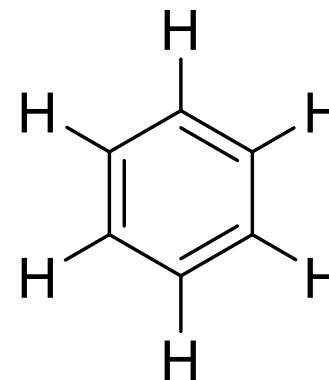


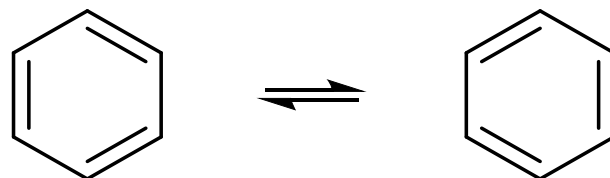
Benzene e Derivati

Benzene

- Il benzene (C_6H_6) è il più semplice tra gli IDROCARBURI AROMATICI (o areni)
- Ha 4 gradi di insaturazione
- È planare
- Tutti i legami C-C hanno la stessa lunghezza

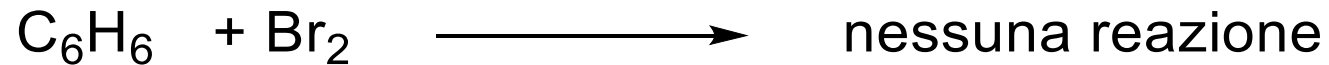


Kekulé (1829-1896) descrisse la sua struttura come un equilibrio tra due forme

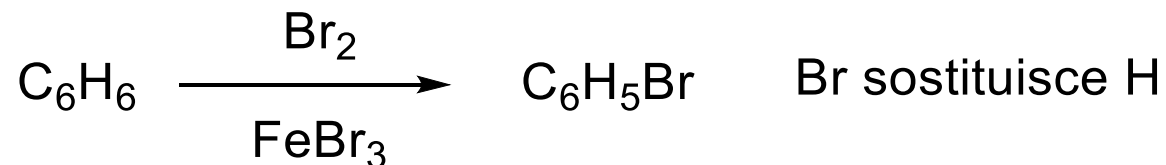


Benzene

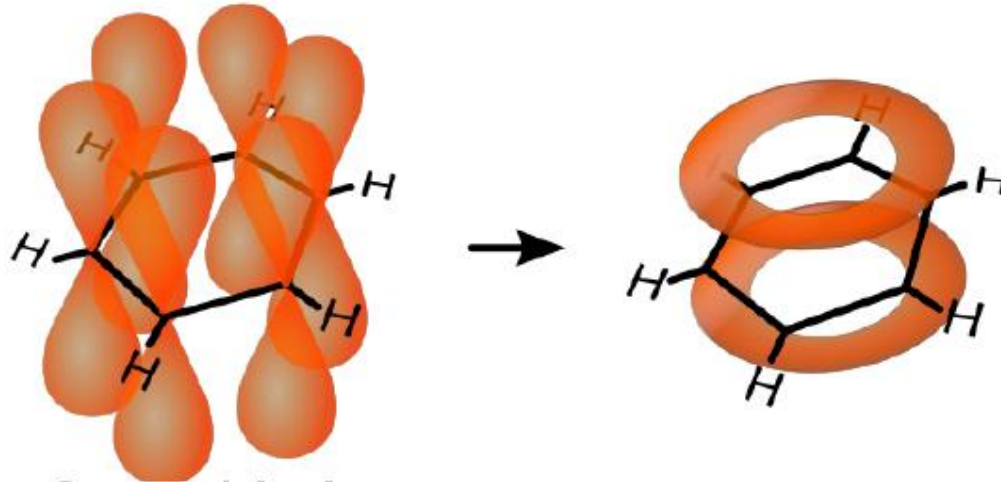
- Mentre gli idrocarburi insaturi (alcheni e alchini) danno facile reazione di addizione, il benzene NO!



- Il benzene è molto stabile e reagisce con bromo solo in presenza di un catalizzatore, FeBr_3 (un acido di Lewis)
- La reazione è una sostituzione non una addizione



Legami delocalizzati



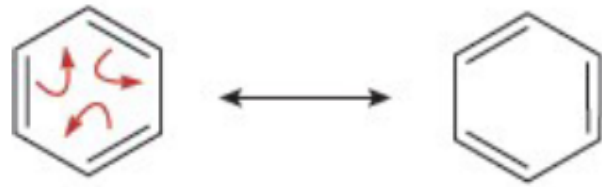
Sei orbitali 2p
con 1 elettrone ciascuno

Nuvola elettronica con 6 elettroni
delocalizzati su tutta la molecola

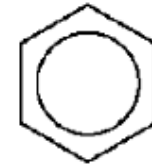
Risonanza

- Le strutture di risonanza (forme limite di risonanza) non sono reali
- Nessuna singola struttura di risonanza può adeguatamente rappresentare la reale struttura di una specie con elettroni delocalizzati
- Le strutture di risonanza NON sono isomeri, differiscono solo per la distribuzione degli elettroni, non dei nuclei
- Le strutture di risonanza NON sono in equilibrio

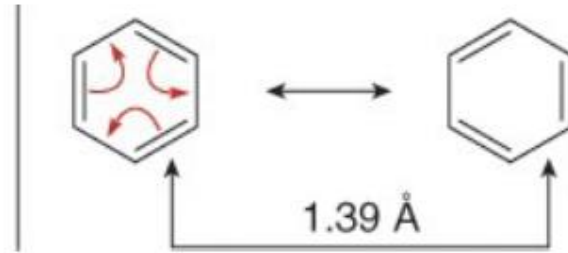
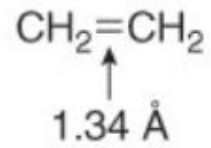
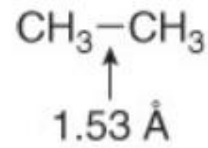
Risonanza









Forme limite di risonanza



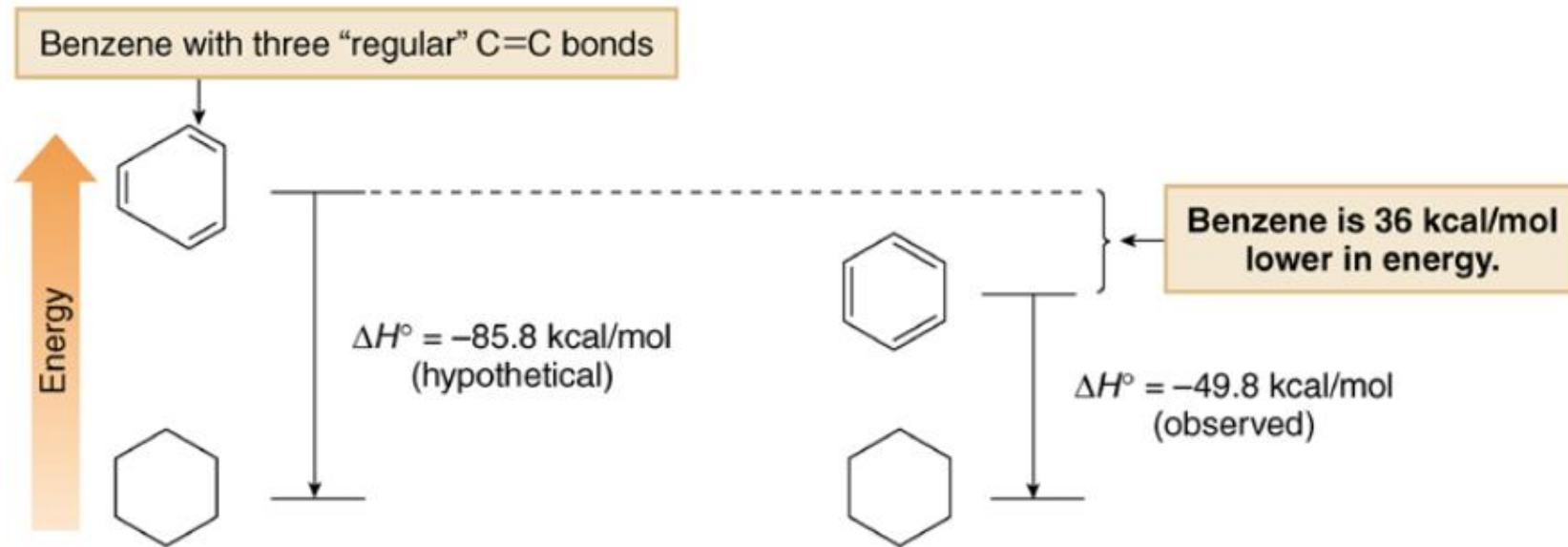
Ibrido di risonanza



Aromaticità, energia di risonanza

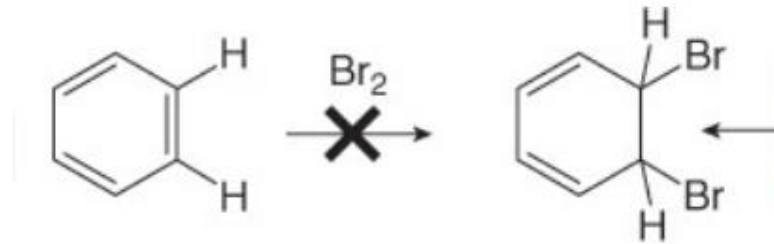
| | | | ΔH_{found} (Kcal/mol) | $\Delta H_{expected}$ (Kcal/mol) | $\Delta H_{found-exp}$ (Kcal/mol) |
|-----|---|--|---|-------------------------------------|--------------------------------------|
| [1] |  cyclohexene | $\xrightarrow[\text{Pd-C}]{\text{H}_2}$ |  | -28.6 | |
| [2] |  1,3-cyclohexadiene | $\xrightarrow[\text{Pd-C}]{2 \text{ H}_2}$ |  | -55.4 | -57.2 1.8 |
| [3] |  benzene | $\xrightarrow[\text{Pd-C}]{3 \text{ H}_2}$ |  | -49.8 | -85.8 36 |

