**Objective 6.** Identify an aromatic compound and apply substitution, elimination, and oxidation-reduction principles to aromatic side chain reactions.

**Skills:** Draw structure  
ID structural features and reactive sites (alpha C, beta C, LG, etc.)  
ID Nu\(^-\) and E\(^+\)  
use curved arrows to show bonds breaking and forming  
show delocalized electrons with resonance structures.

**Key ideas:**  
Aromatic compounds are more stable than conjugated dienes because of delocalization (draw resonance). See criteria for aromaticity.

New reaction is oxidation of R for form acid.
Many Compounds Contain Arenes and Aromatics

benzene  phenol  benzoic acid  salicylic acid

aspirin  Ibuprofen  vanillan

Arene is an aromatic hydrocarbon
Insecticides, pesticides, and germicides contain benzene

methyl parathion
triclosan
bifenthrin
chlorpyrifos
carbaryl
atrazine
Licorice may aid battle against dental cavities (CEN, 2/6/06, p. 25)
Licorice is an important herb in Chinese medicine, and its derivatives are used worldwide as flavoring and sweetening agents in tobacco, gum, candy, and beverages.

Compounds isolated from licorice root (Glycyrrhiza uralensis) exhibit potent antibacterial activity against Streptococcus mutans, an oral pathogen that causes tooth decay (J. Nat. Prod. 2006, 69, 121). Toothpaste companies are interested in the new compounds.
α-tocopherol (form of Vitamin E) is nature’s most potent phenol antioxidant (effective radical scavengers that inhibit oxidation of lipids that contribute to atherosclerosis and Alzheimer’s disease).

Incorporate N in ring = 100x more effective radical scavenger. Why do you think this compound works better?

\[
\begin{align*}
\text{α-tocopherol} & \quad \text{100x more effective radical scavenger than α-tocopherol} \\
\end{align*}
\]

Phenolic H atom transferred to lipid peroxyl radical terminates chain reaction.
A family of broadly emitting carbazolyl compounds (shown here under ultraviolet illumination) may lead to inexpensive OLEDs.
OLEDs need colored compounds

http://cen.acs.org/articles/94/i28/rise-OLED-displays.html

How OLEDs work
An OLED can be manufactured using a variety of substrates, including glass, plastic, and metal. It consists of several layers of organic materials sandwiched between two electrodes. When a voltage is applied across the OLED, a current of electrons flows from the cathode to the anode, adding electrons to the emissive layer and taking them away—or creating electron holes—at the anode. At the boundary between these layers, electrons find holes, fall in, and give up a photon of light. The color of the light depends on the type of organic molecule in the emissive layer. The most advanced OLEDs use electron and hole injection and transport layers to modulate electron movement.
Spray-cast polymer films, shown in their neutral colored state, are made possible by polythiophene synthetic modifications. R = 2-ethylhexyl, R1 = octyl, and R2 = ethyl.
Fluorescent molecules to:
• stain specific cell types (biology),
• monitor enzyme activity (biochem),
• detect molecules in environment (chem)

Are these compounds conjugated?
Are these compounds aromatic?
A new rewritable paper contains *hydrochromic* molecules—dyes that turn colors when exposed to water. Pages impregnated with the dyes can be printed using ordinary ink-jet printer technology by replacing the ink in cartridges with water.
Various hydrochromic molecules switch to colorful isomers when exposed to water.
Organic compounds substituting for components such as wires, transistors, and rectifiers are all covalently bonded. An STM tip initiates polymerization of the diacetylene groups in long-chain carboxylic acid molecules on a surface to form a wire (yellow) that then forms a bond to the single phthalocyanine molecule (blue). R=CH₃(CH₂)₁₅ and R´=HOOC(CH₂)₈.

http://cen.acs.org/articles/89/i20/Wiring-Single-Molecule-Circuit.html
Aromatic compounds have many applications

