Chapter 19
Aromatic Substitution Reactions

Review of Concepts
Fill in the blanks below. To verify that your answers are correct, look in your textbook at the end of Chapter 19. Each of the sentences below appears verbatim in the section entitled Review of Concepts and Vocabulary.

• In the presence of iron, an __________ aromatic substitution reaction is observed between benzene and bromine.
• Iron tribromide is a __________ acid that interacts with Br₂ and generates Br⁺, which is sufficiently electrophilic to be attacked by benzene.
• Electrophilic aromatic substitution involves two steps:
  o Formation of the __________ complex, or arenium ion.
  o Deprotonation, which restores ____________________.
• Sulfur trioxide (SO₃) is a very powerful __________ that is present in fuming sulfuric acid. Benzene reacts with SO₃ in a reversible process called __________.
• A mixture of sulfuric acid and nitric acid produces the nitronium ion (NO₂⁺). Benzene reacts with the nitronium ion in a process called __________.
• A nitro group can be reduced to an _______ group.
• Friedel–Crafts alkylation enables the installation of an alkyl group on ___________. When choosing an alkyl halide, the carbon atom connected to the halogen must be _______ hybridized.
• When treated with a Lewis acid, an acyl chloride will generate an __________ion, which is resonance stabilized and not susceptible to __________ rearrangements.
• When a Friedel–Crafts acylation is followed by a Clemmensen reduction, the net result is the installation of an ______ group.
• An aromatic ring is activated by a methyl group, which is an ______-______ __________.
• All activators are ______-______ directors
• A nitro group deactivates an aromatic ring and is a ______director.
• Most deactivators are ______ directors.
• Strong activators are characterized by the presence of __________ immediately adjacent to the aromatic ring.
• Strong deactivators are powerfully electron-withdrawing, either by __________ or __________
• When multiple substituents are present, the more powerful ___________ dominates the directing effects.
• In a nucleophilic aromatic substitution reaction, the aromatic ring is attacked by a __________. This reaction has three requirements: 1) the ring must contain a powerful electron-withdrawing group (typically a ______ group) 2) the ring must contain a ____________, and 3) the leaving group must be either _______ or ______ to the electron-withdrawing group.
• An elimination-addition reaction occurs via a ____________ intermediate.
Review of Skills

Fill in the blanks and empty boxes below. To verify that your answers are correct, look in your textbook at the end of Chapter 19. The answers appear in the section entitled SkillBuilder Review.

19.1 Identifying the Effects of a Substituent

PLACE EACH OF THE FOLLOWING GROUPS IN THE CORRECT CATEGORY BELOW.

<table>
<thead>
<tr>
<th>ACTIVATORS</th>
<th>DEACTIVATORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRONG</td>
<td>MODERATE</td>
</tr>
<tr>
<td>OR</td>
<td>R</td>
</tr>
</tbody>
</table>

19.2 Identifying Directing Effects for Disubstituted and Polysubstituted Benzene Rings

IN THE FOLLOWING COMPOUND, IDENTIFY THE POSITION THAT IS MOST REACTIVE TOWARDS ELECTROPHILIC AROMATIC SUBSTITUTION.

19.3 Identifying Steric Effects for Disubstituted and Polysubstituted Aromatic Benzene Rings

IN THE FOLLOWING COMPOUND, IDENTIFY THE POSITION THAT IS MOST REACTIVE TOWARDS ELECTROPHILIC AROMATIC SUBSTITUTION.

19.4 Using Blocking Groups to Control the Regiochemical Outcome of an Electrophilic Aromatic Substitution Reaction

IDENTIFY REAGENTS THAT WILL ACHIEVE THE FOLLOWING TRANSFORMATION:

1) 
2) 
3) Br
19.5 Proposing a Synthesis for a Disubstituted Benzene Ring

Identify a three-step process for achieving the following transformation:

1)  
2)  
3)  

19.6 Proposing a Synthesis for a Polysubstituted Benzene Ring

Complete the following retrosynthetic analysis:

\[
\text{O}_2\text{N} \quad \text{Br} \quad \rightarrow \quad \rightarrow \quad \rightarrow \quad \text{C}_6\text{H}_5
\]

19.7 Determining the Mechanism of an Aromatic Substitution Reaction

Indicate the mechanism that operates in each of the three scenarios shown in the following decision tree:

\[
\text{ELECTROPHILIC} \quad \text{NUCLEOPHILIC} \quad \text{YES} \quad \text{NO}
\]

\[
\text{ARE THE REAGENTS NUCLEOPHILIC OR ELECTROPHILIC?} \quad \text{ARE ALL THREE CRITERIA SATISFIED FOR A NUCLEOPHILIC AROMATIC SUBSTITUTION?}
\]
Review of Reactions
Identify the reagents necessary to achieve each of the following transformations. To verify that your answers are correct, look in your textbook at the end of Chapter 19. The answers appear in the section entitled Review of Reactions.

