

# Substituent Effects

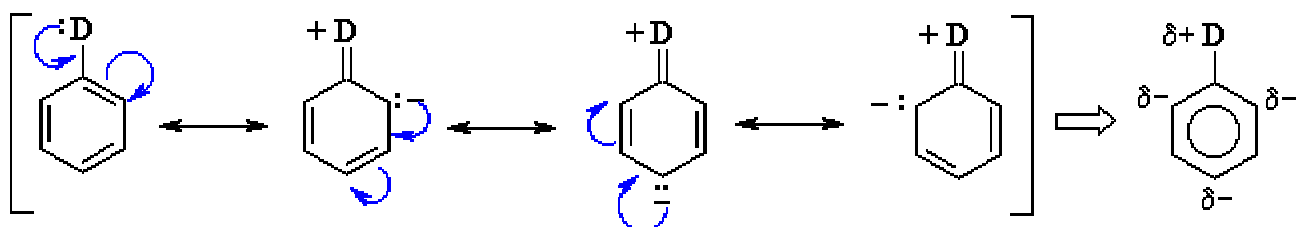
There are two main electronic effects that substituents can exert:

**RESONANCE** effects are those that occur through the  $\pi$  system and can be represented by resonance structures. These can be either electron donating (*e.g.* -OMe) where  $\pi$  electrons are pushed toward the arene or electron withdrawing (*e.g.* -C=O) where  $\pi$  electrons are drawn away from the arene.

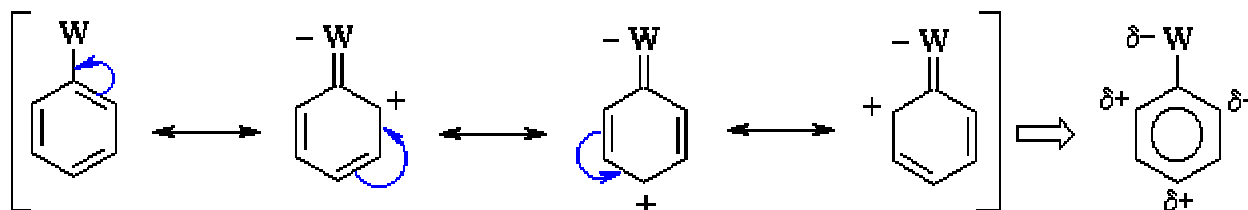
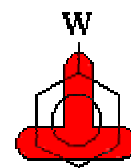
**INDUCTIVE** effects are those that occur through the  $\sigma$  system due to electronegativity type effects. These too can be either electron donating (*e.g.* -Me) where  $\sigma$  electrons are pushed toward the arene or electron withdrawing (*e.g.* -CF<sub>3</sub>, +NR<sub>3</sub>) where  $\sigma$  electrons are drawn away from the arene.

A simplified approach to understanding substituent effects is given here, based on the "isolated molecule approach". The text uses the more rigorous approach of drawing the resonance structures for the intermediate formed by attack at each of the *o*-, *m*- and *p*-positions.

**Electron donating groups (EDG) with lone pairs** (*e.g.* -OMe, -NH<sub>2</sub>) on the atoms adjacent to the  $\pi$  system **activate** the aromatic ring by increasing the electron density on the ring through a **resonance donating effect**. The resonance only allows electron density to be positioned at the **ortho-** and **para-** positions. Hence these sites are **more nucleophilic**, and the system tends to react with electrophiles at these **ortho-** and **para-** sites.

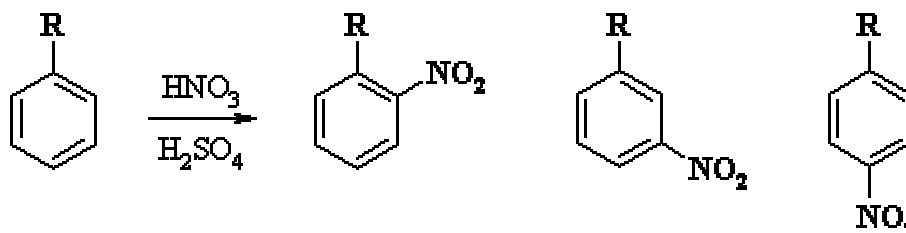


**Electron withdrawing groups (EWG)** with  $\pi$  bonds to **electronegative atoms** (e.g. -C=O, -NO<sub>2</sub>) adjacent to the  $\pi$  system **deactivate** the aromatic ring by decreasing the electron density on the ring through a **resonance withdrawing effect**. The resonance only decreases the electron density at the ortho- and para- positions. Hence these sites are **less nucleophilic**, and so the system tends to react with electrophiles at the **meta** sites.



Halogen substituents are a little unusual in that they are **deactivating** but still direct ortho- / para-. The reason is that they are both inductive electron withdrawing (electronegativity) and resonance donating (lone pair donation). The inductive effect lowers the reactivity but the resonance effect controls the regiochemistry due to the stability of the intermediates.

