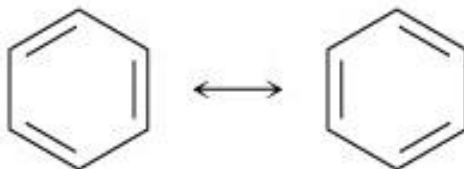
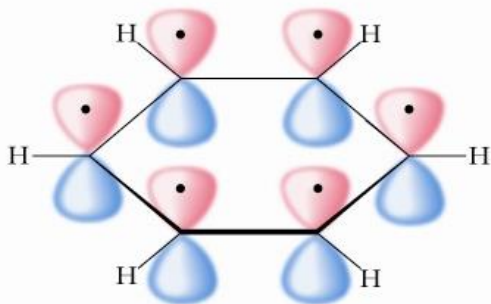
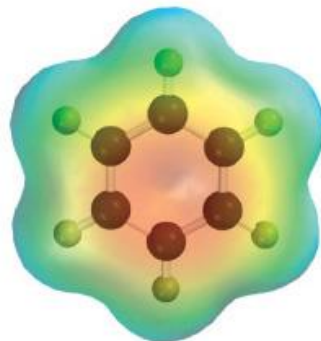
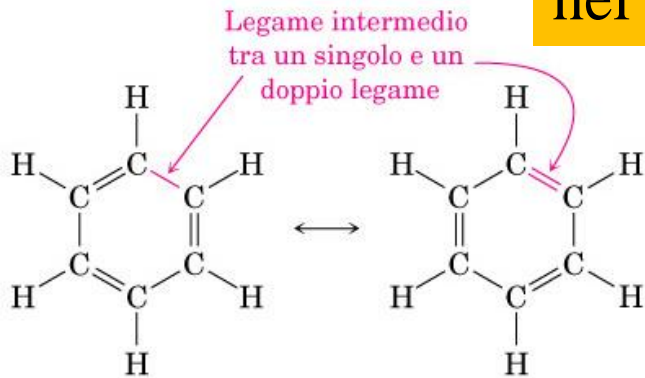


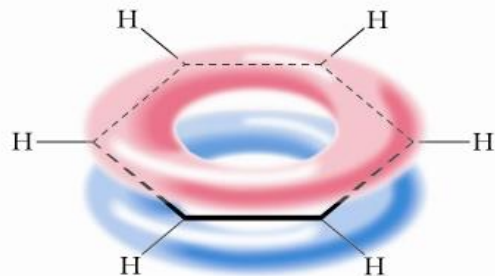
# Benzene e aromaticità



# Doppi legami coniugati nel benzene

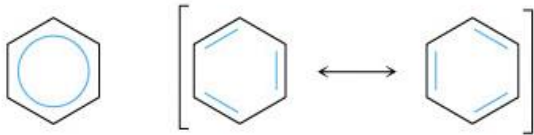


(a)



(b)

# Risonanza del benzene



Rappresentazioni alternative del benzene.  
La rappresentazione con il cerchio deve essere usata con attenzione dal momento che non indica in numero degli elettroni  $\pi$  nell'anello.

## Requisiti per l'aromaticità:

Molecola ciclica

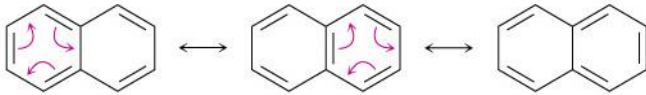
Planare

atomi ibridizzati  $sp^2$

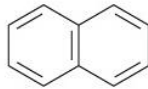
Sistema coniugato continuo di elettroni contenete  $4n+2$

elettroni  $pi$  ( $n$  numero intero positivo)- regola di Huckel

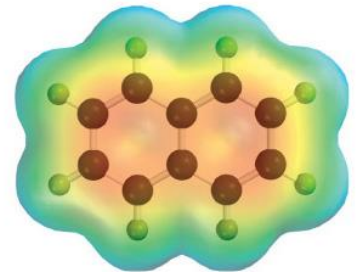
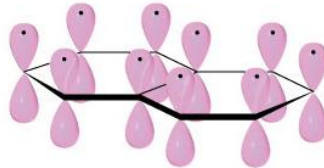
# Idrocarburi policiclici aromatici



**FIGURA 15.12** Il disegno degli orbitali e la mappa di potenziale elettrostatico del naftalene mostrano che i dieci elettroni  $\pi$  sono completamente delocalizzati su entrambi gli anelli.



Naftalene



## Requisiti per l'aromaticità:

Molecola ciclica

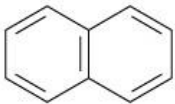
Planare

atomi ibridizzati  $sp^2$

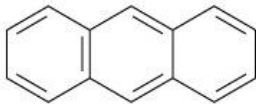
Sistema coniugato continuo di elettroni contenete  $4n+2$

elettroni  $\pi$  ( $n$  numero intero positivo)- regola di Huckel

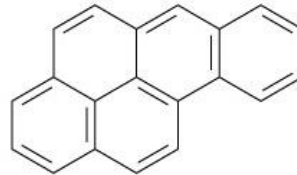
# Idrocarburi policiclici aromatici



**Naftalene**

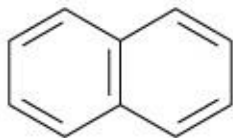


**Antracene**

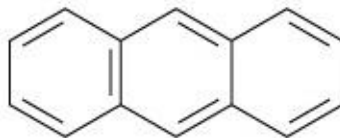


**Benzo[a]pirene**

**3,4-benzopirene**



**Naftalene**



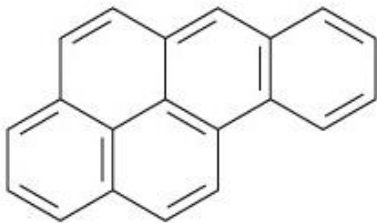
**Antracene**

### **Naftalene:**

Ottenuto per distillazione del catrame o del carbone.

### **Antracene:**

utilizzato nell'industria dei coloranti e come conservante nell'industria del legname, grazie alle sue proprietà insetticide. Non cancerogeno ma persistente, bioaccumulabile e tossico per gli organismi acquatici



**Benzo[a]pirene**

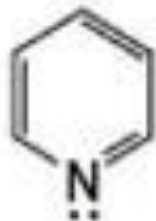
### **Benzopireni:**

contenuti nel catrame, e negli scarti di combustione di molecole ad alto MW. Si formano nella cottura dei cibi alla griglia.

