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Organic Chemistry I Drill (CHEM2210D) - Module 2 - Functional Groups and Infrared Spectroscopy

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MOLECULAR REPRESENTATIONS AND INFRARED SPECTROSCOPY

A STUDENT SHOULD BE ABLE TO:

1. Given a Lewis (dash or dot), condensed, bond-line, or wedge formula of a compound, draw the other representations.

2. Give examples of, and recognize when given the structure, representatives of the following classes of compounds. Also, draw isomers of given compounds.

   - Hydrocarbons (compounds containing C and H only)
     - Saturated - alkanes (1°, 2°, 3° H and 1°, 2°, 3°, and 4° C)
     - Unsaturated - alkenes (olefins), alkynes, aromatics
   - Organic compounds containing halogens
     - Alkyl halides = haloalkanes (1°, 2°, 3°)
   - Compounds containing oxygen:
     - C–O single bonds only: alcohols (1°, 2°, 3°), ethers, phenols
     - C=O compounds: aldehydes, ketones, carboxylic acids, esters, acyl halides, anhydrides
   - Compounds containing nitrogen: amines (1°, 2°, 3°), amides, nitriles, nitros
   - Compounds containing sulfur: thiols, sulfides

3. Identify bond types present in molecules from infrared (IR) spectroscopy data, and predict features of the IR spectrum of molecules from their structures. Important IR absorption frequencies to know include:
   - O–H (alcohols, hydrogen bonded): 3200-3600 cm⁻¹, strong and broad
   - N–H: 3200-3600 cm⁻¹, medium intensity
   - O–H (carboxylic acids): 2500-3500 cm⁻¹, broad peaks of variable intensity
   - C=O: 1650-1800 cm⁻¹, strong absorption

   If you need to use other frequencies to identify other functional groups (and sometimes you will), a table of IR frequencies will be provided.

4. Know basic IR theory (Hooke’s Law), especially the relationship between energy, wavenumbers, and wavelength.

5. Apply concepts learned in Module 1.
## Simplified Table of Main IR Frequencies

<table>
<thead>
<tr>
<th>Wavenumber, cm(^{-1})</th>
<th>Bond</th>
<th>Peak Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3200 – 3600</td>
<td>O-H (alcohol)</td>
<td>Strong and broad</td>
</tr>
<tr>
<td>2500 – 3500</td>
<td>O-H (carboxylic acid)</td>
<td>Very broad (over ~ 500 cm(^{-1})); often looks like distorted baseline; can obscure C-H bands.</td>
</tr>
<tr>
<td>3200 – 3600</td>
<td>N-H (amine, amide)</td>
<td>Doublet in case of NH(_2) group in a primary amine or amide</td>
</tr>
<tr>
<td>3300</td>
<td>(\equiv)C-H terminal alkyne</td>
<td>Usually sharp and strong</td>
</tr>
<tr>
<td>3000 – 3100</td>
<td>(=)C-H alkene or aromatic</td>
<td>Often weak; shoulder peak adjacent to sp(^3) C-H</td>
</tr>
<tr>
<td>2800 – 3000</td>
<td>C-H (sp(^3) carbon - hydrogen)</td>
<td>Strong, broad and multi-banded</td>
</tr>
<tr>
<td>2100 – 2300</td>
<td>C≡N nitrile</td>
<td>Medium intensity</td>
</tr>
<tr>
<td>2100 – 2300</td>
<td>C≡C(H) alkyne</td>
<td>Medium intensity for terminal alkynes, very weak for internal</td>
</tr>
<tr>
<td>1650 – 1800</td>
<td>C=O (amides, ketones, aldehydes carboxylic acids, esters, etc.)</td>
<td>Very strong; lower frequency for amides and when C=O is conjugated</td>
</tr>
<tr>
<td>1600 – 1680</td>
<td>C=C alkene, aromatic</td>
<td>Check to see if you have sp(^2) C-H &gt;3000 cm(^{-1}) (if not, it’s completely substituted)</td>
</tr>
<tr>
<td>1000-1300</td>
<td>C-O</td>
<td></td>
</tr>
</tbody>
</table>
To best prepare for this module, please work appropriate Skill Builder problems in the textbook. Also, all students should attend the IR lab (Organic I lab) to work problems.

