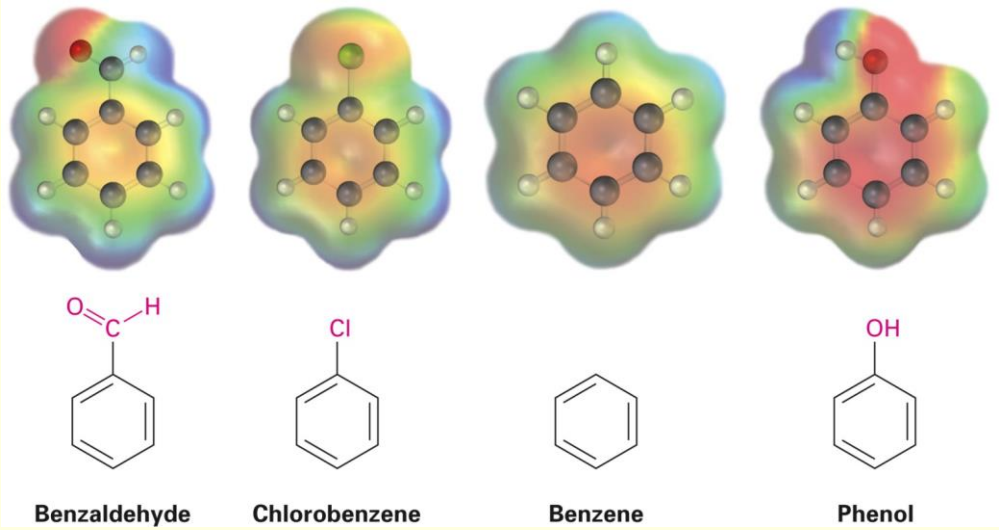
Chapter 5.
Aromatic Compounds

스마트헬스케어학부 의공학전공

임해균 교수

5.7 An Explanation of Substituent Effects

- Activating groups donate electrons to the ring, stabilizing the carbocation intermediate
- Deactivating groups withdraw electrons from the ring, destabilizing the carbocation intermediate



Compare the electrostatic potential maps of benzaldehyde (deactivated), chlorobenzene (weakly deactivated), and phenol (activated) with that of benzene.

The ring is more positive (yellow) when an electron-withdrawing group such as CHO or Cl is present and more negative (red) when an electrondonating group such as OH is present

- Electron donation or withdrawal may occur by either an *inductive effect* and a *resonance effect.*
- **Inductive effect** - withdrawal or donation of electrons through a σ bond
- **Resonance effect** - withdrawal or donation of electrons through a π bond due to th**e overlap of a *p* orbital on the substituent** with a ***p* orbital on the aromatic ring**

Orienting Effects in Aromatic Rings: Ortho- and Para-Directors

- OH groups activate: direct further substitution to positions ortho and para to themselves