Contenuti nel fumo di sigaretta e negli scarichi dei motori Diesel.

Cancerogeni.

# Alcuni eterocicli aromatici



piridina



pirrolo



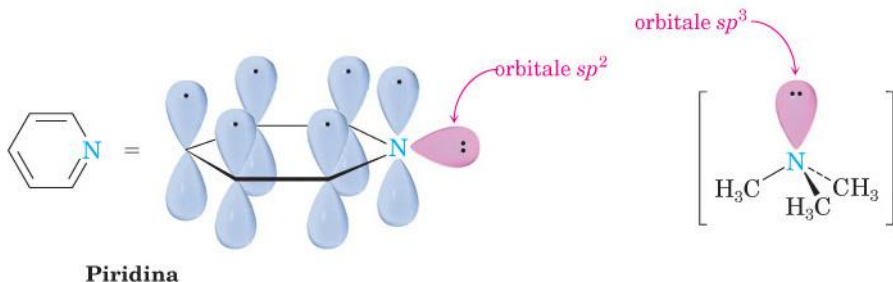
furano



tiofene

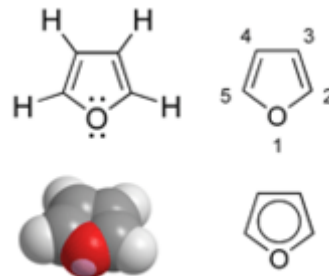
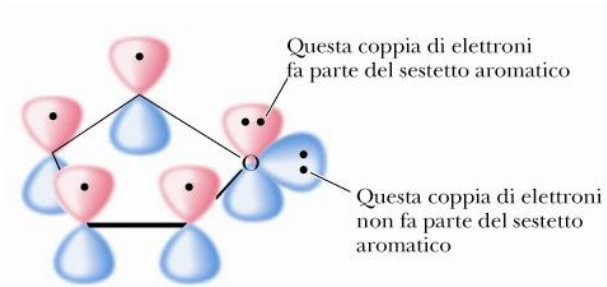


# Piridina: eterociclo aromatici a sei termini



Il doppietto spaiato dell'azoto non partecipa all'aromaticità: reattività basica

# Aromaticità del furano



## Requisiti per l'aromaticità:

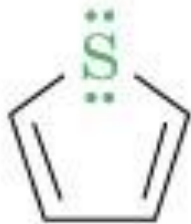
Molecola ciclica

Planare

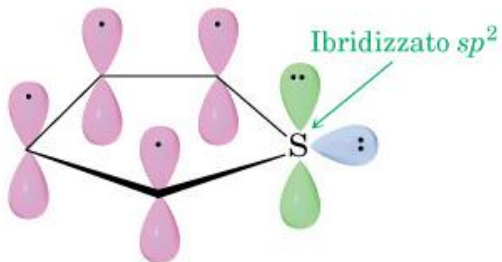
atomi ibridizzati  $sp^2$

Sistema coniugato continuo di elettroni contenete  $4n+2$

elettroni  $\pi$  ( $n$  numero intero positivo)- regola di Huckel

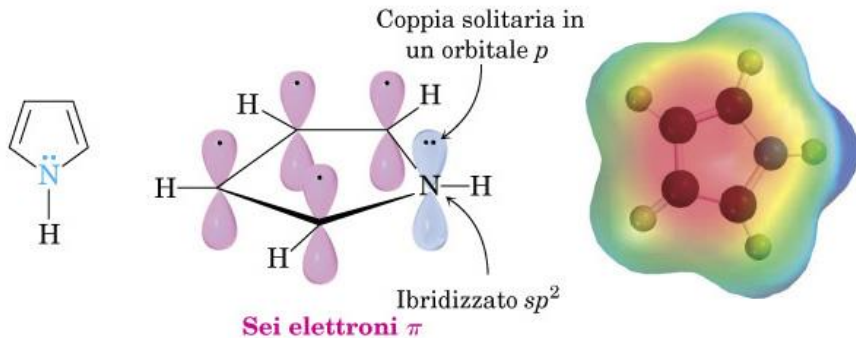


## Aromaticità del tiofene



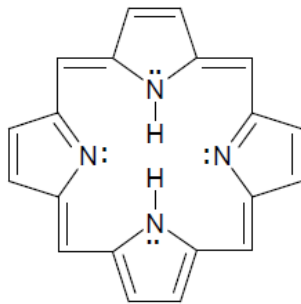
**Tiofene**

# Aromaticità del pirrolo

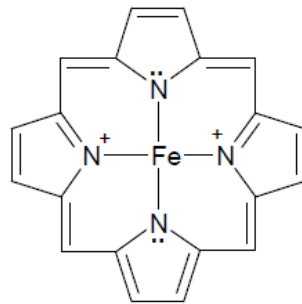


Il doppietto spaiato dell'azoto partecipa all'aromaticità: non ha reattività basica

**Il pirrolo gioca un ruolo fondamentale nei sistemi biologici che sono in grado di chelare metalli quali le porfirine:**



anello porfirinico



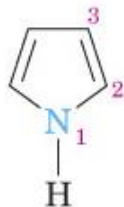
gruppo eme

**il sistema a base di queste strutture è la porfina, un sistema coniugato planare a 18 elettroni**

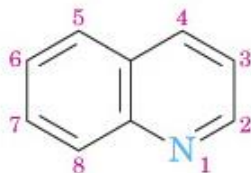
# Eterocicli aromatici contenenti N



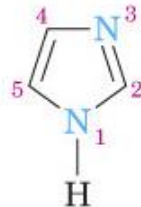
**Piridina**



**Pirrolo**



**Chinolina**



**Imidazolo**

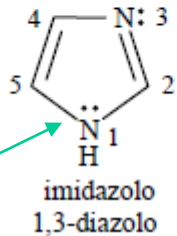


**Indolo**

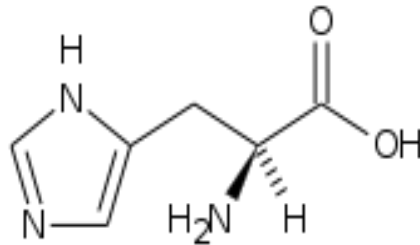
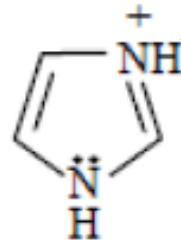


