Learning Guide for Chapter 2 - Introduction to Organic molecules

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I. Ways to represent organic molecules

The molecule which causes the odor of ripe bananas is shown in several different ways below. Identify each and explain its characteristics.

molecular formula

\[
\text{C}_2\text{H}_4\text{O}_2
\]

# of atoms of each element

1st C, then H, all others in alphabetical order

not specific enough - could be more than one compound

Lewis structure

shows all atoms, bonds, e- pairs

identifies a specific molecule

takes too long to draw, uses incorrect angles

condensed structure

H's written next to C's

extra condensed version - uses ( ) to put it all on one line

often used in print

still takes too long to draw, uses incorrect angles

often doesn't show e- pairs

line structure

shows bonds between C atoms, O's N's, e- pairs

correct angles, easiest to draw, but requires a special program to create on computer

(name)

isopentyl acetate

gives structure if you know how to interpret it

easy to print
Here is the line structure for tert-butyl alcohol. What is its molecular formula, condensed structure, and line structure?

- **name:** tert-butyl alcohol
- **condensed structure:** \( \text{CH}_3\text{C}(-\text{CH}_3)\text{C}(-\text{CH}_3)\text{O} \)
- **molecular formula:** \( \text{C}_4\text{H}_{10}\text{O} \)

Give a molecular formula and condensed structure for the following line structures.

<table>
<thead>
<tr>
<th>Line Structure</th>
<th>Molecular Formula</th>
<th>Condensed Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>HO(-\text{CH}_2\text{CH}_2\text{OH} )</td>
<td>( \text{C}_2\text{H}_6\text{O}_2 )</td>
<td>( \text{C}_2\text{H}_6\text{O}_2 )</td>
</tr>
<tr>
<td>( \text{O} : \text{C}(-\text{CH}_3)\text{Cl} )</td>
<td>( \text{C}_3\text{H}_6\text{O} )</td>
<td>( \text{C}_3\text{H}_6\text{O} )</td>
</tr>
<tr>
<td>( \text{O} : \text{C}(-\text{CH}_3)\text{Cl} )</td>
<td>( \text{C}<em>5\text{H}</em>{12}\text{O} )</td>
<td>( \text{C}<em>5\text{H}</em>{12}\text{O} )</td>
</tr>
</tbody>
</table>

Give a line structure for the following condensed structures.

<table>
<thead>
<tr>
<th>Condensed Structure</th>
<th>Line Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{O} : \text{C}(-\text{CH}_3)\text{Cl} )</td>
<td>( \text{H}_2\text{C}(-\text{CH}_2\text{CH}_3\text{O})\text{Cl} )</td>
</tr>
<tr>
<td>( \text{O} : \text{C}(-\text{CH}_3)\text{Cl} )</td>
<td>( \text{H}_2\text{C}(-\text{CH}_2\text{C}(-\text{CH}_2\text{Cl})\text{Cl} )</td>
</tr>
</tbody>
</table>
II. Classification of Organic Molecules

Why is it important to put organic compounds into categories?

there are so many compounds, we group them together by how they behave

How do chemists decide what categories to create?

how they react

General terms:

compounds with only C, H:  hydrocarbon

compounds containing a benzene ring:  aromatic

compounds which don't have a benzene ring:  aliphatic

compounds containing carbon-carbon double or triple bonds (not in a benzene ring):  unsaturated

(comp not in benzene rings)

compounds which don't have a carbon-carbon double or triple bond (or a benzene ring):  saturated

Label the following compounds with all terms that apply to them.
What is a functional group? the part of the compound that reacts
pattern of atoms that react a certain way

**Hydrocarbon functional groups**

<table>
<thead>
<tr>
<th>functional group</th>
<th>description</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>pentane</td>
<td>alkane</td>
<td>only C-C single bonds end in: -ane</td>
</tr>
<tr>
<td>2-pentene</td>
<td>alkene</td>
<td>C=C (not in benzene ring) end in: -ene</td>
</tr>
<tr>
<td>2-pentyne</td>
<td>alkyne</td>
<td>C≡C (I may use C---C to indicate a triple bond in notes) end in: -yne</td>
</tr>
</tbody>
</table>

Label the alkanes, alkenes, and alkynes below.
Functional groups containing only oxygen:

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>Description</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH</td>
<td>1-propanol</td>
<td>alcohol (C-OH) end in: -ol contain: -hydroxy-</td>
</tr>
<tr>
<td>COC</td>
<td>propanoic acid</td>
<td>carboxylic acid (C=O) end in: -acid</td>
</tr>
<tr>
<td></td>
<td>diethyl ether</td>
<td>ether (C-O-C) end in: -ether contain: -methoxy- etc</td>
</tr>
<tr>
<td></td>
<td>methyl propanoate</td>
<td>ester (C=O-C) end in: -ate</td>
</tr>
<tr>
<td></td>
<td>acetic anhydride</td>
<td>anhydride (C=O-C) end in: -anhydride</td>
</tr>
<tr>
<td>only C=O</td>
<td>propanal</td>
<td>aldehyde (C=O-H) H must be written! end in: -al contain: -oxo-</td>
</tr>
<tr>
<td></td>
<td>3-pentanone</td>
<td>ketone (C=O-C) end in: -one end in: -ketone contain: -oxo-</td>
</tr>
</tbody>
</table>
Label the following compounds with the functional group they contain.

ether
aldehyde
aromatic ketone
unsaturated alcohol
carboxylic acid
anhydride
ketone
alcohol
ester
alcohol ether
carboxylic acid

Functional groups containing nitrogen:

<table>
<thead>
<tr>
<th>functional group</th>
<th>description</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{NH}_2 )</td>
<td>amine C-N</td>
<td>end in: -amine contain: -amino-</td>
</tr>
<tr>
<td>( \text{NH}_2 )</td>
<td>amide C=O w/N on one side</td>
<td>end i: -amide</td>
</tr>
<tr>
<td>( \equiv \text{N} )</td>
<td>nitrile C≡N</td>
<td>end in: -nitrile contain: -cyano-</td>
</tr>
<tr>
<td>( \text{NO}_2 )</td>
<td>nitro C-NO₂</td>
<td>contain: -nitro-</td>
</tr>
</tbody>
</table>
Label the compounds below.

\[
\begin{align*}
&\text{amine} & \text{nitrile} & \text{amide} & \text{unsaturated amine} \\
&\text{ketone nitro} & \text{amide alcohol} & \text{notice-not also an amine}\end{align*}
\]

**Functional groups containing halogens:**

<table>
<thead>
<tr>
<th>functional group</th>
<th>description</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethyl chloride</td>
<td>alkyl halide</td>
<td>C-X   (X = halogen) end in: fluoride, chloride bromide, or iodide contain: -fluoro-, -chloro-, -bromo-, or -iodo-</td>
</tr>
<tr>
<td>bromobenzene</td>
<td>aryl halide</td>
<td>&quot; &quot; directly attached!</td>
</tr>
<tr>
<td>acetyl chloride</td>
<td>acid chloride</td>
<td>end in: -chloride (other acid halides exist, but are too reactive to be useful)</td>
</tr>
</tbody>
</table>

Label the compounds below.

\[
\begin{align*}
&\text{alkyl halide} & \text{aromatic acid chloride} & \text{aryl halide} & \text{aromatic alkyl halide} & \text{acid chloride alkyl halide} \\
&\text{alkyl halide} & \text{aryl halide} & \text{aryl halide} & \text{aryl halide bromobenzene} & \text{alkyl halide benzyl bromide}\end{align*}
\]

How are these two compounds different?
What would each of the following compounds become if a C=O was added next to the existing functional group?

- **without C=O**
  - alkane
  - ketone
  - alcohol
  - amine
  - ether

- **with C=O**
  - alkyl chloride
  - acid chloride
  - carboxylic acid
  - amide
  - ester
  - anhydride

What can you tell about the following compounds from their names?

- N-ethylpropanamine
  - amine

- 3-methoxy-1-propanol
  - ether
  - alcohol

- 3-bromobenzamide
  - amide
  - aromatic
  - could be alkyl or aryl halide
  - can't tell until you know the structure

- 3-oxo-pentanoic acid
  - carboxylic acid
  - aldehyde or ketone

- 4-nitro-2-pentene
  - unsaturated (not an alkene - contains an N)
  - nitro group
  - note - likewise an compound may end in ane or yne but not be an alkane or alkyne if there is an N, O, or X

- methyl 3-cyanobenzoate
  - ester
  - nitrile
  - aromatic
Identify the functional groups present in the following compounds. Which are aromatic? Which are unsaturated?

