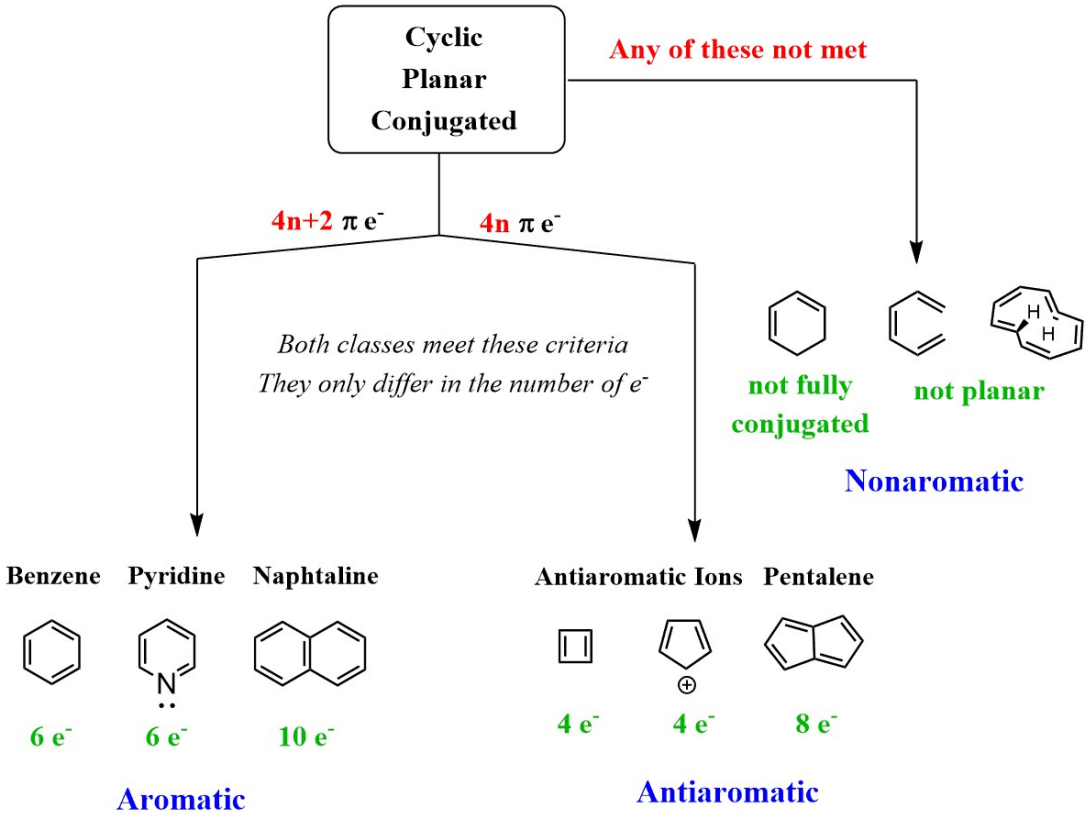
Classification of Aromatic, Antiaromatic and Nonaromatic Compounds



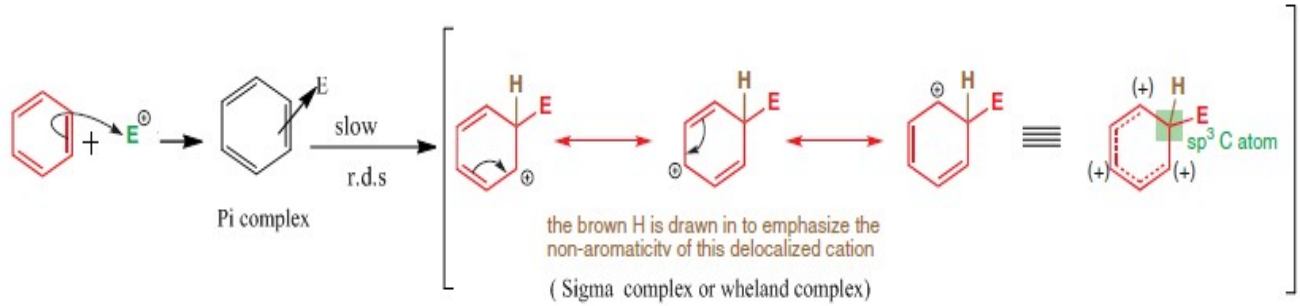
Electrophilic Aromatic Substitution (EAS)S_EAr:

Electrophilic Aromatic Substitution: a **reaction** in which the **hydrogen atom** of **an aromatic** ring is **replaced** as a result of an **electrophilic** attack on the **aromatic ring**.

