Chemistry 108 lecture notes     Chapter 4: An Introduction to Organic Compounds

Chapter 4 Lecture Notes

Chapter 4 Educational Goals
1. Given the formula of a molecule, the student will be able to draw the line-bond (Lewis) structure.
2. Understand and construct condensed structural formulas and skeletal structures given the line-bond (Lewis) structures.
3. Given the line bond structure, determine the formal charge for O & N.
4. Define electronegativity and explain its relationship to polar covalent bonds. Give a simple rule that can be used to predict whether or not a covalent bond is polar.
5. List the five basic shapes about an atom in a compound and describe the rules used to predict the molecular shape. Explain how shape plays a role in determining overall polarity.
6. Describe the noncovalent interactions that attract one compound to another.
7. Describe the four families of hydrocarbons.
8. Explain the difference between constitutional isomers, conformations, and the stereoisomers known as geometric isomers. Give examples of two different classes of hydrocarbons that can exist as geometric isomers.
9. Define the term functional group and describe the features that distinguish hydrocarbons, alcohols, carboxylic acids, and esters from one another.

Line Bond Structures

We draw line bond structures to see how ________________ are bonded together in molecules.
Line bond structures can be very simple as in the case of H₂, Or very complex as in the case of large molecules such as DNA.

Drawing Line Bond Structures

Step 1: Count the total number of ________________ from all the atoms in the molecule.

Example: H₂O

<table>
<thead>
<tr>
<th>Atom</th>
<th>Number of Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>2 x 1e⁻ = 2e⁻</td>
</tr>
<tr>
<td>O</td>
<td>1 x 6e⁻ = 6e⁻</td>
</tr>
</tbody>
</table>

Total number of valence e⁻ = 8e⁻

The line bond structure of H₂O will have 8 electrons
Step 2: Draw the “Skeleton Structure”
– Attach the atoms together with ____________ ____________ in the most symmetric way possible.

Example: H₂O

Which of the skeleton structures is the most symmetric?

a) \[ \text{H} - \text{H} - \text{O} \]
b) \[ \text{H} - \text{O} - \text{H} \]
c) \[ \text{O} - \text{H} - \text{H} \]

Step 3: Subtract the number of electrons used to make the skeleton structure from the total number of valence electrons.

– How many electrons are in the skeleton structure? _________

\[
\begin{align*}
\text{Total number of valence } e^- & \quad 8e^- \\
\text{Minus electrons used in skeleton} & \quad -4e^- \\
\text{Electrons remaining to be added} & \quad 4e^-
\end{align*}
\]

Step 4: Add the remaining electrons as ____________ ____________ as evenly as possible on all atoms except hydrogen.

Step 5: Check for ____________________________.

– Are there 8 electrons around all atoms (except hydrogen)?

YES!

If NO, use ____________ ____________ to make double or triple bonds.

Step 6 (if needed): Use lone pairs to make ____________ or ____________ bonds until the octet rule is satisfied for all atoms in the molecule.
Let’s do a couple of examples to see how that works!

We will do O₂, N₂, and NH₃

Example O₂

Step 1: Count the total number of valence electrons from all the atoms in the molecule. How many valence electrons in O₂?

Calculate valence electrons in O₂ below:

Step 2: Draw the “Skeleton Structure”
– Attach the atoms together with single bonds in the most symmetric way possible.

Step 3: Subtract the number of electrons used to make the skeleton structure from the total number of valence electrons.

Total # of electrons in structure ______
(from step 1 above)

# of electrons used in skeleton - ______
(from step 2 above)

Remaining # electrons to be added= ______

Step 4: Add the remaining electrons as lone pairs as evenly as possible on all atoms except hydrogen.

Step 5: Check for Octets
– Are there 8 electrons around all atoms (except hydrogen)?
– If NO, use lone pairs to make double or triple bonds.

Example N₂
Step 1: Count the total number of valence electrons from all the atoms in the molecule. How many **valence electrons** in \( \text{N}_2 \)?

Calculate valence electrons in \( \text{N}_2 \) below:

Step 2: Draw the “Skeleton Structure”
   – Attach the atoms together with single bonds in the most symmetric way possible.

Step 3: Subtract the number of electrons used to make the skeleton structure from the total number of valence electrons.

Total # of electrons in structure \( \quad \) ______
(from step 1 above)

\# of electrons used in skeleton \( - \) ______
(from step 2 above)

Remaining # electrons to be added= ______

Step 4: Add the remaining **electrons as lone pairs** as evenly as possible on all atoms except hydrogen.

Step 5: Check for Octets
   • Are there 8 electrons around all atoms (except hydrogen)?
   • If NO, use lone pairs to make double or triple bonds.
**Draw the line bond structure for ammonia: NH₃**

### Step 1: Count the total number of valence electrons from all the atoms in the molecule.

Chemical formula of molecule: ________

<table>
<thead>
<tr>
<th>Atom</th>
<th># of atoms</th>
<th># of valence electrons</th>
<th>totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

Total # of electrons in line bond structure = ________

### Step 2: Draw the “Skeleton Structure” - Attach the atoms together with single bonds in the most symmetric way possible.