CEN, 6/25/01, p. 11 molecules that act as switches

CEN, 1/3/00, p. 22 molecular rectifier used in nanowires
Molecular Wire Conducts Easily

Wire tethered to gold substrate.
Wire lengths range from 1 to 6 repeating units (2.4 nm to 11.0 nm).
Longest wire has conductance of 2.9 nanosiemens (3 orders of magnitude higher than other carbon based wires of comparable length.)
Naming Arenes
R groups: Phenyl group and benzyl group

Common Names for Substituted benzenes: Table 11.1, p. 436

toluene
aniline
anisole
Disubstituted benzenes are named ortho, meta, and para:
1,2 = Ortho
1,3 = meta
1,4 = para

Name the following compounds. Use common name to start.

ortho-xylene  meta-xylene  para-xylene
Aromatic Means Extra Stability

Criteria:
1. Conjugated (alternating C-C and C=C bonds)
2. Ring
3. Planar
4. Huckel Rule: $4n + 2 \pi$ electrons = 2, 6, 10, .. \( \pi \) e-.
\( \pi \) electrons are delocalized.
5. Smells (aroma)?

**Antiaromatic** compounds have $4n \pi$ electrons.

Are antiaromatic compounds as stable as aromatic compounds?
**Benzene is Aromatic**

1. Conjugated (alternating C-C and C=C bonds)
2. Ring
3. Planar
4. $6\pi$ electrons = fits Huckel Rule ($4n + 2$)

Why is each C-C the same length? [source](http://cen.acs.org/articles/89/i46/Switching-Off-Aromaticity.html)

Scientists use laser pulse to switch off aromaticity.

[source](http://www.chem.ucalgary.ca/courses/351/Carey5th/Ch11/ch11-3.html)
The smell of BACON is aromatic (from LearnBacon.com)

2,5-dimethylpyrazine  2-ethyl-3,5-dimethylpyrazine

Apply the 4 rules to show these 2 compounds are aromatic.
1. Conjugated?
2. Ring?
3. Planar?
4. fits Huckel Rule (4n + 2 pi electrons)?
**Objective:** Identify the aromatic compound

cyclopentadiene  
cyclopentadiene anion  
pyridine  
pyrrole  
furan
DNA Bases are Aromatic
How many $\pi$ electrons does each base have?

- Purine
- Adenine
- Guanine
- Pyrimidine
- Thymine
- Cytosine
Which Biomolecule Is Aromatic?

pyridoxyl
Vitamin B₆

NAD⁺

glucose
At Ames Research Center, NASA chemists search for clues to life
CENEAR 77 51 pp. 29-32, December 20, 1999

Interstellar ices may spawn biologically important molecules

Interstellar ices
(H₂O, CH₃OH, NH₃, CO, CH₄, HCN, PAHs)

Oxidized aromatics
(vitamins)

Heterocycles
(bases)

Polyols
(alcohols)

Amines
(amino acids)

2-Naphthol
Adenine
Ribose
Urea
Hexamethylenetetramine

1,4-Naphthoquinone
Lumichrome
Paraformaldehyde
Alanine

Polycyclic aromatic hydrocarbons and simpler molecules that make up interstellar ices could be the source of many types of biologically relevant molecules, according to one theory being investigated in the Ames astrochemistry laboratory. So far, the chemists have made the molecules shown in red in experiments that simulate the conditions of these ices in interstellar space. The rest, reasonable in theory, are on their “wish list.”

