

Kofaktory, koenzymy a prosthetické skupiny

kofaktory – nízkomolekulární sloučeniny potřebné pro enzymovou katalýzu, účastní se katalýzy

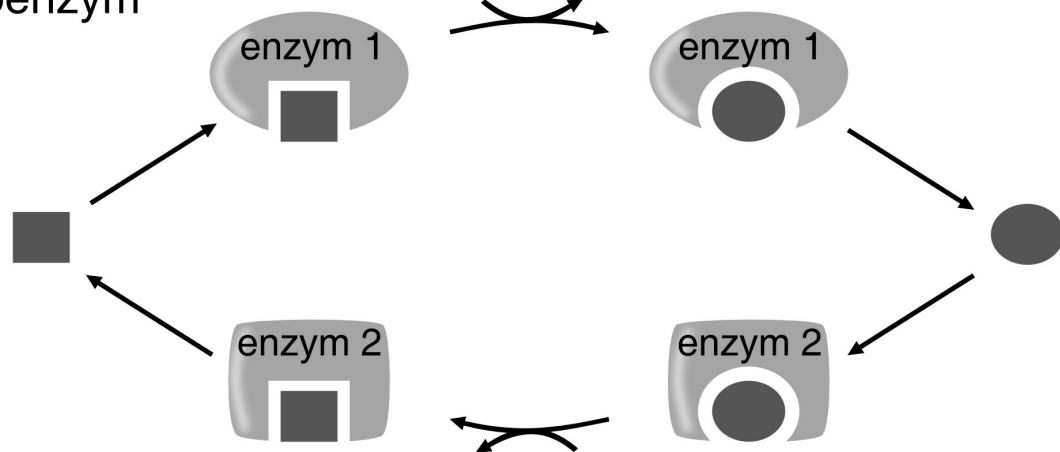
- koenzymy
- prosthetické skupiny
- kovalentní modifikace aminokyselinových zbytků
- ionty kovů
- pomocné molekuly
(kys. askorbová při hydroxylaci Pro)

kofaktory **nejsou**:

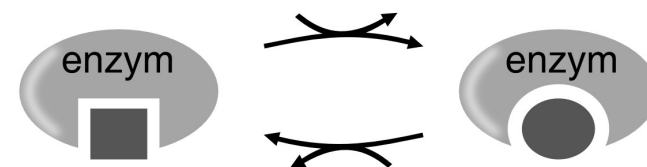
- stabilizující sloučeniny
- allosterické aktivátory
- post-translační modifikace mimo aktivní místo
- proteinové podjednotky

Kofaktory, koenzymy a prosthetické skupiny

koenzym



prosthetická skupina



Kofaktory, koenzymy a prosthetické skupiny

koenzymy – regulérní substráty, jsou v organismu obsaženy v nízké koncentraci a v rámci metabolismu se obnovují (např. NAD⁺)

prosthetické skupiny – jsou kovalentně nebo nekovalentně navázány na enzym, jsou součástí katalyzátoru a jsou obnovovány během katalytického cyklu enzymu (např. pyridoxalfosfát)

Pozor! Někdo používá pojem „koenzym“ pro nekovalentně a „prosthetická skupina“ pro kovalentně navázanou součást katalyzátoru

Kofaktory, koenzymy a prosthetické skupiny

apoenzym – enzym, který potřebuje prosthetickou skupinu, ale nemá ji

holoenzym – apoenzym po navázání prosthetické skupiny

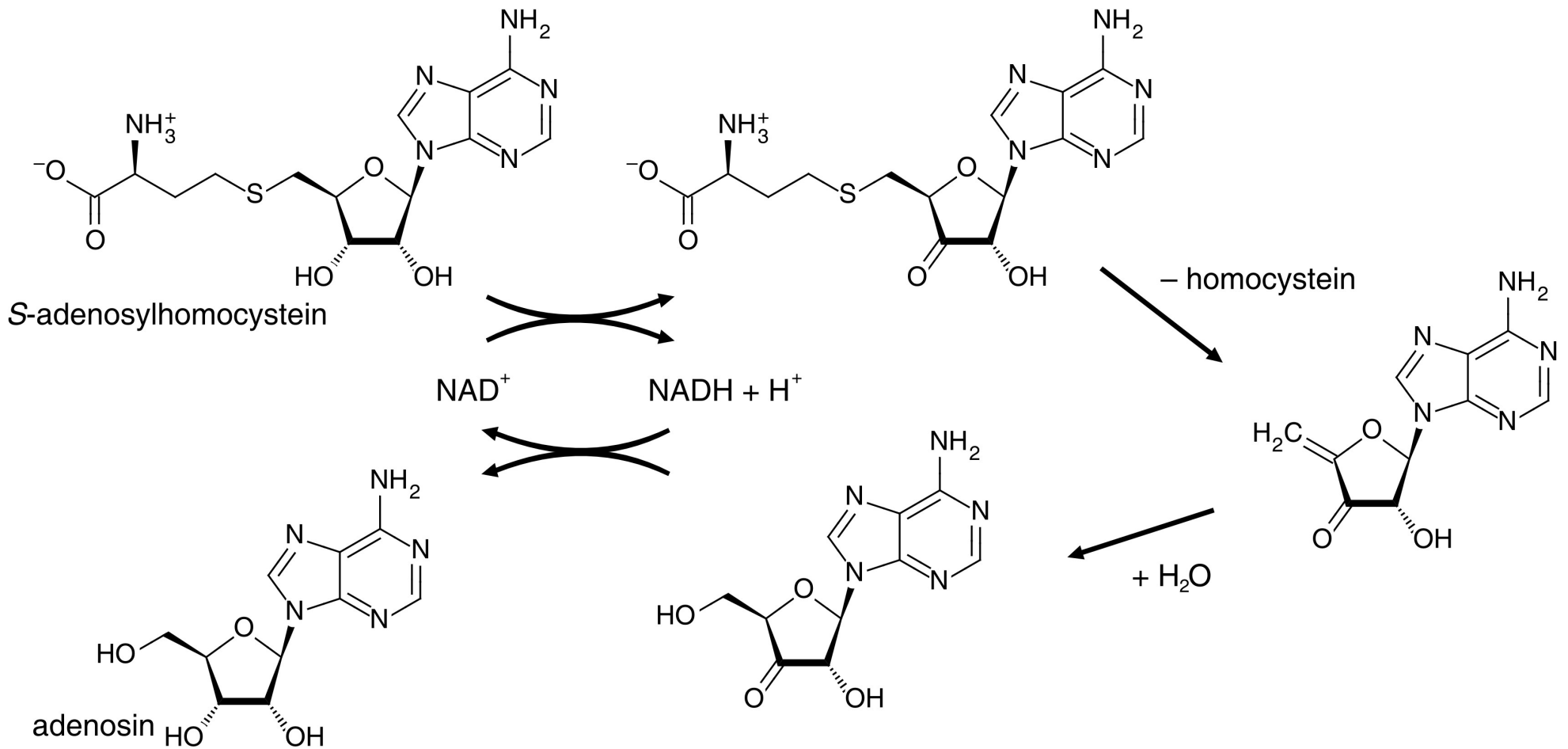
Kofaktory, koenzymy a prosthetické skupiny

<http://enzyme.expasy.org/enzyme-bycofactor.html>

5,10-methenyltetrahydrofolate	L-ascorbate
5,6,7,8-tetrahydrobiopterin	magnesium
5,6,7,8-tetrahydropteridine	Manganese
Ascorbate	Metal ions
Bile salt	MIO
Biotin	Molybdenum
Bis(molybdopterin guanine dinucleotide)molybdenum cofactor	Molybdenum cofactor
Calcium	Molybdopterin
CoA	Molybdopterin cytosine dinucleotide
Cobalamin	Molybdopterin guanine dinucleotide
Cobalt	Monovalent cation
Coenzyme F430	NAD(+)
Copper	NADP(+)
Dipyrromethane	NADPH
Divalent cation	NAD(P)H
Divalent metal cation	NH(4)(+)
FAD	nickel
FADH(2)	Potassium
Fe(2+)	Protoheme IX
Ferriheme b	Pyridoxal 5'-phosphate
Ferriprotoporphyrin IX	Pyrroloquinoline quinone
Flavin	Pyruvate
Flavoprotein	Riboflavin
FMN	S-adenosyl-L-methionine
FMNH(2)	Selenium
Glutathione	Siroheme
Heme	Sodium
Heme b	Thiamine diphosphate
Heme c	Thiamine phosphate
Heme-thiolate	Tryptophan tryptophylquinone
iron	Tungsten
Iron-sulfur	Tungsten-molybdopterin
	Vanadium
	Zinc
	Zn(2+)

Kofaktory, koenzymy a prosthetické skupiny

S-adenosylhomocysteinasa



Vitamíny

Exogenní esenciální faktory pro určitou skupinu organismů. Jsou charakterizovány nízkou spotřebou. Často se uplatňují v katalýze.