**Pirimidina**

# L'imidazolo

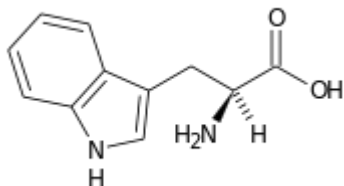
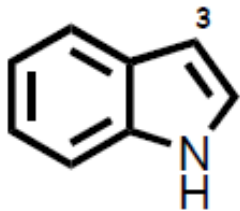


Doppio che  
partecipa  
all'aromaticità:  
no basico

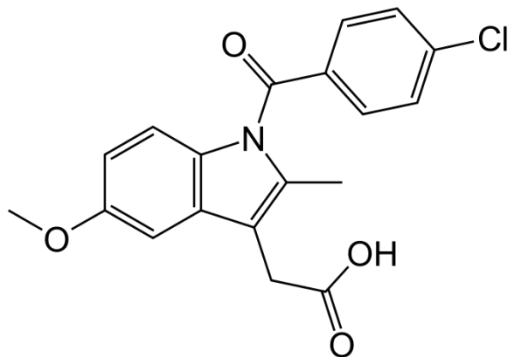


Istidina: un  
amminoacido

# L'indolo

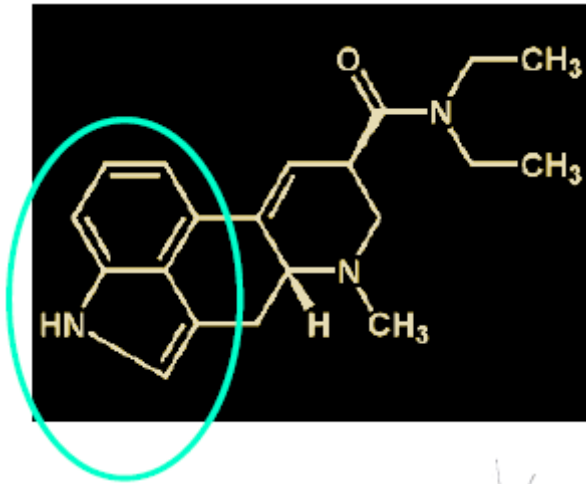


Triptofano (amminoacido)



Indometacina  
(antiinfiammatorio non steroideo)

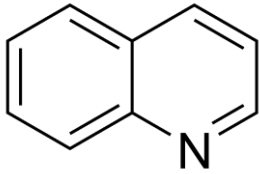




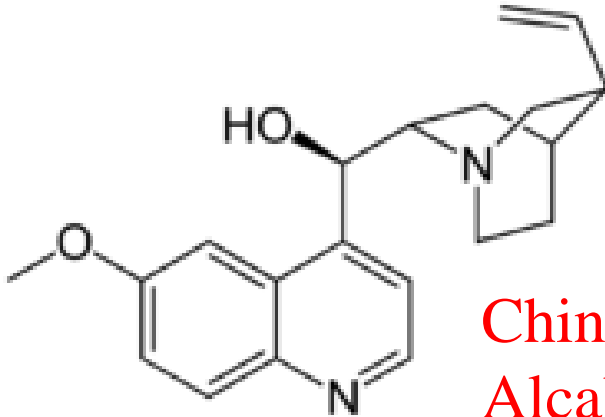
LSD  
dietilamide  
dell'acido lisergico

*Claviceps purpurea* è un ascomicete parassita delle graminacee il cui nome comune è *ergot*. Genera nelle piante infette degli sclerozi a forma di corna o speroni. Questi sono i corpi fruttiferi del fungo in cui sono contenuti diversi alcaloidi tra cui l'acido lisergico. Questi hanno vari tipi di effetti su persone e animali che li assumono. Sono vasocostrittori e interagiscono con il sistema nervoso centrale in particolare con i recettori della serotonina.





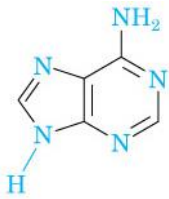
chinolina



**Chinino**

**Alcaloide antimalarico**

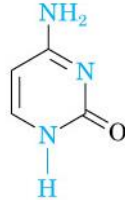
# Basi azotate degli acidi nucleici



**Adenina (A)**  
DNA  
RNA



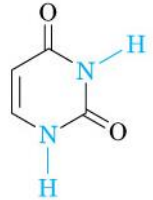
**Guanina (G)**  
DNA  
RNA



**Citosina (C)**  
DNA  
RNA









**Timina (T)**  
DNA



**Uracile (U)**  
RNA

**Come l'aromaticità del  
benzene influisce sulla  
reattività dei gruppi  
funzionali legati all'anello**

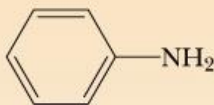
Ammina	Struttura	$pK_a$
<b>Ammoniaca</b>	$NH_3$	9.26
<b>Ammine primarie</b>		
metilammina	$CH_3NH_2$	10.64
etilammina	$CH_3CH_2NH_2$	10.81
cicloesilammina	$C_6H_{11}NH_2$	10.66
<b>Ammine secondarie</b>		
dimetilammina	$(CH_3)_2NH$	10.73
dietilammina	$(CH_3CH_2)_2NH$	10.98
<b>Ammine terziarie</b>		
trimetilammina	$(CH_3)_3N$	9.81
trietilammina	$(CH_3CH_2)_3N$	10.75
<b>Ammine aromatiche</b>		
anilina		4.63
4-metilnilina		5.08
4-cloroanilina		4.15
4-nitroanilina		1.0
<b>Ammine eterocicliche aromatiche</b>		
piridina		5.25
imidazolo		6.95

\* Per ciascuna ammina,  $pK_a + pK_b = 14.00$ .