Electrophilic Aromatic Substitution

Nucleophilic Aromatic Substitution

Elimination-Addition
Solutions

19.1.

\[ \text{Base} \]

19.2.

\[ \text{- SO}_3 \]
19.3.

\[
\begin{align*}
&\text{D-O-SO-O-D} \\
&\text{D} \\
&\text{H D H D H D} \\
&\text{D} \\
&\text{O O O O H} \\
&\text{H D D H D} \\
&\text{D} \\
\end{align*}
\]

19.4.

\[
\begin{align*}
&\text{HONO} \rightarrow \text{HONO}_2 \rightarrow \text{HONO}_2^+ \rightarrow \text{HONO}_2^+ + \text{H}_2\text{O} \\
&\text{nitrone ion}
\end{align*}
\]

\[
\begin{align*}
&\text{HNO}_2 \rightarrow \text{HNO}_2^+ \\
&\text{HNO}_2^+ + \text{H}_2\text{O} \rightarrow \text{HNO}_2 \rightarrow \text{HNO}_2^+ \\
&\text{HNO}_2^+ \rightarrow \text{HNO}_2^+ + \text{H}_2\text{O} \\
&\text{NO}_2^+ \\
&\text{NO}_2
\end{align*}
\]

19.5.

a) \[\text{\large \text{c}}\]

b) \[\text{\large \text{b}}\]

c) \[\text{\large \text{c}}\] + \[\text{\large \text{c}}\]
19.6.

\[
\begin{array}{c}
\text{Cl-} \quad \text{Cl-} \quad \text{Cl-} \\
\text{H} \\
\end{array}
\]
19.7.

19.8.
a) It is necessary to perform an acylation followed by a Clemmensen reduction to avoid carbocation rearrangements.
b) It is necessary to perform an acylation followed by a Clemmensen reduction to avoid carbocation rearrangements.
c) It is necessary to perform an acylation followed by a Clemmensen reduction to avoid carbocation rearrangements.
d) The compounds can be made using a direct Friedel–Crafts alkylation.

19.9. It cannot be made via alkylation because the carbocation required would undergo a methyl shift to give a tertiary carbocation. It cannot be made via acylation followed by a Clemmensen reduction, because the product of a Clemmensen reduction has two benzylic protons. This compound has only one benzylic proton, which means that it cannot be made via a Clemmensen reduction.
19.10.

\[
\begin{align*}
\text{CHO}_2 \quad \text{CHO}_2 & \quad \text{CHO}_2 \\
\text{CHO}_2 \quad \text{CHO}_2 & \rightarrow \quad \text{CHO}_2 \\
\text{CHO}_2 \quad \text{CHO}_2 & \quad \text{CHO}_2 \\
\end{align*}
\]

19.11.

\[
\begin{align*}
\text{C}_6\text{H}_4\text{Br} & \quad + \quad \text{C}_6\text{H}_4\text{Br} \\
\end{align*}
\]

19.12.

\[
\begin{align*}
\text{C}_6\text{H}_4\text{NO}_2 \quad \text{OEt} & \quad + \quad \text{C}_6\text{H}_4\text{NO}_2 \quad \text{OEt} \\
a) \\
\end{align*}
\]
19.13. As shown below, attack at C4 or C6 produces a sigma complex in which two of the resonance structures have a positive charge next to an electron-withdrawing group (NO$_2$). These resonance structures are less contributing to the resonance hybrid, thereby destabilizing the sigma complex. In contrast, attack at C5 produces a sigma complex for which none of the resonance structures have a positive charge next to a nitro group.
19.14. The chlorine atom in chlorobenzene deactivates the ring relative to benzene. If benzene requires a Lewis acid for chlorination, than chlorobenzene should certainly require a Lewis acid for chlorination.

19.15. Ortho attack and para attack are preferred because each of these pathways involves a sigma complex with four resonance structures (shown below). Attack at the meta position involves formation of a sigma complex with only three resonance structures, which is not as stable as a sigma complex with four resonance structures. The reaction will proceed more rapidly via the lower energy sigma complex, so attack takes place at the ortho and para positions in preference to the meta position.

