

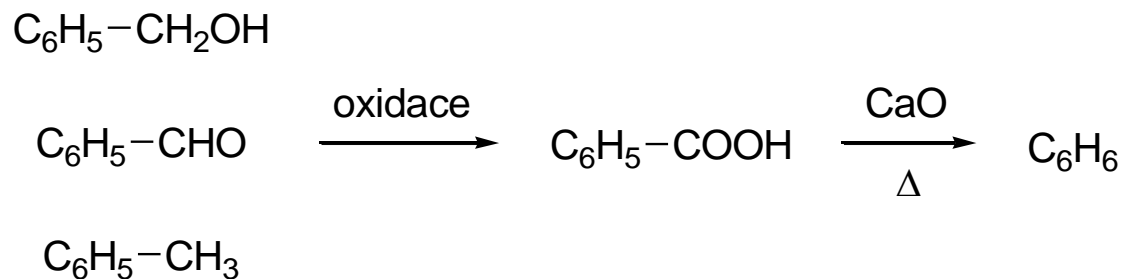
6.1. Úvod

Řada látek s C_6H_5 - skupinou byla izolovaná z přírodních zdrojů:

benzylalkohol (izolován z mandlového oleje),

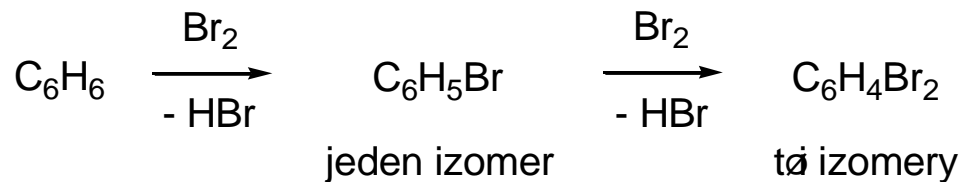
benzaldehyd (také izolován z mandlového oleje)

toluen (izolován z tolu balzámu)



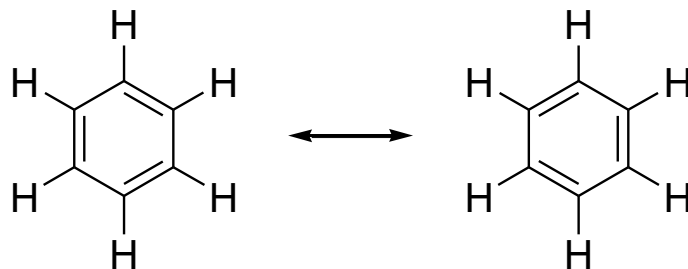
Benzen byl izolován M. Faradayem v roce 1825 ze stlačeného svítiplynu.

Reakce benzenu

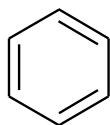
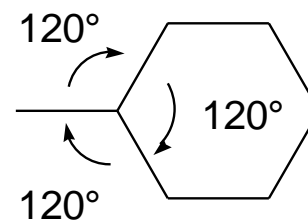
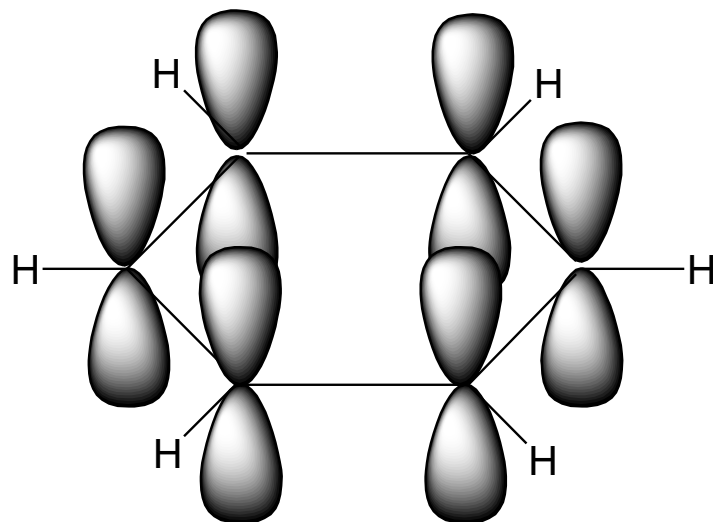


Struktura benzenu

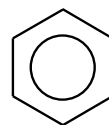
1865 Kekulé

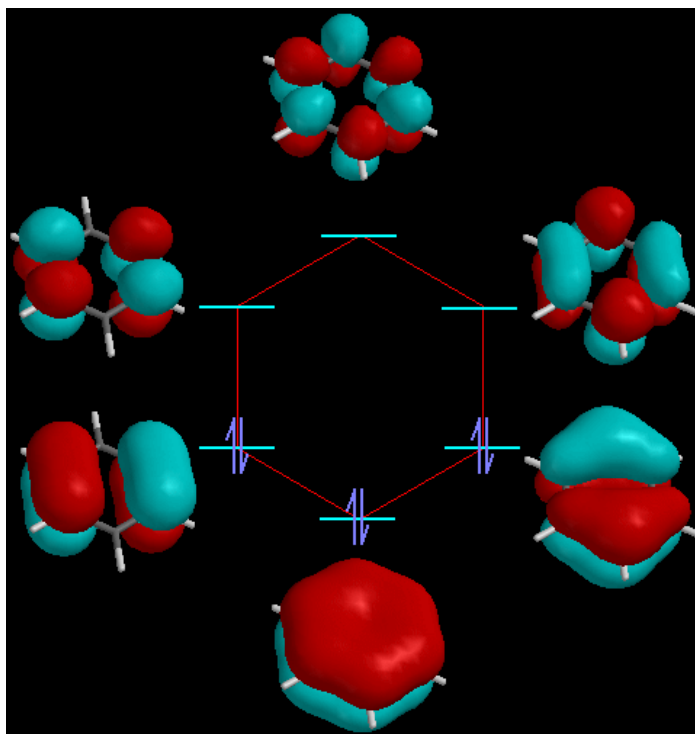
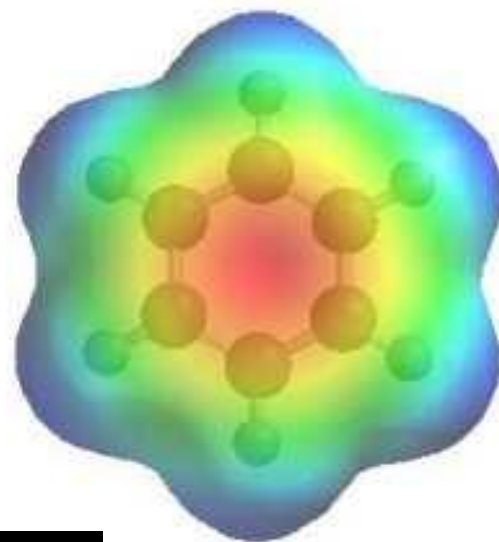
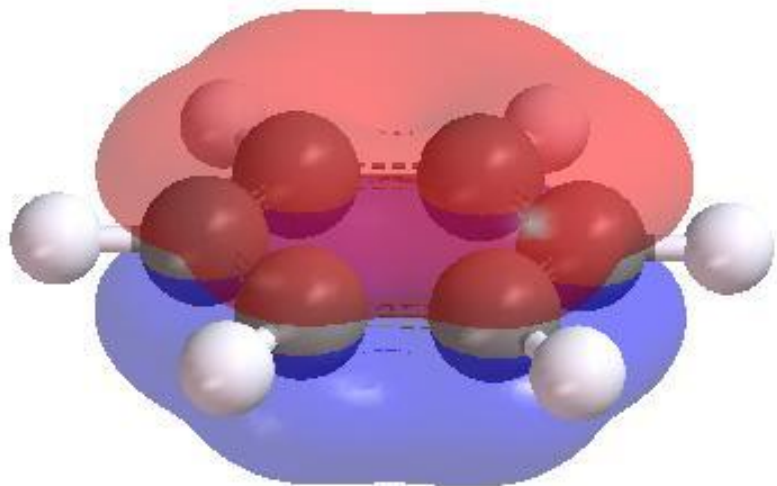


Všechny vazebné délky mezi atomy uhlíku jsou stejné a mají délku 1.39 Å
 délkou jednoduché vazby 1.54 Å
 délka dvojné vazby 1.34 Å



Kekulého vzorec

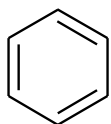
delokalizovaný
 π oblak



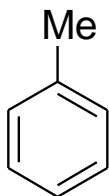
6.2. Názvosloví aromatických uhlovodíků

Třída aromatických uhlovodíků se nazývá **areny**

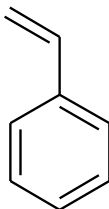
Názvy substituovaných benzenů se odvozují od mateřského uhlovodíku tedy benzenu.



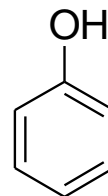
benzen



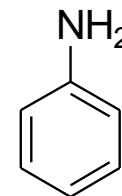
toluen



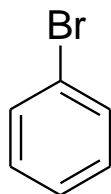
styren



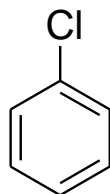
fenol



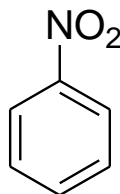
anilin



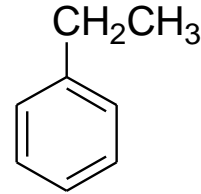
brombenzen



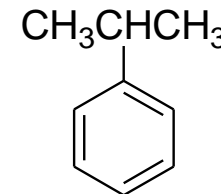
chlorbenzen



nitrobenzen

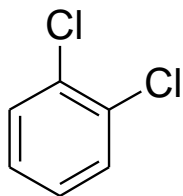


ethylbenzen

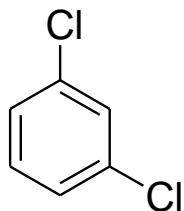


isopropylbenzen

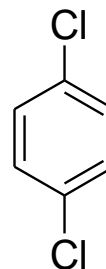
Jestliže jsou přítomny v molekule dva substituenty, tak se jejich vzájemná uspořádání vůči sobě označují předponami *ortho*, *meta* a *para*, často se však používá jejich zkrácený zápis *o-*, *m-* a *p-*.



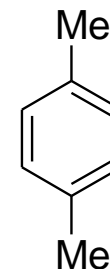
ortho-dichlorbenzen
o-dichlorbenzen



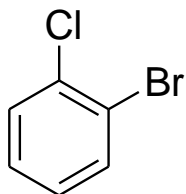
meta-dichlorbenzen
m-dichlorbenzen



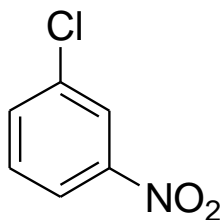
para-dichlorbenzen
p-dichlorbenzen



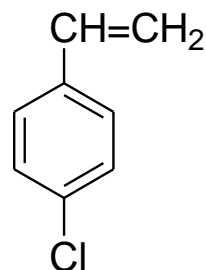
para-xylen
p-xylen



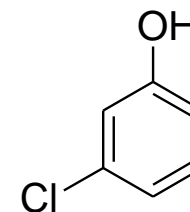
o-bromchlorbenzen



m-nitrochlorbenzen

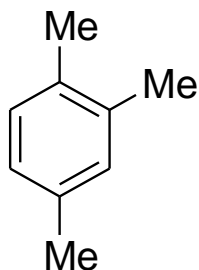


p-chlorstyren

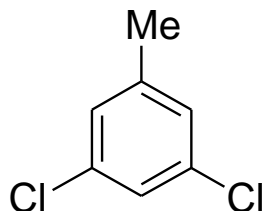


m-chlorfenol

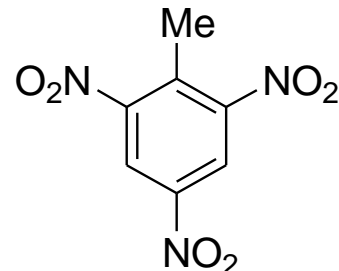
Podle systematického názvosloví by se však vzájemná poloha jednotlivých substituentů měla vyjadřovat pomocí číselných lokantů. V případě *ortho*, *meta* a *para* odpovídají vzájemnému uspořádání 1,2, 1,3 a 1,4.



