

# Composti aromatici

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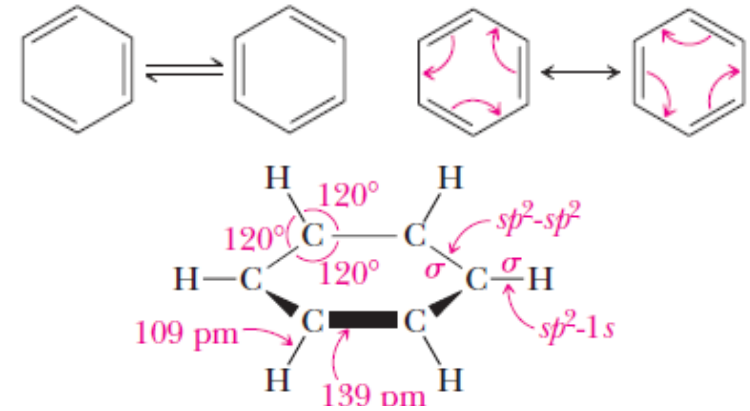
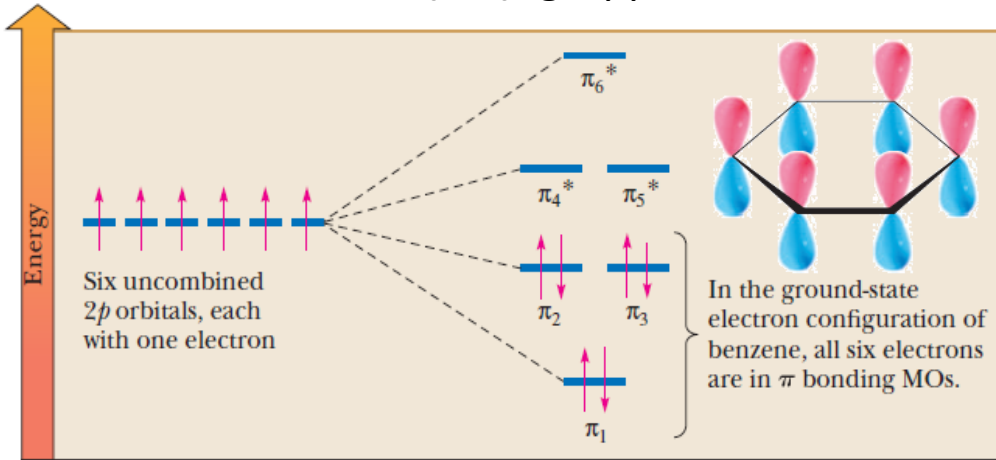
[francesca.scaramuzzo@uniroma1.it](mailto:francesca.scaramuzzo@uniroma1.it)

# Definizione e struttura

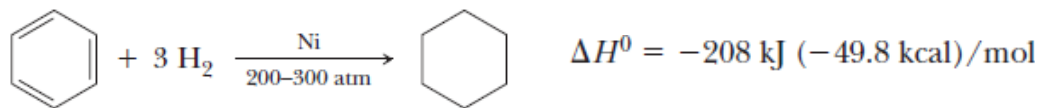
**Composto aromatico:** composto che soddisfa le regole dell'aromaticità di Hückel

**Arene:** idrocarburo aromatico

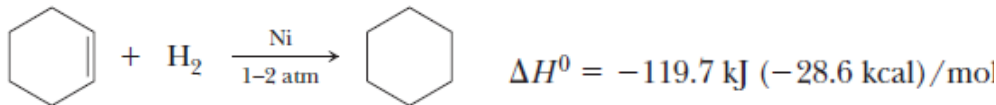
**Arile (-Ar):** gruppo derivato da un arene per rimozione di un -H



**Energia di risonanza:** differenza di energia tra un ibrido di risonanza e la più stabile delle sue ipotetiche strutture contribuenti, nelle quali gli elettroni sono localizzati su atomi particolari e in legami particolari

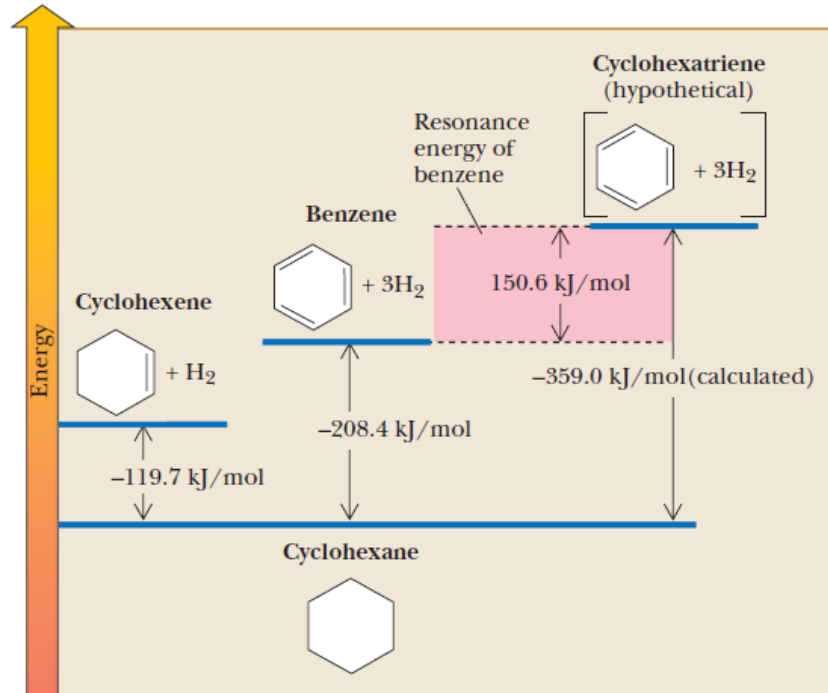


Benzene                      Cyclohexane



Cyclohexene

Cyclohexane



# L'aromaticità



*Ciclobutadiene:*  
*instabile*

*Benzene:*  
*aromatico*



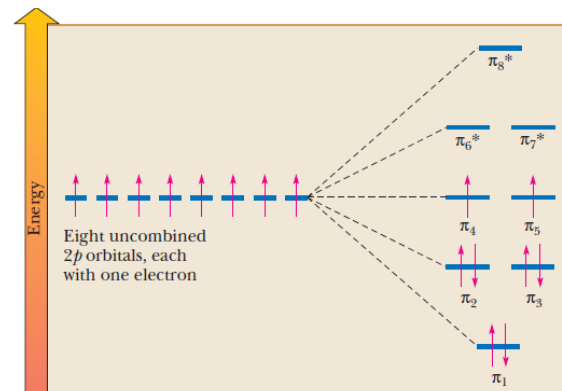
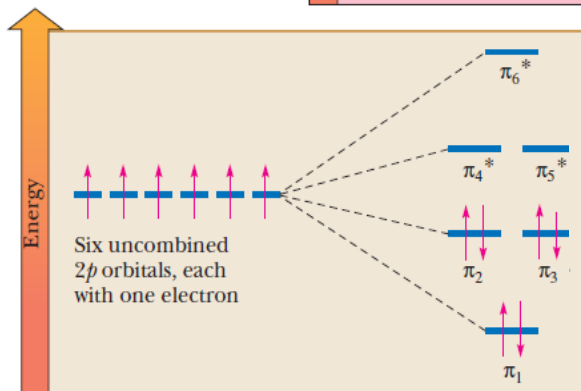
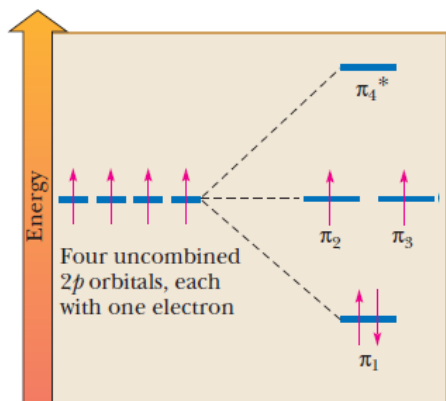
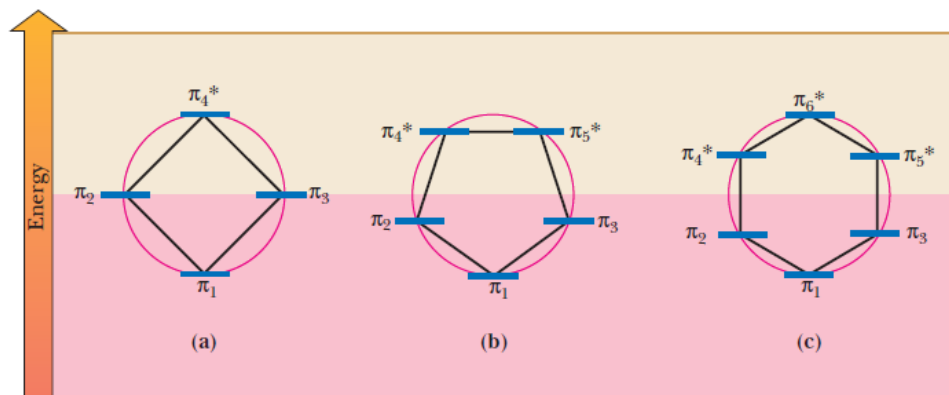
*Cicloottatetraene:*  
*alchene*

