Objective 12: Apply VSEPR theory to determine shape. Identify polar bonds from electronegativity. Determine polarity of molecule from shape. Determine IM forces from polarity. Intro to organic compounds and functional groups. Draw skeletal structures. Intro to Biochemistry.

Quiz Practice problems

Key ideas:

Structure determines Shape; Shape determines Properties, e.g., polarity. Polarity determine intermolecular (IM) forces.
Polarity helps us determine whether one substance is soluble in another substance.
“Like dissolves like” rule – a polar substance is soluble in a polar solvent; a non-polar substance is soluble in a non-polar solvent.
Intermolecular forces help us explain why one substance is soluble in another.
Chemical forces are classified as strong forces or weak forces.
The strong forces are the interatomic forces - ionic bonds and covalent bonds.
The weak forces are intermolecular forces – London forces, dipole-dipole forces, and hydrogen bonds.

Structure Determines Shape.

You know how to draw a Lewis structure.
A central atom in a structure has two or more atoms bonded to it.
You can determine the shape (geometry) at a central atom by applying Valence Shell Electron Pair Repulsion (VSEPR) Theory.
Look at # of lone pairs and bonding pairs around a central atom.
Treat a double bond or triple bond like one bonding pair.

Table 1. Shape based on VSEPR Theory

# of bonding pairs	# of lone pairs	shape
4	0	tetrahedral
3	1	Trigonal pyramid
2	2	bent
3	0	Trigonal planar
2	1	bent
2	0	linear

Shape Determines Polarity.

You’ve heard of polarity before: the Earth has a north pole and south pole. A magnet has a (+) pole and (-) pole.
A polar substance has a partial positive (+) charge on one end and partial negative (-) charge on the other end.
A non-polar substance has a uniform distribution of charge around it so there is no (+) pole or (-) pole.
In chemistry, there are two types of polarity:

1. bond polarity

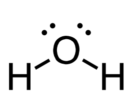
A covalent bond can be a polar covalent bond or non-polar covalent bond.
The difference in electronegativity between the two atoms in a bond determines whether a bond is polar or non-polar.
Electronegativity is the ability of an atom in a bond to attract electrons toward itself. It is like each atom in the bond having a “tug of war” for the electrons that are shared between them.
The more electronegative atom in a bond has a partial negative charge (wins the tug of war). The less electronegative atom in a bond has a partial positive charge
See an electronegativity table.
F is the most electronegative element.
Non-metals are more electronegative than metals. Remember non-metals gain electrons and metals lose electrons.

2. molecular polarity

A molecule can be polar or non-polar.
A polar molecule has a partial positive (+) charge on one end and partial negative (-) charge on the other end.
Molecular polarity is determined by bond polarity and shape.

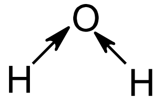
Example 1: H_2 structure is H-H.
The H-H bond is a non-polar bond so neither atom wins the tug of war ==> H_2 is a non-polar molecule.

Example 2: HCl structure is H-Cl.
The H-Cl bond is a polar bond. Cl is more electronegative than H and wins the tug of war ==> HCl is a polar molecule.

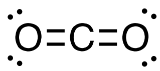
Example 3: H_2O structure is 

The H-O bond is a polar bond. O is more electronegative than H and wins the tug of war.
The shape at the O is bent.

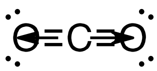
Draw an arrow from the less electronegative H to more electronegative O for each O-H bond.



Imagine each H pushing on the O at the angle shown.
Does the O move? YES ==> this means water is polar.
The O has a partial negative charge (more electrons around the O) and each H has partial positive charges (less electrons around the H's).

Example 4: CO_2 structure is 

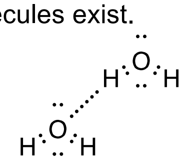
The C-O bond is a polar bond. O is more electronegative than C and wins the tug of war.
The shape at the C is linear.
Draw an arrow from the less electronegative C to more electronegative O for each C-O bond.