1,2,4-trimethylbenzen



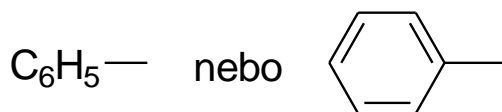
3,5-dichlortoluen



2,4,6-trinitrotoluen

V chemické literatuře se vyskytují jména dvou speciálních skupin: fenylová (Ph) a benzylová (Bn) skupina.

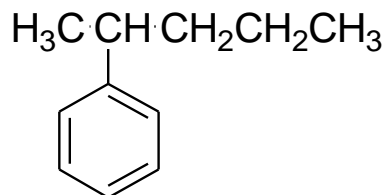
Pro obecné vyjádření aromatického kruhu se používá symbol Ar.



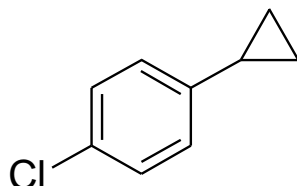
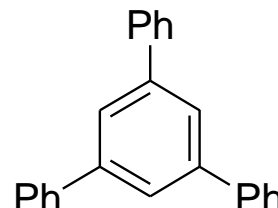
fenylová skupina



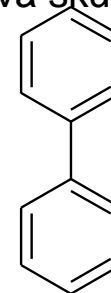
benzylová skupina



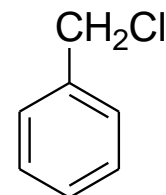
2-fenylpentan

*p*-chlorfenyl-
cyklopropan

1,3,5-trifenylbenzen



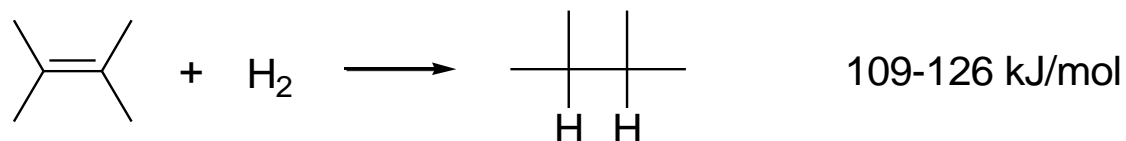
bifenyl



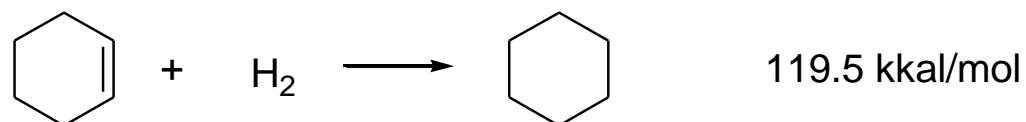
benzylchlorid

6.3. Rezonanční energie benzenu

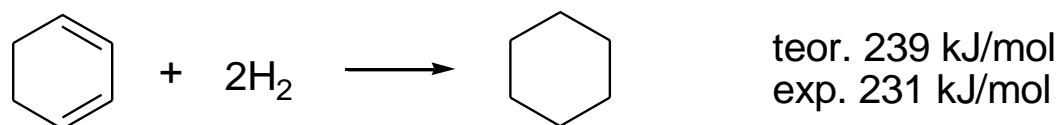
Hydrogenace dvojné vazby je vždy exothermická reakce



Hydrogenační teplo cyklohexenu je 119.5 kJ/mol

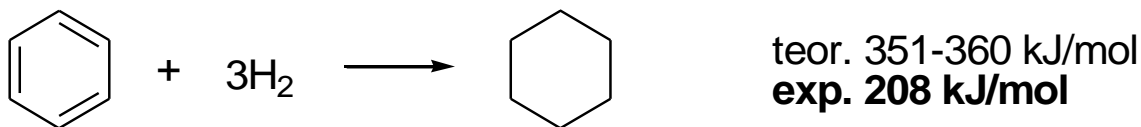


Hydrogenací cyklohexadienu by se mělo uvolnit dvojnásobné množství tepla, tj. asi 239 kJ/mol. Naměřená experimentální hodnota činí 232 kJ/mol



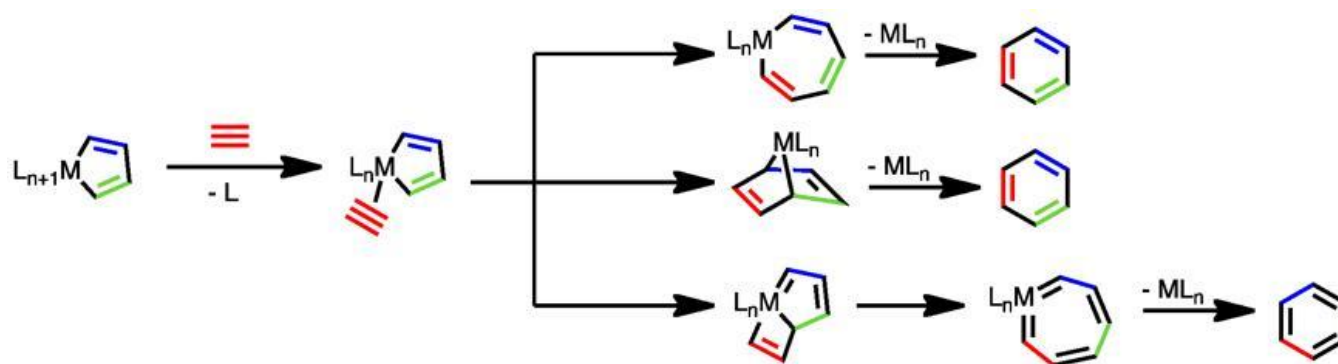
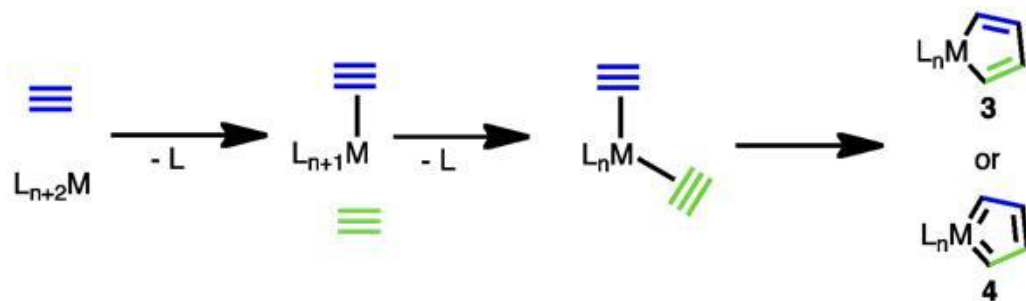
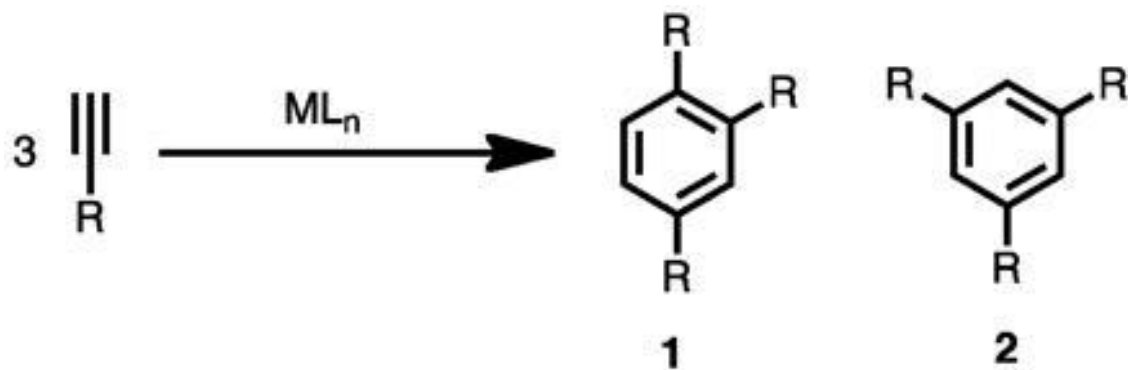
Teplo uvolněné při hydrogenaci tří dvojných vazeb hypotetického 1,3,5-cyklohexatrienu by se mělo pohybovat v rozmezí 351-360 kJ/mol.

Změřené hydrogenační teplo benzenu činí pouze 208 kJ/mol, což je zhruba o 150 kJ/mol méně než bylo předpokládáno.

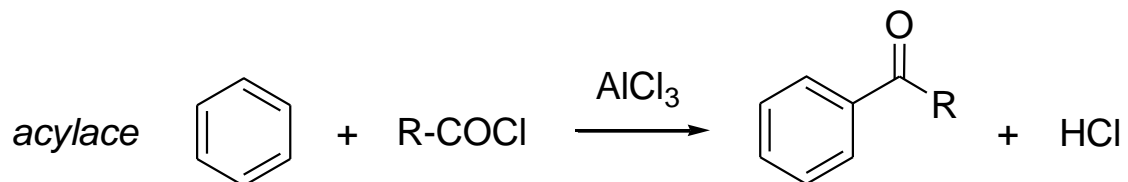
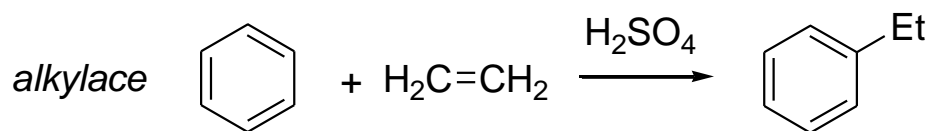
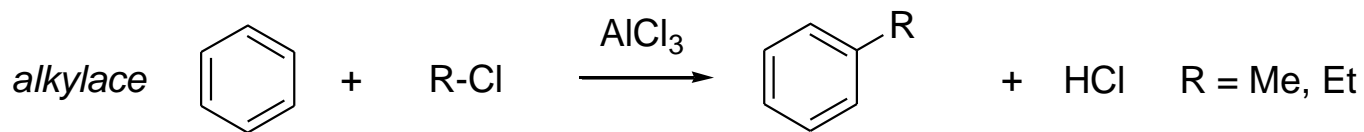
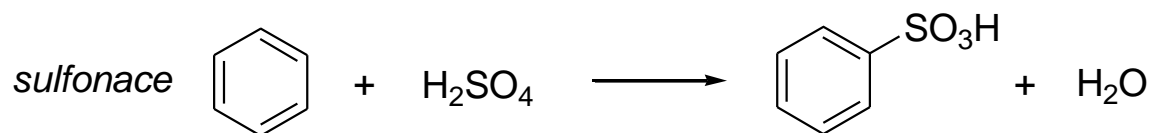
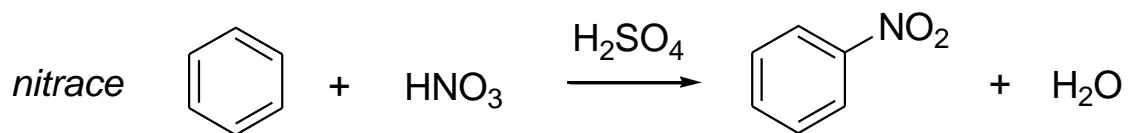
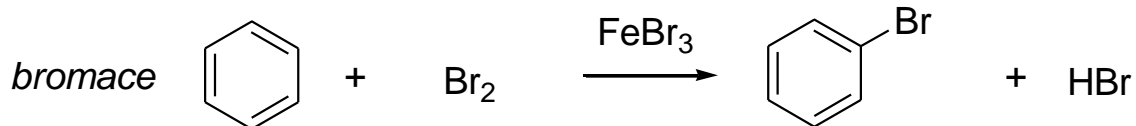
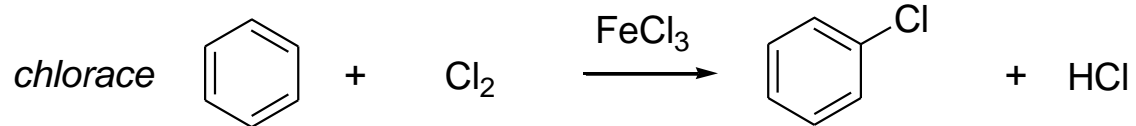


stabilizační či *rezonanční energie* sloučeniny je rozdíl energie skutečné molekuly (rezonančního hybridu) a vypočítané energie nejstabilnější přispívající struktury.