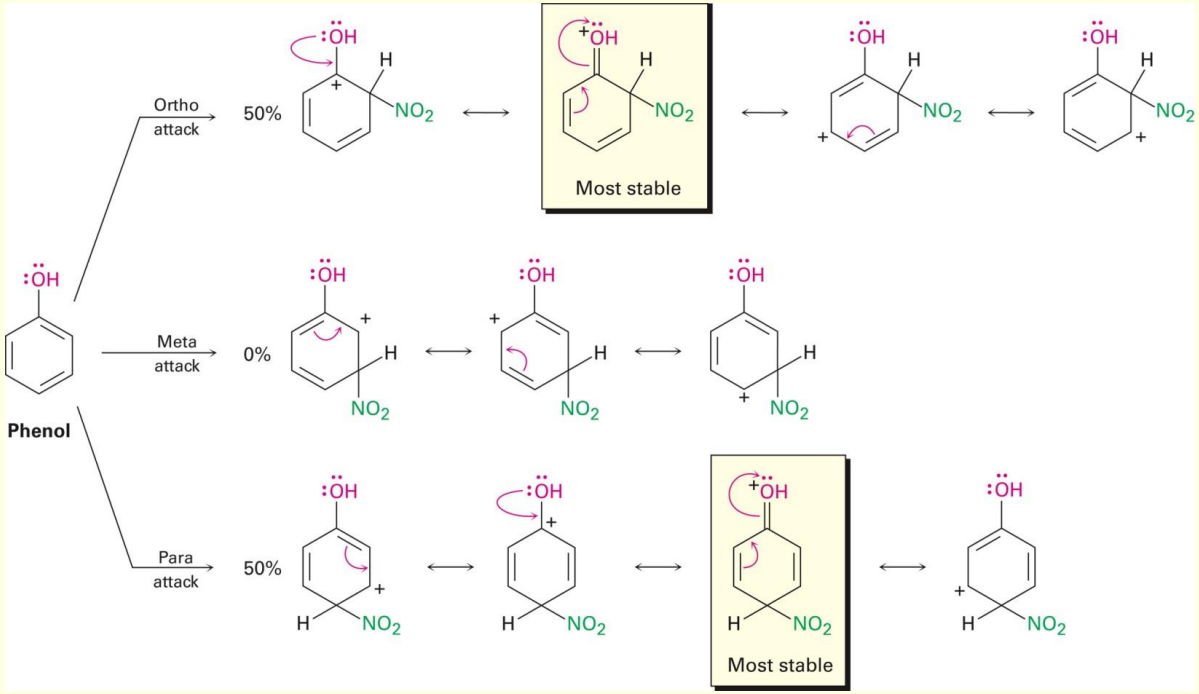


Figure 5.7 Carbocation intermediates in the nitration of phenol. The ortho and para intermediates are more stable than the meta intermediate because they have more resonance forms, including a particularly favorable one that allows the positive charge to be stabilized by electron donation from the substituent oxygen atom.

Substituents with a lone pair electrons

In general, any substituent that has a lone pair of electrons on the atom **directly bonded** to the aromatic ring allows an electron-donating resonance interaction to occur and thus acts as an ortho and para director.

Orienting Effects in Aromatic Rings: Meta-Directors

- Inductive and resonance effects reinforce each other
- Ortho and para intermediates destabilized by deactivation of carbocation intermediate by C=O group
- (least stable)It places the positive charge directly on the carbon that bears the aldehyde group, where it is disfavored by a repulsive interaction with the positively polarized carbon atom of the C=O group.

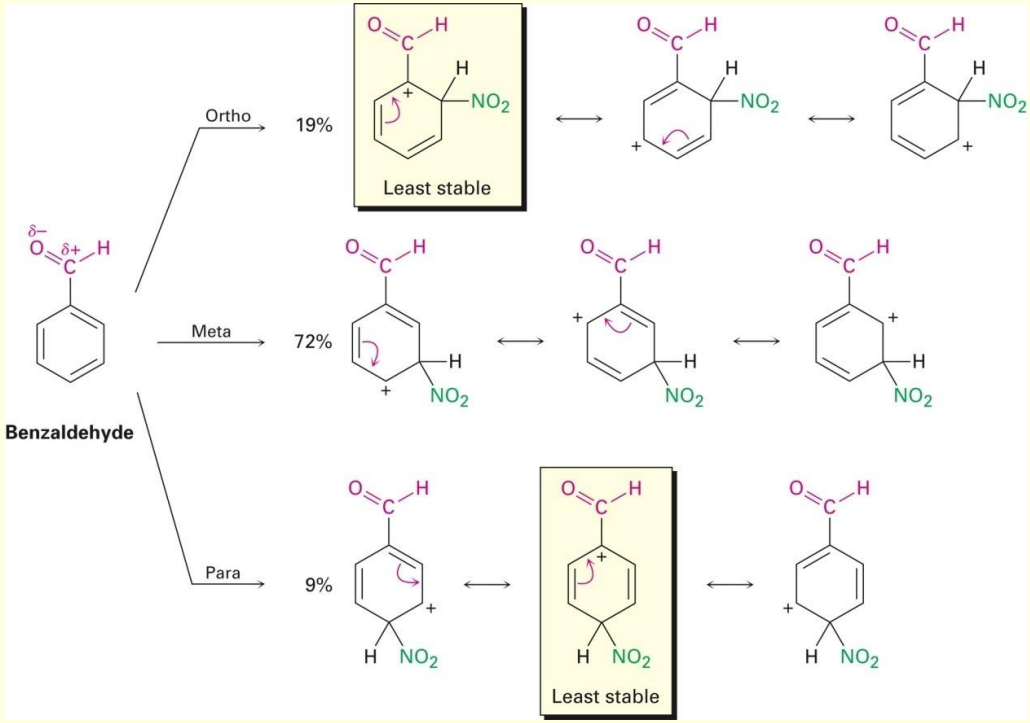
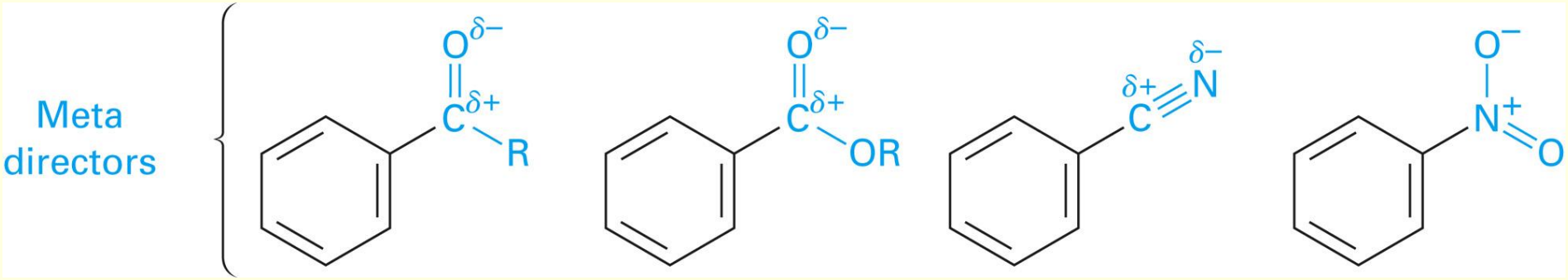