Provitamíny: prekurzory vitamínů (např. karoten)

Antivitamíny: sloučeniny, které kompetují s vitamíny, nebo je vyvazují

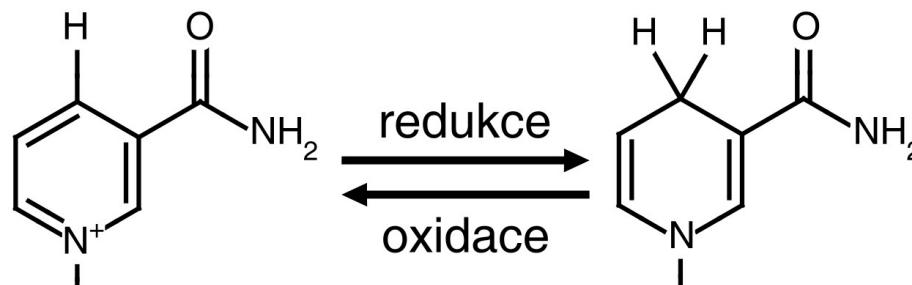
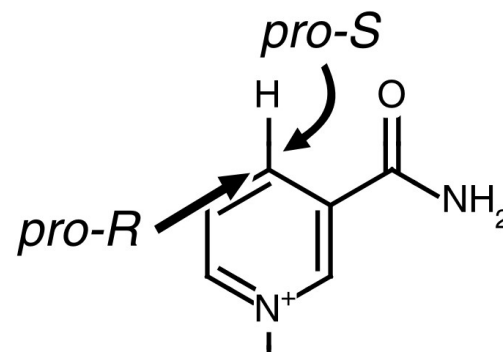
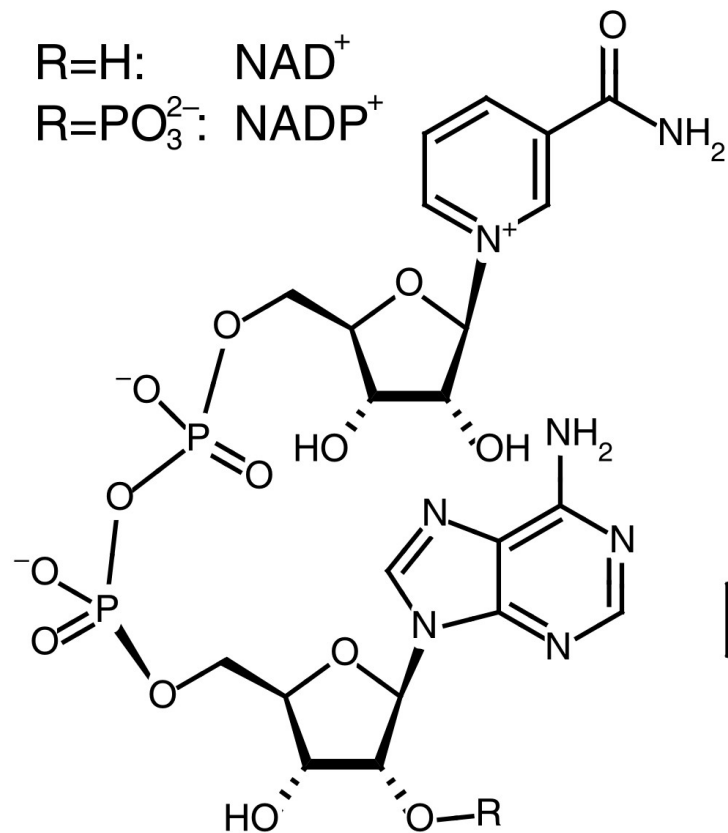
Hypo/a/vitaminosa: nedostatek vitamínu

Hypervitaminosa: otrava vitamínem

NAD(P)⁺

nikotinamidadenindinukleotid(fosfát) – koenzym

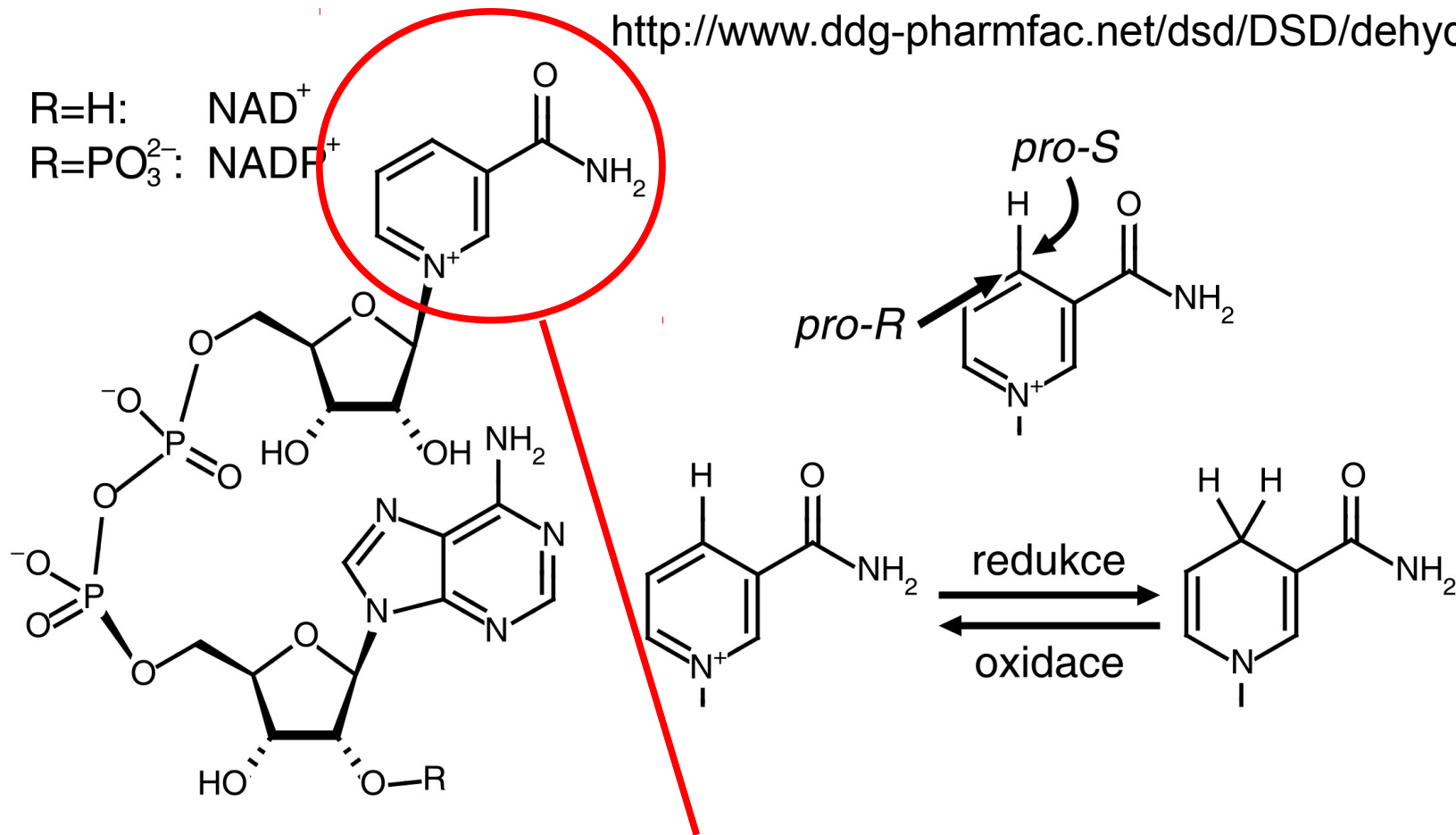
<http://www.ddg-pharmfac.net/dsd/DSD/dehydrog.htm>



NAD(P)⁺

nikotinamidadenindinukleotid(fosfát) – koenzym

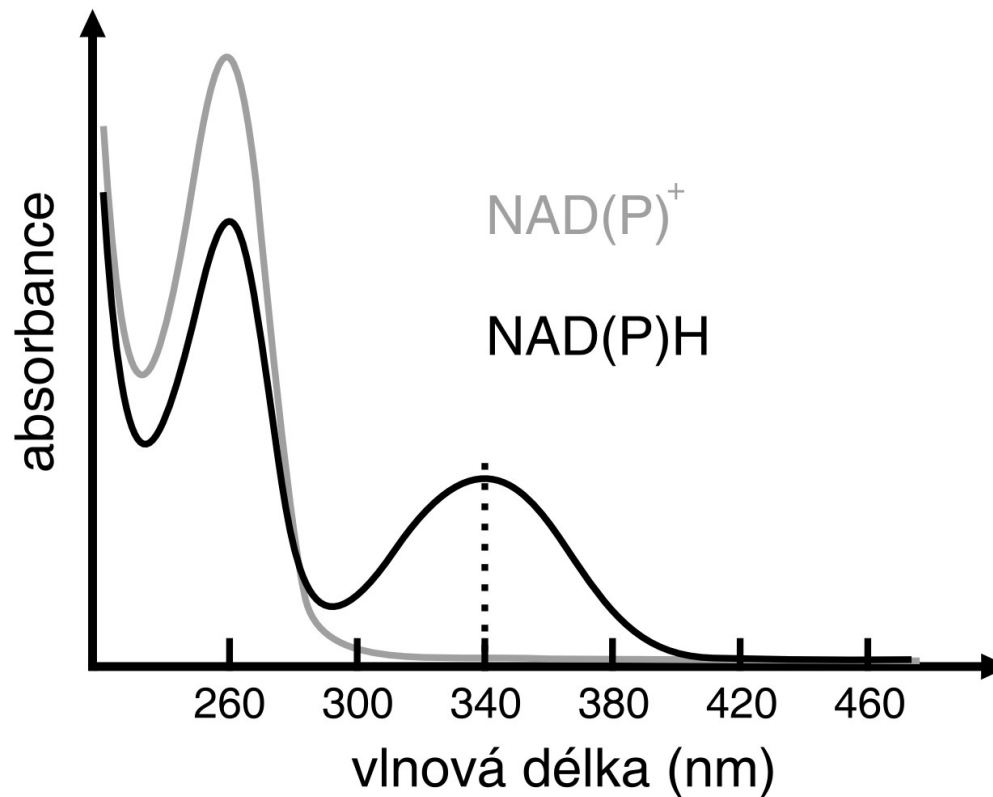
<http://www.ddg-pharmfac.net/dsd/DSD/dehydrog.htm>



Nikotinamid (niacin, vitamin B₃, PP)

