Unit 8: Chemical Bonding

8.0 I can explain the chemical & physical properties of materials by applying concepts of periodicity, arrangements of atoms, ions, or molecules and the electrostatic forces between them.

8.1 I can illustrate covalent bond formation using Lewis Dot Structures.

Differences in Electronegativity

Electronegativity also allows us to predict the _____ that occurs between two elements.

This gives us a _____ definition of ionic and covalent bonds!

If the difference in electronegativities is...

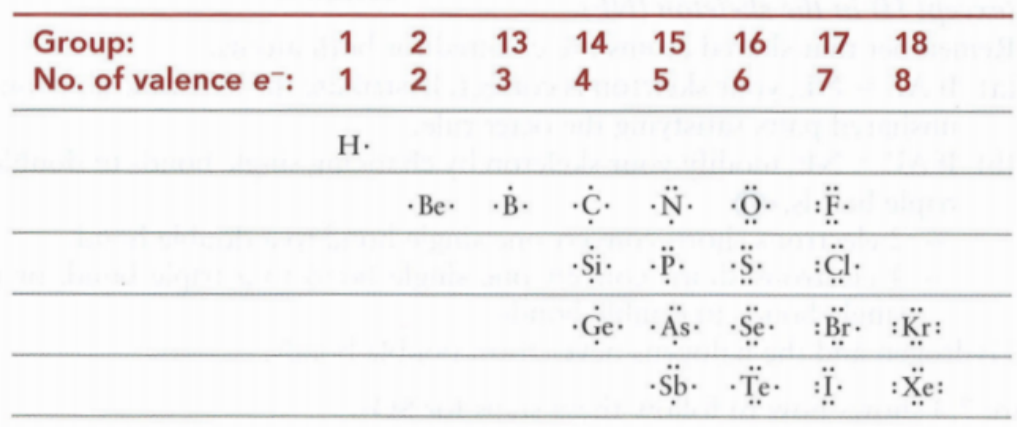
- 0.0-1.6 then the compound is likely ...
- 1.6-2.0 then the compound is likely ...
- Above 2.0 then the compound is likely ...

Lewis Dot Structures

Represent …

Rules for writing

- write symbol of element
- put one dot for each valence electron
  - place dots around four sides one at a time
  - pair them up when forced to



Octet/Duet Rule

Lewis pointed out that noble gas electronic configurations (_____) tended to be very stable

He suggested that nonmetals will _____ electrons to acquire a noble gas electronic configuration

- That means they will share with other nonmetals to have ____ electrons

Octet rule:

Covalent Bonds

Covalent bonds usually occur in molecular compounds…

In covalent bonds, the valence electrons are _____, spending some of their time with each atom.

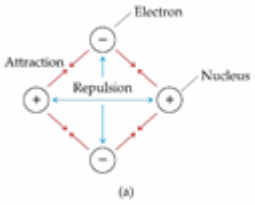
Electrons are shared to ..

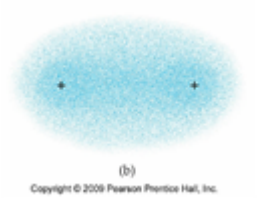
Electrons are shared …

Picture of a covalent bond

a. The attractions and repulsions among electrons and nuclei

b. Electron distribution in the hydrogen molecule.





**Attractive forces must be greater than repulsive ones

Lewis Structures

Structural Formulas

Show bonds between atoms as _____, rather than pairs _____

Examples:

Another Pattern?

We would expect that group 7A would bond _____ to form its octet, 6A would bond _____, 5A would bond _____ and 4A would bond _____

Types of Covalent Bonds

A single covalent bond is formed when …

A double covalent bond is formed when …

A triple covalent bond is formed when …

Bond strength:

Bond length:

Practice: Covalent Bonds

The C-O bond length is carbon monoxide, CO, is 1.13Å, whereas the C-O bond length in CO_2 is 1.24Å. Knowing that CO_2 has a double bond, do you think that carbon monoxide has a single, double or triple bond between the C and O atoms?