Syntéza benzenu [2+2+2]-cyklotrimerizací alkynů

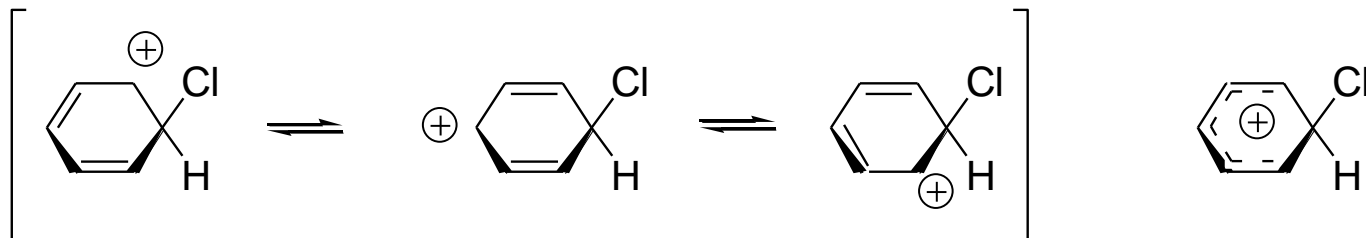
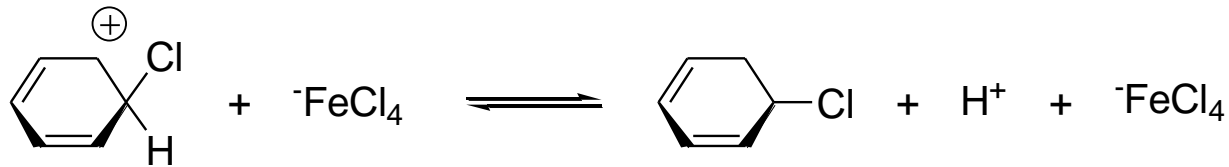
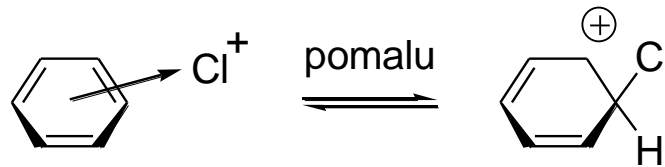
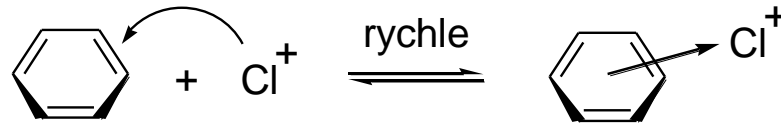
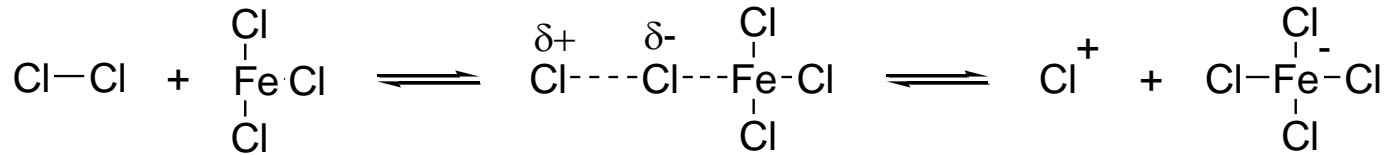


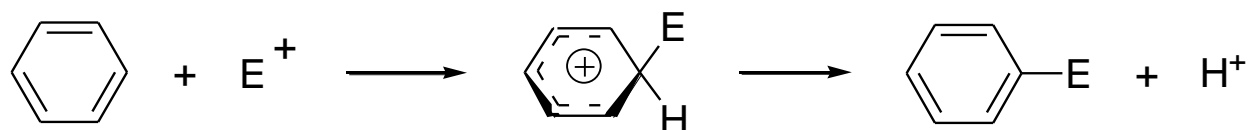
6.4. Elektrofilní aromatická substituce



Halogenace

Prvním krokem je atak benzenového jádra *elektrofilní* částicí

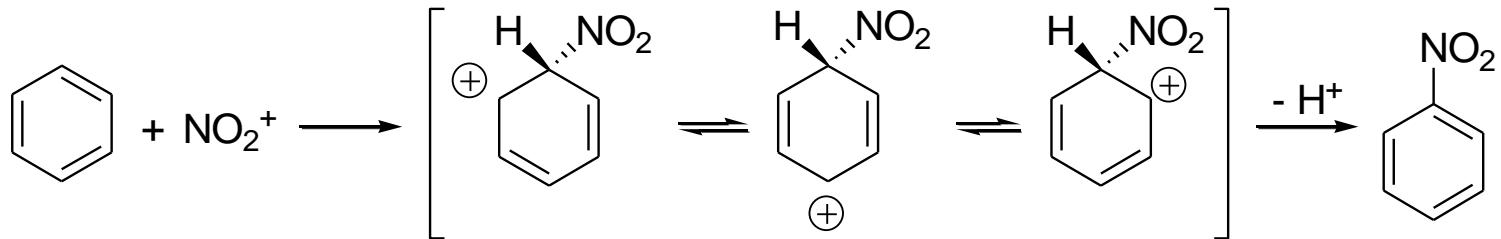
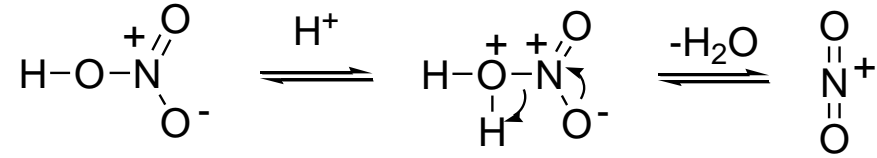




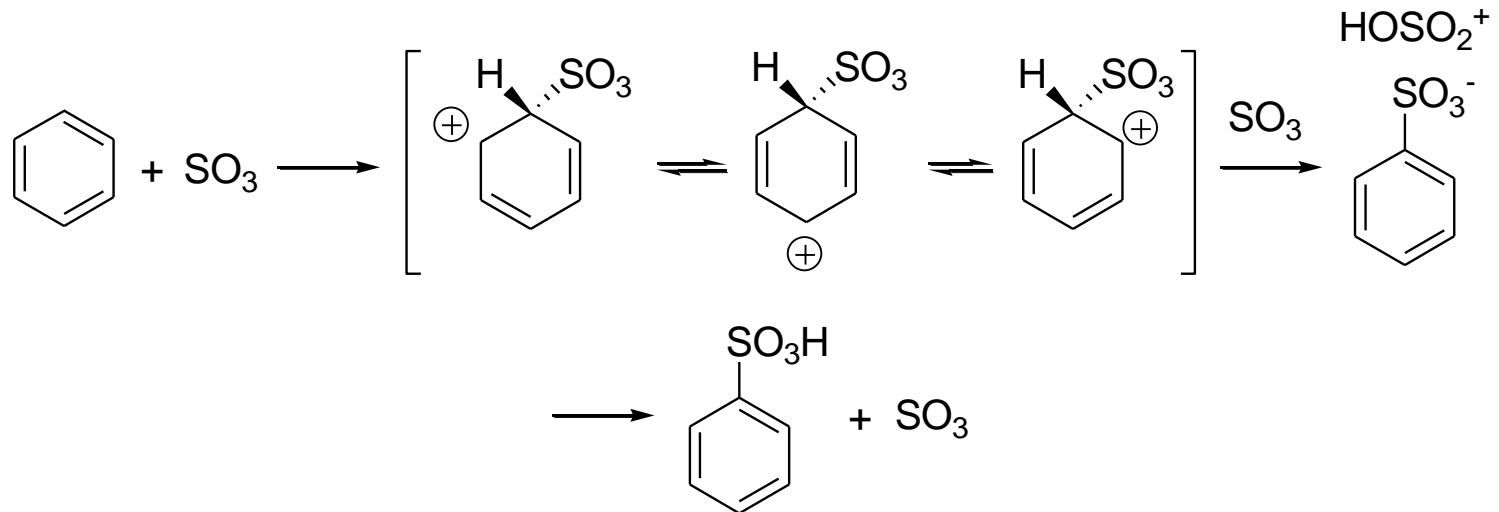
Existuje celá řada elektrofilů, které se účastní elektrofilní aromatické substituce.

E^+	Elektrofil	Process
$\text{X}^{\delta+} \dots \text{Fe}^{\delta-} \text{X}_4$	haloniový kation	halogenace
NO_2^+	nitroniový kation	nitrace
SO_3 nebo SO_3H^+	oxid sírový nebo jeho protonovaná forma	sulfonace
R^+	karbokation	alkylace