Figure 5.8

The meta intermediate is more favorable than ortho and para intermediates because it has three favorable resonance forms rather than two.



Substituents with a positively polarized atom (δ^+)

In general, any substituent that has a positively polarized atom directly attached to the ring makes one of the resonance forms of the orthoand para intermediates unfavorable, and thus acts as a meta director.

Worked Example 5.4

Predicting the Product of an Electrophilic Aromatic Substitution Reaction

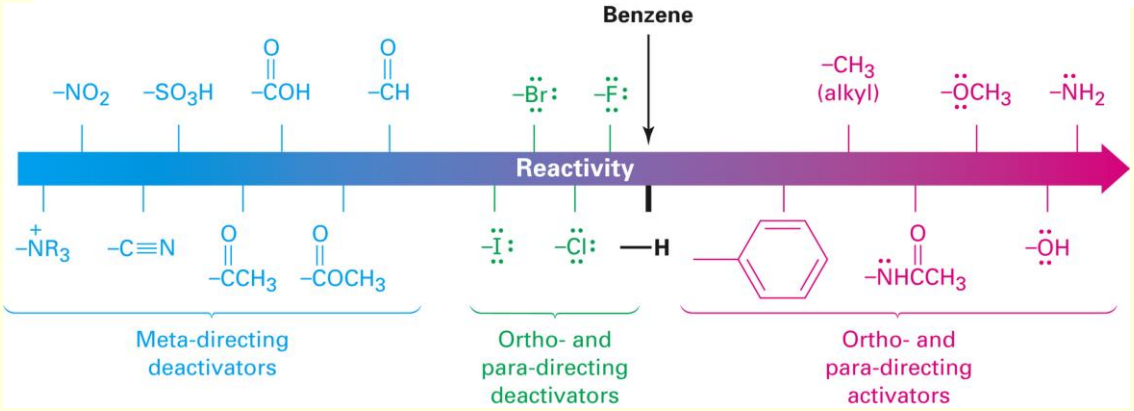
What product(s) would you expect from bromination of aniline, $C_6H_5NH_2$?

Strategy

Look at Figure 5.6 to see whether the $-NH_2$ substituent is ortho- and para-directing or meta-directing. Because an amino group has a lone pair of electrons on the nitrogen atom, it is ortho- and para-directing and we expect to obtain a mixture of *o*-bromoaniline and *p*-bromoaniline.

Solution

Aniline **o-Bromoaniline** **p-Bromoaniline**



Problem 5.13 What product(s) would you expect from sulfonation of the following compounds?