A STUDENT WHO HAS MASTERED THE OBJECTIVES FOR THIS UNIT SHOULD BE ABLE TO SOLVE THE FOLLOWING PROBLEMS AND RELATED ONES:

1.1 Draw complete Lewis structures (showing all atoms, bonds as lines, and non-bonding valence electrons as dots) for the following compounds. Also, name the functional groups.

a) \((\text{CH}_3\text{)}_2\text{CHCH}_2\text{CH}_3\)  
b) \(\text{CH}_3\text{(CH}_2\text{)}_2\text{CHOHCH}_3\)

c)  
d) \(\text{CH}_2\text{OCH}_3\)

e) \(\text{f) (CH}_3\text{CH}_2\text{)}_2\text{CCH}_2\text{CHO}\)

1.2 Draw a bond-line structure for each of the following compounds. Use dashes and wedges to indicate three-dimensional geometry where appropriate.

a) \((\text{C}_2\text{H}_5\text{)}_3\text{C(CH}_2\text{)}_2\text{CH(CH}_3\text{)(CH}_3\text{)}(\text{CH}_2\text{)}_2\text{CH}_3\)  
b) \(\text{ClH}_2\text{CCH}_2\text{CCC(O)CH(NH}_2\text{)OCH}_2\text{CHO}\)

c) \((\text{CH}_3\text{CH}_2\text{)}_2\text{CO(CH}_2\text{)}_2\text{CH}≡\text{CH(CH}_2\text{)}_2\text{OC(CH}_2\text{CH}_3\text{)}_3\)  
d) \(\text{CH}_3\text{CH}_2\text{CBr}_2\text{CH}_2\text{O(CH}_2\text{)}_2\text{CO}_2\text{H}\)

e) \((\text{CH}_3\text{)}_2\text{CHCH(CH}_3\text{)(CH}_2\text{)}_2\text{CH(CH}_3\text{)}(\text{CH}_2\text{)}_2\text{CH}_3\)  
f) \((\text{CH}_3\text{CH}_2\text{CH}_2\text{)}_2\text{CHCH}_2\text{CH}_2\text{C≡N}\)
1.2  Draw both condensed and bond-line structures for (a), (b); draw a bond-line formula for (c); and name the functional groups present.

1.3  Draw both condensed and bond-line structures for (a), (b); draw a bond-line formula for (c); and name the functional groups present.

1.4  Write condensed formulas for each of the following and name each functional group.

2.1 Draw the structure of an example of each of the following classes of compounds. **Do not use the symbol “R.”**

a) alkane  

b) ether  

c) 1° amine

d) 3° alcohol  

e) aldehyde  

f) 1° alkyl halide  

g) thiol  

h) alkyne  

i) acyl chloride

2.2 Name the functional group or groups in each of the following molecules. Indicate 1°, 2°, or 3° where appropriate.

a) CH₃CH₂CH=CH₂  

b) \[ \text{Ph}-\text{COOH} \]

c) \[ \text{Ph}-\text{COCH₃} \]

d) \[ \text{C}_\text{NH} \]

e) \[ \text{HO}-\text{CCH-CH≡C}-\text{CH₃} \]

f) \[ \text{H₃C}-\text{COOCH₂CH₃} \]
2.2

Draw all carbon and hydrogen atoms for each. Indicate the substitution level (1°, 2°, 3°, 4°) of each carbon and (1°, 2°, 3°) each hydrogen.

2.3

Based on the IR data given, what functional group(s) can be present in these compounds?

a) A strong absorption at 1710 cm\(^{-1}\), no N in the molecular formula, no strong absorption 3200-3600 cm\(^{-1}\)

b) A strong absorption at 1720 cm\(^{-1}\) and a broad absorption between 2500-3500 cm\(^{-1}\).

c) An oxygen-containing compound with a strong absorption at 3350 cm\(^{-1}\), no N in the molecular formula, no band at 1650-1800 cm\(^{-1}\).