Le ammine aromatiche sono basi più deboli rispetto alle ammine alifatiche

## Ammine aromatiche

anilina



4-metilnilina



4-cloroanilina



4-nitroanilina



$pK_a$   
acido coniugato

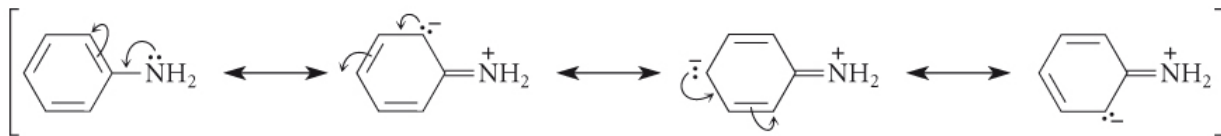
4.63

5.08

4.15

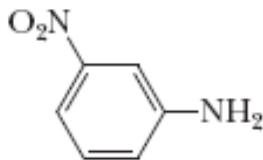
1.0

**Perché l'anilina è una base più debole rispetto alle ammine alifatiche?**

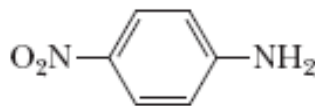


**Il gruppo nitro è elettron attrattore e attira il doppietto dell' N dell'anilina.**

**L'effetto del gruppo nitro (elettron attrattore) in *para* è massimo:** Massima stabilizzazione del doppietto elettronico, scarsa reattività basica



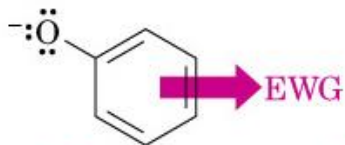
3-Nitroanilina  
 $pK_a$  2.47



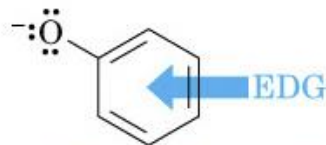
4-Nitroanilina  
 $pK_a$  1.0

Acidi coniugati

- **Gruppi elettron attrattori stabilizzano il doppietto elettronico e diminuiscono la reattività basica**
- **Gruppi elettron donatori destabilizzano la base e la rendono più reattiva**

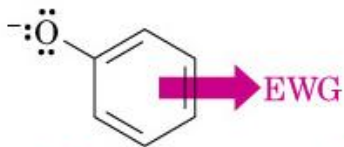


I gruppi elettron-attrattori (EWG)

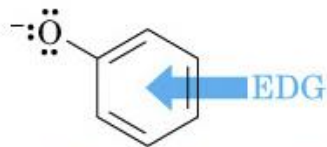


I gruppi elettron-donatori (EDG)

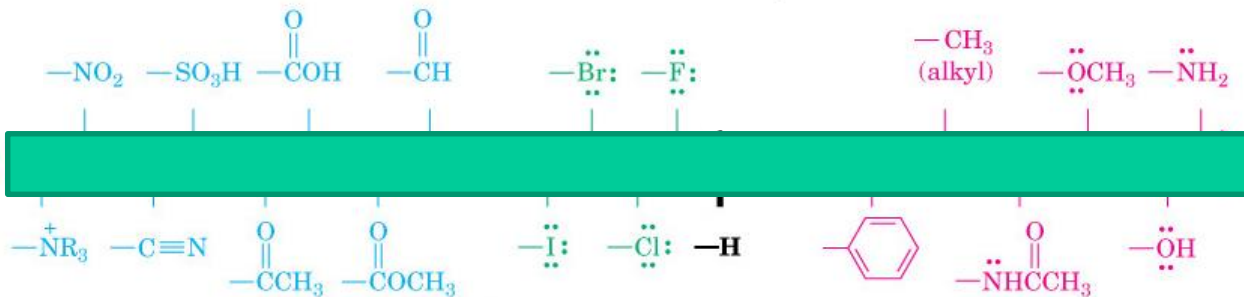




I gruppi elettron-attrattori (EWG)



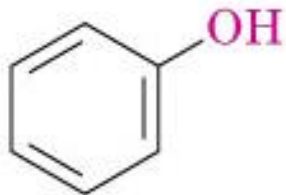
I gruppi elettron-donatori (EDG)



elettron attrattori

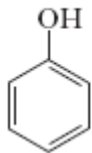
elettron donatori

# Fenolo

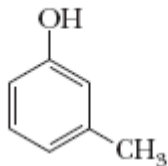


**Fenolo: p.e. = 181.7°C**

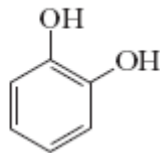
# Derivati del Fenolo



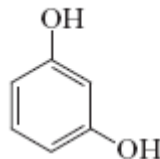
Fenolo



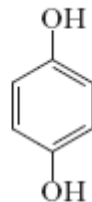
3-Metilfenolo  
(*m*-Cresolo)



1,2-Benzendiolo  
(Catecolo)

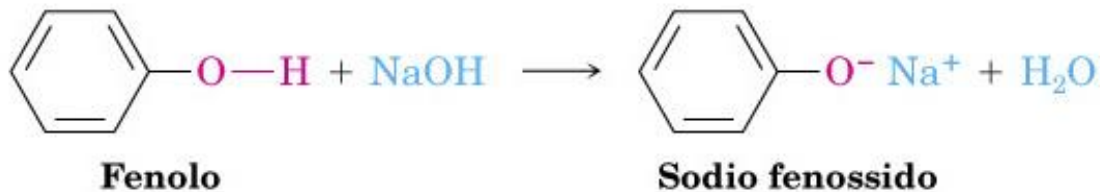


1,3-Benzendiolo  
(Resorcinolo)



1,4-Benzendiolo  
(Idrochinone)

Il fenolo è un acido più forte degli alcol

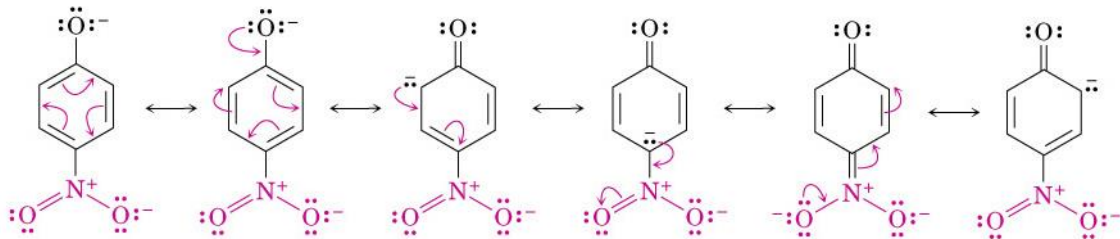


pKa=9.95

Il fenolo è un acido sufficientemente forte da poter formare sali se trattato con NaOH



