

CH 310 N

TH 2-3:30

LECTURE 21

**Textbook Assignment: Chapter 21 & 22**

**Homework (for credit): POW 10 posted**

**Today's Topics: Benzene & Reactions of Its Derivatives**

*Notice & Announcements:*

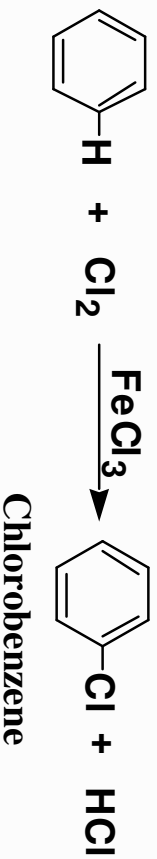
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# Reactions of Benzene & Its Derivatives

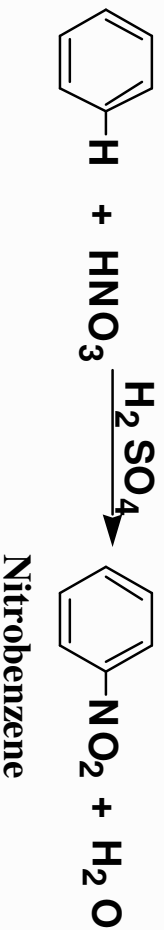
## Reactions of Benzene

The most characteristic reaction of aromatic compounds is substitution at a ring carbon:

Halogenation:



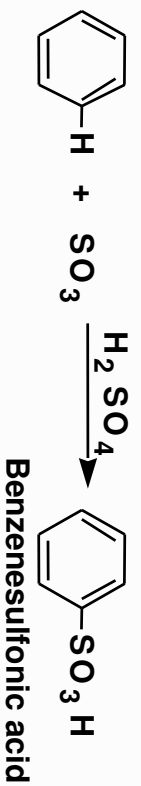
Nitration:



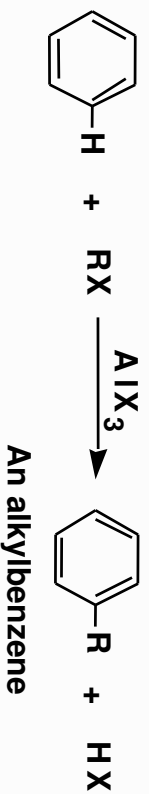
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## Reactions of Benzene

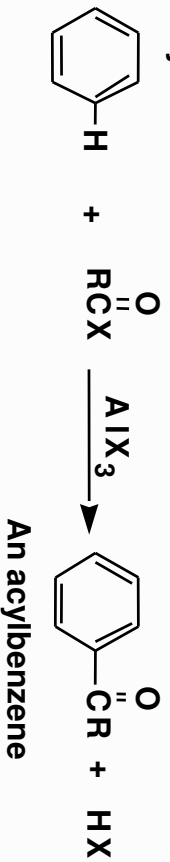
Sulfonation:



Alkylation:



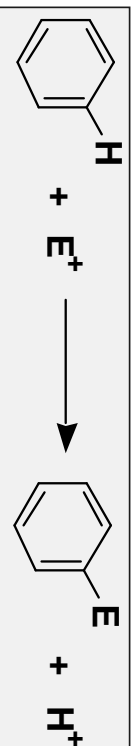
Acylation:



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## Electrophilic Aromatic Substitution

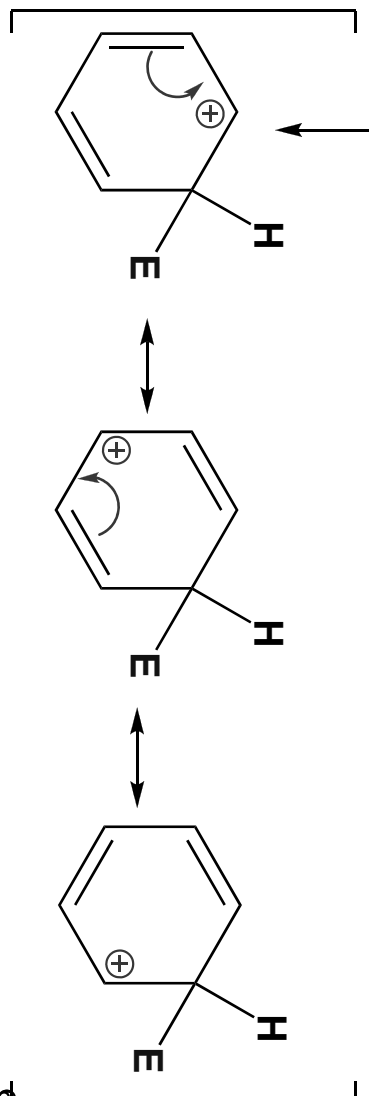
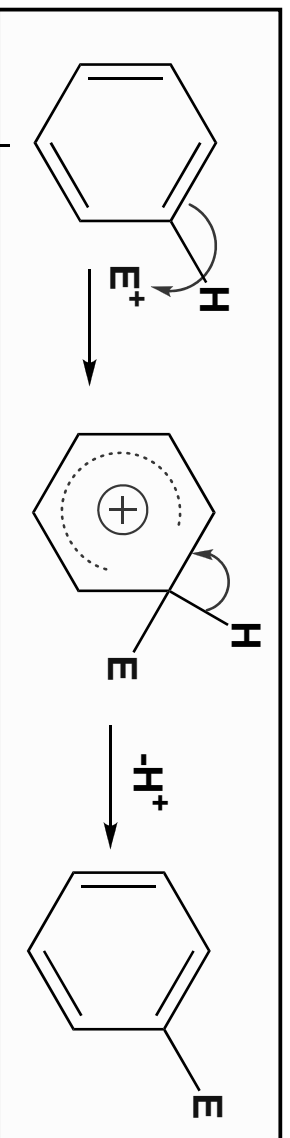
- Electrophilic aromatic substitution: a reaction in which a hydrogen atom of an aromatic ring is replaced by an electrophile