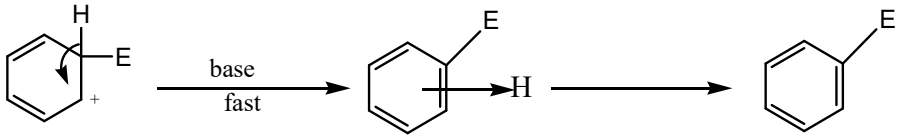
mechanism of electrophilic aromatic substi tution (addition – elimination):

The mechanism of electrophilic aromatic substitution involves an initial rate determining interaction of the **π system** with the **electrophile** to give a **benzenonium** or **Arenium Ion intermediate** (**σ-complex** **or** **wheland complex**), which undergoes a rapid **de-protonation by the base** in the **second step** to restore **aromaticity**.

Step 1: An **electrophile attacks** the **pi electrons** of the **aromatic benzene ring** which results in the formation of a **resonance stabilized carbocation**. This **carbocation** is called the **arenium ion** and has **three resonance** contributors. Electrophilic attack is a **very slow process**. It is endergonic and has **high activation energy due to the loss of aromaticity**.



Step 2: The **carbocation intermediate** is **attacked** by a **base** and **loses a proton**. These electrons are used to reform a **pi bond** and **restore aromaticity**. As opposed to the first step, this step is fast and exergonic because aromaticity is regained. It is important to note that the carbocation loses a proton where the electrophile attacked the benzene ring.



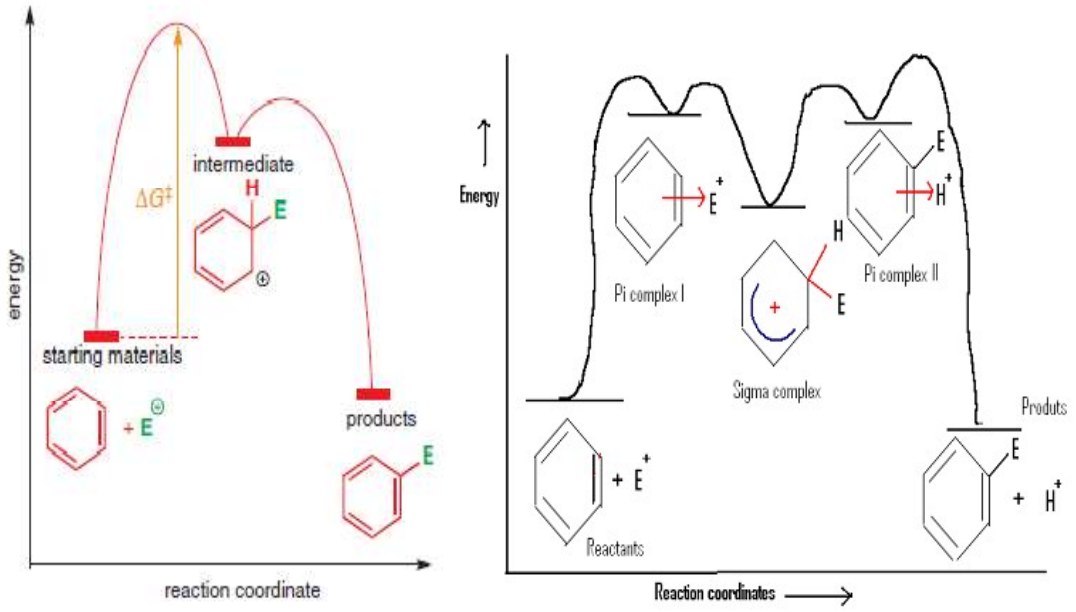
Pi complex

Evidences of mechanism:

1- The **rate law** of the reaction should be the **same** as the S_N2 process, in which the proton elimination-cum- transition state formation step is considered to be the rate determining step.

