Unit 4 – Conservation of Mass and Stoichiometry

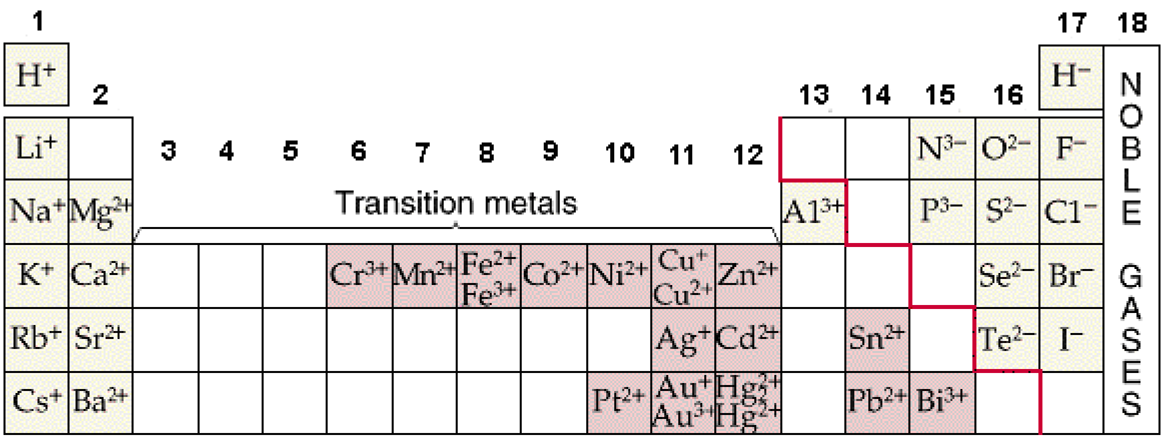
7-1 Chemical Names and Formulas

I. Significance of a Chemical Formula

- A. Molecular formulas
  - 1. Number of atoms of each element in one molecule of a compound
    - C_2H_6 = ethane (2 carbon atoms, 6 hydrogen atoms)
- B. Ionic Compounds
  - 1. Represents the simplest whole number ratio of the compounds cations and anions
    - $Al_2(SO_4)_3$ = aluminum sulfate (2 aluminum ions, 3 sulfate ions)

II. 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

III. Binary Ionic Compounds

- A. Binary Compounds
  - 1. Compounds composed of two different elements
- B. 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
- C. Naming Binary Ionic Compounds from Their Formulas
  - 1. Name the cation
  - 2. Name the anion
- D. 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

E. Compounds Containing Polyatomic Ions
   1. Oxyanions
      a. Polyatomic anions that contain oxygen
   2. Naming a series of similar polyatomic ions

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

   3. Naming compounds containing polyatomic ions
      a. Same as for monatomic ions
   4. 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

IV. 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

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

7-3 Using Chemical Formulas

I. Formula Masses
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

II. Molar Mass as a Conversion Factor
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

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

III. Percentage Composition

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

$CuSO_4 \bullet 5H_20$

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

8-1 Describing Chemical Reactions

I. Introduction

A. Reactants

1. Original substances entering into a chemical rxn

B. Products

1. The resulting substances from a chemical rxn

Reactants → 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. Indications of a Chemical Reaction

A. Evolution of Heat and Light

1. Evidence of energy being released (exothermic rxn)

B. Production of a Gas

1. CO_2, H_2, H_2S are some gases produced by chemical rxns

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

C. Formation of a Precipitate

1. Precipitate is a solid that is produced as a result of a chemical rxn in solution

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

III. Characteristics of Chemical Equations

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 → 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 8-2	**Symbols Used in Chemical Equations**
Symbol	*Explanation*
$\longrightarrow$	"yields" ; indicates result of a rxn
$\rightleftarrows$	Used in place of a single arrow to indicate a reversible rxn
(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
$\xrightarrow{2\text{ atm}}$	Pressure at which the rxn is carried out, in this case 2 atmospheres
$\xrightarrow{\text{Pressure}}$	Pressure at which rxn is carried out exceeds normal atmospheric pressure
$\xrightarrow{25\,^\circ\text{C}}$	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