Imagine each O pulling on the C at the angle shown.
Does the C move? NO ==> this means CO_2 is non-polar.
Electrons are uniformly distributed around the C and two O's. One end does not have a partial negative charge and the other end does not have a partial negative charge.

Polarity Determine Intermolecular (IM) Forces.
3 types of IM forces:
1. London forces – exist in all substances (polar and non-polar).
2. dipole-dipole forces – exist in polar substances only.
3. hydrogen bonds – special type of dipole-dipole force in which a H is situated between two very electronegative atoms (F, Cl, O, or N) on 2 different molecules.

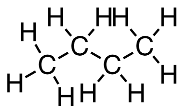
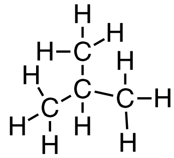
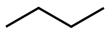
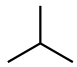
Important **Example 5**: H_2O.
Water is polar.
London forces, dipole-dipole forces, and hydrogen bonds exist between water molecules.
The dashed line between the H on the top water and O on the bottom water is a H bond. More H bonds between these two water molecules exist.



Example 6: Natural gas, which is used in stoves and Bunsen burners, is methane, CH_4.
Central atom is carbon, which has 4 bonding pairs and 0 lone pairs.
C is slightly more electronegative than H.
C-H bond is (slightly) polar. Many textbooks state the C-H bond is non-polar.
Table 1 shows the shape of this carbon is tetrahedral.
Draw an arrow from the less electronegative atom to more electronegative atom.
Imagine the push-pull like you did in the previous examples.
Methane is non-polar.
London forces exist between methane molecules.

You learned how to draw the Lewis structure of a molecule. Most compounds are **organic** compounds. These compounds contain C and H, and also O, N, F, Cl, Br. Biomolecules are organic compounds.
For bigger organic molecules, it can be be a lot of work drawing in all of the H's. So scientists draw a **skeletal structure** as a short cut to a Lewis structure.
In a skeletal structure, the C atom labels are not shown.
Every H bonded to a C is not shown. These H's are assumed to be bonded to C.
Remember a single line represents a single covalent bond. In a skeletal structure, a single line is assumed to be a carbon-carbon single bond. The end of each line is a carbon and the H's that are bonded to C are not drawn in.
Remember the **general bonding rules**:
4 bonds to C
3 bonds and 1 lone pair to N
2 bonds and 2 lone pairs to O
1 bond to H

So a skeletal structure that shows two bonds to carbon means there are two additional bonds to H.

Lewis structure		
skeletal structure		

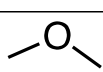
Skills:
From Lewis structure, determine shape at a central atom using VSEPR theory.
Determine bond polarity using electronegativity of each atom in the bond.
Determine molecular polarity from shape and bond polarity.
Determine intermolecular forces between molecules from molecular polarity.
Identify organic functional groups in an organic compound.
Draw skeletal structures of organic compounds.

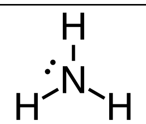
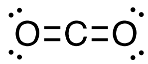
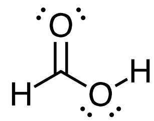
1. a. Determine the shape and polarity of each compound in Table 2.
For the H bond type of IM force, draw a second Lewis structure next to the first one you drew. Look for a H situated between two very electronegative atoms (F, Cl, O, or N) on 2 different molecules.
b. Which compound(s) in Table 2 are soluble in water?
c. Which compound(s) in Table 2 are organic compounds? Identify the functional group(s) in each organic compound.

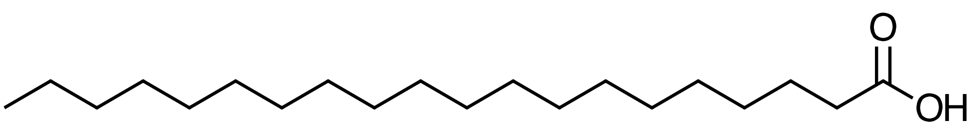
Table 2. Structure, Shape, Polarity of various molecules.