- In this section:
  - several common types of electrophiles
  - how each is generated
  - the mechanism by which each replaces hydrogen

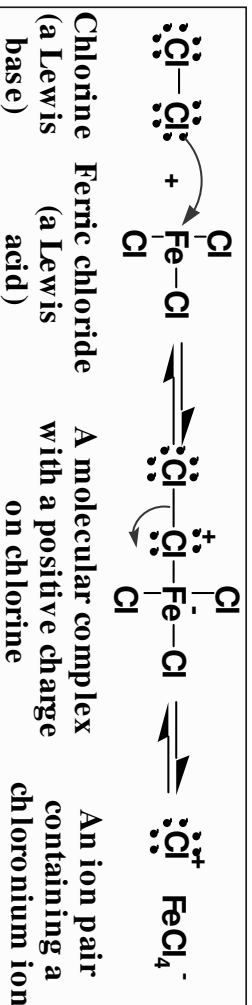
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### Electrophilic Aromatic Substitution (EAS)

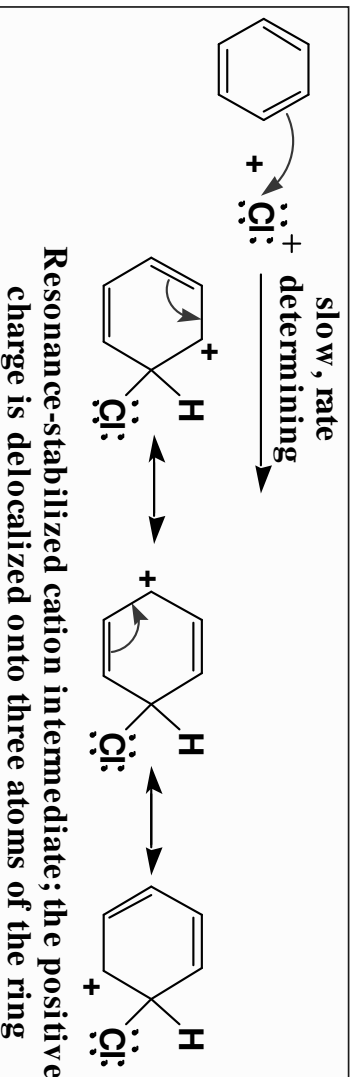


# Chlorination

Step 1 : formation of a chloronium ion

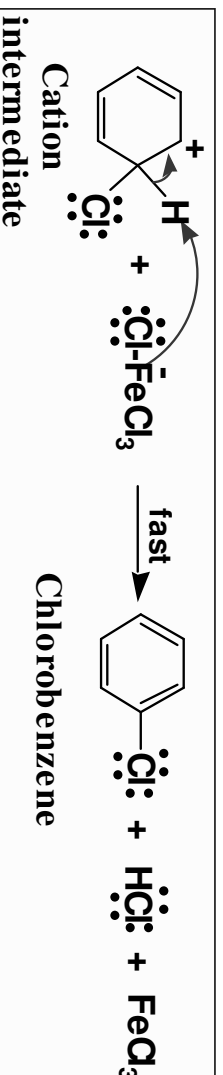


Step 2: attack of the chloronium ion on the ring



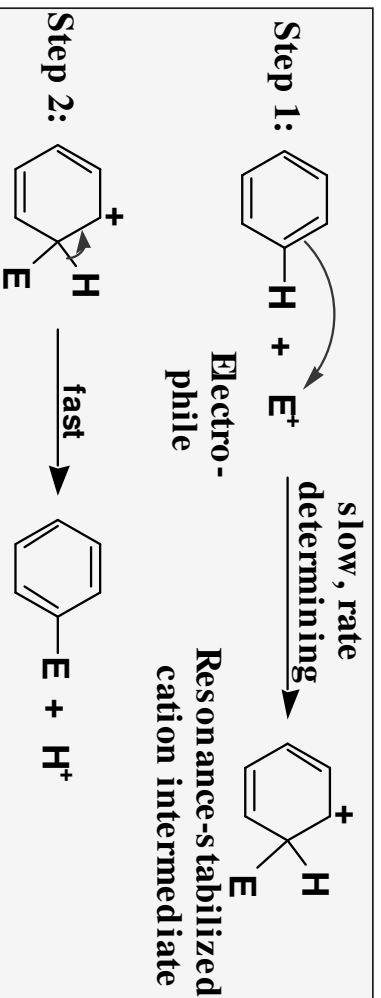
# Chlorination

Step 3: proton transfer regenerates the aromatic character of the ring