Aromaticità, energia di risonanza



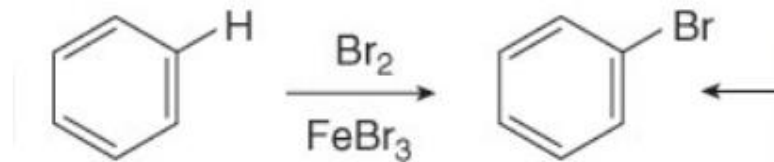
Stabilità del benzene aromaticità

La reazione di addizione non avviene



Verrebbe persa l'aromaticità

Avviene la reazione di sostituzione

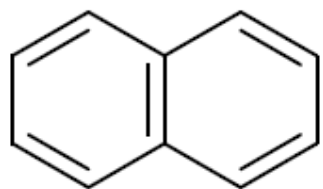


Il prodotto di sostituzione mantiene l'anello aromatico

Criteri di aromaticità

- La molecola deve essere ciclica
- Tutti gli atomi devono essere ibridati sp^2
- La molecola deve essere planare
- La molecola deve avere 2, 6, 10, 14,($4n+2$) elettroni π
 - Regola di Hückel

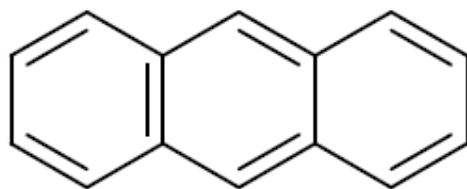
Idrocarburi policiclici aromatici (IPA)



10π

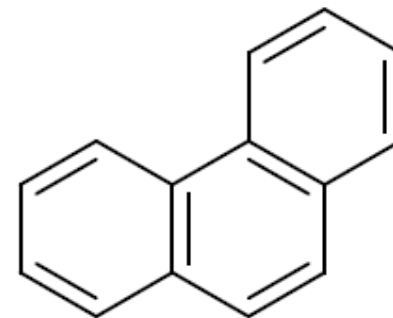
naftalene

$(4n+2)$ elettroni π
 $n = 2$



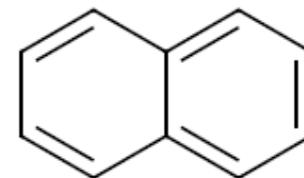
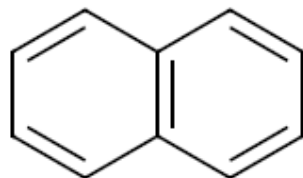
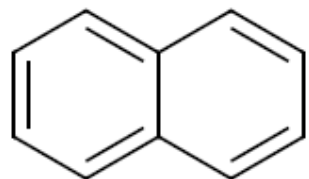
14π

antracene

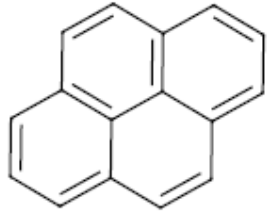


$(4n+2)$ elettroni π
 $n = 3$

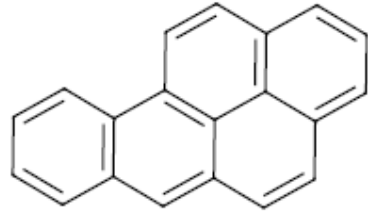
fenantrene



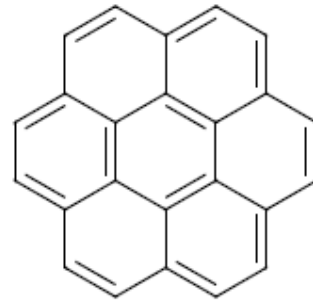
Idrocarburi policiclici aromatici (IPA)



pyrene
16 π

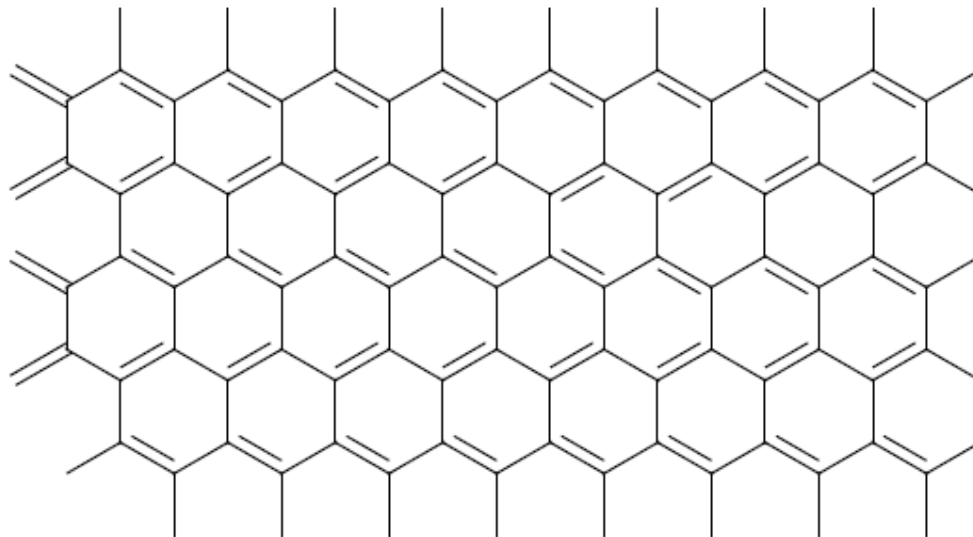


benzopyrene
20 π



coronene
24 π

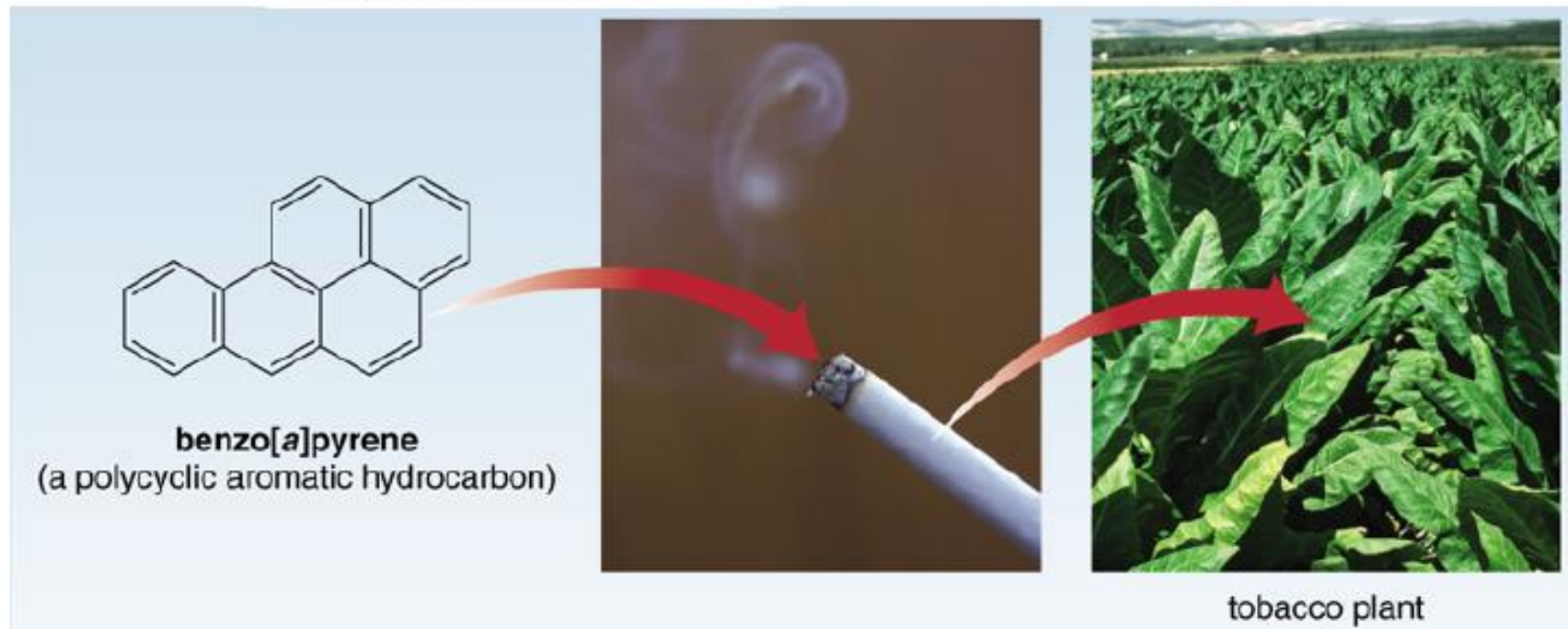
La regola di Hückel non si applica a sistemi grandi: tutti i sistemi policiclici insaturi con più di 3 anelli sono aromatici.



graphene

Interesting Aromatic Compounds

- Benzo[a]pyrene, produced by the incomplete oxidation of organic compounds in tobacco, is found in cigarette smoke.