Central atom is: _______________

Draw skeleton:

### Step 3: Subtract the number of electrons used to make the skeleton structure from the total number of valence electrons.

Total # of electrons in structure (from step 1 above) = ________

# of electrons used in skeleton - ________ (from step 2 above)

Remaining # electrons to be added = ________

### Step 4: Add the remaining electrons as lone pairs as evenly as possible on all atoms except hydrogen.

First: Re-draw skeleton here:

Add remaining electrons to the skeleton as lone pairs

### Step 5: Check for Octets

Check the structure in step 4 for octets (4 pairs) of electrons around each atom.

If octet rule is satisfied, you are done.

If octet rule is not satisfied, change lone pairs into double or triple bonds until octet rule is satisfied for all atoms.
Structural Formulas and Formal Charges

- __________________ are uncharged groups of nonmetal atoms connected to one another by covalent bonds.
- The structure of a molecule can be represented by an electron dot structure or a line-bond (Lewis) structure (____________  ____________).

**Electron dot structure**

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

**Line-bond structure**

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

2-Propanol

The molecular formula of isopropyl alcohol is C\(_3\)H\(_8\)O.
The structural formula of isopropyl alcohol is:

- Which do you think is more informative?

**Structural Formulas**

Three completely different molecules have the same formula of isopropyl alcohol: C\(_3\)H\(_8\)O

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

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

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

Structural formulas, like the line-bond formulas shown above, indicate the relative ____________ of each atom within molecules.

**Formal Charge**

In addition to describing the structure of molecules, structural formulas also provide information about where the ____________ ____________ is sometimes located in molecules and polyatomic ions.
Example: The nitrate ion ($\text{NO}_3^-$), consists of a nitrogen atom covalently bonded to three oxygen atoms.

- The __________ charge of the ion is shown as a superscript to the right.
- The ______________ charge on each atom is shown.

**Polyatomic Ion Examples**

Polyatomic ions are charged groups of nonmetal atoms that are connected by covalent bonds.  

(a) The net charge of the ion is shown as a superscript to the right.  

(b) The formal charge on each atom is shown.

**What do I need to know about formal charges in this class?**

*We will keep track of formal charges on two atoms: __________ and ____________*

- If oxygen has just __________ single bond going to it, it has a formal charge of $(1-)$.

- In other cases, it will have no formal charge.

- If nitrogen has a __________ ____________ on it, then it will have no formal charge.

- In __________ other cases, it will have a $(1+)$ formal charge.
Group Work

The line-bond structure glycine, an amino acid present in many proteins, is shown below. Assign formal charges to the nitrogen and each oxygen atom in this compound.

Condensed Structural Formulas

- A condensed structural formula describes the attachment of atoms to one another, without showing all of the ____________________.
- For example, a carbon with 3 attached hydrogen atoms can be written “CH₃”
- In condensed structures, bonds are not shown for carbon atoms that are in a ______________ sequence, or hydrogen-carbon and hydrogen-oxygen bonds. All other bonds are drawn.

Line-bond structure |
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
</tr>
<tr>
<td>H</td>
</tr>
<tr>
<td>H</td>
</tr>
</tbody>
</table>

Propane

Condensed formula |
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃CH₂CH₃</td>
</tr>
</tbody>
</table>

H | H | H | H |
| H | C | C | C | C | H |
| H | H | F | H |

2-Fluorobutane

Condensed formula |
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃CH₂CHCH₃</td>
</tr>
<tr>
<td>F</td>
</tr>
</tbody>
</table>

H | O | O | H |
| H | C | C | C | C | H |
| H | C | C | C | C | H |
| H | C | C | H |

Aspirin
Skeletal Structures

- In skeletal structures, covalent bonds are represented by lines, carbon atoms are ________ shown, and hydrogen atoms are drawn only when attached to atoms other than ____________.

- To read a skeletal structure, you assume that the carbon atom appears where ____________ (bonds) meet and at the ______________ of each line.

**Example:** Draw condensed and skeletal structures of diethyl ether, a compound once used as a general anesthetic.

```
H H  H H
H – C – C – O – C – H
H H  H H
```

```
H  H  H  H
H – C – C – O – C – H
H  H  H  H
```
Group Work
Research suggests that drinking green tea may help boost the immune system. Ethylamine (below), produced when one of the compounds in green tea is broken down in the liver, may be responsible for this immune response. Draw condensed and skeletal structures for this molecule.

Draw condensed structure here

Draw skeletal structure here

Online Homework Condensed Structures

For online homework, draw all carbon-carbon bonds.

SEE Chapter 4 online homework:

Video: Guide to Drawing molecules
- and-
Practice Drawing Molecules
Polar Covalent Bonds, Shape, and Polarity

Molecular Shape

Definition of Molecular Shape: the three-dimensional arrangement of a molecule’s ____________ in space.