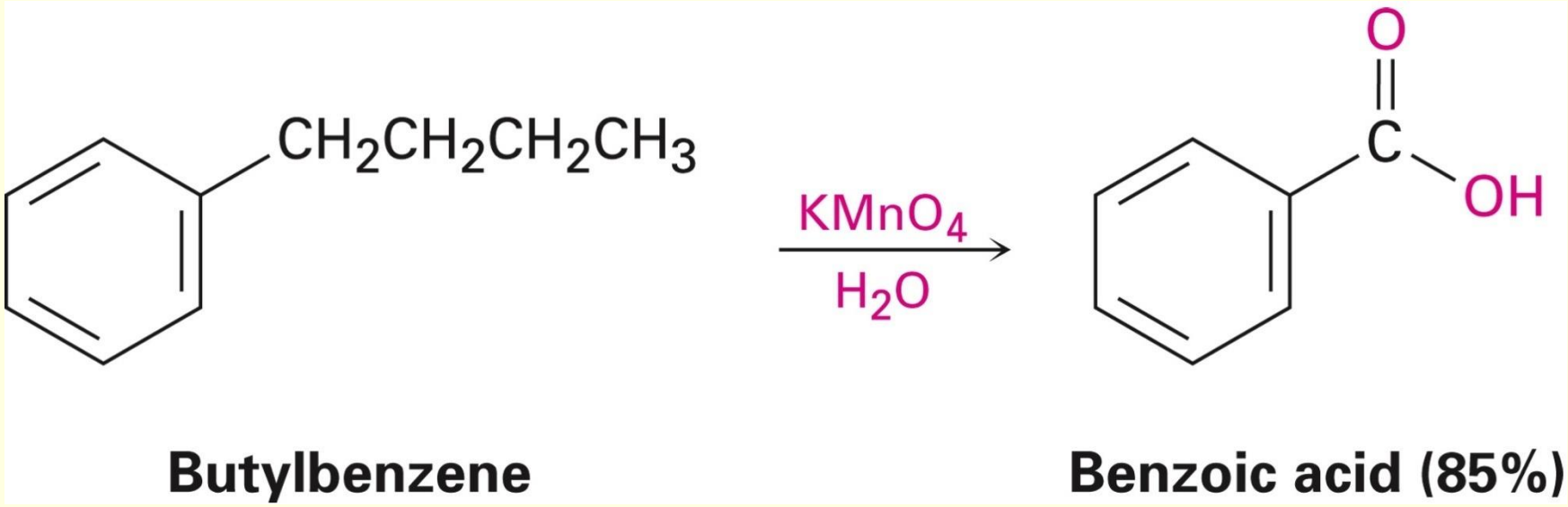
(a) Nitrobenzene **(b)** Bromobenzene **(c)** Toluene
(d) Benzoic acid **(e)** Benzonitrile

Problem 5.14 Draw resonance structures of the three possible carbocation intermediates to show how a methoxyl group ($-OCH_3$) directs bromination toward ortho and para positions.