## Criterio di aromaticità di Hückel:

- Essere ciclico
- Avere un orbitale  $p$  su ciascun C dell'anello
- Essere planare o quasi planare
- Avere  $4n + 2$  elettroni  $\pi$  nella distribuzione ciclica degli orbitali  $p$

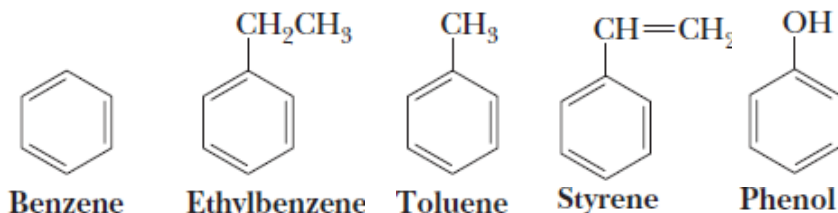
**Composto antiaromatico:** composto che soddisfa i primi 3 criteri dell'aromaticità di Hückel, ma ha  $4n$  elettroni  $\pi$  nella distribuzione ciclica degli orbitali  $p$

**Circonferenza di Frost:** modo grafico per determinare le energie relative degli orbitali molecolari  $\pi$  per composti planari, completamente coniugati e monociclici

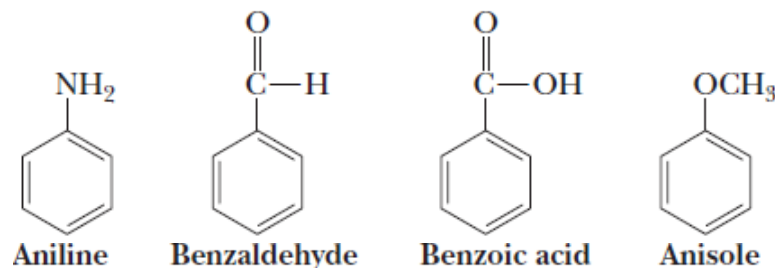


# Nomenclatura

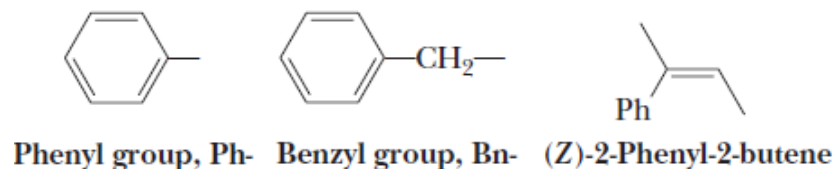
- **Alchilbenzeni monosostituiti:** denominati come derivati del benzene
- La IUPAC mantiene i nomi comuni per alchilbenzeni monosostituiti semplici



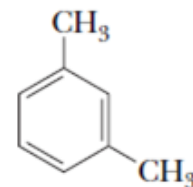
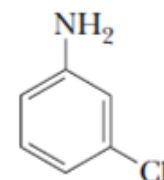
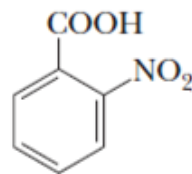
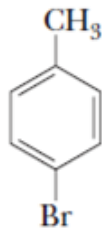
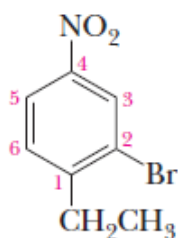
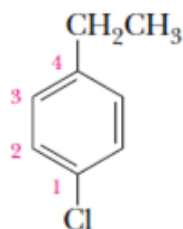
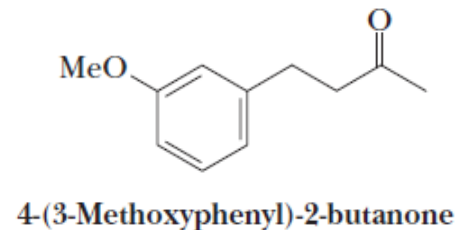
- **Gruppo fenile (-Ph):** gruppo arilico derivato togliendo -H dal benzene
- **Gruppo benzile (-Bn):** gruppo derivato dal toluene togliendo un -H dal suo gruppo metilico
- In presenza di altri gruppi funzionali, il gruppo -Ph è considerato un sostituito



- **Benzeni disostituiti:** posizione sostituenti definita da numeri o con termini orto (1,2), meta (1,3), para (1,4)



- **Benzeni polisostituiti:** posizione sostituenti definita da numeri
- Se uno dei sostituenti conferisce alla molecola un nome particolare, il composto viene denominato come un derivato della molecola con nome particolare



1-Chloro-4-ethylbenzene  
(*p*-Chloroethylbenzene)

2-Bromo-1-ethyl-4-nitrobenzene

4-Bromotoluene  
(*p*-Bromotoluene)

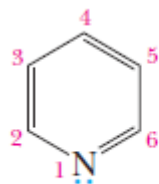
2-Nitrobenzoic acid  
(*o*-Nitrobenzoic acid)

3-Chloroaniline  
(*m*-Chloroaniline)

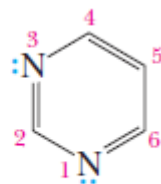
*m*-Xylene

# Nomenclatura

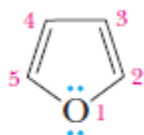
- Composti eteroaromatici:** composti aromatici in cui almeno uno dei vertici è occupato da un eteroatomo



Pyridine



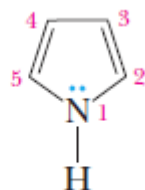
Pyrimidine



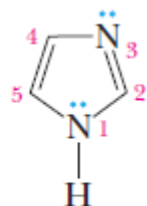
Furan



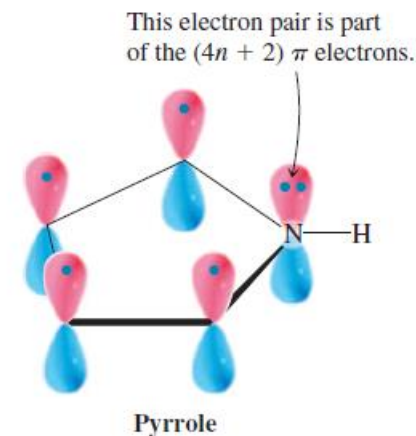
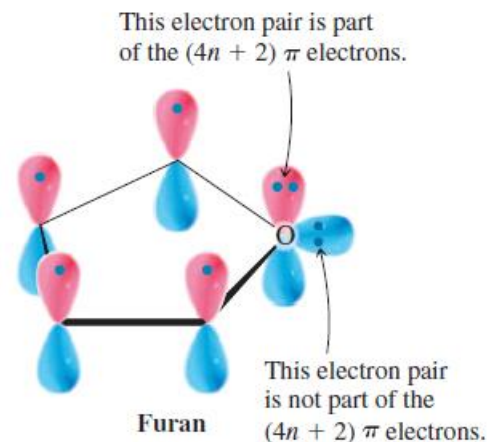
Thiophene



