Phenols, Ethers, and Organic Sulfur Compound
Phenols - Structure

General Structure - A “hydroxy” (OH) group attached **directly** to an aromatic ring:

- Phenol
- α-Naphthol
- β-Naphthol

Note: 

- is not a phenol.
Phenols are named as aromatic compounds, using the **ortho-**, **meta-**, and **para-** prefixes or appropriate numbering.

- **2-nitrophenol**
  - or **ortho-nitrophenol**
- **3-chlorophenol**
  - or **meta-chlorophenol**
- **4-methylphenol**
  - or **para-methylphenol**
- **2,4-dibromophenol**
- **4-bromo-2-chloro-5-isopropyl-phenol**
# Phenols - Physical Properties

Low Melting Solids  
Soluble in Nonpolar Solvents  
Also, Quite soluble in Water

<table>
<thead>
<tr>
<th>Name</th>
<th>Phenol</th>
<th>Catechol</th>
<th>Resorcinol</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.P.</td>
<td>40.5 ºC</td>
<td>105 ºC</td>
<td>110 ºC</td>
</tr>
<tr>
<td>Solubility in water</td>
<td>8.3 g/100mL</td>
<td>43 g/100mL</td>
<td>110 g/100mL</td>
</tr>
</tbody>
</table>
Phenols - Acidity

In water, phenol dissociates slightly as a weak acid.
(Another name for phenol itself is “carbolic acid”)

\[
\begin{align*}
\text{Acid} & \quad \text{Base} & \quad \text{Base} & \quad \text{Acid} \\
\text{OH} & \quad + \quad \text{H}_2\text{O} & \quad \xrightarrow{\text{H}\text{O}} & \quad \text{O}^- & \quad + \quad \text{H}_3\text{O}^+ \\
\end{align*}
\]
Phenols - Acidity

\[ \text{CH}_3\text{CH}_2\text{OH} \quad \text{Dissolve in water} \quad \text{CH}_3\text{CH}_2\text{O}^- + \text{H}_3\text{O}^+ \]

An alcohol

\[ \text{A phenol} \quad \text{Dissolve in water} \quad \text{O}^- + \text{H}_3\text{O}^+ \]
Phenols - Acidity

How acidic is Phenol?

\[ pK_a = \text{A general measure of acidity.} \]

The lower the \( pK_a \), the stronger the acid.

<table>
<thead>
<tr>
<th>Compound</th>
<th>( pK_a )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>nonacids</strong></td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td>16</td>
</tr>
<tr>
<td>Water</td>
<td>15.7</td>
</tr>
<tr>
<td><strong>weak acids</strong></td>
<td></td>
</tr>
<tr>
<td>Phenol</td>
<td>9.9</td>
</tr>
<tr>
<td>Acetic Acid</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>strong acids</strong></td>
<td></td>
</tr>
<tr>
<td>Phosphoric Acid</td>
<td>-2.1</td>
</tr>
<tr>
<td>Hydrochloric Acid</td>
<td>-7</td>
</tr>
</tbody>
</table>
Acidity of Alcohols

\[2 \text{H}_2\text{O} + 2 \text{Na} \rightarrow 2 \text{Na}^+ \text{OH}^- + \text{H}_2\]
Water
Sodium hydroxide

\[2 \text{CH}_3\text{OH} + 2 \text{Na} \rightarrow 2 \text{Na}^+ \text{OCH}_3^- + \text{H}_2\]
Methanol
Sodium methoxide
Phenols - Chemical Properties

Acid-Base Reactions

Phenol + NaOH → Sodium phenoxide + HOH
6. Complete the following reaction and name the organic reactant and product.

\[
\text{NaOH} + \text{H}_2\text{O} \rightarrow \text{C}_7\text{H}_6\text{O}_3\text{NNa} + \text{H}_2\text{O}
\]

4-methyl-3-nitro phenol

sodium 4-methyl-3-nitro phenoxide
7. **Review:** What structural feature is present in some alcohols which enables the molecules to undergo **intramolecular dehydration**?

8. **Review:** What structural feature is present in some alcohols which enables the molecules to undergo **oxidation**?

9. **Review:** What structural feature is present in alcohols which enables the molecules to undergo a reaction with sodium (Na) metal?

10. **Review:** What structural feature is present in a specific class of alcohols which enables the molecule to undergo a reaction with aqueous NaOH?
Phenols - Chemical Properties

Acid-Base Reactions

\[
\text{Phenol} + \text{NaOH} \rightarrow \text{Sodium phenoxide} + \text{H}_2\text{O}
\]

Oxidation-Reduction Reactions

\[
\text{Hydroquinone} \xrightarrow{\text{OXIDATION}} \text{Paraquinone} + 2\text{H}^+ \xleftarrow{\text{REDUCTION}} \text{Hydroquinone}
\]
Phenols - Examples of Important Compounds

- o-phenyl phenol
- 4-hexylresorcinol
- Butylated hydroxy anisole (BHA)
- Butylated hydroxy toluene (BHT)
Structure of Ethers
Structure of Ethers

- dimethyl ether
- diethyl ether
Chemical Properties of Alcohols

**Intermolecular Dehydration Reactions**

The reaction is run under different conditions than the "intramolecular" dehydration.