Molecular Shape can be determined from the line bond structure using Valence Shell Electron Pair Repulsion Theory (VSEPR).

Predicting Molecular Shape

VSEPR Theory

• The shape around the central atom(s) can be predicted by assuming that the areas of electrons (often called electron groups - E.G.) on the central atom will ________________ each other.
  • Each ________________ ______________ counts as 1 electron group (EG)
    – single, double or triple __________ count as 1 EG
  • Each ________________ ______________ counts as 1 electron group (EG)
    – Even though lone pairs are not attached to other atoms, they do “occupy space” around the central atom.
Predicting Molecular Shape

Step 1. Get Electron Arrangement

What happens if 2 negatively charged balloons are placed into a hollow, clear plastic sphere?

Electrostatic ____________________ will cause the balloons to move as far apart from each other as possible.

The same thing happens with____________________
____________________

Draw the line bond structure for CO$_2$ in the box below:

The central atom goes in the ____________________________ of the sphere.

How many electron groups are around the central atom?___________

There are ________________ electron groups around the central atom!

Each bonded atom counts as ____________ electron group.

The electron groups are placed as ________________ apart from each other as possible!
Example: 3 Electron Groups

- What happens if 3 negatively charged balloons are placed into a hollow, clear plastic sphere?

Electrostatic repulsion will cause the balloons to move as far apart from each other as possible.

Draw the line bond structure for \( \text{SO}_3 \) in the box below:

The central atom goes in the middle of the sphere.

How many electron groups are around the central atom?

There are ________ electron groups around the central atom!

Each bonded atom counts as one electron group.

The electron groups are placed as far apart from each other as possible!

All electron groups are on the same __________ and are at __________ angles.

Let’s rotate the ball to see the 120° bond angles
**Example: 4 Electron Groups**

What happens if 4 negatively charged balloons are placed into a hollow, clear plastic sphere?

Electrostatic repulsion will cause the balloons to move as far apart from each other as possible.

Draw the line bond structure for a **methane** molecule (CH$_4$) in the box below:

The central atom goes in the middle of the sphere.

How many electron groups are around the central atom?

There are ________ electron groups around the central atom!

The electron groups are placed as far apart from each other as possible!

This arrangement is a 4-sided, 3 dimensional structure with electron groups at ____________ angles.

Another way to visualize the tetrahedral shape:
Electron Arrangement Review

2 Electron Groups:

![2 Electron Groups Image](image1)

3 Electron Groups:

![3 Electron Groups Image](image2)

4 Electron Groups:

![4 Electron Groups Image](image3)

Predicting Molecular Geometry

Step 1. Get Electron Arrangement – no problem now!

**Step 2.** Determine Molecular Shape based on the arrangement of bonded__________.

- Treat lone pairs as ________________________!!!

Let’s do an example: Draw the line bond structure of CO₂

- How many electron groups are around the central atom?________________

What is the bond angle in a 2-electron group arrangement?

- Choices: a) 180°, b) 120°, c) 110°
Now build a model of CO$_2$.

- Use the black sphere for the central Carbon atom.
- Use two metal springs for each double bond.
- Use the red spheres for the oxygens.

This molecular shape is called ________________.

We write the general notation for this shape as ____________.

- A = the central atom
- B = bonded atoms
- E = a lone pair (none seen in this example)
The molecular shape of a __________ molecule is always ________________!

- Fill in the box for 2EG with 1 lone pair on the Molecular Shape Table on the previous page.

Let’s do an example: Draw the line bond structure of SO₃

How many electron groups are around the central atom? ________________

- What is the bond angle in a 3-electron group arrangement?
  Choices: a) 180°, b) 120°, c) 110°

- Now build a model of SO₃
  - Use the black sphere for the central sulfur atom.
  - Use wood sticks for single bonds and two metal springs for double bonds.
  - Attach the red spheres with wood sticks for the oxygens.

  This molecular shape is called ___________________________
  ___________________________.

  We write the general notation for this shape as ____________.

Draw this shape and geometry name in the Molecular Shape Table on page 16.

Another example: Draw the line bond structure of ozone gas O₃

How many electron groups are around the central atom? ________________

- What is the bond angle in a 3-electron group arrangement?
  Choices: a) 180°, b) 120°, c) 110°

- Now build a model of O₃
  - Use the black spheres for the oxygen atoms.
  - Use two metal springs for the double bond.
  - Use wood sticks for the single bond.
When determining molecular shape, we treat the lone pairs as if they were ________.
This molecular shape is called ________________.
We write the general notation for this shape as _____________________.

Draw this shape and geometry name in the Molecular Shape Table on page 15.

Another example: Draw the line bond structure of methane gas CH₄

How many electron groups are around the central atom? ________
What is the bond angle in a 4-electron group arrangement?
Choices: a) 180°, b) 120°, c) 110°

• Now build a model of CH₄
  • Use a black sphere for the central carbon atom.
  • Use wood sticks for single bonds.
  • Use yellow spheres for the hydrogens.