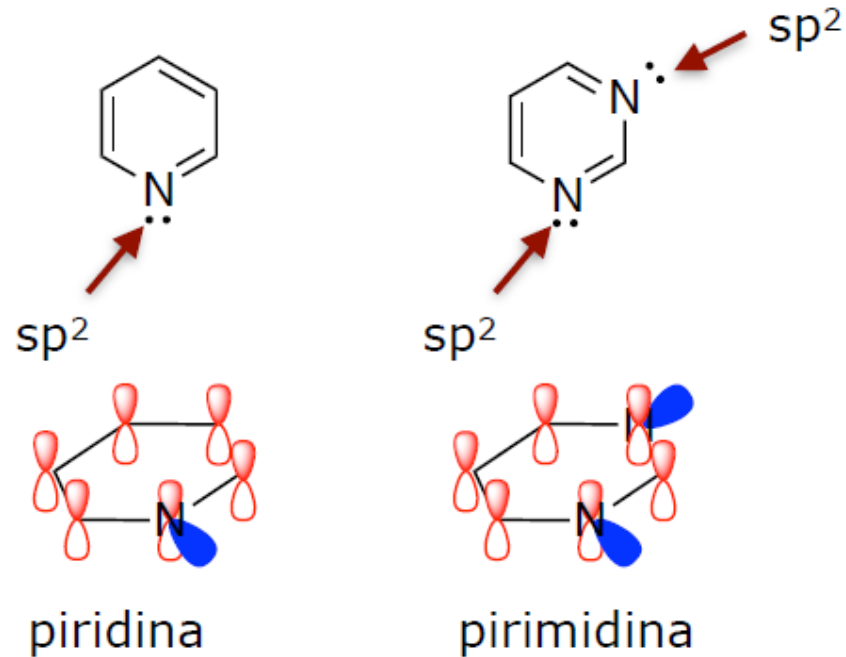


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© Corbis

- When ingested or inhaled, **benzo[a]pyrene** and other similar PAHs are oxidized to **carcinogenic products**.

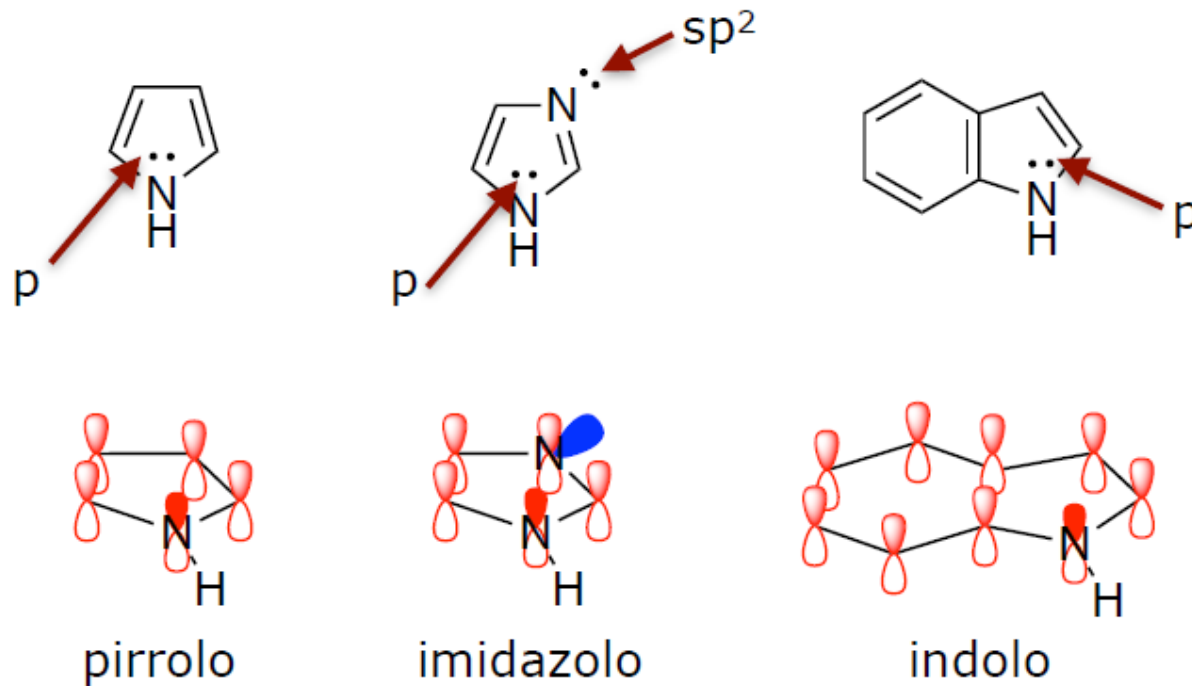
Composti Eterociclici Aromatici



Il doppietto dell'azoto è in un orbitale sp^2

Piridina e pirimidina sono sostanze basiche e debolmente nucleofile

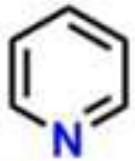
Composti Eterociclici Aromatici



Il doppietto dell'azoto è nell'orbitale 2p e fa parte degli elettroni π delocalizzati, contribuisce all'aromaticità del sistema
Pirrolo e indolo non sono sostanze basiche

Composti eterociclici aromatici

Esempi di composti eterociclici aromatici



Piridina



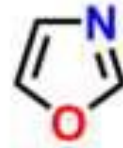
Pirrolo



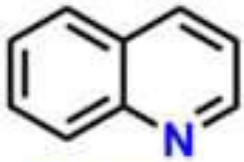
Furano



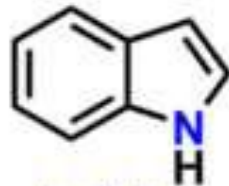
Tiofene



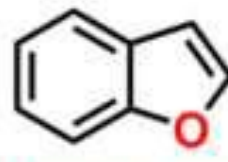
Ossazolo



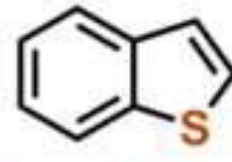
Chinolina



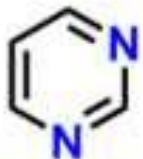
Indolo



Benzofurano



benzotiofene



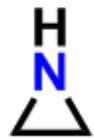
Pirimidina



Imidazolo

Composti eterociclici non aromatici

Esempi di composti eterociclici non aromatici



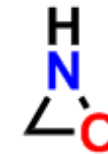
Aziridina



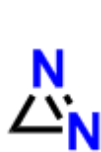
Ossirano



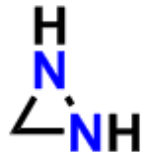
Tiirano



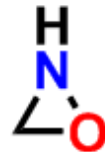
Ossaziridina



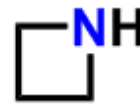
Diazirina



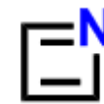
Diaziridina



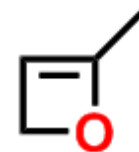
Ossaziridina



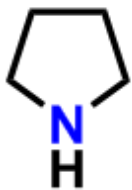
Azetidina



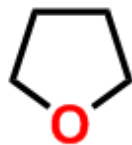
Azete



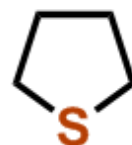
2-Metilossete



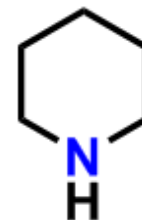
Pirrolidina



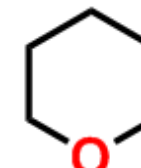
Tetraidrofurano



Tetraidrotiofene



Piperidina



Tetraidropirano

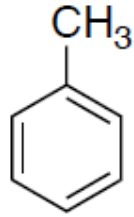
I 20 amminoacidi comunemente presenti nelle proteine

| Catene laterali non polari | | | |
|----------------------------|---------------------|--|-----------------------|
| | Alanina (Ala, A) | | Fenilalanina (Phe, F) |
| | Glicina (Gly, G) | | Prolina (Pro, P) |
| | Isoleucina (Ile, I) | | Triptofano (Trp, W) |
| | Leucina (Leu, L) | | Valina (Val, V) |
| | Metionina (Met, M) | | |

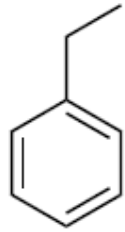
| Catene laterali polari | | | |
|------------------------|---------------------------|-------------------------|-------------------|
| | Asparagina (Asn, N) | | Serina (Ser, S) |
| | Glutammina (Gln, Q) | | Treonina (Thr, T) |
| Catene laterali acide | | Catene laterali basiche | |
| | Acido aspartico (Asp, D) | | Arginina (Arg, R) |
| | Acido glutammico (Glu, E) | | Istidina (His, H) |
| | Cisteina (Cys, C) | | Lisina (Lys, K) |
| | Tirosina (Tyr, Y) | | |

Nota: Ciascuna funzione ionizzabile è mostrata nella forma presente in concentrazione maggiore a pH 7.0 in soluzione acquosa.

