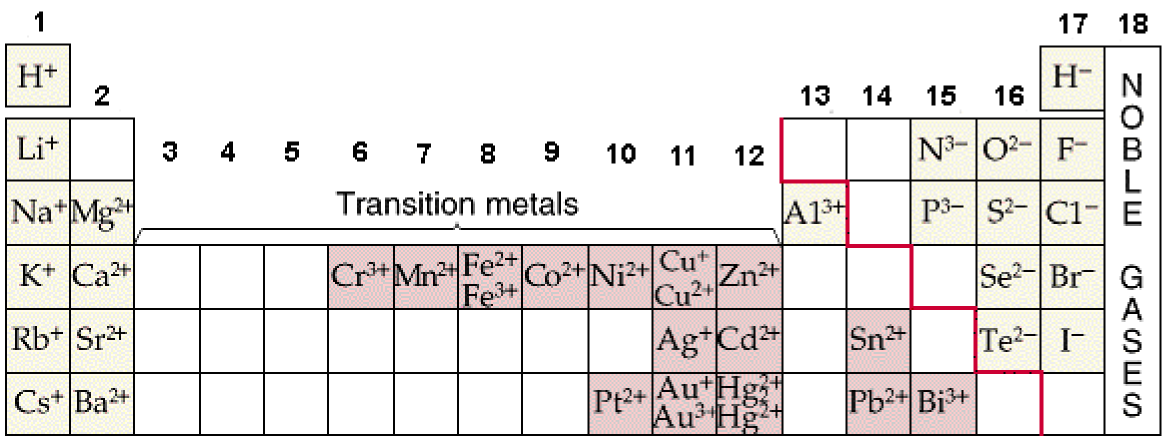
Unit 4 – Conservation of Mass and Stoichiometry

9.1 Naming Ions

I. Monatomic Ions

A. Monatomic ions

1. Ions formed from a single atom



B. Naming Monatomic Ions

1. Monatomic cations are
   a. Identified by the element's name
2. Monatomic anions
   a. Drop the ending of the element name
   b. Add an "–ide" ending

II. Polyatomic Ions

A. Oxyanions

1. Polyatomic anions that contain oxygen

Formula	***Name***
NO_2^-	Nitrite
NO_3^-	Nitrate
SO_3^{2-}	Sulfite
SO_4^{2-}	Sulfate
OH^-	Hydroxide
PO_4^{3-}	Phosphate
CO_3^{2-}	Carbonate
ClO_3^-	Chlorate
$C_2H_3O_2^-$	Acetate

B. Naming a series of similar polyatomic ions

ClO^-	ClO_2^-	ClO_3^-	ClO_4^-
Hypochlorite	Chlorite	Chlorate	Perchlorate

9.2 Naming and Writing Formulas for Ionic Compounds

I. Binary Ionic Compounds

- A. Binary Compounds
  1. Compounds composed of two different elements
- B. Naming Binary Ionic Compounds from Their Formulas
  1. Name the cation
  2. Name the anion
- C. The Stock System of Nomenclature
  1. Roman numerals are used to denote the charge of metals that can form two or more cations.
  2. The numeral is enclosed in parentheses and placed immediately after the metal name
     - a. Iron(II) and Iron(III), pronounced "iron two" and "iron three"
  3. Roman numerals are never used:
     - a. For anions
     - b. For metals that form only one ion
- D. Writing Formulas for Binary Ionic Compounds
  1. Write the symbols for the ions side by side. ALWAYS write the cation first!
  2. Cross over the charges by using the absolute value of each ion's charge as the subscript for the other ion
  3. Check that the subscripts are in smallest whole number ratio
- E. The Stock System of Nomenclature
  1. Roman numerals are used to denote the charge of metals that can form two or more cations.
  2. The numeral is enclosed in parentheses and placed immediately after the metal name
     - a. Iron(II) and Iron(III), pronounced "iron two" and "iron three"
  3. Roman numerals are never used:
     - a. For anions
     - b. For metals that form only one ion
- F. Naming compounds containing polyatomic ions
  - a. Same as for monatomic ions
- G. Writing formulas including polyatomic ions
  - a. Use parentheses when you need MORE THAN one of a polyatomic ion
  - b. Parentheses are NEVER used for monatomic ions, regardless of how many are in the formula

9.3 Naming and Writing Formulas for Molecular Compounds

I. Naming Binary Molecular Compounds

- A. Binary Molecular Compounds
  1. Covalently bonded molecules containing only two elements, both nonmetals
- B. Naming
  1. Least electronegative element is named first
  2. First element gets a prefix if there is more than 1 atom of that element
  3. Second element ALWAYS gets a prefix, and an "-ide" ending