## EAS: General Mechanism

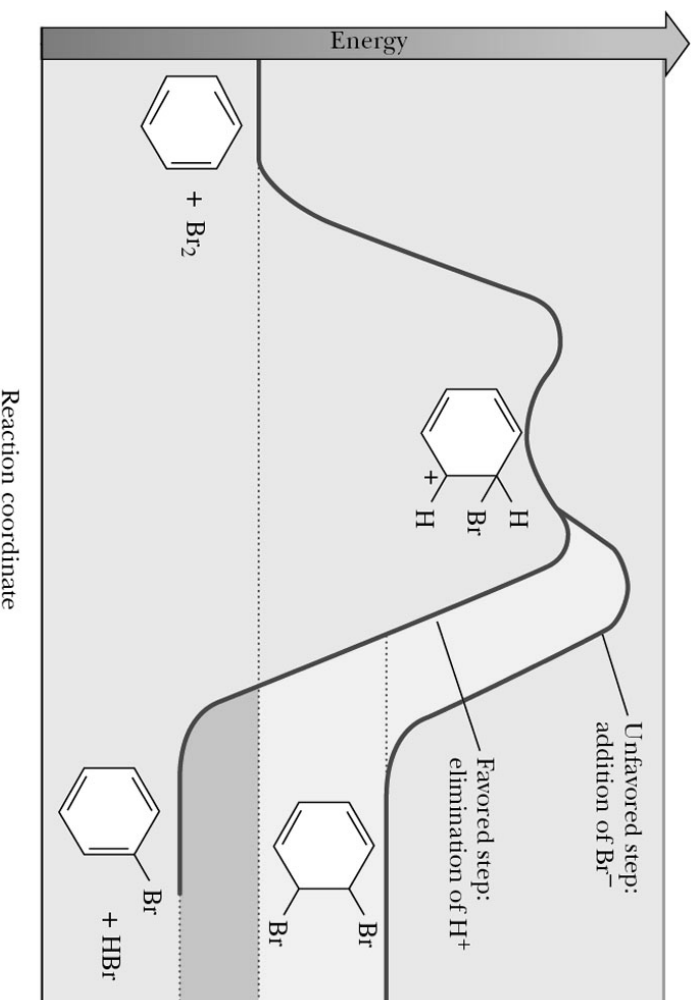
- A general mechanism



- General question: what is the electrophile and how is it generated?

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## Bromination

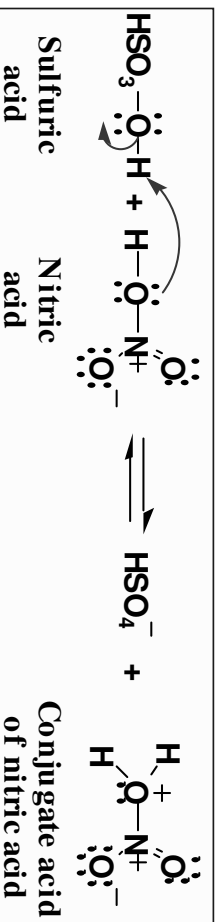


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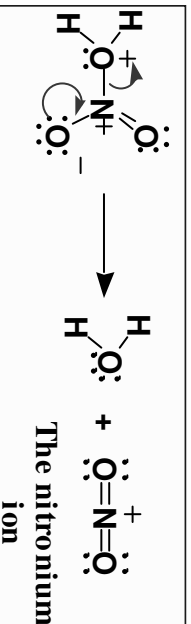
## Nitration

- Generation of the **nitronium ion**,  $\text{NO}_2^+$

– Step 1: proton transfer to nitric acid



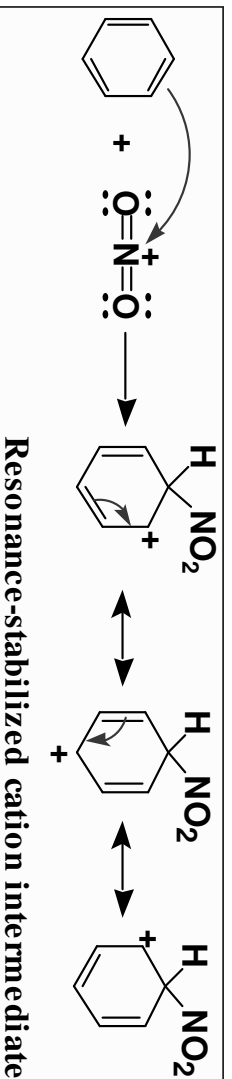
– Step 2: loss of  $\text{H}_2\text{O}$  gives the nitronium ion, a very strong electrophile