19.16.
   a) The nitro is strongly deactivating and meta-directing.
   b) An acyl group is moderately deactivating and meta-directing.
   c) A bromine atom weakly deactivating and ortho, para-directing.
   d) This group is moderately deactivating and meta-directing.
   e) This group is moderately deactivating and meta-directing.
   f) This group is moderately activating and ortho, para-directing.

19.17. This ring is moderately activated
19.18.

Increasing reactivity toward electrophilic aromatic substitution

19.19.

a)

b)

O

N

CH₃

NO₂

O

N

CH₃

NO₂

C

B

D

A

19.20.

a)
b)

\[
\begin{align*}
\text{O} & \text{Me} \quad \text{Br} & \quad \text{O} & \text{Me} \quad \text{Br} \\
\text{Br} & \quad \text{FeBr}_3 & \quad \text{Br} & \quad \text{FeBr}_3
\end{align*}
\]

\[\text{Br}_2\]

\[\text{FeBr}_3\]

c)

\[
\begin{align*}
\text{Br} & \quad \text{Fuming} & \quad \text{H}_2\text{SO}_4 & \quad \text{Br} \\
\text{O} & \quad \text{O} & \quad \text{H}_3\text{O} & \quad \text{S}
\end{align*}
\]

19.21.

\[
\begin{align*}
\text{Br} & \quad \text{Br} & \quad \text{Br} & \quad \text{Br} \\
\text{Br} & \quad \text{Br} & \quad \text{Br} & \quad \text{Br}
\end{align*}
\]

19.22.

\[
\begin{align*}
a) & \quad \text{HO} & \quad \text{NO}_2 \\
b) & \quad \text{O}_2\text{N} & \quad \text{OMe} \\
c) & \quad \text{O}_2\text{N} & \quad \text{OMe}
\end{align*}
\]

19.23. All three available positions are sterically hindered.

19.24.

\[
\begin{align*}
\text{O} & \quad \text{O} \\
\text{Br} & \quad \text{Br}
\end{align*}
\]

\[\text{Br}_2\]

\[\text{FeBr}_3\]

19.25.

a) Yes   b) No   c) Yes   d) No

\[ \text{HO}_3\text{S} \xrightarrow{\text{dilute } \text{H}_2\text{SO}_4} \text{SO}_3\text{H} \]

19.27.

a) The nitro group must be installed in a position that is *meta* to each of the OH groups. Even with a blocking group, *meta* attack cannot be achieved on a highly activated ring.
b) The position that must undergo bromination is too sterically hindered because of the presence of the *tert*-butyl groups.

19.28.

a) Cl\(_2\), AlCl\(_3\)
b) HNO\(_3\), H\(_2\)SO\(_4\)
c) Br\(_2\), FeBr\(_3\)
d) CH\(_3\)CH\(_2\)Cl, AlCl\(_3\)
e) CH\(_3\)CH\(_2\)COCl, followed by HCl, Zn[Hg], heat
f) (CH\(_3\))\(_2\)CHCl, AlCl\(_3\)
g) HNO\(_3\), H\(_2\)SO\(_4\), followed by HCl, Zn
h) CH\(_3\)Cl, AlCl\(_3\), followed by KMnO\(_4\), NaOH, heat, followed by H\(_3\)O\(^+\)
i) CH\(_3\)Cl, AlCl\(_3\)

19.29.

a)

b)

c)

d)

e)

f)

19.30.

a)  

1) Br\(_2\), AlBr\(_3\)
2) Fuming H\(_2\)SO\(_4\)
3) HNO\(_3\), H\(_2\)SO\(_4\)
4) dilute H\(_2\)SO\(_4\)
5) HCl, Zn

b)  

1) HNO\(_3\), H\(_2\)SO\(_4\)
2) Cl\(_2\), AlCl\(_3\)
c) 1) \( \text{CH}_2\text{CH}_2\text{COCl}, \text{AlCl}_3 \)  
2) \( \text{HCl}, \text{Zn[Hg]}, \text{heat} \)  
3) \( \text{HNO}_3, \text{H}_2\text{SO}_4 \)  
4) \( \text{HCl}, \text{Zn} \)

---

d) 1) \( \text{HNO}_3, \text{H}_2\text{SO}_4 \)  
2) \( \text{Cl}_2, \text{AlCl}_3 \)  
3) \( \text{HCl}, \text{Zn} \)

---

e) 1) \( \text{CH}_2\text{Cl}, \text{AlCl}_3 \)  
2) \( \text{excess NBS}, \text{heat} \)  
3) \( \text{Br}_2, \text{AlBr}_3 \)