Examples: N_2O_3 = dinitrogen trioxide
CO = carbon monoxide, **not** monocarbon monoxide

Numerical Prefixes										
Number	1	2	3	4	5	6	7	8	9	10
Prefix	mono	di	tri	tetra	penta	hexa	hepta	octa	nona	deca

9.4 Naming and Writing Formulas for Acids and Bases

I. Naming Acids

- A. Binary Acids
  1. Acids that consist of two elements, usually hydrogen and one of the halogens
- B. Oxyacids
  1. Acids that contain hydrogen, oxygen and a third element (usually a nonmetal)
- C. Naming Acids
  1. Refer to the "Naming Acids" worksheet

II. Naming Bases

A. Bases are ionic compounds and are named in the same way as other ionic compounds

9.5 The Laws Governing Formulas and Names

I. The Law of Definite Proportions

"In samples of any chemical compound, the masses of the elements are always in the same proportions."

Translation:

"Each compound has a definite, unchanging chemical formula."

10. 1 The Mole: A Measurement of Matter

I. What is a Mole?

A. The Mole
1. The amount of substance that contains as many particles are there are in exactly 12 grams of carbon-12
2. The amount of substance that contains the Avogadro number of particles

B. Avogadro's Number
1. The number of particles in exactly one mole of a pure substance
2. Avogadro's number = 6.022×10^{23}

II. The Mass of a Mole of an Element

A. Molar Mass
1. The mass of one mole of a pure substance
   a. Units are grams/mole (or g/mol)
   b. Molar mass of an element equals the average atomic mass in gram units

B. Finding Molar Mass
1. Average atomic mass is given on every periodic table

III. The Mass of a Mole of a Compound

A. Formula Mass
1. The sum of the average atomic masses of all the atoms represented in the formula of a molecule, formula unit, or ion

Formula Mass of glucose, $C_6H_{12}O_6$:

C = 12.01 amu	6 x 12.01 amu = 72.06 amu
H = 1.01 amu	12 x 1.01 amu = 12.12 amu
O = 16.00 amu	6 x 16.00 amu = 96.00 amu
	Formula Mass = 180.18 amu

B. Molar Masses
1. A compound's molar mass is numerically equal to it formula mass, but expressed in units of grams/mole (g/mol)

Molar Mass of glucose, $C_6H_{12}O_6$ = 180.18 g/mol

10. 2 Mole-Mass and Mole-Volume Relationships

I. The Mole-Mass Relationship

A. Converting moles of compound to grams

$$Amount\ \ in\ moles\ x\ molar\ mass(g/mol) = Mass\ in\ grams$$

B. Converting grams of compound to mass

$$Mass\ in\ grams\ x \frac{1}{molar\ \ mass(g/mol)} = Amount\ of\ \ moles$$

II. The Mole-Volume Relationship

A. Standard Temperature and Pressure (STP)

1. Standard Temperature = 0° or 273K
2. Standard Pressure = 101.3 kPa or 1 atmosphere

B. Standard Molar Volume

1. The volume occupied by one mole of any gas at STP
2. 1 mole of any gas at STP occupies 22.4 liters of volume

C. Determining Densities

1. Density = m/v
2. density at STP = mass of one mole / 22.4 liters

10.3 Percent Composition and Chemical Formulas

I. <u>Percentage Composition</u>

A. Percentage Composition

1. The percentage by mass of each element in a compound

$$\frac{Mass\ \ of\ \ element\ \ in\ \ 1\ \ mol\ \ of\ \ compound}{molar\ \ mass\ \ of\ \ compound}\ \ x\ \ 100 = \%\ \ element\ \ in\ \ compound$$

B. Hydrates

1. Crystalline compounds in which water molecules are bound in the crystal structure

Copper (II) sulfate pentahydrate

$CuSO_4 \bullet 5H_2O$

a. The raised dot means "Water is loosely attached" It does **NOT** mean multiply when determining formula weight

II. <u>Empirical Formula</u>

A. Definition:

The symbols for the elements combined in a compound, with subscripts showing the smallest whole-number ratio of the different atoms in the compound

B. Calculation of Empirical Formula

1. Assume a 100 g sample of the compound
2. Treat % as grams
3. Convert grams to moles using molar mass of each element
4. Place each mole quantity in ratio to the smallest number of moles
   a. Construct element ratios from the nearest resulting whole numbers