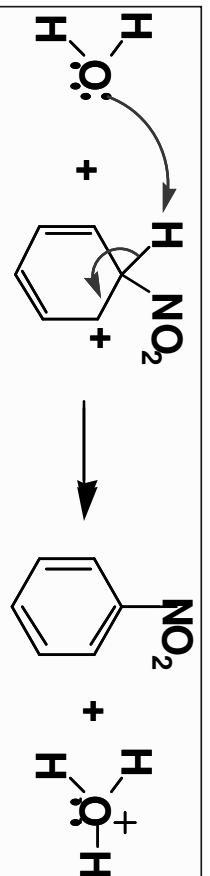
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## Nitration

Step 1: attack of the nitronium ion (an electrophile) on the aromatic ring (a nucleophile)



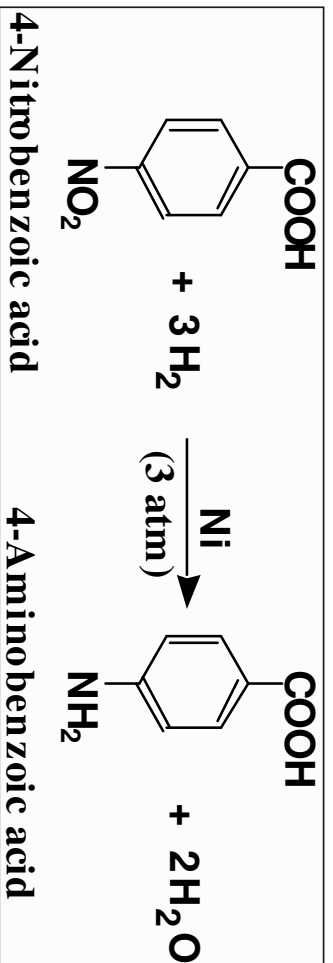
Step 2: proton transfer regenerates the aromatic ring



1 2

## Nitration

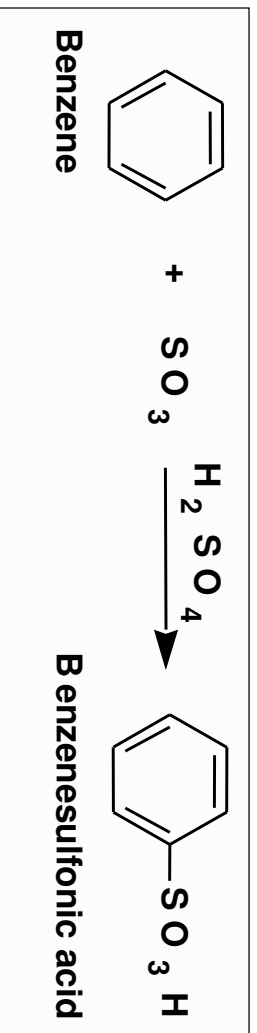
- A particular value of nitration is that the nitro group can be reduced to a 1° amino group



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## Sulfonation

- Carried out using concentrated sulfuric acid containing dissolved sulfur trioxide

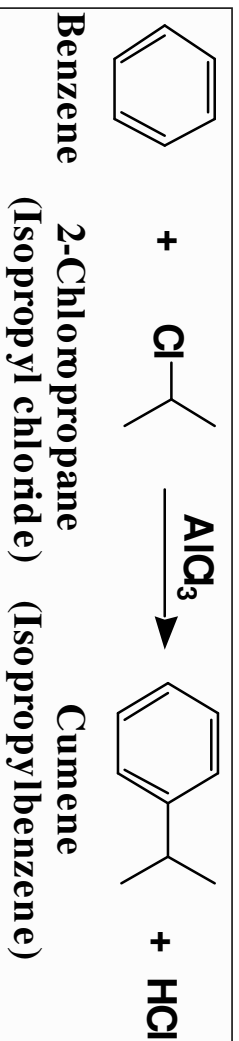


(SO<sub>3</sub> in H<sub>2</sub>SO<sub>4</sub> is sometimes called “fuming” sulfuric acid.)

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## Friedel-Crafts Alkylation

- Friedel-Crafts alkylation forms a new C-C bond between an aromatic ring and an alkyl group



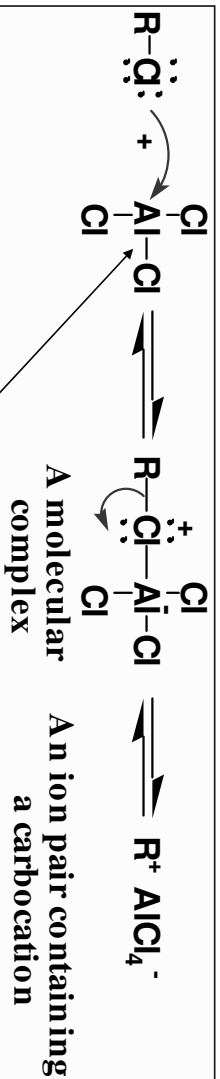
The electrophilic partner is a carbocation;  
it will arrange to the most stable ion: allylic > 3° > 2° > 1°