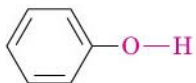
# Gruppi elettron attrattori stabilizzano la base coniugata e aumentano l'acidità del fenolo



Il gruppo nitro stabilizza la base coniugata del p-nitro fenolo

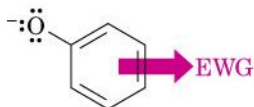
Perciò il *p*-nitro fenolo (pKa=7.15)  
è un acido più forte del fenolo

pKa=9.95

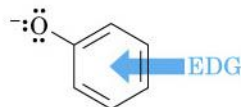


Fenolo

- **Gruppi elettron attrattori stabilizzano la base coniugata e aumentano l'acidità dei fenoli**
- **Gruppi elettron donatori destabilizzano la base coniugata e diminuiscono l'acidità dei fenoli**



**I gruppi elettron-attrattori (EWG)**  
stabilizzano lo ione fenossido,  
determinando così un aumento  
dell'acidità del fenolo



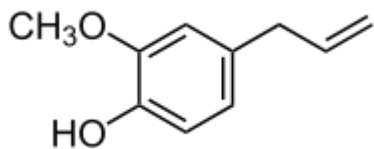
**I gruppi elettron-donatori (EDG)**  
destabilizzano lo ione fenossido,  
determinando così una diminuzione  
dell'acidità del fenolo

# pKa

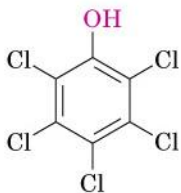
- **Alcol benzilico** 16-18
- Fenolo 9.95
- 4-clorofenolo 9.18
- 2-nitrofenolo 7.17
- 4-nitrofenolo 7.15
- 3-nitrofenolo 8.4
- 2,4-dinitrofenolo 3.96



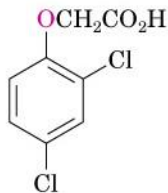
# Derivati del fenolo nelle sostanze naturali



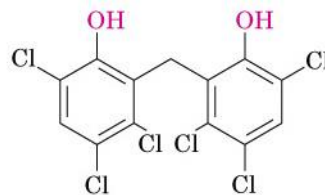
Eugenolo (componente principale olio aromatico chiodi di garofano, noce moscata, cannella)



**Pentaclorofenolo**  
(conservante del legno)



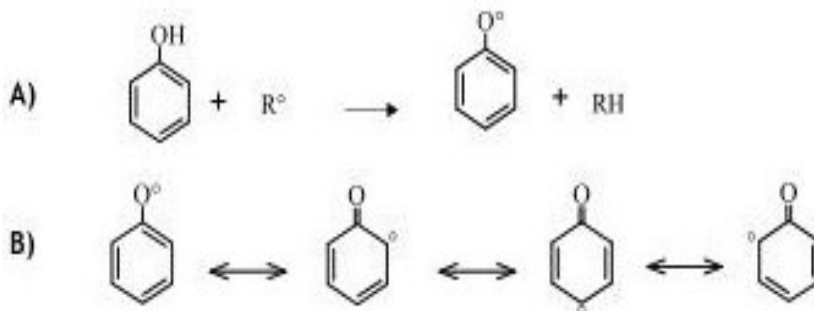
**Acido 2,4-diclorofenossiacetico,**  
**2,4-D (erbicida)**



**Esaclorofene**  
(antisettico)

# Derivati fenolici come antiossidanti

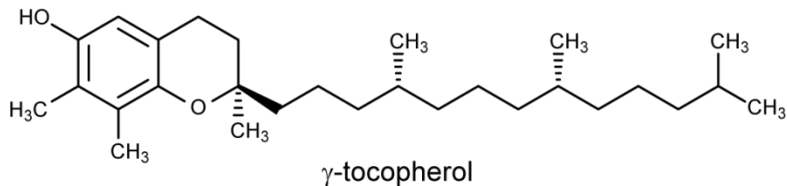
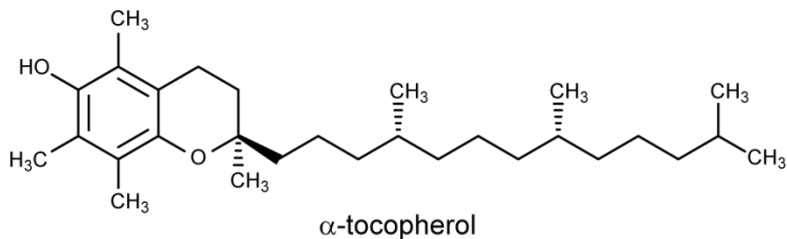
## MECCANISMO ANTIOSSIDANTE



- Attraverso la rottura omolitica del legame, il gruppo fenolico cede l'atomo di idrogeno con l'elettrone spaiato al radicale, inattivandolo.
- L'elettrone spaiato del fenossiradicale formato si delocalizza sull'anello aromatico, stabilizzando la molecola e rendendola meno reattiva.

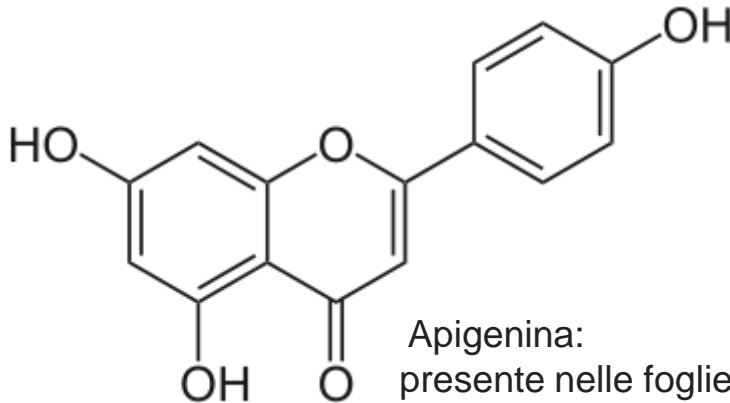
# Derivati fenolici come antiossidanti

- Tocoferoli (Vitamina E)