Rate = k [Benzene][E^+].....step 1

The first step involves the temporary disruption of the aromatic π system, and is therefore rate determining, it must have the **higher-energy transition state**. The **intermediate** is **unstable** and has a **much higher energy** than either the **starting material** or the **products**, close to that of the transition states for its formation and breakdown. The **two transition states will be similar in structure** to the intermediate and we shall use the intermediate as a model for the important first transition state.

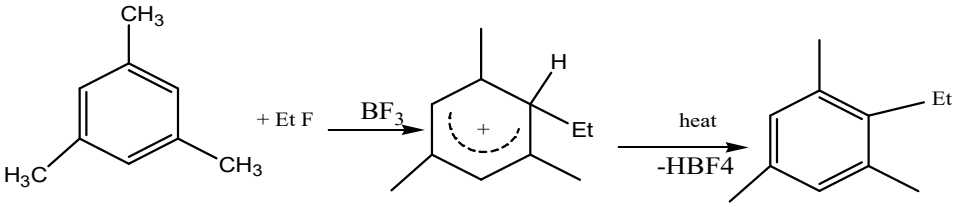


Figer 1: Energy profile diagram for aromatic electrophilic substitution.

Notes:

1- Intermediates energy minima.
2- Transition states: energy maxima.
3- **Wheland** intermediate is **not aromatic** but stabilized by delocalization.
4- Generally under kinetic control.

2- **Isolation** of **Wheland** intermediates (Arenium Ion): **Direct observation**.



mesitylene Sigma complex

supper acid : FSO_3F_2 , $HF\text{-}SbF_5$, CF_3SO_3H

Comparison between Sigma and Pi complex:

sigma complex

1- The formation of a sigma complex follows the initial formation of a complex known as a pi complex.
2- Sigma complex involve the actual bonding.
3- Lower energy and higher stability.

pi complex

1- In contrast t the sigma complex, the pi complex does not involve actual bonding.
2- The electron transfer does not occur during the pi complex formation.
3- Higher energy and less stability than sigma complex.

Orientation and reactivity of aromatic ring:

Activating: *Ortho,para* Directors	Deactivating: *Meta* Directors
Strongly activating	—NO_2
—NH_2 (—NHR, —NR_2)	—$N(CH_3)_3^+$
—OH	—CN
	—COOH (—COOR)
Moderately activating	—SO_3H
—OCH_3 (—OC_2H_5, etc.)	—CHO, —COR
—$NHCOCH_3$	
	Deactivating: *Ortho,para* Directors
Weakly activating	—F, —Cl, —Br, —I
—C_6H_5	
—CH_3 (—C_2H_5, etc.)	

Substituted rings are divided into **three groups** based on the **type of the substituent** that the ring carries:

1- **Activated rings**: the substituents on the ring are groups that **donate electrons**, and ***ortho***, ***para*** **directing**.

Examples: of activating groups in the relative order from the most activating group to the least activating:

$-NH_2$, $-NR_2$> -OH, -OR> -NHCOR> $-CH_3$ and other alkyl groups

2- **Deactivated rings**: the substituents on the ring are groups that **withdraw electrons**, and ***meta*** **directing**.

Examples: of deactivating groups in the relative order from the most deactivating to the least deactivating:

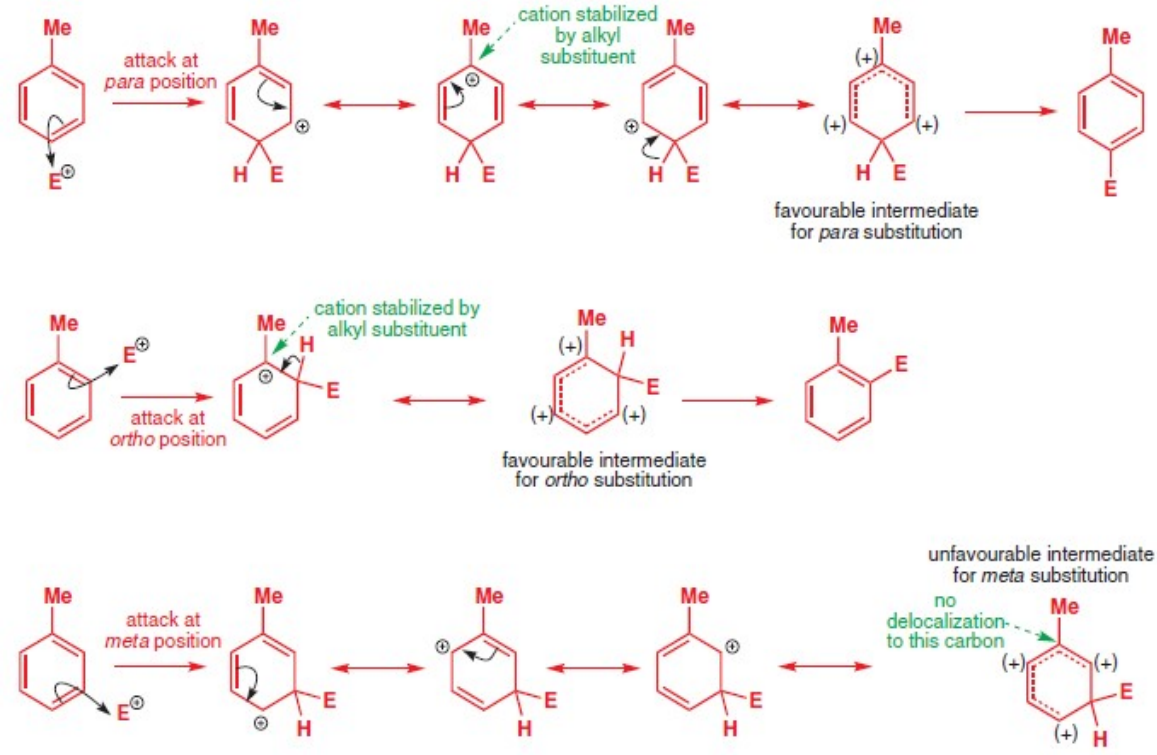
$-NO_2$, $-CF_3$> -COR, -CN, $-CO_2R$, $-SO_3H$ > Halogens

3- **Deactivating** (**halogens**) the substituents on the ring are groups that **withdraw electrons**, and ***ortho***, ***para*** **directing**.

Examples: of deactivating groups in the relative order from the most deactivating to the least deactivating: F> Cl > Br > I

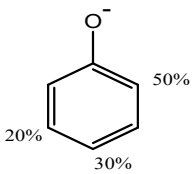
The order of reactivity of the benzene rings toward the electrophilic substitution when it is substituted with a **halogen groups**, follows the order of **electronegativity**. The ring that is substituted with the **most**

electronegative halogen is the most reactive ring (less deactivating substituent) and the ring that is substituted with the **least electronegatvie halogen is the least reactive ring** (more deactivating substituent), when we compare rings with halogen substituent's. Also the size of the halogen affects the reactivity of the benzene ring that the halogen is attached to. As the **size of the halogen increase**, the **reactivity of the ring decreases**.



The factors effects on orientation *ortho* and *para*:

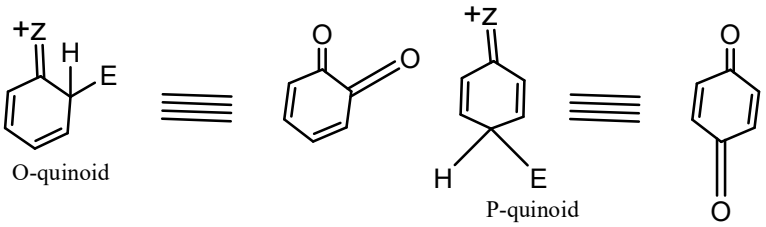
1- **Charge Distributions:** charge distribution in the Wheland complex. Therein the positive charges only appear *ortho* and *para* to the attacked C atom, and in each case they equal.