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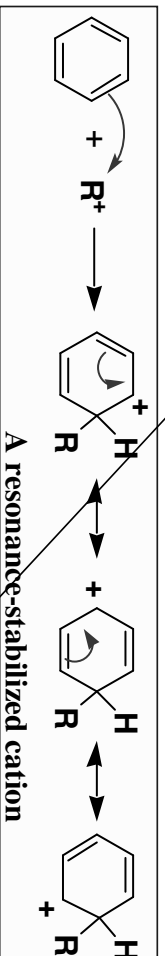
## Friedel-Crafts Alkylation

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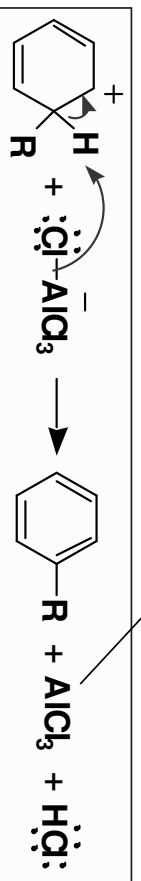
Step 1: formation of an alkyl cation as an ion pair



Step 2: attack of the alkyl cation on the aromatic ring



Step 3: proton transfer regenerates the aromatic ring

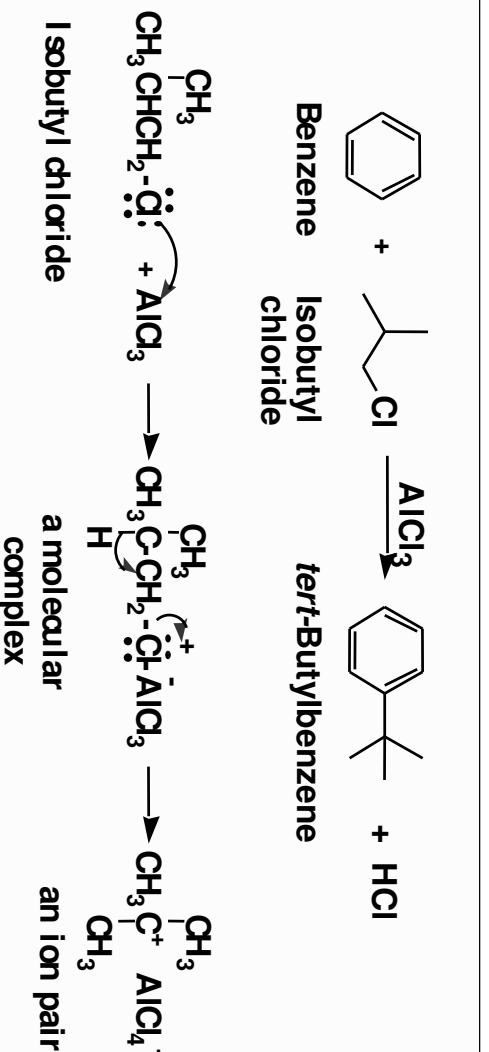


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## Friedel-Crafts Alkylation

There are two major limitations on Friedel-Crafts alkylations:

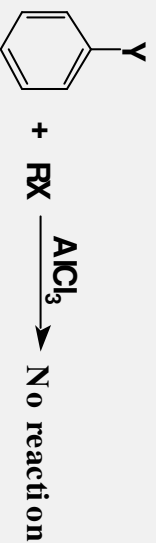
1. carbocation rearrangements are common:



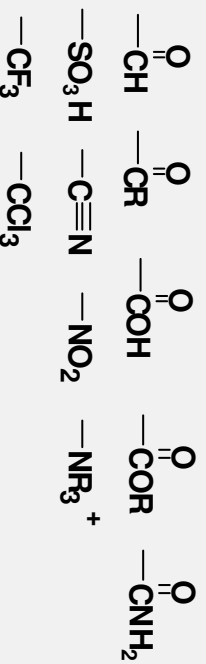
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## Friedel-Crafts Alkylation