- **p-aminobenzoic acid - PABA**
  - Aromatic
  - Amine
  - Carboxylic acid

- **vanillin**
  - Aromatic
  - Alcohol
  - Ether

- **methyl salicylate**
  - Aromatic
  - Alcohol
  - Ester

- **testosterone**
  - Unsaturated
  - Alcohol

- **heroin**
  - Aromatic
  - Amine
  - Ether
  - Ester
III. Physical Properties of Organic Molecules

List some physical properties of organic compounds.

- color, odor, state of matter, melting point, boiling point, density, water solubility, etc

What determines the physical properties of a compound?

- the structure of its molecules

What can we predict by looking at the structure of molecules?

- water solubility, density compared to water
- relative bp/mp of 2 compounds

Intermolecular forces

What is an intermolecular force?  
force that attracts molecules to each other

What are the three intermolecular forces?  How do they compare in strength?

- van der Waals < dipole < H-bonding
  - weakest  
  - strongest

How are these different from covalent and ionic bonds?

- covalent - between atoms the same molecule
- ionic - between two ions in the same compound
- intermolecular - between two molecules

Which is stronger, a **covalent bond** or a hydrogen bond?

- even the strongest IMF is weaker than a chemical bond

What causes Van der Waals forces?

- temporary dipoles - caused by collisions between molecules

What kinds of molecules experience Van der Waals forces?  **all molecules**

In what kinds of molecules will van der Waals forces be significant?

- molecules that don't have any polar bonds

Example: butane

- \[ + \quad - \quad + \quad - \quad + \quad - \quad + \quad \]
What factors affect the strength of Van der Waals forces?  
- more surface area = more Van der Waals attraction  
- less surface area = more surface area

What are dipole forces?
attraction of partially positive and partially negative ends of two different molecules

What kinds of molecules experience dipole forces?
molecules with polar bonds (except those involving H)

Example: chloromethane

What factors affect the strength of dipole forces?
- how strong the polar bond is  
- how many nonpolar bonds are also present

\[
\begin{align*}
H_3C\equiv Cl: & < H_3C\equiv F: & \text{C-F is more polar than C-Cl} \\
H_3C\equiv Cl: & > & \text{lots of nonpolar C-H bonds dilute the effect}
\end{align*}
\]

What is hydrogen bonding?
an attraction between partially + H and lone pair of e- on O or N

What kinds of molecules experience hydrogen bonding?
molecules with N-H and O-H bonds (alcohols, amines, COOH, amides)

Example: methyl amine

What factors affect the strength of hydrogen bonding?

bigger effect:  
- \( H_3C\equiv N\equiv H \) < \( H_3C\equiv O\equiv H \)  
- O is more EN than N - stronger dipole = more attraction

smaller effect:  
- \( H_3C\equiv N\equiv H \) > \( H_3C\equiv N\equiv CH_3 \)  
- more H's on N or O = more opportunities for H-bonding
What will be the most important intermolecular force for each of the following molecules?

- Dipole forces
- H-bonding
- Van der Waals
- Dipole
- H-bonding

**States of matter and transitions between them**

What are the three states of matter that an organic compound can be in?

**solid, liquid, gas**

Consider a container of fireflies, a container of apples, and a container of snakes.

Which is most like a gas? Why?  **fireflies**

- lots of movement, lots of energy, lots of space between them
- fairly small "molecules"
- no organization, escape if container is opened

Which is most like a solid? Why?  **apples**

- no movement, low energy, not much space between them
- high degree of organization (especially if carefully stacked!) keep the same shape

Which is most like a liquid? Why?  **snakes**

- some movement, some energy, some space between them
- medium sized "molecules"
- not much organization - similar to gas flow, but don't expand

What happens when a solid changes to a liquid?  **it melts**

- molecules break out of their arrangement
- start moving around, spread out

What is a melting point?

- the temperature at which a specific compound melts

  - Water: 0° C; liquid at room temp - mp below RT (25°C)
  - Sucrose: 185°C; solid at room temp - mp above RT

How does the size of the molecule affect the melting point? Why is this so?