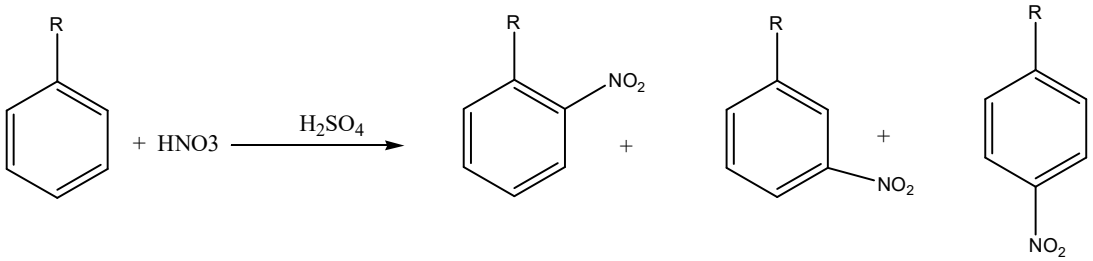
phenoxide anion

2- **Electron donating groups (EDG) with lone pairs** (*e.g.* **-OMe, -NH_2**) 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. These sites are **more**

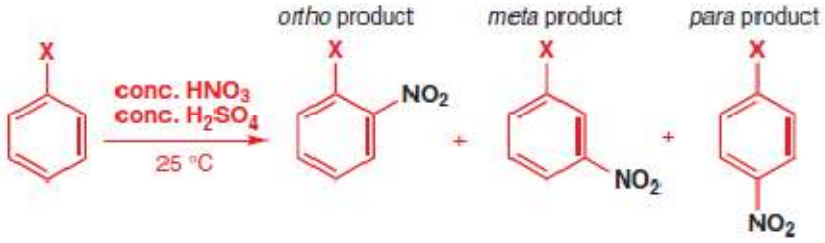
nucleophilic, and the system tends to react with electrophiles at these *ortho*- and *para*- sites , these case give structure resonance the same *p*-quinoid and *o*-quinoid.



3- Steric effects in electrophilic aromatic substitution: Besides the electronic effects, substitutents 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 "blocks" the ortho- positions**.



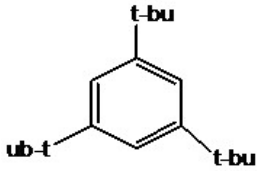
-R	%	%	%
$-CH_3$	58	4	37
$-CH_2CH_3$	49	6	49
$-CH(CH_3)_2$	30	8	62
$-C(CH_3)_3$	16	11	73



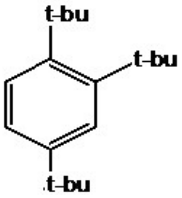
	Products formed (%)		
Compound	*ortho*	*meta*	*para*
PhF	13	0.6	86
PhCl	35	0.9	64
PhBr	43	0.9	56
PhI	45	1.3	54

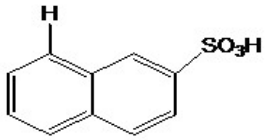
Examples:

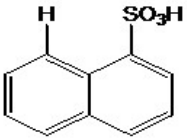
No steric hindrance



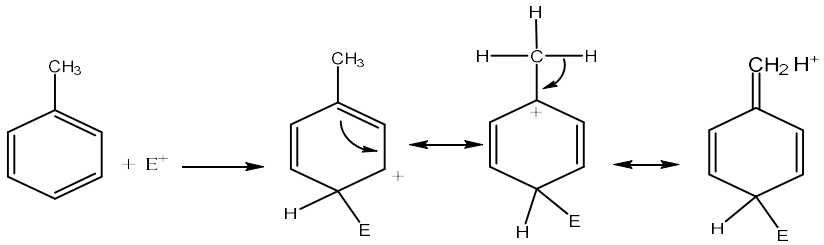
Steric hindrance



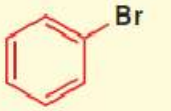
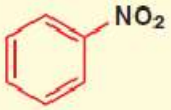
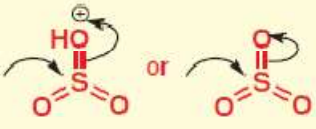
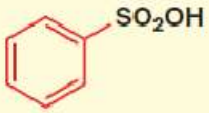
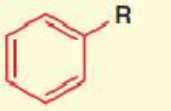
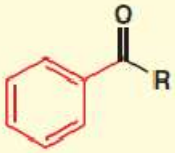




hyperconjugation : intraction of the electron in sigma bond C-H with an adjacent pi orbital or sigma