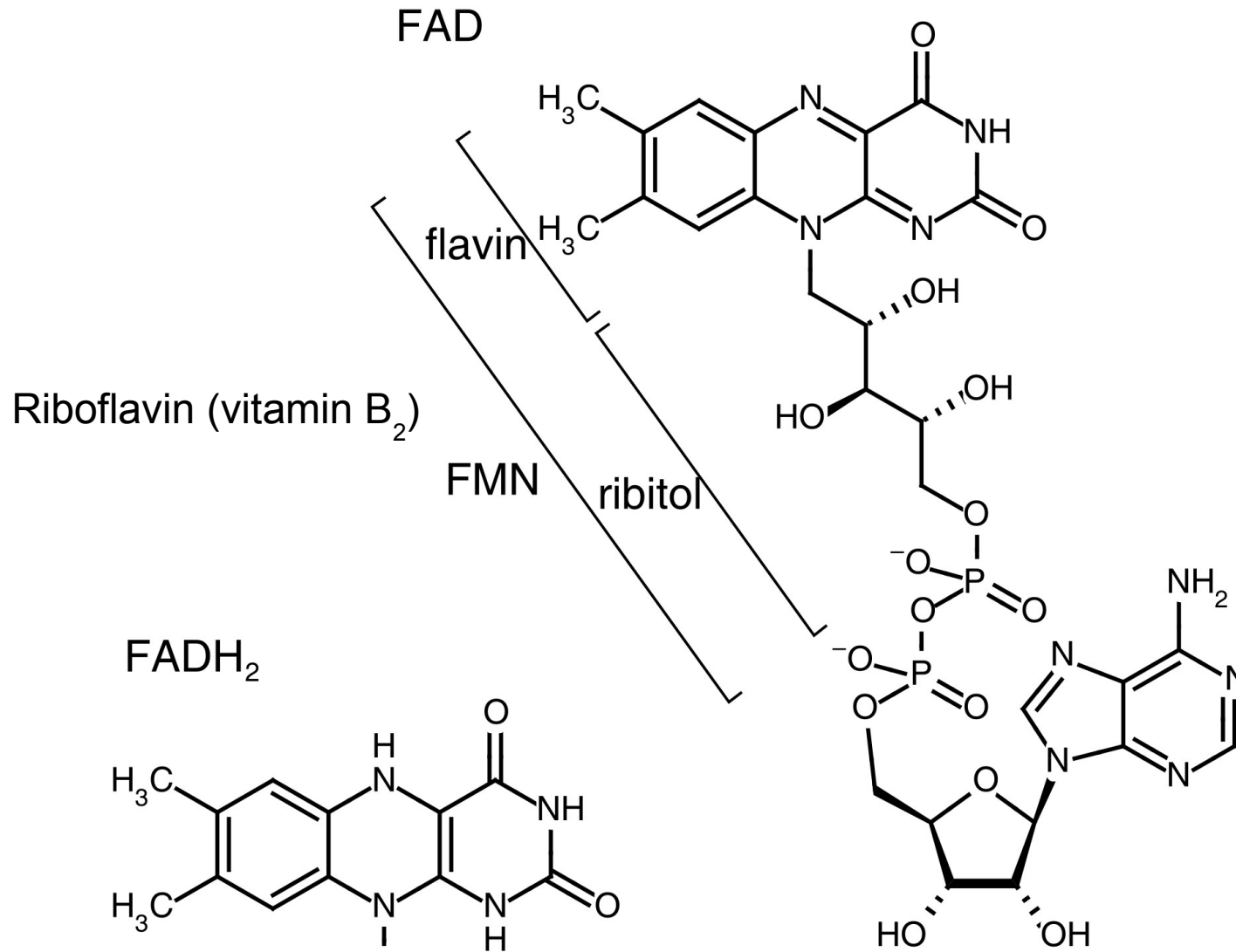
NAD(P)⁺

nikotinamidadeninindinukleotid(fosfát) – koenzym



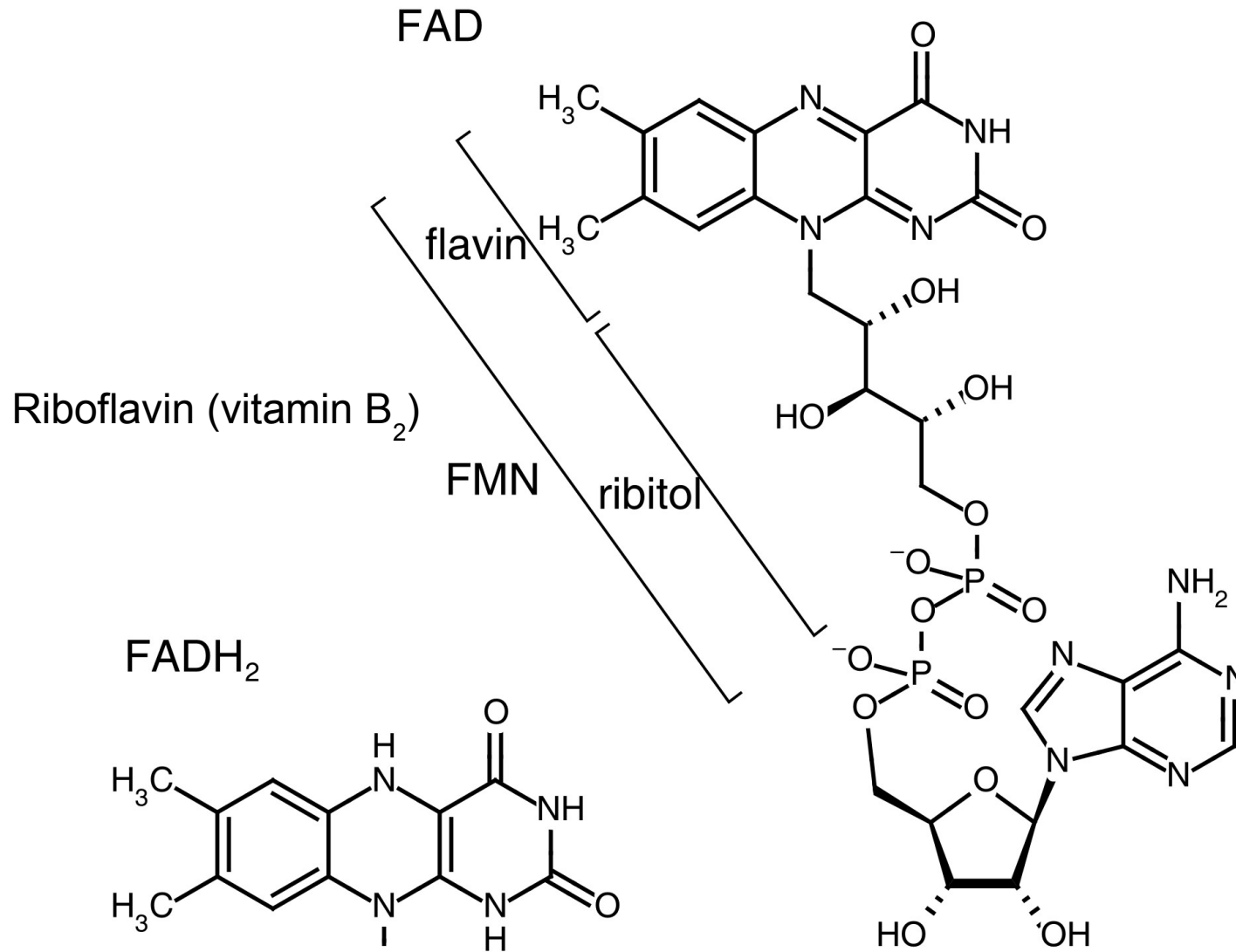
FAD

Flavinadeninindinukleotid – prosthetická skupina



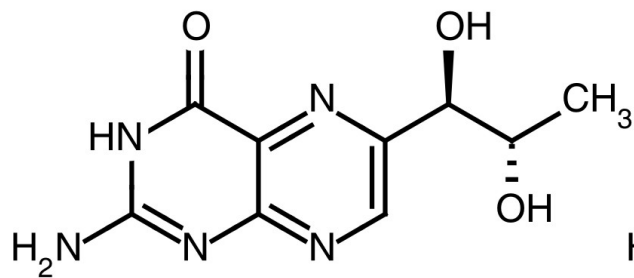
FAD

Flavinadeninindinukleotid – prosthetická skupina

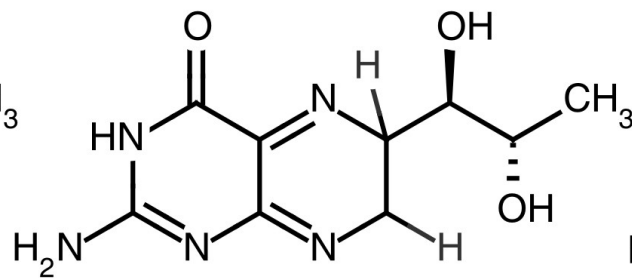


Pteriny

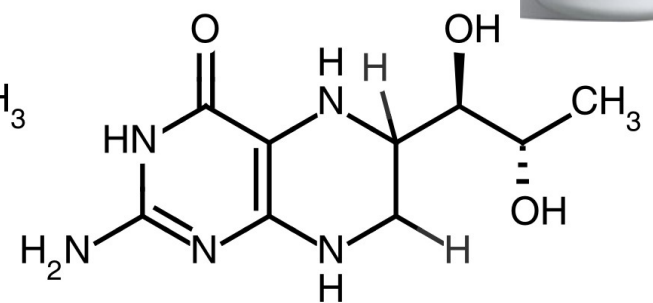
biopterin – koenzym



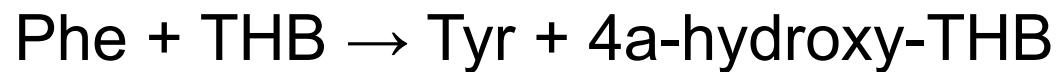
biopterin



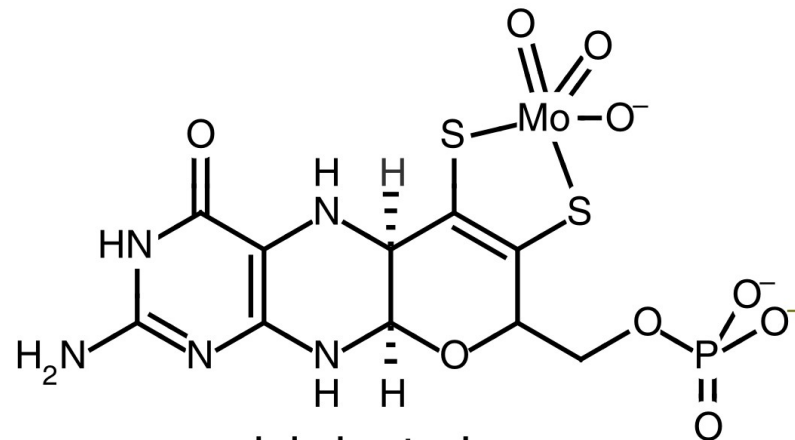
dihydrobiopterin



tetrahydrobiopterin



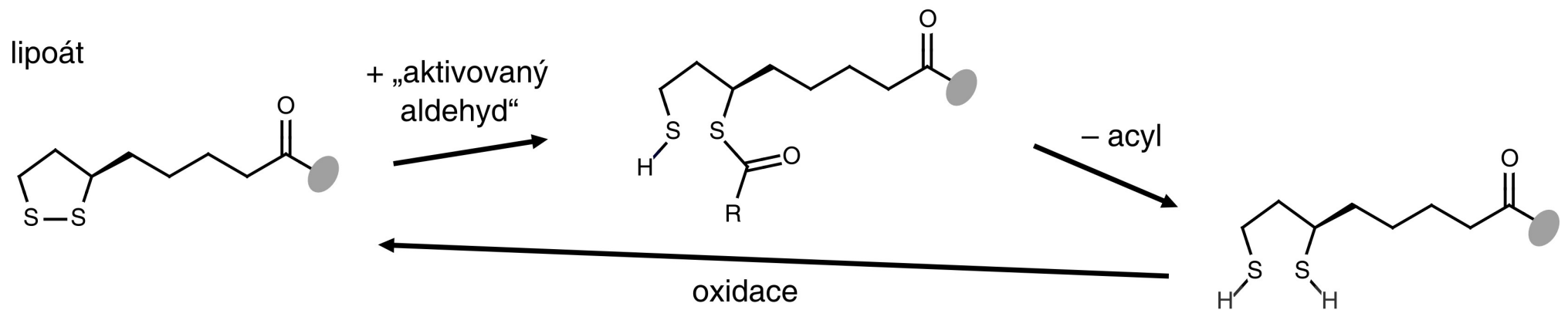
molybdopterin – např. prosthetická skupina ve xanthinoxidase



molybdopterin

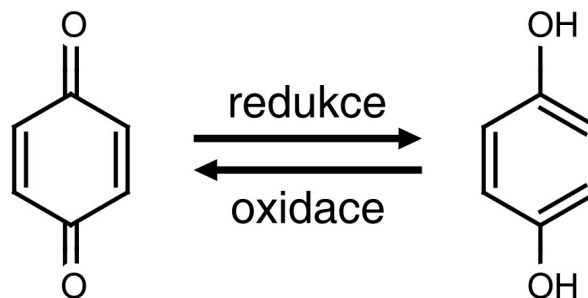
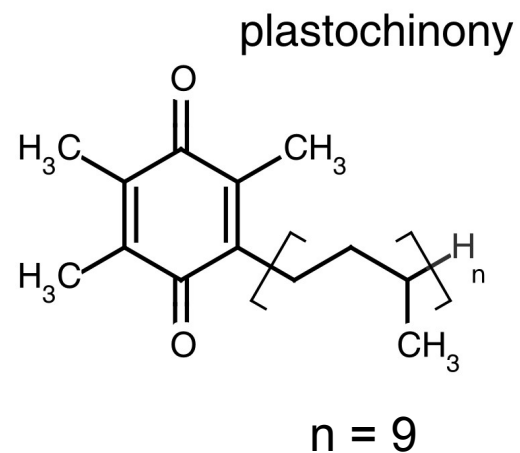
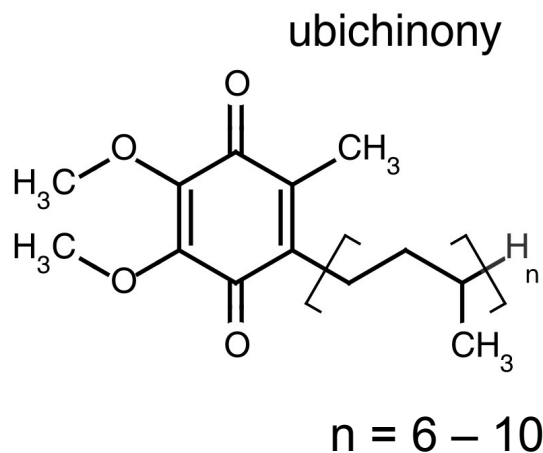
Lipoová kyselina

– prosthetická skupina



Chinony