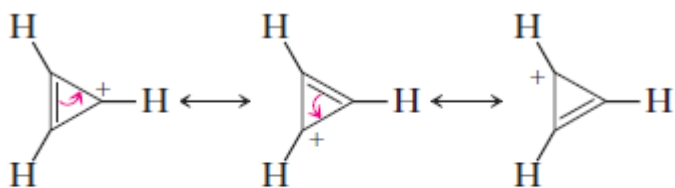
Pyrrole



Imidazole

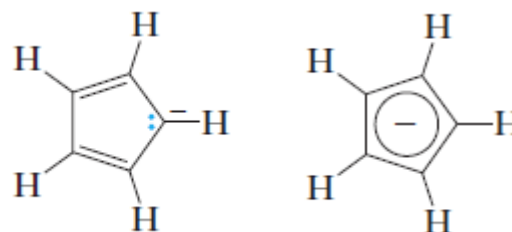


- Ioni aromatici**

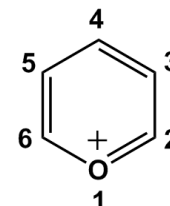


Cyclopropenyl cation

(a hybrid of three equivalent contributing structures)



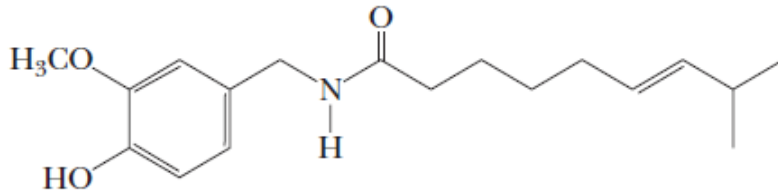
Cyclopentadienyl anion



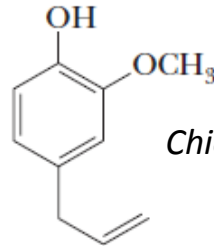
Pyrylium cation

# I composti aromatici in natura e in chimica farmaceutica

## Metaboliti vegetali

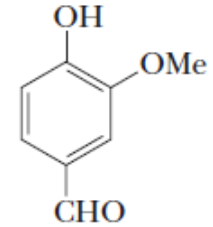


**Capsaicin**  
(from various types of peppers)



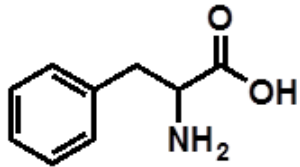
**Eugenol**

*Chiodi di garofano  
analgesico*

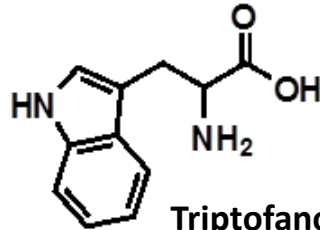


**4-Hydroxy-3-methoxybenzaldehyde  
(Vanillin)**

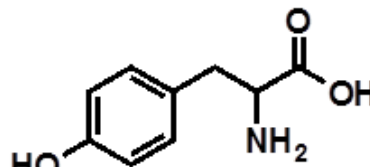
## Amminoacidi



**Fenilalanina**

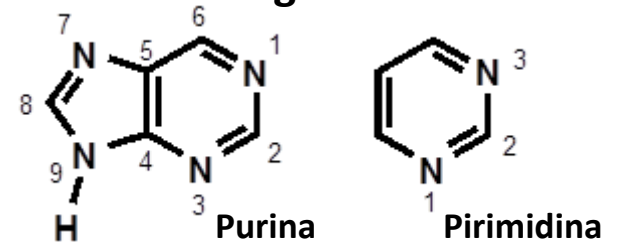


**Triptofano**



**Tirosina**

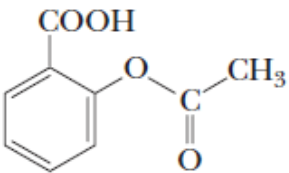
## Basi azotate degli acidi nucleici



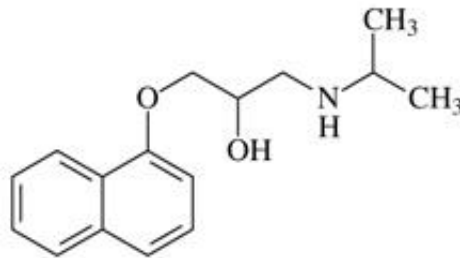
**Purina**

**Pirimidina**

## Farmaci

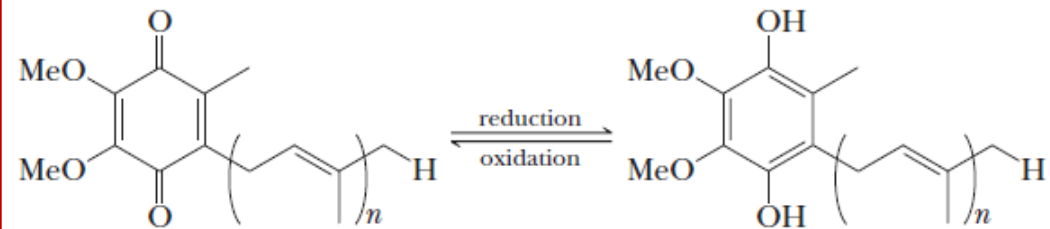


**Acetylsalicylic  
acid  
(Aspirin)**



**Propranololo**

## Trasportatori di elettroni

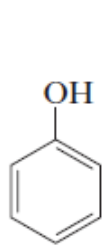


**Coenzyme Q  
(oxidized form)**

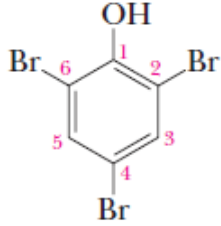
**Coenzyme Q  
(reduced form)**

# Fenoli

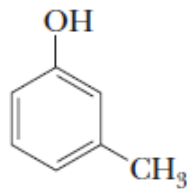
**Fenolo:** composto che contiene un gruppo –OH legato a un anello aromatico



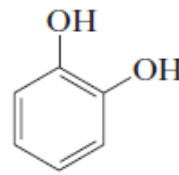
Phenol



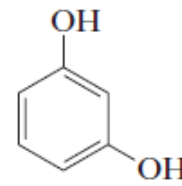
2,4,6-Tribromophenol



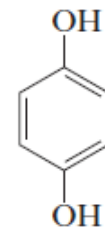
3-Methylphenol  
(*m*-Cresol)



1,2-Benzenediol  
(Catechol)

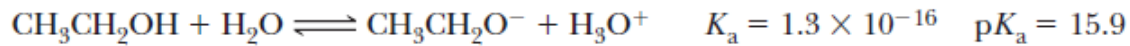
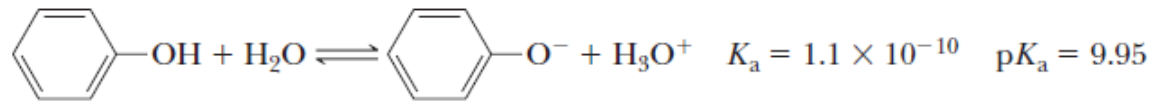


1,3-Benzenediol  
(Resorcinol)



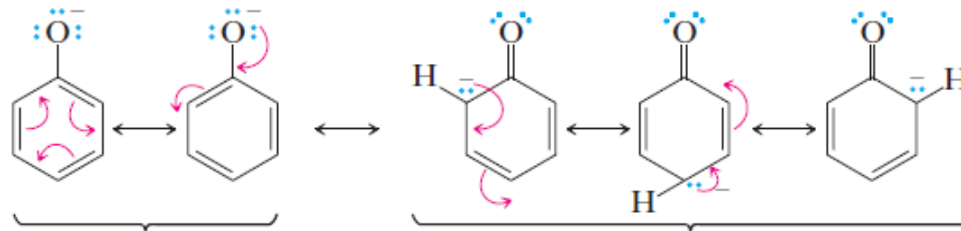
1,4-Benzenediol  
(Hydroquinone)

## Acidità dei fenoli



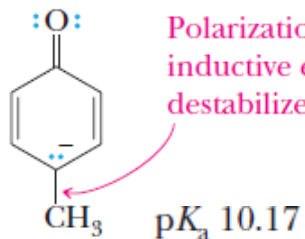
- Effetto induttivo elettrone-attrattore di C sp<sup>2</sup>

- Delocalizzazione di carica

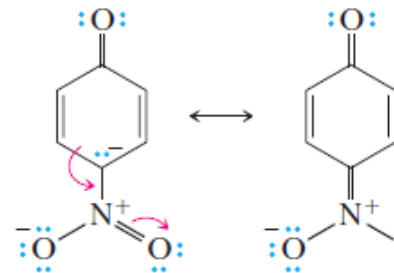


These two Kekulé structures are equivalent

These three contributing structures delocalize the negative charge onto carbon atoms of the ring



