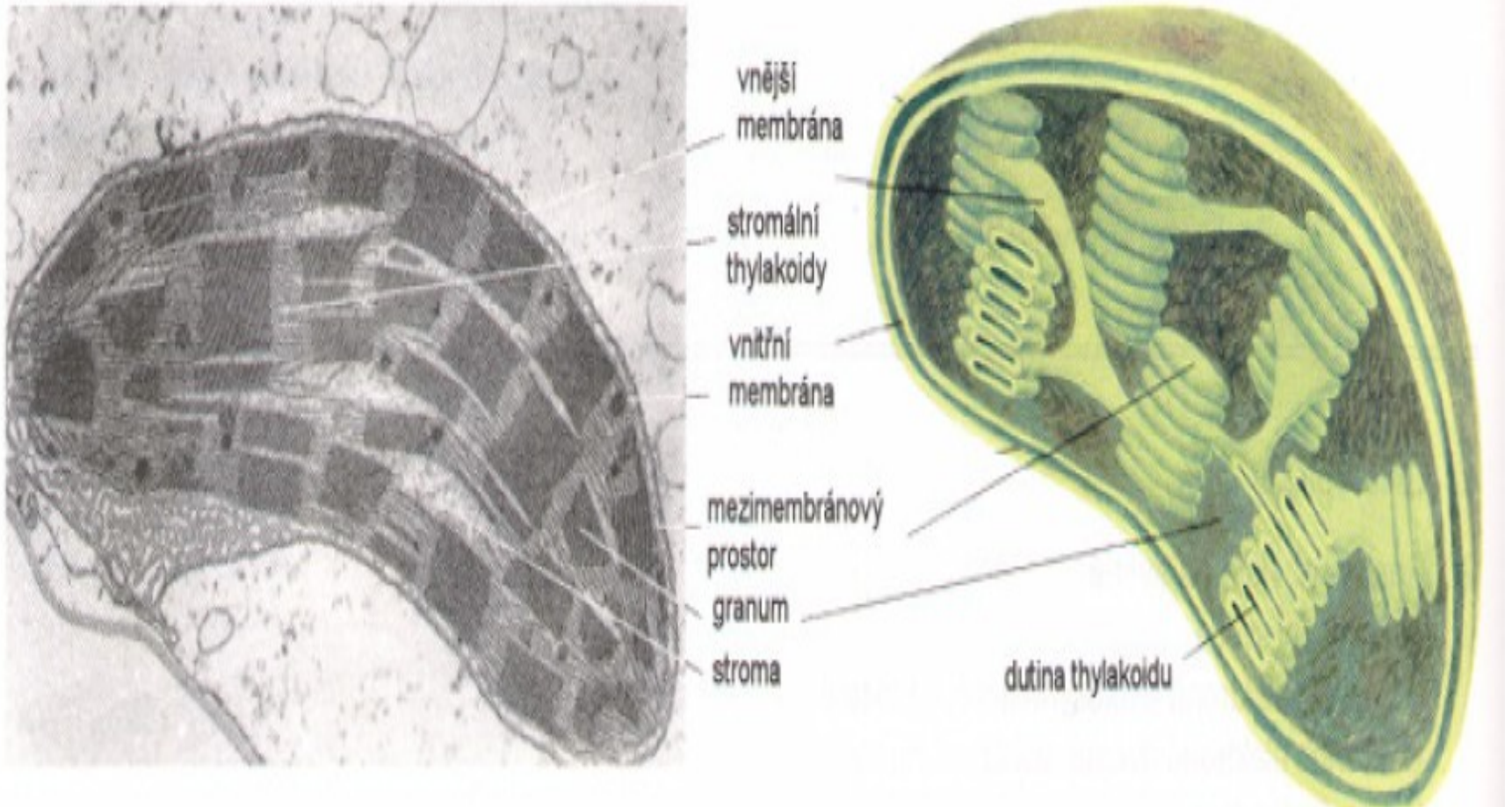


# Světelná a temná fáze





# Chloroplast





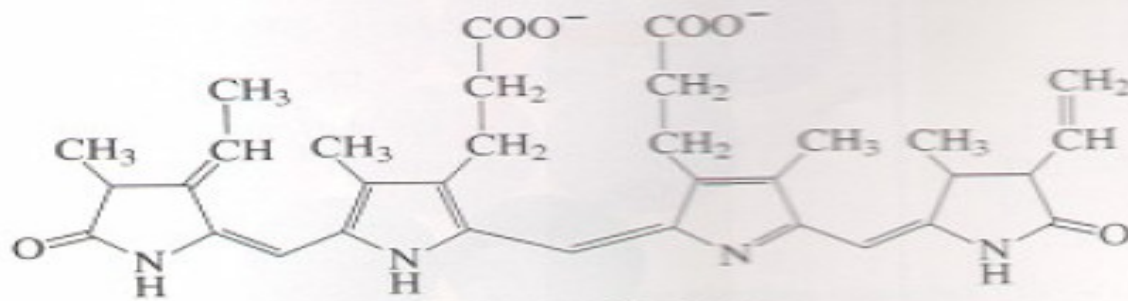
# Pomocná barviva



(a)  $\beta$ -Carotene



(b) Lutein



(c) Phycoerythrobilin

absorpce

chlorofyl a

chlorofyl b

sluneční spektrum

karotenoidy

fykoerythrin

fykocyanin

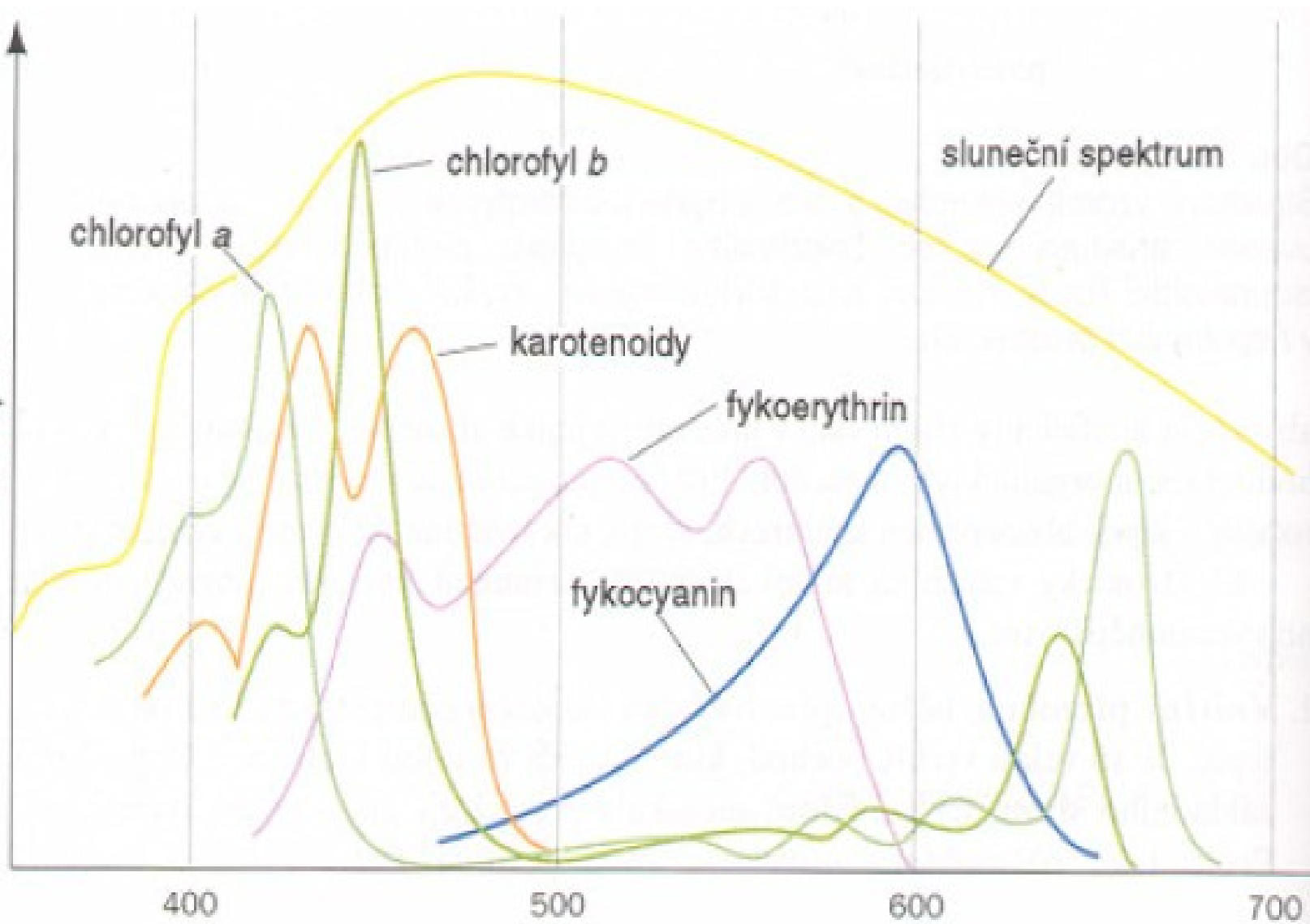
400

500

600

700

vlnová délka (nm)