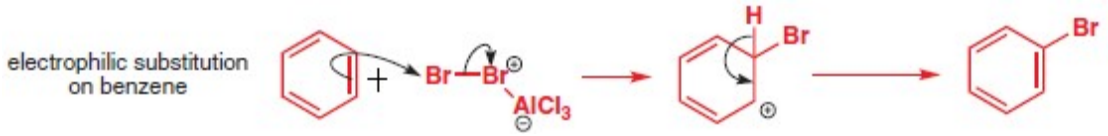


Reactions of benzene: (electrophilic aromatic substitution):

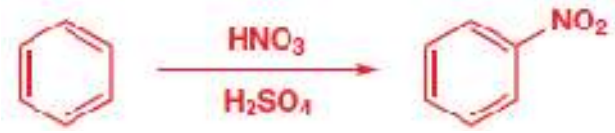
Reaction	Reagents	Electrophile	Product
bromination	Br_2 and Lewis acid, e.g. $AlCl_3$, $FeBr_3$, Fe powder		
nitration	$HNO_3 + H_2SO_4$		
sulfonation	concentrated H_2SO_4 or $H_2SO_4 + SO_3$ (oleum)		
Friedel–Crafts alkylation	RX + Lewis acid usually $AlCl_3$		
Friedel–Crafts acylation	RCOCl + Lewis acid usually $AlCl_3$		

1- **Halogenation of benzene:**

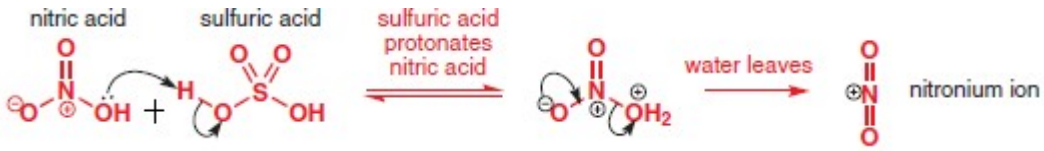
Mechanism:



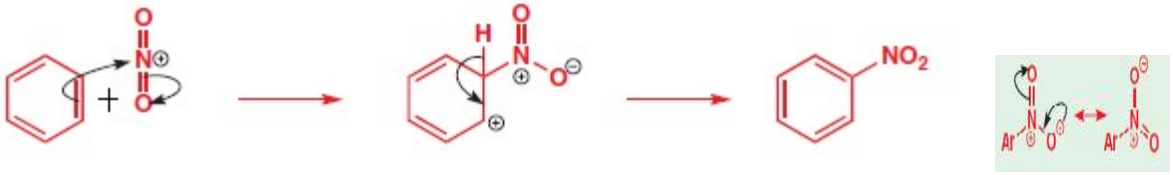
2- **Nitration of benzene:** Use concentrated nitric and sulfuric acids



Mechanism: Sulfuric acid is the stronger acid and it produces the powerful electrophile NO_2^+ by protonating the nitric acid so that a molecule of water can leave.



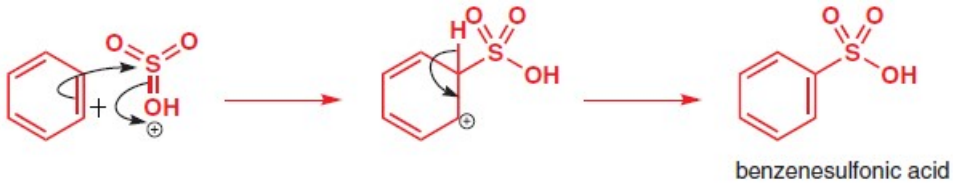
The nitronium ion (NO_2^+) is linear, it's isoelectronic with CO_2, with an sp-hybridized nitrogen atom at the centre. It's this nitrogen that is attacked by benzene, breaking one of the N=O bonds to avoid a five-valent nitrogen.



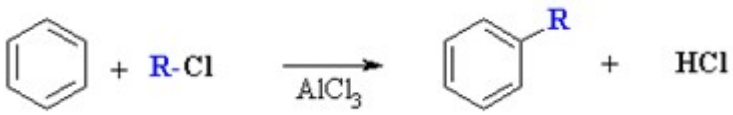
3- **Sulfonation of benzene:**

Mechanism: Benzene reacts slowly with sulfuric acid alone to give benzenesulfonic acid. One molecule of sulfuric acid protonates another and loses a molecule of water.