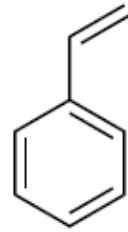
Nomenclatura del benzene monosostituito



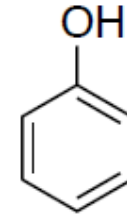
metilbenzene
toluene



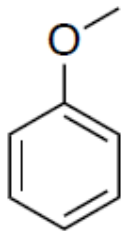
etilbenzene



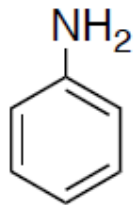
vinilbenzene
stirene



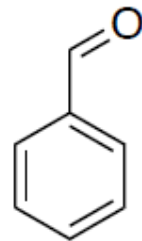
idrossibenzene
fenolo



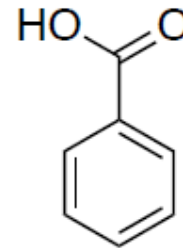
metossibenzene
fenilmetiletere
anisolo



amminobenzene
anilina



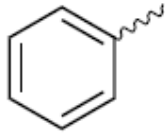
benzaldeide



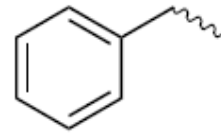
acido benzoico

Nomenclatura del benzene monosostituito

$C_6H_5^-$
Ph

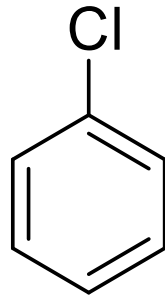


gruppo
fenile

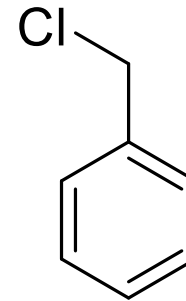


gruppo
benzile

$C_6H_5CH_2^-$



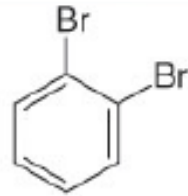
Clorobenzene



Benzil cloruro

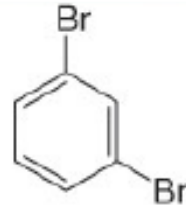
Nomenclatura del benzene disostituito

Benzene 1,2-disostituito:
Isomero *orto*



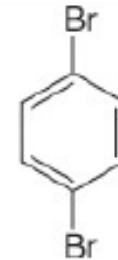
1,2-dibromobenzene
o-dibromobenzene

Benzene 1,3-disostituito:
Isomero *meta*

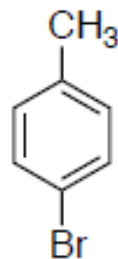


1,3-dibromobenzene
m-dibromobenzene

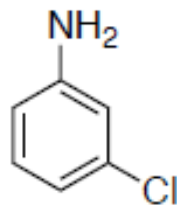
Benzene 1,4-disostituito:
Isomero *para*