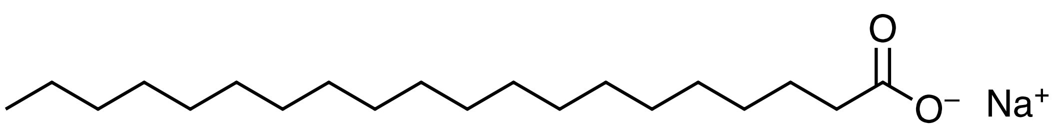
Compound	Structure	# of bonding pairs	# of lone pairs	shape	Polarity	IM forces
CH_4	H ·· H : C : H ·· H	4	0	tetrahedral	Non-polar	London
CH_3OH		2 on O	2 on O	Bent at O ______ at C		London Dipole-dipole H bonds
CH_3OCH_3 ether				_____ at C _____ at O _____ at other C		
NH_3						
CO_2					Non-polar	
C_2H_4						
C_2H_2						
HCOOH						
$C_9H_{19}COOH$ Fat molecule						
$C_9H_{19}COO^-Na^+$ soap molecule						

Answers:
a. Table 2. Structure, Shape, Polarity of various molecules.

Compound	Structure	# of bonding pairs	# of lone pairs	shape	Polarity	IM forces
CH_4	H ·· H : C : H ·· H	4	0	tetrahedral	Non-polar	London
CH_3OH	—OH	2 on O	2 on O	Bent at O tetrahedral at C	Polar	London Dipole-dipole H bonds
CH_3OCH_3 ether		2 on O 4 on each C	2 on O	tetrahedral at C bent at O tetrahedral at other C	Polar	London Dipole-dipole

NH_3		3	1	Trigonal pyramid	Polar	London Dipole-dipole H bonds
CO_2		4	0	linear	Non-polar	London
C_2H_4	=	4 on each C	0	Trigonal planar at each C	Non-polar	London
C_2H_2	≡	4 on each C	0	Linear at each C	Non-polar	London
HCOOH		4 on C 2 on O	0 on C 2 on O	Trigonal planar at each C Bent at O	Polar	London Dipole-dipole H bonds
$C_9H_{19}COOH$ Fat molecule		4 on each C 2 on O	0 on each C 2 on O	Tetrahedral at 9 C's Trigonal planar at 1 C Bent at O	Non-polar part is C_9H_{19} part Polar part is COOH	London Dipole-dipole H bonds
$C_9H_{19}COO^-Na^+$ soap molecule		4 on each C	O on each C	Tetrahedral at 9 C's Trigonal planar at 1 C	Non-polar part is C_9H_{19} part Polar part is COO^-	London Dipole-dipole H bonds

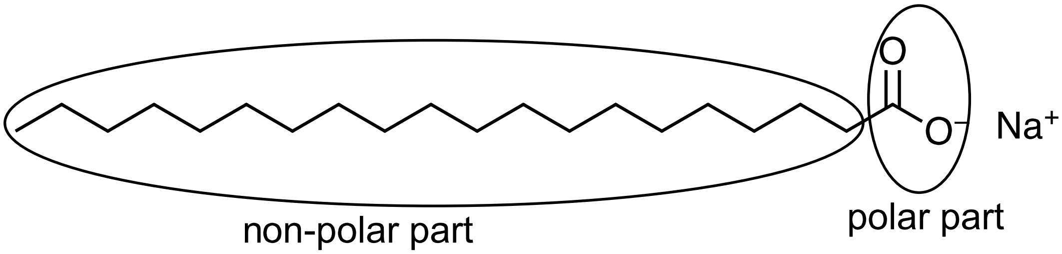
Fat molecule: 