3.2 An oxygen-containing compound does not have IR signals in either the 3200-3600 cm\(^{-1}\) region or the 1650-1800 cm\(^{-1}\) region. Which of the following functional groups fits this IR spectrum?

a) ROH  b) RCOOH  c) RCOR  d) ROR
3.3  For each of the following compounds, determine whether or not you would expect the IR spectrum to exhibit a signal to the left of 3000 cm\(^{-1}\).

a) \(
\begin{array}{c}
\text{O} \\
\end{array}
\)

b) \(
\begin{array}{c}
\text{N} \\
\end{array}
\)

c) \(
\begin{array}{c}
\text{NH}_2 \\
\end{array}
\)

d) \(
\begin{array}{c}
\text{CH} \\
\end{array}
\)

e) \(
\begin{array}{c}
\text{O} \\
\end{array}
\)

f) \(
\begin{array}{c}
\text{CH} \\
\end{array}
\)

g) \(
\begin{array}{c}
\text{OH} \\
\end{array}
\)

h) \(
\begin{array}{c}
\text{O} \\
\end{array}
\)

3.4  What IR frequencies would enable a chemist to distinguish between these molecules?

a) \(\text{CH}_3\text{CH}_2\text{OH}\) and \(\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3\)

b) \(
\begin{array}{c}
\text{O} \\
\end{array}
\)

\(\text{H}_3\text{C}\text{CHC}==\text{CHCH}_2\text{CH}_3\) and \(\text{H}_3\text{C}==\text{C}==\text{CCH}_3\)

c) 

3.5  An unknown compound having the formula \(\text{C}_6\text{H}_{13}\text{N}\) had one peak in its IR spectrum at 3350 cm\(^{-1}\) and peaks around 2900 cm\(^{-1}\). Which of the following compounds is consistent with this?

a) \(
\begin{array}{c}
\text{N} \\
\text{H} \\
\end{array}
\)

b) \(
\begin{array}{c}
\text{N} \\
\text{CH}_3 \\
\end{array}
\)

c) \(
\begin{array}{c}
\text{N} \\
\text{H} \\
\end{array}
\)

d) \(
\begin{array}{c}
\text{N} \\
\text{H}_2 \\
\end{array}
\)
3.6 For each of the following IR spectra, identify whether it is consistent with the structure of an alkane, an alkene, an alkyne, a ketone, an alcohol, a carboxylic acid, a primary amine, a secondary amine, amide, or ester. Explain.

a)

![Image of IR spectrum a)

b)

![Image of IR spectrum b)

c)

![Image of IR spectrum c)

4.1 Explain what wavenumbers are. How does reciprocal centimeters relate to wavelength?
4.2 Is the absorption for a sp C-H or a sp\(^3\) C-H higher in energy. Explain.

5.1 a) Draw all constitutional isomers of C\(_3\)H\(_9\)N and identify the functional group present in each one. Indicate 1\(^\circ\), 2\(^\circ\), or 3\(^\circ\) if appropriate.

b) Draw at least four constitutional isomers of C\(_4\)H\(_6\)O\(_2\) with as many functional groups as possible. Identify each functional group. Some molecules may have more than one.

5.2 Which of the following compounds is the most soluble in water? Which is the most soluble in hexanes?

a) CH\(_3\)CH\(_2\)NH\(_2\)  b) CH\(_3\)(CH\(_2\))\(_4\)C-OH

c) CH\(_3\)(CH\(_2\))\(_4\)CH\(_3\)  d) (C\(_2\)H\(_5\))\(_2\)CHCH\(_2\)Br

5.3 Which compound has the highest boiling point? Which has the lowest?

a) (CH\(_3\)CH\(_2\))\(_3\)N  b) \[\text{苯酚} \]

c)  d) CH\(_3\)CH\(_2\)-S-CH\(_2\)CH\(_3\)

5.4 Provide hybridizations and approximate bond angles around the atoms that are in bold. You may need to add lone pairs to complete the octet.

a) CH\(_3\)S-CH=CH-C-H  b) (CH\(_3\))\(_2\)N-CH\(_2\)-C\(_{\equiv}\)N

<table>
<thead>
<tr>
<th>Hybridization</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>bond angle</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SOLUTIONS TO SAMPLE PROBLEMS:

1.1 Functional groups: a) alkane; b) 2º alcohol; c) alkene; d) ether; e) ester d) aldehyde.

a) \[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

b) \[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}.
\]

c) \[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{H} \\
\end{array}
\]

d) \[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{H} \\
\end{array}
\]

e) \[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{H} \\
\end{array}
\]