Lewis Dot Structures

Rules for determining total electrons and bonding electrons

- write octet number above each element: 2 for H, 8 for everything else
- write valence electrons below each element (include additional e^-)
- add top numbers
- add bottom numbers (total electrons in the final LDS)
- difference between top and bottom = shared electrons

Rules for drawing LDS

- Least electronegative element tends to go in the middle (not including H): normally the first element written in a formula)
- Most other elements are listed around the central atom (or you need more info)
- Add single bonds between all atoms first
- Add remaining electrons to satisfy octets

Class Examples

CO_2 SO_3^{2-}

Practice: Lewis Dot Structures

SO_3 NF_3

SO_2 N_2

NO^+ C_2H_4

Exceptions

It looks like the octet rule works all the time, but there are cases where it is broken…

1. Molecules and polyatomic ions containing an …
2. Molecules and polyatomic ions in which an atom has …
3. Molecules and polyatomic ions in which an atom has …

Odd # of Electrons

There are a few molecules and ions that contain an odd number of valence electrons, like …

It is impossible to complete the octet in these structures.

Draw and analyze formal charges to determine which LDS is preferred.

Example: NO, which is preferred?

Less than an Octet of Valence Electrons

- Rare, though usually occurs in compounds containing:
  - Boron
  - Beryllium
- Example: Draw LDS and assign formal charges for BF_3

More than an Octet of Valence Electrons

Most exceptions occur here!

Expanded shells occur only in …

At period 3, there is the presence of a ____ orbital which can be used to hold extra e- i.e.

	Group 15	Group 16	Group 17	Group 18
3rd period	P	S	Cl	
4th period	As	Se	Br	Kr
5th period	Sb	Te	I	Xe

Fill the …

Examples: Expanded Octets

ICl_4^- AsF_6^-

SO_4^{2-}

Practice: Exceptions

Draw the following:

$BeCl_2$

I_3^{-1}

SF_4

XeF_4

NO_2

XeF_2

8.0 I can explain the chemical & physical properties of materials by applying concepts of periodicity, arrangements of atoms, ions, or molecules and the electrostatic forces between them.

8.2 I can illustrate covalent bond formation using Lewis Dot Structures.

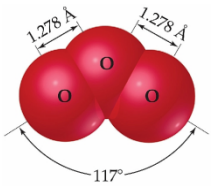
- **I can explain resonance and draw valid resonance structures using Lewis Dot Structures.**

Resonance

Consider ozone, which has 2 valid structures:

If the ozone molecule oscillated between one and the other you should see one bond being shorter (the double bond, 1.21Å) than the other (single bond, 1.48Å)

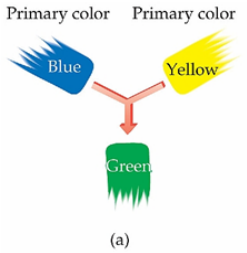
What we actually see is a completely new molecule with a bond length between a double and a single bond



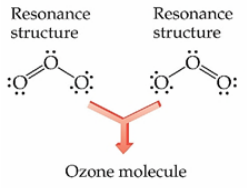
In reality, neither bond is different than the other (notice the radius is the same)

A blending

We can show this as follows:



These are called resonance structures-ozone is really a blend of two pictures since neither is more correct than the other



Resonance Structures

Show the valid possible electron dot structures that describe the bonding in a molecule

- DOES NOT imply multiple structures with the electrons constantly shifting around
- DOES mean actual structure is a weighted average of the possible resonance structures

Examples:

NO_3^{-1}

Practice: Resonance

Draw the following, including resonance if necessary.

SO_3

SO_3^{2-}

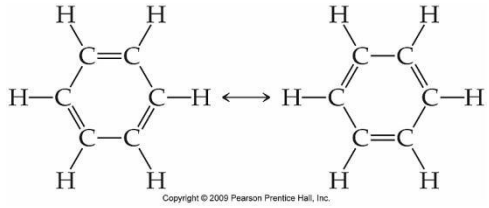
HCO_2^{1-}

Benzene

Benzene is an important organic molecule that is present in _____ (so named for the smelliness of some)

Benzene contains …

Two structures can be drawn that satisfy the octet rule:



What does it really look like?

It looks like there are alternating double and single bonds, but experiments have determined that each C---C bond has a bond length of 1.40Å.

So scientists show benzene as…

8.0 I can explain the chemical & physical properties of materials by applying concepts of periodicity, arrangements of atoms, ions, or molecules and the electrostatic forces between them.