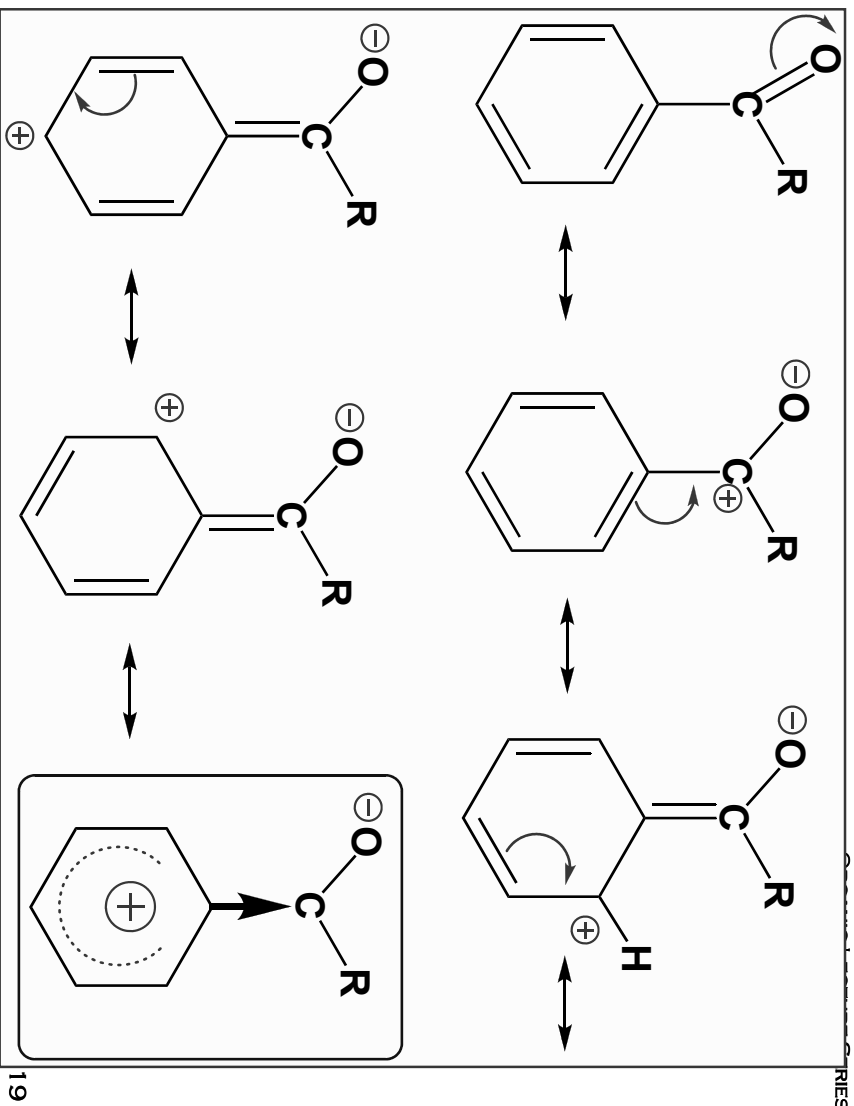
2. F-C alkylation fails on benzene rings bearing one or more of these strongly **electron-withdrawing groups**



When Y Equals Any of These Groups, the Benzene Ring Does Not Undergo Friedel-Crafts Alkylation



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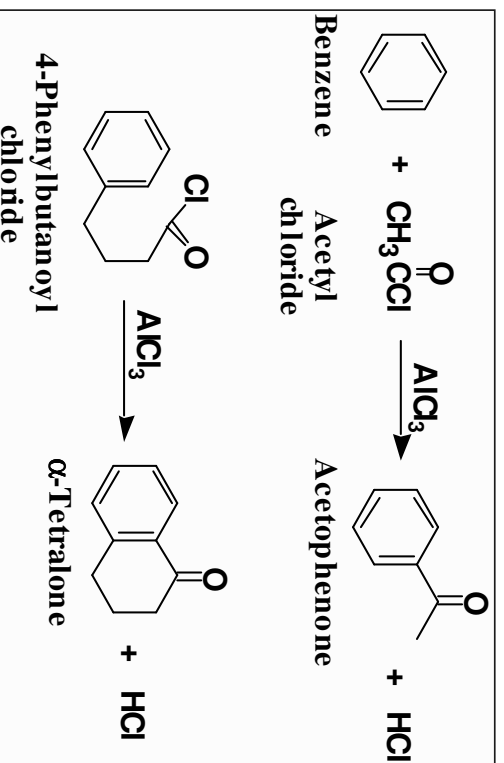
## The “De-activation” of Aromatic Systems



Note: deactivation refers to the **rate** of EAS

## Friedel-Crafts Acylation

- Friedel-Crafts **acylation** forms a new C-C bond between a benzene ring and an acyl group:

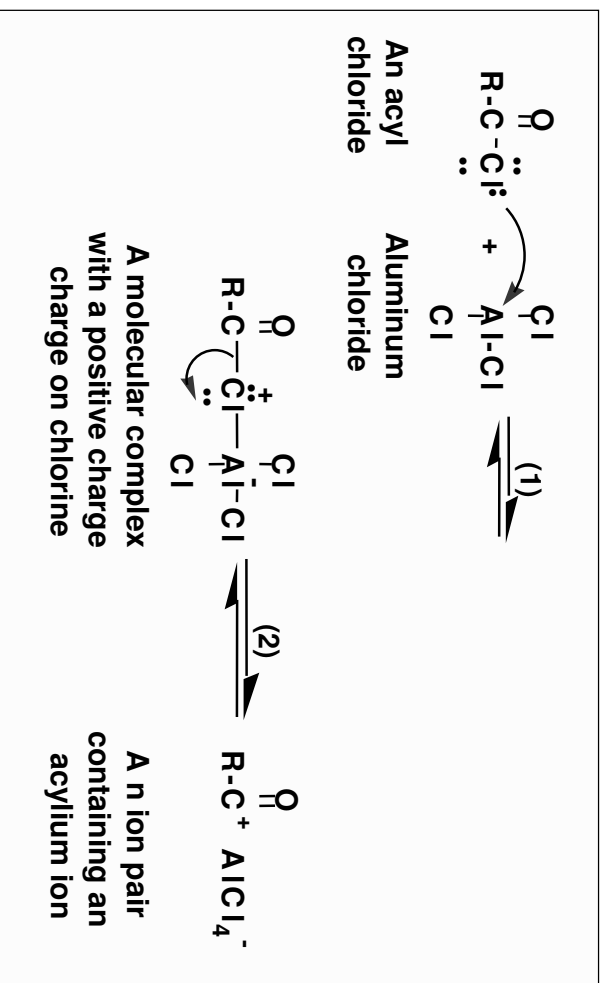


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- The electrophile is an **acylium ion**