This molecular shape is called _____________________________.
We write the general notation for this shape as ________________

Example: Draw the line bond structure of ammonia NH₃

• How many electron groups are around the central atom? ________________
• What is the bond angle in a 4-electron group arrangement?
  Choices: a) 180°, b) 120°, c) 110°

• Now build a model of NH₃
  • Use a black sphere for the central nitrogen atom.
  • Use wood sticks for single bonds.
  • Use yellow spheres for the hydrogens.

When determining molecular geometry, we treat the lone pair as if it was invisible!
This molecular shape is called__________________.
We write the general notation for this shape as ______________.

Draw this shape and geometry name in the Molecular Shape Table on page 16.

**Example: Draw the line bond structure of a water molecule H₂O**

- How many electron groups are around the central atom? ____________
- What is the bond angle in a 4-electron group arrangement?
  Choices: a) 180°, b) 120°, c) 110°

Now build a model of H₂O

- Use a black sphere for the central oxygen atom.
- Use wood sticks for *single bonds*.
- Use yellow spheres for the hydrogens

When determining molecular shape, we treat the lone pairs as if they were invisible!

This molecular shape is called______________.
We write the general notation for this shape as ____________.

Draw this shape and geometry name in the Molecular Shape Table on page 16.
Why is a molecule’s polarity important?
- Polarity is responsible for many physical and chemical properties of substances:
  - Freezing/melting point
  - Boiling/condensation point
  - How molecules interact with other molecules (including solvents and surfaces)
  - How large molecules such as DNA and proteins fold-up on themselves
  - How antibodies and enzymes bind with their target molecules

We must know 2 things to determine if a molecule is polar:

1) ________________________________
   - No problem now!!!
   - ________________________________

2) ________________________________
   - Are there polar bonds in the molecule?
Bond Polarity
• Unequal sharing of electrons in a covalent bond results in ______________ bonds.

  Let’s consider 2 simple molecules: 
    • \( H_2 \) and \( HCl \)

The 2 electrons that are shared in the \( H_2 \) molecule are shared ______________ between the two hydrogen atoms.
• Each hydrogen atom has an equal attraction for the electrons in the bond.

The 2 electrons that are shared in the \( HCl \) molecule are __________ ______________ shared between the hydrogen and the chlorine atom.

The electrons have a stronger attraction to the \textit{chlorine} atom than to the hydrogen.

Covalent bonding between _________ atoms results in unequal sharing of the electrons.

  – The electrons spend more ______________ near the Cl atom.
  – One end of the bond has larger electron __________ than the other.

The result is ________ ______________ .

• The end with the larger electron density gets a ______________ ______________ charge.
• The end that is electron deficient gets a partial ______________ charge.

An ______________ ______________ is created by equal but opposite charges that are separated by short distances.

We use an ______________ with a cross to represent an electric dipole.

  – The arrow always points in the ______________ direction.

Electronegativity
The ability for atoms to attract the electrons in a covalent bond is called ______________.

  • Hydrogen has an electronegativity of 2.1
  • Chlorine has an electronegativity of 3.0

The __________________________ the difference in electronegativity between

the two bonded atoms, the __________________________ the dipole.
You try it!
Which molecule has a larger dipole?

HF or HBr

Calculate the differences in the electronegativities (E.N.) for each of the molecules.

E.N. for H= _____  \( \text{H} \text{F} \)  E.N. for F = _____  
Electronegativity. Difference for HF = ______

E.N. for H= _____  \( \text{H} \text{Br} \)  E.N. for Br = _____  
Electronegativity. Difference for HBr = ______

The larger the difference in electronegativity between the two bonded atoms, the stronger the dipole—therefore HF has the largest dipole!

Polarity of Diatomic Molecules Summary:

<table>
<thead>
<tr>
<th>Non-Polar Molecules</th>
<th>Polar Molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homonuclear Diatomic</td>
<td>Heteronuclear Diatomic</td>
</tr>
</tbody>
</table>

That is easy for diatomic molecules, but what about the polarity of molecules with more than two atoms?
Polarity of Small Molecules

We must look at what happens when we ______________ ____________ up all the dipoles.

Example: CO₂

There are 2 polar bonds in an CO₂ molecule.

This results in two ______________.

\( \delta^- \quad \delta^+ \quad \delta^- \)

- The oxygens have a _______________ negative charge.
- The carbon has a partial positive charge.

Since the molecule is symmetric, the dipoles cancel each other and the molecule is ___________________.

- Symmetric small molecules with are non-polar molecules.

Let’s look at what happens when we add up all the dipoles in another molecule:
Example: H₂O

There are 2 polar bonds in an H₂O molecule.

This results in two dipoles.

The oxygen has a partial negative charge.

The hydrogens have a partial positive charge.

Since the molecule is not symmetric, the dipoles do not cancel each other and the molecule is___________________.

Since dipoles in non-symmetric molecules do not cancel each other out, they add up to yield a molecule with a dipole.

Non-symmetric small molecules with polar bonds are polar molecules.