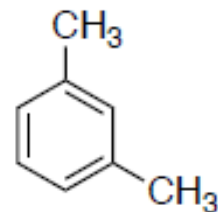
1,4-dibromobenzene
p-dibromobenzene



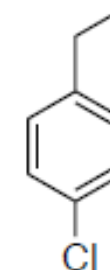
4-bromotoluene
p-bromotoluene



3-cloroanilina
m-cloroanilina

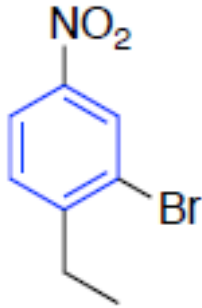


1,3-dimetilbenzene
m-xilene

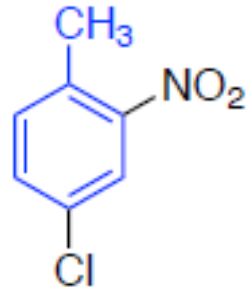


1-cloro-4-etilbenzene
p-cloroetilbenzene

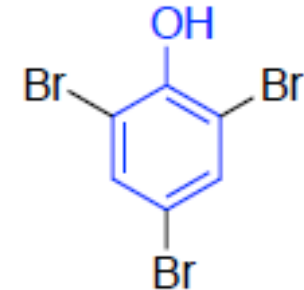
Nomenclatura: 3 o Più Sostituenti



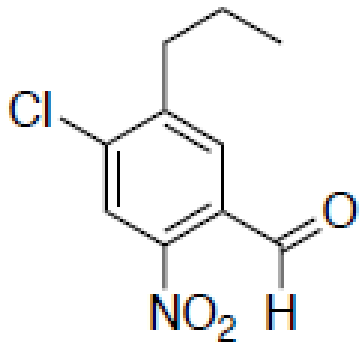
2-bromo-1-etil-4-nitrobenzene



4-cloro-2-nitro-toluene

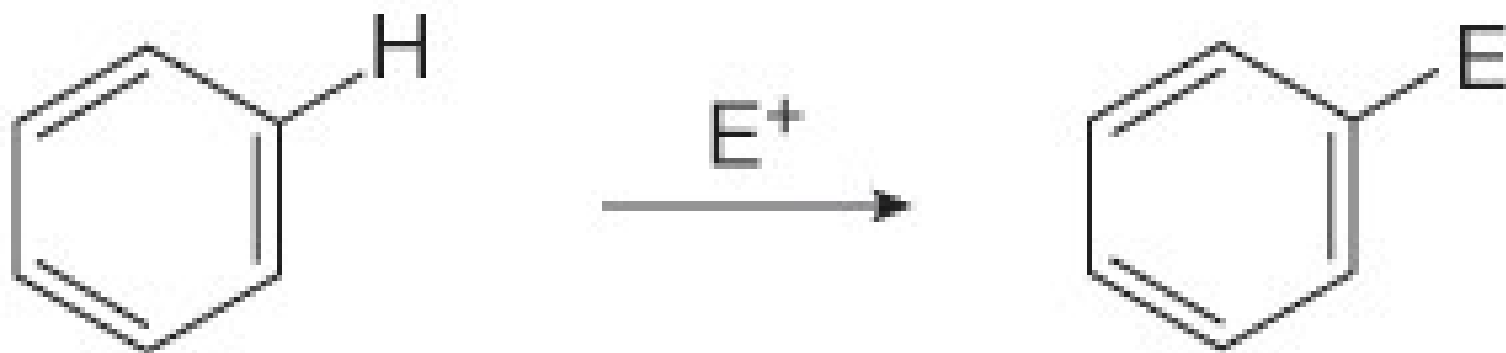


2,4,6-tribromofenolo

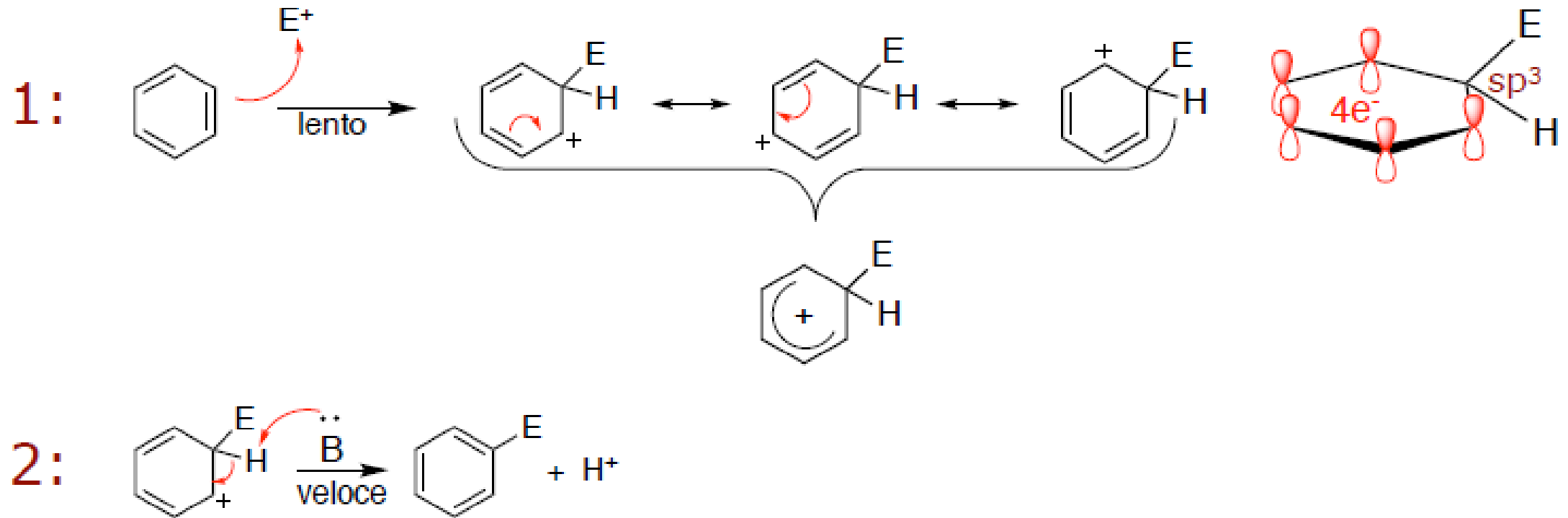


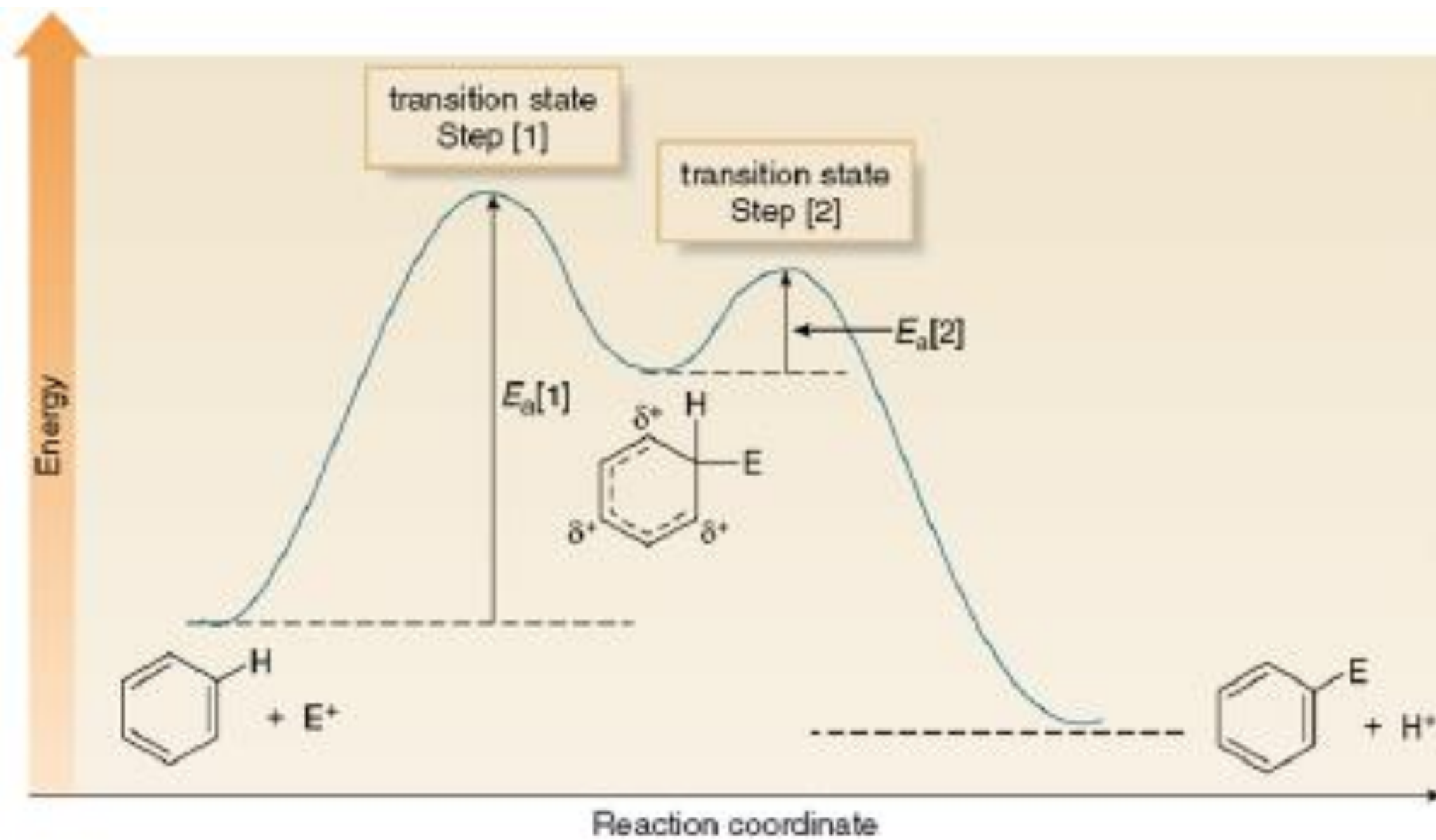
4-cloro-2-nitro-5-propilbenzaldeide

Sostituzione elettrofila aromatica

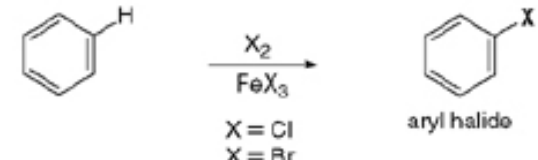
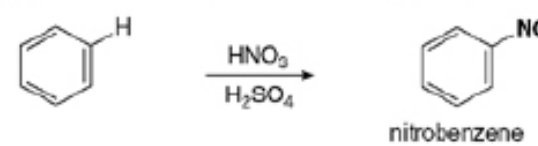
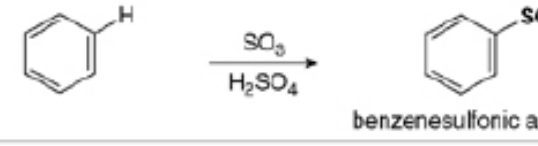

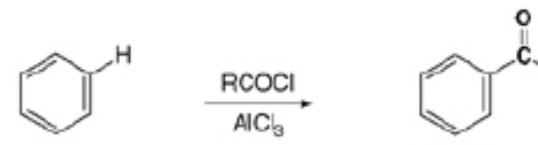


Meccanismo



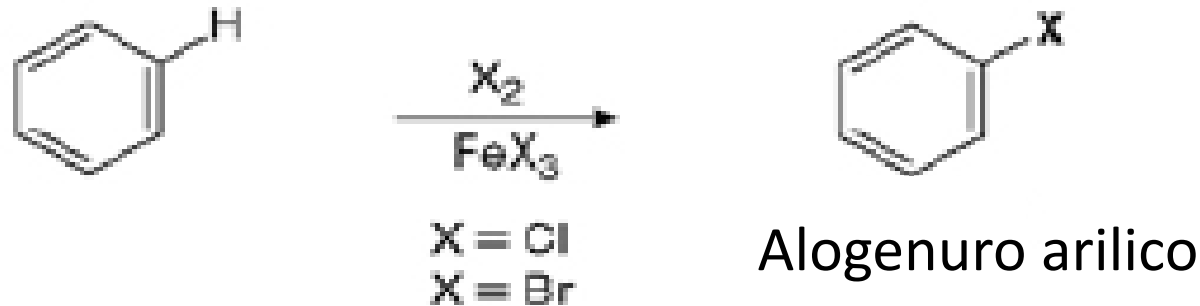


Sostituzione elettrofila aromatica

| Reaction | Electrophile |
|--|--|
| <p>[1] Halogenation—Replacement of H by X (Cl or Br)</p>  <p>$\text{C}_6\text{H}_6 \xrightarrow[\text{FeX}_3]{\text{X}_2} \text{C}_6\text{H}_5\text{X}$ X = Cl X = Br</p> <p>aryl halide</p> | <p>$\text{E}^+ = \text{Cl}^+ \text{ or } \text{Br}^+$</p> |
| <p>[2] Nitration—Replacement of H by NO_2</p>  <p>$\text{C}_6\text{H}_6 \xrightarrow[\text{H}_2\text{SO}_4]{\text{HNO}_3} \text{C}_6\text{H}_5\text{NO}_2$</p> <p>nitrobenzene</p> | <p>$\text{E}^+ = \overset{+}{\text{N}}\text{O}_2$</p> |
| <p>[3] Sulfonation—Replacement of H by SO_3H</p>  <p>$\text{C}_6\text{H}_6 \xrightarrow[\text{H}_2\text{SO}_4]{\text{SO}_3} \text{C}_6\text{H}_5\text{SO}_3\text{H}$</p> <p>benzenesulfonic acid</p> | <p>$\text{E}^+ = \overset{+}{\text{S}}\text{O}_3\text{H}$</p> |
| <p>[4] Friedel-Crafts alkylation—Replacement of H by R</p>  <p>$\text{C}_6\text{H}_6 \xrightarrow[\text{AlCl}_3]{\text{RCl}} \text{C}_6\text{H}_5\text{R}$</p> <p>alkyl benzene (arene)</p> | <p>$\text{E}^+ = \text{R}^+$</p> |
| <p>[5] Friedel-Crafts acylation—Replacement of H by RCO</p>  <p>$\text{C}_6\text{H}_6 \xrightarrow[\text{AlCl}_3]{\text{RCOCl}} \text{C}_6\text{H}_5\text{COR}$</p> <p>ketone</p> | <p>$\text{E}^+ = \text{RCO}^+$</p> |

Reazione di alogenazione: sostituzione di H con X (Cl o Br)

Elettrofilo

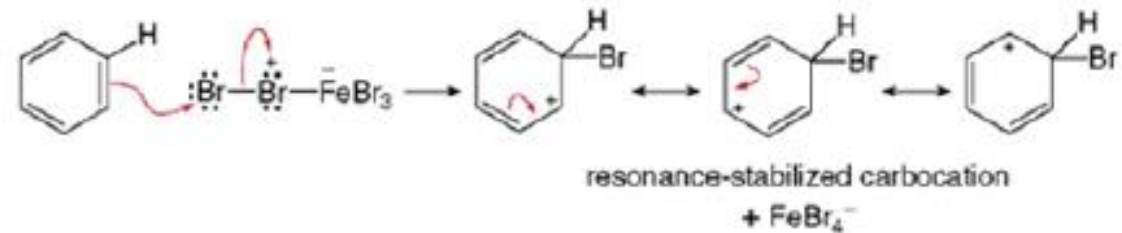


$E^+ = \text{Cl}^+ \text{ or } \text{Br}^+$

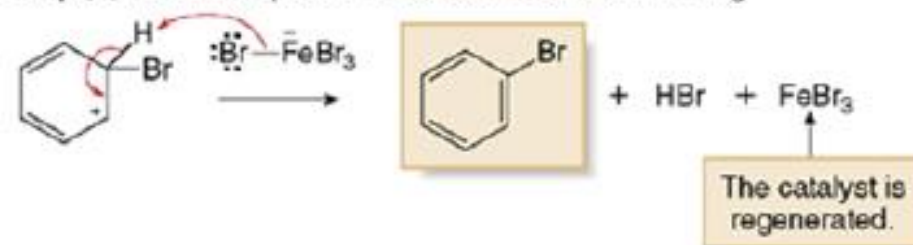
Step [1] Generation of the electrophile



Step [2] Addition of the electrophile to form a carbocation

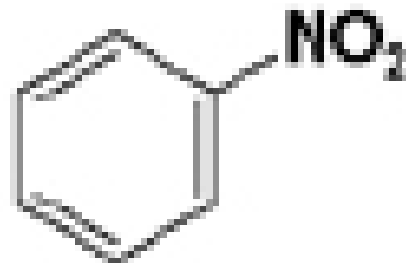
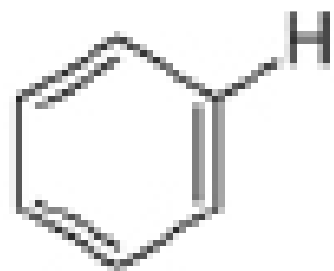