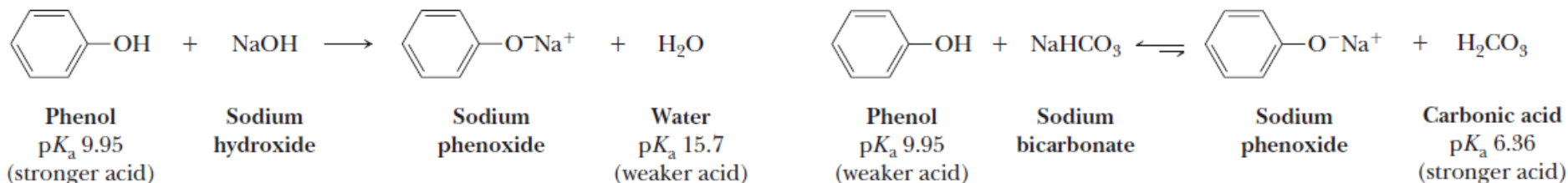
Polarization of this C—C bond by the electron-releasing inductive effect of the sp<sup>3</sup> carbon of the methyl group destabilizes this contributing structure



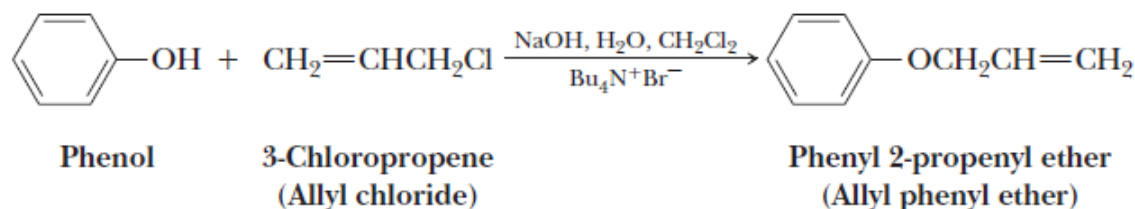
Delocalization of negative charge onto oxygen further increases the resonance stabilization of phenoxide ion

$\text{p}K_a$  7.15

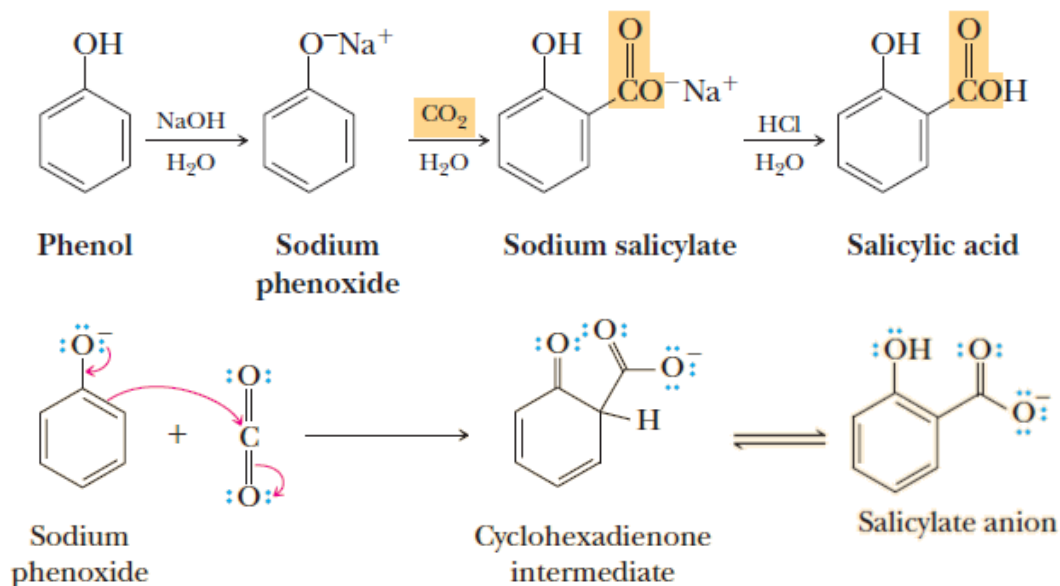
# Reazioni acido-base dei fenoli



# Preparazione di eteri alchil-arilici

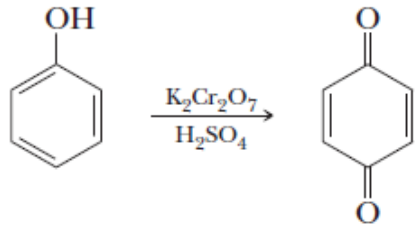


# Carbossilazione di Kolbe



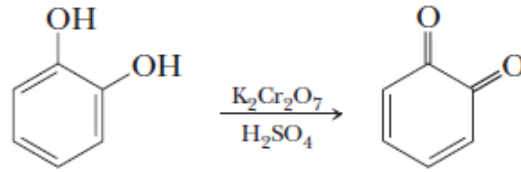


# Ossidazione a chinoni



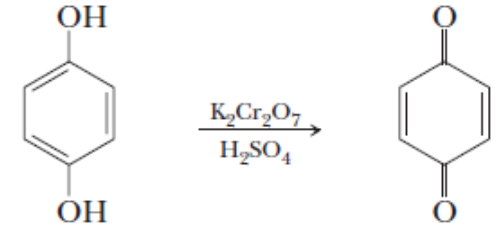
Phenol

1,4-Benzoquinone  
(*p*-Quinone)



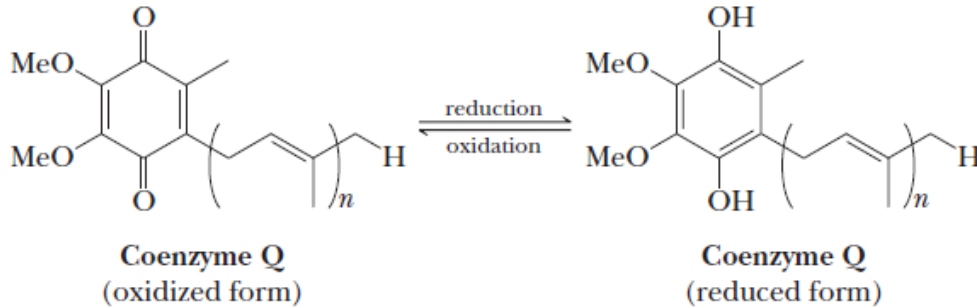
1,2-Benzenediol  
(Catechol)

1,2-Benzoquinone  
(*o*-Quinone)



1,4-Benzenediol  
(Hydroquinone)

1,4-Benzoquinone  
(*p*-Quinone)

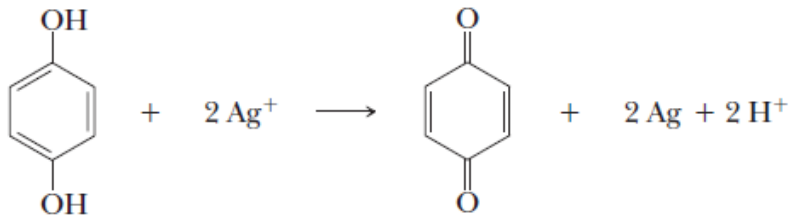


Coenzyme Q  
(oxidized form)

Coenzyme Q  
(reduced form)

$$6 < n < 10$$

- Ancorato nella membrana mitocondriale interna
- Trasportatore di  $e^-$  nella catena respiratoria

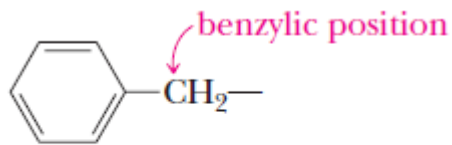


1,4-Benzenediol  
(Hydroquinone)

1,4-Benzoquinone  
(*p*-Quinone)

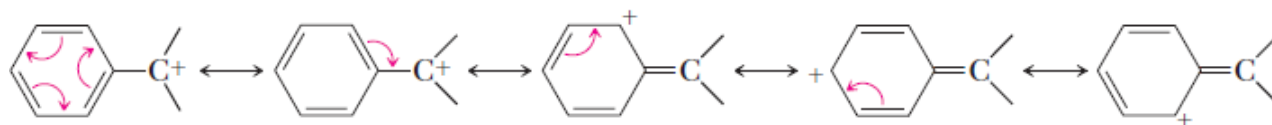
- Reazione utilizzata per sviluppare fotografie b/n