Polarity of Small Molecules:
General Rule:
Symmetric molecules have the central atom surrounded by ________________ electron groups.

Example:
Polarity of Small Molecules Summary Chart:

<table>
<thead>
<tr>
<th>Non-Polar Molecules</th>
<th>Polar Molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symmetric Molecules</td>
<td>Non-Symmetric Molecules</td>
</tr>
<tr>
<td>Symmetric molecules have the central atom surrounded by identical electron groups.</td>
<td>Central atom surrounded by non-identical electron groups.</td>
</tr>
</tbody>
</table>

Polarity of Large Molecules

- In this course, we will be working with large molecules (organic and biochemistry).
- Large molecules will be considered polar (or have polar regions) if they have __________ bonds.
  - The important highly-polar covalent bonds, especially in organic and biochemistry, are those in which either hydrogen or carbon atoms are covalently attached to nitrogen, oxygen, fluorine, or chlorine atoms.

Summary:

<table>
<thead>
<tr>
<th>Polar large molecules contain one or more of the following bonds:</th>
<th>Non-Polar Molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-N H-N</td>
<td>None of these bonds</td>
</tr>
<tr>
<td>C-O H-O</td>
<td></td>
</tr>
<tr>
<td>C-F H-F</td>
<td></td>
</tr>
<tr>
<td>C-Cl H-Cl</td>
<td></td>
</tr>
</tbody>
</table>

Understanding check

The compound on the right has been used to kill any insect larvae present in cereal and dried fruit.

1) What size class would the molecule below be categorized as?
   a) Diatomic molecule
   b) Small molecule
   c) Large molecule

2) This molecule is ________.
   a) polar
   b) non polar
**Polarity of Large Molecules**
- Look for “highly polar bonds”
  - Example:
    - Cyclohexane vs. Cyclohexanol

\[ \text{C-H bonds} = \text{Non-polar} \quad \text{O-H, C-O bond} = \text{Polar} \]

**Dipoles are attracted to other dipoles by electrostatic forces!**
- Polar molecules have strong attractions to other polar molecules because the positive end of a dipole is attracted to the negative end of another dipole.
- Next, will see how the polarity of molecules influences properties such as melting and boiling points of compounds.

**Noncovalent Interactions/Intermolecular Forces**
Why are some molecular compounds solid while others are gaseous and others are liquid at room temperature?
- Lets take a magnified look at these three phases of matter on the molecular scale!

Representations of the gas, liquid, and solid states.

Adding \____________ to liquids will overcome the forces holding the molecules together—boiling.

Adding energy to solids will overcome the forces holding the molecules together—\____________.
What forces hold molecules together to make liquids and solids?

The attractive forces that hold molecules together are called ________________ forces.

3 Types of Intermolecular Forces

- 1) Dipole-Dipole
- 2) Hydrogen Bonding
- 3) London Forces (Induced Dipole Forces)

1) Dipole-Dipole Forces

Dipoles are attracted to other dipoles by electrostatic forces!

- Polar molecules have strong attractions to other polar molecules because the positive end of a dipole is attracted to the negative end of another dipole.

Example: HCl

Dipole-Dipole Attraction

The forces of attraction between polar molecules are known as ________________ forces.

2) Hydrogen Bonding

A particularly strong type of intermolecular force is called ________________ ________________.

When hydrogen is covalently bonded to a very electronegative atom, it is strongly attracted to a ________ ________ on another electronegative atom.

Hydrogen bonding only occurs between a hydrogen bonded to N, O, or F, and a lone pair on a N, O, or F!!!
Example: Hydrogen Bonding in Water

Example: H₂O

The hydrogens are strongly attracted to a lone pair on the oxygen.

3) **London Dispersion Forces**
   - If we cool a non-polar molecule such as N₂ or O₂, it will turn liquid, then solid.
   - What forces hold these molecules together? – London dispersion forces.

Also known as ___________________ dipole force.

Caused by electrons on one molecule ______________ the electron cloud on another.

- All molecules have London dispersion forces (not just non-polar molecules)
- London dispersion forces are **weaker** than hydrogen bonding forces.
- ___________molecules have ___________London dispersion forces.

**Intermolecular Forces Conclusion**

- Intermolecular Forces
  - Three types:
    - Dipole-dipole
    - Hydrogen bonding
    - London Dispersion Forces
  - Much weaker than ionic or covalent bonds

- Larger attractive forces between molecules in pure substance means:
  - higher ___________ point
  - higher ___________ point
• Like __________________ Like
  – Polar molecules dissolve in polar solvents
  • Example: Water, alcohol
  – Non-polar molecules dissolve in non-polar solvents
  • Example: Oils and gasoline

**Molecular Solids**

Molecular solids are made of *molecule*
arranged in a pattern that
________________________ the attractive
forces between the molecules.

• Example (figure on right for ice)

**Other Important Noncovalent Interactions**

*Noncovalent interactions* are interactions that do not involve the sharing of valence electrons such as covalent bonding.

