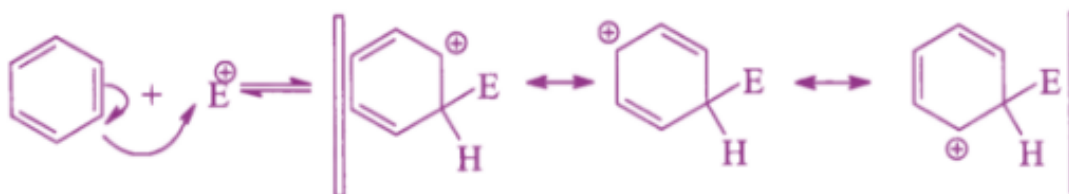


Electrophilic aromatic substitution

Electrophilic Aromatic Substitution: Effect of Substituent Groups

Overview:

- Electrophilic Aromatic Substitution (EAS) is a type of reaction where an electrophile replaces a hydrogen atom on an aromatic ring.



- The nature of substituent groups already present on the aromatic ring plays a crucial role in determining both the reactivity of the ring and the position (orientation) where the new group will be introduced.

Substituent Effects:

- Substituent groups can be classified based on how they influence:
 - Rate** of reaction (activating or deactivating the ring)
 - Orientation** of incoming electrophile (ortho, meta, para positions)

Types of Effects:

1. Inductive Effect (I-effect):

- Electron-withdrawing or electron-donating character through sigma bonds.
- **Example:** $-\text{NO}_2$ exerts a strong $-I$ effect, pulling electrons away from the ring.
- **Example:** $-\text{CH}_3$ exerts a $+I$ effect, pushing electrons toward the ring.

2. Resonance Effect (R-effect or Mesomeric effect):

- Delocalization of electrons via π -bond systems.
- Electron-donating via resonance ($+R$) groups: $-\text{OH}$, $-\text{NH}_2$, $-\text{OR}$
- Electron-withdrawing via resonance ($-R$) groups: $-\text{NO}_2$, $-\text{CHO}$, $-\text{COOH}$

Combined Effect:

- The overall effect of a substituent is a combination of its inductive and resonance behavior.
- Example:** Halogens like $-\text{Cl}$ and $-\text{Br}$ have $-I$ effect (electron-withdrawing) but also $+R$ effect (donate lone pairs into the ring). This creates unique behavior (deactivating yet ortho/para directing).

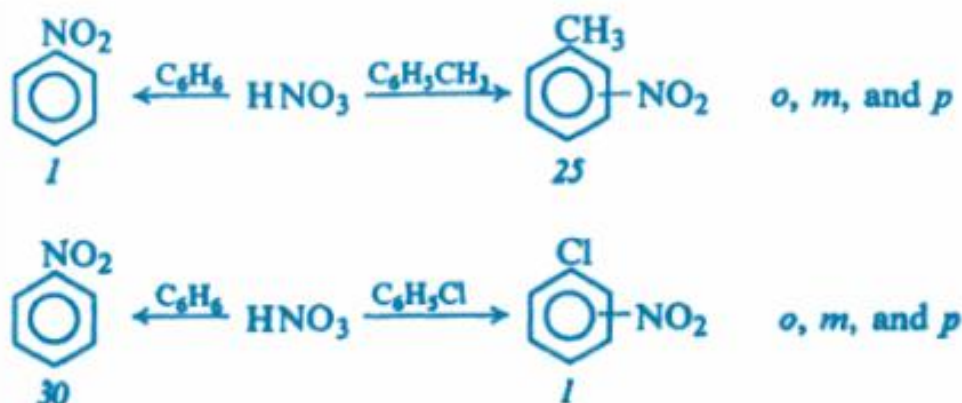
Examples:

- **Phenol (–OH group):** The –OH group donates electron density via resonance, activating the ring and directing new substituents to the ortho and para positions.
- **Nitrobenzene (–NO₂ group):** The –NO₂ group withdraws electron density via both inductive and resonance effects, deactivating the ring and directing incoming groups to the meta position.

Determination of Orientation in EAS

Overview

- Orientation refers to the position on the aromatic ring where the incoming electrophile is directed due to the influence of existing substituent(s).
- There are three main positions for substitution relative to an existing substituent on a monosubstituted benzene ring:
 - **Ortho (o):** Adjacent carbon (1,2-position).
 - **Meta (m):** One carbon away (1,3-position).
 - **Para (p):** Opposite carbon (1,4-position).



Orientation depends on the nature of the substituent already present:

1. Ortho/Para Directing Groups (Activating):

- **Examples:** –OH, –NH₂, –CH₃, –OCH₃.
- These groups have lone pairs or are electron-releasing, increasing electron density at ortho and para positions through +R effect.
- Stabilize the intermediate sigma complex (arenium ion) at o/p positions better.

2. Meta Directing Groups (Deactivating):

- **Examples:** –NO₂, –CN, –SO₃H, –COOH, –CHO.
- These groups are electron-withdrawing, lowering electron density at ortho and para positions.
- Meta positions become relatively more reactive.

- Stabilize the intermediate sigma complex best when the electrophile attacks the meta position.

3. Halogens (-X):

- Halogens like -Cl, -Br, -I are deactivating but ortho/para directing.
- Due to their lone pairs, they exhibit a +R effect (resonance donation) but also a strong -I effect (inductive withdrawal).
- The net result: overall slower reaction (due to deactivation), but when it occurs, it goes to o/p positions.