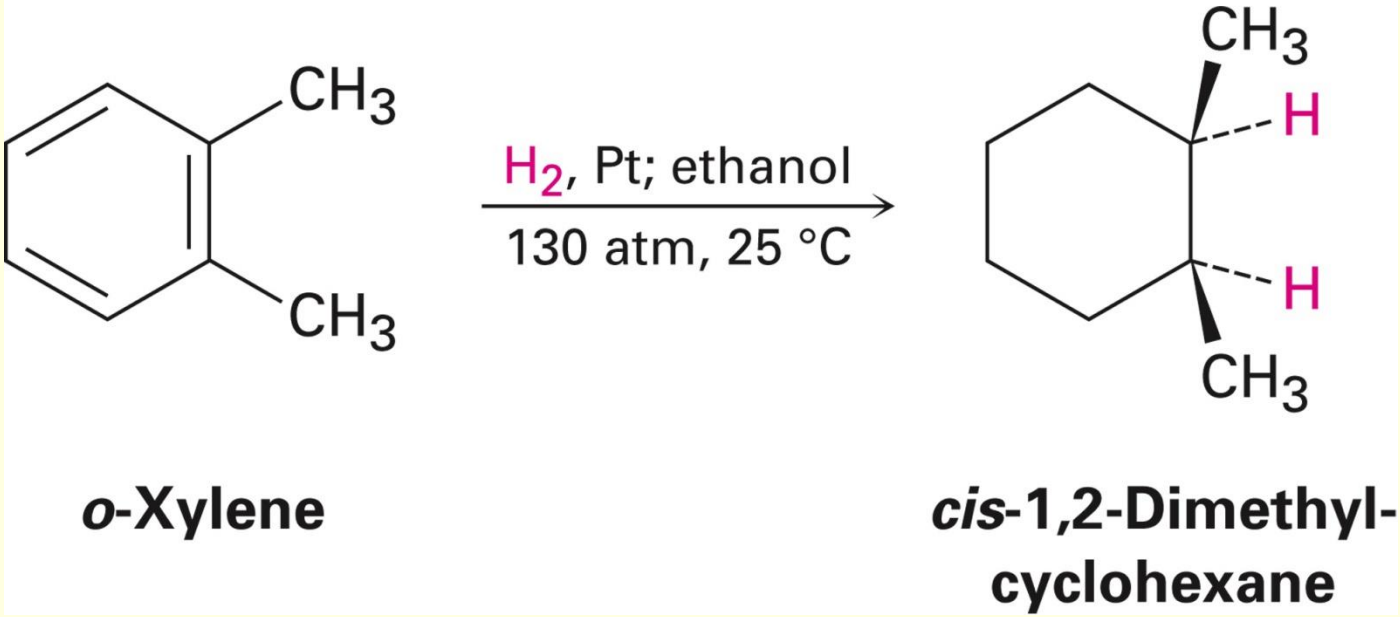
Problem 5.15 Draw resonance structures of the three possible carbocation intermediates to show how an acetyl group, $CH_3C{=}O$, directs bromination toward the meta position.

5.8 Oxidation and Reduction of Aromatic Compounds

- Alkyl side chains can be oxidized to —CO_2H by strong reagents such as $KMnO_4$ if they have a C-H next to the ring
- Converts an alkylbenzene into a benzoic acid, Ar—R $\rightarrow$ Ar—CO_2H

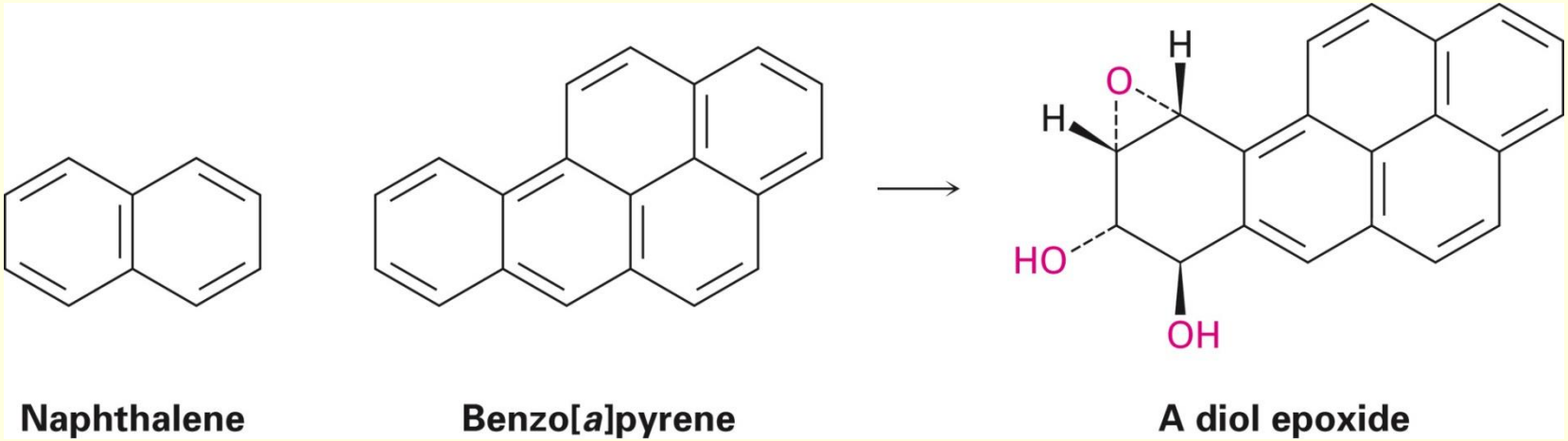


Reduction of Aromatic Compounds requires powerful reducing conditions (high pressure or rhodium catalysts)



