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# Efeitos de substituintes na reatividade de sistemas aromáticos

Reações de compostos aromáticos e seus mecanismos

Fenóis e haletos de arila: substituição nucleofílica aromática

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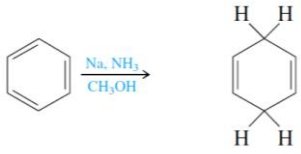
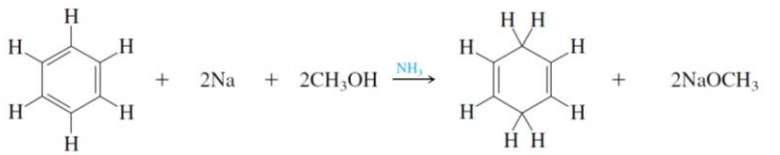
## A redução de Birch




Benzene 1,4-Cyclohexadiene (80%)

**The overall reaction:**




Benzene Sodium Methanol 1,4-Cyclohexadiene Sodium methoxide

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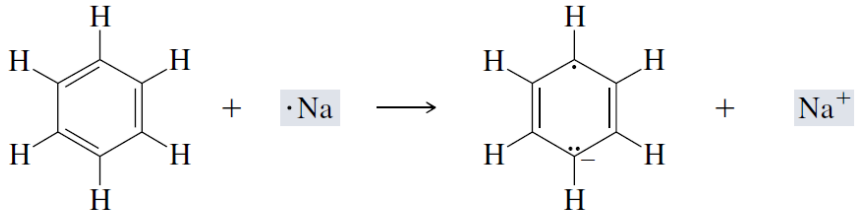
# Mecanismo da reação

Passo 1:




Benzene | Sodium | Benzene anion radical | Sodium ion

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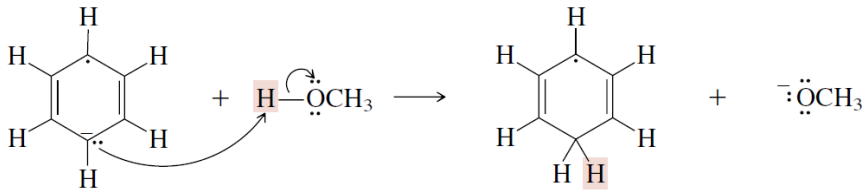
# Mecanismo da reação...

Passo 2:




Benzene anion radical | Methanol | Cyclohexadienyl radical | Methoxide ion

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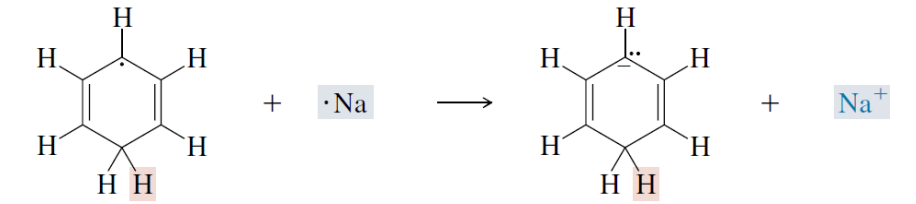
# Mecanismo da reação...

Passo 3:




Cyclohexadienyl radical | Sodium | Cyclohexadienyl anion | Sodium ion

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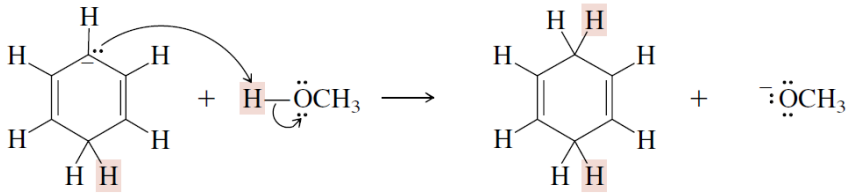
# Mecanismo da reação...

Passo 4:




Cyclohexadienyl anion | 1,4-Cyclohexadiene | Methoxide ion

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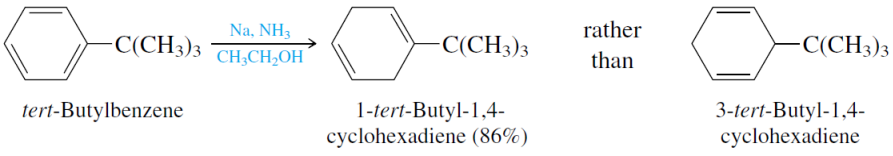
# Ex: Explique a formação do produto da reação de Birch




*tert*-Butylbenzene

1-*tert*-Butyl-1,4-cyclohexadiene (86%)

3-*tert*-Butyl-1,4-cyclohexadiene

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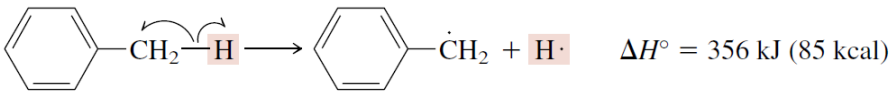
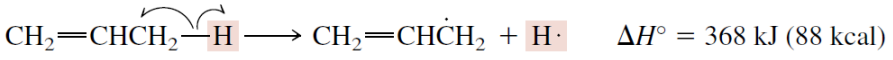
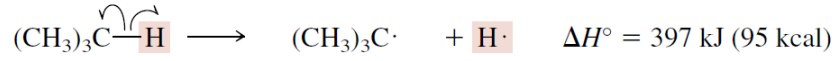
# Halogenação de alquilbenzenos via radical livre



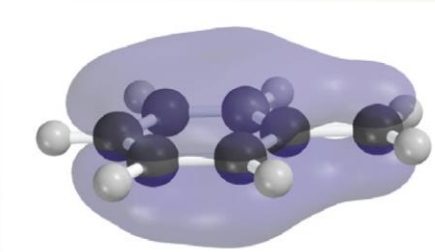

Toluene — Benzyl radical



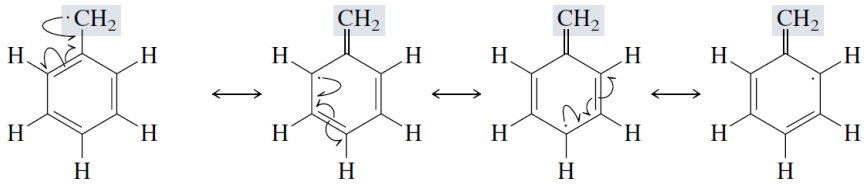

Propene — Allyl radical




2-Methylpropane — *tert*-Butyl radical

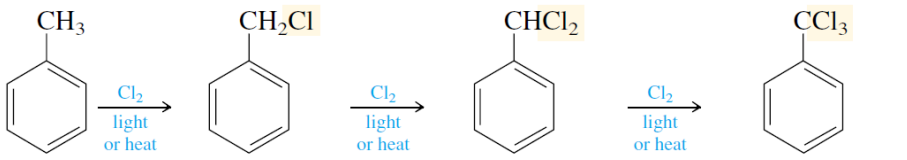


O radical é estabilizado por sobreposição do orbital *p* semi-preenchido com o sistema π do anel aromático.

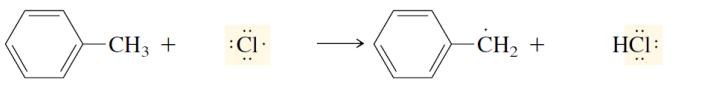



Most stable Lewis structure of benzyl radical

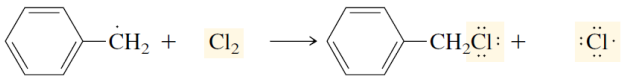

Benzotricloreto é usado para fazer tinturas e outros produtos químicos.