8.2 I can illustrate covalent bond formation using Lewis Dot Structures.

- **I can calculate formal charge and use those values to determine plausible Lewis Dot Structures.**

In resonance structures, remember that the atoms all stay in the same place but the electrons can be placed in different locations

Sometimes you can draw LDS where the atoms themselves are arranged differently!

CH_4O

Formal Charge

Determines how plausible a Lewis structure is

- "accounting" procedure for charge distribution in a molecule
- can be used on resonance structures and unique structures

Equation:

- FC of all atoms must add up to net charge of molecule

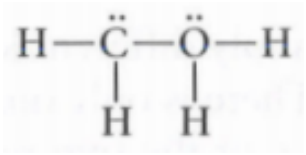
Determining the likelihood of a structure existing in nature:

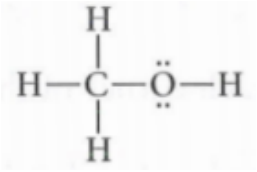
1.

2.

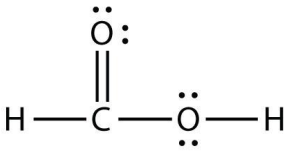
Formal Charge Examples

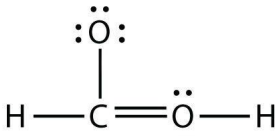
Determine formal charge on each element then determine which is the most likely LDS.





Determine formal charge on each element then determine which is the most likely LDS.





Practice: Lewis Dot Structures and Formal Charge

- The cyanate ion (NCO^-) has three possible LDS.
    - Draw each of the three LDS and assign formal charges to each atom (rearrange electrons NOT atoms).

    - Circle the preferred LDS.

Practice: Lewis Dot Structures and Formal Charge

- H_3CSH is an organic compound.
    - Draw 3 unique structures for H_3CSH (rearrange H atoms this time).

    - Assign formal charges to determine which LDS is the preferred one.

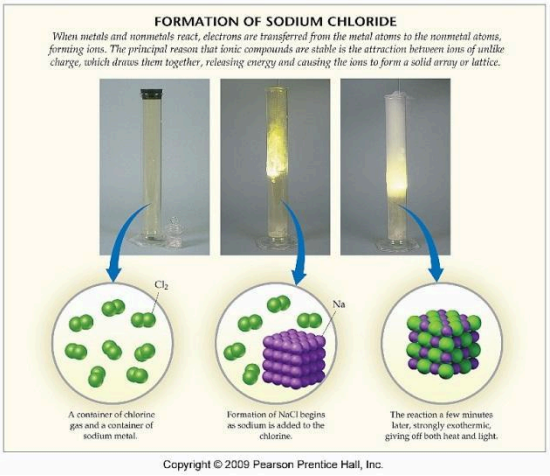
8.0 I can explain the chemical & physical properties of materials by applying concepts of periodicity, arrangements of atoms, ions, or molecules and the electrostatic forces between them.

8.3 I can describe how bonding is the result of forces, proximity, and energy (lattice energy and bond energy)

Salt

Sodium metal reacts violently with chlorine gas to produce sodium chloride according to the following equation:

$Na(s) + \frac{1}{2}Cl_2(g) \rightarrow NaCl(s) \quad \Delta H_f^o = -410.9\ kJ$



- Notice that the ΔH_f^o is _____ suggesting an _____ reaction
- Generally speaking, the formation of an ionic compound is accompanied by...

Electron Transfer

Occurs when …

Arrow indicates transfer from sodium (low ionization energy) to chlorine (high electron affinity)

Practice: Electron Transfer

Draw a picture showing the electron transfer between the following elements:

Na and S

Al and O

Stability of ionic compounds

The attraction of opposite charges draws ions together, …

Lattice Energy-

For table salt:

$NaCl(s) \longrightarrow Na^+(g) + Cl^-(g) \qquad \Delta H_{lattice} = +788$ kj/mol

Lattice Energies

Lattice Energies for Some Ionic Compounds

Compound	Lattice Energy (kJ/mol)	Compound	Lattice Energy (kJ/mol)
LiF	1030	$MgCl_2$	2326
LiCl	834	$SrCl_2$	2127
LiI	730		
NaF	910	MgO	3795
NaCl	788	CaO	3414
NaBr	732	SrO	3217
NaI	682		
KF	808	ScN	7547
KCl	701		
KBr	671		
CsCl	657		
CsI	600		