---

f) 1) \( \text{Br}_2, \text{AlBr}_3 \)  
2) \( \text{CH}_3\text{Cl}, \text{AlCl}_3 \)  
3) \( \text{excess NBS}, \text{heat} \)

---

g) 1) \( \text{AlCl}_3, \)  
2) \( \text{HCl}, \text{Zn[Hg]}, \text{heat} \)  
3) \( \text{Fuming } \text{H}_2\text{SO}_4 \)  
4) \( \text{CH}_3\text{Cl}, \text{AlCl}_3 \)  
5) \( \text{Dilute } \text{H}_2\text{SO}_4 \)

---

h) 1) \( (\text{CH}_3)_2\text{CHCl}, \text{AlCl}_3 \)  
2) \( \text{Fuming } \text{H}_2\text{SO}_4 \)  
3) \( \text{HNO}_3, \text{H}_2\text{SO}_4 \)  
4) \( \text{Dilute } \text{H}_2\text{SO}_4 \)
19.31. The para product will be more strongly favored over the ortho product if the tert-butyl group is installed first. The steric hindrance provided by a tert-butyl group is greater than the steric hindrance provided by an isopropyl group. Of the following two possible pathways, the first should provide a greater yield of the desired product.

19.32. 

a) Nitration cannot be achieved effectively in the presence of an amino group. 
b) Each of the two alkyl groups is ortho-para directing, but the two groups are meta to each other. A Friedel-Crafts acylation will not work in this case (see solution to problem 19.9)

19.33. 

a)
b) The sixth position is sterically hindered by the presence of the Cl atoms. 

c) The ring is deactivated because all five groups are deactivators.
19.36. \[
\begin{align*}
\text{Ph} & \quad 1) \text{Cl}_2, \text{AlCl}_3 \\
& \quad 2) \text{HNO}_3, \text{H}_2\text{SO}_4 \\
& \quad 3) \text{NaOH}, \text{heat} \\
& \quad 4) \text{H}_3\text{O}^+ \\
& \quad 5) \text{HCl}, \text{Zn}
\end{align*}
\]

19.37. 
a) Each additional nitro group serves as a reservoir of electron density and provides for an additional resonance structure in the sigma complex, thereby stabilizing the sigma complex and lowering the energy of activation for the reaction.
b) No, a fourth nitro group would not be *ortho* or *para* to the leaving group, and therefore cannot function as a reservoir.

19.38. 

19.39. \[
\text{Ph} \quad 1) \text{Cl}_2, \text{AlCl}_3 \\
& \quad 2) \text{NaOH}, \text{heat} \\
& \quad 3) \text{CH}_3\text{I}
\]

19.40. 
a) \[
\begin{align*}
\text{Br} & \quad \overset{-\text{OH}}{\text{H}} \\
& \quad \overset{-\text{Br}}{\text{H}} \\
& \quad \overset{-\text{OH}}{\text{H}} \\
& \quad \overset{-\text{OH}}{\text{H}} \\
& \quad \overset{-\text{OH}}{\text{H}}
\end{align*}
\]
b) 

\[ \begin{align*}
\text{H} & \quad \text{Br} \quad \text{Br} \\
\text{FeBr}_3 & \rightarrow \\
\text{Br} \quad \text{FeBr}_3 & \quad \text{H} \quad \text{Br} \\
\text{FeBr}_3 & \rightarrow \\
\text{Br} \quad \text{FeBr}_3 & \quad \text{H} \quad \text{Br} \\
+ \text{FeBr}_3 + \text{HBr}
\end{align*} \]

c) 

\[ \begin{align*}
\text{O}_2\text{N} & \quad \text{I} \\
\text{NH}_2 & \quad \text{NH}_2 \\
\text{O}_2\text{N} & \quad \text{NH}_2
\end{align*} \]
19.41. 

\[
\begin{align*}
\text{Cl} & \quad \text{NaOH} \quad \text{heat} \\
& \quad \text{HO} + \text{HO} + \text{HO}
\end{align*}
\]

19.42. 

a) 

\[
\begin{align*}
\text{NO}_2 & \quad \text{ONa} \\
& \quad \text{Br}
\end{align*}
\]

b) 

c) No 

d) Yes

19.43. 