1.2 Bond-line structures:

a) \((\text{C}_2\text{H}_5)_3\text{C}(\text{CH}_2)_2\text{CH}(\text{C}_2\text{H}_5)\text{CH}(\text{CH}_3)(\text{CH}_2)_2\text{CH}_3\)  
b) \(\text{ClH}_2\text{CCH}_2\text{CCC(O)}\text{CH(NH}_2)\text{OCH}_2\text{CHO})

\[
\begin{array}{c}
\text{Cl} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

c) \((\text{CH}_3\text{CH}_2)_3\text{CO}(\text{CH}_2)_2\text{CH}≡\text{CH(\text{CH}_2)_2OC(\text{CH}_2\text{CH}_3)_3}\)  
d) \(\text{CH}_3\text{CH}_2\text{CBr}_2\text{CH}_2\text{O(\text{CH}_2)_2CO}_2\text{H}\)

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]
1.2  continued

e) \((\text{CH}_3)_2\text{CHCH(CH}_3)(\text{CH}_2)_2\text{CH(C}_2\text{H}_5)(\text{CH}_2)_2\text{CH}_3\)  
f) \((\text{CH}_3\text{CH}_2\text{CH}_2)_2\text{CHCH}_2\text{CH}_2\text{C}≡\text{N}\)

![Image of a compound structure](image)

1.3  Functional groups: a) alkene; b) aldehyde, 2° alkyl halide; c) alkene, ketone

a) \(\text{CH}_3\text{CH}_2\text{CH(}\text{CH}_3\text{)CH}≡\text{CH}_2\)  
b) \(\text{CHOCHCl(}\text{CH}_2)_2\text{CH(CH}_3)_2\)

![Image of a compound structures](image)

1.4  a) alkene, 2° alcohol, carboxylic acid; b) alkyne; c) thiol, alkene; d) sulfide

a) \(\text{CH}_2≡\text{C(}\text{CH}_3\text{)CH(OH)(}\text{CH}_2)_2\text{C(}\text{CH}_3)_2\text{CH}_2\text{CO}_2\text{H}\)  
b) \((\text{C}_2\text{H}_5)_2\text{CHC≡C(}\text{CH}_2)_3\text{CH}_3\)  
or \(\text{CH}_3\text{CH}_2\text{CH(C}_2\text{H}_5)\text{C≡C(}\text{CH}_2)_3\text{CH}_3\)

c) \((\text{CH}_3)_2\text{CHCH(SH)CH}≡\text{CHC(}\text{CH}_3)_3\)  
d) \((\text{CH}_3)_2\text{CHCH}_2\text{S(}\text{CH}_2)_2\text{CH(C}_2\text{H}_5)\text{C(}\text{CH}_3)_3\)

2.1  There are numerous other correct answers. These are just one possible answer.

a)  alkane  b)  ether  c)  1° amine

\(\text{CH}_3\text{CH}_2\text{CH}_3\)  \(\text{CH}_3\text{OCH}_2\text{CH}_3\)  \(\text{NH}_2\text{-CH}_2\text{-CH}_2\text{CH}_3\)
2.1 continued
d) $3^\circ$ alcohol  
e) aldehyde  
f) $1^\circ$ alkyl halide

\[
\begin{align*}
\text{CH}_3 & \quad \text{O} \\
\text{H}_3\text{C} - \text{C} - \text{CH}_2\text{CH}_3 & \quad \text{CH}_3\text{CH}_2\text{CH}_2\text{Br} \\
\text{OH} & \quad \text{CH}_3\text{CH}_2\text{CH}_2 \quad \text{H} \\
\end{align*}
\]

g) thiol  
h) alkyne  
i) acyl chloride

\[
\begin{align*}
\text{CH}_3\text{CH}_2\text{CH}_2\text{SH} & \quad \text{CH}_3\text{CH}_2\text{C} \equiv \text{CCH}_3 \\
\end{align*}
\]

2.2
a) alkene  
b) aromatic, carboxylic acid  
c) aromatic, ketone  
d) amide  
e) $2^\circ$ alcohol, alkyne  
f) ester  
g) aromatic ring, anhydride  
h) thiol  
i) sulfide