Results

- Strong attractions lead to ionic solids which…
  - o
  - o
  - o
- Lattice energy increases as…
  - o
  - o

Practice: Lattice Energies

WITHOUT looking at table 8.2, arrange the following ionic compounds in order of increasing lattice energy:

NaF, CsI, CaO

Covalent Bond Strength

The strength of the bond between two nonmetal atoms determines …

Bond enthalpy:

Always a _____ value since energy is required to break bonds

Higher ΔH value =

Stronger bonds are …

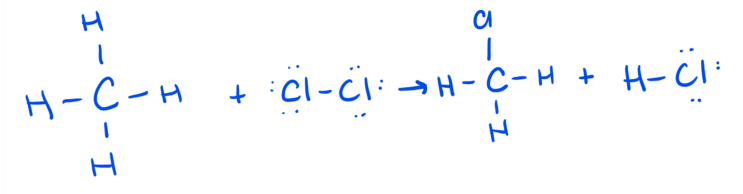
Bond Enthalpies

Allows for quick estimate on whether a reaction with be …

Equation:

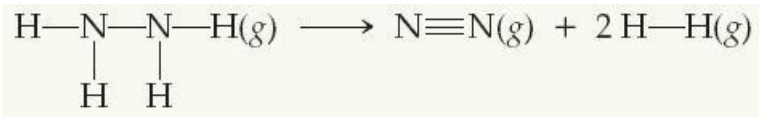
Example: Enthalpies of Reactions

$$CH_{4(g)} + Cl_{2(g)} \rightarrow CH_3Cl_{(g)} + HCl_{(g)}$$



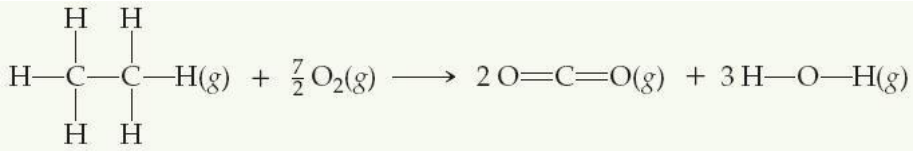
Practice: Enthalpies of Reactions

Using Table 8.4, estimate ΔH for the reaction:



Practice: Enthalpies of Reactions

Using Table 8.4, estimate ΔH for the following reaction (where we explicitly show the bonds involved in the reactants and products):



Bond Enthalpy and Bond Length:

Bond	Bond Length (Å)	Bond Strength (kJ/mol)	Bond	Bond Length (Å)	Bond Strength (kJ/mol)
C-C	1.54	348	N-N	1.47	163
C=C	1.34	614	N=N	1.24	418
C≡C	1.20	839	N≡N	1.10	941
C-N	1.43	293	N-O	1.36	201
C=N	1.38	615	N=O	1.22	607
C≡N	1.16	891	O-O	1.48	146
C-O	1.43	358	O=O	1.21	495
C=O	1.23	799			
C≡O	1.13	1072			

As bond length _____ bond strength _____

8.0 I can explain the chemical & physical properties of materials by applying concepts of periodicity, arrangements of atoms, ions, or molecules and the electrostatic forces between them.

8.4 I can use Lewis diagrams and VSEPR to predict the geometry of molecules.

VSEPR Theory

Valence shell electron pair repulsion

Electron pairs repel; molecules adjust their shapes to minimize repulsions (move as far apart as possible)

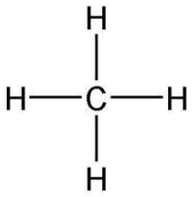
Electron domains:

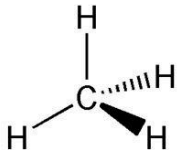
Bonding domains:

Nonbonding domains:

Drawing in 3D

1. Formula ☑
2. Lewis dot structure ☑
3. Molecular geometry
4. 3D Picture





Formula to Lewis Dot Structure to Molecular Geometry to Picture

Formula to LDS (review)

- Octet above
- Valence below = total e-
- Difference = shared e-
- Least electronegative in the center

LDS to Molecular Geometry

- Count nonbonding domains
- Count bonding domains
- Give molecular geometry

Redraw molecule in “3-D”

- Straight line → on the same plane
- Wedge → pointing towards you
- Dashed line → pointing away from you

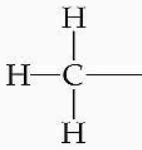
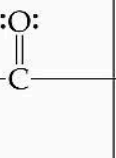
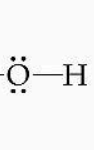
Practice: 3-D versions

Draw the following molecules in 3D, indicate molecular geometry!