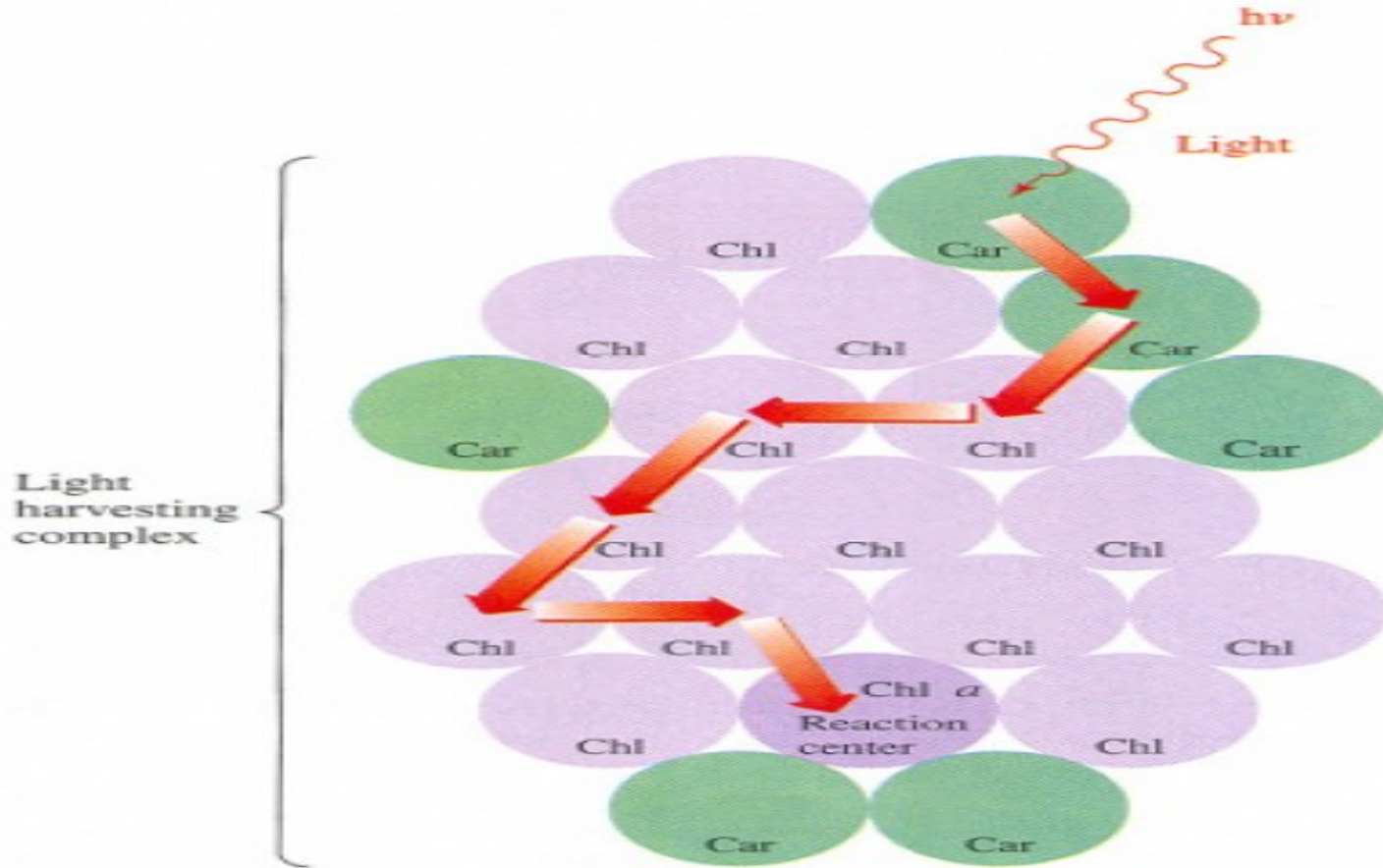
## Světelná fáze

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

### NADP

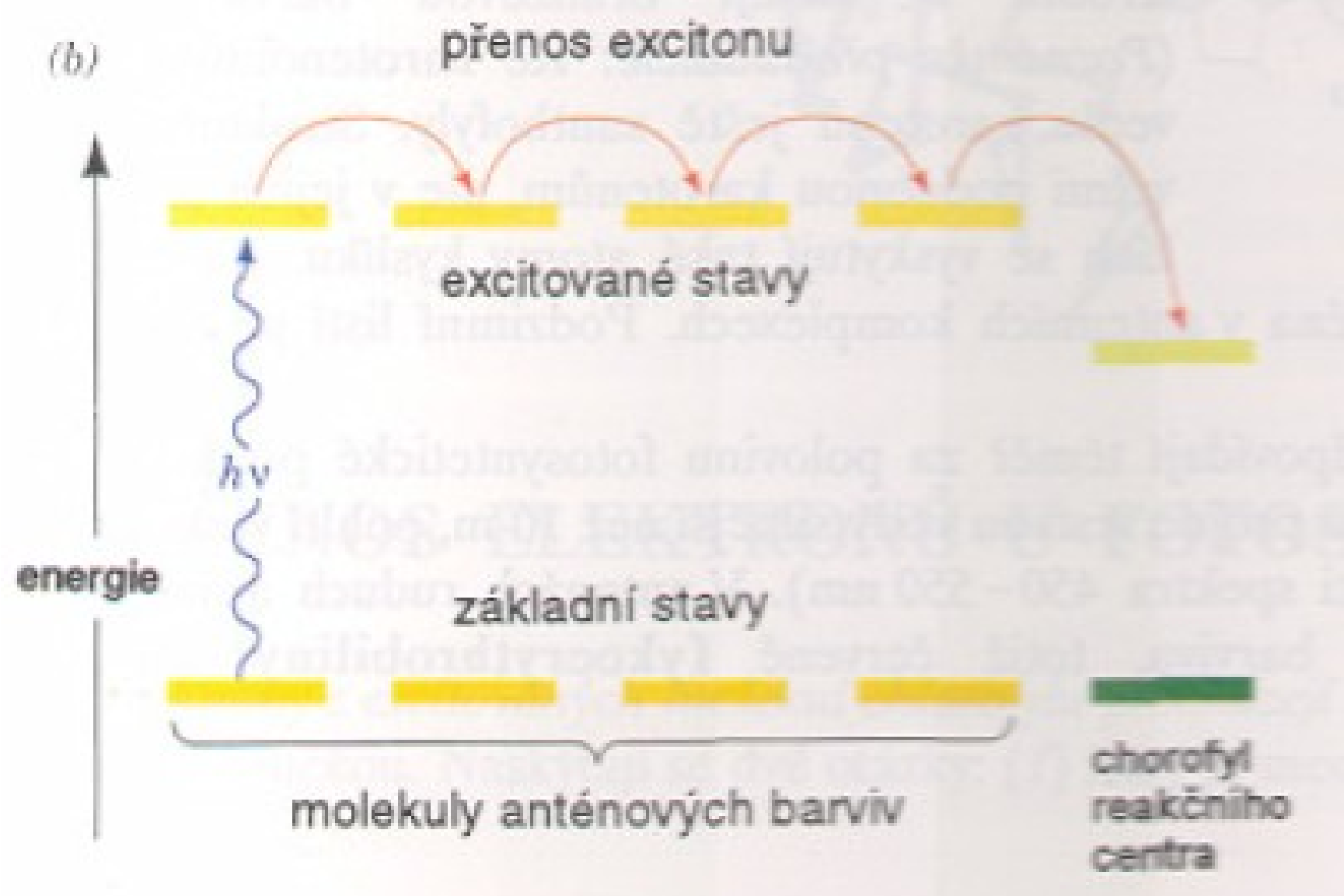
- fotolýza vody -  $\text{H}_2\text{O} \rightarrow 2 \text{H}^+ + 2 \text{e}^- + \frac{1}{2} \text{O}_2$
- spřažení transportu elektronů se syntézou ATP