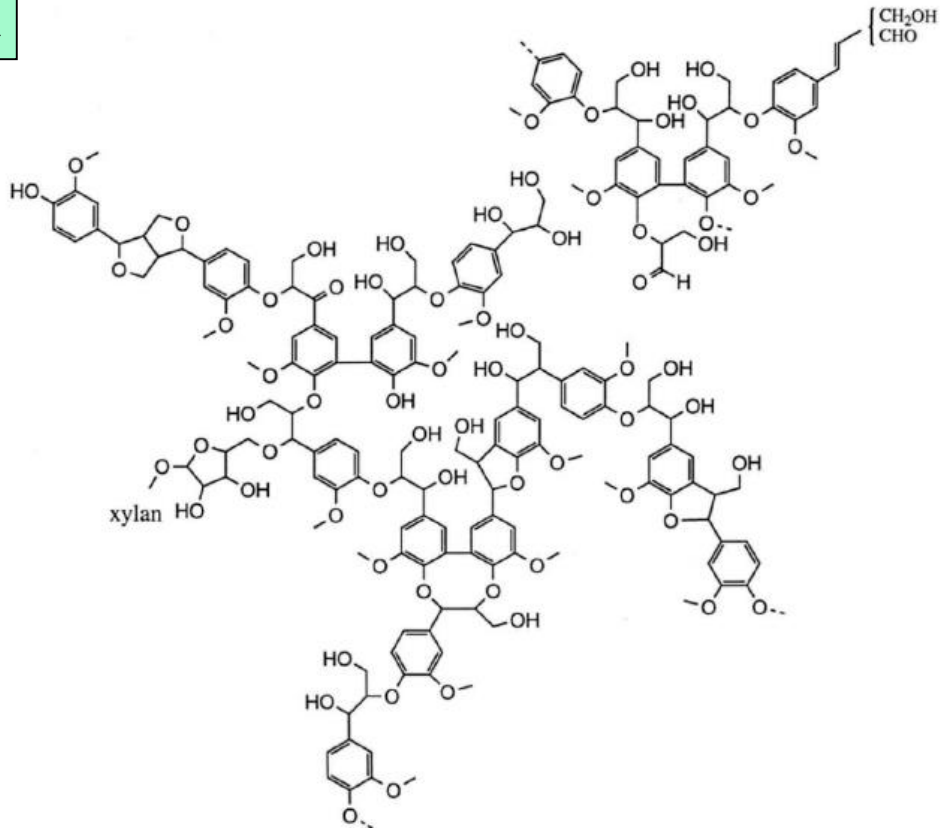
# POLIFENOLI: presenti negli alimenti: flavonoidi, acidi fenolici, lignine

## FLAVONOIDI (metaboliti secondari delle piante)



Apigenina:  
presente nelle foglie di sedano, prezzemolo,  
camomilla. Proprietà spasmolitiche.

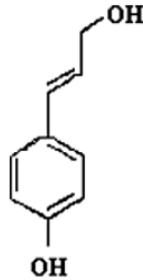
# Lignina



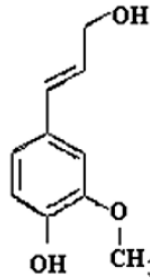
4. A structural model of softwood lignin according to Brunow *et al.*, 1998.

# Lignina: precursori

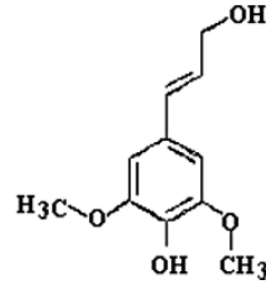
Nella lignina  
formano  
legami eterei  
tramite  
reazioni  
**radicaliche**  
catalizzate da  
enzimi



p-cumaril  
alcohol



Coniferil  
alcohol

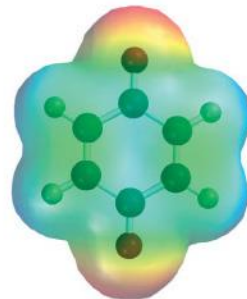
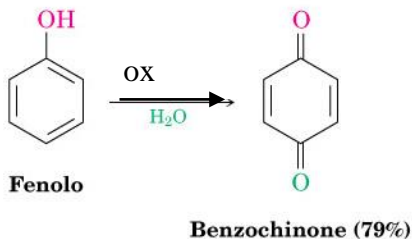


Sinapil  
alcohol

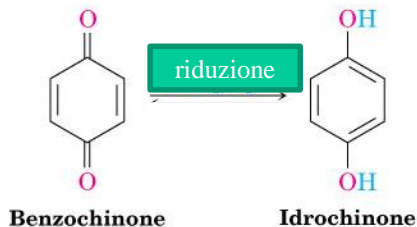
**Nei sistemi biologici i fenoli possono  
essere facilmente ossidati a  
benzochinoni che funzionano da  
«scambiatori di elettroni»**

# Benzochinoni: scavengers elettronici

I fenoli possono  
essere ossidati a  
benzochinoni



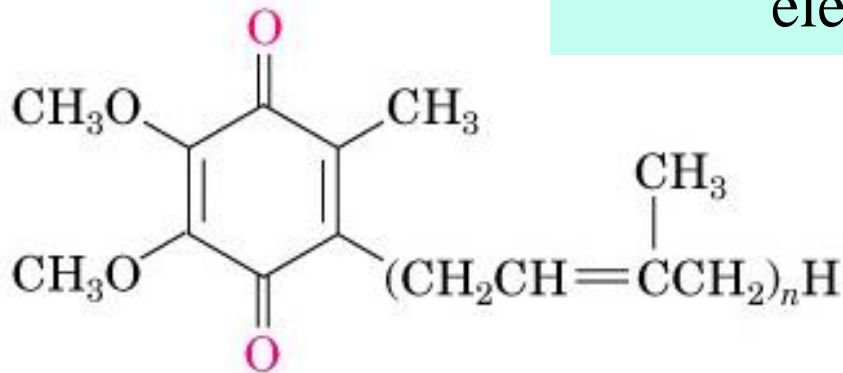
Un prodotto di  
(parziale)  
riduzione dei  
benzochinoni  
sono gli  
idrochinoni





