

Unit 4 – Conservation of Mass and Stoichiometry

9.1 Naming Ions

I. Monatomic Ions

A. Monatomic ions

1. Ions formed from a single atom

1	H⁺	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Li ⁺	Mg ²⁺	Transition metals										Al ³⁺		N ³⁻	O ²⁻	F ⁻	NOBLE GASES	
	K ⁺	Ca ²⁺				Cr ³⁺	Mn ²⁺	Fe ²⁺	Fe ³⁺	Co ²⁺	Ni ²⁺	Cu ⁺	Cu ²⁺	Zn ²⁺			Se ²⁻		Br ⁻
	Rb ⁺	Sr ²⁺										Ag ⁺	Cd ²⁺		Sn ²⁺		Te ²⁻		I ⁻
	Cs ⁺	Ba ²⁺									Pt ²⁺	Au ⁺	Au ³⁺	Hg ²⁺	Hg ³⁺	Pb ²⁺	Bi ³⁺		

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

<i>Formula</i>	<i>Name</i>
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 ₂ H ₃ O ₂ ⁻	Acetate

B. Naming a series of similar polyatomic ions

ClO⁻
Hypochlorite

ClO₂⁻
Chlorite

ClO₃⁻
Chlorate

ClO₄⁻
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 as 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, $C_6H_{12}O_6$:

$$\begin{array}{l} C = 12.01 \text{ amu} \quad 6 \times 12.01 \text{ amu} = 72.06 \text{ amu} \\ H = 1.01 \text{ amu} \quad 12 \times 1.01 \text{ amu} = 12.12 \text{ amu} \\ O = 16.00 \text{ amu} \quad \underline{6 \times 16.00 \text{ amu} = 96.00 \text{ amu}} \\ \text{Formula Mass} = 180.18 \text{ amu} \end{array}$$

B. Molar Masses

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

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

10.2 Mole-Mass and Mole-Volume Relationships

I. The Mole-Mass Relationship

A. Converting moles of compound to grams

$$\text{Amount in moles} \times \text{molar mass}(\text{g/mol}) = \text{Mass in grams}$$

B. Converting grams of compound to mass

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

- 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. Percentage Composition
 - A. Percentage Composition
 - 1. The percentage by mass of each element in a compound

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

- B. Hydrates
 - 1. Crystalline compounds in which water molecules are bound in the crystal structure
 - Copper (II) sulfate pentahydrate
CuSO₄ • 5H₂O
 - a. The raised dot means "Water is loosely attached" It does **NOT** mean multiply when determining formula weight

- II. Empirical Formula
 - 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. Molecular Formula
 - 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. (empirical formula wt.)_x = molecular weight
 - b. (empirical formula)_x = molecular formula

Example : (empirical formula = HO molecular wt. = 34.02)

(HO weight)_x = 34.02

HO = 17.01 (1.01 + 16.00)

(17.01)_x = 34.02

 x = 2

Molecular formula is (HO)₂

∴ Molecular formula is H₂O₂

11.1 Describing Chemical Reactions

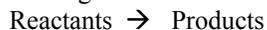
I. Introduction

A. Reactants

1. Original substances entering into a chemical rxn

B. Products

1. The resulting substances from a chemical rxn



C. Chemical Equation

1. Represents with symbols and formulas, the identities and relative amounts of the reactants and products in a chemical rxn

II. Writing Chemical Equations

A. The equation must represent known facts

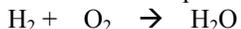
1. This can be done with a **word equation**:

"hydrogen reacts with oxygen to form water"



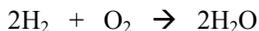
B. The equation must contain the correct formulas for reactants and products

1. This is done with a formula equation



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



D. Additional symbols used in Chemical equations

Table 11.1 Symbols Used in Chemical Equations	
<i>Symbol</i>	<i>Explanation</i>
+	Used to separate two reactants or products
\rightarrow	"Yields," separates reactants from products
\rightleftharpoons	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
$\xrightarrow{\text{Pt}}$	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
$\xrightarrow{25^\circ\text{C}}$	Temperature at which the rxn is carried out, in this case 25 °C
$\xrightarrow{\text{MnO}_2}$	Formula of catalyst, in this case manganese dioxide, used to alter the rate of the reaction