Toluene — Benzyl chloride — (Dichloromethyl)-benzene — (Trichloromethyl)-benzene




Toluene — Chlorine atom — Benzyl radical — Hydrogen chloride




Benzyl radical — Chlorine — Benzyl chloride — Chlorine atom

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A EPA classificou o benzotricloreto como provável carcinógeno humano.

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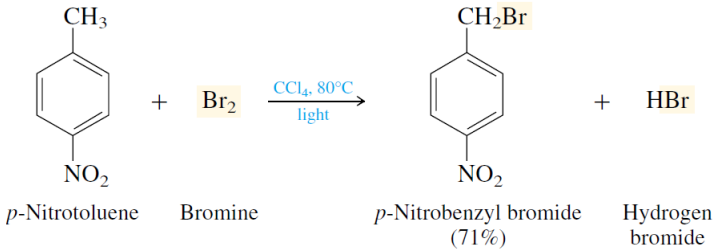
Ex: escreva os passos para a bromação benzílica em condições de iniciação fotoquímica




*p*-Nitrotoluene | Bromine | *p*-Nitrobenzyl bromide (71%) | Hydrogen bromide

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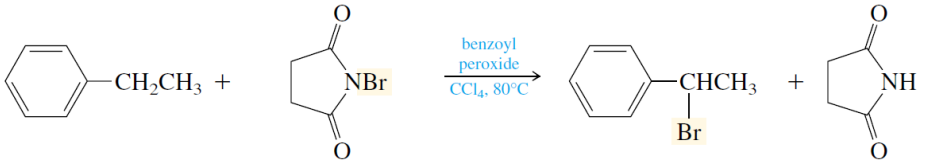
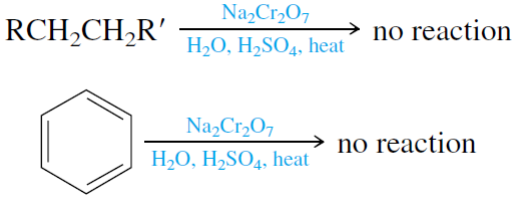
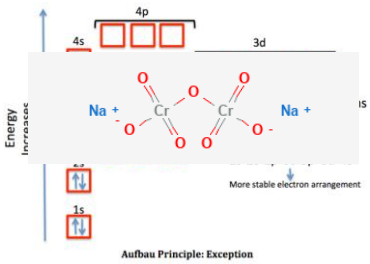
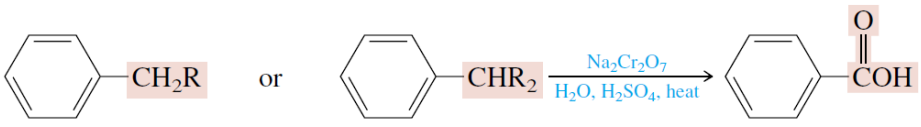
# O NBS é um agente conveniente para a reação de bromação via radical-livre. Escreva os passos para a seguinte reação



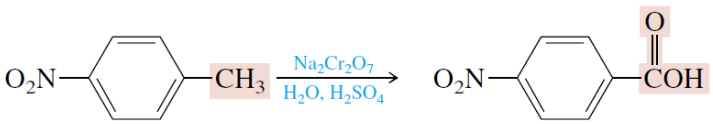

Ethylbenzene | *N*-Bromosuccinimide (NBS) | 1-Bromo-1-phenylethane (87%) | Succinimide




Alkylbenzene | Benzoic acid




*p*-Nitrotoluene | *p*-Nitrobenzoic acid (82–86%)

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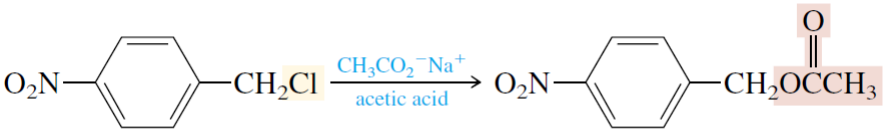
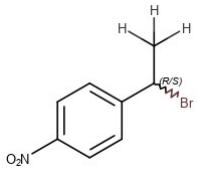
# Substituição em haletos benzílicos




*p*-Nitrobenzyl chloride — *p*-Nitrobenzyl acetate (78–82%)

Qual será o produto da reação quando o Nu for o etóxido de sódio e o substrato for, p.ex., o 1-(1-bromoethyl)-4-nitrobenzene. Explique.

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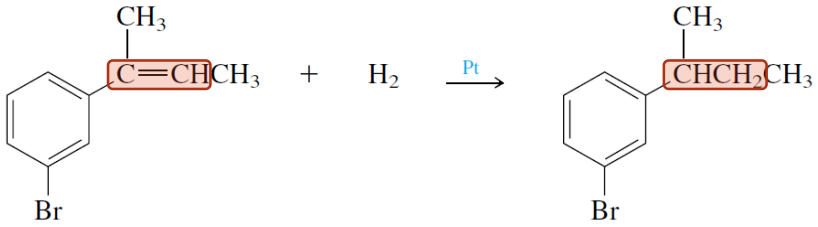
# Reações de adição em alquenilbenzenos




2-(*m*-Bromophenyl)-2-butene — Hydrogen — 2-(*m*-Bromophenyl)butane (92%)

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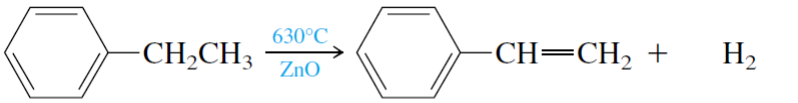
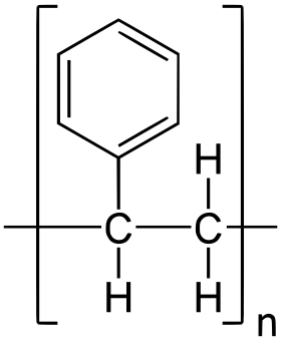
# Preparação de alquenilbenzenos




Ethylbenzene — Styrene — Hydrogen

O etilbenzeno ocorre naturalmente no alcatrão de carvão e no petróleo.

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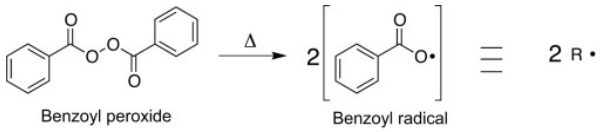
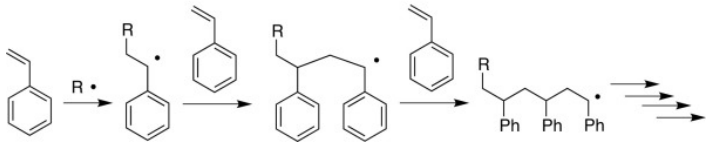
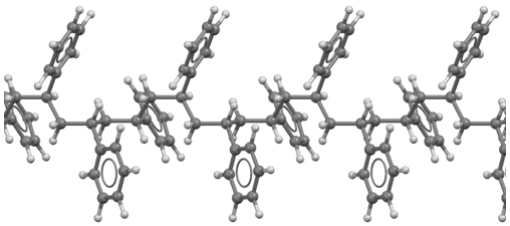
# Síntese do poliestireno