## Friedel-Crafts Acylation

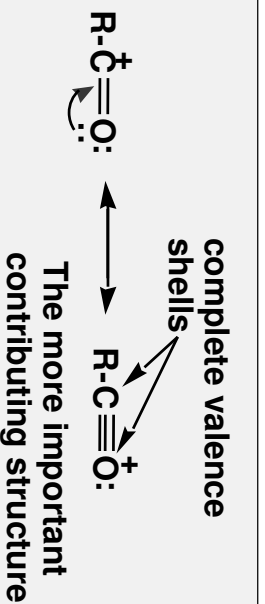
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## Friedel-Crafts Acylation

– an acylium ion is a resonance hybrid of two major contributing structures

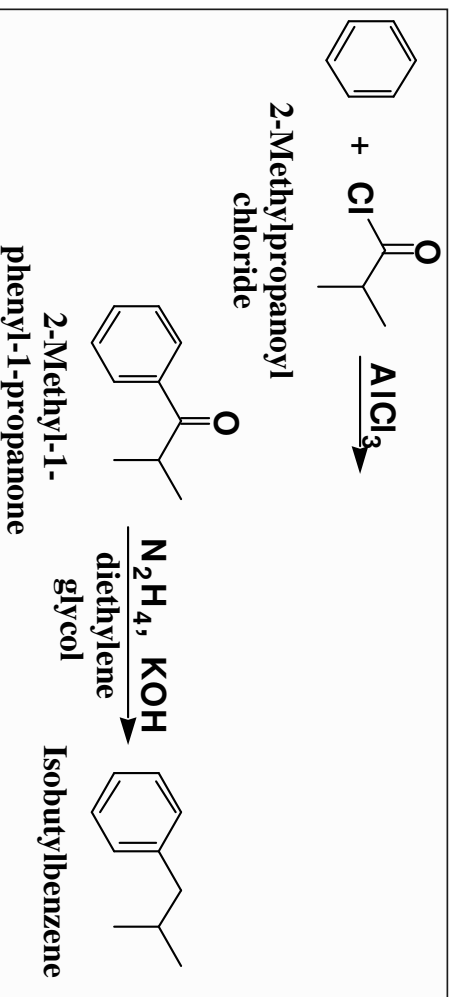


- F-C acylations are free of a major limitation of F-C alkylations; **acylium ions do not rearrange.**

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## Friedel-Crafts Acylation

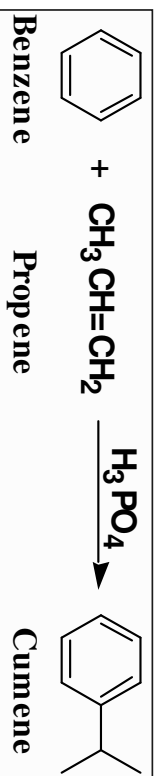
A special value of F-C acylations is preparation of unarranged alkylbenzenes:



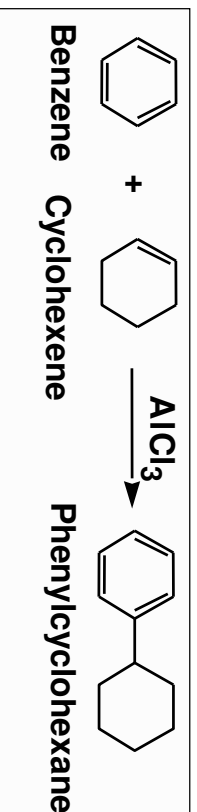
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## Other Aromatic Alkylations

- Carbocations are also generated by:
  - treatment of an alkene with a proton acid, most commonly  $\text{H}_2\text{SO}_4$ ,  $\text{H}_3\text{PO}_4$ , or  $\text{HF}/\text{BF}_3$



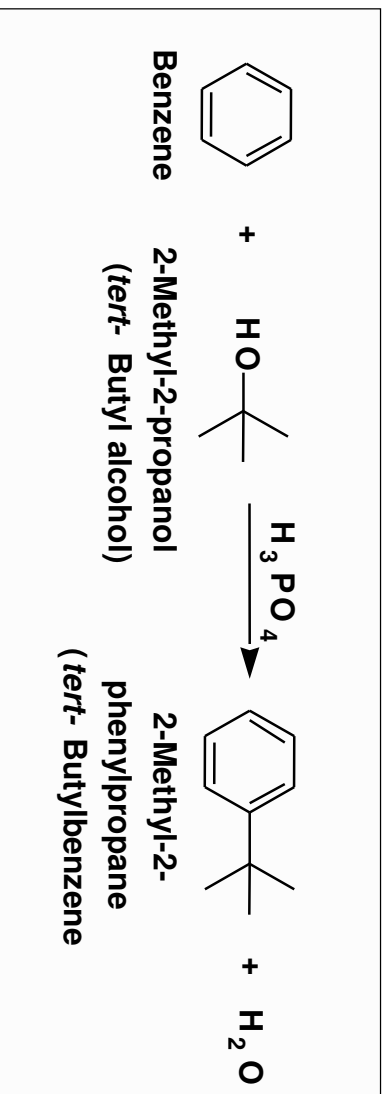
– by treating an alkene with a Lewis acid