Soap molecule 

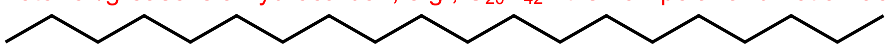
b. The polar compounds in Table 2 are soluble in water: CH_3OH, CH_3OCH_3, NH_3, HCOOH.
The fat molecule is insoluble in water. The non-polar part is much bigger than the polar part of fat.
The soap molecule is insoluble in water. The non-polar part is much bigger than the polar part of fat.

c. CH4, CH_3OH, CH_3OCH_3, C_2H_4, C_2H_2, HCOOH, $C_9H_{19}COOH$ are organic compounds.
CH_4 - alkane
CH_3OH - alcohol
CH_3OCH_3 - ether
C_2H_4 - alkene
C_2H_2 - alkyne
HCOOH - acid
$C_9H_{19}COOH$ – alkane and acid

In Lab 9, you will try to remove a stain using a chemical. You can use polarity to remove a stain. A polar substance is soluble in a polar solvent; a non-polar substance is soluble in a non-polar solvent ("Like dissolves like" rule).
2. Many substances are used as cleaning agents. Soap and TSP are two common cleaners.
a. Describe how soap works. Give the name, chemical formula, and draw the Lewis structure of a typical soap molecule. How is soap similar to a fat molecule?
b. Soap removes dirt. Is dirt polar or non-polar?
c. TSP (trisodium phosphate) is a common cleaner and degreaser. What type of substance is TSP? TSP works to remove kitchen grease, e.g., vegetable or animal grease, but not motor oil/grease. Explain how TSP works to remove grease.
Answers:
a. Soap has a polar part and non-polar part:

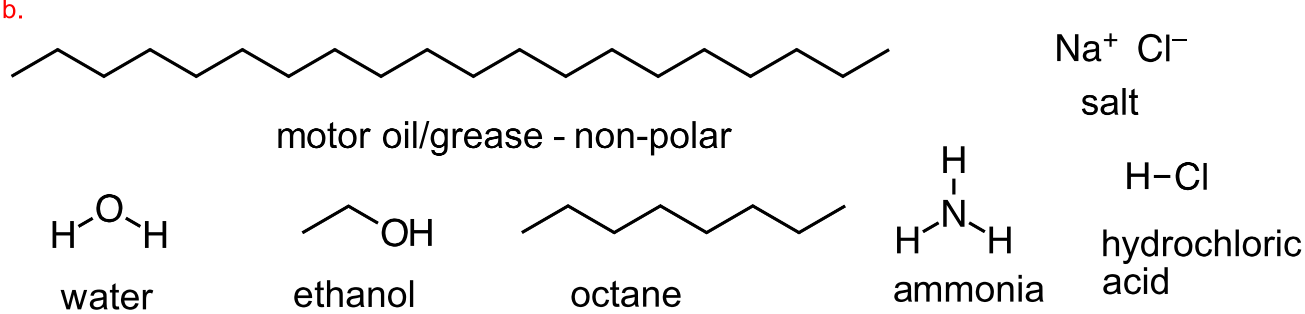


The non-polar part of soap is attracted to non-polar dirt. London forces exist between the non-polar part of soap and non-polar dirt.
Water is attracted to the polar part of soap.
So washing your hands with soap removes non-polar dirt. Then, rinsing your hands with water removes the soap and the dirt.
Soap is similar to a fat molecule in that one H in fat is replaced by Na ion. This converts the molecular fat compound into an ionic compound.
b. Dirt is non-polar.
c. TSP is a base.
TSP removes kitchen grease in an acid-base reaction.
TSP is a base and kitchen grease - the –COOH part of a fat molecule (see fat molecule structure in Question 1) is an acid (called a carboxylic acid in organic chemistry).
Motor oil/grease is a hydrocarbon, e.g., $C_{20}H_{42}$. It is non-polar and not an acid or base.