III. <u>Molecular Fornula</u>

A. Definition

A formula for a molecular compound that represents ALL of the atoms found in a single molecule of that compound

The molecular formula is either the same as the empirical formula, or it is a whole number multiple of the empirical formula

B. Calculation of Molecular Formula

1. Necessary Information
   a. Empirical Formula
   b. Molecular mass
2. Calculations
   a. $(\text{empirical formula wt.})_x$ = molecular weight
   b. $(\text{empirical formula})_x$ = molecular formula

<u>Example</u> : (empirical formula = HO molecular wt. = 34.02)

$(\text{HO weight})_x = 34.02$

HO = 17.01 (1.01 + 16.00)

$(17.01)_x = 34.02$

$x = 2$

Molecular formula is $(HO)_2$

$\therefore$ Molecular formula is H_2O_2

11.1 Describing Chemical Reactions

I. <u>Introduction</u>

- A. Reactants
  - 1. Original substances entering into a chemical rxn
- B. Products
  - 1. The resulting substances from a chemical rxn

    Reactants $\rightarrow$ Products
- C. Chemical Equation
  - 1. Represents with symbols and formulas, the identities and relative amounts of the reactants and products in a chemical rxn

II. <u>Writing Chemical Equations</u>

- A. The equation must represent known facts
  - 1. This can be done with a ***word equation***:

    "hydrogen reacts with oxygen to form water"

    Hydrogen + Oxygen $\rightarrow$ Water

- B. The equation must contain the correct formulas for reactants and products
  - 1. This is done with a formula equation

    $H_2 + O_2 \rightarrow H_2O$

- C. The law of conservation of atoms must be satisfied
  - 1. Balancing is done with coefficients - small whole numbers that appear in front of a formula

    $2H_2 + O_2 \rightarrow 2H_2O$

- D. Additional symbols used in Chemical equations

Table 11.1	**Symbols Used in Chemical Equations**
Symbol	*Explanation*
+	Used to separate two reactants or products
$\rightarrow$	"Yields," separates reactants from products
$\leftrightarrows$	Used in place of a single arrow to indicate a reversible reactions
(s)	Reactant or product in the solid state. Also a precipitate
(l)	Reactant or product in the liquid state.
(aq)	Reactant or product in an aqueous solution (dissolved in water)
(g)	Reactant or product in the gaseous state
$\xrightarrow{\Delta}$	Reactants are heated
$\xrightarrow{Pt}$	A formula written above or below the yield sign indicates its use as a catalyst (in this case, platinum)
$\xrightarrow{\text{Pressure}}$	Pressure at which rxn is carried out exceeds normal atmospheric pressure
$\xrightarrow{25\ °C}$	Temperature at which the rxn is carried out, in this case 25 °C
$\xrightarrow{MnO_2}$	Formula of catalyst, in this case manganese dioxide, used to alter the rate of the reaction

III. <u>Balancing Chemical Equations</u>

- A. Identify the names of reactants and products, and write a word equation
- B. Write a formula equation by substituting correct formulas for the names of the reactants and the products
- C. Balance the formula equation according to the law of conservation of atoms
- D. Count atoms to be sure that the equation is balanced

11.2 Types of Chemical Reactions

I. Combination Reactions (Synthesis Rxns)

A. Two or more substances combine to form a more complex substance

$$A + X \rightarrow AX$$

B. Types of Synthesis Rxns

1. Metals react with oxygen to form oxides
$$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$$
2. Metals react with sulfur to form sulfides
$$8Ba(s) + S_8(s) \rightarrow 8BaS(s)$$
3. Nonmetals react with oxygen to form oxides
$$C(s) + O_2(g) \rightarrow CO_2(g)$$
4. Metals react with halogens to form salts (halogen means "salt maker")
$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$
5. Active metal oxides react with water to form metallic hydroxides
$$MgO(s) + H_2O(l) \rightarrow Mg(OH)_2(s)$$
6. Nonmetal oxides react with water to form oxyacids (acid rain)
$$SO_2(g) + H_2O \rightarrow H_2SO_3(aq)$$

II. Decomposition Reactions

A. Decomposition Rxns

1. One substance breaks down to form two or more simpler substances
$$AX \rightarrow A + X$$

B. Six Kinds of Decomposition Rxns

1. Metallic carbonates, when heated, form metallic oxides and carbon dioxide
$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$
2. Metallic hydroxides , when heated, decompose into metallic oxides and water
$$Ca(OH)_2(s) \rightarrow CaO(s) + H_2O(g)$$
3. Metallic chlorates, when heated, decompose into metallic chlorides and oxygen
$$2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$$