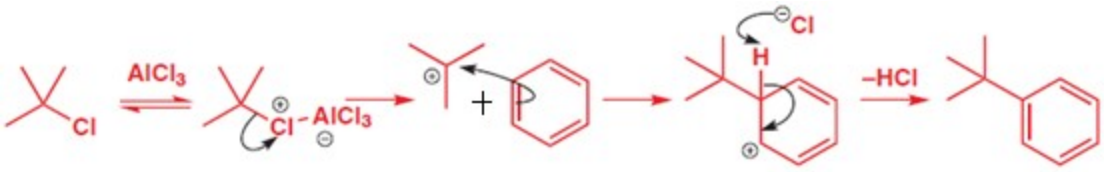
The cation produced is very reactive and attacks benzene by the same mechanism we have seen for bromination and nitration slow addition to the π system followed by rapid loss of a proton to regenerate aromaticity.



4- **Friedel-Crafts alkylation:**



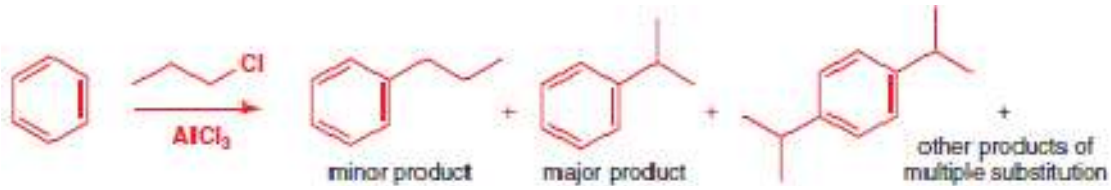
Mechanism:



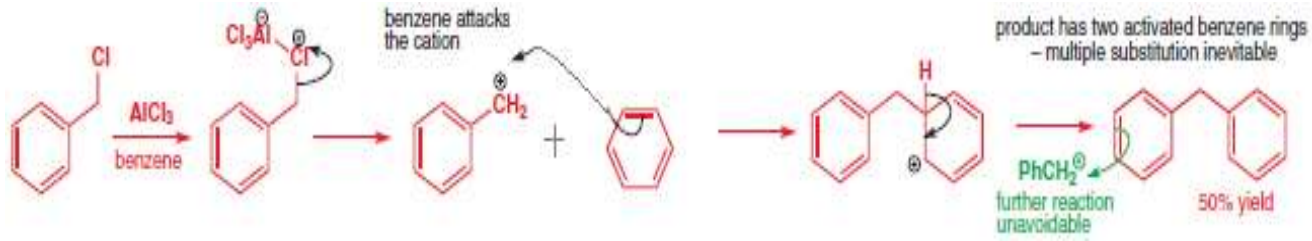
limitations of Friedel-Crafts Alkylation:

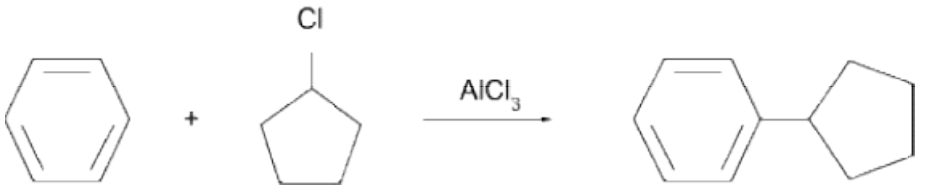
1- Carbocation Rearrangement - Only certain alkylbenzenes can be made due to the tendency of cations to rearrange.
2- Friedel-Crafts fals when used with compounds such as nitrobenzene and other strong deactivating systems.
3- Polyalkylation - Products of Friedel-Crafts are even more reactive than starting material. Alkyl groups produced in Friedel-Crafts Alkylation are electron-donating substituents meaning that the products are more susceptible to electrophilic attack than what we began with.