- CO_2
- SO_3
- SF_4
- SO_2
- SO_3^{2-}
- NF_3
- O_3
- IF_5
- $SnCl_3^{1-}$
- N_2

Shapes of larger molecules

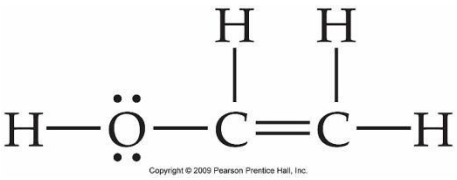
Look at each individual interior atom and determine geometry around it!

			
Number of electron domains	4	3	4
Electron-domain geometry	Tetrahedral	Trigonal planar	Tetrahedral

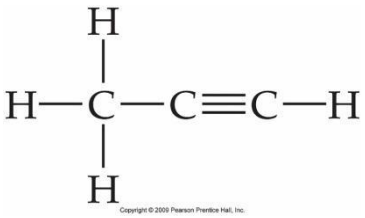
Practice: Large molecules

Predict the molecular geometry and redraw in 3D

polyvinyl alcohol



propyne



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8.5 I can use Lewis diagrams and VSEPR to make predictions about polarity.

Isn't a Covalent Bond always the same?

True, a covalent bond is defined as a bond in which electrons are shared between nonmetals, but there are 2 types of covalent bonds

Nonpolar bonds:

i.e.

Polar bonds:

i.e.

Polar vs. Nonpolar Bond

Bond Polarity

Results from difference in electronegativity

Electronegativity difference scale

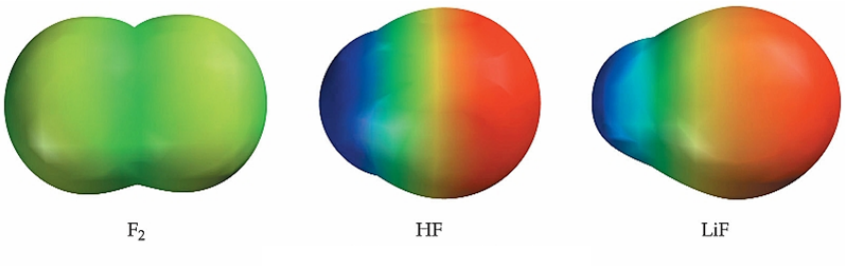
$0 \leq 0.4$

$0.4 < 2.0$

2.0 and above

Practice: Bond Polarity

Calculate the difference in electronegativity and determine if the following are nonpolar, polar or ionic based on your answers.



Practice: Bond Polarity

In each case, which bond is more polar? Calculate electronegativity difference.

B-Cl or C-Cl

P-F or P-Cl

Bond Polarity

You can indicate bond polarity in 2 ways:

Dipole Moments

Using the arrow symbol, you can see that a polar molecule can have different “charges” on different parts of the molecule.

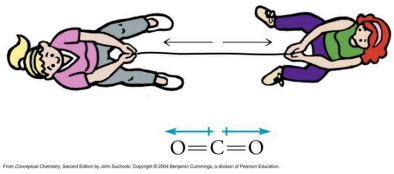
Molecule Polarity

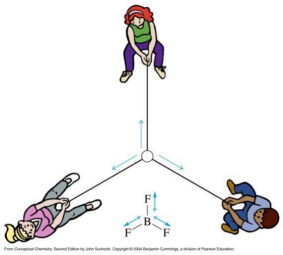
We can use bond polarity and molecular shape to determine the …

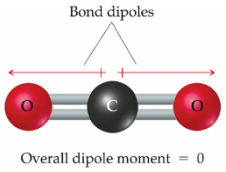
Add polarity indicators to your 3D drawing and see how they affect one another