Benzoyl peroxide — Benzoyl radical



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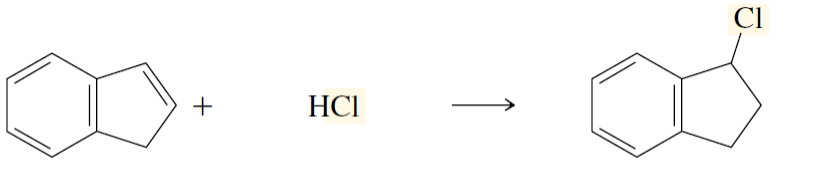
# Explique a regiosseletividade de adição do HCl ao indeno




Indene + Hydrogen chloride → 1-Chloroindane (75–84%)

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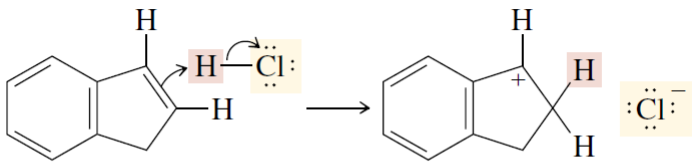
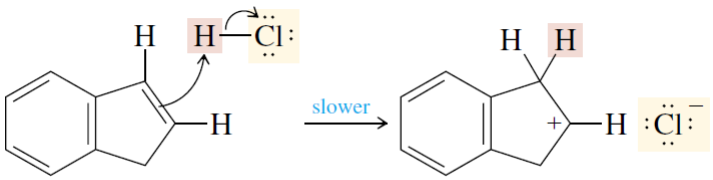
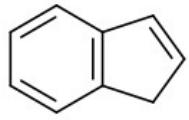
# Solução



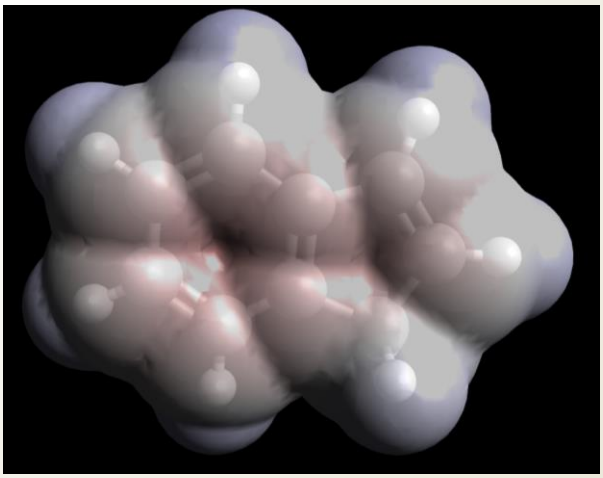

Carbocation that leads to observed product

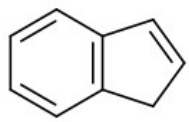



Less stable carbocation

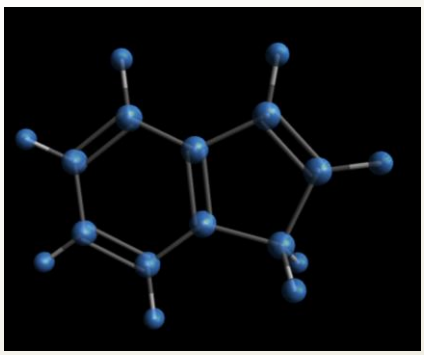


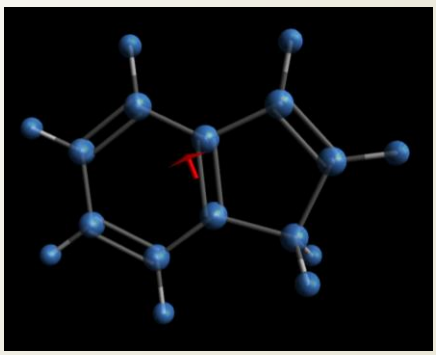
## Aprenda por modelos via mapas de potencial eletrostático

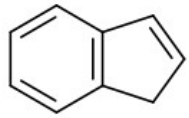




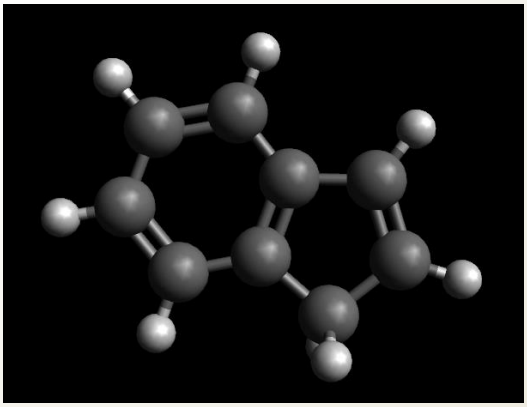
## Aprenda por modelos via mapas de potencial eletrostático

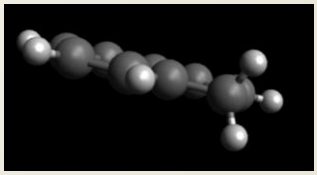


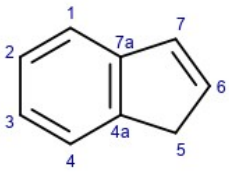




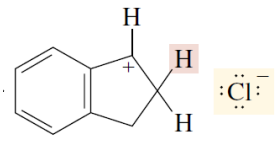
# Aprenda por modelos via mapas de potencial eletrostático



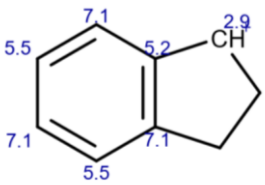


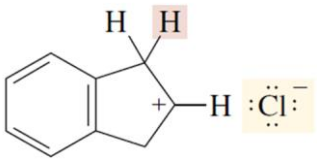



# Eletronegatividade do orbital π

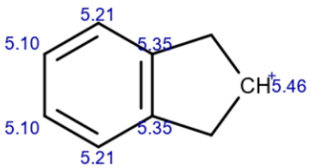



Carbocation that leads to observed product




Less stable carbocation




C 2.6

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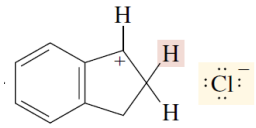
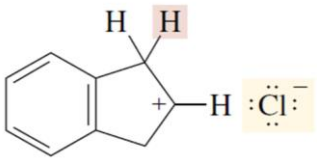
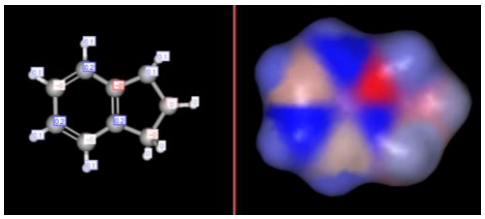
# Cargas totais