"H" and "OH" on two different molecules

Also called "condensation" or "dehydration synthesis" - an extremely important reaction in biochemistry.

\[
\begin{align*}
\text{C}_2\text{H}_6\text{O} & \quad + \quad \text{C}_2\text{H}_6\text{O} \\
\text{diethyl ether} & \quad \text{C}_4\text{H}_{10}\text{O} & \quad + \quad \text{H}_2\text{O}
\end{align*}
\]
Common Nomenclature

For simple carbon groups, the two groups attached to the ether oxygen are named as alkyl groups and “ether” is added to the name.

- ethyl methyl ether
- diethyl ether
- ethyl phenyl ether
Nomenclature of Ethers

IUPAC System

Shorter carbon chains are named as “alkoxy-” groups.

1-chloro-3-methoxypentane  2-bromo-4-ethoxy-1-fluorobenzene
A compound may contain two functional groups, in which case priorities are assigned.

Name: 3-Methoxy-2-butanol
Important Anaesthetics

- Halothane: 
  \[
  \begin{align*}
  &F \quad Cl \\
  &F \quad C \quad Cl \quad H \\
  &F \quad C \quad O \quad C \quad F \\
  &F \quad H \quad H
  \end{align*}
  \]

- Enflurane: 
  \[
  \begin{align*}
  &H \quad F \quad F \\
  &F \quad C \quad Cl \quad H \\
  &F \quad C \quad O \quad C \quad F \\
  &H \quad F \\
  &H
  \end{align*}
  \]

- Isoflurane: 
  \[
  \begin{align*}
  &F \quad Cl \\
  &F \quad C \quad C \quad O \quad C \quad F \\
  &F \quad H \quad H \\
  &F \quad H \quad H
  \end{align*}
  \]

- Methoxyflurane: 
  \[
  \begin{align*}
  &Cl \quad C \quad C \quad O \quad C \quad H \\
  &Cl \quad F \quad H \\
  &Cl \quad F \quad H \\
  &H \quad H
  \end{align*}
  \]
Boiling points of ethers increase with molecular weight and decrease with increased branching.

- Dimethyl ether (bp = -24.5°C)
- Ethyl methyl ether (bp = -10.8°C)
- Diethyl ether (bp = 34.5°C)
Physical Properties of Ethers

Attractive forces between ether molecules include only dispersion forces making their boiling points similar to alkanes of similar molecular weight.

Hexane, boiling point 69 °C

Butyl methyl ether, boiling point 71 °C

1-Pentanol, boiling point 138 °C
As a general rule, one polar atom (O,N) can “solubilize” four to six carbon atoms.
# Organic Sulfur Compounds

## Structures

<table>
<thead>
<tr>
<th>Structure</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-S-H</td>
<td>Thiols (Mercaptans)</td>
<td></td>
</tr>
<tr>
<td>R-S-R</td>
<td>Thioethers (Sulfides)</td>
<td></td>
</tr>
<tr>
<td>R-S-S-R</td>
<td></td>
<td>(Disulfides)</td>
</tr>
</tbody>
</table>

## Nomenclature

<table>
<thead>
<tr>
<th>Structure</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃-S-H</td>
<td>Mercaptan (Methanethiol)</td>
</tr>
<tr>
<td>CH₃-S-CH₃</td>
<td>Dimethyl Sulfide (Dimethyl Thioether)</td>
</tr>
<tr>
<td>CH₃-S-S-CH₃</td>
<td>Dimethyl disulfide</td>
</tr>
</tbody>
</table>

## Physical Properties

- Distinct odors and flavors
- Lower boiling points than alcohols (Why?)
- Weak Acids: Phenols > Thiols > Alcohols
Thiols are easily “oxidized” to disulfides and

\[
\text{RSH} + \text{HSR} \xrightarrow{[\text{O}]} \text{RSSR}
\]

Two thiol molecules \quad A \text{disulfide}

**Disulfides are easily “reduced” to thiols.**

\[
\text{RSSR} \xrightarrow{[\text{H}]} \text{RSH} + \text{RSH}
\]

This reaction takes place within large protein structures:
Mercaptans = “Mercury capturing”

\[ \text{R-SH} + \text{Hg}^{2+} + 2 \text{H}^+ \rightarrow \text{R-S} \]

Process is called “chelation”
Where Do We Find Thiols??

- **Ethanethiol** ($\text{CH}_3\text{CH}_2\text{SH}$)
- **3-Methyl-1-butanol** ($\text{CH}_3\text{CHCH}_2\text{CH}_2\text{SH}$)
- **2-Butene-1-thiol** ($\text{CH}_3\text{CH}==\text{CHCH}_2\text{SH}$)
Where Do We Find Disulfides??
Stereochemistry - Review of Isomerism

Isomers

Structural Isomers

Stereoisomers
Stereochemistry - Review of Isomerism

Isomers

Structural Isomers

Stereoisomers

Cis-trans Isomers

Isomers with chiral centers
We can imagine the mirror image of an object.

In some cases, the mirror image and the original object are identical.

In some cases, the mirror image and the original object are not identical.
Stereochemistry - “Handedness” in Everyday Objects

(a) (b) (c) (d)
Enantiomers - compounds that have the following characteristics:

1) Molecules of two compounds are mirror images of each other.

2) Molecules of two compounds are nonsuperimposable.

The characteristics of enantiomers are often the result of a single “chiral” carbon atom.
All tetrahedral carbons are not chiral.
1, 2, 3, and 4 must be different groups. What are “different” groups?
Stereochemistry - Examples of Enantiomers

bromochlorofluoromethane
Stereochemistry - Examples of Enantiomers

2-bromobutane
Stereochemistry - Examples of Enantiomers

L-carvone (spearmint)  D-carvone (caraway seeds)