# Reazioni in posizione benzilica

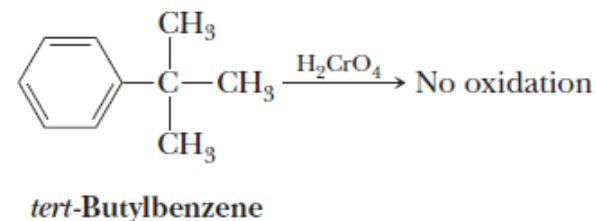
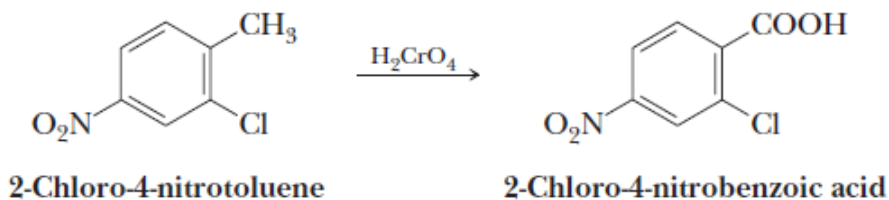


Benzyl group

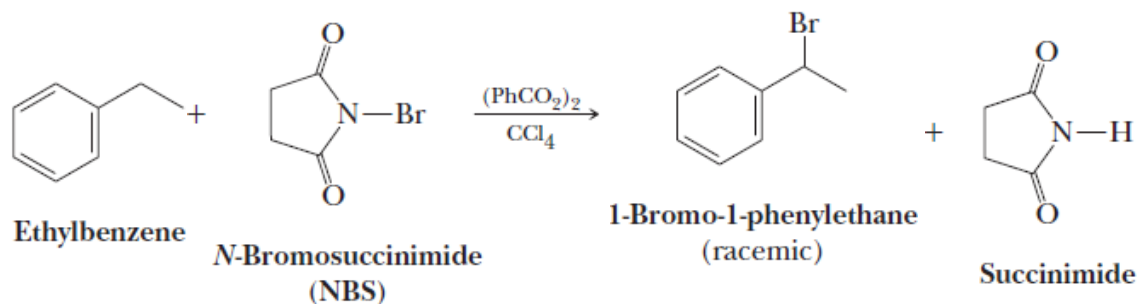
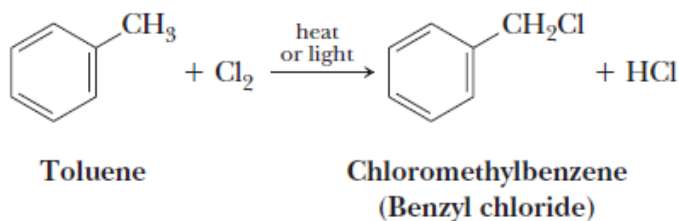
**C benzilico:** C sp<sup>3</sup> legato a un anello benzenico



## Ossidazione

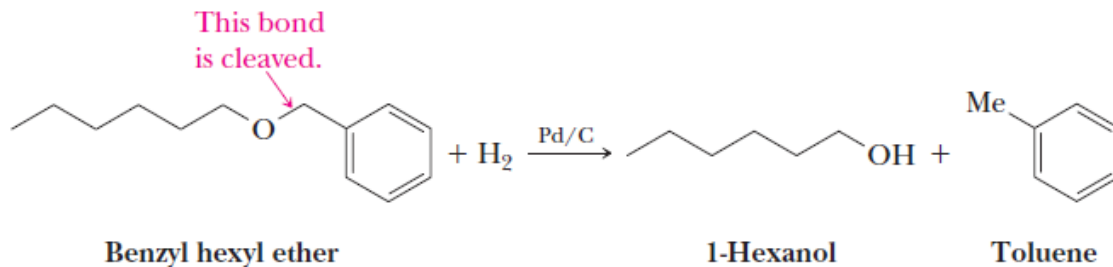


## Alogenazione



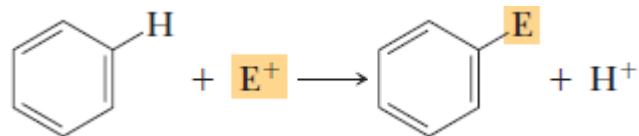
**Reazione regioselettiva**

## Idrogenolisi di eteri benzilici

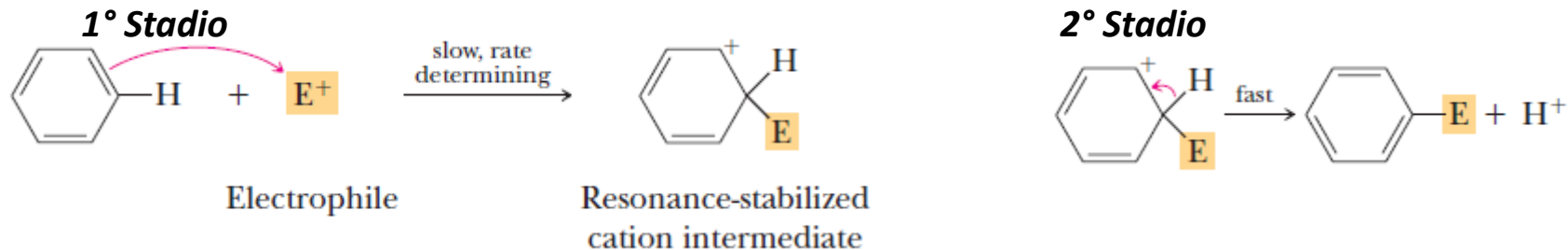


# Sostituzione elettrofila aromatica

Reazione su un anello aromatico nella quale un -H viene sostituito da un elettrofilo

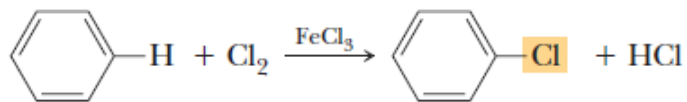


## Meccanismo generale



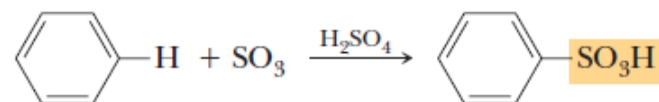
## Esempi

Halogenation:



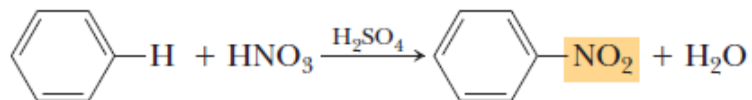
Chlorobenzene

Sulfonation:



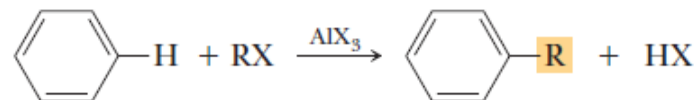
Benzenesulfonic acid

Nitration:



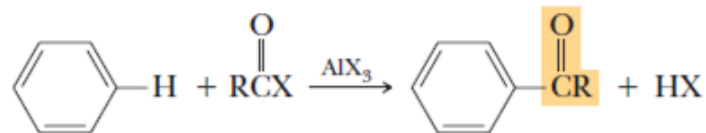
Nitrobenzene

Alkylation:



An alkylbenzene

Acylation:

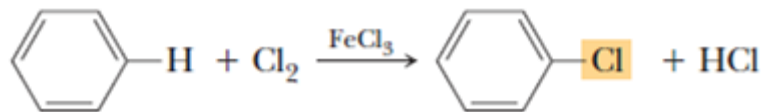


An acylbenzene

# Sostituzione elettrofila aromatica

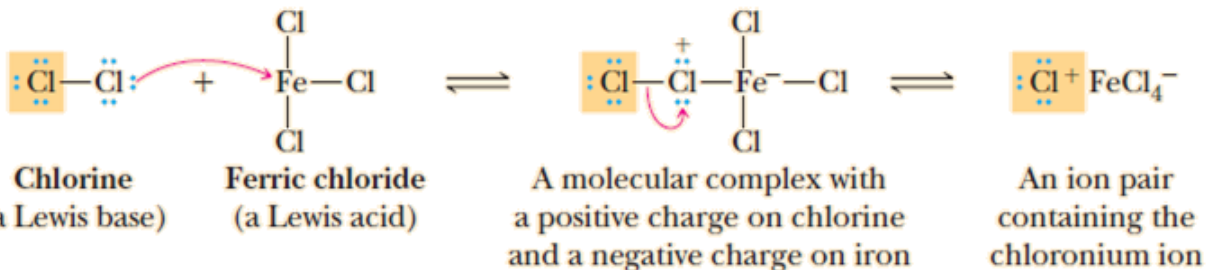
Reazione su un anello aromatico nella quale un -H viene sostituito da un elettrofilo