Step [3] Loss of a proton to re-form the aromatic ring



ione cloronio
o bromonio

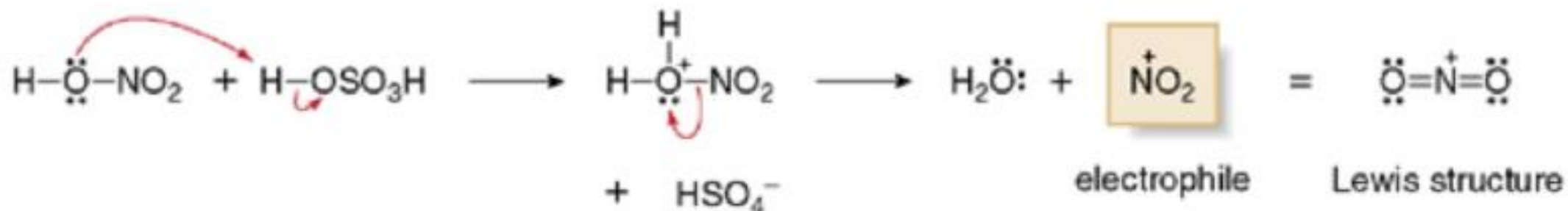
Reazione di nitrazione: sostituzione di H con NO₂



nitrobenzene

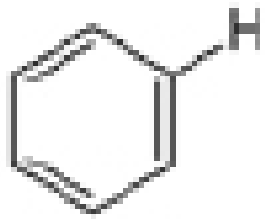


ione nitronio



Reazione di solfonazione: sostituzione di H con HSO₃

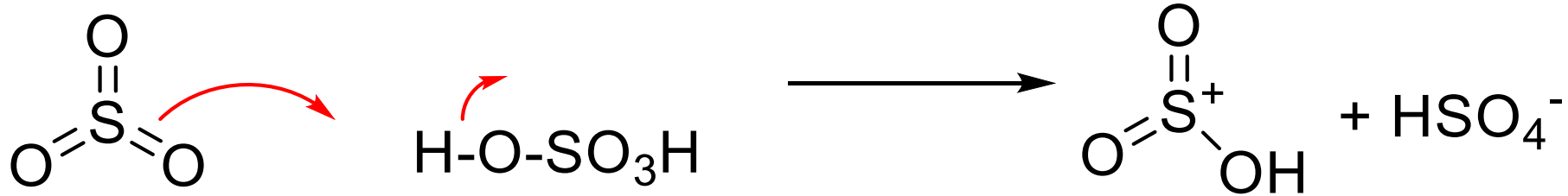
Elettrofilo



Acido benzensolfonico

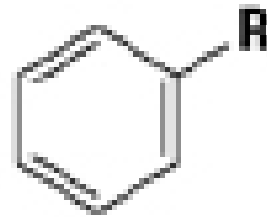
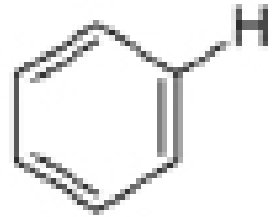


Ione solfonio

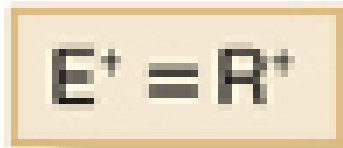


Reazione di alchilazione di Friedel-Crafts: sostituzione di H con R

Elettrofilo



Alchil benzene



carbocatione



Elettrofilo

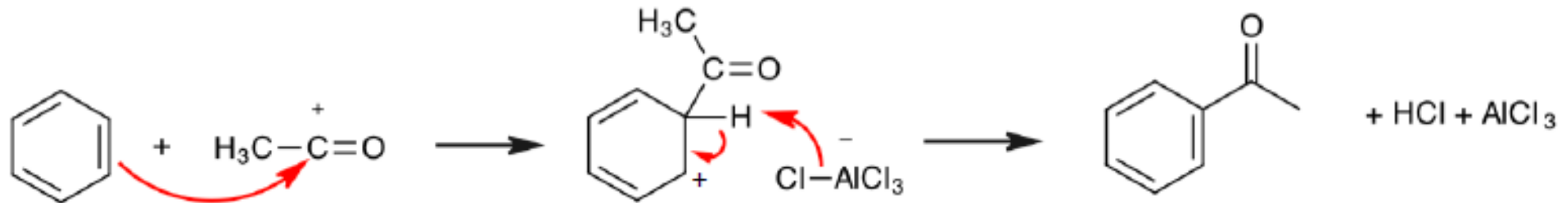
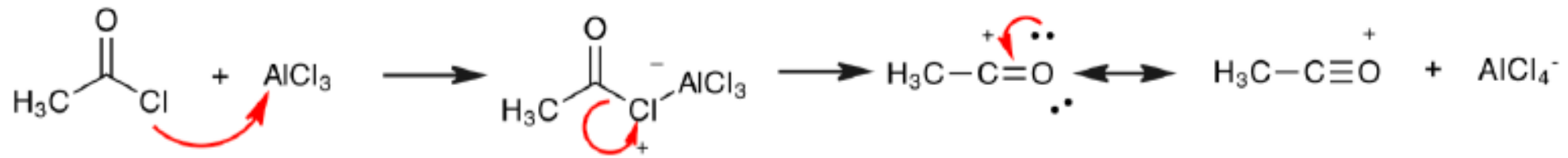
Reazione di acilazione di Friedel-Crafts: sostituzione di H con RCO