• Other noncovalent interactions due to the attraction of permanent charges:
  • Salt bridges
  • Ion-dipole interactions

• A *salt bridge* is another name for ionic bond that occurs in protein.

• It is an electrostatic attractive force between a negative formal charge and a positive formal charge in protein.

• A protein molecule (represented by the ribbon structure to the right) contains positive and negative formal charges. The charges are attracted to each other through salt bridge interactions (indicated by the dashed double arrow).

• *Ion-dipole* interactions occur between ions with a full charge and atoms with a partial charge.
### Summary of Noncovalent Interactions

<table>
<thead>
<tr>
<th>Noncovalent Interaction</th>
<th>Interaction Between:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydrogen Bonding</strong></td>
<td>Electrostatic attractive force between the partially positive charged hydrogen end of an O-H, N-H, or F-H bond and the negative charge of a lone pair on an O, F, or N.</td>
</tr>
<tr>
<td><strong>Dipole-Dipole</strong></td>
<td>Electrostatic attractive force between two polar molecules.</td>
</tr>
<tr>
<td><strong>London Dispersion Forces</strong></td>
<td>Electrostatic attractive force between any two molecules.</td>
</tr>
<tr>
<td><strong>Ion-Dipole</strong></td>
<td>Electrostatic attractive force between a dipole and an ion or formal charge. The partially positive charge of a dipole is attracted to a negatively charged ion or a negative formal charge. The partially negative charge of a dipole is attracted to a positively charged ion or positive formal charge.</td>
</tr>
<tr>
<td><strong>Salt Bridge</strong></td>
<td>Electrostatic attractive force between a negative formal charge and a positive formal charge in protein.</td>
</tr>
</tbody>
</table>
An Introduction to Organic Compounds

Hydrocarbons

- **Hydrocarbons** contain only carbon and hydrogen atoms.
- There are different types of hydrocarbons:
  - alkanes
  - alkenes
  - alkynes
  - aromatic compounds

<table>
<thead>
<tr>
<th>Family</th>
<th>Key Feature</th>
<th>Class</th>
<th>Example</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkanes</td>
<td>Atoms joined by single bonds only</td>
<td>Saturated</td>
<td>CH₃CH₂CH₃</td>
<td>Propane</td>
</tr>
<tr>
<td>Alkenes</td>
<td>At least one carbon–carbon double bond</td>
<td>Unsaturated</td>
<td>CH₂=CHCH₃</td>
<td>Propene</td>
</tr>
<tr>
<td>Alkynes</td>
<td>At least one carbon–carbon triple bond</td>
<td>Unsaturated</td>
<td>HC≡CCH₃</td>
<td>Propyne</td>
</tr>
<tr>
<td>Aromatic compounds</td>
<td>Contains a ring of alternating single and double bonds</td>
<td>Unsaturated</td>
<td><img src="image" alt="Benzene" /> or <img src="image" alt="Benzene" /></td>
<td>Benzene</td>
</tr>
</tbody>
</table>

**Alkanes**

are molecules that consist only of carbon and hydrogen atoms and contain only single bonds.
• **Examples of alkanes:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Condensed structural formula</th>
<th>Three-dimensional structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td></td>
</tr>
<tr>
<td>Ethane</td>
<td>CH₃CH₃</td>
<td></td>
</tr>
<tr>
<td>Propane</td>
<td>CH₃CH₂CH₃</td>
<td></td>
</tr>
</tbody>
</table>

Those were examples of ___________ alkanes, which means that their carbon chains are *unbranched.*

**Properties of Alkanes**

• Alkanes contain only nonpolar covalent bonds, are _______________ molecules, and are attracted to one another by *London forces.*

• The more carbon atoms in a normal alkane, the higher its _______________ point.
  – The longer the alkane, the greater it’s surface area and the stronger the London forces that holds it to other molecules.

<table>
<thead>
<tr>
<th>Structural Formula</th>
<th>IUPAC Name</th>
<th>Common Name</th>
<th>Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>Methane</td>
<td></td>
<td>-164</td>
</tr>
<tr>
<td>CH₃CH₃</td>
<td>Ethane</td>
<td></td>
<td>-89</td>
</tr>
<tr>
<td>CH₃CH₂CH₃</td>
<td>Propane</td>
<td></td>
<td>-42</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₃</td>
<td>Butane</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₂CH₃</td>
<td>Pentane</td>
<td></td>
<td>36</td>
</tr>
</tbody>
</table>
Chemistry 108 lecture notes  Chapter 4: An Introduction to Organic Compounds

Naming Alkanes

- **IUPAC rules**, devised by the International Union of Pure and Applied Chemistry, are a widely used method of naming organic compounds.

- Using the IUPAC rules involves identifying an alkane’s ______________  ______________
  (the longest continuous chain of carbon atoms in the molecule) and ______________
  (atoms or groups of atoms attached to the parent chain).

- In alkanes, the substituents, called ______________  ______________, are constructed solely of carbon and hydrogen atoms.