**Ubichinoni:  
scavengers elettronici**

Le forme ossidate e ridotte vengono sfruttate nei sistemi biologici per trasferire elettroni



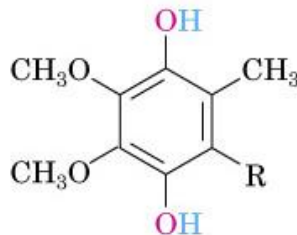
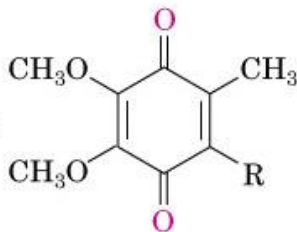
**Ubichinoni ( $n = 1-10$ )**

# Ubichinoni: scavengers elettronici

Stadio 1



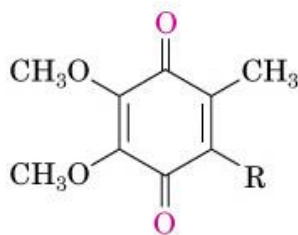
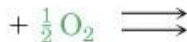
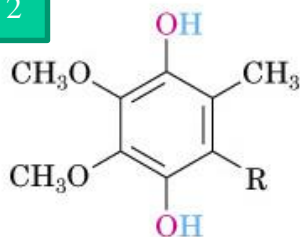
**Forma  
ridotta**



**Forma  
ossidata**

Trasferimento di  
elettroni dal NADH al  
benzochinone che si  
trasforma in  
idrochinone

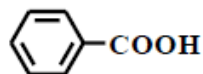
Stadio 2



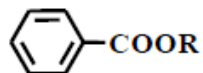
L'idrochinone viene  
ossidato dall'ossigeno  
e trasferisce e- con  
formazione di acqua

# Derivati del benzene

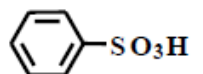
Priorità	Composto base	Nome base	Priorità	Composto base	Nome base
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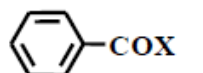
acido benzoico



alchil benzoato

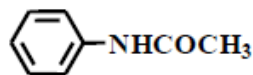


acido benzen  
solfonico

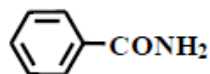


benzoil  
alogenuro

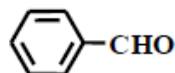
X = Cl, Br



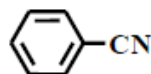
acetanilide



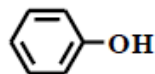
benzammide



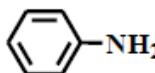
benzaldeide



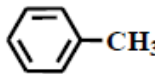
benzonitrile



fenolo



anilina

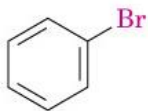


toluene

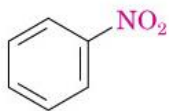


benzene

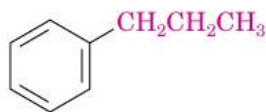
# Ulteriori derivati del benzene



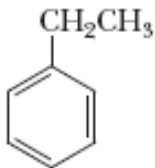
**Bromobenzene**



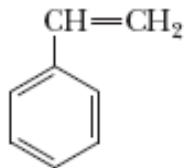
**Nitrobenzene**



**Propilbenzene**

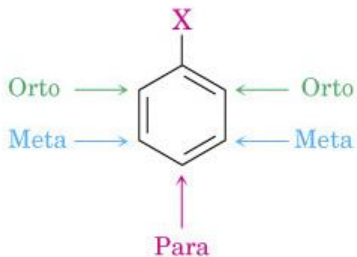


**Etilbenzene**

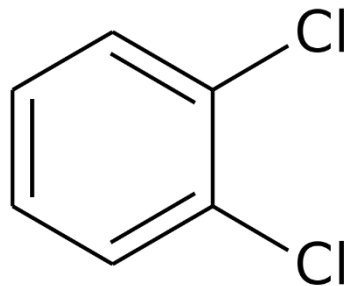


**Stirene**

# Benzene disostituito

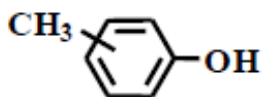


1,2-diclorobenzene  
oppure  
*o*-diclorobenzene

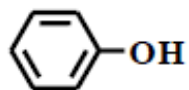


Composto  
base

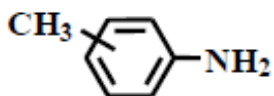
Nome base



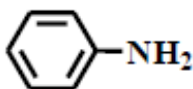
cresolo\*



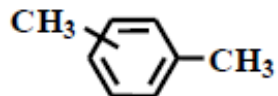
fenolo



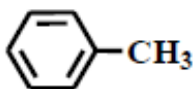
toluidina\*



anilina



xilene\*

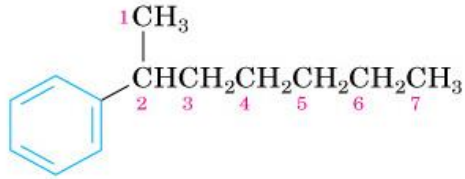


toluene

# Il gruppo sostituyente fenilico

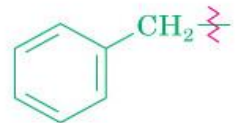


**Gruppo fenilico**



**2-Fenileptano**

# Il gruppo benzilico

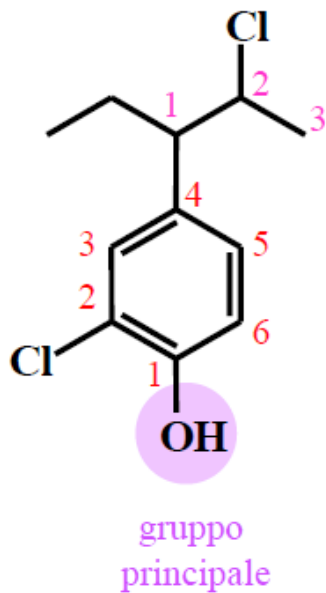


**Gruppo benzilico**



# **Nomenclatura dei derivati del benzene**

## Esempio



Numerare gli altri carboni nella direzione che permetta il più basso set di numeri  
A parità di numeri, vince il sostituito con iniziale più bassa nell'ordine alfabetico