4. Some acids, when heated, decompose into nonmetallic oxides and water
$$H_2SO_4(aq) \rightarrow H_2O(l) + SO_3\,(g)$$
5. A few oxides, when heated, decompose
$$2PbO_2(s) \rightarrow 2PbO(s) + O_2\,(g)$$
6. Some decomposition rxns are produced by an electric current
$$2NaCl(s) \rightarrow 2Na(s) + Cl_2\,(g)$$

III. Single-Replacement Reactions

A. Single-Replacement Rxns I

1. One substance is replaced in its compound by another substance
$$A + BX \rightarrow AX + B$$
$$Y + BX \rightarrow BY + X$$

B. Four Types of Decomposition Rxns

1. Replacement of a metal in a compound by a more active metal
$$Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$$
2. Replacement of hydrogen in water by active metals
$$Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2\,(g)$$
3. Replacement of hydrogen in acids by metals
$$Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2\,(g)$$
4. Replacement of halogens by more active halogens
$$Cl_2(g) + 2KBr(aq) \rightarrow 2KCl(aq) + Br_2\,(g)$$

C. Activity Series

1. A list of elements organized according to the ease with which the elements undergo certain chemical rxns
2. Each element in the list displaces from a compound any of the elements below it. The larger the interval between elements in a series, the more vigorous the replacement rxn.
3. Metals may replace other metals
4. Halogens may replace other halogens

Activity Series of the Elements		
Activity of metals (partial list)		*Activity of halogens*
Li	Decreasing Activity ↓	F_2
K		Cl_2
Ca		Br_2
Na		I_2
Mg		
Al		
Zn		
Fe		
Pb		
Hydrogen		
Cu		
Hg		
Ag		
Au		

IV. <u>Double-Replacement Reactions</u>

A. Double-Replacement Rxn

1. The ions of two compounds exchange places in an aqueous solution to form two new compounds

B. Types of Double-Replacement Rxns

1. Formation of a Precipitate

$$BaCl_2(aq) + Na_2SO_4(aq) \rightarrow 2NaCl(aq) + BaSO_4(s)$$

2. Formation of a Gas

$$FeS(aq) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2S(g)$$

3. Formation of Water

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$

V. <u>Combustion Reactions</u>

A. Combustion Rxns

1. A substance combines with oxygen, releasing a large amount of energy in the form of light and heat

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

B. Hydrocarbon combustion always produces carbon dioxide and water

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$$

11.3 Reactions in Aqueous Solution

I. <u>Dissociation</u>

A. Dissociation

1. The separation of ions that occurs when an ionic compound dissolves

a. One formula unit of NaCl produces two ions

b. One mole of NaCl produces two moles of ions

$$NaCl(s) \xrightarrow{H_2O} Na^+(aq) + Cl^-(aq)$$

c. One formula unit of $CaCl_2$ produces three ions

d. One mole of $CaCl_2$ produces three moles of ions

$$CaCl_2(s) \xrightarrow{H_2O} Ca^{2+}(aq) + 2Cl^-(aq)$$

II. Predicting the Formation of a Precipitate

A. Solubility Rules

1. No compound is completely insoluble
2. Compounds of very low solubility can be considered insoluble
3. Dissociation equations cannot be written for insoluble compounds

General Solubility Guidelines
1. Most sodium, potassium, and ammonium compounds are soluble in water.
2. Most nitrates, acetates, and chlorates are soluble
3. Most chlorides are soluble, except those of silver, mercury(I), and lead. Lead(II) chloride is soluble in hot water
4. Most sulfates are soluble, except those of barium, strontium, and lead
5. Most carbonates, phosphates, and silicates, are insoluble, except those of sodium, potassium, and ammonium
6. Most sulfides are insoluble, except those of calcium, strontium, sodium, potassium, and ammonium

B. Precipitation Reactions

1. A reaction between two soluble compounds in solution, resulting in at least one insoluble product
   a. Write the dissociation equations for the reacting compounds

$$Na_2SO_4(s) \xrightarrow{H_2O} 2Na^+(aq) + SO_4^{\ 2-}(aq)$$
$$BaCl_2(s) \xrightarrow{H_2O} Ba^{2+}(aq) + 2Cl^-(aq)$$

   b. Identify the insoluble product if there is one

$$Na_2SO_4(aq) + BaCl_2(aq) \rightarrow 2NaCl(aq) + BaSO_4(s)$$

III. Net Ionic Equations

A. Definition

1. An equation that includes only those compounds and ions that undergo a chemical change in a reaction in an aqueous solution