## Clorurazione

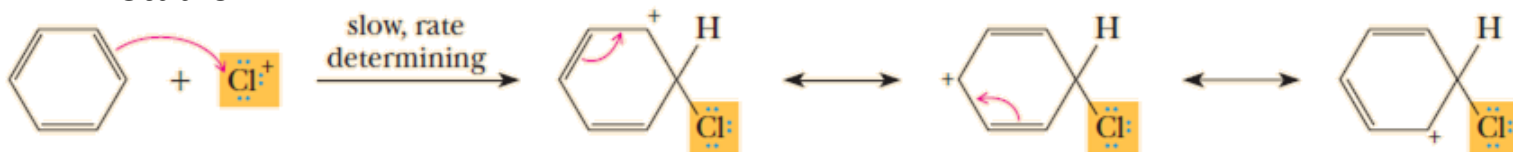


Chlorobenzene

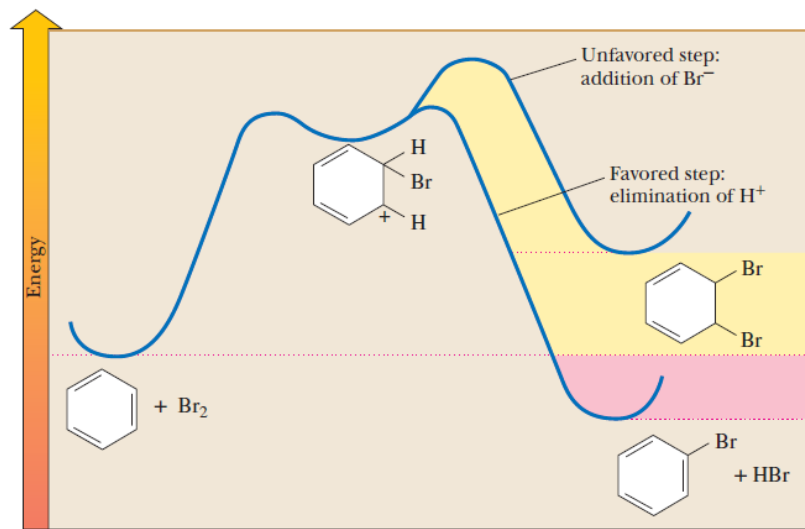
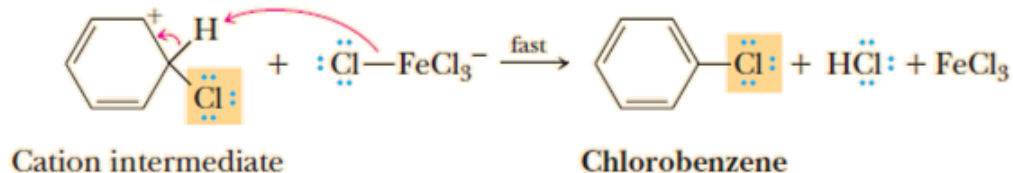
### 1° Stadio



### 2° Stadio



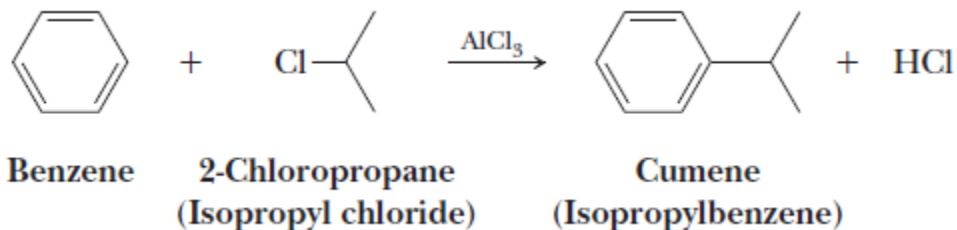
### 3° Stadio



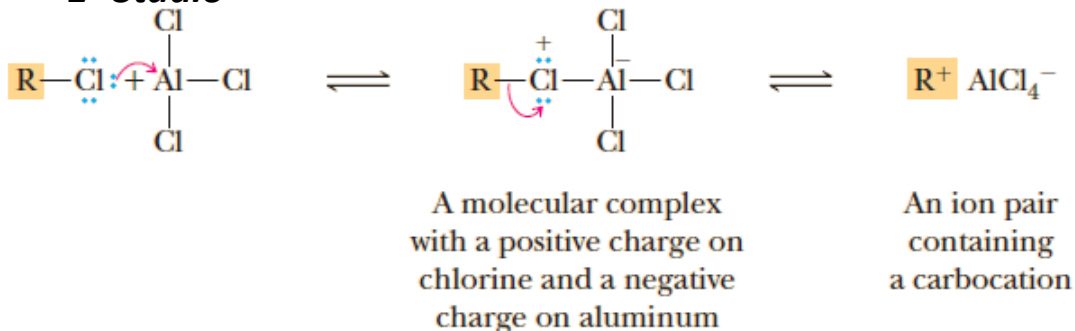
# Sostituzione elettrofila aromatica

Reazione su un anello aromatico nella quale un -H viene sostituito da un elettrofilo

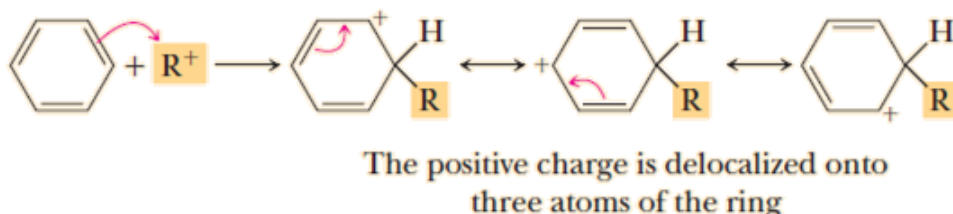
## Alchilazione di Friedel-Crafts



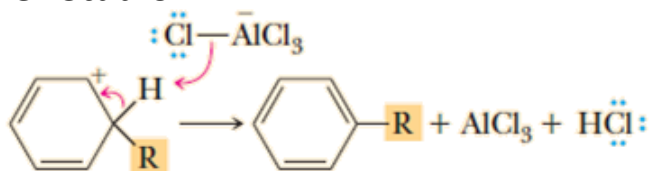
### 1° Stadio



### 2° Stadio



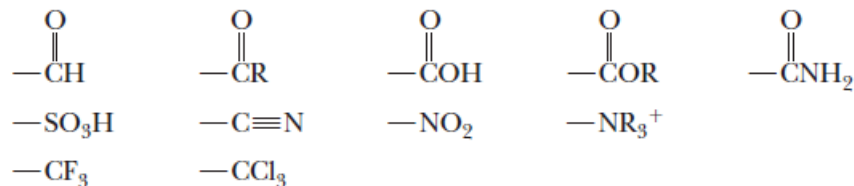
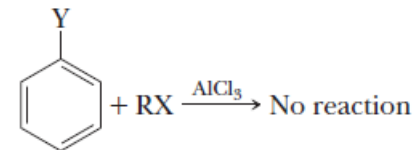
### 3° Stadio



- Sono possibili riarrangiamenti

La reazione non è fattibile in presenza di:

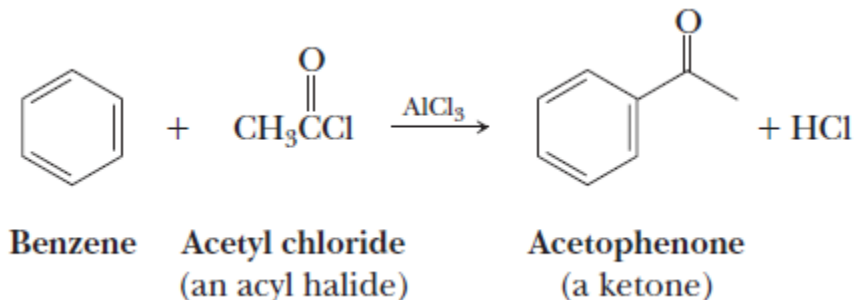
- alogenuri vinilici e arilici
- sostituenti elettron-attrattori sull'anello



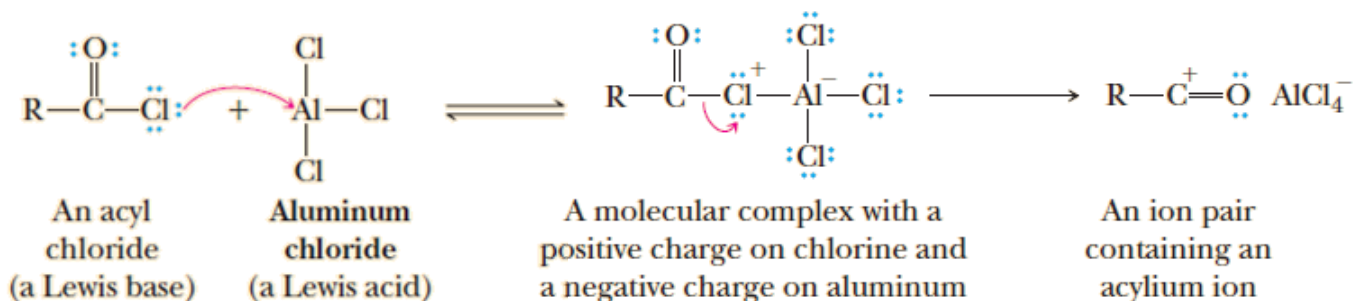
# Sostituzione elettrofila aromatica

Reazione su un anello aromatico nella quale un -H viene sostituito da un elettrofilo

## Acilazione di Friedel-Crafts

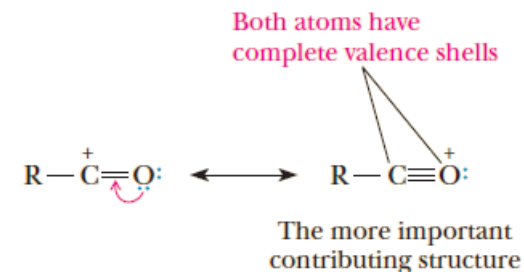


### 1° Stadio



2° e 3° stadio sono simili all'alchilazione


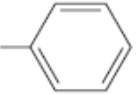
**Ione acilonio:** catione stabilizzato per risonanza con struttura  $[\text{RC}=\text{O}]^+$  o  $[\text{ArC}=\text{O}]^+$



L'acilazione non ha le limitazioni dell'alchilazione

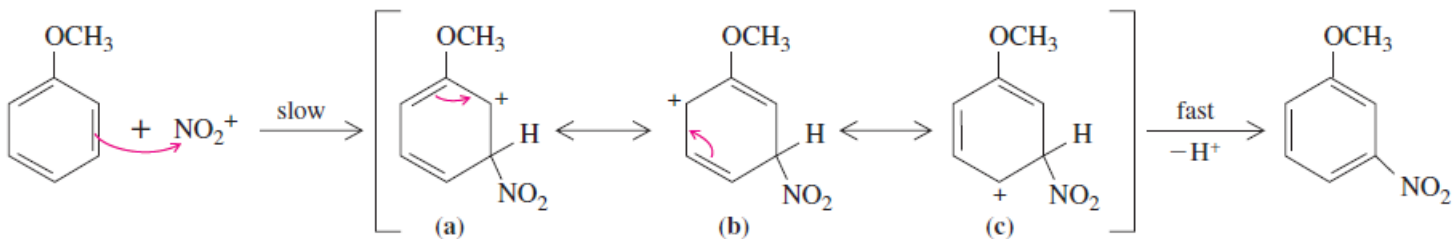
# Polisostituzioni

- La sostituzione elettrofila aromatica su un benzene monosostituito può portare al prodotto orto, meta o para sostituito
- I sostituenti influenzano l'orientazione dei nuovi gruppi
  - Sostituenti orto-para orientanti
  - Sostituenti meta orientanti
- I sostituenti influenzano la velocità delle ulteriori sostituzioni
  - Sostituenti attivanti
  - Sostituenti disattivanti

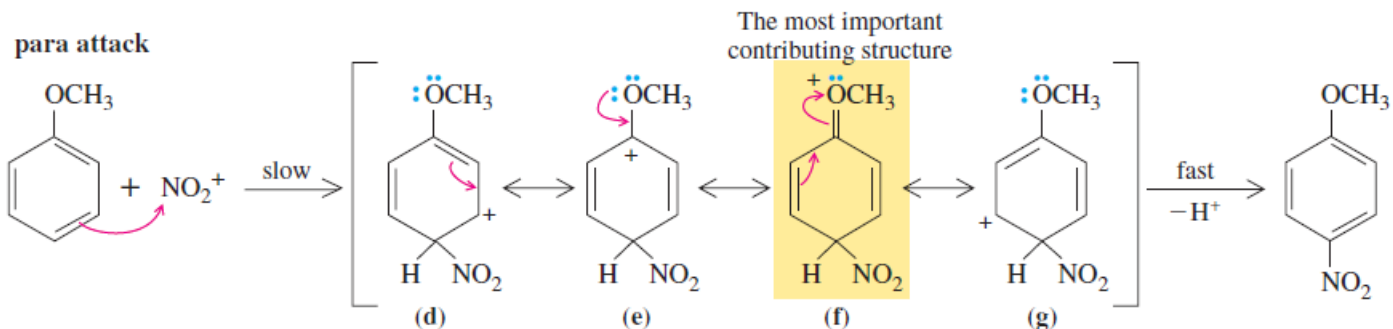
Ortho-Para Directing	Strongly activating	$-\ddot{\text{N}}\text{H}_2$	$-\ddot{\text{N}}\text{HR}$	$-\ddot{\text{N}}\text{R}_2$	$-\ddot{\text{O}}\text{H}$	$-\ddot{\text{O}}\text{R}$	Relative importance in directing further substitution 		
	Moderately activating	$-\ddot{\text{N}}\text{H}\overset{\text{O}}{\parallel}\text{CR}$	$-\ddot{\text{N}}\text{H}\overset{\text{O}}{\parallel}\text{CAr}$	$-\ddot{\text{O}}\overset{\text{O}}{\parallel}\text{CR}$	$-\ddot{\text{O}}\overset{\text{O}}{\parallel}\text{CAr}$				
	Weakly activating	$-\text{R}$							
	Weakly deactivating	$-\ddot{\text{F}}:$	$-\ddot{\text{Cl}}:$	$-\ddot{\text{Br}}:$	$-\ddot{\text{I}}:$				
Meta Directing	Moderately deactivating	$-\overset{\text{O}}{\parallel}\text{CH}$	$-\overset{\text{O}}{\parallel}\text{CR}$	$-\overset{\text{O}}{\parallel}\text{COH}$	$-\overset{\text{O}}{\parallel}\text{COR}$	$-\overset{\text{O}}{\parallel}\text{CNH}_2$		$-\overset{\text{O}}{\parallel}\text{SOH}$	$-\text{C}\equiv\text{N}$
	Strongly deactivating	$-\text{NO}_2$	$-\text{NH}_3^+$	$-\text{CF}_3$	$-\text{CCl}_3$				