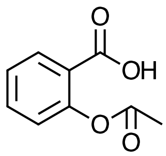
motor oil/grease - non-polar

3. You are fixing your car and get grease all over your hands. Grease is a high molecular weight, non-polar substance. You have the following substances at your disposal to clean your hands: water, alcohol (ethanol: C_2H_5OH), gasoline (octane: C_8H_{18}), ammonia, hydrochloric acid, and salt (sodium chloride).
a. Identify the ionic compounds. Give reasons.
b. Draw the Lewis structure of each compound. Then, determine the molecular geometry, whether the molecule is polar or non-polar, and the intermolecular forces that exist in this substance. If the molecule has more than one central atom, circle one of the central atoms and determine the molecular geometry at that central atom.
c. Using your knowledge of solubility, liquid properties, and intermolecular forces, which substance would you use to clean your hands? Choose <u>one</u> substance only. Give reasons for your choice.
Answers:
a. Salt (NaCl) is an ionic compound. It contains a metal (Na) and non-metal (Cl).
b.

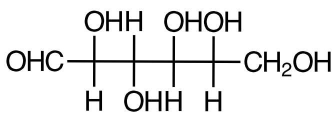


Grease – tetrahedral at each C, non-polar, London forces
Water – bent at O, polar, London forces, dipole-dipole forces, hydrogen bonds
alcohol (ethanol: C_2H_5OH) - tetrahedral at each C, bent at O, polar, London forces, dipole-dipole forces, hydrogeng bonds
gasoline (octane: C_8H_{18}) - tetrahedral at each C, non-polar, London forces
ammonia – trigonal pyramid at N, polar, London forces, dipole-dipole forces, hydrogen bonds
hydrochloric acid – no central atoms, polar, London forces, dipole-dipole forces, hydrogen bonds
salt – polar, London forces, dipole-dipole forces, hydrogen bonds can form to Cl^-.
c. Use the non-polar octane to clean the non-polar grease off your hands.
"Like dissolves like" – non-polar substances are soluble in non-polar substances.

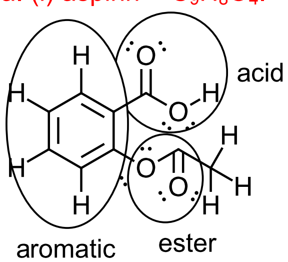
4. a. Aspirin is a common over-the-counter pain reliever. The skeletal structure of Aspirin is shown below.
(i) Write the chemical formula. Draw in the H's and lone pairs.
(ii) Circle each functional group. Write the name of the group next to your circle.
(ii) Aspirin is slightly soluble in water. Explain why.



b. Glucose is the sugar (carbohydrate) that our body uses (metabolism) as a fuel.
(i) Write the chemical formula. Draw in the H's and lone pairs. On the left side of the structure, the "OHC" is shown. Show the bonding in the OHC part.
(ii) Circle each functional group. Write the name of the group next to your circle.
(iii) Is glucose soluble in water? Give reasons.

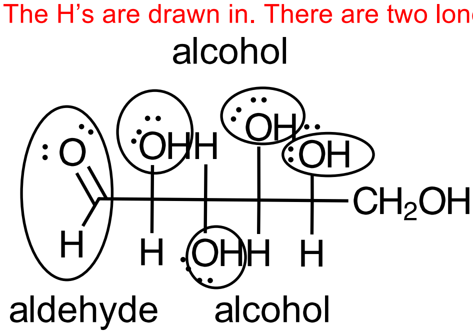


Answers:
a. (i) aspirin = $C_9H_8O_4$.



(ii) aromatic, acid, ester functional groups.
(iii) Most of the aspirin molecule is the non-polar aromatic ring. This part is insoluble in water.
The acid part of aspirin is polar. This part is soluble in water.
The ester part of aspirin is polar. This part is soluble in water.

b. (i) glucose = $C_6H_{12}O_6$.
The H's are drawn in. There are two lone pairs on each O.



(ii) aldehyde and alcohol groups.
(iii) Both glucose and water are polar so glucose is soluble in water.
Both compounds have London forces, dipole-dipole forces, hydrogen bonds.
Hydrogen bonds can form between glucose and water, e.g., between a H in water and O in glucose.