1. Gruppo principale: **OH**

**Fenolo**

2. Numerazione anello:

3. Sostituito complesso:

**(2-cloro-1-etilpropil)**

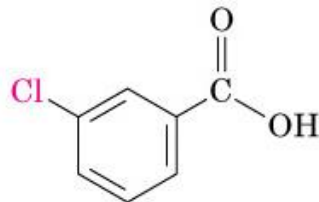
4. Assemblaggio:

**2-cloro-4-(2-cloro-1-etilpropil)fenolo**

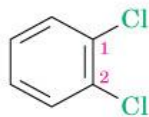
# Esempi di nomenclatura dei derivati del benzene



**2,6-Dibromofenolo**



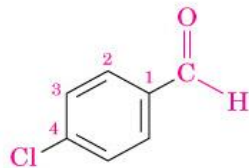
**Acido *m*-clorobenzoico**



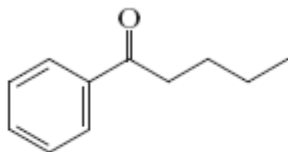
**orto-Diclorobenzene**  
1,2 disostituito



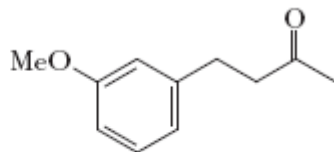
**meta-Xilene**  
1,3 disostituito



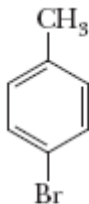
**para-Clorobenzaldeide**  
1,4 disostituito



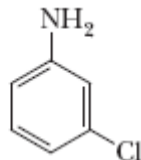
1-Fenil-1-pentanone



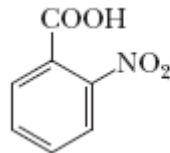
4-(3-Metossifenil)-2-butanone



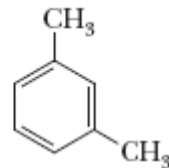
4-Bromotoluene  
(*p*-Bromotoluene)



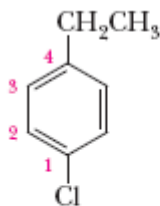
3-Cloroanilina  
(*m*-Cloroanilina)



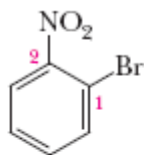
Acido 2-nitrobenzoico  
(Acido *o*-nitrobenzoico)



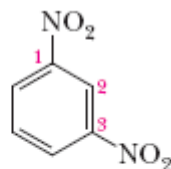
*m*-Xilene



1-Cloro-4-etilbenzene  
(*p*-Cloroetilbenzene)



1-Bromo-2-nitrobenzene  
(*o*-Bromonitrobenzene)



1,3-Dinitrobenzene  
(*m*-Dinitrobenzene)



# Aromatico?



ciclopropene

$Sp^2 + Sp^3$



catione  
ciclopropenile

$n=0$



anione  
ciclopropenile

Numero pari  
di coppie

## Requisiti per l'aromaticità:

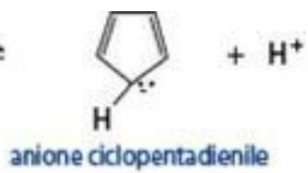
Molecola ciclica

Planare

atomi ibridizzati  $sp^2$

Sistema coniugato continuo di elettroni contenete  $4n+2$

elettroni  $\pi$  ( $n$  numero intero positivo)- regola di Huckel

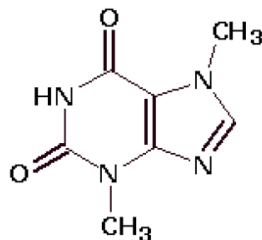


1,3,7-trimethyl-3,7-dihydro-  
1*H*-purine-2,6-dione



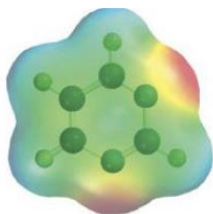
**Caffeina**

3,7-dimethyl-3,7-dihydro-  
1*H*-purine-2,6-dione



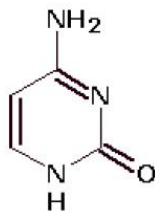
**Teobromina**





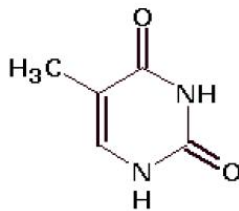
### Pirimidina

4-aminopirimidin-  
2 (1*H*)-one



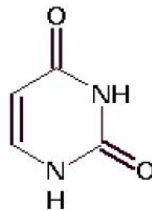
**Citosina**

5-metilpirimidin-  
2,4 (1*H*,3*H*)-dione

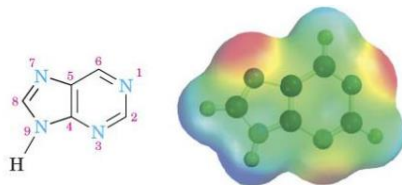


**Timina**

pirimidin-2,4  
(1*H*,3*H*)-dione



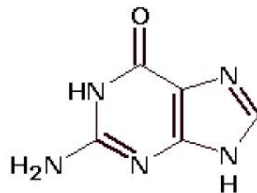
**Uracile**



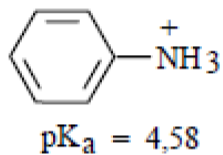
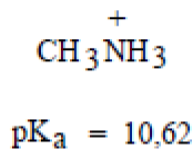
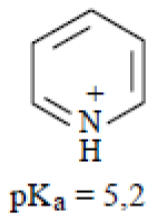
Purina



Adenina



Guanina

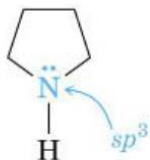


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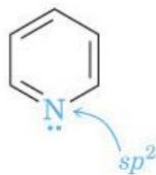
Doppio sp<sup>2</sup>

Doppio sp<sup>3</sup>

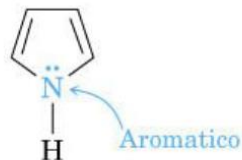
Doppio delocalizzato



[ **Ione pirrolidinio**  
 $pK_a = 11.27$  ]



[ **Ione piridinio**  
 $pK_a = 5.25$  ]



[ **Ione pirrolinio**  
 $pK_a = 0.4$  ]

← Basicità