Nitrace

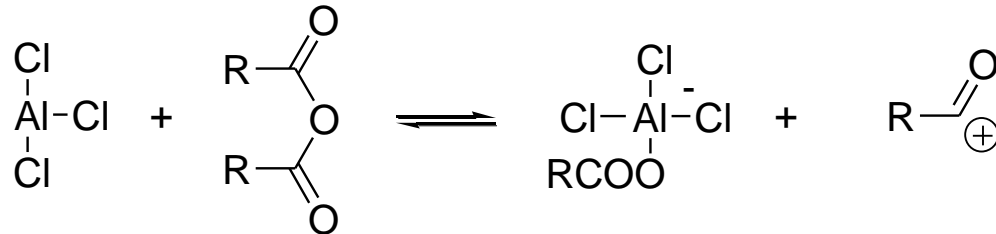
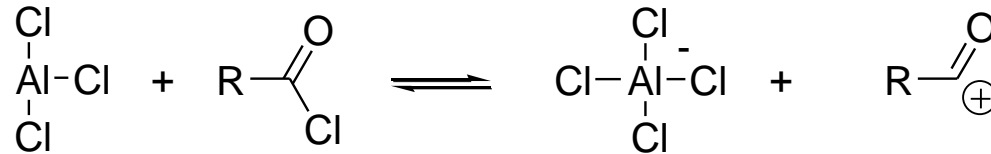
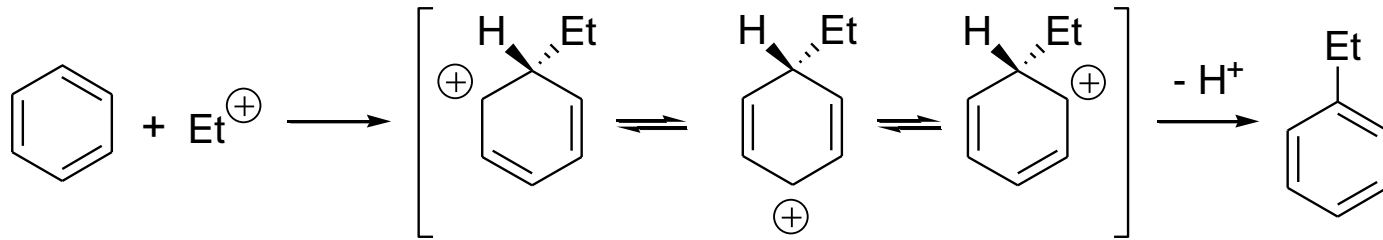
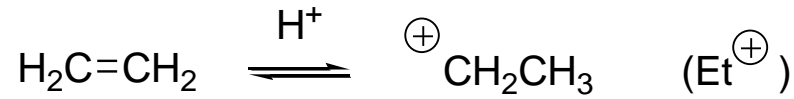
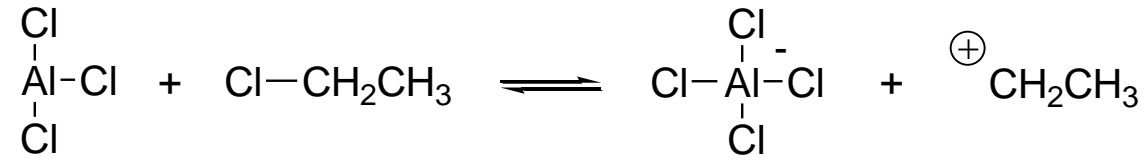


Sulfonace



Alkylace

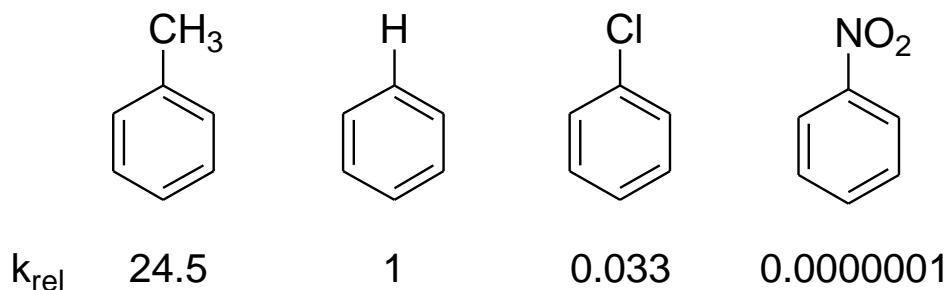
Friedel-Craftsova reakce



6.5. Řídící efekty elektrofilní substituce

Při elektrofilní substituci benzenů nesoucích různé funkční skupiny dochází k jejich různému vlivu na průběh elektrofilní aromatické substituce. To se může projevit dvěma způsoby:

- rozdílnou rychlostí substituce a
- vznikem různých regioizomerů.



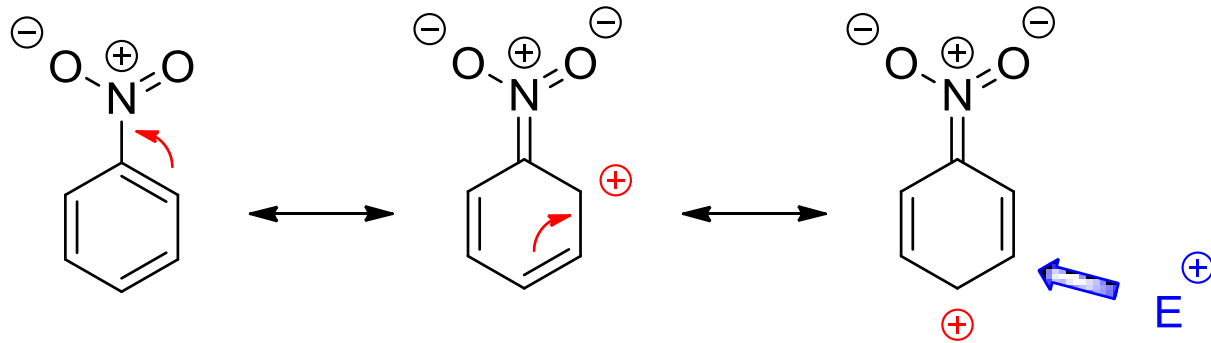
Ortho a para řídící substituenty
(substituenty I. třídy)

-NH₂, -NHR, -NR₂
 -OH, -OCH₃, -OR
 -CH₃, -CH₂CH₃ (alkyl)
 -F, -Cl, -Br, -I

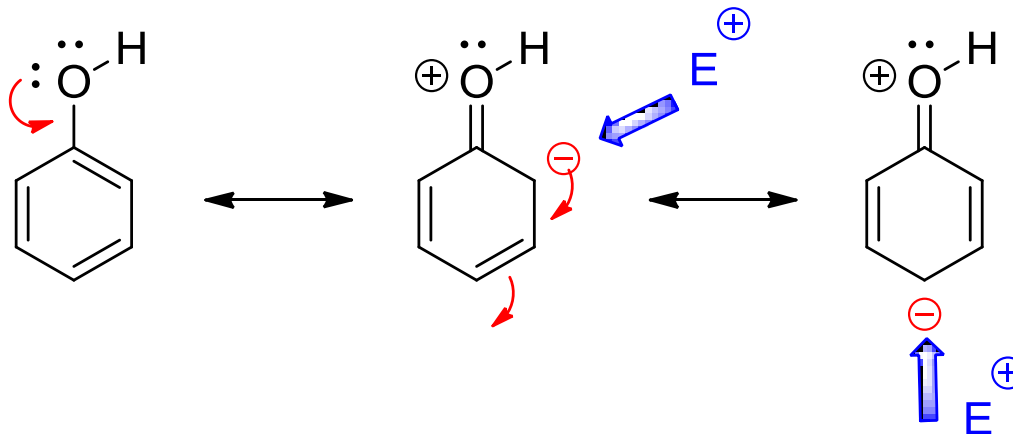
Meta řídící substituenty
(substituenty II. třídy)

-NO₂,
 -CN
 -(C=O)R, -(C=O)OH, -(C=O)OR
 -SO₃H

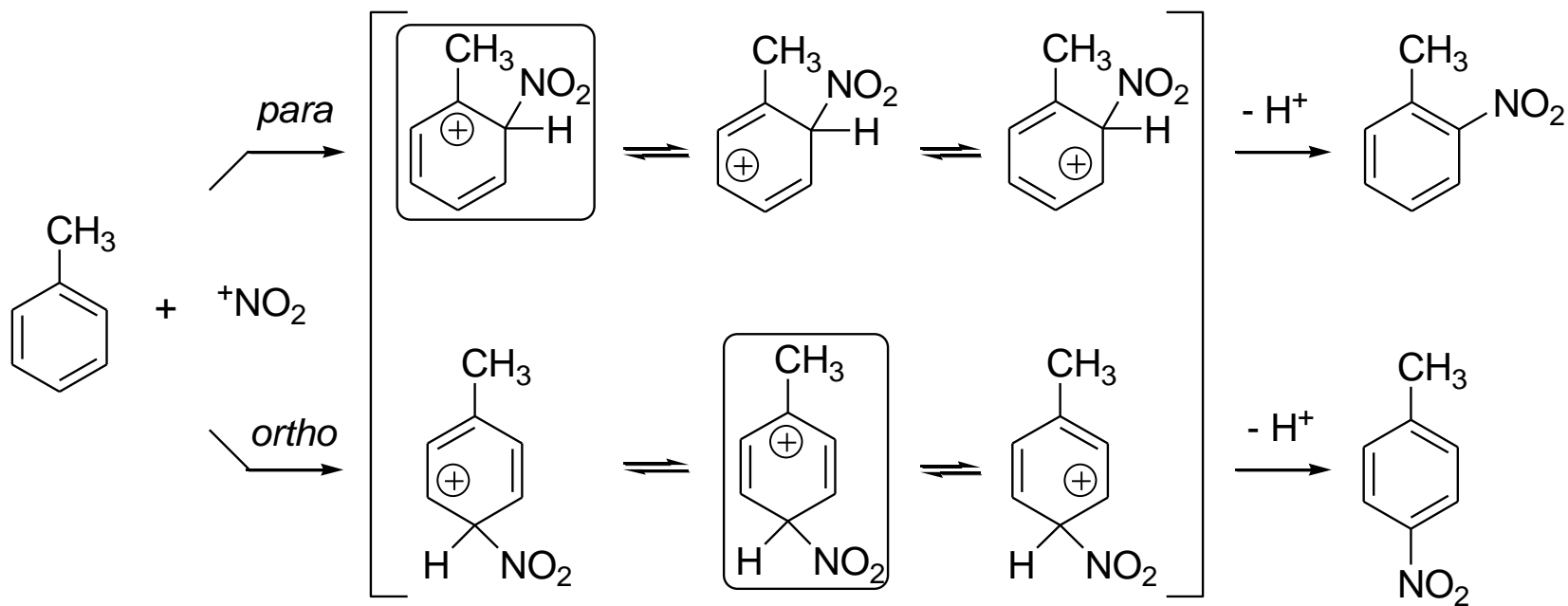
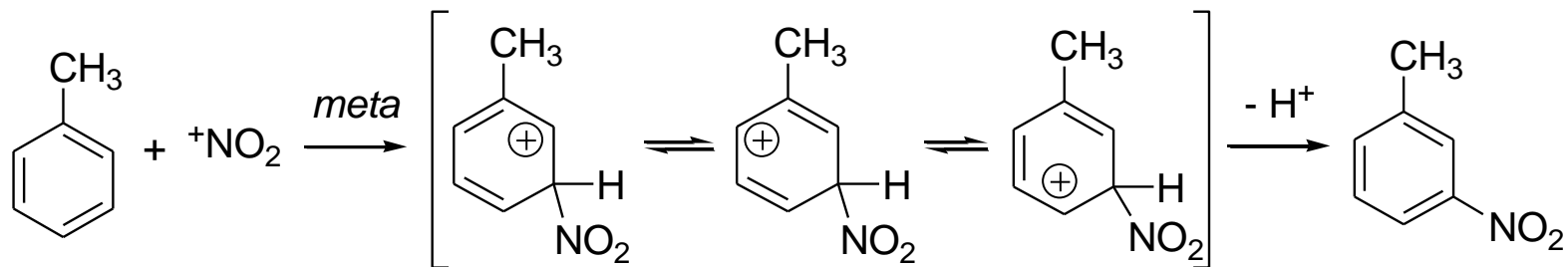
Elektron-akceptorní skupiny