Ubichinony a Plastochinony – koenzymy



Hem

Hemy (více druhů) – prosthetické skupiny

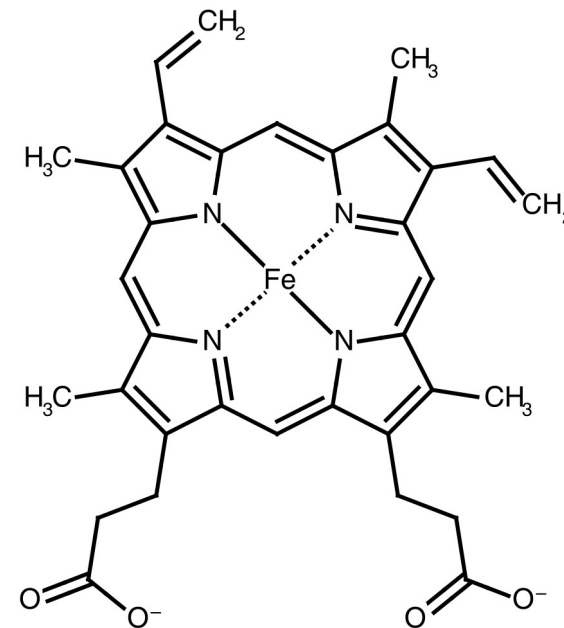
Vázána buď pomocí koordinačně-

Kovalentních vazeb nebo adicí

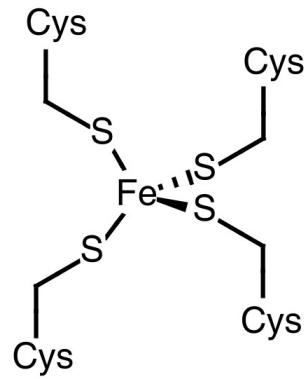
Cys na vinyly

Funkce:

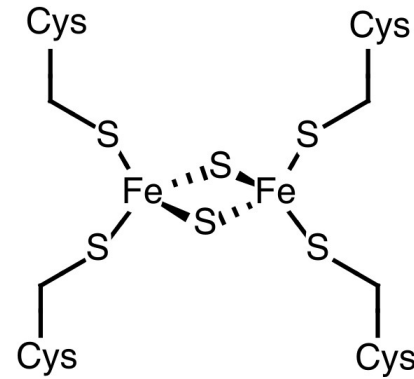
- přenos e^-
- přenos O_2
- enzymy katalasa,
peroxidasa atd.



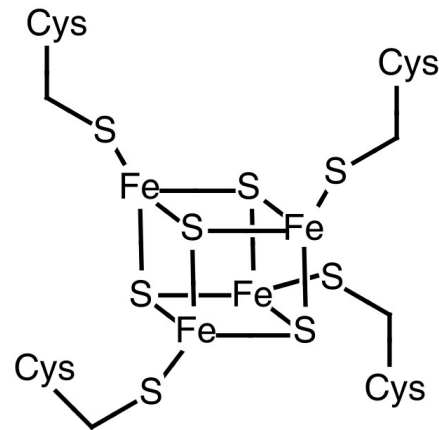
FeS centra



Fe-S



2Fe-2S



4Fe-4S

Glutathion

koenzym

tripeptid (γ -Glu-Cys-Gly, GSH)

oxidace: $2 \text{ GSH} \rightarrow \text{GSSG}$

ATP

Aktivované monosacharidy

koenzymy

UDP-Glc, UDP-Gal, UDP-GalNAc, UDP-GlcNAc,
UDP-GlcUA, UDP-Xyl, GDP-Man, GDP-Fuc,
CMP-Neu5Ac

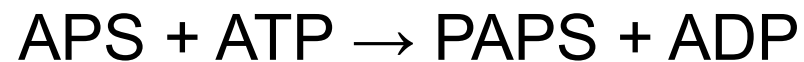
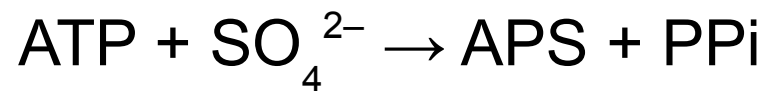
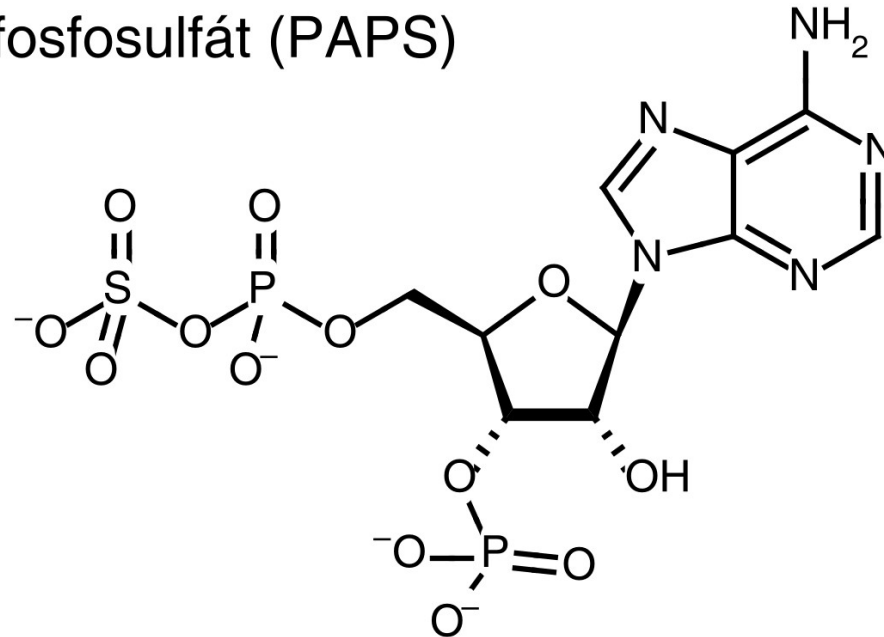
Další podobné donory:

CDP-cholin, CDP-ethanolamin ...