# Proces zachycení záření kvantosomy





(b)



přenos excitonu

excitované stavy

základní stavy

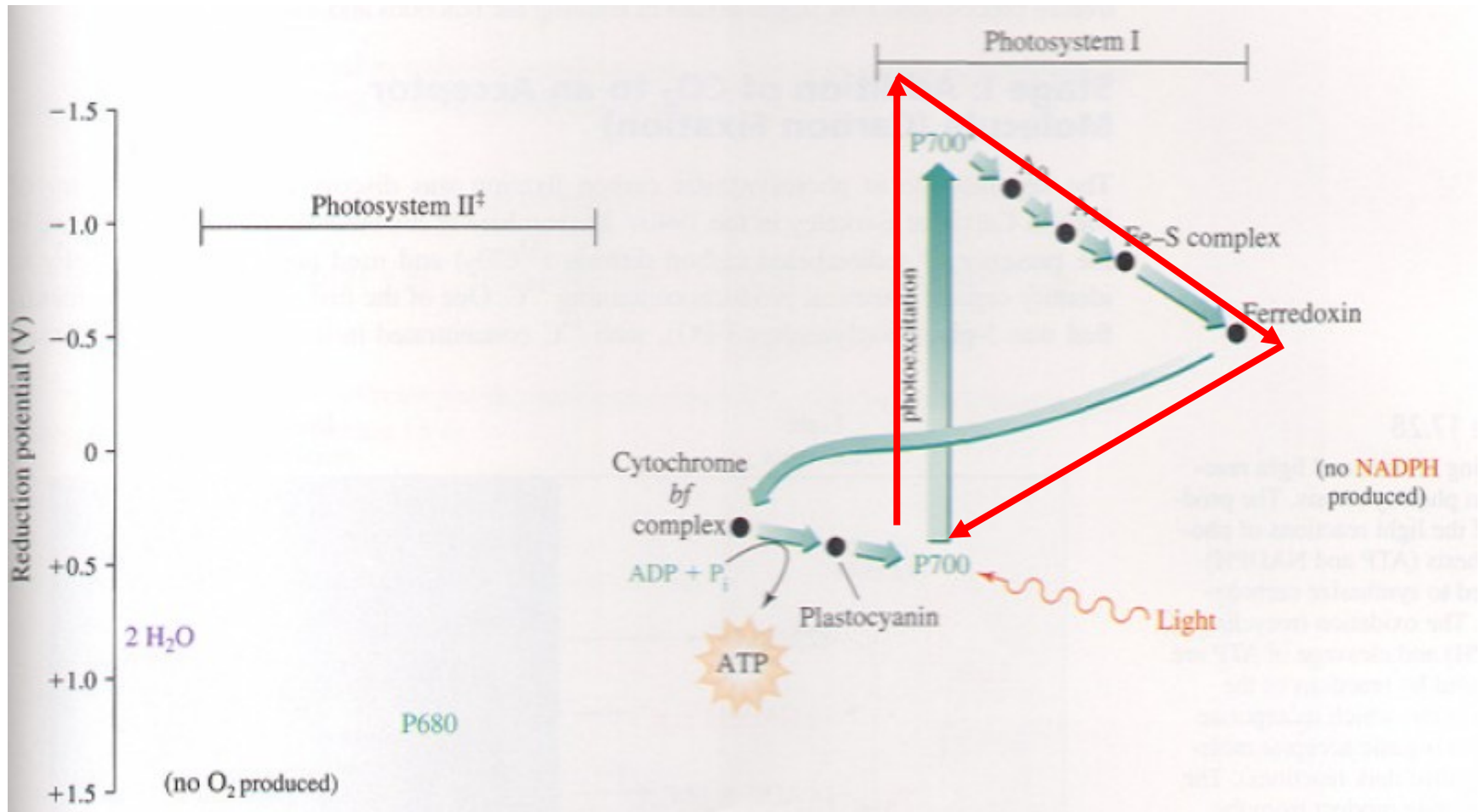
molekuly anténových barviv

chorofyl  
reakčního  
centra

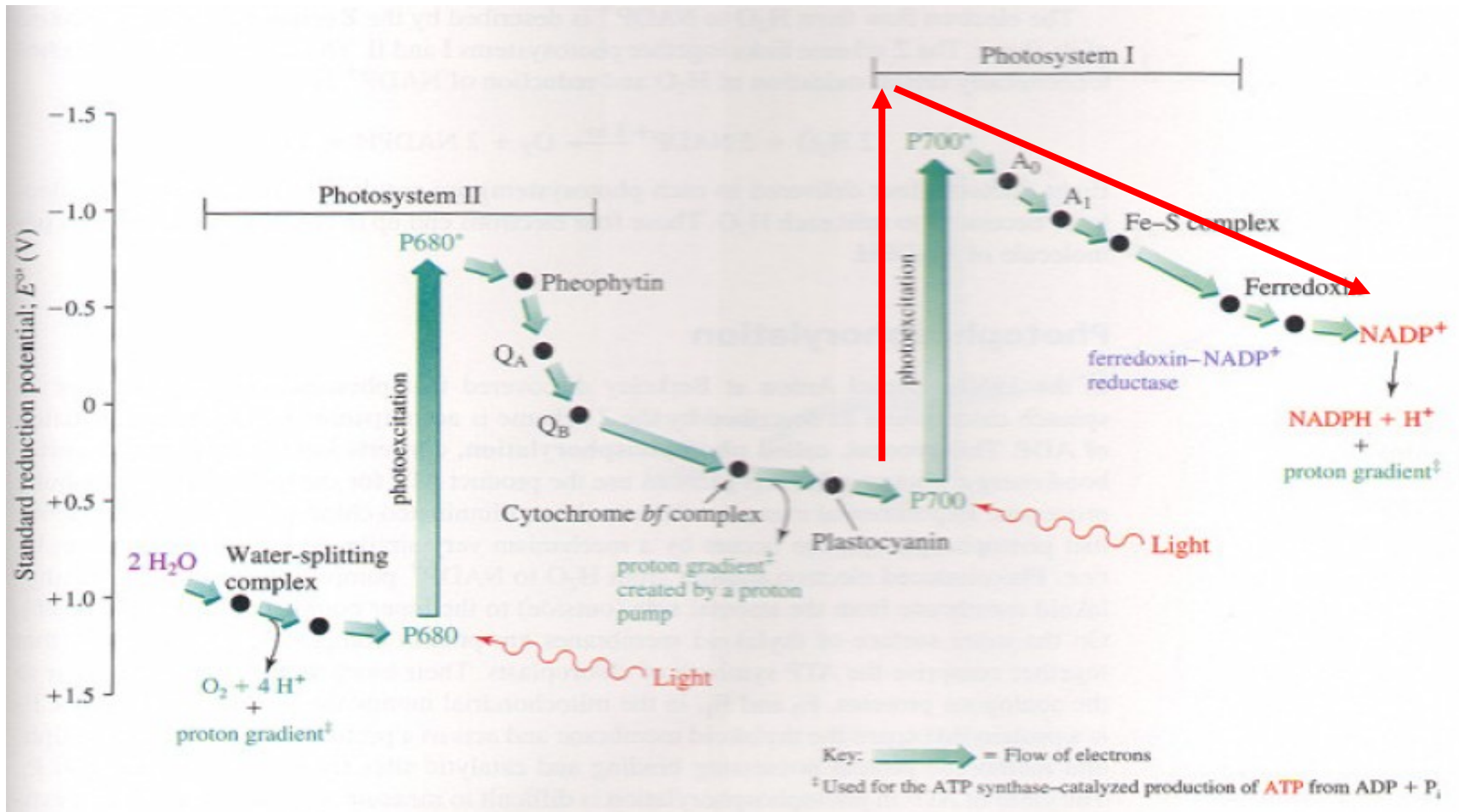
energie

$h\nu$