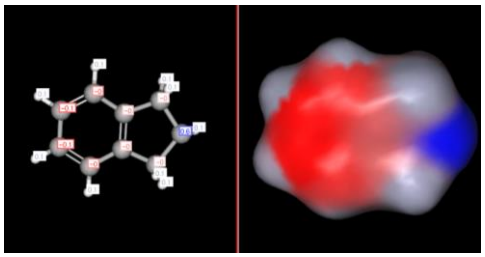


Carbocation that leads to observed product



Less stable carbocation





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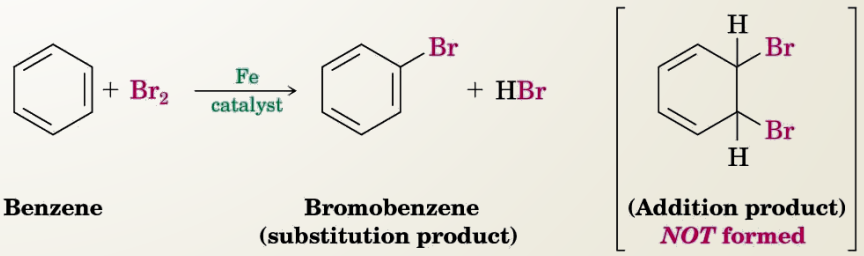
# Estrutura e estabilidade do benzeno

- O benzeno reage lentamente com $Br_2$ para produzir bromobenzeno (Br substitui H)
- Esta é a **substituição** ao invés da reação de **adição** rápida comum aos compostos com C = C, sugerindo que no benzeno há uma barreira de energia mais alta




**Benzene** | **Bromobenzene (substitution product)** | **(Addition product) *NOT* formed**

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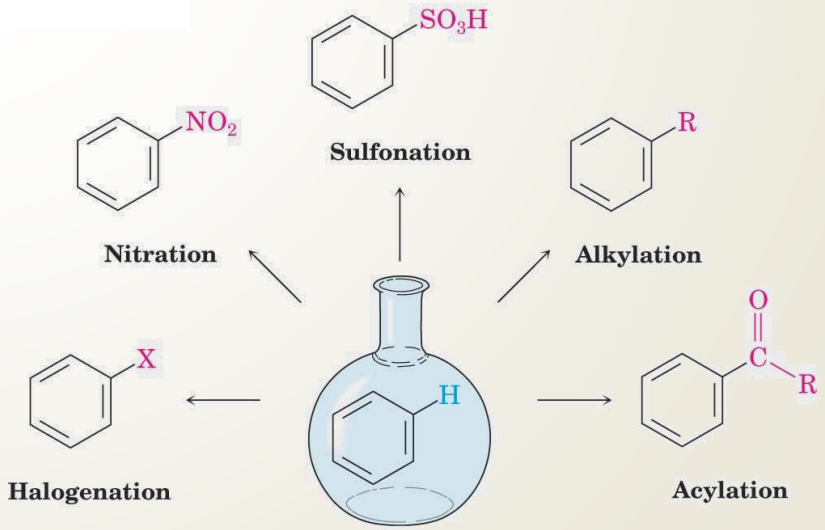
# Reações do benzeno

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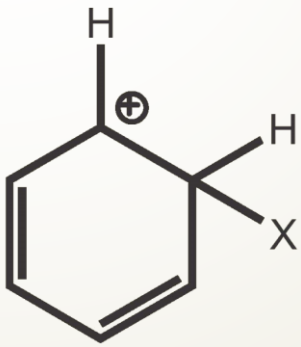
# Substituições Aromáticas




George Willard Wheland

1907-1974

- A reação com o bromo envolve um mecanismo semelhante a muitas outras reações do benzeno com eletrófilos
- O intermediário catiônico foi proposto pela primeira vez por G. W. **Wheland**, da Universidade de Chicago e é frequentemente chamado de intermediário Wheland

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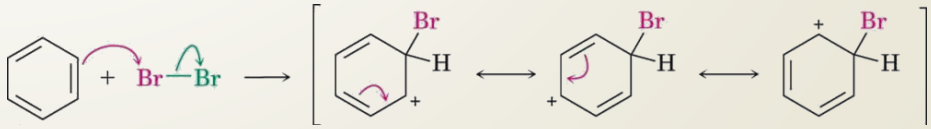
# Bromação

- A adição de bromo ocorre em duas etapas
- Na primeira etapa, os elétrons π agem como um nucleófilo em direção ao $Br_2$ (em complex com o $FeBr_3$)
- O intermediário não é aromático e, portanto, possui alto teor de energia:



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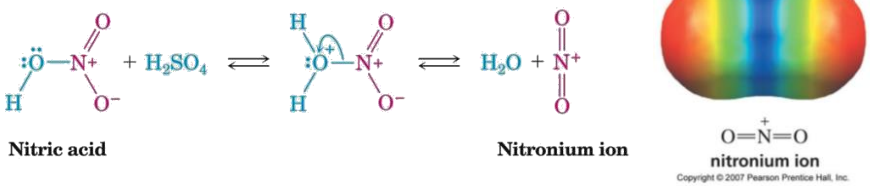
# Nitração Aromática

- A combinação de ácido nítrico e ácido sulfúrico produz $NO_2^+$ (íon nitrônio)
- A reação com benzeno produz nitrobenzeno:



Nitric acid

Nitronium ion



nitronium ion

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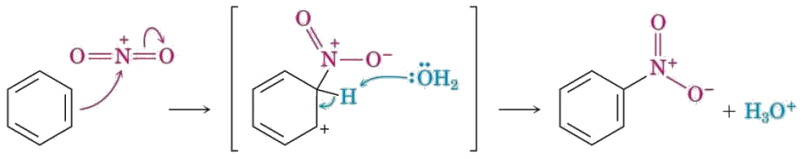

Nitrobenzene

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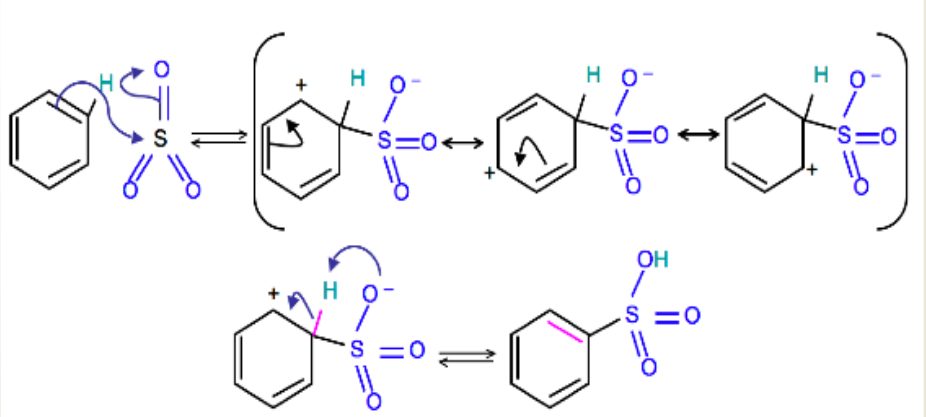
# Sulfonação Aromática

- Substituição de H por $SO_3$ (sulfonação)
- Reação com uma mistura de ácido sulfúrico e $SO_3$
- A espécie reativa é o trióxido de enxofre ou seu ácido conjugado
- A reação ocorre via intermediário de Wheland e é reversível



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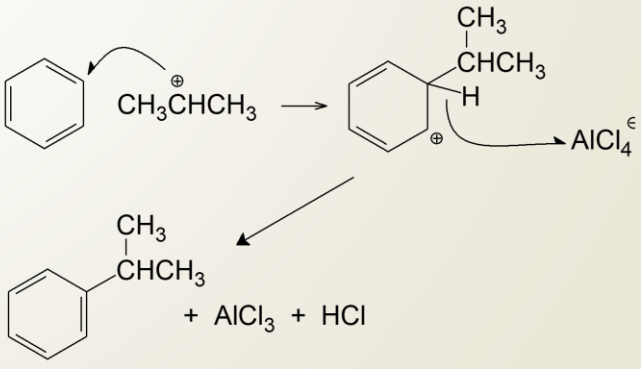
# Alquilação de anéis aromáticos: a reação de Friedel-Crafts