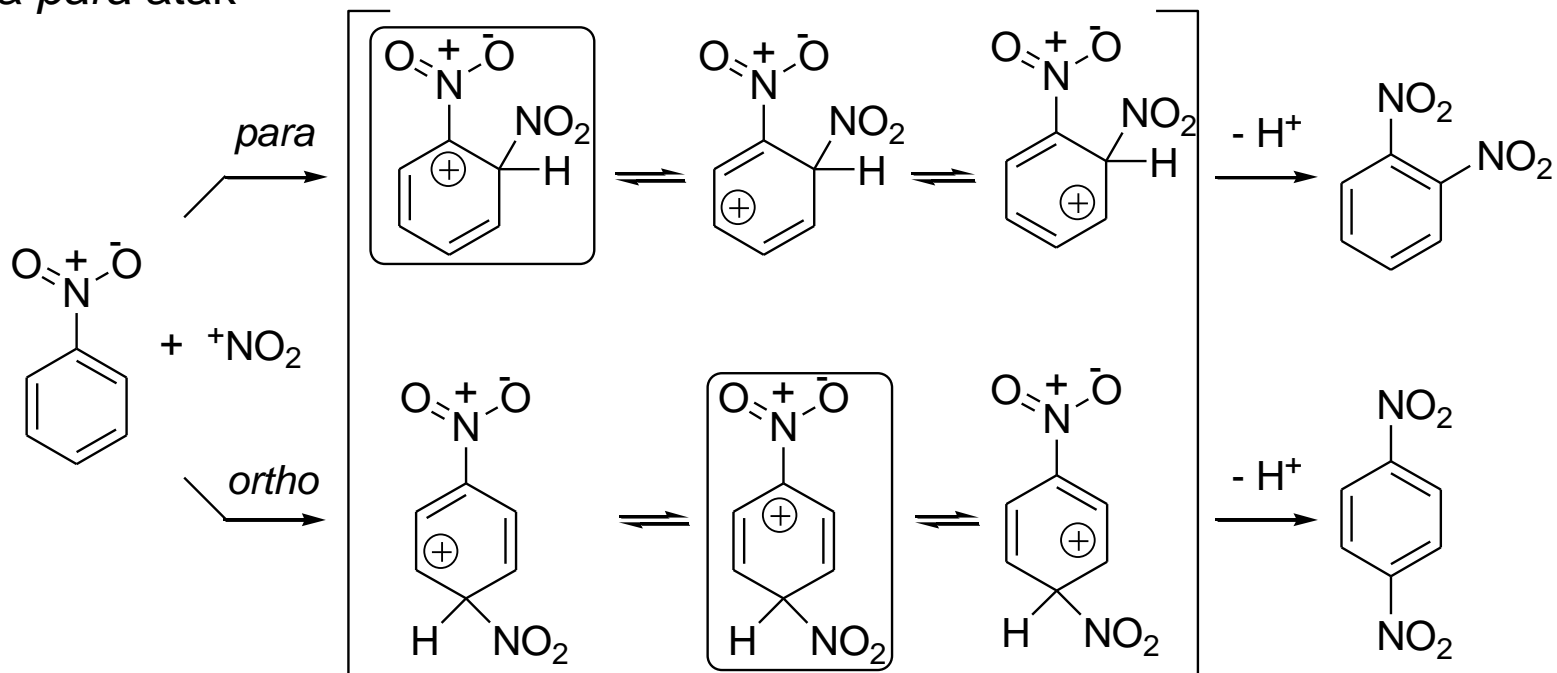
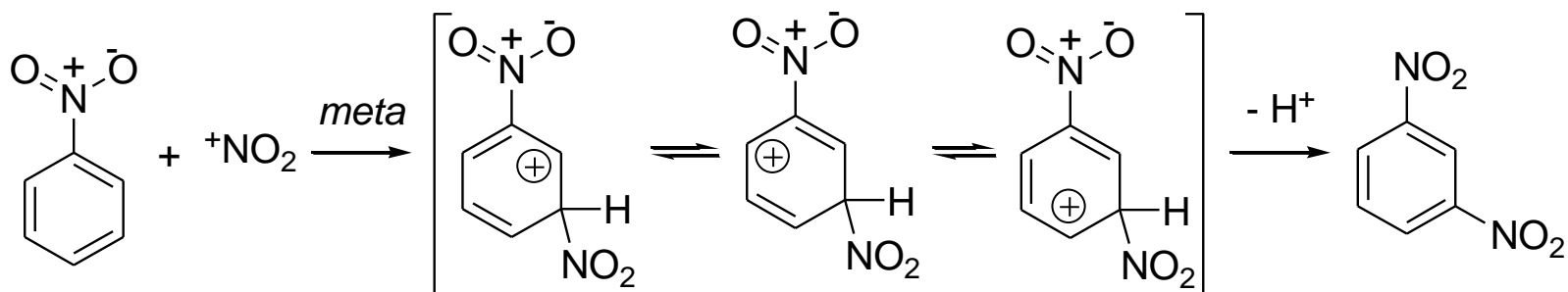
Elektron-donorní skupiny



Nitrace toluenu

ortho a para atak*meta atak*

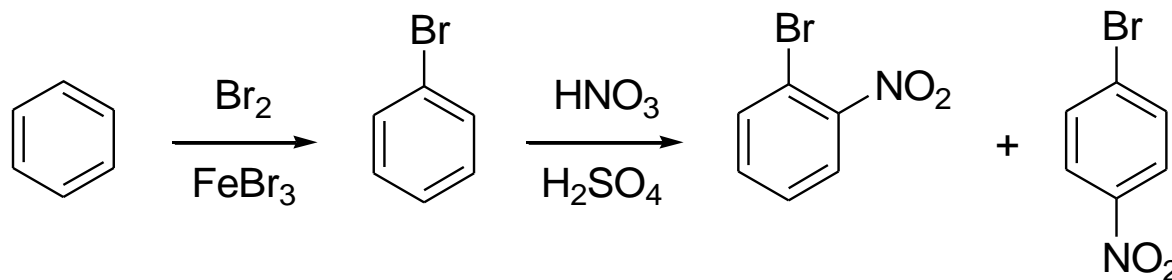
Nitrace nitrobenzenu

ortho a para atak*meta atak*

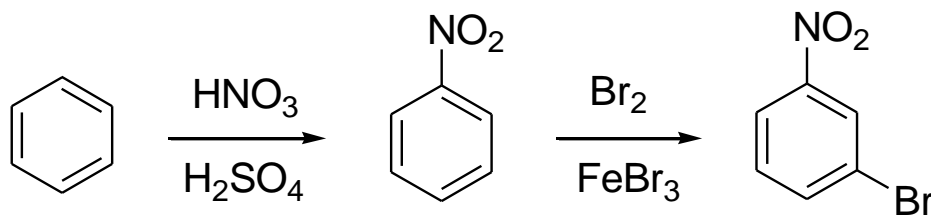
6.6. Význam řídicích efektů pro cílenou substituci aromatických sloučenin

Vhodnou kombinací jednotlivých elektrofilních aromatických substitucí se mohou připravit různé izomery.

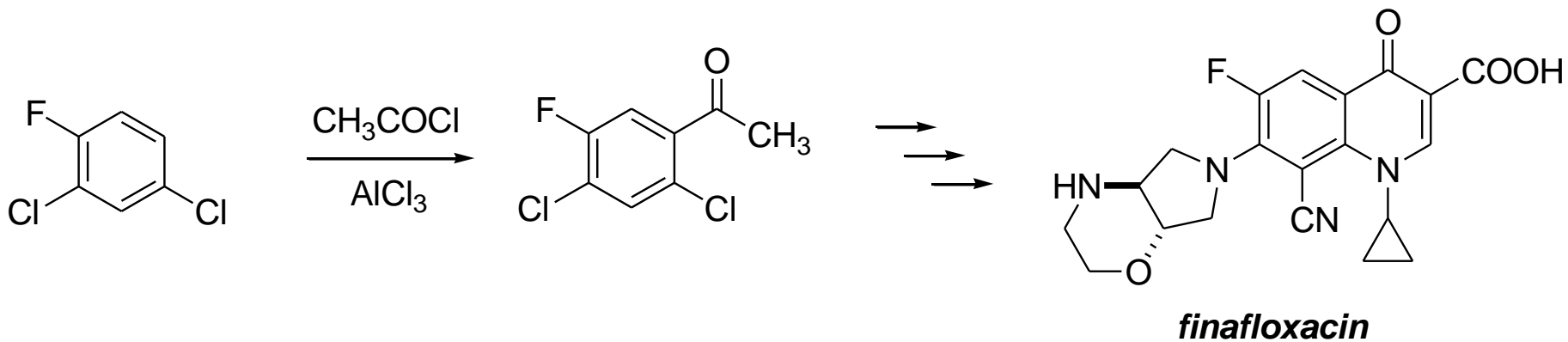
Příprava 1-brom-2-nitro- a 1-brom-4-nitrobenzenu



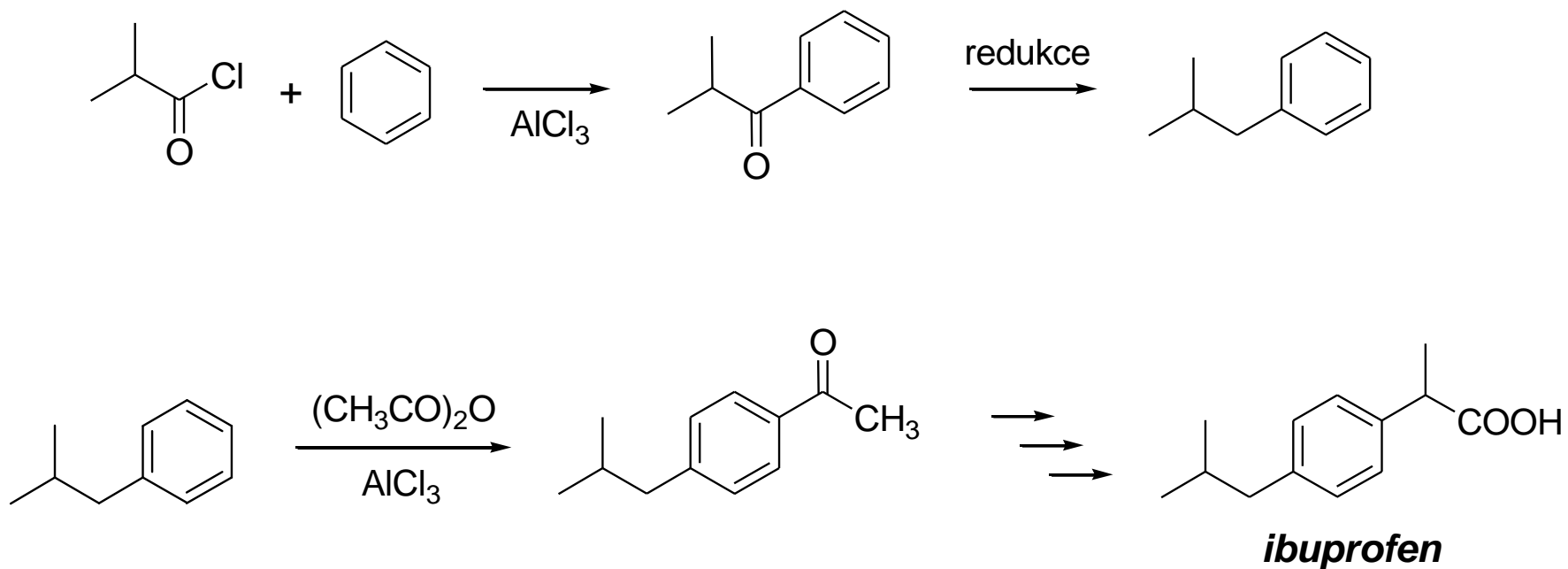
Příprava 1-brom-3-nitrobenzenu



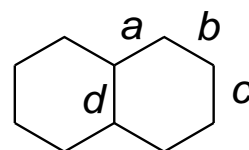
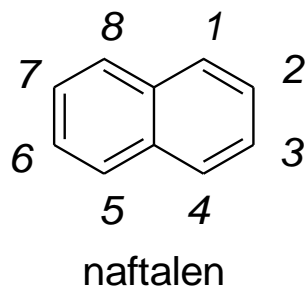
Syntéza finafloxacinu (látka účinná proti *Helicobacterium pylori*)