\[
\begin{align*}
\text{O=Cl} & \quad \text{AlCl}_3 \\
\text{AlCl}_3 & \quad \text{EtCl} \\
\text{Fuming H}_2\text{SO}_4 & \quad \text{HNO}_3, \text{H}_2\text{SO}_4 \\
\text{HCl, Zn[Hg], heat} & \quad \text{EtCl} \\
\text{KMnO}_4, \text{NaOH, heat} & \quad \text{excess NBS, heat} \\
\text{Br}_2 & \quad \text{EtCl} \\
\text{Br}_2 & \quad \text{Cl}_2 \\
\text{H}_2\text{N} & \quad \text{HCl, Zn} \\
\end{align*}
\]
19.44. Increasing Reactivity toward Electrophilic Aromatic Substitution

\[
\begin{array}{cccccc}
& \text{Br} & \text{Br} & \text{Br} & \text{Br} & \text{Br} \\
\text{Br} & \text{Br} & \text{Br} & \text{Br} & \text{Br} \\
\text{Br} & \text{Br} & \text{Br} & \text{Br} & \text{Br} \\
\text{Br} & \text{Br} & \text{Br} & \text{Br} & \text{Br} \\
\text{Br} & \text{Br} & \text{Br} & \text{Br} & \text{Br} \\
\end{array}
\]

19.45.

\[
\begin{array}{cc}
\text{NO}_2 & \text{HO} \text{OMe} \\
\text{least activated} & \text{most activated}
\end{array}
\]

19.46.

\[
\text{NO}_2 \text{Br} + \text{O}_2 \text{N} \text{Br} \quad \text{NO}_2 \text{H} + \text{O}_2 \text{N}
\]

a) \quad \text{O}_2 \text{N} \text{NO}_2 \\
b) \quad \text{O}_2 \text{N} \text{CO} \\
c) \quad \text{O}_2 \text{N} \text{OMe} \\
d) \quad \text{O}_2 \text{N} \text{OMe}
\]

19.47.

\[
\begin{array}{cccccc}
\text{Cl} & \text{OH} & \text{O} \text{H} & \text{OH} & \text{NO}_2 \\
\text{SO}_3 \text{H} & \text{SO}_3 \text{H} & \text{SO}_3 \text{H} & \text{SO}_3 \text{H} & \text{SO}_3 \text{H} \\
\text{Br} & \text{SO}_3 \text{H} & \text{SO}_3 \text{H} & \text{SO}_3 \text{H} & \text{SO}_3 \text{H} \\
\end{array}
\]
19.48.
a) This group is an activator and an ortho,para-director.
b) This group is an activator and an ortho,para-director.
c) This group is an activator and an ortho,para-director.
d) This group is a deactivator and an ortho,para-director.
e) This group is a deactivator and a meta-director.
f) This group is a deactivator and a meta-director.
g) This group is a deactivator and a meta-director.
h) This group is a deactivator and a meta-director.
i) This group is a deactivator and an ortho,para-director.
j) This group is a deactivator and a meta-director.

19.49.

\[
\begin{align*}
\text{a)} & \quad \text{Cl} \quad \text{Cl} \\
\text{b)} & \quad \text{unreactive} \\
\text{c)} & \quad \text{unreactive} \\
\text{d)} & \quad \text{I} \\
\text{e)} & \quad \text{I} \\
\text{f)} & \quad \text{unreactive} \\
\text{g)} & \quad \text{unreactive} \\
\text{h)} & \quad \text{unreactive}
\end{align*}
\]

19.50.

\[
\begin{align*}
\text{a)} & \quad \text{Br} \\
\text{b)} & \quad \text{NO}_2 \\
\text{c)} & \quad \text{Br} \\
\text{d)} & \quad \text{Br} \\
\text{e)} & \quad \text{SO}_3\text{H} \\
\text{f)} & \quad \text{O} \quad \text{COH} \\
\text{g)} & \quad \text{O} \quad \text{COH} \\
\text{h)} & \quad \text{Br} \\
\text{i)} & \quad \text{Br} \quad \text{NO}_2
\end{align*}
\]
19.51.

\[
\begin{align*}
\text{O}_2\text{N} \quad \text{HNO}_3 / \text{H}_2\text{SO}_4
\end{align*}
\]

19.52.

\[
\begin{align*}
\text{H} \quad \text{HOSO}_3\text{H}
\end{align*}
\]

19.53.