- Substituição aromática de um $R^+$
- O cloreto de alumínio promove a formação do carbocátion



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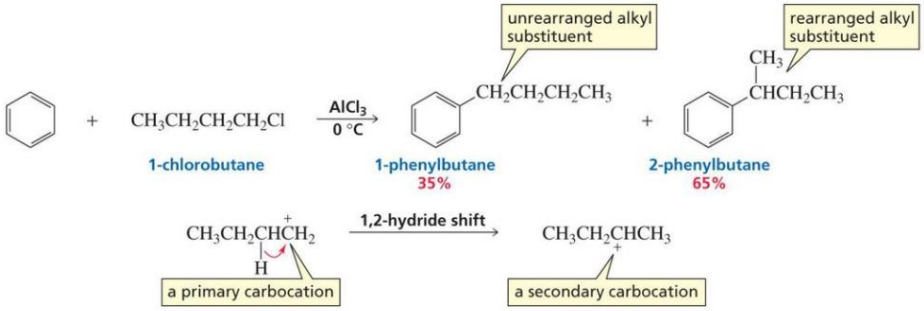
# Alquilação de anéis aromáticos: a reação de Friedel-Crafts

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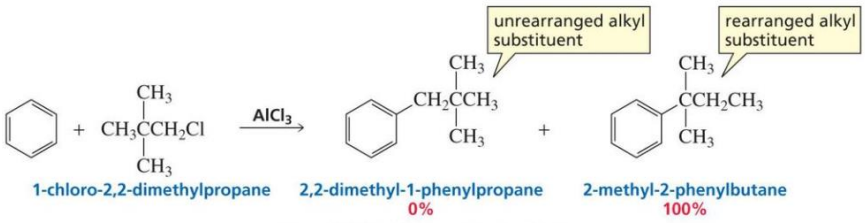
# Alquilação de anéis aromáticos: a reação de Friedel-Crafts

Explique por que há formação apenas do 2-metil-2-fenilbutano

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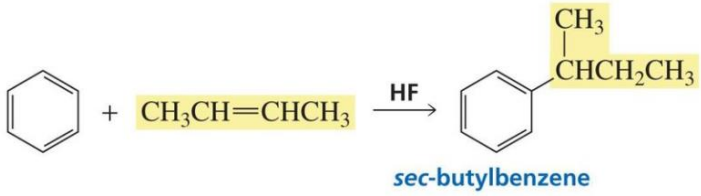
**alkylation of benzene by an alkene**

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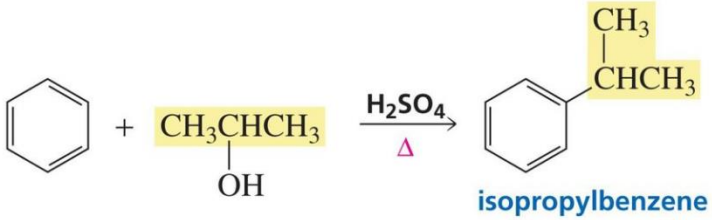
**alkylation of benzene by an alcohol**

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Constituinte do óleo bruto e de combustíveis refinados.

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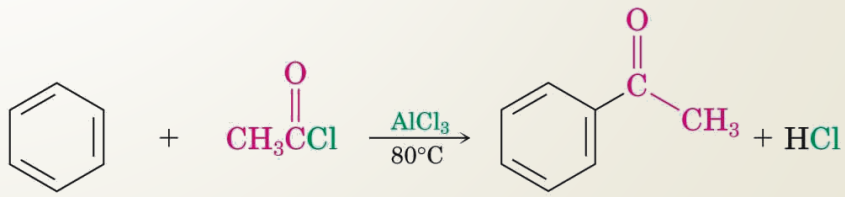
# Acilação de Fiedel-Crafts

- A reação de um cloreto de ácido (RCOCl) e um anel aromático na presença de $AlCl_3$ introduz o grupo acila, —COR
  - Benzeno com cloreto de acetila produz acetofenona




**Benzene** **Acetyl chloride** **Acetophenone (95%)**

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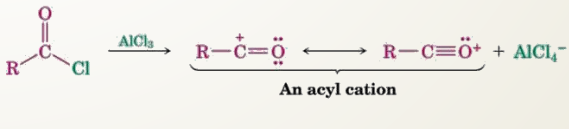
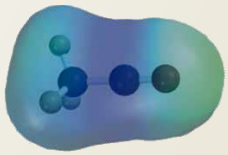
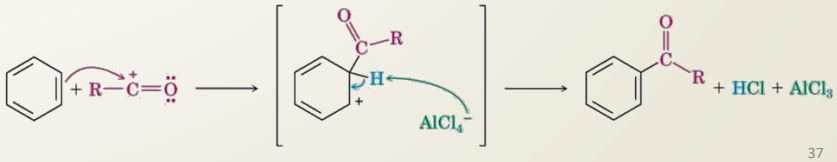
# Mecanismo de acilação de Friedel-Crafts

- Semelhante à alquilação
- Eletrófilo reativo: cátion de acila estabilizado por ressonância
- Um cátion acila não se reorganiza



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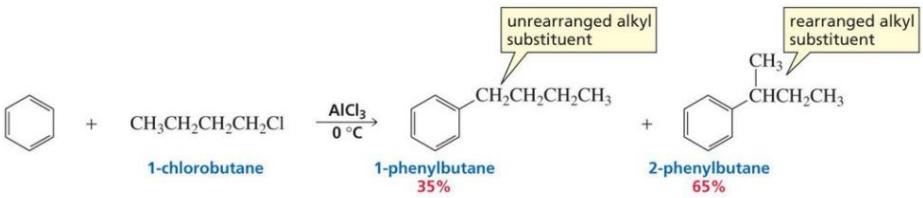
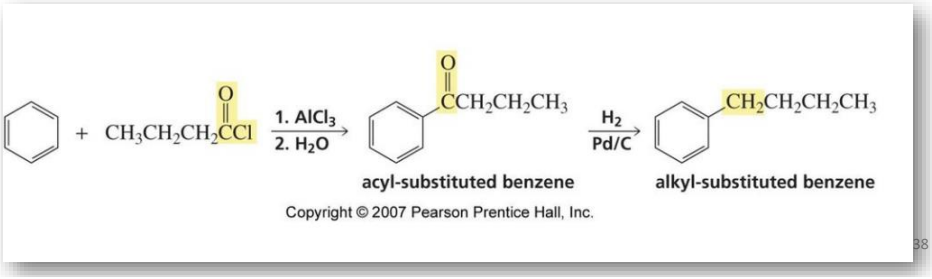
# Como produzir 1-fenilbutano?