2.3
a)

```
C=1^\circ;H=1^\circ \quad \rightarrow \quad \text{CH}_3
```

b)

```
C=2^\circ;H=2^\circ \quad \rightarrow \quad \text{CH}_3
```

3.1
a) aldehyde, ketone, ester, anhydride  
b) carboxylic acid  
c) alcohol

3.2

d
3.3  a) no  b) no  c) yes  d) no  e) yes  f) yes  g) yes  h) no

3.4  a) 3200-3400 cm$^{-1}$ (OH)  b) 1620-1680 cm$^{-1}$ (C=C) and 3000-3100 cm$^{-1}$ (=C-H)  c) 3000-3100 cm$^{-1}$ (=C-H)

3.5  a

3.6  a) primary amine (NH doublet, ~3350 and 3330, sp$^3$ C-H 3000-2800 cm$^{-1}$)  
b) alcohol (broad OH, 3310 cm$^{-1}$, sp$^3$ C-H 3000-2800 cm$^{-1}$)  
c) ketone (C=O, 1720 cm$^{-1}$, sp$^3$ C-H 3000-2800 cm$^{-1}$)

4.1  Wavenumbers are the same as reciprocal centimeters. This describes how many waves there are in one centimeter. As the wavenumber increases, more waves fit in 1 centimeter and the wavelength decreases. As wavelength decreases, energy increases. Hence, the smaller the wavenumber, the higher the energy.

4.2  sp C-H absorbs at ~3300 cm$^{-1}$, sp$^3$ C-H absorbs between 2800-3000 cm$^{-1}$. Since 3300 cm$^{-1}$ is higher than 3000 cm$^{-1}$, the sp C-H is higher in energy.

5.1  a)

\[
\begin{array}{cccc}
\text{H}_3\text{C} & \text{C} & \text{C} & \text{NH}_2 \\
\text{H}_2 & \text{H}_2 & \text{H}_2 & \text{H}_2 \\
\text{1$^\circ$ amine} & \text{1$^\circ$ amine} & \text{2$^\circ$ amine} & \text{3$^\circ$ amine}
\end{array}
\]

b) There are many other C$_4$H$_6$O$_2$ isomers.

\[
\begin{array}{cccc}
\text{O} & \text{OH} & \text{O} & \text{OH} \\
\text{alkene; carboxylic acid} & \text{ether; ketone} & \text{ester; alkene} & \text{2$^\circ$ alcohol, aldehyde}
\end{array}
\]

5.2  a) is most soluble in water; c) is most soluble in hexanes

5.3  b) has the highest BP; c) has the lowest BP

5.4  a)

\[
\begin{array}{cccc}
\text{sp}^3 & \text{sp}^3 & \text{sp}^2 & \text{sp}^2 \\
109.5^\circ & 109.5^\circ & 120^\circ & 120^\circ
\end{array}
\]

b) (CH$_3$)$_2$N$\cdots$CH$_2$C$\equiv$N

\[
\begin{array}{cccc}
\text{sp}^3 & \text{sp} \\
109.5^\circ & 180^\circ
\end{array}
\]
1. Name the functional group in each of the following compounds, indicating 1°, 2°, or 3° if appropriate.
   a) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3 \) b) \( \text{H}_3\text{C}-\text{CH}\text{N}-\text{CH}_3 \) c) \( \text{(CH}_3\text{)}_3\text{CCH}_2\text{C}=\text{O} \)

2. Give specific examples (do not use \( R \)) for each of the following types of compounds.
   a) 3° alcohol b) ester c) aldehyde d) sulfide

3. Which of these compounds has a band in its IR spectrum nearest 3030 cm\(^{-1}\)?
   a) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3 \) b) \( \text{CH}_3\text{OCH}_2\text{CH}_3 \) c) \( \text{CH}_3\text{CH}_2\text{CH}=\text{O} \) d) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \)

4. Which of the following functional groups does not show any absorption bands in the 3200-3500 cm\(^{-1}\) region of the infrared spectrum?
   a) alcohols b) primary amines c) secondary amines d) tertiary amines

5. What IR frequencies would enable a chemist to distinguish between these?
   \( \text{(CH}_3\text{CH}_2\text{)}_3\text{N} \) and \( \text{(CH}_3\text{CH}_2\text{)}_2\text{NH} \)