PAPS

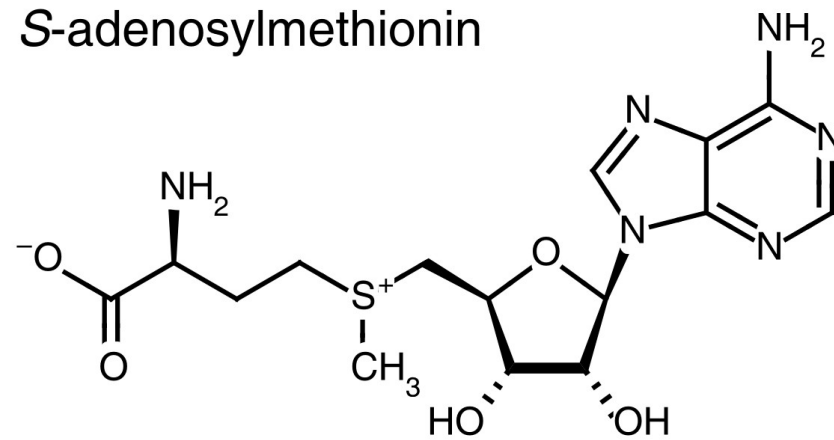
3'-fosfoadenosin-5'-fosfosulfát – koenzym

3'-Fosfoadenosin-5'-fosfosulfát (PAPS)



SAM

S-adenosylmethionin – koenzym



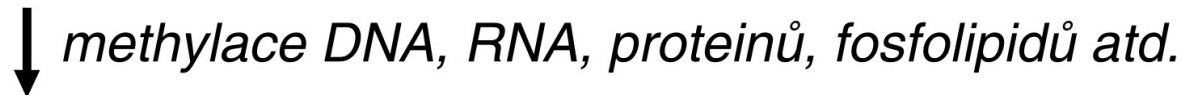
proteiny



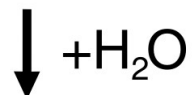
methionin



S-adenosylmethionin



S-adenosylhomocystein



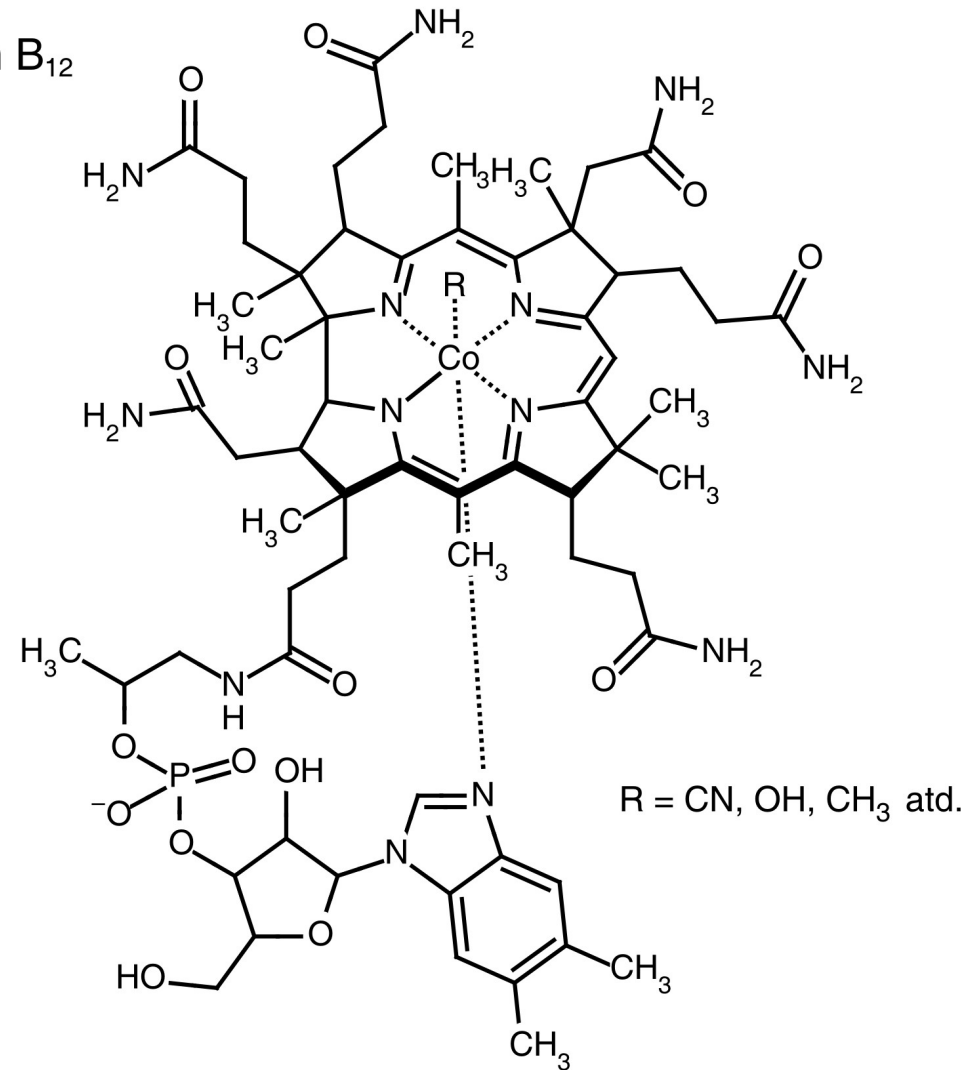
homocystein

kobalamin

prostetická skupina

methioninsynthasa
propanedioldehydratasa
glyceroldehydratasa
methylaspartátammonolyasa
ethanolaminammonolyasa
 β -lysin-5,6-aminomutasa
D-lysin-5,6-aminomutasa
D-ornithin-4,5-aminomutasa
leucin-2,3-aminomutasa
methylaspartátmutasa
methylmalonyl-CoA-mutasa
2-methyleneglutarátmutasa

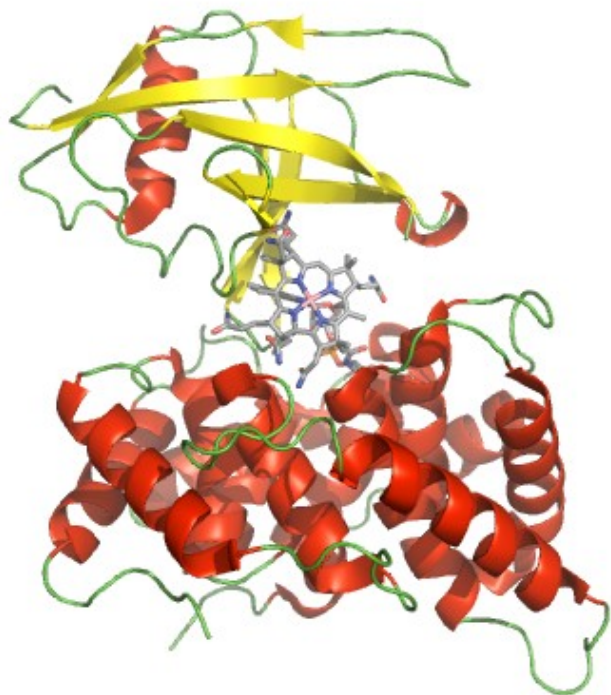
vitamin B₁₂



Vitamín B₁₂

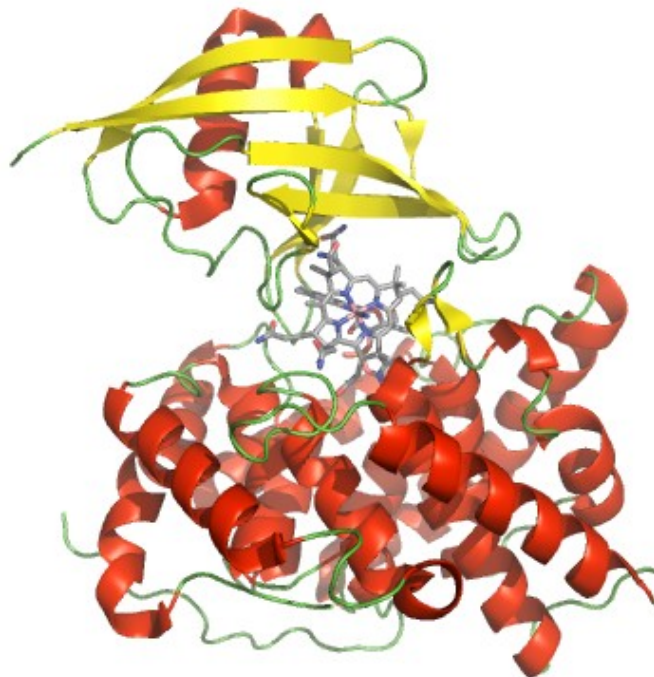
kobalamin prosthetická skupina

2PMV



vnitřní faktor

4KKI



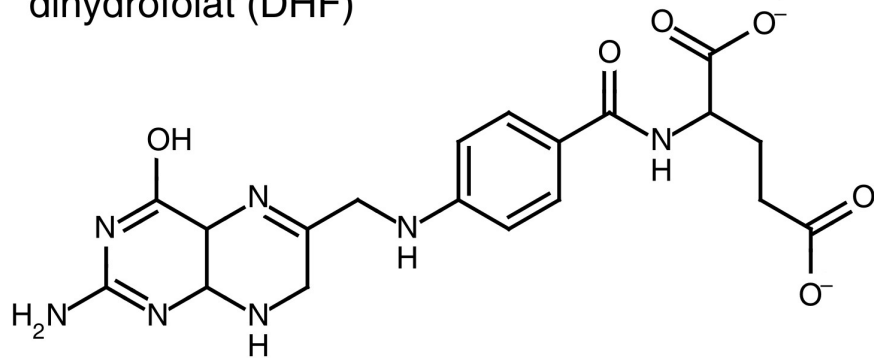
haptokorin
(transcobalamin I)

?

