Chapter 14: Alcohols, Phenols, Thiols, and Ethers

Suggested problems: 1, 2, 13, 4, 23, 33, 39, 40, 50, 52

Objectives

- Identify functional groups for alcohols, phenols, thiols, and ethers.
- Identify some simple alcohols and some characteristic applications.
- Understand how structures of alcohols, thiols, and ethers affect their physical properties.
- Given product or reactant, predict reactant or product for an alcohol oxidation.
- Distinguish thiol groups and disulfide bonds as oxidized or reduced.
- Know the exceptions to the inertness of ethers.

Alcohols

- A hydroxyl group (-OH) replaces –H in an alkane chain
- General formula ROH
- -OH is not the ionic hydroxide group!
  - The hydroxyl group is covalently bonded to a carbon
  - Hydroxide is an ion
Properties of Alcohols

- What kind of bond is C-O?
- What about O-H?
- Hydrogen bond —

- How many H-bonds can an alcohol form?

Alcohols

- Boiling point
  
  b.p. alkane       b.p. alcohol

- Solubility

  What do you think happens to solubility as the number of carbons increases?

Properties of Alcohols

<table>
<thead>
<tr>
<th>Structural Formula</th>
<th>Name</th>
<th>Molecular Weight</th>
<th>bp (°C)</th>
<th>Solubility in Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃OH</td>
<td>methanol</td>
<td>32</td>
<td>65</td>
<td>infinite</td>
</tr>
<tr>
<td>CH₃CH₃</td>
<td>ethane</td>
<td>30</td>
<td>-89</td>
<td>insoluble</td>
</tr>
<tr>
<td>CH₃CH₂OH</td>
<td>ethanol</td>
<td>46</td>
<td>78</td>
<td>infinite</td>
</tr>
<tr>
<td>CH₃CH₂CH₃</td>
<td>propane</td>
<td>44</td>
<td>-42</td>
<td>insoluble</td>
</tr>
<tr>
<td>CH₃CH₂CH₂OH</td>
<td>1-propanol</td>
<td>60</td>
<td>97</td>
<td>infinite</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₃</td>
<td>butane</td>
<td>58</td>
<td>0</td>
<td>insoluble</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₂OH</td>
<td>1-butanol</td>
<td>74</td>
<td>117</td>
<td>8g/100g</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₂CH₃</td>
<td>pentane</td>
<td>72</td>
<td>36</td>
<td>insoluble</td>
</tr>
</tbody>
</table>
**Alcohols**

**Nomenclature**
1. Select the longest carbon chain that contains the -OH group as the parent alkane and number it from the end that gives the -OH the lower number.
2. Change the ending of the parent alkane from -e to -ol and use a number to show the location of the -OH group; for cyclic alcohols, the carbon bearing the -OH group is carbon-1.
3. Name and number substituents and list them in alphabetical order.

**Some important alcohols**
- **Methanol**
  - How many carbons?
  - Wood alcohol, grain alcohol
- **Ethanol**
  - How many carbons?
  - Drinking alcohol, additive in gasohol, antibacterial,
  - Solvent (tincture)
- **Isopropanol – isopropyl alcohol**
  - How many carbons?
  - Rubbing alcohol – cools skin, antiseptic

**Combustion of Alcohol**
- **Methanol**
  - Fuel in some race cars
  - Canned heat
- **Ethanol**
  - Used in gasohol
  - Flambe desserts
Oxidation of Alcohols

- Oxidation –

\[
\text{CH}_3\text{OH} + [\text{O}] \rightarrow \text{CH}_2\text{O} + \text{H}_2\text{O} + \text{OH}^- \]

- We will look at this reaction in the body –
  - Metabolism of alcohol
  - Enzyme catalyzed

Oxidation of Methanol

- Toxic
  - In the liver methanol is oxidized as on the previous page.
    - Alcohol dehydrogenase
  - Formaldehyde may bind to proteins and DNA
  - Formic acid changes the pH of the blood.
    - Acidosis, retinal or optic nerve damage
    - Blindness – 15 ml in adults
    - Death – 100 ml in adults, can occur at lower doses

Oxidation of Ethanol

- Draw the products of oxidation of ethanol

- ADH prefers to bind to ethanol over methanol
- Acetaldehyde
  - Binds to proteins – cannot signal kidneys to absorb water – leads to dehydration – dehydration in brain – headaches
  - Acetic acid – used in fatty acid synthesis
  - The oxidation of EtOH slows fatty acid metabolism
Blood Alcohol test

- Oxidation of ethanol
  - Color change of chromate

\[
\text{CH}_3\text{OH} + \text{Cr}^{6+} \rightarrow \text{CH}_3\text{O}^\text{+} + \text{Cr}^{3+}
\]

Alcohols: multiple –OH groups

- Diol – two hydroxy groups
- Triol – three hydroxy groups
- IUPAC names for diols, triols, and so on retain the final “-e” in the name of the parent alkane
- Glycol – common name for diol with –OH on adjacent carbons

<table>
<thead>
<tr>
<th>CH₂OH₂</th>
<th>CH₃CH₂OH₂</th>
<th>CH₃CH(OH)₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH</td>
<td>HO</td>
<td>OH</td>
</tr>
<tr>
<td>1,2-Ethanediol (Ethylene glycol)</td>
<td>1,2-Propanediol (Propylene glycol)</td>
<td>1,2,3-Propanetriol (Glycerol, Glycerin)</td>
</tr>
</tbody>
</table>

Examples

- Ethylene glycol – Antifreeze
  - Oxidizes in body
  - Forms calcium oxalates –
    - salts that precipitate in kidneys – renal damage
    - Inhibits blood clotting
- Propanetriol – glycerol, glycerine
  - Ear drops, cosmetics
  - Nitroglycerin – dynamite and vasodilator
  - Ear drops, cosmetics
  - Nitroglycerin – dynamite and vasodilator
Another Aromatic Group

- Phenols
  - A hydroxy group bonded to a benzene ring
  - Can phenols h-bond with each other?
  - Can they h-bond with water?