1. **Name the parent chain.**

- The parent chain is named by combining a numbering prefix which specifies the number of carbon atoms in the parent, with “____________”, which identifies the molecule as an alkane.

- **3 carbons = “prop”; alkane = “ane”**  **Propane is an alkane with 3 carbons.**

Prefixes for Naming Organic Compounds:

2. Name any alkyl group substituents.

<table>
<thead>
<tr>
<th>Number of Carbon Atoms</th>
<th>Alkyl Group Name</th>
<th>Condensed Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>methyl</td>
<td>— CH₃</td>
</tr>
<tr>
<td>2</td>
<td>ethyl</td>
<td>— CH₂CH₃</td>
</tr>
<tr>
<td>3</td>
<td>propyl</td>
<td>— CH₂CH₂CH₃</td>
</tr>
<tr>
<td>3</td>
<td>isopropyl</td>
<td>— CHCH₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[\text{CH}_3]</td>
</tr>
<tr>
<td>4</td>
<td>butyl</td>
<td>— CH₂CH₂CH₂CH₃</td>
</tr>
<tr>
<td>4</td>
<td>isobutyl</td>
<td>— CH₂CHCH₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[\text{CH}_3]</td>
</tr>
<tr>
<td>4</td>
<td>sec-butyl</td>
<td>— CHCH₂CH₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[\text{CH}_3]</td>
</tr>
<tr>
<td>4</td>
<td>tert-butyl (or t-butyl)</td>
<td>— CH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[\text{CH}_3]</td>
</tr>
</tbody>
</table>
3. Determine the point of attachment of alkyl groups to the parent chain.

The parent chain is numbered from the end nearer the ____________ alkyl group.

4. Construct the name of the alkane by placing the alkyl groups in alphabetical order and specifying their position numbers, followed by the name of the parent chain.

3-ethyl-2-methylheptane

The labels di, tri, tetra, etc., are added if two or more identical substituents are present.

- Note: DO NOT CONSIDER THE PREFIXES (di-, tri-, tetra-) FOR LISTING THE ALKYL GROUPS IN ALPHABETICAL ORDER; ALPHABETIZE BASED ON THE ALKYL GROUP NAME ONLY (methyl, ethyl, propyl, isopropyl, etc).

Examples:

2,2,3-trimethylhexane

5-ethyl-3,3-dimethyloctane

In the example on the right (5-ethyl-3,3-dimethyloctane), we list ethyl before dimethyl because e comes before m.

Give the correct IUPAC name for these molecules.
**Constitutional Isomers**
Molecules that have the same molecular formula, but different atomic connections are called ____________________ ____________________.

Constitutional Isomers of C₆H₁₄
Constitutional isomers always have a different name from one another.

Group Work: Draw the constitutional isomers for (C₄H₁₀).

**Conformations**
- Rotation about ____________________ ____________________ allows most molecules to assume a number of different 3-dimensional shapes.
- The shapes that a molecule can take because of bond rotations are called conformations.
- The different conformations of a molecule:
  - have the same molecular formula
  - have the same atomic connections
  - have a different 3-dimensional shape
Conformations of Butane
Rotation about the bond between carbons 2 and 3 in butane gives rise to different conformations (three-dimensional shapes) for the molecule.

Cycloalkanes

In some alkanes, called cycloalkanes, carbon atoms are joined into rings.

<table>
<thead>
<tr>
<th>Name</th>
<th>Line-bond structure</th>
<th>Skeletal structure</th>
<th>Side-view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclopropane</td>
<td><img src="image" alt="Cyclopropane" /></td>
<td><img src="image" alt="Cyclopropane" /></td>
<td><img src="image" alt="Cyclopropane" /></td>
</tr>
<tr>
<td>Cyclobutane</td>
<td><img src="image" alt="Cyclobutane" /></td>
<td><img src="image" alt="Cyclobutane" /></td>
<td><img src="image" alt="Cyclobutane" /></td>
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<tr>
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<td>Cyclohexane</td>
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</table>
**Naming Cycloalkanes**

- **When naming cycloalkanes**, the ring is usually designated as the parent, which is named by combining “_____________” with the alkane name.

- Example:

```
Cyclohexane
```

- When a ring holds more than one alkyl group, the ring is numbered from the position and in the direction that gives the _______________ numbers.

```
CH₃

CH₃

1,2-dimethylcyclopentane

Not 1,5-dimethylcyclopentane

1,3-dimethylcyclopentane

Not 1,4-dimethylcyclopentane
```

When there is only one substituent, the “1-” is omitted

```
CH₃

methylcyclopentane
```
When more than one of the same substituent is present on the same carbon, the following method is used:

- When substituents are non-identical, the ring-carbon attached to substituent that comes first in alphabetical order is assigned position number one.
- Example:

```
Stereoisomers
- The __________________________ rotation of the carbon-carbon single bonds in __________________________ has an interesting side effect in that it allows for the existence of stereoisomers, molecules that:
  - have the same molecular formula
  - have the same atomic connections
  - have a different 3-dimensional shape
  - are interchanged only by breaking bonds

- We will study various types of stereoisomers in this course. The first type that we will learn about are called geometric isomers.
- When stereoisomers exist because of __________________________ __________________________ __________________________, the stereoisomers are called geometric isomers.
```
Geometric Isomers

- Geometric isomers come in pairs – one is \textit{cis} and one is \textit{trans}.