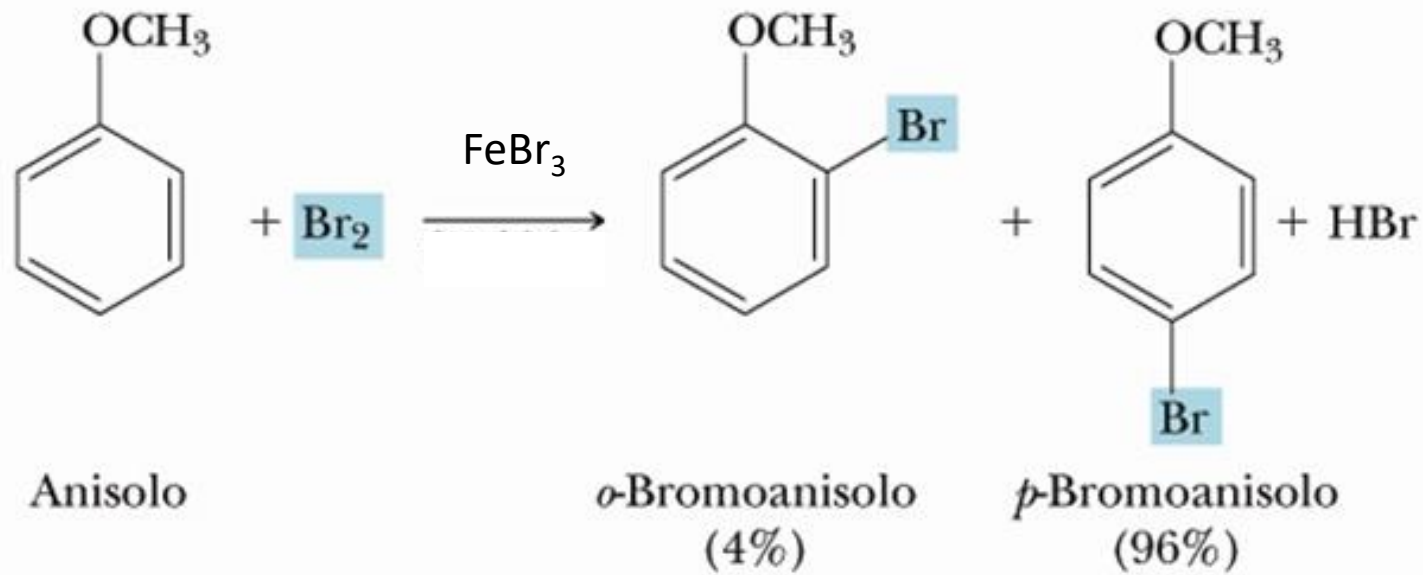
Aril chetone



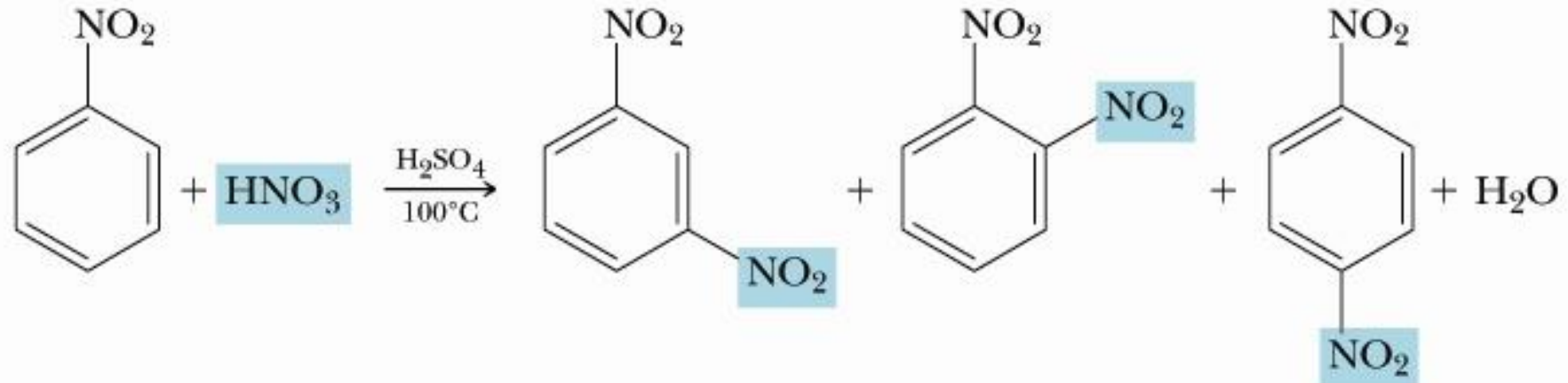
Ione acilio



Disostituzione



Disostituzione



Nitrobenzene

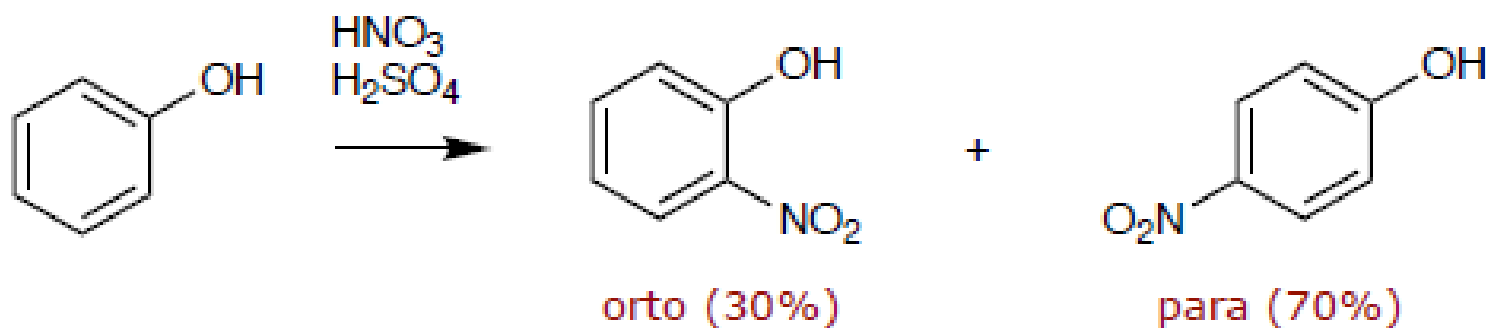
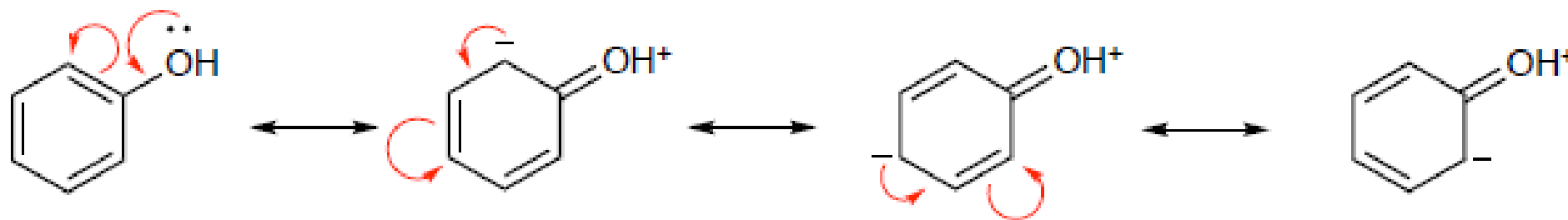
m-Dinitro-
benzene
(93%)

o-Dinitro-
benzene

p-Dinitro-
benzene

Meno del 7% in totale

Sostituenti contenenti lone pairs aumentano la densità elettronica nelle posizioni *orto* e *para* per risonanza perché gli elettroni sono delocalizzati dal sostituyente verso l'anello (effetto +R)



Sostituenti contenenti doppi o tripli legami polari ($\text{Ar}-\text{Y}=\text{Z}$), diminuiscono la densità di carica elettronica nelle posizioni *orto* e *para* perché gli elettroni sono delocalizzati dall'anello verso il sostituente (effetto $-\text{R}$)

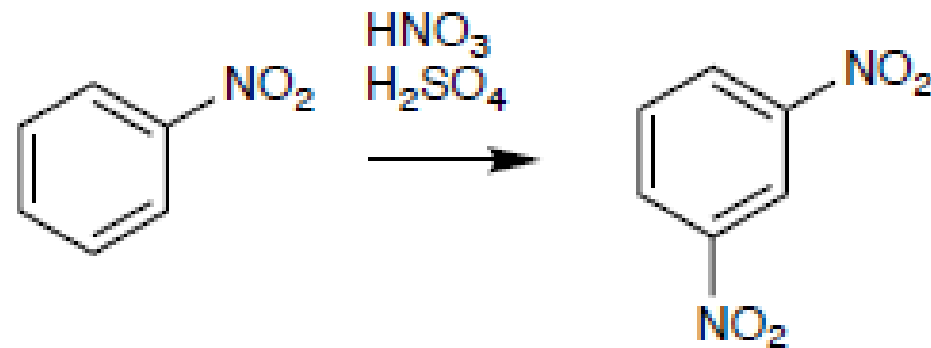
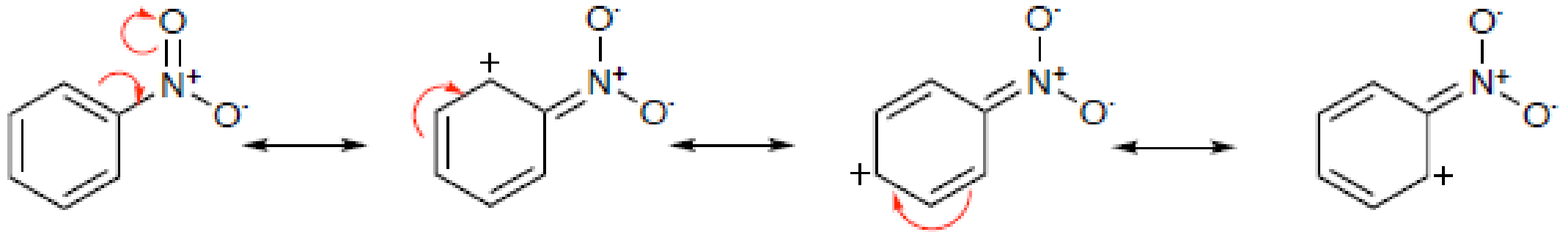

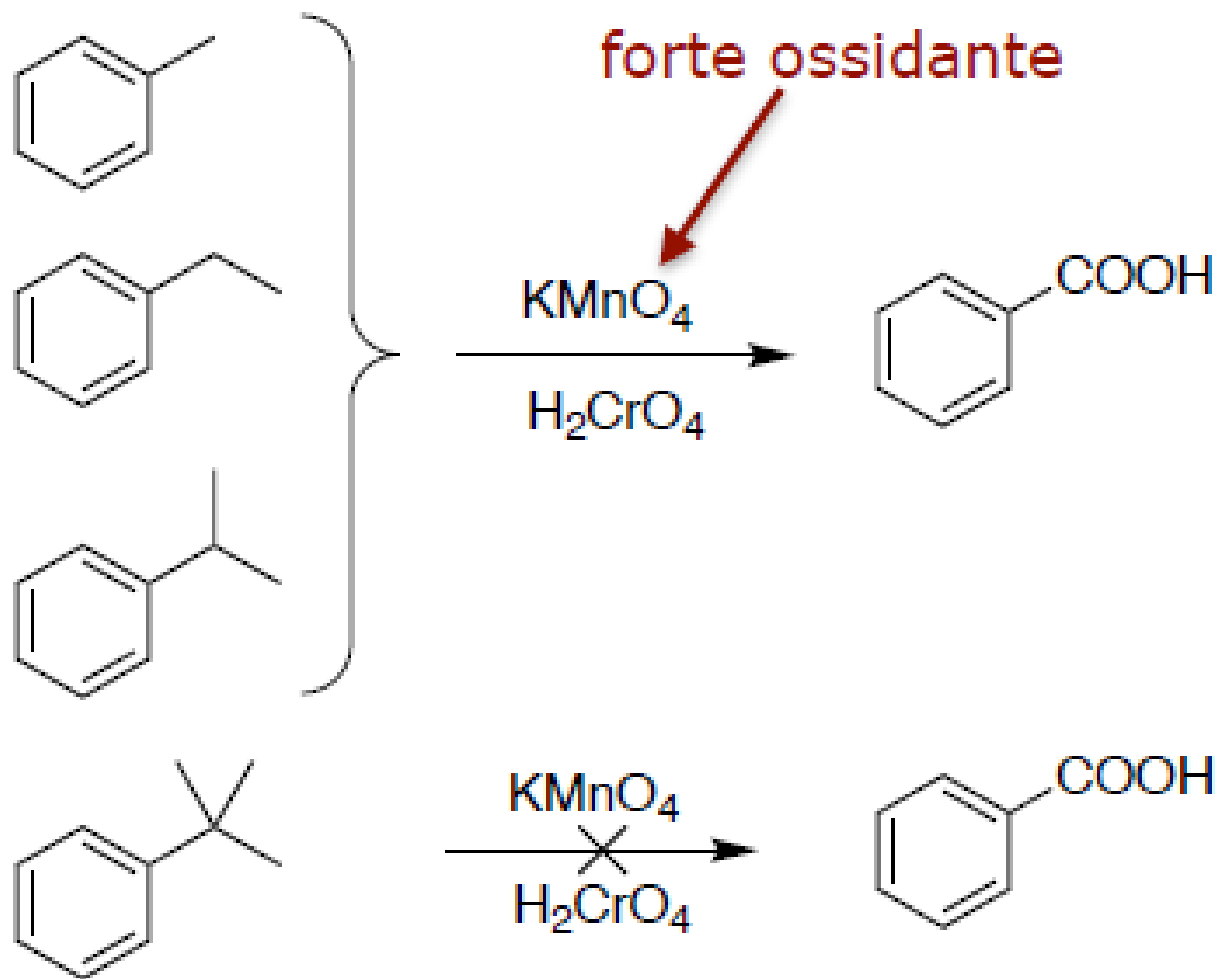


TABELLA 9.1 Effetto dei sostituenti su un'ulteriore sostituzione elettrofila aromatica