5.9 Other Aromatic Compounds

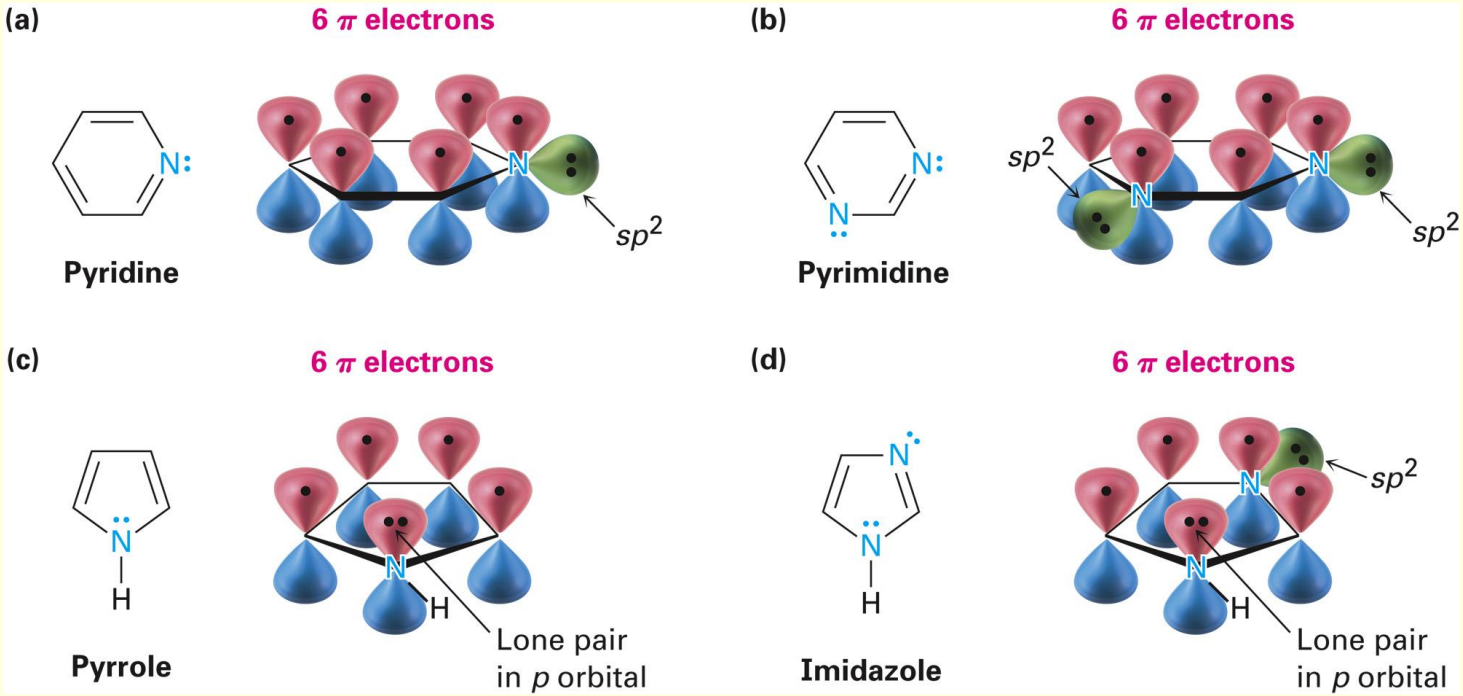
- Aromatic compounds can have rings that share a set of carbon atoms (fused rings): **polycyclic aromatic compound**
- Compounds from fused benzene or aromatic heterocycle rings are themselves aromatic