6. Which of the following compounds has the highest boiling point?
   a) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3 \) b) \( \text{CH}_3\text{OCH}_2\text{CH}_3 \) c) \( \text{CH}_3\text{CH}_2\text{CH}=\text{O} \) d) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \)

7. Which of the following compounds is the most soluble in water? Which is the most soluble in hexanes?
   a) \( \text{CH}_3\text{CH}_2\text{-S-CH}_2\text{CH}_3 \) b) \( \text{CH}_3(\text{CH}_2)_5\text{CH}_3 \)
   c) \( \text{CH}_3\text{-O-CH}_2\text{CH}_3 \) d) \( \text{CH}_3(\text{CH}_2)_5\text{CH}_2\text{Br} \)
1. Draw structures as indicated.
   a) Lewis structure of
   \[
   \begin{array}{c}
   \text{H} \\
   \text{N} \\
   \text{B} \\
   \text{H}
   \end{array}
   \]
   b) an isomer of
   \[
   \begin{array}{c}
   \text{O}
   \end{array}
   \]
   c) condensed formula for
   \[
   \text{CH}_3(\text{CH}_2)_3\text{CH(OH)CH=CH(CH}_3)_2
   \]
   d) a bond-line formula for
   \[
   \text{CH}_3(\text{CH}_2)_3\text{CH(OH)CH=CH(CH}_3)_2
   \]

2. Consider the molecule below. Give:
   \[
   \begin{array}{ccc}
   \text{H} & \equiv & C \\
   \text{CH}_2 & & \text{C} \\
   & & \equiv \text{CH}_3
   \end{array}
   \]
   a) the hybridization of C2 ______
   b) the hybridization of C4 ______
   c) the O-C4-C5 bond angle ______

3. Draw the structure of an example (do not use R) of each of the following classes of compounds.
   a) 1° amine  b) acyl chloride  c) ether  d) 2° alkyl bromide

4. Name the functional group or groups present in each of the following molecules. Indicate 1°, 2°, or 3° when appropriate.
   a) \[
   \begin{array}{c}
   \text{O}
   \end{array}
   \]
   b) \[
   \begin{array}{c}
   \text{SH}
   \end{array}
   \]
   c) \[
   \begin{array}{c}
   \text{H}_3\text{C} \\
   \text{C} \\
   \text{CH}_2\text{CH}_3
   \end{array}
   \]

5. Draw at least four constitutional isomers of C₃H₁₁NO₂ with as many functional groups as possible. Identify each functional group. Some molecules may have more than one.
Multiple Choice

1. An oxygen-containing compound which shows no IR absorption at 1650-1800 cm\(^{-1}\) or 3200-3400 cm\(^{-1}\) is likely to be what type of compound?
   a) an amide     b) an alcohol     c) a ketone     d) an ether

2. Which of these compounds has a band in its IR spectrum at 1650-1800 cm\(^{-1}\)?
   a)                                     b)                                     c)  OH    d)                                     
   ![Image](cyclohexane.png)

3. Which of the following compounds has the **highest** boiling point?
   a) CH\(_3\)CH\(_2\)CH\(_3\)     b) CH\(_3\)CH\(_2\)CH\(_2\)CH\(_2\)CH\(_2\)OH
   c) CH\(_3\)OCH\(_2\)CH\(_3\)     d) CH\(_3\)CH\(_2\)CH\(_2\)OH

4. Which of the following compounds is the **least soluble** in water?
   a) CH\(_3\)CH\(_2\)CH\(_2\)Br     b) (CH\(_3\))\(_2\)CHCH\(_2\)CH\(_2\)OH
   c) CH\(_3\)CH\(_2\)CH\(_2\)OH     d) (CH\(_3\))\(_2\)CHCH\(_2\)CH\(_2\)Br

5. Indicate which of the four compounds below is responsible for the IR spectrum shown below. **Explain your answer.**
   ![Image](ir-spectrum.png)
   a) CH\(_3\)CH\(_2\)CH\(_2\)C≡CCH\(_3\)     b) CH\(_3\)CH\(_2\)CH\(_2\)OH
   c) CH\(_3\)CH\(_2\)CH\(_2\)C≡CH     d) CH\(_3\)CH\(_2\)CH\(_2\)CH\(_2\)OH

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