B. Writing a Net Ionic Equation

1. Write a complete ionic equation

$$2Na^+(aq) + SO_4^{2-}(aq) + Ba^{2+}(aq) + 2Cl^-(aq) \rightarrow 2Na^+(aq) + 2Cl^-(aq) + BaSO_4(s)$$

2. Generate a net ionic equation by eliminating spectator ions

$$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$$

Spectator ions are those ions that do not take part in a chemical rxn and are found in solution both before and after the rxn: Na^+(aq) and Cl^-(aq) in this rxn

12.1 Introduction to Stoichiometry

I. Interpreting Chemical Equations

A. Quantitative Information

1. # of moles, atoms, molecules in a reaction
2. Equality exists in each direction
3. The fact that a rxn can be written does not mean that the rxn can take place

12.2 Chemical Calculations

I. Writing and Using Mole Ratios

A. Mole Ratio

1. A conversion factor that relates the amounts in moles of any two substances involved in a chemical reaction
2. Mole ratio is used to convert:

given moles → unknown moles

B. Molar Mass

1. Molar mass of compounds and elements is used to convert:

given mass → given moles

and

unknown moles → unknown mass

II. Calculations Involving Moles and Mass

A. Four problem Types, One Common Solution

given mass → given moles → unknown moles → unknown mass

1. Given and unknown quantities are in moles
2. Given is an amount in moles and the unknown is a mass (usually in grams)
3. Given is a mass in grams and the unknown is an amount in moles
4. Given is a mass in grams and the unknown is a mass in grams

III. A Common Method for Solving All Stoichiometry Problems

A. Mass-Mass Problems

1. Start with a known mass of reactant or product, find an unknown mass of another reactant or product
2. All other stoichiometry problems are derivations (shortened versions) of this larger solution:

Find moles of given using molar mass →	Use mole ratios to find moles of unknown →	Find grams of unknown using molar mass

$$given\ (in\ grams)\ x \left(\frac{1 mole\ of\ given}{given's\ molar\ mass\ in\ grams} \right) x \left(\frac{moles\ of\ unknown\ in\ balanced\ equation}{moles\ of\ given\ in\ balanced\ equation} \right) x \left(\frac{unknown's\ molar\ mass\ in\ grams}{1 mole\ of\ unknown} \right) = grams$$

B. Steps to Solving Problems

1. Start with a correctly balanced chemical equation
   a. Use key words in the problem statement to identify substances as either reactants or products.
2. Determine what units you've been given and what you are being asked to find
3. Label each step with the correct units!
   a. the units from the numerator of the first step become the units in the denominator of the next step, and so forth
4. Stop when you have an answer with the units that you are searching for

IV. Other Stoichiometric Calculations

A. Gas Volume

1. Assuming STP, each mole of gas occupies 22.4 L of volume
2. Non-STP problems are covered later in the text

B. Number of Molecules

1. One mole of any substance contains 6.02×10^{23} molecules

12.3 Limiting Reactants and Percent Yield

I. Limiting Reactant

A. Definition of Limiting Reactant

1. The reactant that limits the amounts of the other reactants that can combine and the amount of product that can form in a chemical reaction

" I want to make chocolate chip cookies. I look around my kitchen (I have a BIG kitchen!) and find 40 lbs. of butter, two lbs. of salt, 1 gallon of vanilla extract, 80 lbs. of chocolate chips, 200 lbs. of flour, 150 lbs. of sugar, 150 lbs. of brown sugar, ten lbs. of baking soda and TWO eggs. It should be clear that it is the number of eggs that will determine the number of cookies that I can make."

B. Excess Reactant

1. The substance that is not used up completely in a reaction

C. Identifying the Limiting Reactant

1. Convert grams of each reactant to moles if the problem has not already done so for you
2. Use molar ratios from the balance chemical equation to determine which reactant is limiting, and which reactant is in excess

D. Stoichiometry with Limiting Reactants

1. All calculations should start with the amount of the limiting reactant, not the excess reactant

II. Percent Yield

A. Theoretical Yield

1. The maximum amount of product that can be produced from a given amount of reactant

B. Actual Yield

1. The measured amount of a product obtained from a reaction

C. Calculating Percent Yield

1. The ratio of the actual yield to the theoretical yield, multiplied by 100

$$percent\ \ yield = \frac{actual\ \ yield}{theoretical\ \ yield}\ \ x\ \ 100$$