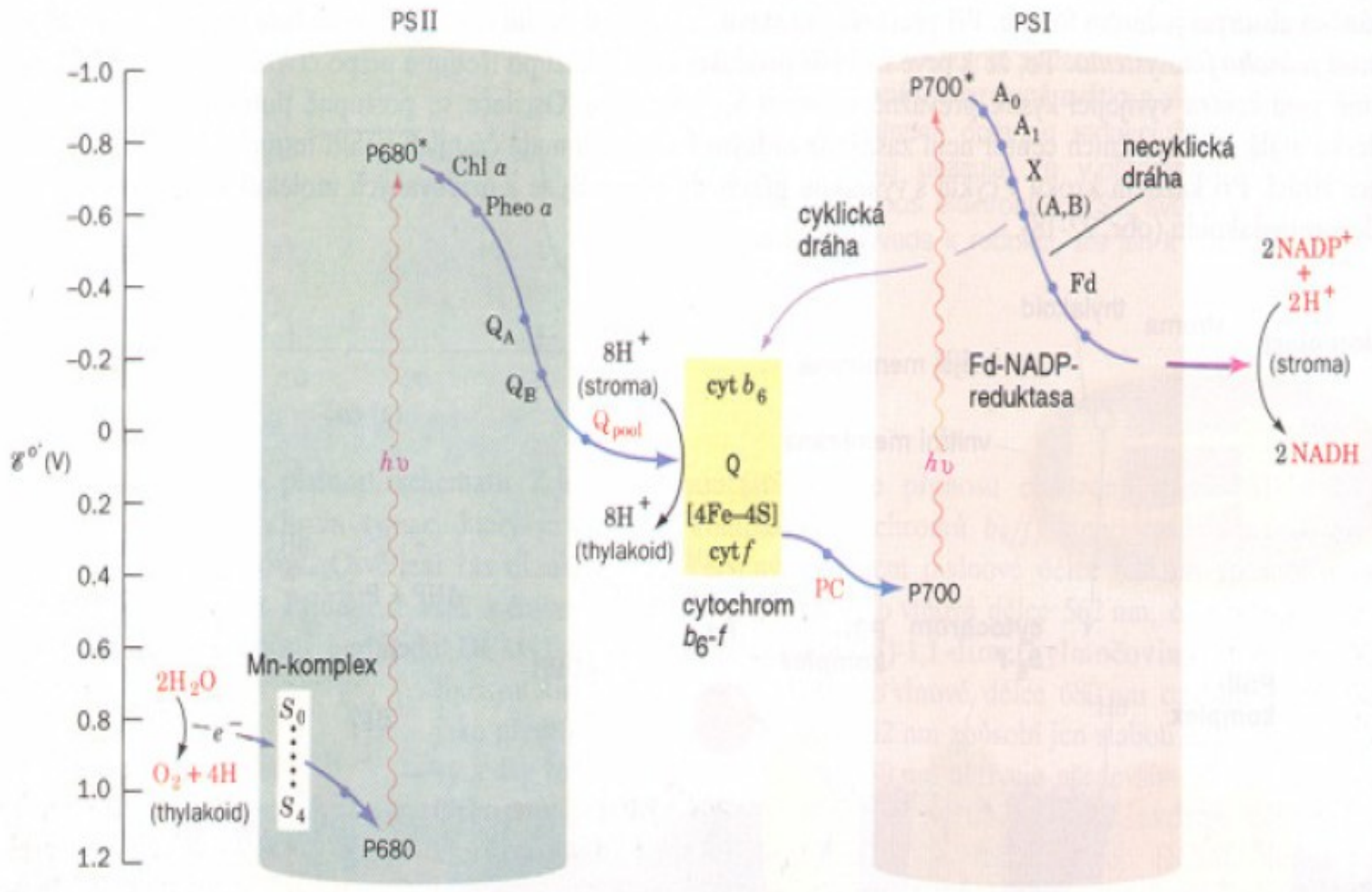
# Cyklický tok- produkce ATP



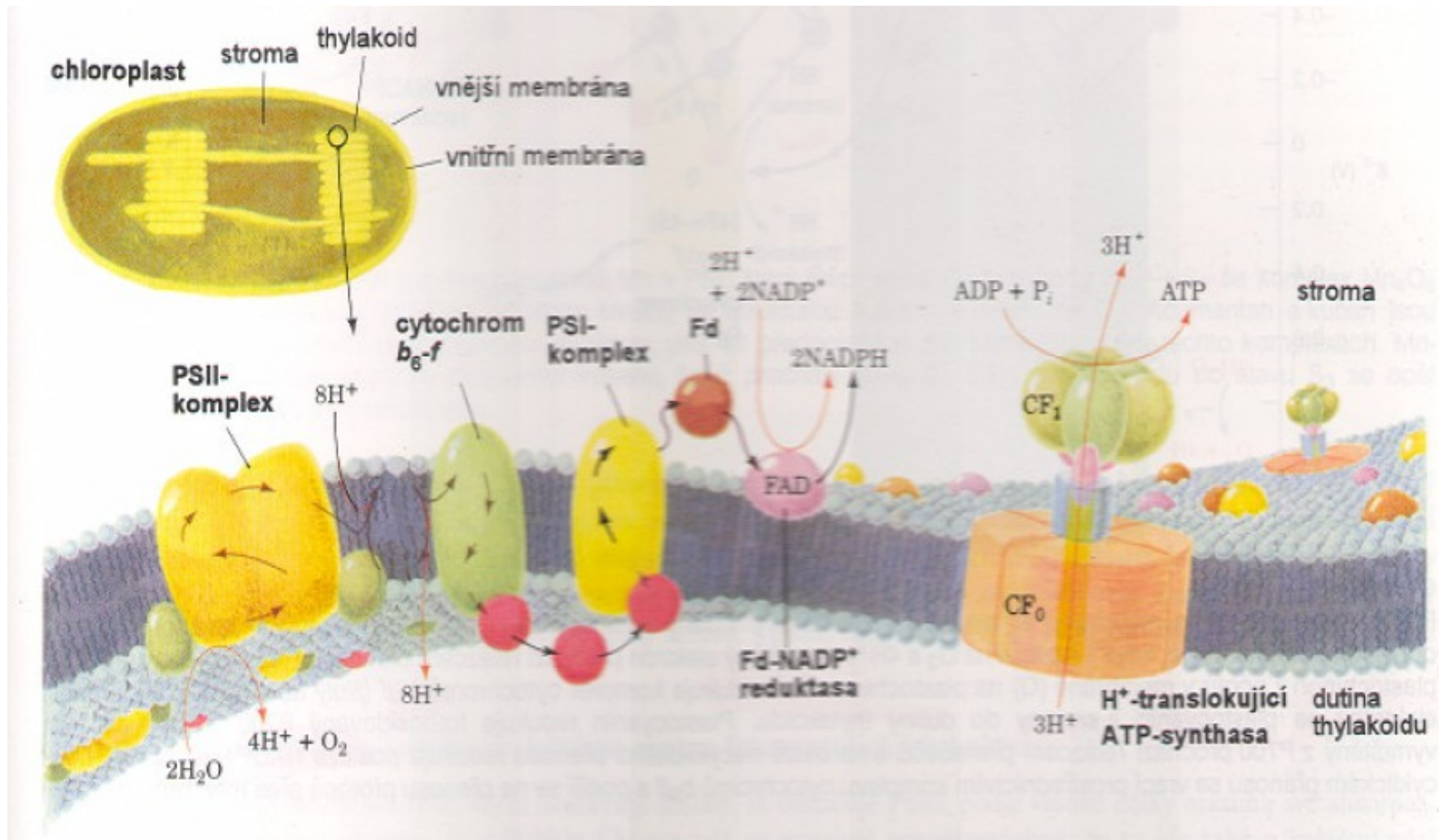
# Necyklický tok- produkce NADPH



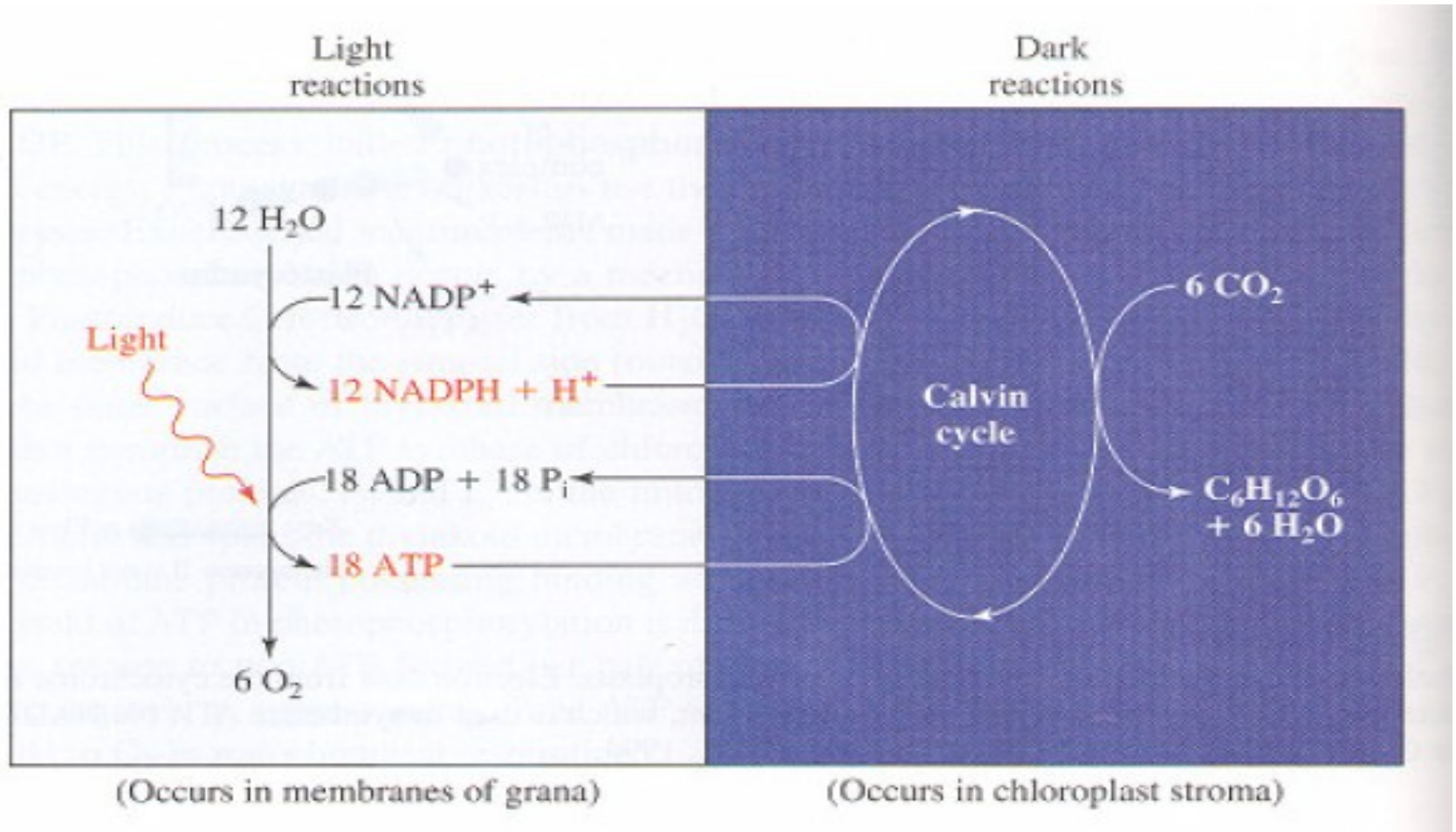
## Schéma fotosystémů I a II



# Spřažení toku elektronů a fotofosforylace

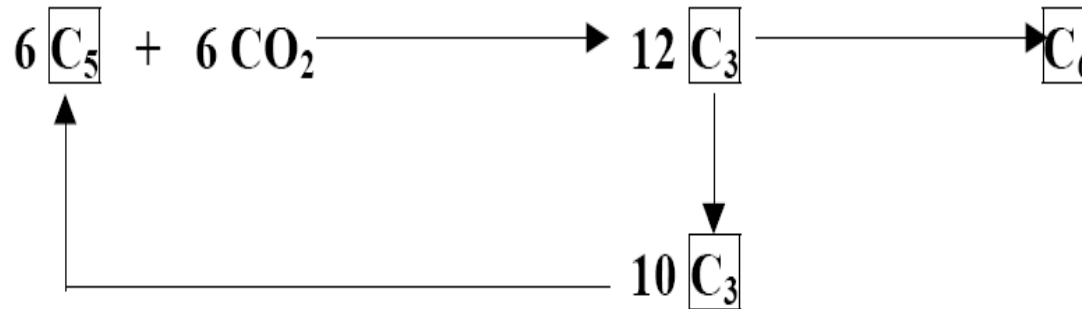