a)

\[
\begin{align*}
\text{ClCl} \quad \text{AlCl}_3
\end{align*}
\]

\[
\begin{align*}
\text{ClCl} \quad \text{AlCl}_3 + \text{HCl}
\end{align*}
\]
d) 

\[ \text{HCl} + \text{AlCl}_3 \rightarrow \text{HCl} + \text{AlCl}_3 \]

\[ \text{C}_6\text{H}_5\text{H} \rightarrow \left[ \begin{array}{c} +\text{H} \\ +\text{H} \end{array} \right] \left[ \begin{array}{c} +\text{H} \\ +\text{H} \end{array} \right] \left[ \begin{array}{c} +\text{Br} \\ +\text{Br} \end{array} \right] \]

\[ \text{C}_6\text{H}_5\text{H} \rightarrow \text{C}_6\text{H}_5\text{Br} \]

\[ \text{C}_6\text{H}_5\text{Br} + \text{FeBr}_3 + \text{HBr} \]

e) 

\[ \text{Br}_2 + \text{Fe} \rightarrow \text{Br}_2 \text{FeBr}_3 \]

\[ \text{Br}_2 \text{FeBr}_3 \rightarrow \text{Br}_2 \text{FeBr}_3 \]

\[ \text{C}_6\text{H}_5\text{H} \rightarrow \left[ \begin{array}{c} +\text{Br} \\ +\text{Br} \end{array} \right] \left[ \begin{array}{c} +\text{Br} \\ +\text{Br} \end{array} \right] \left[ \begin{array}{c} +\text{Br} \\ +\text{Br} \end{array} \right] \]

\[ \text{C}_6\text{H}_5\text{Br} + \text{FeBr}_3 + \text{HBr} \]
19.54.

a)
b)

\[
\begin{align*}
\text{HCl} + \text{AlCl}_3 & \rightarrow \text{HCl} + \text{AlCl}_3 \\
\text{HCl} & \rightarrow \text{AlCl}_3 \\
\text{HCl} & \rightarrow \text{AlCl}_3 \\
\text{HCl} & \rightarrow \text{AlCl}_3 \\
\text{HCl} & \rightarrow \text{AlCl}_3 \\
\text{HCl} & \rightarrow \text{AlCl}_3 \\
\end{align*}
\]
19.55.

19.56.

19.57.
a) The second step of the synthesis will not work, because a strongly deactivated ring will not undergo a Friedel-Crafts alkylation. The product of the first step, nitrobenzene, will be unreactive in the second step.
b) The second step of the synthesis will not efficiently install a propyl group, because a carbocation rearrangement can occur, which will result in the installation of an isopropyl group.
c) The second step of the synthesis will not install the acyl group in the meta position. It will be installed in a position that is either ortho or para to the bromine atom.
d) The second step of the synthesis will not install the bromine atom in the ortho position, because of steric hindrance from the tert-butyl group. Bromination will occur primarily at the para position.

19.59.

a)

b)

c)

d)
19.60.

\[
\begin{align*}
\text{Br}^+ & \rightarrow \text{NH}_2^- \\
\text{Br}^- & \rightarrow \text{NH}_2^- \\
\end{align*}
\]

19.61.

\[
\begin{align*}
\text{O}_2\text{N} & \quad \text{OH} \\
\text{NO}_2 & \quad \text{NO}_2 \\
\text{NO}_2 & \quad \text{NO}_2 \\
\end{align*}
\]

2,4,6-trinitrophenol
(picric acid)
19.62.
19.63.

19.64.

d) The nitroso group should be ortho-para directing, because attack at the ortho or para position generates a sigma complex with an additional resonance structure.

e) The nitroso group is a deactivator, yet it is an ortho-para director, just like a chlorine atom.

19.65.
19.66.
a) Toluene is the only compound containing an activated ring, and it is expected to undergo a Friedel-Crafts reaction most rapidly to give ortho-ethyltoluene and para-ethyltoluene.
b) Anisole is the most activated compound (among the three compounds), and is expected to undergo a Friedel-Crafts reaction most rapidly to give ortho-ethylanisole and para-ethylanisole.

19.67.

\[
\begin{array}{ccc}
\text{Compound A} & \text{Compound B} \\
\end{array}
\]

19.68.

a) 

\[
\begin{align*}
\text{OCH}_3 & \text{OCH}_3 \\
& \rightarrow \\
& \text{NO}_2 \\
\end{align*}
\]

\[
\begin{align*}
\text{B} & \text{r} \\
& \rightarrow \\
& \text{Br} \\
\end{align*}
\]

b) 

\[
\begin{align*}
\text{OCH}_3 & \rightarrow \\
& \text{NO}_2 \\
\end{align*}
\]

\[
\begin{align*}
\text{Br} & \text{Br} \\
& \rightarrow \\
& \text{Br} \\
\end{align*}
\]

\[
\begin{align*}
\text{AlBr}_3 & \\
& \rightarrow \\
\end{align*}
\]