Syntéza ibuprofenu (nesteroidní protizánětlivá látka)

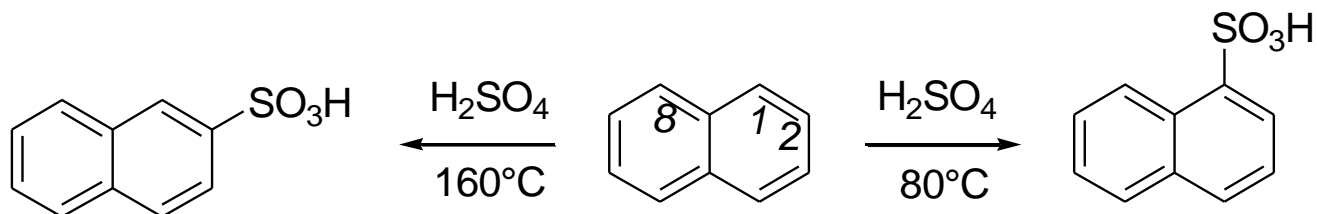


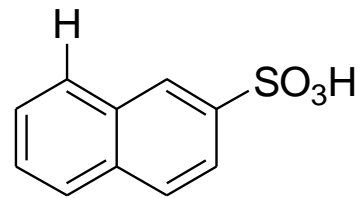
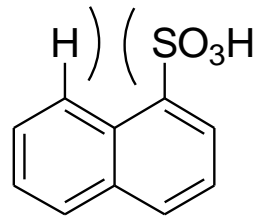
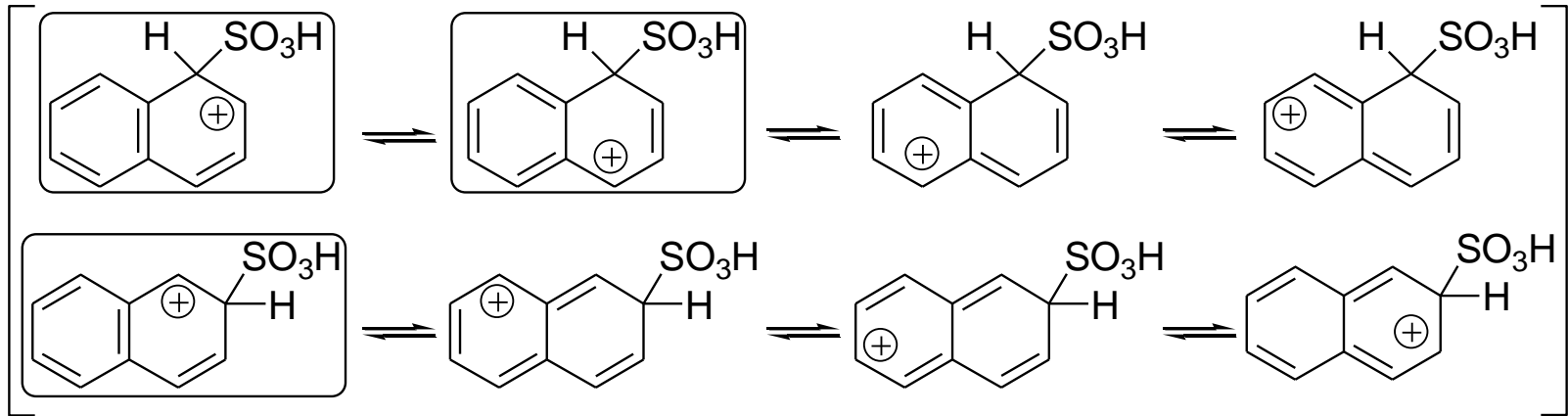
6.7. Polycyclické aromatické sloučeniny

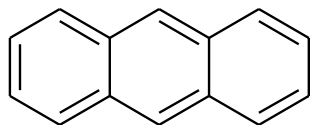


$$\begin{aligned}
 a &= 1.42\text{A} \\
 b &= 1.36\text{A} \\
 c &= 1.40\text{A} \\
 d &= 1.39\text{A}
 \end{aligned}$$

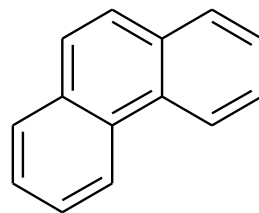
Sulfonace benzenu je závislá na reakční teplotě (vratná reakce)



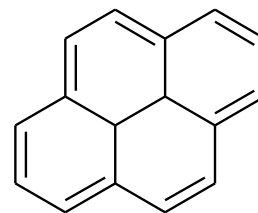




antracen

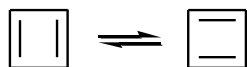


fenatren

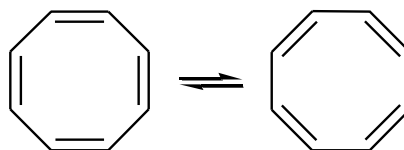


pyren

6.8. Hückelovo pravidlo a aromaticita



cyklobutadien
(4π elektrony)



cyklooktatraen
(8π elektronů)

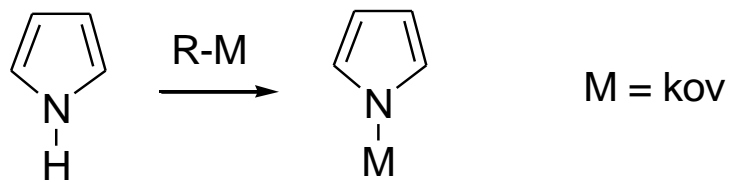
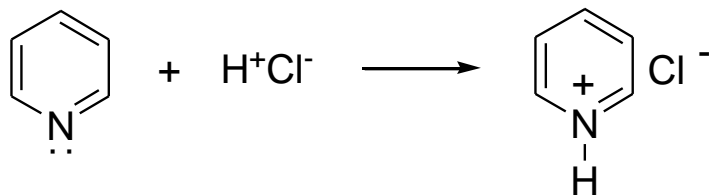
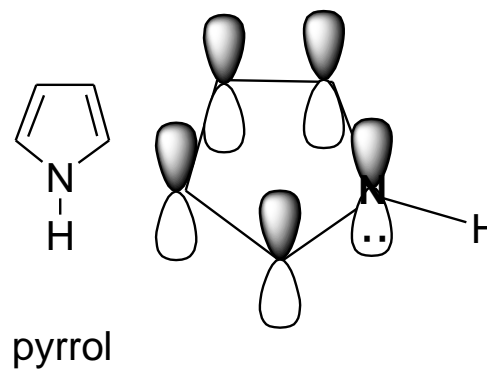
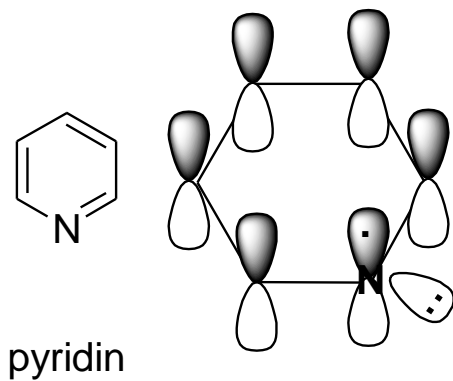


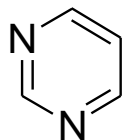
vanièková konformace
cyklooktatraenu

Planární monocyklické systémy s $(4n+2)\pi$ elektrony ($n = 0, 1, 2$ atd.), tj. systémy s 2, 6, 10, 14, atd. konjugovanými π elektrony, jsou aromatické (Hückelovo pravidlo)

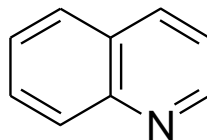
systémy s $4n$ π elektrony, tj. systémy s 4, 8, 12, 16, atd. konjugovanými π elektrony, nejsou aromatické.

6.9. Heterocyklické aromatické sloučeniny

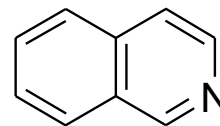




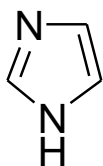
pyrimidin



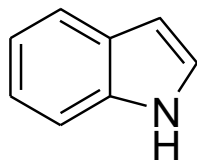
chinolin



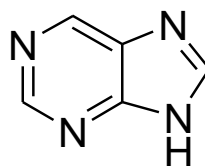
isochinolin



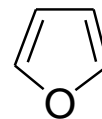
imidazol



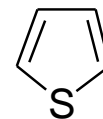
indol



purin



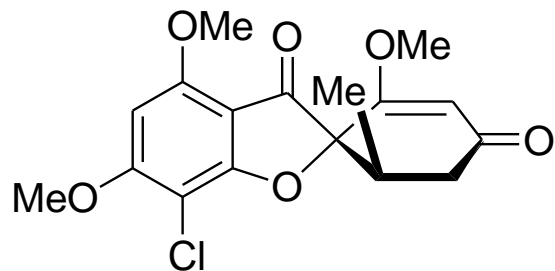
furan



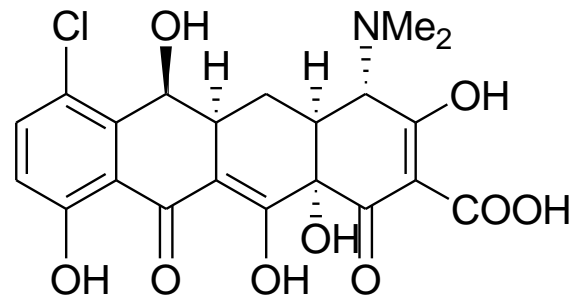
thiofen

6.10. Halo a nitroaromáty v přírodě

Chlorované aromatické sloučeniny

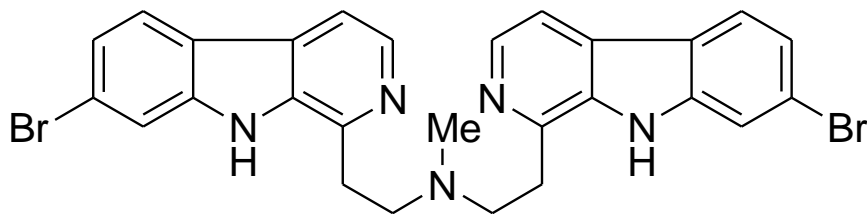


griseofulvin

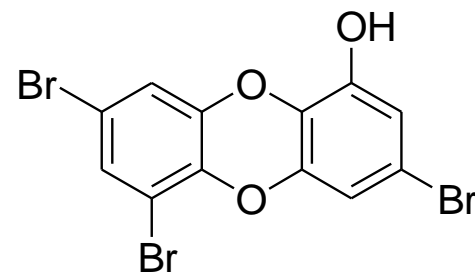


aureomycin

Bromované aromatické sloučeniny

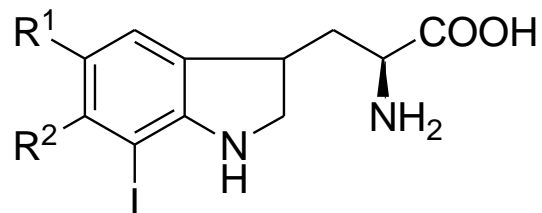
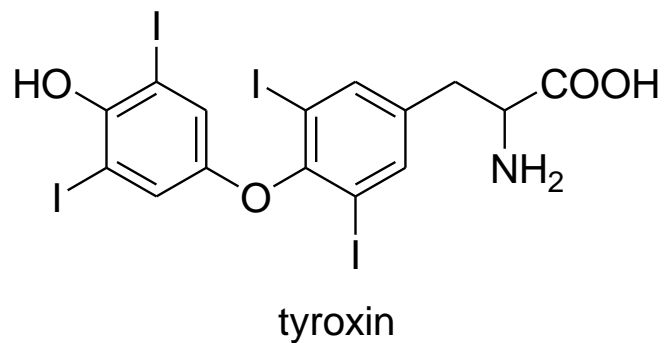


plakortamin C



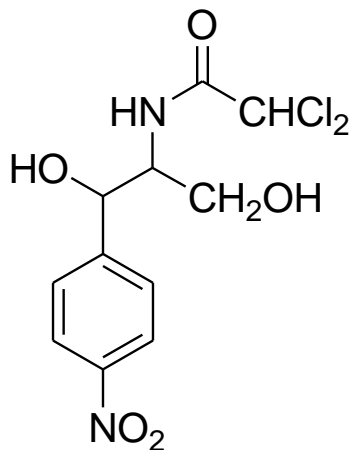
spongiotoxin C

Jodované aromatické sloučeniny



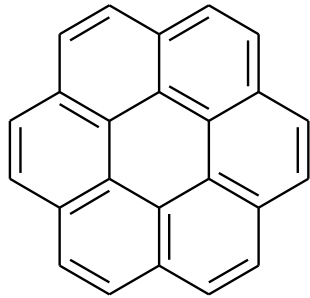
plakohypaphorin A, R¹ = R² = H
 plakohypaphorin B, R¹ = H, R² = I
 plakohypaphorin C, R¹ = I, R² = H