# Polisostituzioni

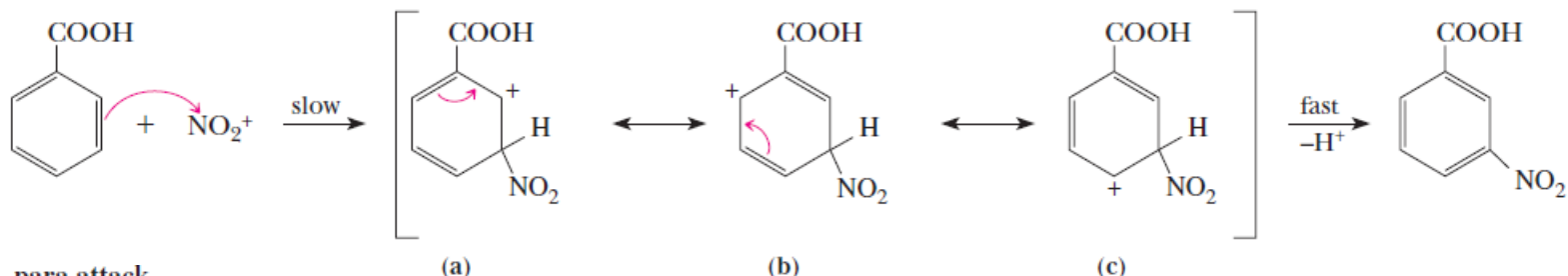
meta attack



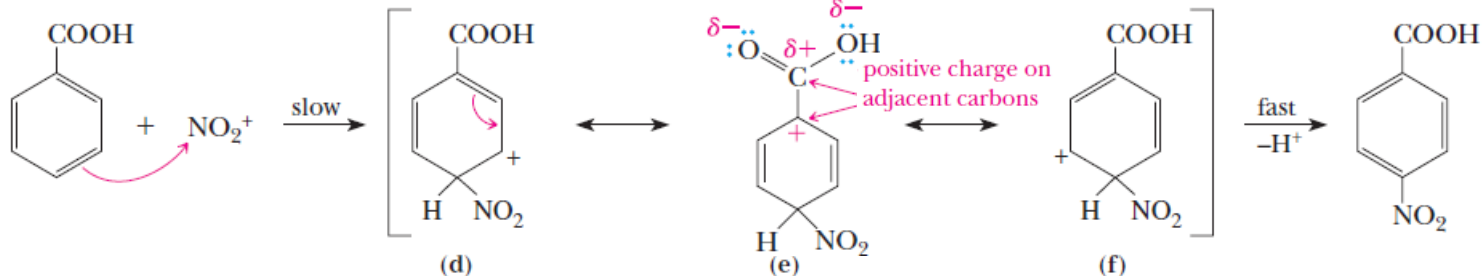
para attack



meta attack



para attack



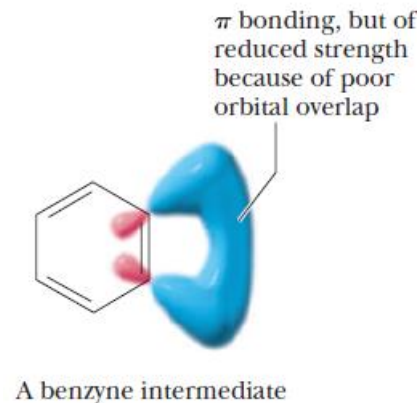
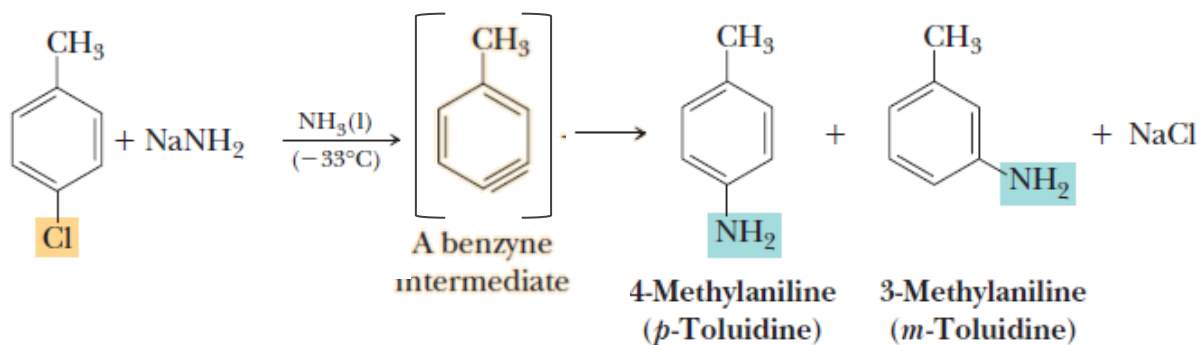
The most disfavored contributing structure



# Sostituzione nucleofila aromatica

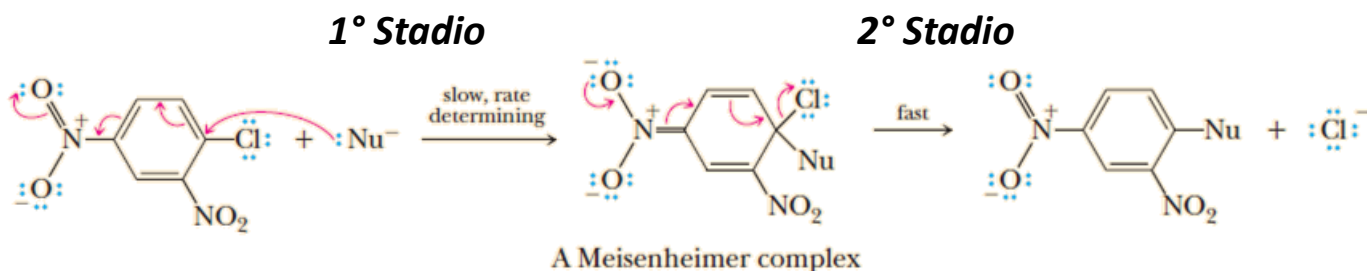
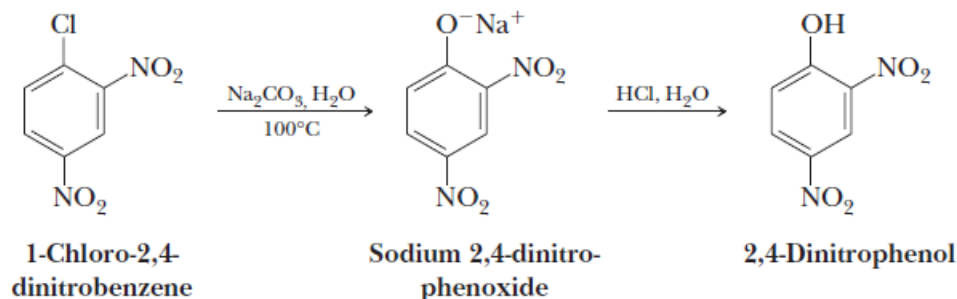
Reazione nella quale un nucleofilo legato ad un anello aromatico viene sostituito da un altro nucleofilo

## Sostituzione nucleofila via intermedio benzino



## Sostituzione nucleofila mediante addizione-eliminazione

In presenza di gruppi nitro in orto o in para rispetto all'alogeno



# Esercizi riassuntivi

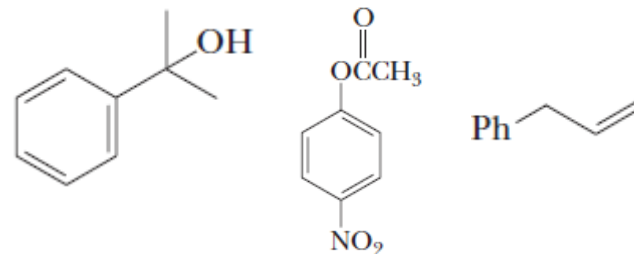
## Esercizio

Scrivere le formule di struttura dei seguenti composti:

- a) 3,4-dimetossibenzaldeide
- b) etil-4-amminobenzoato

## Esercizio

Scrivere i nomi dei seguenti composti

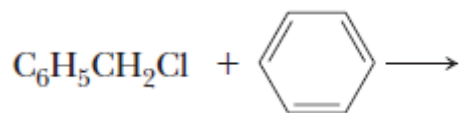


## Esercizio

Scrivere le formule di struttura dei seguenti composti: fenolo, 2,4-dinitrofenolo, alcol benzilico. Disporre i 3 composti in ordine di acidità crescente e giustificare la risposta.

## Esercizio

Completare la seguente alchilazione di Friedel Crafts e scrivere i nomi di reagenti e prodotto



## Esercizio

Quale prodotto si ottiene per vigorosa ossidazione dell'1,4-dimetilbenzene (p-xilene) in acido cromico? Scrivere le formule di struttura di reagenti e prodotti.

## Esercizio

Completare le seguenti reazioni di sostituzione elettrofila aromatica e scrivere i nomi di reagenti e prodotto/i