# Světelná a temná fáze



## Temná fáze

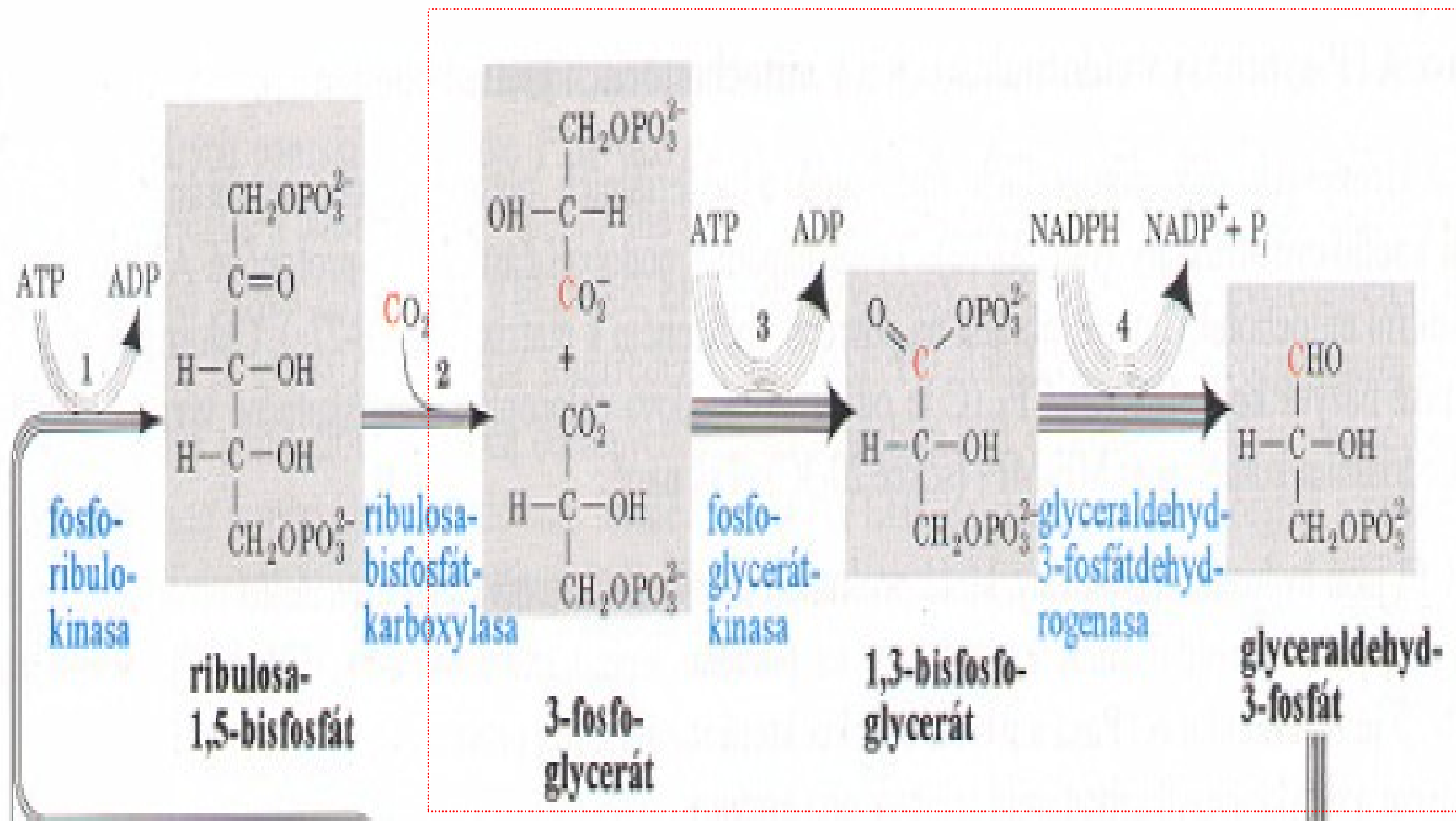
M.CALVIN



### C<sub>3</sub> rostliny

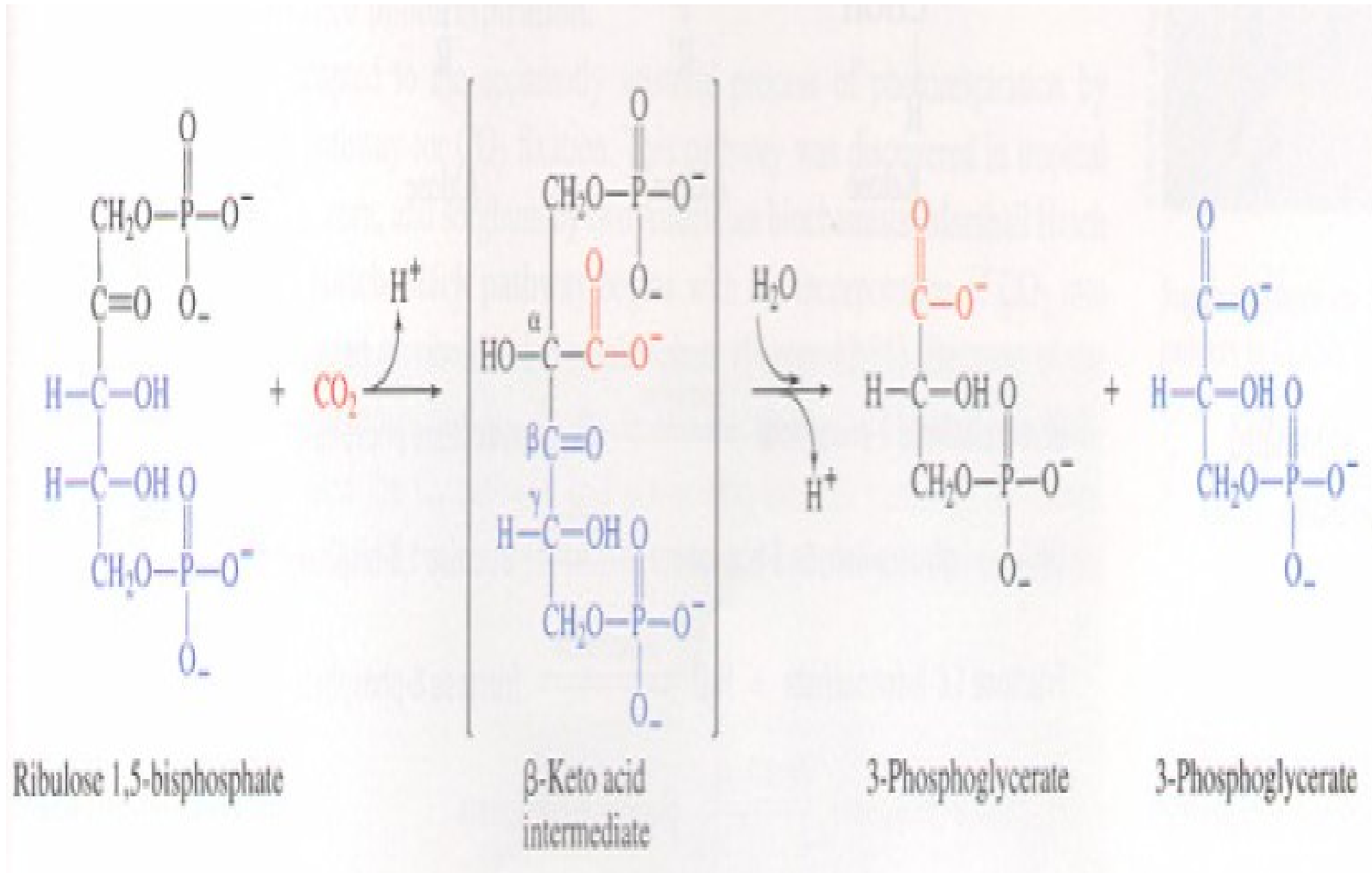
- většina rostlin a řas
- akceptor CO<sub>2</sub> ribulosa-5-P
- produkt 3-P-glycerát