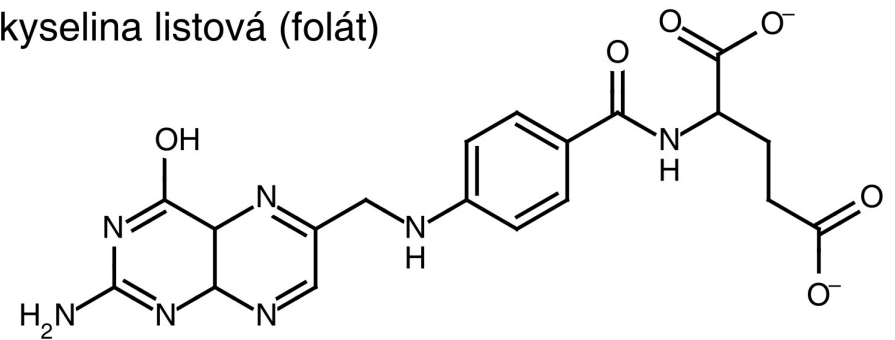
transcobalamin II

foláty koenzymy

dihydrofolát (DHF)

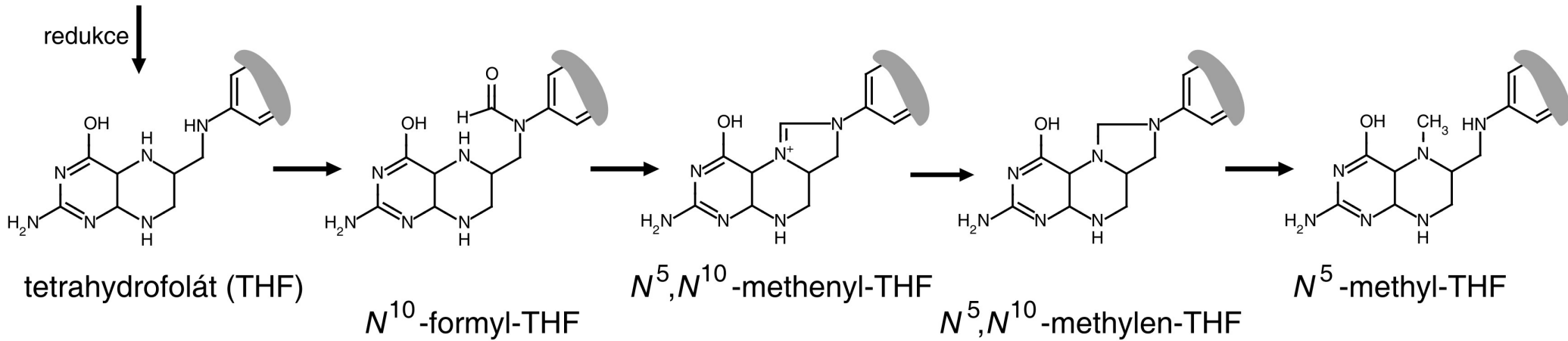


kyselina listová (folát)



redukce

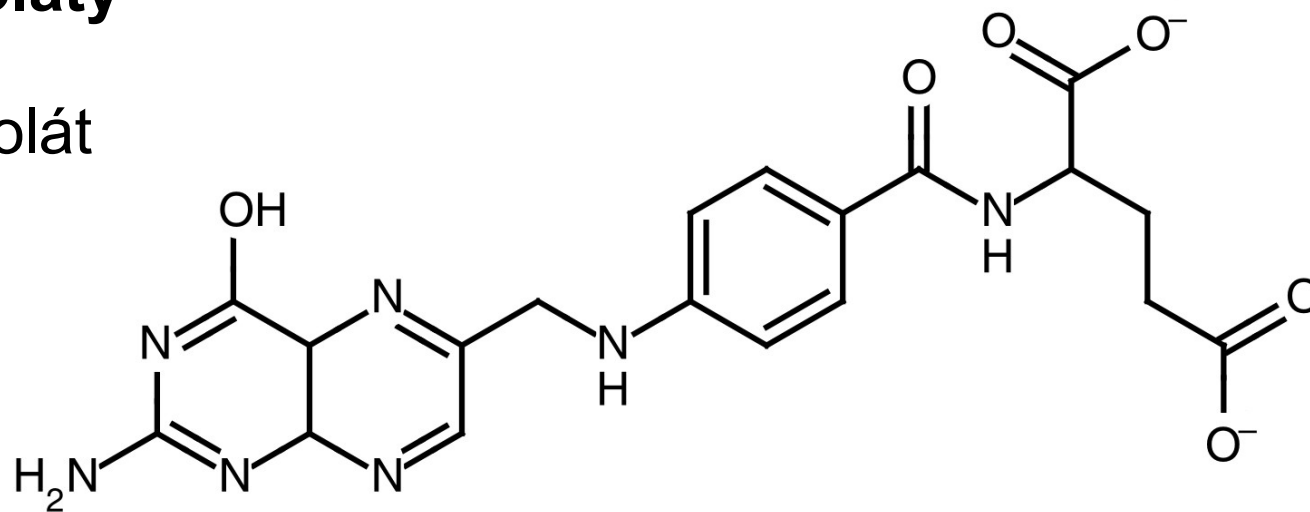
redukce



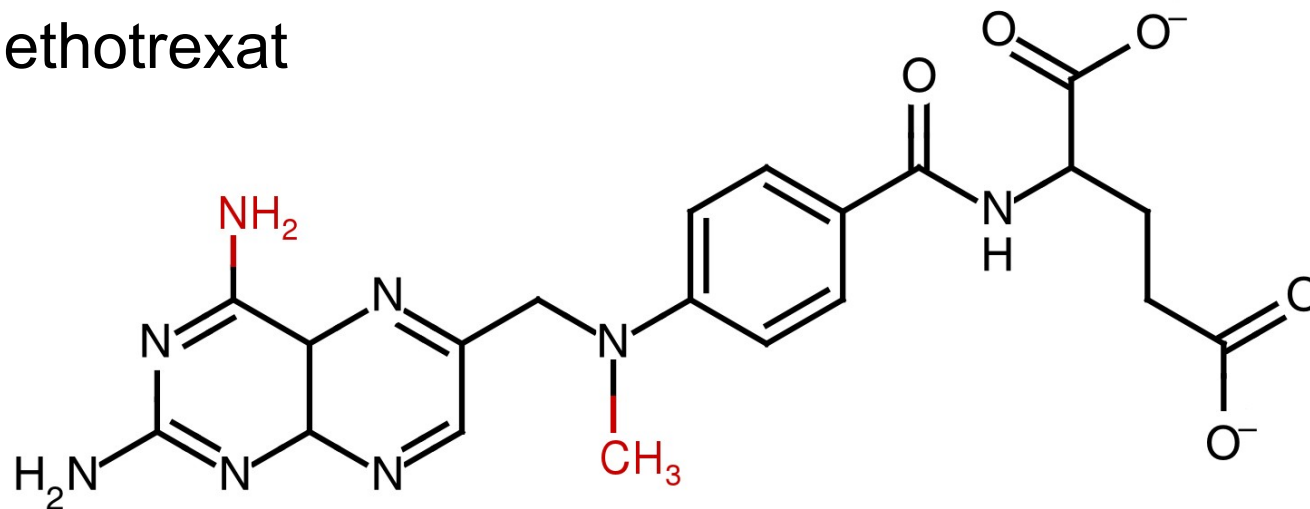
kyselina listová – vitamin B₉

foláty

Folát

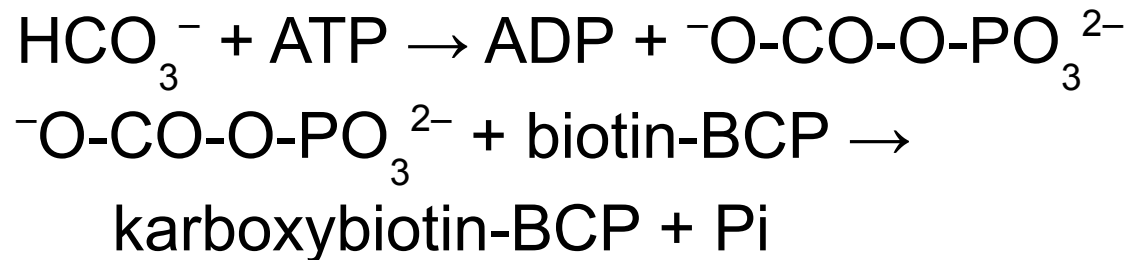
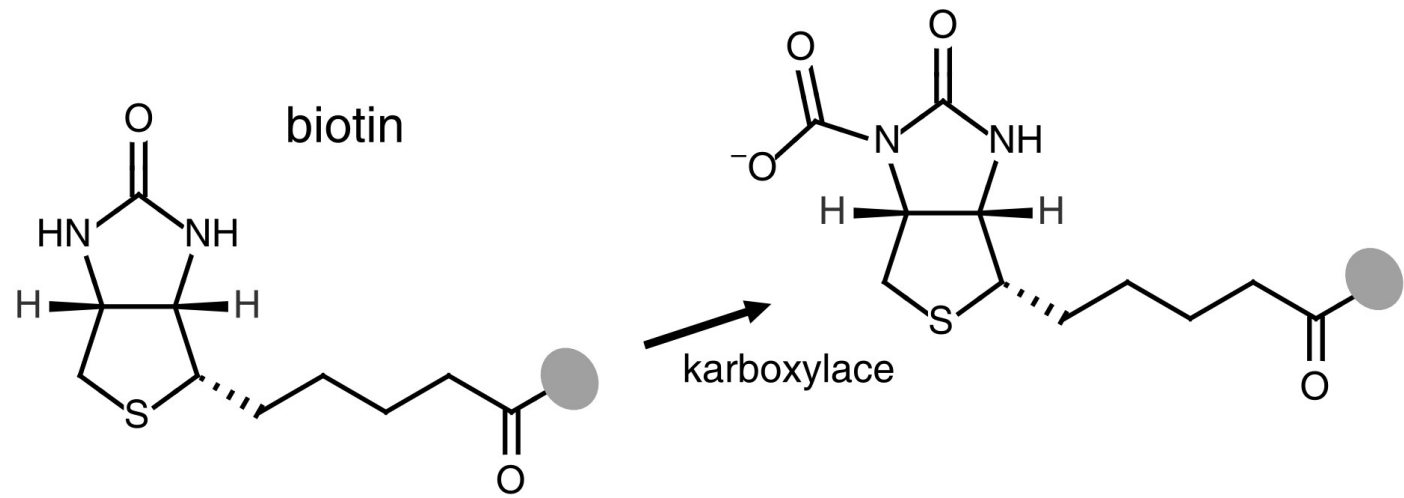