Besides the electronic effects, substituents can also influence product distributions due to steric effects. From the following data, notice how the yield of the para-nitro product increases as the size of the alkyl group -R increases and "block" the ortho- positions.

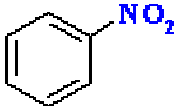
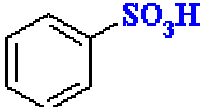
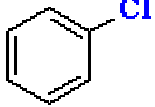
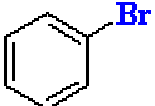
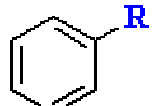
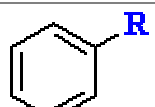
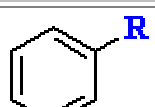
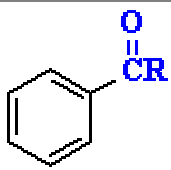


-R	%	%	%
-CH <sub>3</sub>	58	4	37
-CH <sub>2</sub> CH <sub>3</sub>	49	6	49
-CH(CH <sub>3</sub> ) <sub>2</sub>	30	8	62
-C(CH <sub>3</sub> ) <sub>3</sub>	16	11	73

## Reactions and Reagents:

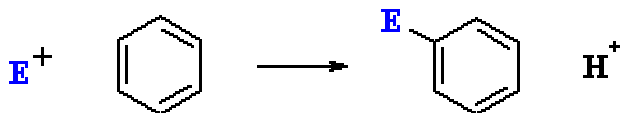
The following pointers may aid your understanding of these reactions:

- Recognise the **electrophile** present in the reagent combination
- The **electrophile** adds first to the arene
- Substitution is preferred over addition in order to preserve the stable aromatic character

Reaction	Reagents	Electrophile	Product	Comments
<a href="#">Nitration</a>	HNO <sub>3</sub> / H <sub>2</sub> SO <sub>4</sub>	NO <sub>2</sub> <sup>+</sup>		E <sup>+</sup> formed by loss of water from nitric acid
<a href="#">Sulfonation</a>	H <sub>2</sub> SO <sub>4</sub> or SO <sub>3</sub> / H <sub>2</sub> SO <sub>4</sub>	SO <sub>3</sub>		Reversible
<a href="#">Halogenation</a>	Cl <sub>2</sub> / Fe or FeCl <sub>3</sub>	Cl <sup>+</sup>		E <sup>+</sup> formed by Lewis acid removing Cl <sup>-</sup>
	Br <sub>2</sub> / Fe or FeBr <sub>3</sub>	Br <sup>+</sup>		E <sup>+</sup> formed by Lewis acid removing Br <sup>-</sup>
<a href="#">Alkylation</a>	R-Cl / AlCl <sub>3</sub>	R <sup>+</sup>		E <sup>+</sup> formed by Lewis acid removing Cl <sup>-</sup>
	R-OH / H <sup>+</sup>	R <sup>+</sup>		E <sup>+</sup> formed by loss of water from alcohol
	C=C / H <sup>+</sup>	R <sup>+</sup>		E <sup>+</sup> formed by protonation of alkene
<a href="#">Acylation</a>	RCOCl / AlCl <sub>3</sub>	RCO <sup>+</sup>		E <sup>+</sup> formed by Lewis acid removing Cl <sup>-</sup>

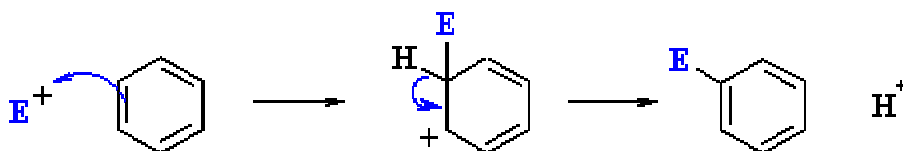
## Electrophilic Aromatic Substitution

Overall an electrophilic aromatic substitution can be represented as follows:



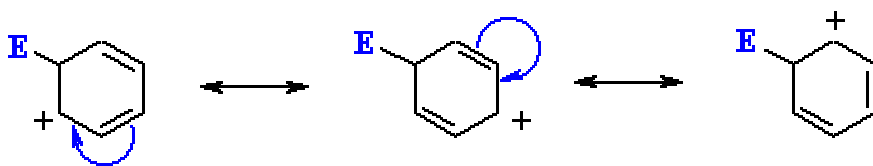
There are three fundamental components to an electrophilic substitution reaction:

1. formation of the new  $\sigma$  bond from a  $C=C$  in the arene nucleophile
2. removal of the proton by breaking the  $C-H$   $\sigma$  bond
3. reform the  $C=C$  and restore aromaticity



The mechanism is represented by the following series of events:

- Formation of the reactive electrophile,  $E^+$
- Slow reaction of the arene  $C=C$  with the  $E^+$  to give a resonance stabilised carbocation (see below)
- Loss of  $H^+$  from the carbocation to restore the  $C=C$  and the aromatic system



The reaction of the electrophile  $E^+$  with the arene is the slow step since it results in the loss of aromaticity even though the resulting cation is still resonance stabilised.