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## Other Aromatic Alkylations

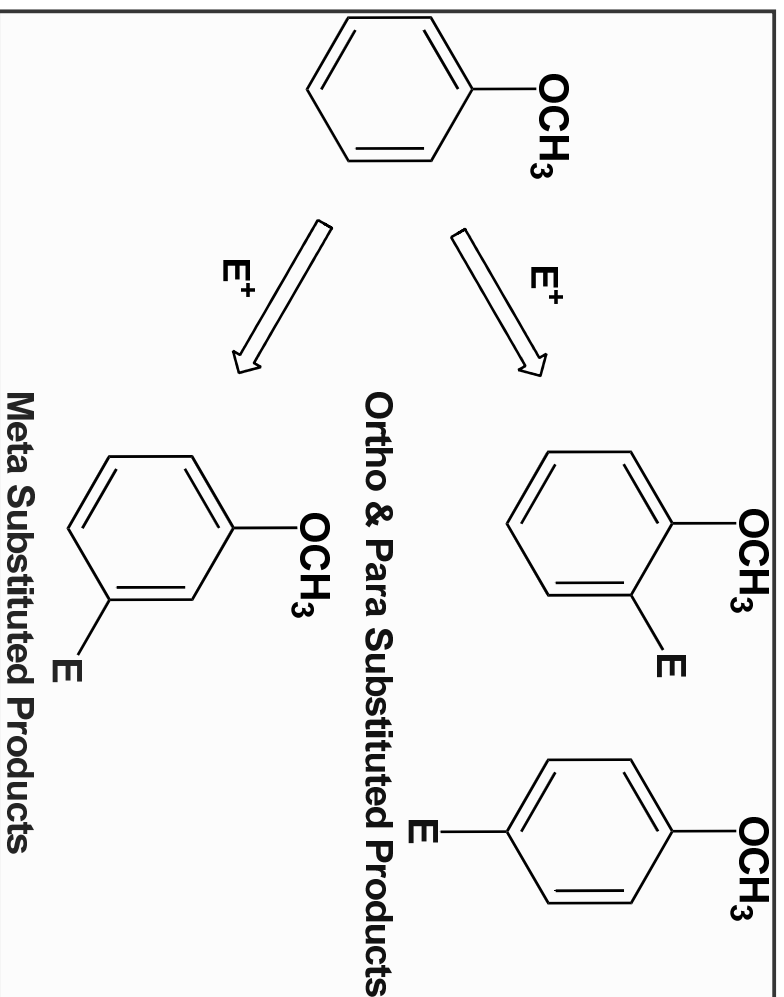
– and by treating an alcohol with  $\text{H}_2\text{SO}_4$  or  $\text{H}_3\text{PO}_4$



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## Di- and Polysubstitution

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## Di- and Polysubstitution

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Orientation of nitration for monosubstituted benzenes:

Substituent	ortho +				
	ortho	meta	para	para	meta
—OCH <sub>3</sub>	44	-	55	99	trace
—CH <sub>3</sub>	58	4	38	96	4
—Cl	70	-	30	100	trace
—Br	37	1	62	99	1
—COOH	18	80	2	20	80
—CN	19	80	1	20	80
—NO <sub>2</sub>	6.4	93.2	0.3	6.7	93.2

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## Di- and Polysubstitution

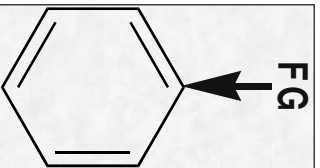
- Orientation:
  - certain substituents direct preferentially to ortho & para positions; others to meta positions
  - substituents are classified as either **ortho-para directing** or **meta directing** toward further substitution

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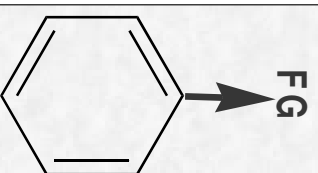
## Di- and Polysubstitution

- Rate
  - certain substituents cause the rate of a second substitution to be greater than that for benzene itself; others cause the rate to be lower
  - substituents are classified as **activating** or **deactivating** toward further substitution

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**If the FG is an e<sup>-</sup> donating substituent, then the ring system becomes more electron rich and is said to be "activated" towards electrophilic aromatic substitution. EAS is at a faster rate.**



**If the FG is an e<sup>-</sup> withdrawing substituent, then the ring system becomes more electron poor and is said to be "deactivated" towards electrophilic aromatic substitution. EAS occurs at a slower rate.**