Nitrované aromatické sloučeniny



chlormafenikol

Aromatické uhlovodíky v přírodě



$C_{24}H_{12}$, karpatit



Karpatite

Comments: Pale greenish karpatite with minor red cinnabar.

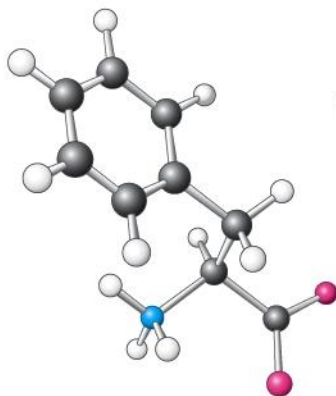
Location: 4th of July mine, New Idria district, San Benito Co., California, USA. **Scale:** Picture size 5 mm.

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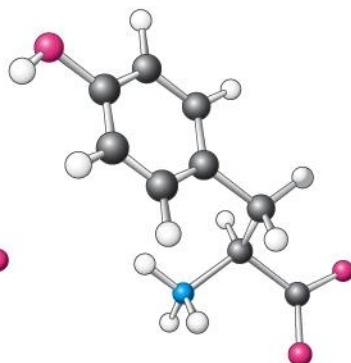
<http://www.webmineral.com/data/Karpatite.shtml>

<http://www.webmineral.com/data/Karpatite.shtml>

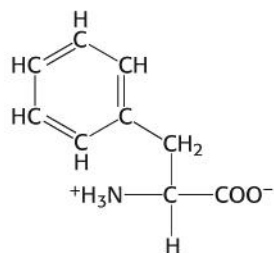
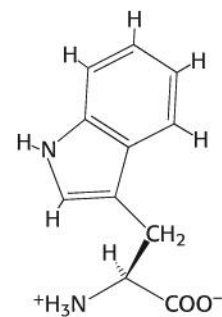
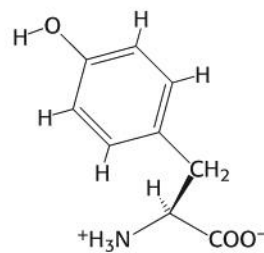
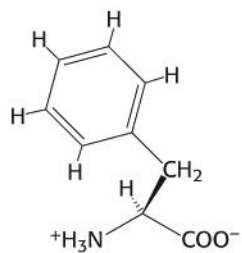
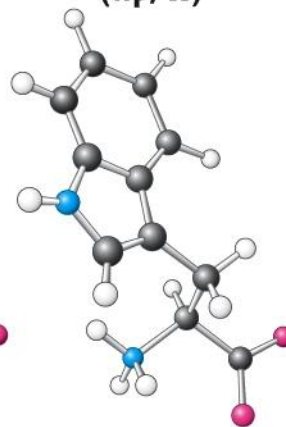
**Phenylalanine
(Phe, F)**