\[
\begin{align*}
\text{1) } \text{HNO}_3, \text{H}_2\text{SO}_4 & \\
\text{2) } \text{Br}_2, \text{AlBr}_3 & \\
& \rightarrow \\
\end{align*}
\]

c) 

\[
\begin{align*}
\text{NO}_2 & \rightarrow \\
\text{O}_3 & \\
\end{align*}
\]

\[
\begin{align*}
\text{Fuming H}_2\text{SO}_4 & \\
\text{HNO}_3, \text{H}_2\text{SO}_4 & \\
\text{Dilute H}_2\text{SO}_4 & \\
\text{K MnO}_4, \text{NaOH, heat} & \\
\text{H}_3\text{O}^+ & \\
& \rightarrow \\
\end{align*}
\]

d) 

\[
\begin{align*}
\text{NO}_2 & \rightarrow \\
\text{O}_3 & \\
\end{align*}
\]

\[
\begin{align*}
\text{K MnO}_4, \text{NaOH, heat} & \\
\text{H}_3\text{O}^+ & \\
\text{HNO}_3, \text{H}_2\text{SO}_4 & \\
& \rightarrow \\
\end{align*}
\]
19.69.

- a) 
  \[
  \begin{align*}
  &\text{O} \\
  &\text{O} \\
  &\text{Br} \\
  &\text{O} \\
  &\text{Cl}
  \end{align*}
  \]

- b) 
  \[
  \begin{align*}
  &\text{NO}_2 \\
  &\text{O} \\
  &\text{OCH}_3
  \end{align*}
  \]

- c) 
  \[
  \begin{align*}
  &\text{SO}_3\text{H}
  \end{align*}
  \]

- d) 
  \[
  \begin{align*}
  &\text{Br} \\
  &\text{NO}_2 \\
  &\text{NO}_2
  \end{align*}
  \]

19.70.

- a) 
  \[
  \begin{align*}
  &\text{O}_2\text{N} \\
  &\text{Cl} \\
  &\text{O} \\
  &\text{Cl}
  \end{align*}
  \]
  \[
  \begin{align*}
  &\text{H}_3\text{CO} \\
  &\text{OCH}_3
  \end{align*}
  \]

- b) 
  \[
  \begin{align*}
  &\text{H}_3\text{CO} \\
  &\text{Cl}
  \end{align*}
  \]
  \[
  \begin{align*}
  &\text{OCH}_3
  \end{align*}
  \]
19.71. Attack at the C2 position proceeds via an intermediate with three resonance structures:

In contrast, attack at the C3 position proceeds via an intermediate with only two resonance structures:

The intermediate for C2 attack is lower in energy than the intermediate for C3 attack. The transition state leading to the intermediate of C2 attack will therefore be lower in energy than the transition state leading to the intermediate of C3 attack. As a result, C2 attack occurs more rapidly.

19.72.

**a)**

\[
\begin{align*}
&\text{1) } \text{Cl}_2, \text{AlCl}_3 \\
&\text{2) } \text{HNO}_3, \text{H}_2\text{SO}_4 \\
&\text{3) } \text{NaOH} \\
&\text{4) } \text{CH}_3\text{I} \\
&\text{5) } \text{Br}_2, \text{AlBr}_3
\end{align*}
\]

**b)**

\[
\begin{align*}
&\text{1) } (\text{CH}_3)_2\text{CHCl}, \text{AlCl}_3 \\
&\text{2) } (\text{CH}_3)_2\text{CHCl}, \text{AlCl}_3 \\
&\text{3) } \text{HNO}_3, \text{H}_2\text{SO}_4 \\
&\text{4) } \text{KMnO}_4, \text{NaOH}, \text{heat} \\
&\text{5) } \text{H}_3\text{O}^+
\end{align*}
\]

**c)**

\[
\begin{align*}
&\text{1) } \text{HNO}_3, \text{H}_2\text{SO}_4 \\
&\text{2) } \text{Cl}_2, \text{AlCl}_3 \\
&\text{3) } \text{HCl}, \text{Zn}
\end{align*}
\]
d) \[ \text{BrCl} \]

1) \((\text{CH}_3)_3\text{CCl}, \text{AlCl}_3\)

2) \(\text{HNO}_3, \text{H}_2\text{SO}_4\)

3) \(\text{Br}_2, \text{AlBr}_3\)

4) \(\text{Cl}_2, \text{AlCl}_3\)

---

e) \[ \text{CH}_3\text{CH}_2\text{COCl}, \text{AlCl}_3 \]