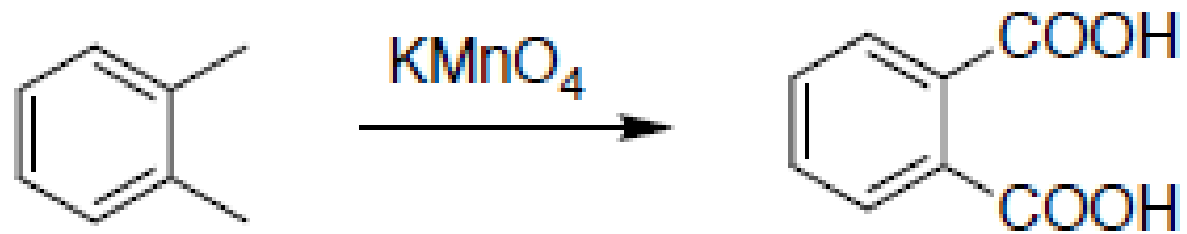
| | | | | | | |
|----------------------|----------------------------|---|--|--|---|---|
| Orto-para orientanti | fortemente attivanti | $-\ddot{\text{N}}\text{H}_2$ | $-\ddot{\text{N}}\text{HR}$ | $-\ddot{\text{N}}\text{R}_2$ | $-\ddot{\text{O}}\text{H}$ | $-\ddot{\text{O}}\text{R}$ |
| | moderatamente attivanti | $-\ddot{\text{N}}\overset{\text{O}}{\parallel}\text{HCR}$ | $-\ddot{\text{N}}\overset{\text{O}}{\parallel}\text{HCAr}$ | $-\ddot{\text{O}}\overset{\text{O}}{\parallel}\text{CR}$ | $-\ddot{\text{O}}\overset{\text{O}}{\parallel}\text{CAr}$ | |
| | debolmente attivanti | $-\text{R}$ |  | | | |
| | debolmente disattivanti | $-\ddot{\text{F}}:$ | $-\ddot{\text{Cl}}:$ | $-\ddot{\text{Br}}:$ | $-\ddot{\text{I}}:$ | |
| Meta orientanti | moderatamente disattivanti | $-\overset{\text{O}}{\parallel}\text{CH}$ | $-\overset{\text{O}}{\parallel}\text{CR}$ | $-\overset{\text{O}}{\parallel}\text{COH}$ | $-\overset{\text{O}}{\parallel}\text{COR}$ | $-\overset{\text{O}}{\parallel}\text{CNH}_2$ $-\overset{\text{O}}{\parallel}\text{SOH}$ |
| | fortemente disattivanti | $-\text{NO}_2$ | $-\text{NH}_3^+$ | $-\text{CF}_3$ | $-\text{CCl}_3$ | |

Importanza relativa nell'influencare l'ulteriore sostituzione

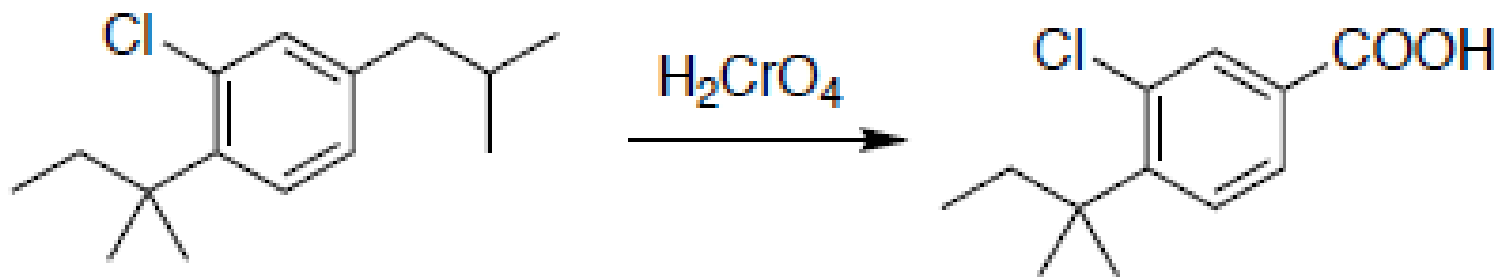
Ossidazione di Alchilbenzeni



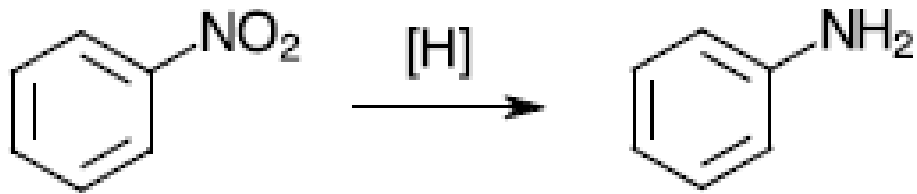
Ossidazione di Alchilbenzeni



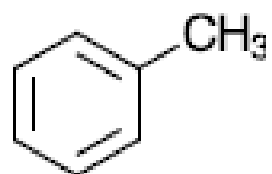
orto-xilene



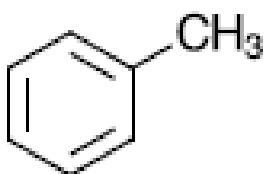
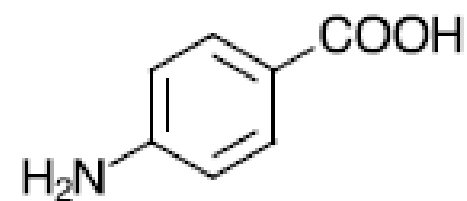
Riduzione di Nitrobenzeni



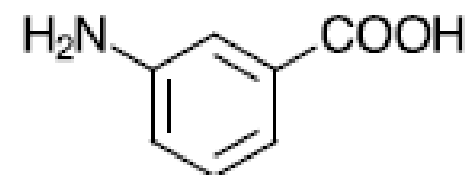
riducenti: H_2/Ni o Pd o Pt
 Fe, H^+
 Zn, H^+



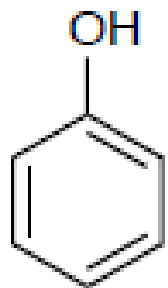
?



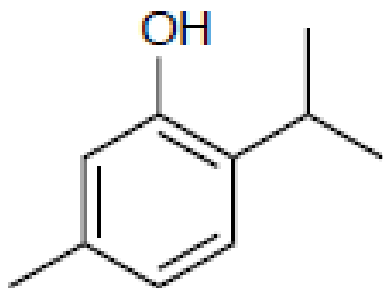
?



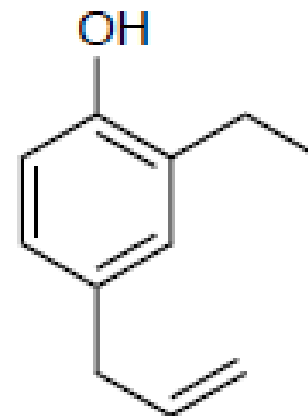
Fenoli (Alcoli Aromatici)



fenolo

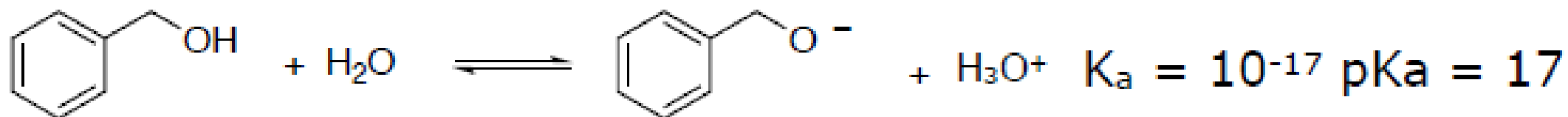


timolo
(timo)

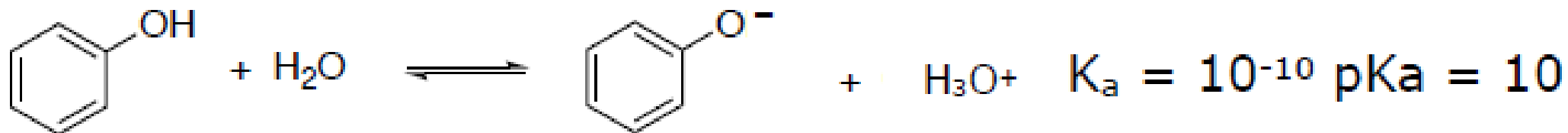


eugenolo
(chiodo di garofano)

Acidità dei Fenoli



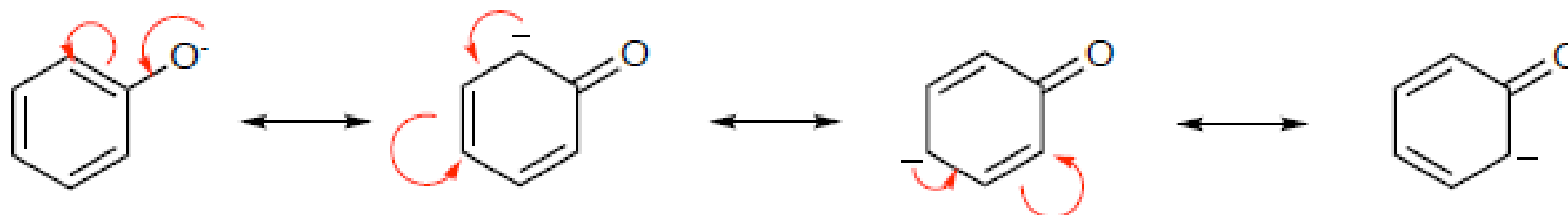
Alcol benzilico



Fenolo

Acidità dei Fenoli

L'anione fenato é stabilizzato dalla delocalizzazione della carica sull'anello aromatico



Sostituenti elettron attrattori aumentano l'acidità del fenolo perché favoriscono la delocalizzazione