Phenol: Examples

- Disinfectant properties
  - thymol
  - hexylresorcinol
  - \( \alpha \)-phenylphenol

- Irritants
  - urushiol
  - capsaicin

Phenols as Antioxidants

- Autoxidation
  - Addition of oxygen able to occur with oxygen available from air
  - High energy radical reactions
  - Eventually leads to rancid oils
  - May occur in lipoproteins – products deposited on arterial walls leads to cardiovascular disease
  - Also suspected in aging
Phenols as Antioxidants

- Vitamin E is a natural antioxidant
- BHT and BHA are synthetic antioxidants
- radical scavengers

Thiols

- **Thiol**: a compound containing an -SH (sulfhydryl) group
  - the most outstanding property of low-molecular-weight thiols is their stench
  - they are responsible for smells such as those from rotten eggs and sewage
  - the scent of skunks is due primarily to these two thiols

\[ \text{CH}_3 \text{CH}═\text{CHCH}_2\text{SH} \quad \text{2-Butene-1-thiol} \]
\[ \text{CH}_3 \text{CHCH}_2\text{SH} \quad \text{3-Methyl-1-butanethiol} \]

Properties

- Compare the boiling points and solubilities for a thiol and a similarly sized alcohol.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Boiling Point</th>
<th>Solubility</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{CH}_2\text{CH}_2\text{SH} )</td>
<td>35 °C</td>
<td>6.8 g/L</td>
</tr>
<tr>
<td>( \text{CH}_3\text{CH}_2\text{OH} )</td>
<td>78 °C</td>
<td>fully miscible</td>
</tr>
</tbody>
</table>

Which compound has stronger intermolecular forces? Why?
Reactions of Thiols

- The most common reaction of thiols in biological systems is their oxidation to disulfides, the functional group of which is a disulfide (-S-S-) bond.
  - Thiols are readily oxidized to disulfides by O₂.
  - Disulfides, in turn, are easily reduced to thiols by several reducing agents.

\[
2\text{HOCH}_2\text{CH}_2\text{SH} \xrightarrow{\text{oxidation}} \text{HOCH}_2\text{CH}_2\text{S-SCH}_2\text{CH}_2\text{OH} \xrightarrow{\text{reduction}} \text{HOCH}_2\text{CH}_2\text{SH} \quad \text{A disulfide}
\]

Disulfide bonds

- A structural protein in your body, the keratin that make up your hair, contains thiol groups.
  - Many of those thiol groups have been oxidized.
  - The disulfide bonds determine the shape of the hair.

What happens if a reducing agent is added to the hair? Draw the resulting structure.

Permanent waves in hair.

- Once the disulfide bonds are reduced, the shape of the protein can be changed.
  - The hair is wrapped around rollers.
  - An oxidizing agent is then added.
    - What happens to the thiol groups in the hair?

- What is the overall result of the process?
**Thiols and heavy metals**

- Thiols also react with heavy metals that form salt bridges with the sulfur atoms.

- Negative: heavy metals interrupt our proteins
- Treatments:
  - Some other proteins in our body are designed with thiol groups to bind these metals and get rid of them
  - Raw egg whites and milk are given – contain large amounts of sulfur containing protein.

**Ethers**

- The functional group of an ether is an oxygen atom bonded to two carbon atoms
  - the simplest ether is dimethyl ether
  - the most common ether is diethyl ether

![Dimethyl Ether](image1)

![Diethyl Ether](image2)

**Cyclic Ethers**

- Ethylene oxide
- Tetrahydrofuran (THF)
**Physical Properties**

- Ethers are polar compounds
  - Although not as polar as alcohols
  - Can ethers H-bond with each other?

- Consequently, boiling points of ethers are close to those of hydrocarbons of similar molecular weight
- How do the b.p. compare with those of alcohols?
- Which will be a gas at room temperature?

![Chemical structures of Ethanol and Dimethyl Ether]

- Ethanol: CH₃CH₂OH, bp 78°C
- Dimethyl Ether: CH₃OCH₃, bp -24°C

**Physical Properties**

- Can ethers H-bond with water?

- Not as soluble as alcohols in water.
  - CH₃CH₂CH₂CH₂OH, 118 °C, soluble
  - CH₃CH₂OCH₂CH₃, 35 °C, slightly soluble

- Good organic solvent – can dissolve things not soluble in water.

**Reactions of Ethers**

- Ethers resemble hydrocarbons in their resistance to most chemical reactions.

- Because of their general *inertness* and good solvent properties, ethers such as diethyl ether and THF are excellent solvents in which to carry out organic reactions

- Ethylene oxide is reactive.

- However, ethers are very *flammable*, so care must be taken in their use

- As well, *oxidation* creates unstable (explosive) compounds.
Ether Inertness

Good solvents

Tetrahydrofuran (THF)

Exception: Ethylene oxide

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Reactions of Ethers - Autoxidation

- High energy radical reaction as with alkenes.
  - What is the reagent? (oxidizing agent?)

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Ethers as anesthetics

- Diethyl ether introduced in 1850s
  - Crazy chemist anesthetized himself!

- Disadvantages
  - Flammability
  - Nausea, respiratory irritation

- Halogenated ethers and halogenated alkanes now used
  - Forane (isoflurane)
Review

- Alcohols
- Phenols
- Thiols
- Ethers