Methotrexat



biotin

prostetická skupina

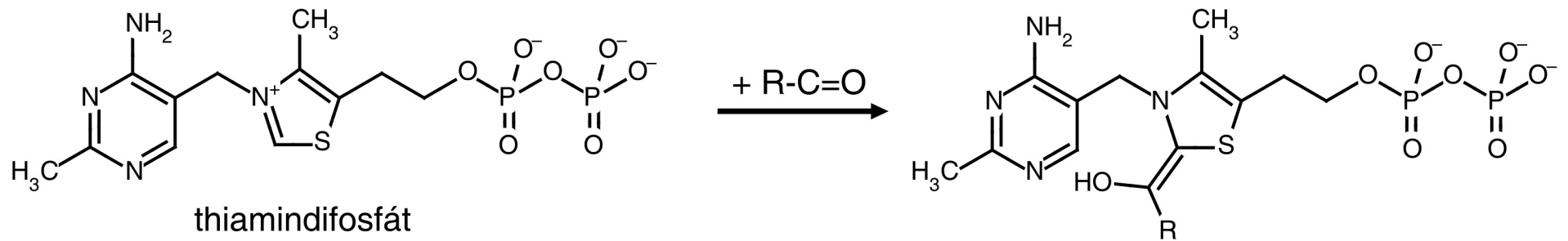


vitamin H

antivitaminy – avidin a streptavidin

thiamindifosfát

prosthetická skupina

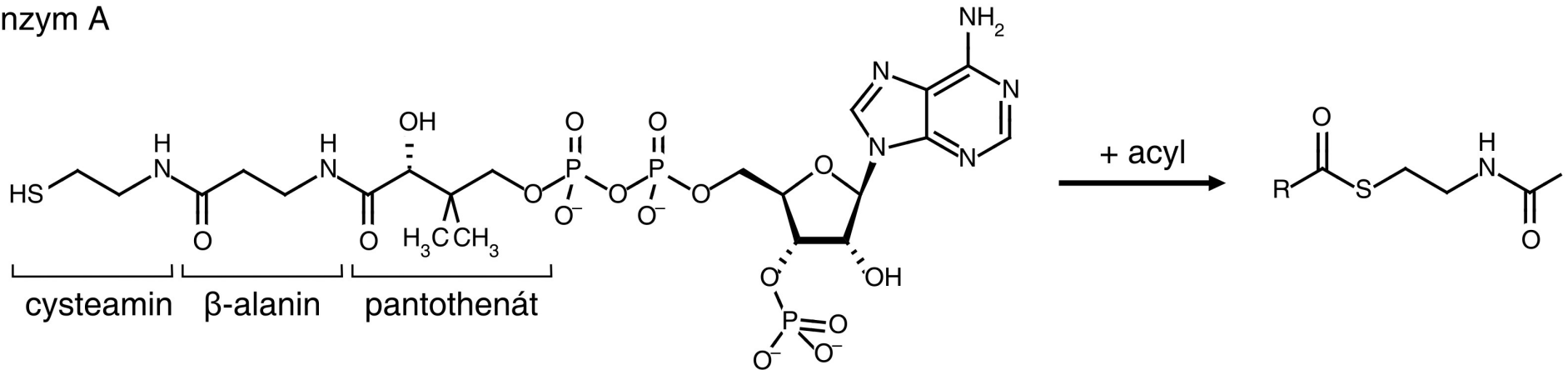


vitamin B₁

koenzym A

koenzym

koenzym A

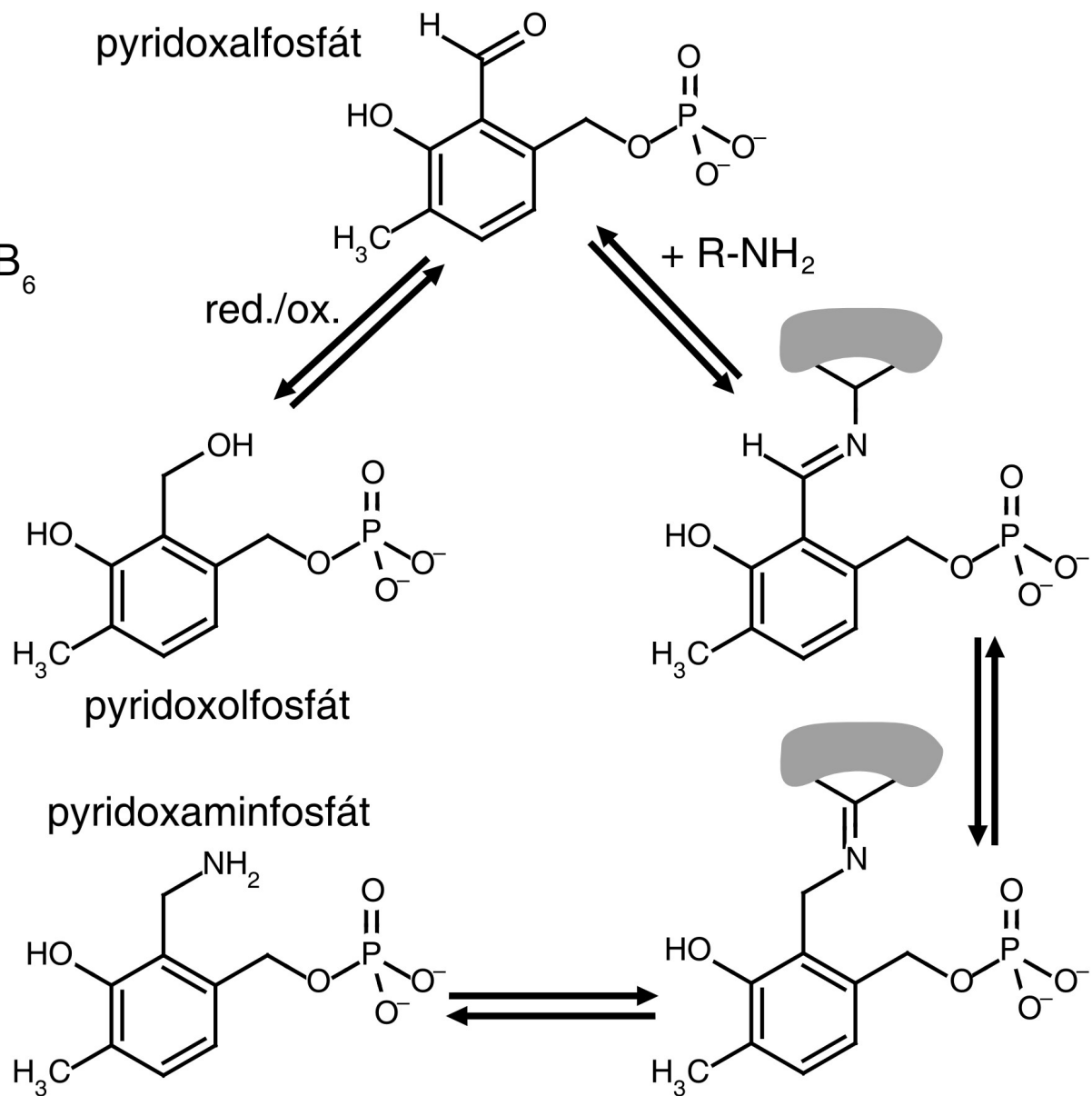


kys. pantothenová - vitamin B₅

podobné uspořádání v ACP – acyl carrier protein

pyridoxalfosfát prosthetická skupina

pyridoxin - vitamin B₆



pyridoxalfosfát prostheticá skupina

Glycine dehydrogenase (decarboxylating).

Glycine hydroxymethyltransferase.
Glutamate formimidoyltransferase.
Fluorothreonine transaldolase.
Glycine C-acetyltransferase.
5-aminolevulinat synthase.
8-amino-7-oxononanoate synthase.
Serine C-palmitoyltransferase.
Cysteine synthase.
Cystathionine gamma-synthase.
O-phosphoserine sulphydrylase.
Cysteate synthase.
O-phosphoserine sulphydrylase.
Aspartate transaminase.
Alanine transaminase.
Cysteine transaminase.
Glycine transaminase.
Tyrosine transaminase.
Leucine transaminase.
Kynurenine--oxoglutarate transaminase.
2,5-diaminovalerate transaminase.
Histidinol-phosphate transaminase.
Acetylmornithine transaminase.
Alanine--oxo-acid transaminase.
Ornithine aminotransferase.
Asparagine--oxo-acid transaminase.
Glutamine--pyruvate transaminase.
Succinyl-diaminopimelate transaminase.
Beta-alanine--pyruvate transaminase.
4-aminobutyrate--2-oxoglutarate transaminase.
D-amino-acid transaminase.
Diiodotyrosine transaminase.
Thyroid-hormone transaminase.
Tryptophan transaminase.
Pyridoxamine--pyruvate transaminase.
dTDP-4-amino-4,6-dideoxy-D-glucose transaminase.
UDP-N-acetyl-bacillosamine transaminase.
Glycine--oxaloacetate transaminase.
L-lysine 6-transaminase.
2-aminoethylphosphonate--pyruvate transaminase.
2-aminoadipate transaminase.
Branched-chain-amino-acid transaminase.
Aminolevulinat transaminase.
Alanine--glyoxylate transaminase.
Serine--glyoxylate transaminase.
Diaminobutyrate--pyruvate transaminase.
Alanine--oxomalonate transaminase.
5-aminovalerate transaminase.