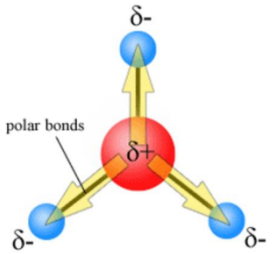
Keep in mind that bond dipoles are vectors, they have …

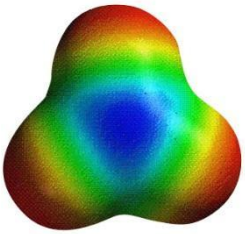
Nonpolar Molecules



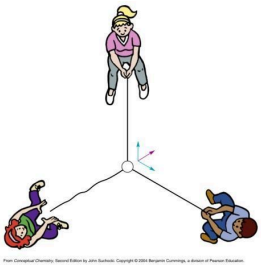


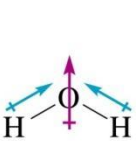


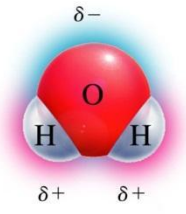


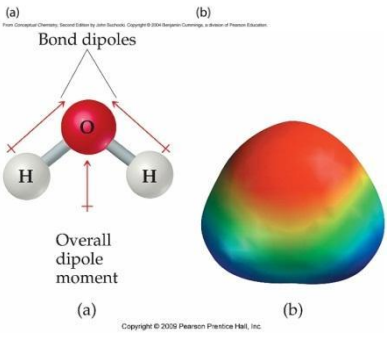


Polar Molecules

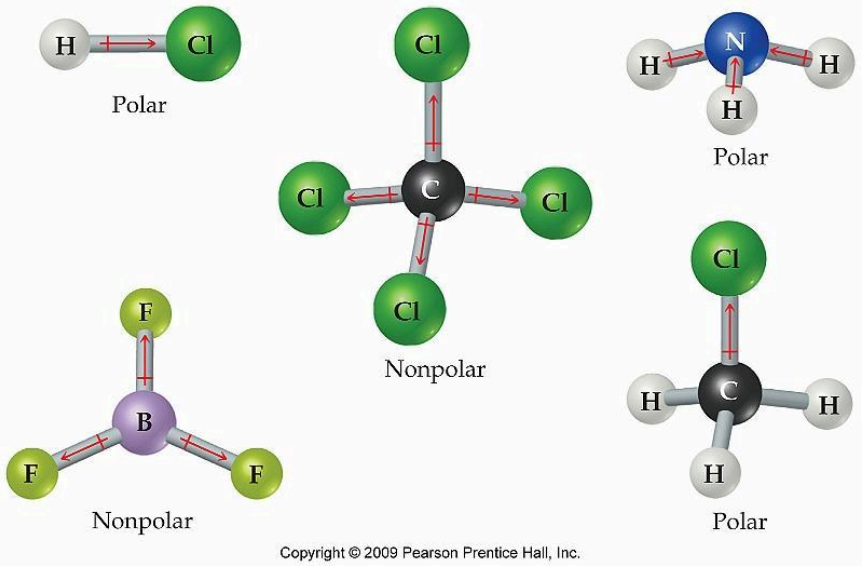








Examples of Polar vs Nonplar



Practice: Polarity of Molecules

Predict whether the following molecules are polar or nonpolar: (a) BrCl, (b) SO_2, (c) SF_6, (d) NF_3, (e) BCl_3

A Little Bit of EVERYTHING!!!!

Phosgene, a substance used in poisonous gas warfare during World War I, is so named because it was first prepared by the action of sunlight on a mixture of carbon monoxide and chlorine gases. Its name comes from the Greek words *phos* (light) and *genes* (born of). Phosgene has the following elemental composition:

12.14% C, 16.17% O, and 71.69% Cl by mass. Its molar mass is 98.9 g/mol.

(a) Determine the molecular formula of this compound.

(b) Draw three Lewis structures for the molecule that satisfy the octet rule for each atom. (The Cl and O atoms bond to C.)

(c) Using formal charges, determine which Lewis structure is the most important one.

(d) Using average bond enthalpies, estimate ΔH for the formation of gaseous phosgene from CO(g) and Cl_2(g).