- bigger molecule = higher mp
- it takes more energy to get big molecules moving, break up IMF
How does the strength of the intermolecular forces affect the melting point and why?

stronger IMF = higher mp
takes more energy to pull the molecules apart from each other

Does atmospheric pressure affect the melting point?  no

What happens when a liquid changes to a gas?  evaporates, or boils
molecules separate from each other
start flying around

What is a boiling point?
the temperature where a specific compound changes from liquid to gas
inside the liquid, not just at the surface
propane: -42.1°C; gas at RT - bp below RT
water: 100°C; liquid at room temp - bp above RT

How does the size of the molecule affect the boiling point? Why is this so?

higher mass = higher bp
it takes more energy to get big molecules flying around

How does the strength of the intermolecular forces affect the boiling point and why?

stronger IMF = higher mp
it's harder to pull the molecules apart from each other

Does atmospheric pressure affect the boiling point? Why?  yes
for gas to form, vapor pressure must equal atmospheric pressure

What state of matter will the following compounds be in at room temperature?

\[
\text{isopentyl acetate} \quad \text{mp} -78°C; \text{bp} 142°C \quad \text{liquid - it will have melted but not yet boiled}
\]

\[
\text{acetamide} \quad \text{mp} 80°C; \text{bp} 221°C \quad \text{solid - it hasn't reached mp yet}
\]

\[
\text{ethyl chloride} \quad \text{mp} -139°C; \text{bp} 12.3°C \quad \text{gas - has already melted and boiled}
\]
Which of the two molecules below would you expect to have a higher melting and boiling point? Why?

1) \( \text{H}_3\text{C} = \text{CH}_3 \) alkane \( \text{H}_2\text{C}\text{CH}_3 \) alkane
   - mass - one is larger
   - IMF: same - vdw
   - bp -88°C bp -0.5°C

2) \( \text{C}_5\text{H}_{12} \) alkane \( \text{C}_5\text{H}_{10} \) alkane
   - mass - about the same
   - IMF - both have van der Waals forces; one has more surface area
   - bp 36°C bp 10°C

3) \( \text{C}_2\text{H}_4\text{O} \) ether \( \text{C}_3\text{H}_8 \) alkane
   - mass - about the same
   - IMF - dipole forces > van der Waals
   - bp -25°C bp -42°C

4) \( \text{CH}_3\text{COOCH}_3 \) anhydride \( \text{CH}_3\text{COCH}_3 \) ketone
   - mass - about the same
   - IMF - both have dipole forces, but one has more polar bonds
   - bp 138°C bp 117°C

5) \( \text{C}_2\text{H}_4\text{O} \) ether \( \text{C}_2\text{H}_5\text{OH} \) alcohol
   - mass - about the same
   - IMF - hydrogen bonding > dipole
   - bp -25°C bp 78°C

6) \( \text{C}_2\text{H}_5\text{NH}_2 \) 2° amine \( \text{CH}_3\text{CH}_{2}\text{NH}_2 \) 1° amine
   - mass - about the same
   - IMF - both have hydrogen bonding, but one has more H's
   - bp 7°C bp 16.6°C
Solubility

What does it mean to say that two substances are soluble in each other?

their molecules (or ions) mix freely with each other

Give an example of:

a solid dissolving in a liquid salt or sugar in water (sea water)
a gas dissolving in a liquid CO₂ in water (soda)
a liquid dissolving in another liquid ethanol and water (beer)

What does it look like when one substance dissolves in another?

solids - disappear, liquids - mixed, don't form boundary

Why does salt dissolve in water?

ions are attracted to the partial charges

Why do ethanol and water dissolve in each other?

both form H-bonds

Why doesn't hexane dissolve in water?

hexane can't get in between the H-bonds

Why are all gases soluble in each other?

the molecules are so far apart that they don't interfere with each other

Would the following compounds be more likely to dissolve in water or hexane?

propylene hexane - can slip into the van der Waals forces
ethanol water - can join in the H-bonding
1-octanol hexane - too many C-H bonds
acetone both - polar bond (dipole forces), but also lots of nonpolar bonds
sodium butanoate water - charges are attracted to polar molecules