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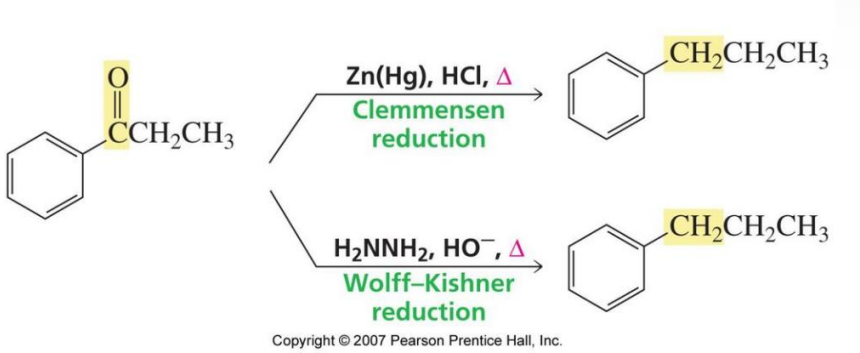
# Redução da carbonila

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# Reações do benzeno

| Reaction and comments | Equation |
|---|---|
| **1. Nitration** Warming benzene with a mixture of nitric acid and sulfuric acid gives nitrobenzene. A nitro group (—$NO_2$) replaces one of the ring hydrogens. | Benzene + $HNO_3$ ($H_2SO_4$, 30–40°C) → Nitrobenzene (95%) + $H_2O$ (Water); Nitric acid |
| **2. Sulfonation** Treatment of benzene with hot concentrated sulfuric acid gives benzenesulfonic acid. A sulfonic acid group (—$SO_2OH$) replaces one of the ring hydrogens. | Benzene + $HOSO_2OH$ (heat) → Benzenesulfonic acid (100%) + $H_2O$ (Water); Sulfuric acid |
| **3. Halogenation** Bromine reacts with benzene in the presence of iron(III) bromide as a catalyst to give bromobenzene. Chlorine reacts similarly in the presence of iron(III) chloride to give chlorobenzene. | Benzene + $Br_2$ ($FeBr_3$) → Bromobenzene (65–75%) + HBr (Hydrogen bromide); Bromine |
| **4. Friedel–Crafts alkylation** Alkyl halides react with benzene in the presence of aluminum chloride to yield alkylbenzenes. | Benzene + $(CH_3)_3CCl$ ($AlCl_3$, 0°C) → *tert*-Butylbenzene (60%) + HCl (Hydrogen chloride); *tert*-Butyl chloride |
| **5. Friedel–Crafts acylation** An analogous reaction occurs when acyl halides react with benzene in the presence of aluminum chloride. The products are acylbenzenes. | Benzene + $CH_3CH_2COCl$ ($AlCl_3$, 40°C) → 1-Phenyl-1-propanone (88%) + HCl (Hydrogen chloride); Propanoyl chloride |

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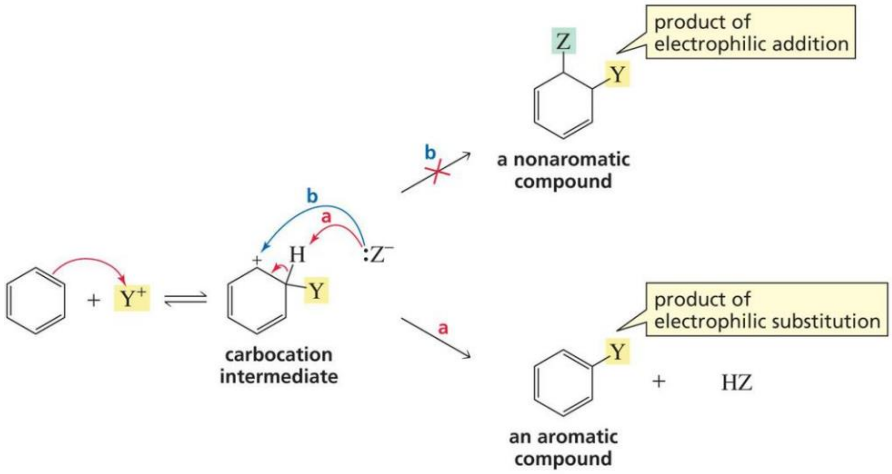
# Caminho comum

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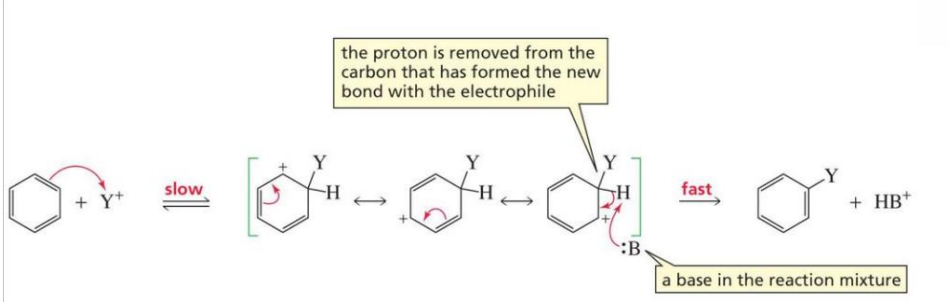
# Caminho comum

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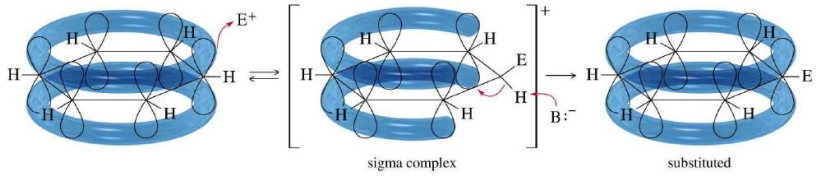
# O complexo σ




Ion benzênio
E.g. ion arênio

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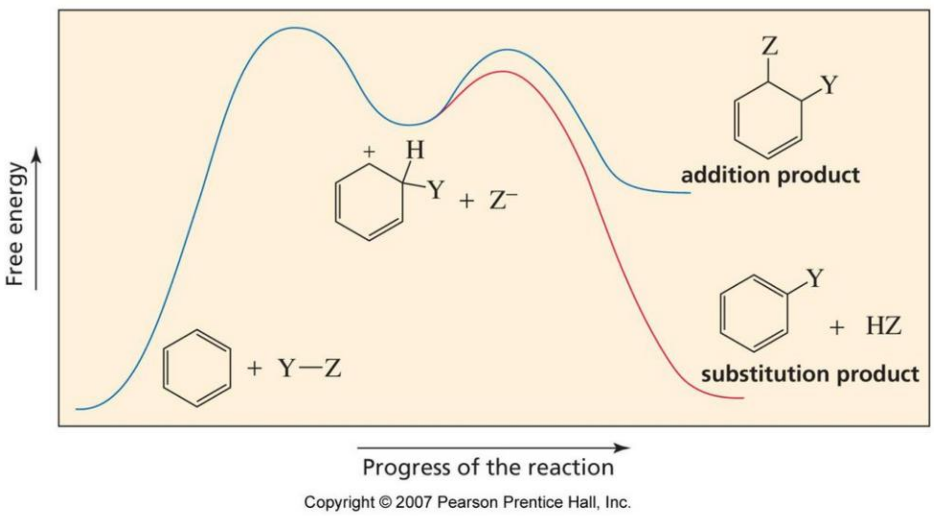
# Caminho comum

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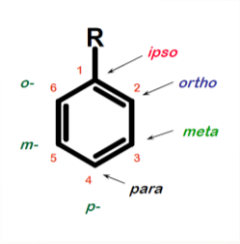
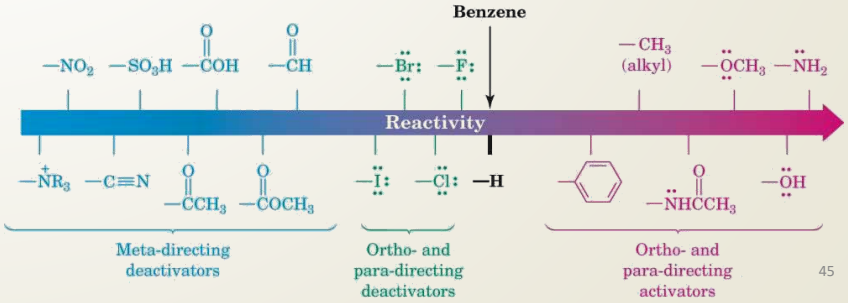