Naphthalene **Benzo[*a*]pyrene** **A diol epoxide**

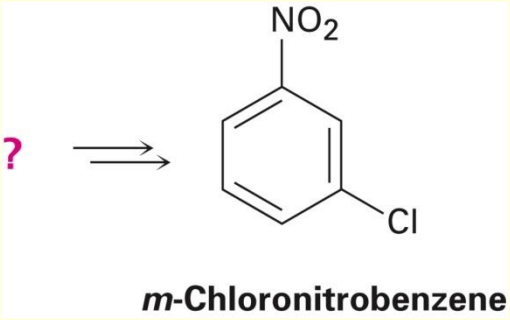
Aromatic Heterocycles

- Heterocyclic compounds contain elements other than carbon in a ring, such as N,S,O
- Aromatic compounds can have elements other than carbon in the ring
- There are many heterocyclic aromatic compounds and many are very common
- Cyclic compounds that contain only carbon are called carbocycles (not homocycles)
- Nomenclature is specialized

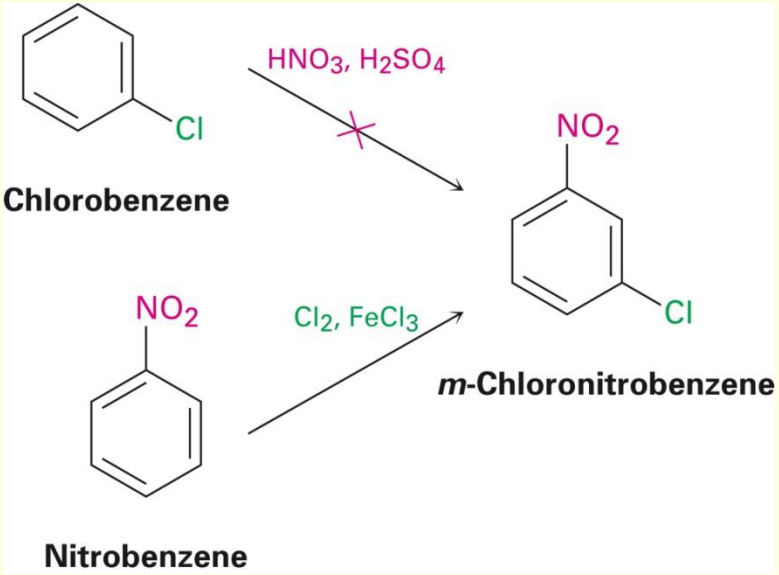


5.10 Organic Synthesis

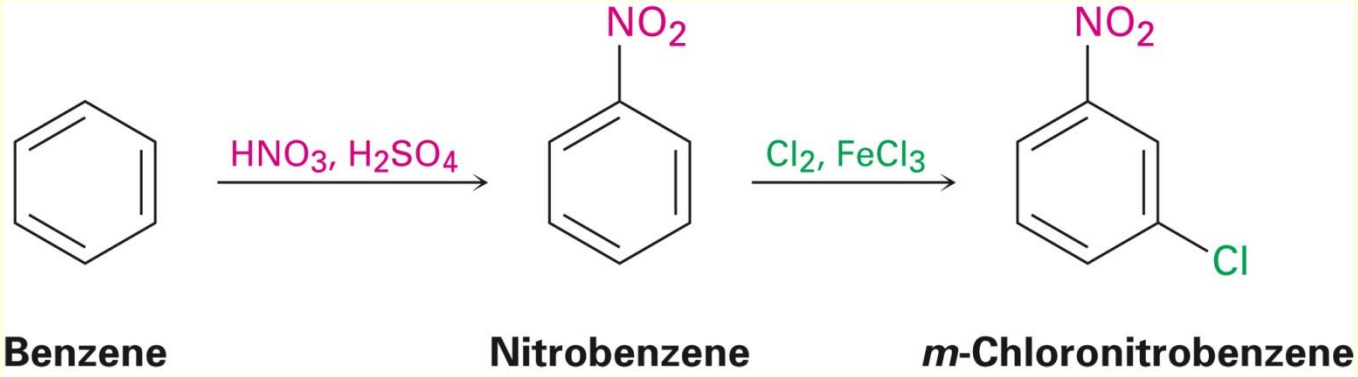
Syntheses of complex molecules from simpler precursors



Strategy



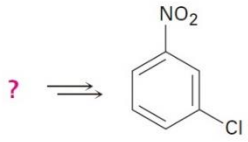
Solution



Worked Example 5.5 Synthesizing a Substituted Aromatic Compound

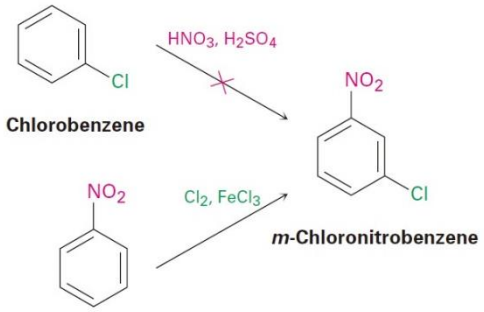
Synthesize *m*-chloronitrobenzene starting from benzene.