- For cycloalkanes, a \textit{cis} geometric isomer has two alkyl groups on the same face of the ring and a \textit{trans} isomer has them on opposite faces.

- \textbf{Important NOTE:} To visualize geometric isomers (\textit{cis} and \textit{trans}), we must draw Side View Structures (as shown above).
- \textit{cis} vs. \textit{trans} cannot be shown using line bond or skeletal structures for \textit{cycloalkanes}.

\textbf{You try it:}

Draw and name the geometric isomers of 1-ethyl-2-methylcyclohexane.
Alkenes, Alkynes, and Aromatic Compounds

Saturated vs. Unsaturated Hydrocarbons
- Saturated hydrocarbons contain only single bonded carbon atoms.
  - alkanes and cycloalkanes
- Unsaturated hydrocarbons contain double or triple bonds between carbon atoms.
  - alkenes, alkynes, and aromatic compounds

Unsaturated Hydrocarbons

- _________ contain carbon-carbon double bonds.
- ________________ contain carbon-carbon triple bonds.
- __________________________ contain benzene rings.

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<td>Contains a ring of alternating single and double bonds</td>
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<td>[diagram]</td>
<td>Benzene</td>
</tr>
</tbody>
</table>

Properties of Unsaturated Hydrocarbons
- Like alkanes, the unsaturated hydrocarbons are nonpolar molecules.
- *London forces* hold members of these hydrocarbon families to one another.
- Increasing molecules size leads to stronger London force attractions and *higher melting and boiling points*.

Naming Unsaturated Hydrocarbons
- **Alkenes** end with “ene”
  
  ethene
  
- **Alkynes** end with “yne”
  
  ethyne
- When naming *alkenes* or *alkynes*, the parent chain is the longest chain of carbon atoms that ________________ the carbon-carbon double or triple bond.
• Numbering the parent begins at the end of the double or triple bond.

• The of the multiple bond is written directly in front of the hydrocarbon parent chain name.
  - Substituents are numbered as in alkanes

Name the following hydrocarbons:

\[
\begin{align*}
\text{CH}_2\text{CH} = \text{CHCH}_2 \text{CHCH}_3 & \quad \text{CH}_3 \\
\text{CH}_3 & \quad \text{CH}_3
\end{align*}
\]

**Naming Aromatic Compounds**
For structures with benzene, use “benzene” as the parent name.

- Benzene
- Methylbenzene (toluene)
- 1,2-Dimethylbenzene (o-xylene)
- 1,3-Dimethylbenzene (m-xylene)
- 1,4-Dimethylbenzene (p-xylene)

ortho \((o)\) = 1,2-
meta \((m)\) = 1,3-
para \((p)\) = 1,4-

**Polycyclic Aromatic Hydrocarbons (PAHs)**
Geometric Isomerism in Alkenes

Free rotations *cannot* occur in multiple bonds as it does in single bonds.

- The _______________________ rotation of the carbon-carbon double bonds in alkenes allows for the existence of *cis* and *trans* stereoisomers.

- Important NOTE: To visualize geometric isomers (*cis* and *trans*), we draw all the bonds at 120° angles from the double bonded carbons! (as shown above).
  - Example: see *cis*- and *trans*-2-pentene (above) condensed structure.

For geometric isomers to exist, neither carbon atom of the double bond may carry two _______ attached atoms or groups of atoms.

Example: Is this the cis or trans geometric isomer of muscalure?
**Functional Groups**

- A _____________________________ is an atom, groups of atoms, or bond that gives a molecule a particular set of chemical properties.
  - Each family of organic compounds is defined by the functional group that it contains.

All ___________________________ contain a hydroxyl (-OH) functional group that is attached to an alkane-type carbon atom.

```
[Hydrocarbon] -OH
```

Example of an alcohol: ethanol

```
H H
H─C─C─\(\cdot\)─H
H H

An alkane-type carbon atom
```

All ___________________________ contain a carboxyl functional group, which is the combination of a hydroxyl (-OH) group next to a carbonyl group (C=O) group.

```
[Hydrocarbon] \(\cdot\)─C─O─\(\cdot\)─H
```

Examples of carboxylic acids:

```
H \(\cdot\)
H─C─C─\(\cdot\)─\(\cdot\)─H
H H
```

```
\[\text{are carboxylate (CO}_2\text{) groups between two hydrocarbons.}
```

```
[Hydrocarbon] \(\cdot\)─C─O─\(\cdot\)─Hydrocarbon
```

Example of an ester:

```
\(\text{CH}_3\text{CH}_2\text{C─O─CH}_2\text{CH}_3\)
```