# Efeitos substituintes em anéis aromáticos

- Os substituintes podem fazer com que um composto seja (muito) mais ou (muito) menos reativo do que o benzeno
- Os substituintes afetam a orientação da reação - a relação posicional é controlada
- Ativadores orto e para-direcionadores, desativadores orto e para-direcionadores e desativadores meta-direcionadores

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## Ativadores / Desativadores

| Effect on rate | Substituent | | Effect on orientation |
|---|---|---|---|
| Very strongly activating | —$\ddot{N}H_2$ | (amino) | Ortho, para-directing |
| | —$\ddot{N}HR$ | (alkylamino) | |
| | —$\ddot{N}R_2$ | (dialkylamino) | |
| | —$\ddot{O}H$ | (hydroxyl) | |
| Strongly activating | —$\ddot{N}HCR$ (O) | (acylamino) | Ortho, para-directing |
| | —$\ddot{O}R$ | (alkoxy) | |
| | —$\ddot{O}CR$ (O) | (acyloxy) | |
| Activating | —R | (alkyl) | Ortho, para-directing |
| | —Ar | (aryl) | |
| | —CH=$CR_2$ | (alkenyl) | |
| Standard of comparison | —H | (hydrogen) | |
| Deactivating | —X (X = F, Cl, Br, I) | (halogen) | Ortho, para-directing |
| | —$CH_2X$ | (halomethyl) | |
| Strongly deactivating | —CH (O) | (formyl) | Meta-directing |
| | —CR (O) | (acyl) | |
| | —COH (O) | (carboxylic acid) | |
| | —COR (O) | (ester) | |
| | —CCl (O) | (acyl chloride) | |
| | —C≡N | (cyano) | |
| | —$SO_3H$ | (sulfonic acid) | |
| Very strongly deactivating | —$CF_3$ | (trifluoromethyl) | Meta-directing |
| | —$NO_2$ | (nitro) | |

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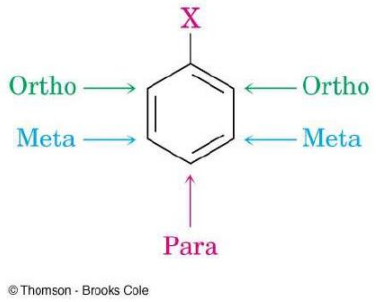
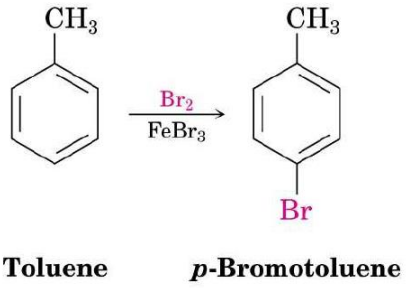
# Ativadores, dirigem o,*p*




Bromação do tolueno

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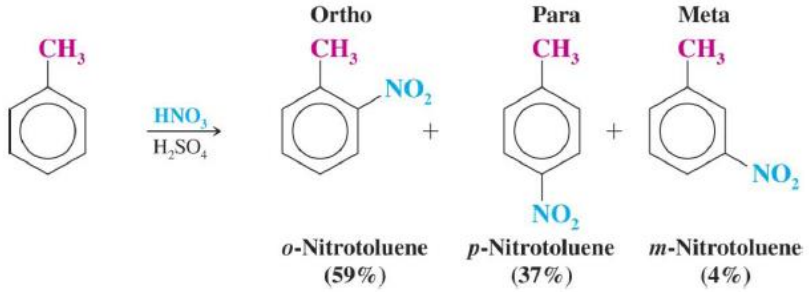


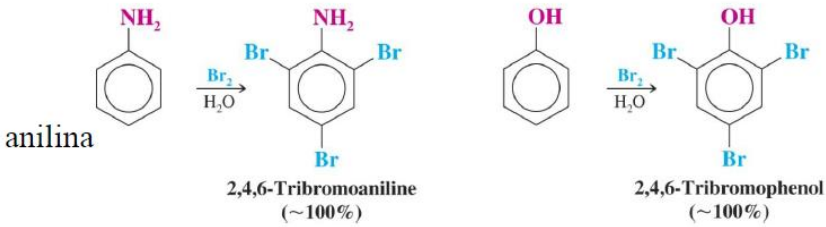

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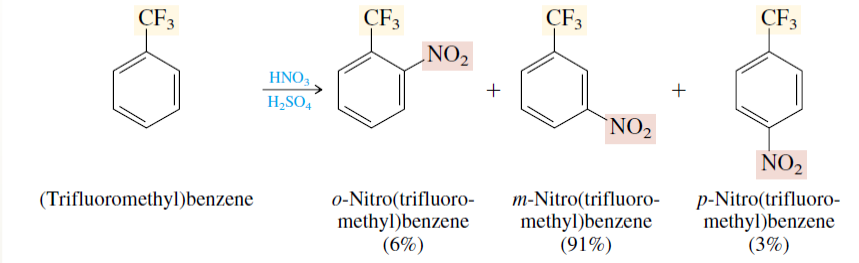


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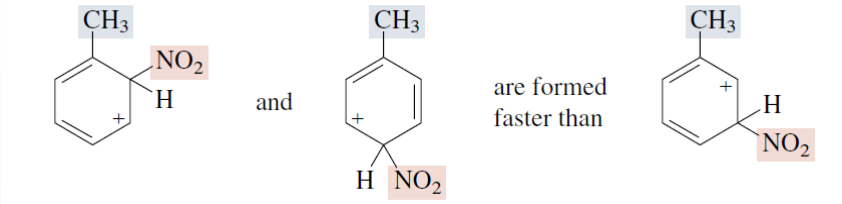
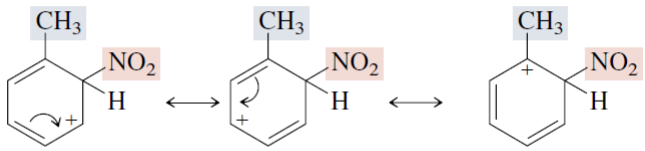
# Velocidade e regiosseletividade na nitração do tolueno




***Ortho attack***



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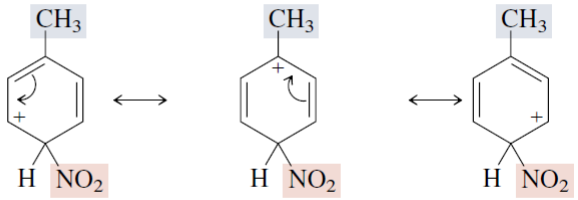
***Para attack***




This resonance form is a tertiary carbocation

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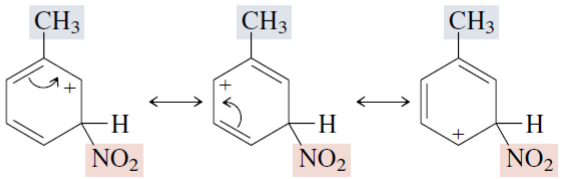
***Meta attack***