IV. Significance of a Chemical Reaction

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

V. Balancing Chemical Equations

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

8-2 Types of Chemical Reactions

I. Synthesis Reactions (Composition Rxns)

A. Synthesis Rxns

1. 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
$$8Ba(s) + S_8(s) \rightarrow 8BaS(s)$$
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

$$Cl_2(g) + 2KBr(aq) \rightarrow 2KCl(aq) + Br_2(g)$$

IV. Double-Replacement Reactions

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. Combustion Reactions

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

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

8-3 Activity Series of the Elements

A. 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

B. Using the Activity Series (Table 8-3 in your book)

1. All metals above hydrogen displace hydrogen from hydrochloric acid or dilute sulfuric acid
2. Metals above magnesium vigorously displace hydrogen from water. Magnesium displaces hydrogen from steam.
3. Metals above silver combine directly with oxygen; those near the top do so rapidly
4. Metals below mercury form oxides only indirectly.
5. Oxides of metals below mercury decompose with mild heating.
6. Oxides of metals below chromium easily undergo reduction to metals by heating with hydrogen
7. Oxides of metals above iron resist reduction by heating with hydrogen
8. Elements near the top of the series are never found free in nature
9. Elements near the bottom of the series are often found free in nature.

<table>
<tr><td colspan="3">Table 8-3 Activity Series of the Elements</td></tr>
<tr><td colspan="2">Activity of metals</td><td>Activity of halogens</td></tr>
<tr><td>Li</td><td rowspan="7">React with cold H2O and acids, replacing hydrogen. React with oxygen, forming oxides.</td><td>F_2</td></tr>
<tr><td>Rb</td><td>Cl_2</td></tr>
<tr><td>K</td><td>Br_2</td></tr>
<tr><td>Ba</td><td>I_2</td></tr>
<tr><td>Sr</td><td rowspan="26"></td></tr>
<tr><td>Ca</td></tr>
<tr><td>Na</td></tr>
<tr><td>Mg</td><td rowspan="7">React with steam (but not cold water) and acids, replacing hydrogen. React with oxygen, forming oxides.</td></tr>
<tr><td>Al</td></tr>
<tr><td>Mn</td></tr>
<tr><td>Zn</td></tr>
<tr><td>Cr</td></tr>
<tr><td>Fe</td></tr>
<tr><td>Cd</td></tr>
<tr><td>Co</td><td rowspan="4">Do not react with water. React with acids, replacing hydrogen. React with oxygen, forming oxides.</td></tr>
<tr><td>Ni</td></tr>
<tr><td>Sn</td></tr>
<tr><td>Pb</td></tr>
<tr><td>H_2</td><td rowspan="5">React with oxygen, forming oxides.</td></tr>
<tr><td>Sb</td></tr>
<tr><td>Bi</td></tr>
<tr><td>Cu</td></tr>
<tr><td>Hg</td></tr>
<tr><td>Ag</td><td rowspan="3">Fairly unreactive, forming oxides only indirectly.</td></tr>
<tr><td>Pt</td></tr>
<tr><td>Au</td></tr>
</table>

9-1 Introduction to Stoichiometry
Composition Stoichiometry - deals with mass relationships of elements in compounds
Reaction Stoichiometry - Involves mass relationships between reactants and products in a chemical reaction

I. <u>Reaction Stoichiometry Problems</u>

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

B. 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

C. Molar Mass

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

given mass → given moles
and
unknown moles → unknown mass

9-2 Ideal Stoichiometric Calculations
Ideal Stoichiometry - All reactants are converted into products

I. <u>A Common Method for Solving All Stoichiometry Problems</u>

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

There are four types of stoichiometry problems, but you do not have to "learn" four different equations for solving them…the techniques are the same for any conversion problems!

9-3 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

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