# Calvinův cyklus



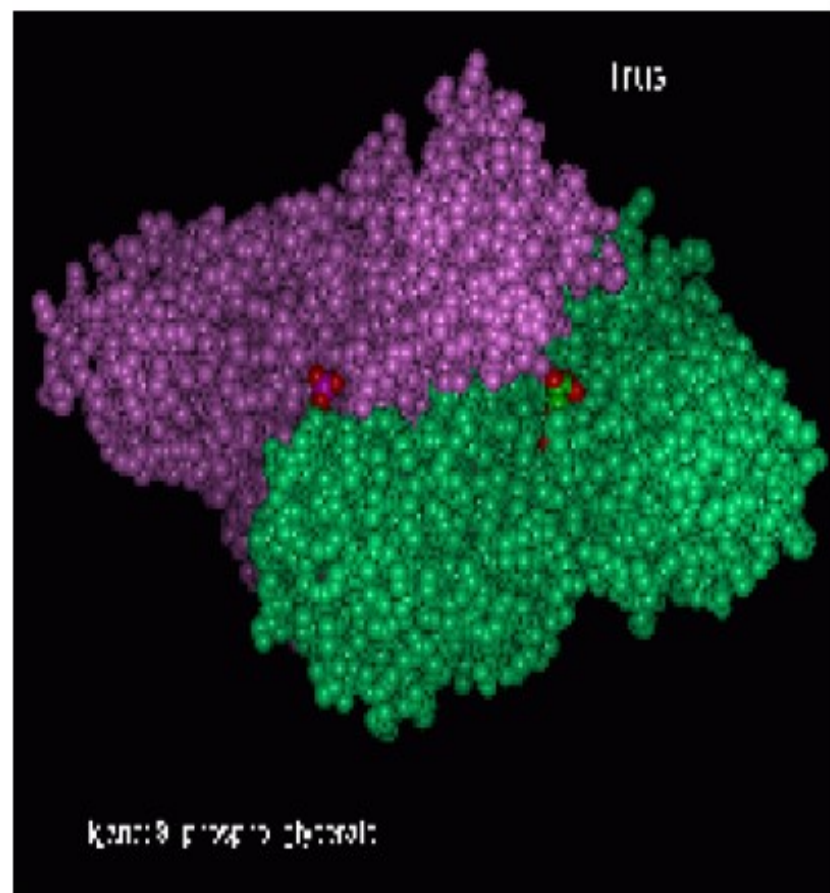


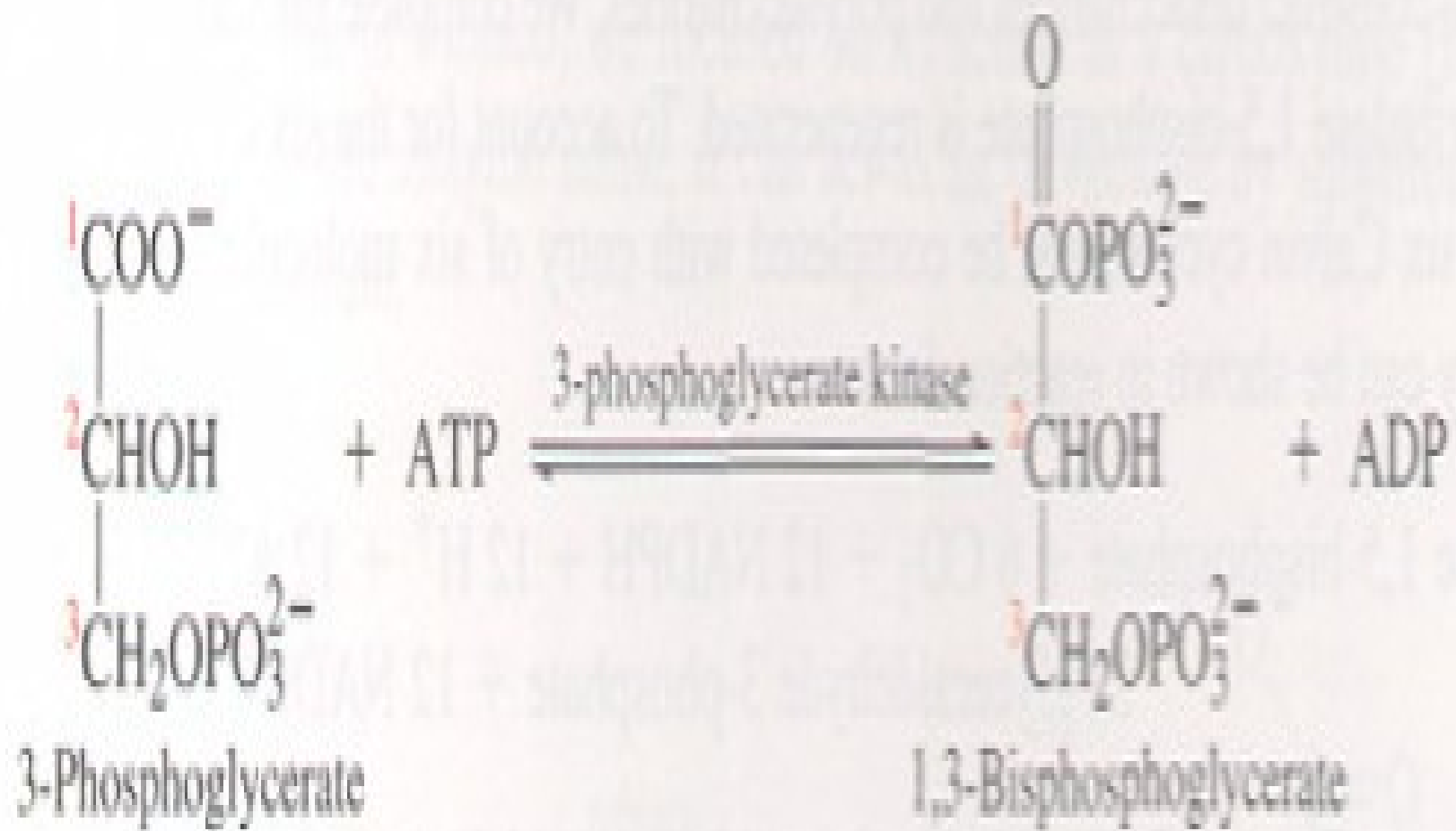