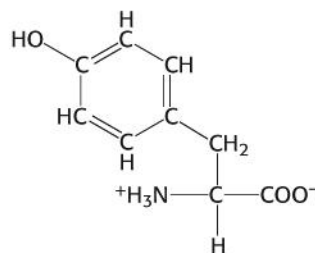
**Tyrosine
(Tyr, Y)**



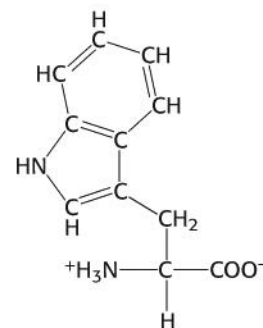
**Tryptophan
(Trp, W)**



**Phenylalanine
(Phe, F)**

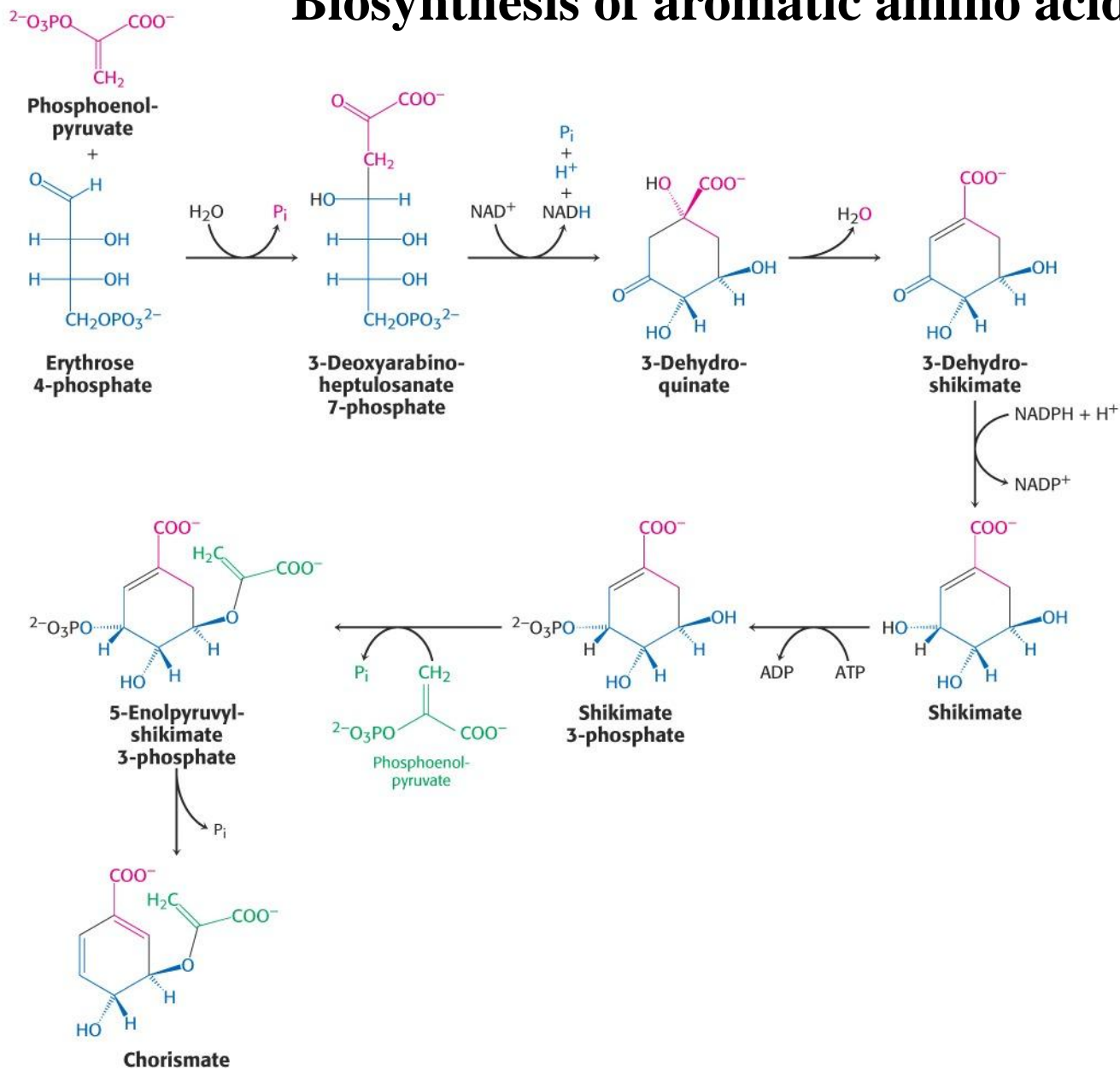


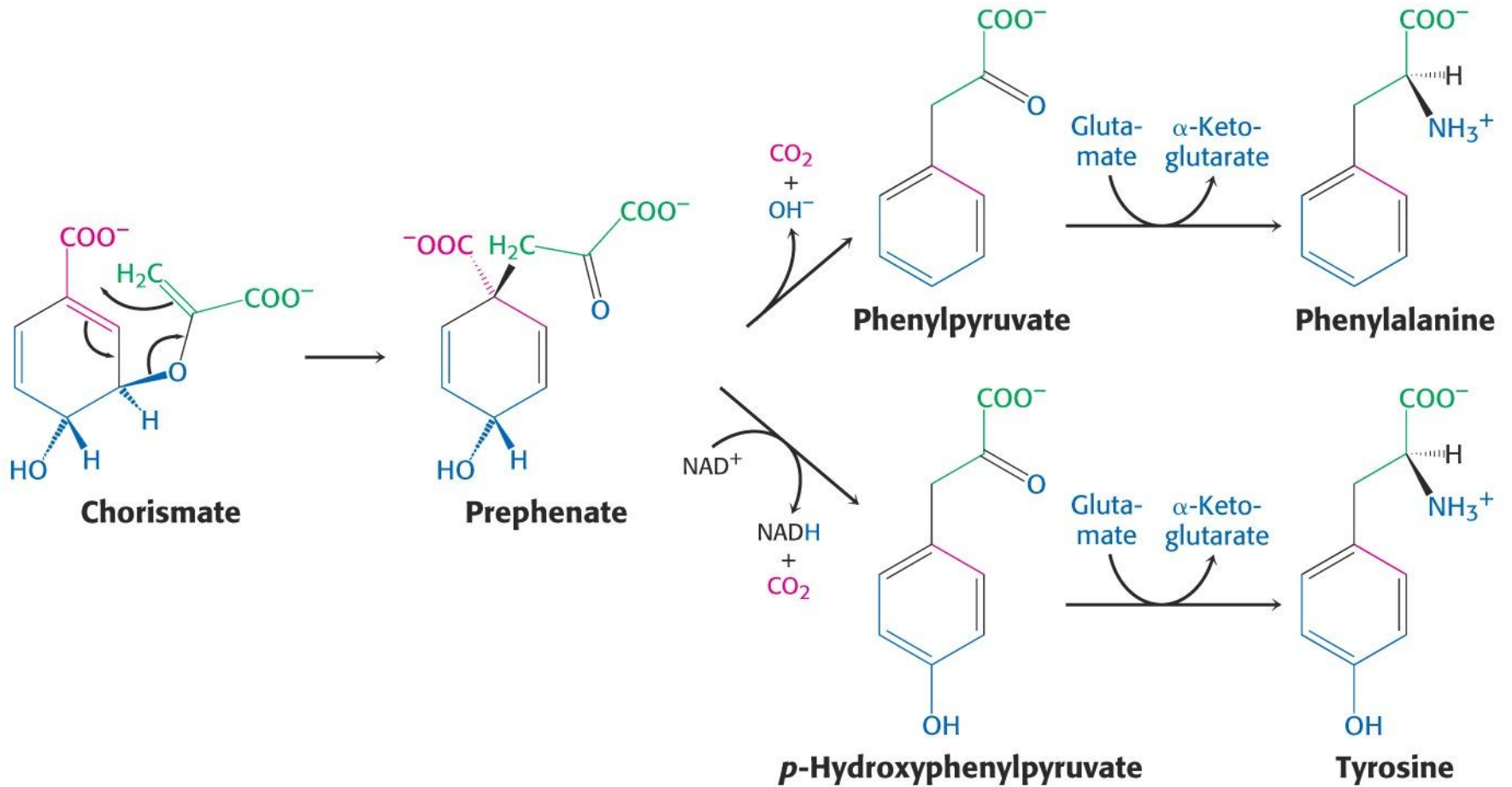
**Tyrosine
(Tyr, Y)**



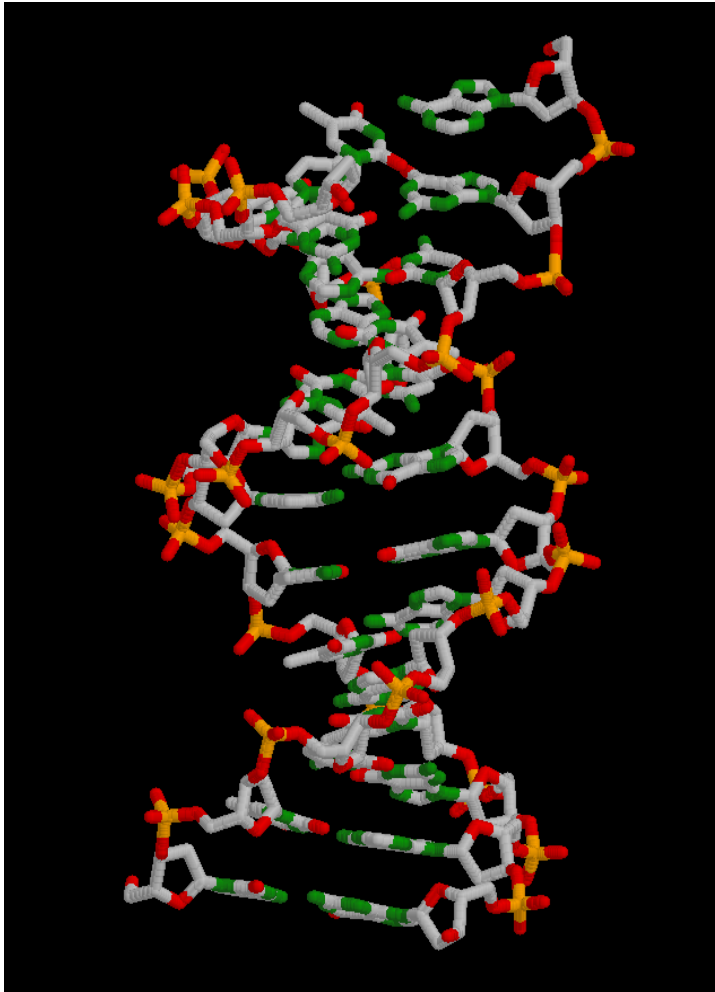
**Tryptophan
(Trp, W)**

Biosynthesis of aromatic amino acids

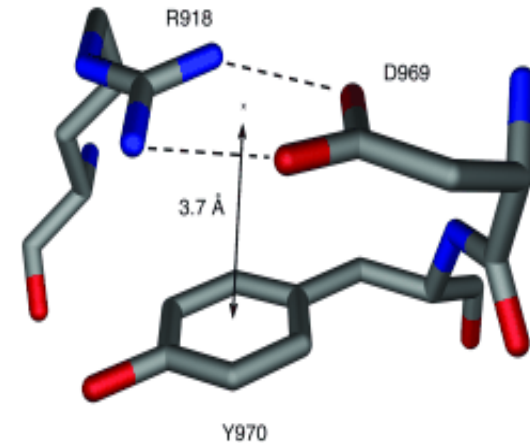
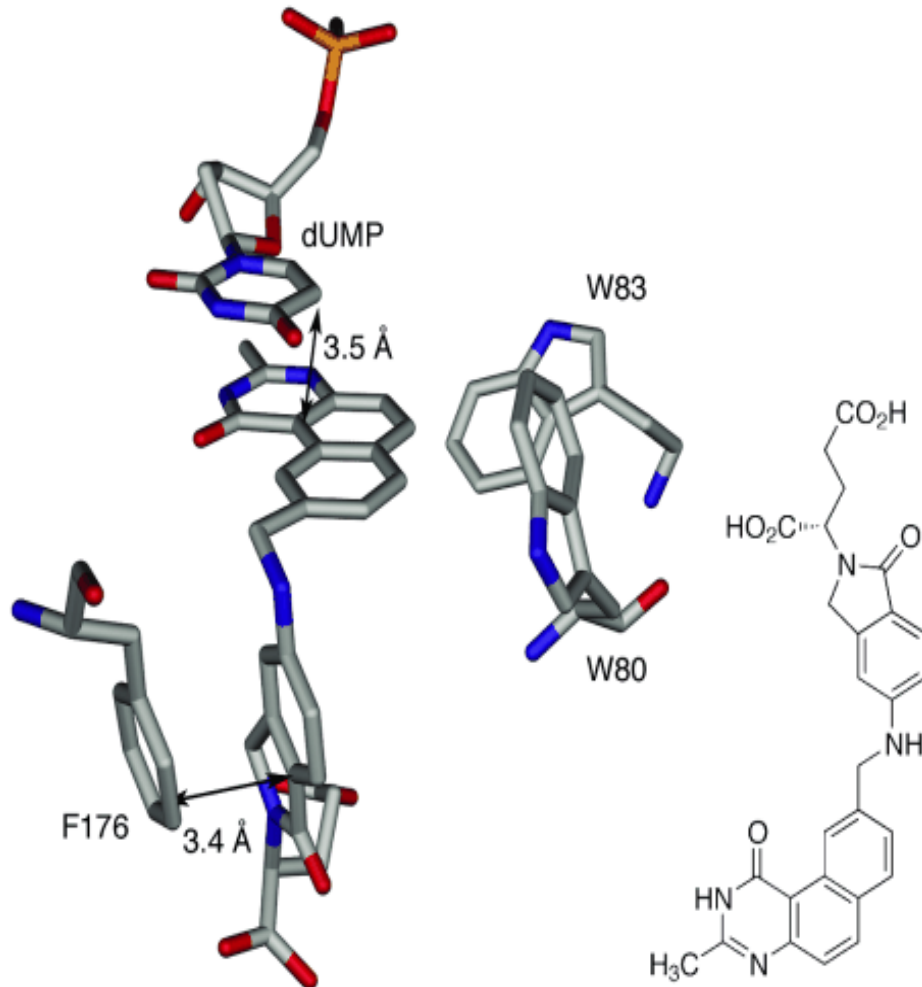




π - π -Interactions (stacking)



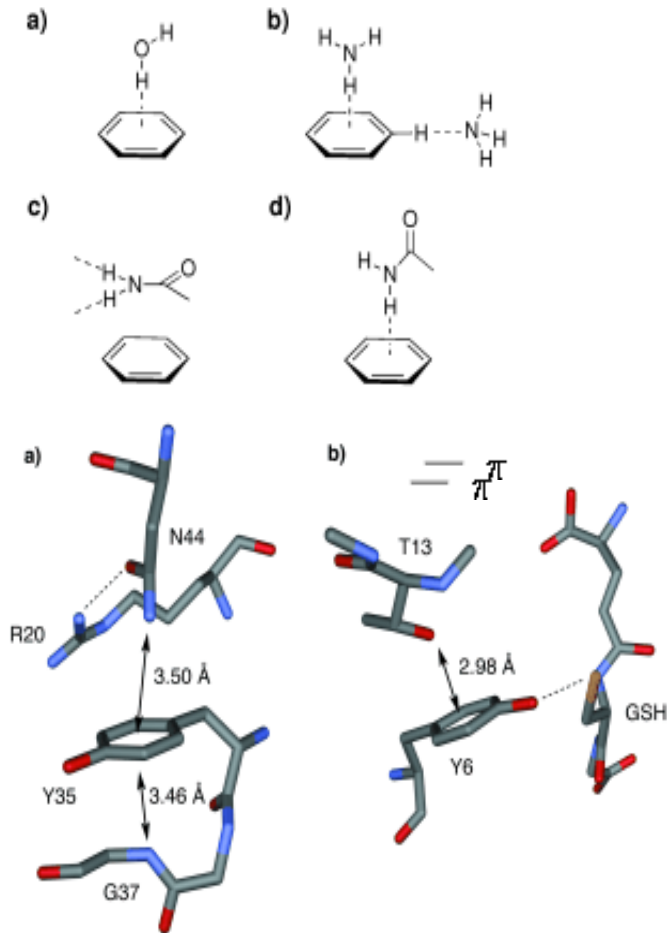
π - π -Interactions (stacking)



Parallel-stacking interaction between Tyr 970A and the H-bonding network between the side chains of Arg 918A and Asp 969A in the feruloyl esterase module of xylanase 10B

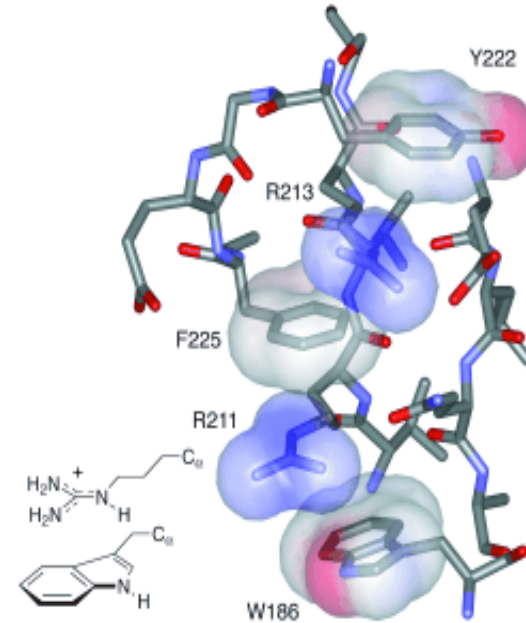
π
Heterocyclic stacking between dUMP and the anticancer drug 1843U89 bound at the active site of thymidylate synthase (PDB code: 1TSD)

H- π -bonds



- a) N-H/ π interaction in the bovine pancreatic trypsin inhibitor (PDB code: 4PTI)
- b) O-H/ π interaction in the complex of glutathione transferase with glutathione (GSH; PDB code: 6GST).

Cation- π -interaction



Alternating cationic (Arg, Lys) and aromatic (Tyr, Phe, Trp) amino acid residues shown by X-ray crystallography (2.8 Å) within the human growth hormone receptor (hGHR) extracellular domain (PDB code: 3HHR).