1) \(\text{CH}_3\text{CH}_2\text{COCl}, \text{AlCl}_3\)

2) \(\text{HNO}_3, \text{H}_2\text{SO}_4\)

3) \(\text{Cl}_2, \text{AlCl}_3\)

---

f) \[ \text{Cl}_2, \text{AlCl}_3 \]

1) \((\text{CH}_3)_2\text{CHCl}, \text{AlCl}_3\)

2) \(\text{Br}_2, \text{AlBr}_3\)

3) \(\text{KMnO}_4, \text{NaOH}, \text{heat}\)

4) \(\text{H}_3\text{O}^+\)

4) \(\text{HNO}_3, \text{H}_2\text{SO}_4\)

5) \(\text{Cl}_2, \text{AlCl}_3\)

---

g) \[ \text{OEt} \]

1) \(\text{Cl}_2, \text{AlCl}_3\)

2) \(\text{HNO}_3, \text{H}_2\text{SO}_4\)

3) \(\text{NaOEt}, \text{heat}\)

4) \(\text{Cl}_2, \text{AlCl}_3\)

---

h) \[ \text{Cl}_2, \text{AlCl}_3 \]

1) \((\text{CH}_3)_2\text{CHCl}, \text{AlCl}_3\)

2) \(\text{CH}_3\text{CH}_2\text{COCl}, \text{AlCl}_3\)

3) \(\text{HNO}_3, \text{H}_2\text{SO}_4\)

4) \(\text{Cl}_2, \text{AlCl}_3\)

---

i) \[ \text{O}_2\text{N} \]

1) \(\text{Cl}_2, \text{AlCl}_3\)

2) \(\text{Br}_2, \text{AlBr}_3\)

3) \(\text{HNO}_3, \text{H}_2\text{SO}_4\)
19.73.

\[ \text{1,2,4-trimethylbenzene} \]

19.74. Bromination at the para position occurs more rapidly because ortho attack is sterically hindered by the ethyl group:

\[
\begin{align*}
\text{Zn} & \quad \text[Hg], \quad \text{HCl, heat} \\
\text{Compound A} & \quad \overset{\text{Zn}[\text{Hg}], \text{HCl, heat}}{\longrightarrow} \quad \text{Compound B} \\
\text{Br}_2 & \quad \text{AlBr}_3 \\
\end{align*}
\]

\[
\begin{align*}
\text{Br} & \quad \text{Br} \\
\text{(major)} & \\
\end{align*}
\]

19.75.

a)

\[
\begin{align*}
\text{AlCl}_3 & \quad \overset{\text{AlCl}_3}{\longrightarrow} \quad \text{Br}_2 \\
\text{Br}_2 & \quad \text{AlBr}_3 \\
\end{align*}
\]

b)

\[
\begin{align*}
\text{AlBr}_3 & \quad \overset{\text{Br}_2, \text{AlBr}_3}{\longrightarrow} \quad \text{Br}_2 \\
\end{align*}
\]

19.76.

a)

b) The reaction proceeds via a carbocation intermediate, which can be attacked from either face, leading to a racemic mixture.
19.77.
The OH group activates the ring toward electrophilic aromatic substitution because the OH group donates electron density via resonance.

![Resonance Structures]

This effect gives electron density primarily to the ortho and para positions, as seen in the resonance structures above. These positions are shielded, and the protons at these positions are expected to produce signals farther upfield than protons at the meta position. According to this reasoning, the meta protons correspond with the signal at 7.2ppm.

19.78.

\[
\text{2,4,6-trinitrotoluene}
\]

19.79.

a) A phenyl group is an ortho-para director, because the sigma complex formed from ortho attack or para attack is highly stabilized by resonance (the positive charge is spread over both rings). The ortho position is sterically hindered while the para position is not, so we expect nitration to occur predominantly at the para position:

![Nitration Reaction]

b) This group withdraws electron density from the ring via resonance (the resonance structures have a positive charge in the ring). As a result, this group is a moderate deactivator, and therefore a meta-director:

![Deactivation Reaction]
19.81.

[Diagram of a chemical reaction showing the formation of Bakelite through step-by-step reactions involving aldehydes, hydroxyl groups, and sulfuric acid.]
19.82. The amino group in $N,N$-dimethylaniline is a strong activator, and therefore, an ortho-para director. For this reason, bromination occurs at the ortho and para positions. However, in acidic conditions, the amino group is protonated to give an ammonium ion. Unlike the amino group, an ammonium ion is a strong deactivator and a meta director. Under these conditions, nitration occurs primarily at the meta position.