# Rubisco

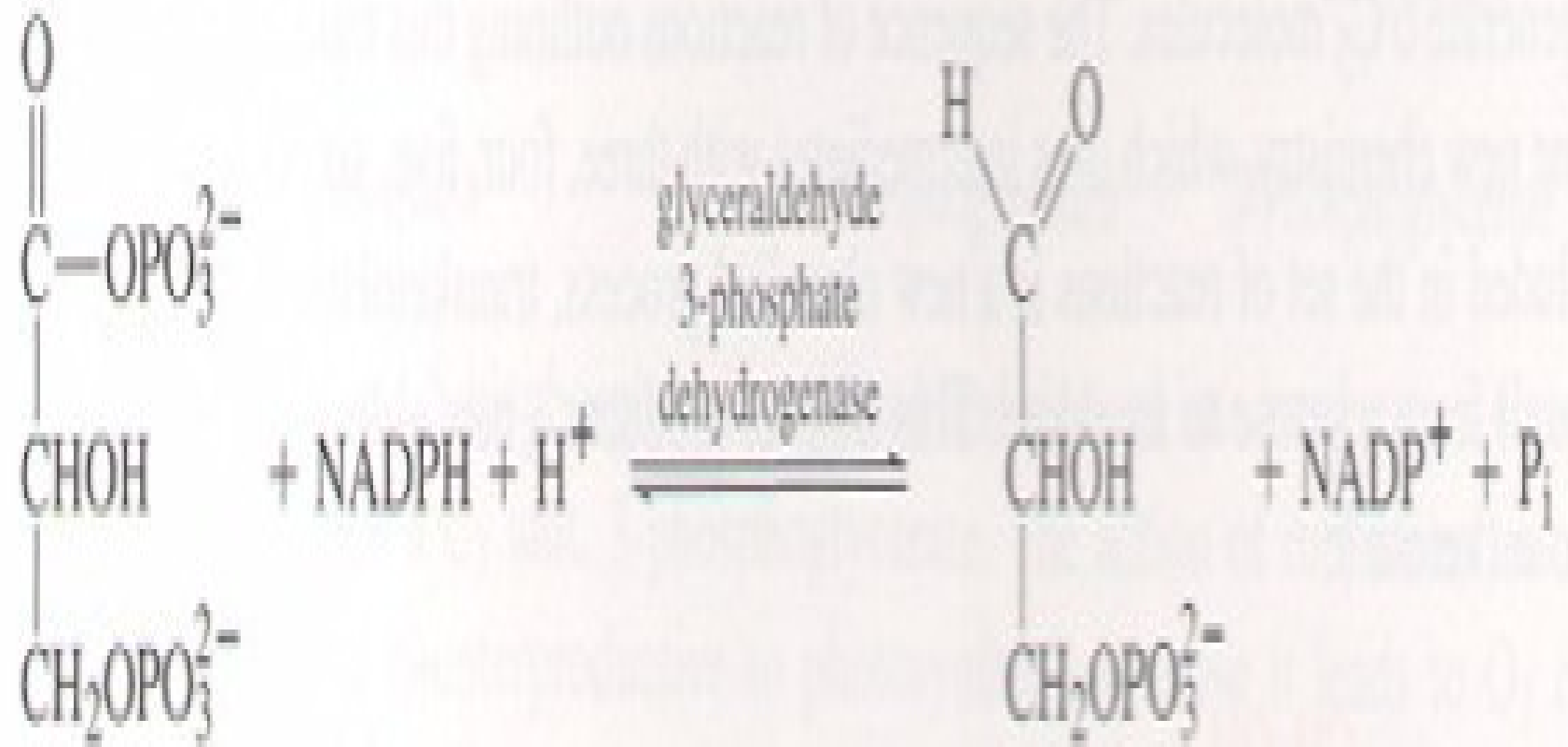


# RUBISCO

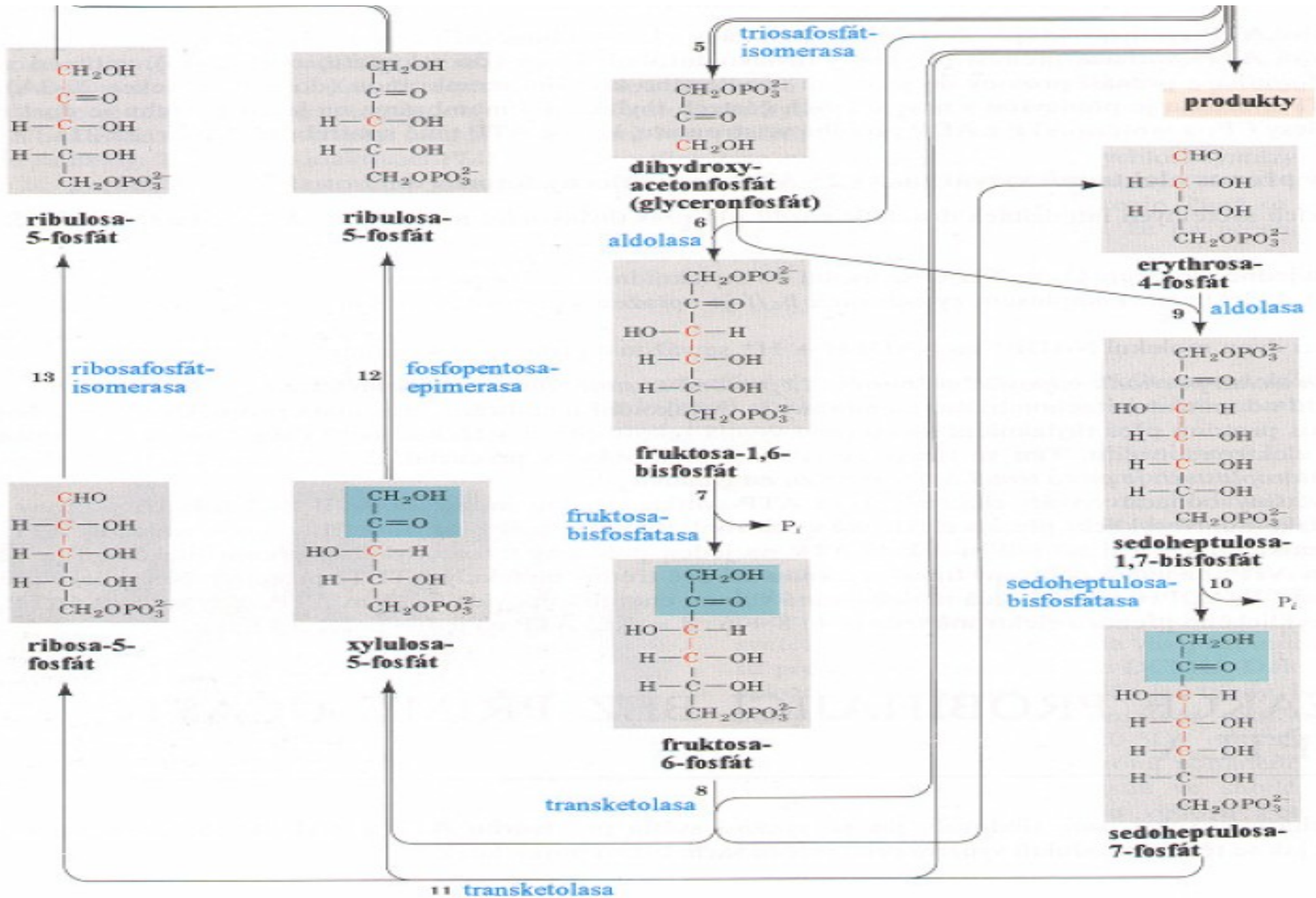
2 podjednotky (1 katalytická)