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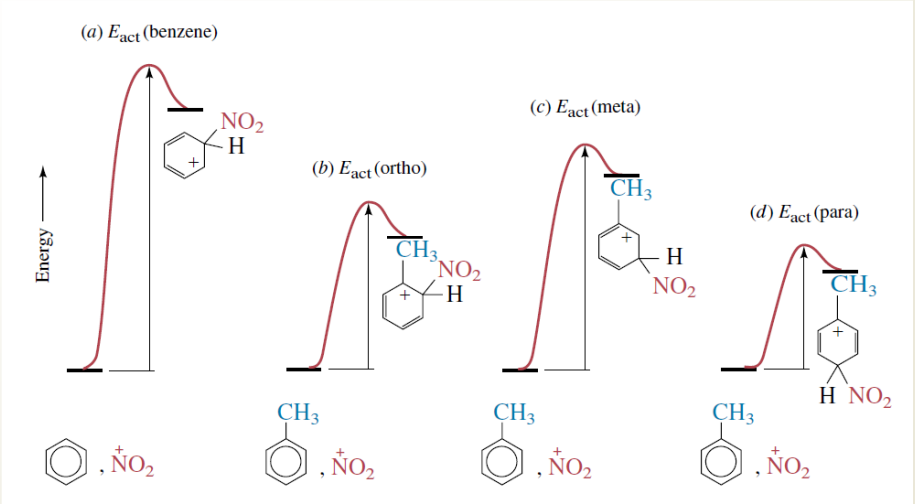
# Diagramas comparativos de energia para ataque do íon nitrônio

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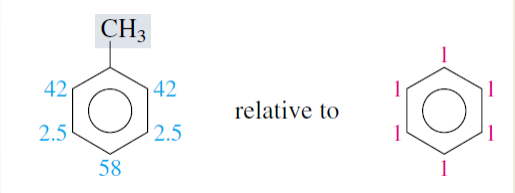
# Velocidades relativas de ataque ao tolueno



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# Faça uma análise similar para a nitração do (trifluorometil)benzeno

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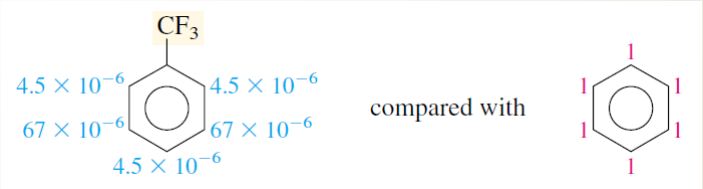
## Velocidades relativas de ataque ao (trifluorometil)benzeno



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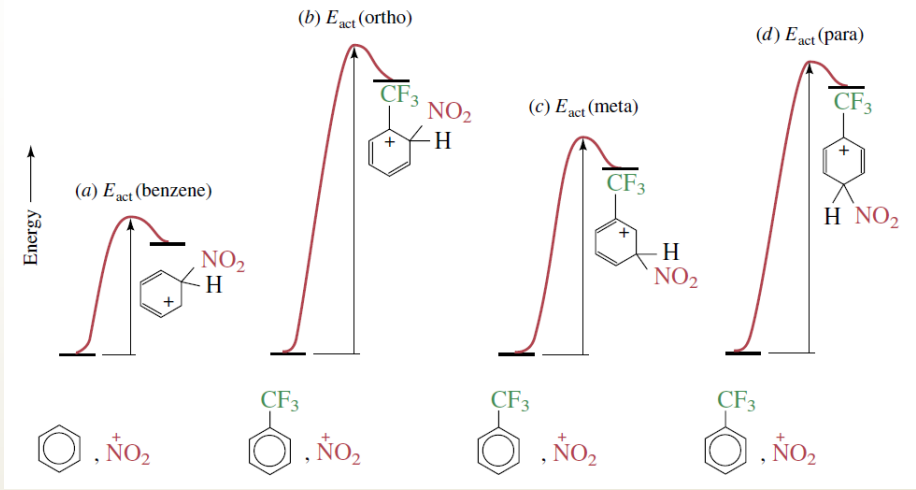
# Diagramas comparativos de energia para ataque do íon nitrônio

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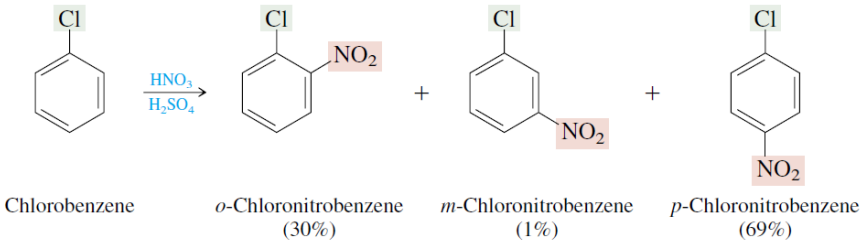
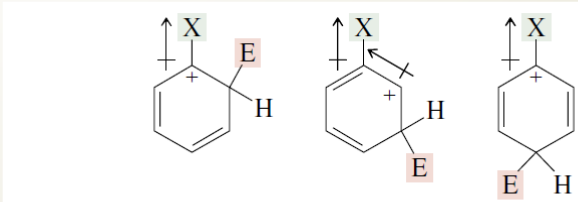
# Halogênios?




All these ions are less stable when X = F, Cl, Br, or I than when X = H

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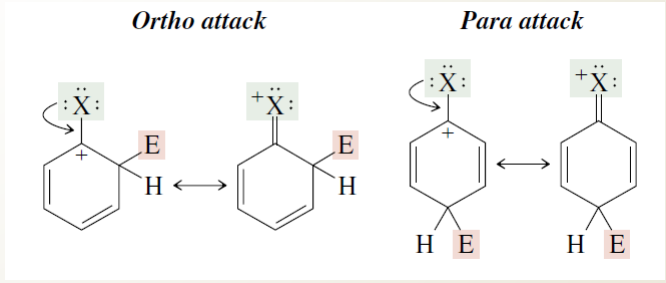


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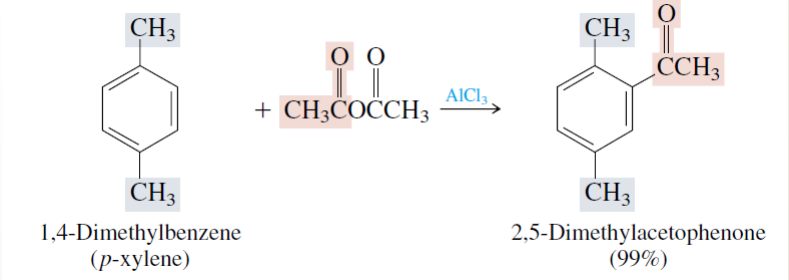
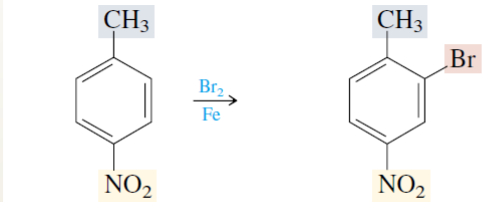
# Efeitos múltiplos




1,4-Dimethylbenzene (*p*-xylene)

2,5-Dimethylacetophenone (99%)




*p*-Nitrotoluene

2-Bromo-4-nitrotoluene (86–90%)

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A partir do benzeno, mostre como sintetizar o *m*-cloroetilbenzeno