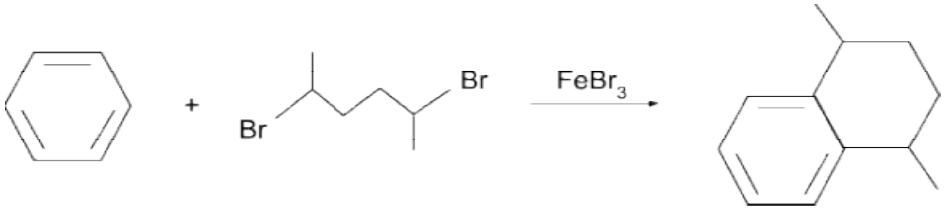
Example:



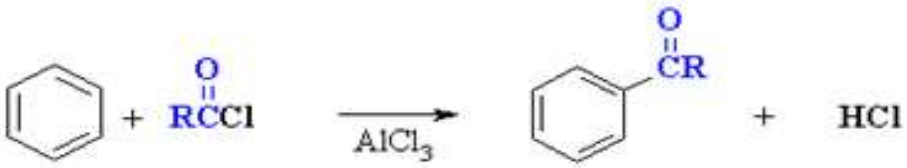
Friedel-Crafts alkylation application:



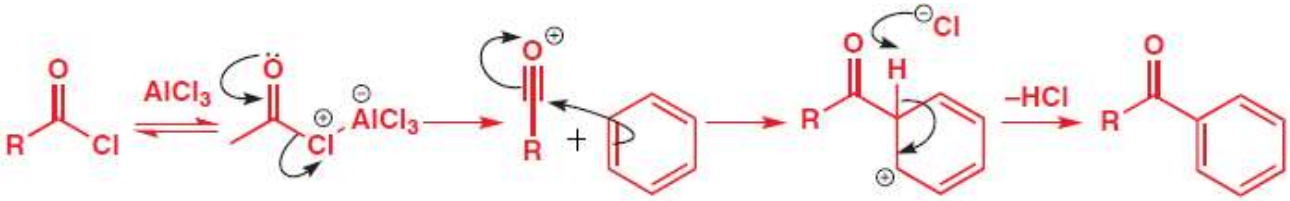




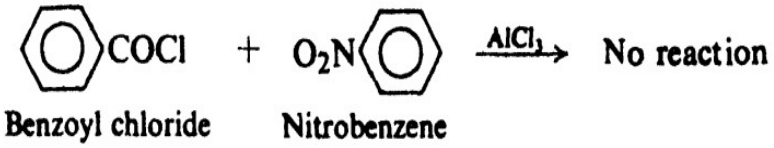
5- Friedel-Crafts acylation:



Mechanism:



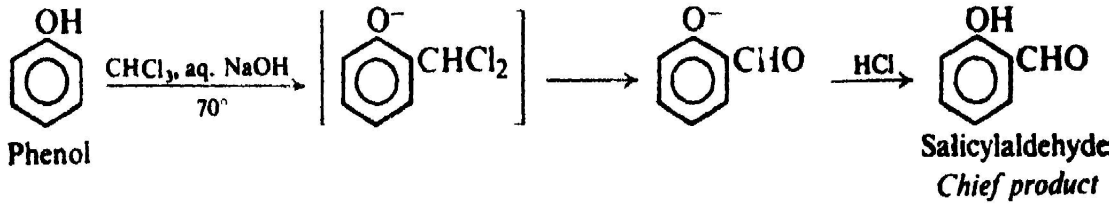
Note: the benzene ring must not contain an electron-withdrawing group such as (NO_2, CN, CHO,...), since as a strongly deactivating group it prevents the Friedel-Crafts reaction.



Friedel-Crafts acylation application:

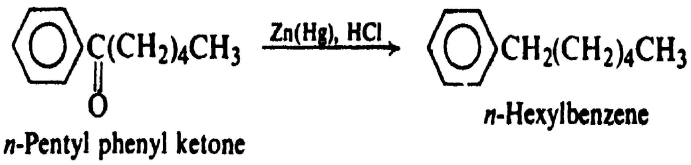
a- Kolbe reaction:

b- Reimer-Tiemann reaction:



c- Reduction to hydrocarbons: formation of alkane.

Example:



6- Hydrogen-deterium exchange:

$$ArH + D^+ \longrightarrow ArD + H^+$$ *Hydrogen exchange*

7- Nitrosation:

$$ArH + HONO \longrightarrow ArN{=}O + H_2O$$

A nitroso compound

Only for highly reactive ArH