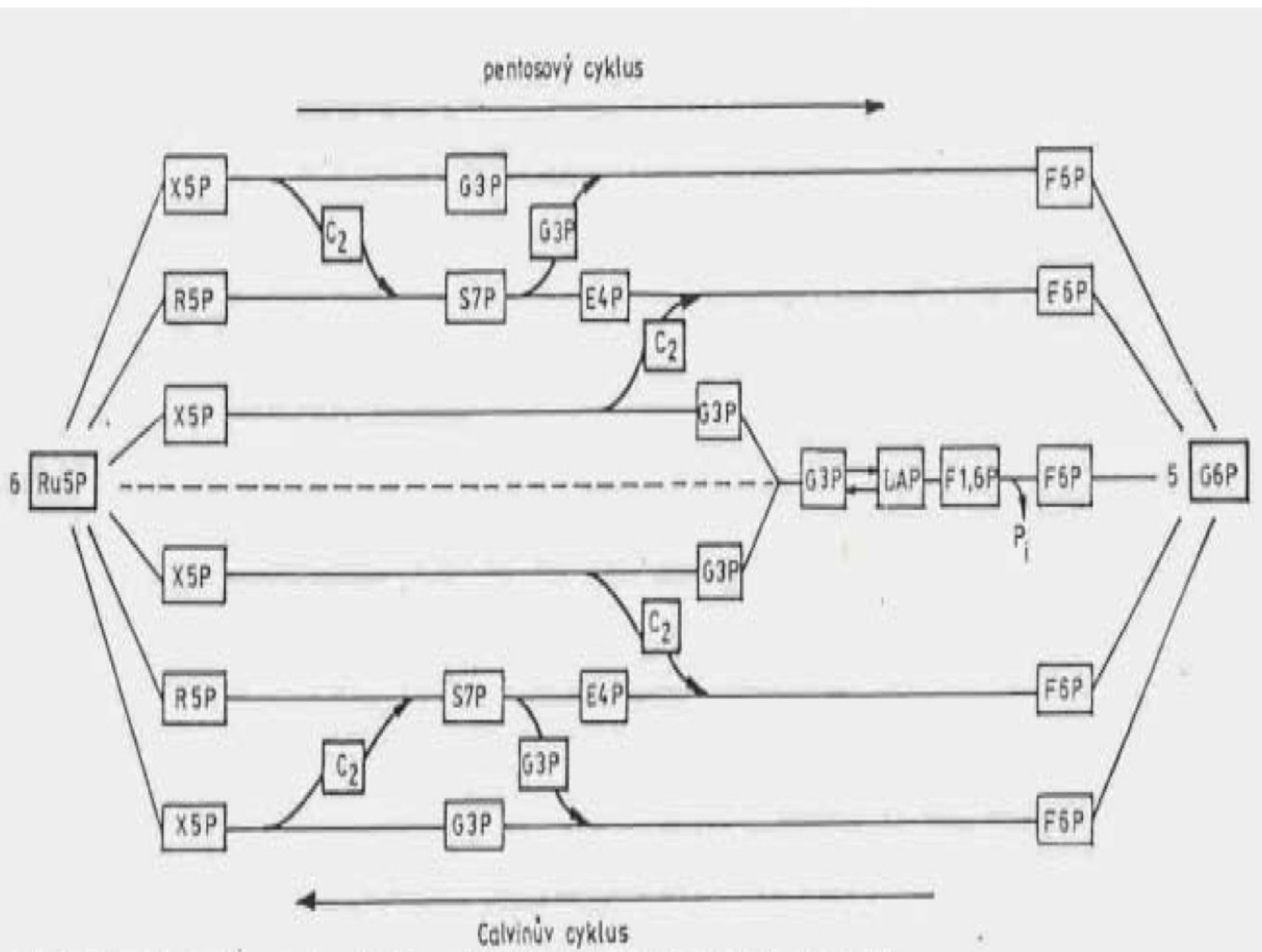


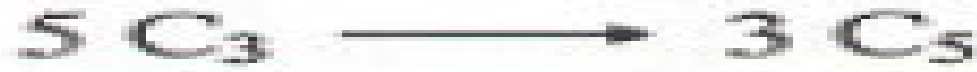




# Calvinův cyklus

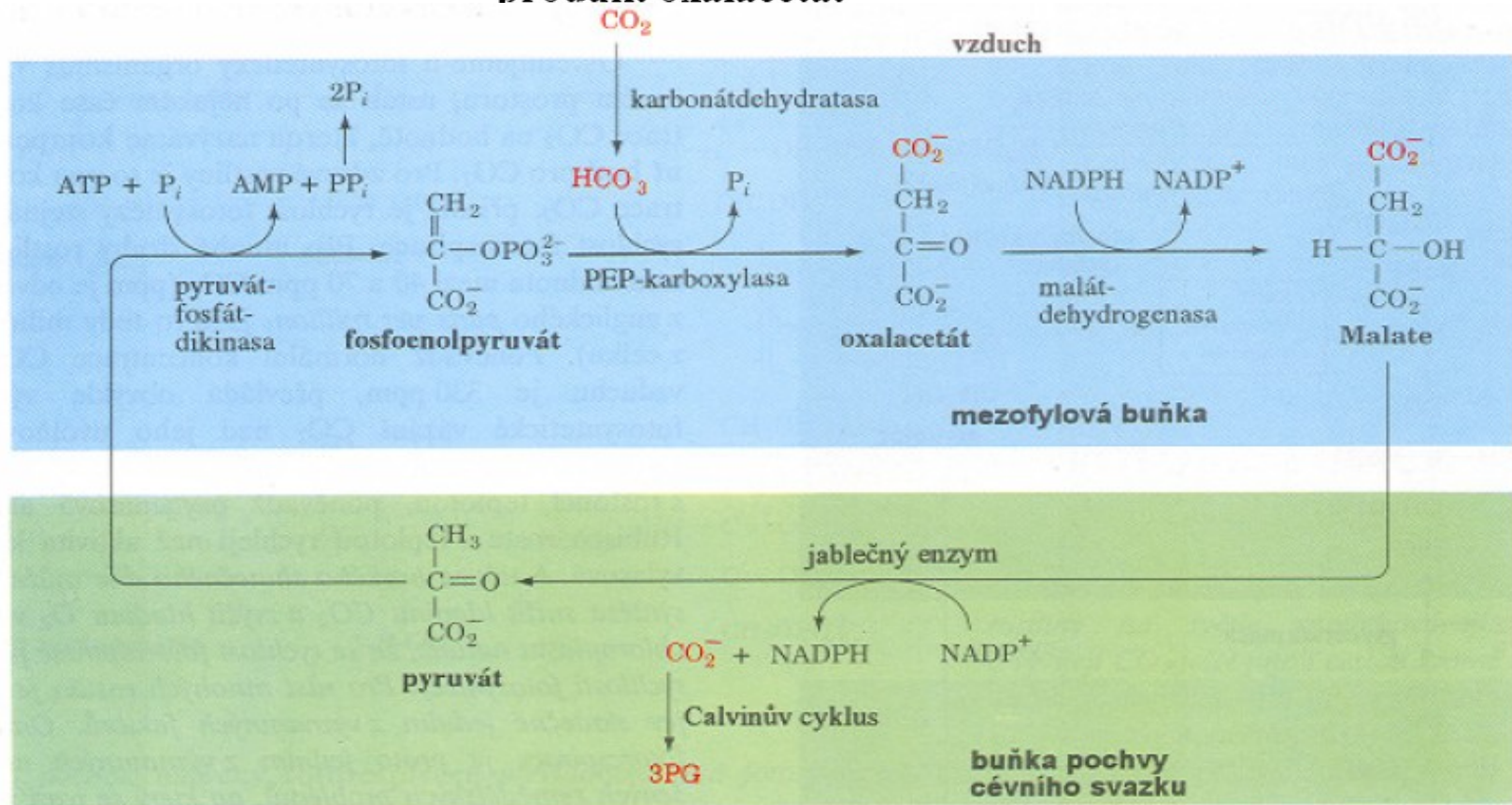






## C<sub>4</sub> rostliny

- rychlerostoucí tropické rostliny
- akceptor CO<sub>2</sub> fosfoenolpyruvát
- produkt oxalacetát



## CAM rostliny

- tučnolisté
- příjem CO<sub>2</sub> probíhá v noci



# Fotorespirace