Dihydroxyphenylalanine transaminase.
Glutamine--scyllo-inositol transaminase.
Serine--pyruvate transaminase.
Phosphoserine transaminase.
Taurine--2-oxoglutarate transaminase.
Aromatic-amino-acid transaminase.
dTDP-4-amino-4,6-dideoxygalactose transaminase.
Adenosylmethionine--8-amino-7-oxononanoate transaminase.
Glutamine--phenylpyruvate transaminase.
N(6)-acetyl-beta-lysine transaminase.
Valine--pyruvate transaminase.
2-aminohexanoate transaminase.
D-4-hydroxyphenylglycine transaminase.
Diaminobutyrate--2-oxoglutarate transaminase.
Taurine--pyruvate aminotransferase.
Aspartate--prephenate aminotransferase.
Glutamate--prephenate aminotransferase.
Nicotianamine aminotransferase.
Succinylornithine transaminase.
Putrescine aminotransferase.
LL-diaminopimelate aminotransferase.
Arginine--pyruvate transaminase.
UDP-4-amino-4-deoxy-L-arabinose aminotransferase.
dTDP-3-amino-3,6-dideoxy-alpha-D-glucopyranose transaminase.
dTDP-3-amino-3,6-dideoxy-alpha-D-galactopyranose transaminase.
UDP-4-amino-4,6-dideoxy-N-acetyl-beta-L-altrosamine transaminase.
4-aminobutyrate--pyruvate transaminase.
UDP-2-acetamido-2-deoxy-ribo-hexuluronate aminotransferase.
GDP-perosamine synthase.
Cysteine desulfurase.
Molybdenum cofactor sulfurtransferase.
L-seryl-tRNA(Sec) selenium transferase.
O-phospho-L-seryl-tRNA(Sec):L-selenocysteinyl-tRNA synthase.

1-aminocyclopropane-1-carboxylate deaminase.
Kynureninase.

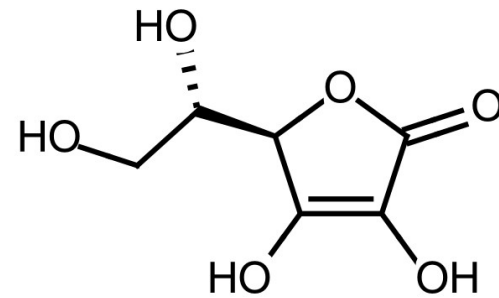
Aspartate 4-decarboxylase.
Valine decarboxylase.
Glutamate decarboxylase.
Hydroxyglutamate decarboxylase.
Ornithine decarboxylase.
Lysine decarboxylase.
Arginine decarboxylase.
Diaminopimelate decarboxylase.
Histidine decarboxylase.
Aminobenzoate decarboxylase.
Tyrosine decarboxylase.
Aromatic-L-amino-acid decarboxylase.

Sulfinolalanine decarboxylase.
Phenylalanine decarboxylase.
2,2-dialkylglycine decarboxylase (pyruvate).
Phosphatidylserine decarboxylase.
Threonine-phosphate decarboxylase.
Diaminobutyrate decarboxylase.
L-glutamyl-[BtrI acyl-carrier protein] decarboxylase.
L-threonine aldolase.
Phenylserine aldolase.
Sphinganine-1-phosphate aldolase.
D-threonine aldolase.
Low-specificity L-threonine aldolase.
L-allo-threonine aldolase.
Aminodeoxychorismate lyase.
3-hydroxy-D-aspartate aldolase.
Tryptophanase.
Tyrosine phenol-lyase.
Tryptophan synthase.
Cystathionine beta-synthase.
Pyrazolylalanine synthase.
3-amino-5-hydroxybenzoate synthase.
Capreomycin synthase.
Threonine synthase.
Ethanolamine-phosphate phospho-lyase.
5-phosphonoxy-L-lysine phospho-lyase.
Glucosaminat ammonia-lyase.
Carbamoyl-serine ammonia-lyase.
Diaminopropionate ammonia-lyase.
Threo-3-hydroxy-L-aspartate ammonia-lyase.
L-serine ammonia-lyase.
D-serine ammonia-lyase.
Threonine ammonia-lyase.
Erythro-3-hydroxy-L-aspartate ammonia-lyase.
Threo-3-hydroxy-D-aspartate ammonia-lyase.
Cystathionine gamma-lyase.
Homocysteine desulfhydrase.
Alliin lyase.
S-alkylcysteine lyase.
Cystathionine beta-lyase.
L-3-cyanoalanine synthase.
Cysteine lyase.
Methionine gamma-lyase.
Cysteine-S-conjugate beta-lyase.
1-aminocyclopropane-1-carboxylate synthase.
Selenocysteine lyase.
L-cysteate sulfo-lyase.
3-chloro-D-alanine dehydrochlorinase.
S-carboxymethylcysteine synthase.

Alanine racemase.
Methionine racemase.
Glutamate racemase.
Arginine racemase.
Amino-acid racemase.
2-aminohexano-6-lactam racemase.
Isopenicillin-N epimerase.
Serine racemase.
D-ornithine 4,5-aminomutase.
Glutamate-1-semialdehyde 2,1-aminomutase.
Glutamate 2,3-aminomutase.

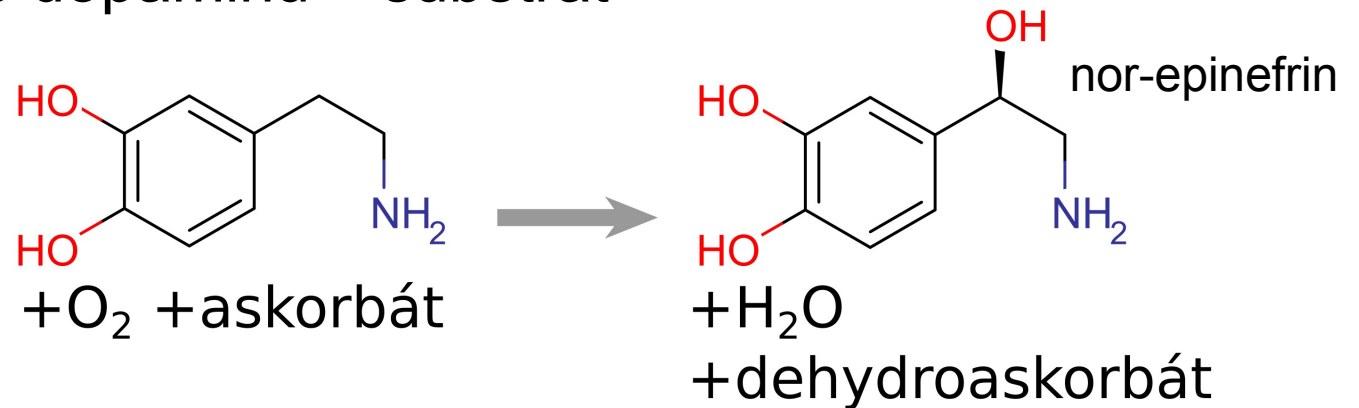
askorbová kyselina

Vitamín C

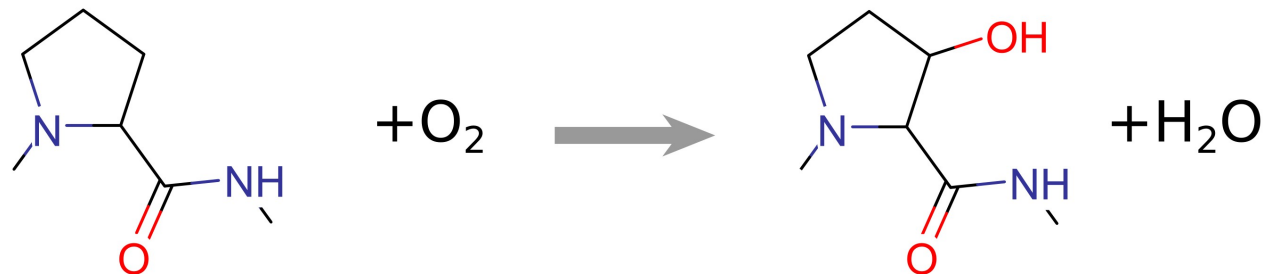


kyselina askorbová

Hydroxylace dopaminu – substrát

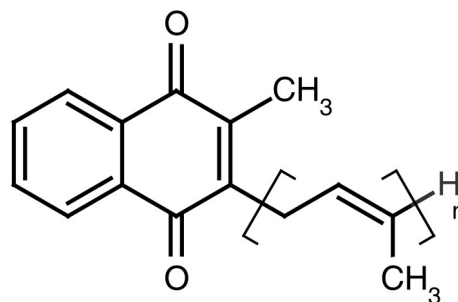


Hydroxylace kolagenu – ochrana Fe^{2+}



a další reakce, antioxidant

Vitamín K



vitamín K₂

nutný pro vznik γ -karboxy-Glu v koagulačních faktorech

Antivitamíny: warfarin

Ostatní vitamíny:

Vitamin A – retinol – fotosenzor v oku, role v signalizaci

Vitamin D – kalciferol – metabolismus vápníku

Vitamíny E – tokoferoly – antioxidanty