Strategy Work backward by first asking, "What is an immediate precursor of *m*-chloronitrobenzene?"



***m*-Chloronitrobenzene**

There are two substituents on the ring, a –Cl group, which is ortho- and para-directing, and an $-NO_2$ group, which is meta-directing. We can't nitrate chlorobenzene because the wrong isomers (*o*- and *p*-chloronitrobenzenes) would result, but chlorination of nitrobenzene should give the desired product.

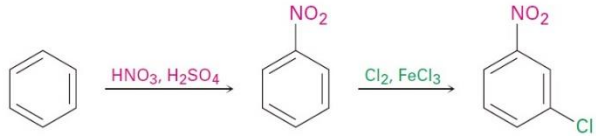


Chlorobenzene ***m*-Chloronitrobenzene**

Nitrobenzene

"What is an immediate precursor of nitrobenzene?" Benzene, which can be nitrated.

Solution We've solved the problem in two steps:

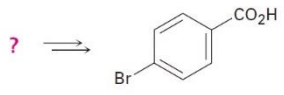


Benzene **Nitrobenzene** ***m*-Chloronitrobenzene**

Worked Example 5.6 Synthesizing a Substituted Aromatic Compound

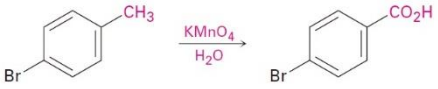
Synthesize *p*-bromobenzoic acid starting from benzene.

Strategy Work backward by first asking, "What is an immediate precursor of *p*-bromobenzoic acid?"



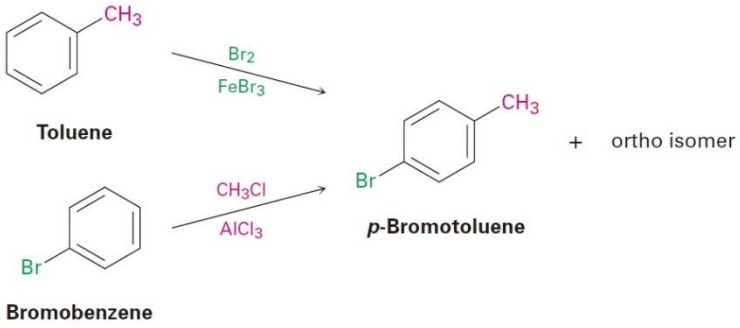
***p*-Bromobenzoic acid**

There are two substituents on the ring, a $-CO_2H$ group, which is meta-directing, and a –Br atom, which is ortho- and para-directing. We can't brominate benzoic acid because the wrong isomer (*m*-bromobenzoic acid) would be formed. We've seen, however, that oxidation of alkylbenzene side chains yields benzoic acids. An immediate precursor of our target molecule might therefore be *p*-bromotoluene.

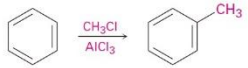


***p*-Bromotoluene** ***p*-Bromobenzoic acid**

"What is an immediate precursor of *p*-bromotoluene?" Perhaps toluene, because the methyl group would direct bromination to the ortho and para positions, and we could then separate isomers. Alternatively, bromobenzene might be an immediate precursor because we could carry out a Friedel–Crafts alkylation and obtain the para product. Both methods are satisfactory.



"What is an immediate precursor of toluene?" Benzene, which can be methylated in a Friedel–Crafts reaction.



Benzene **Toluene**

"Alternatively, what is an immediate precursor of bromobenzene?" Benzene, which can be brominated.

Benzene **Bromobenzene**

Solution Our backward synthetic (*retrosynthetic*) analysis has provided two workable routes from benzene to *p*-bromobenzoic acid.