Key features in an infrared spectrum of a mixture of ionized polycyclic aromatic hydrocarbons match those of spectra of star-forming regions, such as this one from the Orion Nebula.
Largest Aromatic Molecule Known

50 $\pi$ electrons
### Smallest possible aromatic ring

<table>
<thead>
<tr>
<th>Bond length</th>
<th>Ring area</th>
<th>Claim to fame</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_3^+$</td>
<td>87.5 pm</td>
<td>Smallest, lightest σ aromatic species, observed in gas phase</td>
</tr>
<tr>
<td>N$_3^+$</td>
<td>132.9</td>
<td>Smallest π aromatic ring, experimentally unknown</td>
</tr>
<tr>
<td>C$_3^{2+}$</td>
<td>136.4</td>
<td>Smallest double aromatic carbon ring, experimentally unknown</td>
</tr>
<tr>
<td>C$_3$H$_3^+$</td>
<td>136.8</td>
<td>Breslow's classic compound, smallest isolated π aromatic molecule</td>
</tr>
<tr>
<td>C$_3$R$_3^+$</td>
<td>138</td>
<td>Smallest π aromatic compounds for which X-ray structures are available</td>
</tr>
<tr>
<td>B$_3^-$</td>
<td>156.4</td>
<td>Lightest double aromatic species, observed in gas phase</td>
</tr>
<tr>
<td>[B$_3$(CO)$_3$]$^+$</td>
<td>156.5</td>
<td>Frenking and Zhou's π aromatic B$_3^+$ ring, observed in gas phase</td>
</tr>
<tr>
<td>Na$_4$[B$_3$(NR$_2$)$_3$]$_2$</td>
<td>162</td>
<td>Braunschweig's π aromatic B$_3^{2-}$ ring, characterized by X-ray analysis</td>
</tr>
<tr>
<td>Be$_3^{2-}$</td>
<td>207.8</td>
<td>Lightest π aromatic ring, experimentally unknown</td>
</tr>
<tr>
<td>Li$_3^+$</td>
<td>300</td>
<td>σ aromatic cation, possibly made in the gas phase</td>
</tr>
</tbody>
</table>
Triradical breaks the rules

The first example of an organic triradical with three un-paired electrons in an "open-shell" doublet ground state has been reported by the research groups of chemists Paul G. Wenthold of Purdue University and Anna I. Krylov of the University of Southern California [Angew. Chem. Int. Ed., 43, 742 (2004)].

This state is unprecedented in a hydrocarbon and is contrary to the Aufbau principle and Hund's rules, which govern electron occupancy of molecular orbitals.
How do arene side chain reaction and EAS fit into CHM 12 Functional Group Conversions?

Arene side chain reactions are CHM 12A reactions, except for
\[ \text{Ar-R} \rightarrow [\text{O}] \rightarrow \text{Ar-COOH} \]

When you see aromatic compound, you
a) Panic
b) Freeze
c) Think EAS
Arenes Undergo Reactions in the:

**Ring**: Electrophilic Aromatic Substitution (EAS)

**Side Chain**:
- **Halogenation**: alkane $\rightarrow$ R-X at benzylic C (like allylic C)
- **Oxidation**: alkane chain (any # of C’s) $\rightarrow$ -COOH
- **Hydrogenation**: alkene $\rightarrow$ alkane (seen before)
- **Elimination**: R-X $\rightarrow$ alkene (seen before)
Groups Bonded to Benzene (Arene Side Chains) Undergo Reactions We Have Seen Before

?? Conditions: a. H$_2$SO$_4$  
  b. NaOCH$_3$  
  c. KHSO$_4$
Problem solving steps: 1. Identify functional group(s) 
2. Relate reaction conditions to reaction type

Draw the structure or Identify reaction conditions or propose a synthesis:
Problem solving steps: 1. Identify functional group(s) 
2. Relate reaction conditions to reaction type

1. Suggest reagents suitable for carrying out the following conversions. More than one synthetic operation may be necessary.

\[
\text{C}_{6}\text{H}_{5}-\text{CH}_{2}-\text{CH}_{2}-\text{OH} \quad \rightarrow \quad \text{C}_{6}\text{H}_{5}-\text{CH}_{2}-\text{CH}_{2}-\text{C}≡\text{C}
\]
Problem solving steps: 1. Identify functional group(s)  
2. Relate reaction conditions to reaction type

The following reaction has been described in the chemical literature and gives a single organic product in good yield. Identify the product.