Why is this important?

- Understanding the orientation allows chemists to predict the product of electrophilic aromatic substitution and control regioselectivity in synthetic pathways.

Example Cases:

- **Toluene (CH₃-benzene)** reacts with nitrating agents to form ortho- and para-nitrotoluene due to +I and weak +R effects.
- **Nitrobenzene (NO₂-benzene)** reacts slowly with further substitution favoring meta-nitro positions due to strong -I and -R effects.

Determination of Relative Reactivity in EAS

- The relative reactivity of a substituted benzene ring in EAS reactions is governed by the electron density in the aromatic ring.
- Substituent groups either activate or deactivate the ring:
 - Activating groups make the ring more reactive than benzene.
 - Deactivating groups make the ring less reactive than benzene.

Mechanism Behind Reactivity Differences:

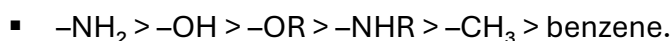
- During EAS, the aromatic ring temporarily loses its aromaticity when it forms a carbocation intermediate (sigma complex).
- Stability of this intermediate is crucial.

Reactivity Influenced by:

1. Activating Groups:

- Donate electron density into the ring.
- Stabilize the carbocation intermediate via resonance or hyperconjugation.
- Lower the activation energy for the reaction.
- Increase reaction rate.

- **Examples (ranked from strongly to weakly activating):**



2. Deactivating Groups:

- Withdraw electron density from the ring.
- Destabilize the carbocation intermediate.
- Increase the activation energy.
- Decrease reaction rate.
- **Examples (ranked from strongly to weakly deactivating):**
 - $-\text{NO}_2 > -\text{CF}_3 > -\text{CN} > -\text{COOH} > -\text{CHO} > \text{halogens} > \text{benzene}$.

3. Comparison with Benzene:

- Benzene is the reference point for reactivity.
- Substituted benzenes are compared in terms of their relative rate of reaction with a given electrophile under identical conditions.

Experimental Determination:

- Relative reactivities are often determined using competitive substitution reactions.
- Equal amounts of substituted benzenes are allowed to react with an electrophile, and the product ratios reveal their relative reactivity.

Classification of Substituent Groups in EAS

- Substituent groups attached to the benzene ring influence both the rate and orientation of electrophilic aromatic substitution (EAS) reactions.
- These groups are classified based on their electronic effects and their directive influence.

Based on Reactivity:

1. Activating Groups:

- Increase the electron density on the benzene ring, making it more reactive towards electrophiles.
- Usually donate electrons via +I (inductive) and/or +R (resonance) effects.
- **Examples:**
 - Strongly activating: $-\text{OH}$, $-\text{NH}_2$, $-\text{OCH}_3$
 - Moderately activating: $-\text{NHR}$, $-\text{NHCOCH}_3$, $-\text{CH}_3$
- **Reaction Rate:** Faster than benzene.

2. Deactivating Groups:

- Withdraw electron density from the ring, making it less reactive towards electrophiles.
- Withdraw electrons via **-I** and/or **-R** effects.
- **Examples:**
 - Strongly deactivating: $-\text{NO}_2$, $-\text{CF}_3$, $-\text{SO}_3\text{H}$, $-\text{CN}$
 - Moderately deactivating: $-\text{CHO}$, $-\text{COOH}$, $-\text{COOR}$
 - Weakly deactivating: Halogens (e.g., $-\text{Cl}$, $-\text{Br}$)
- **Reaction Rate:** Slower than benzene.

Based on Orientation:

1. Ortho/Para Directing Groups:

- Direct incoming electrophile to ortho and para positions.
- Typically electron-donating groups (EDGs).
- Also includes halogens (special case – see below).
- **Examples:** $-\text{CH}_3$, $-\text{OH}$, $-\text{NH}_2$, $-\text{OCH}_3$, $-\text{Cl}$, $-\text{Br}$

2. Meta Directing Groups:

- Direct incoming electrophile to meta position.
- Typically electron-withdrawing groups (EWGs).
- **Examples:** $-\text{NO}_2$, $-\text{COOH}$, $-\text{CHO}$, $-\text{CN}$, $-\text{SO}_3\text{H}$

Special Case – Halogens:

- Halogens ($-\text{Cl}$, $-\text{Br}$, $-\text{I}$, $-\text{F}$) are deactivating due to strong $-\text{I}$ effect.
- However, they are ortho/para directing due to lone pair donation via $+\text{R}$ (resonance).

Substituent	Reactivity	Orientation
$-\text{OH}$, $-\text{NH}_2$, $-\text{OR}$	Activating	Ortho/Para
$-\text{CH}_3$, $-\text{C}_2\text{H}_5$	Activating	Ortho/Para
$-\text{X}$ (Cl , Br , I)	Deactivating	Ortho/Para
$-\text{NO}_2$, $-\text{CN}$, $-\text{COOH}$	Deactivating	Meta
$-\text{CHO}$, $-\text{COCH}_3$	Deactivating	Meta

Mechanism of Nitration

- **Nitration** is a classic electrophilic aromatic substitution where a **nitro group ($-\text{NO}_2$)** is introduced onto an aromatic ring.
- **Overall Reaction:**

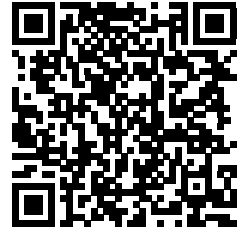


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