III. 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

11.2 Types of Chemical Reactions

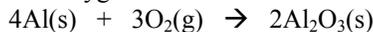
I. Combination Reactions (Synthesis Rxns)

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

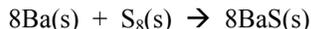


B. Types of Synthesis Rxns

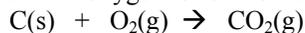
1. Metals react with oxygen to form oxides



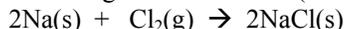
2. Metals react with sulfur to form sulfides



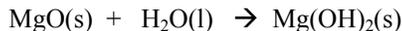
3. Nonmetals react with oxygen to form oxides



4. Metals react with halogens to form salts (halogen means "salt maker")



5. Active metal oxides react with water to form metallic hydroxides



6. Nonmetal oxides react with water to form oxyacids (acid rain)



II. Decomposition Reactions

A. Decomposition Rxns

1. One substance breaks down to form two or more simpler substances



B. Six Kinds of Decomposition Rxns

1. Metallic carbonates, when heated, form metallic oxides and carbon dioxide



2. Metallic hydroxides, when heated, decompose into metallic oxides and water



3. Metallic chlorates, when heated, decompose into metallic chlorides and oxygen



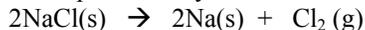
4. Some acids, when heated, decompose into nonmetallic oxides and water



5. A few oxides, when heated, decompose



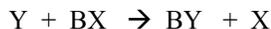
6. Some decomposition rxns are produced by an electric current



III. Single-Replacement Reactions

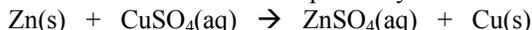
A. Single-Replacement Rxns I

1. One substance is replaced in its compound by another substance



B. Four Types of Decomposition Rxns

1. Replacement of a metal in a compound by a more active metal



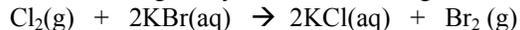
2. Replacement of hydrogen in water by active metals



3. Replacement of hydrogen in acids by metals



4. Replacement of halogens by more active halogens



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	F ₂
K	Cl ₂
Ca	Br ₂
Na	I ₂
Mg	
Al	
Zn	
Fe	
Pb	
Hydrogen	
Cu	
Hg	
Ag	
Au	

IV. Double-Replacement Reactions

A. Double-Replacement Rxn

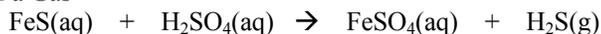
- The ions of two compounds exchange places in an aqueous solution to form two new compounds

B. Types of Double-Replacement Rxns

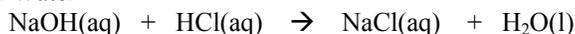
- Formation of a Precipitate



- Formation of a Gas



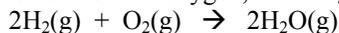
- Formation of Water



V. Combustion Reactions

A. Combustion Rxns

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



- ##### B. Hydrocarbon combustion always produces carbon dioxide and water



11.3 Reactions in Aqueous Solution

I. Dissociation

A. Dissociation

- The separation of ions that occurs when an ionic compound dissolves

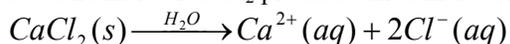
- One formula unit of NaCl produces two ions

- One mole of NaCl produces two moles of ions



- One formula unit of CaCl₂ produces three ions

- One mole of CaCl₂ produces three moles of ions



II. Predicting the Formation of a Precipitate

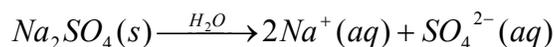
A. Solubility Rules

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

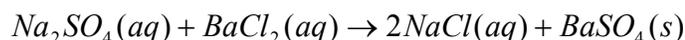
General Solubility Guidelines
1. Most sodium, potassium, and ammonium compounds are soluble in water.
2. Most nitrates, acetates, and chlorates are soluble
3. Most chlorides are soluble, except those of silver, mercury(I), and lead. Lead(II) chloride is soluble in hot water
4. Most sulfates are soluble, 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



- b. Identify the insoluble product if there is one



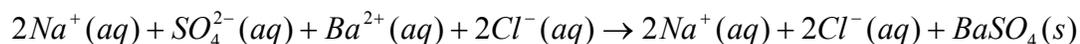
III. Net Ionic Equations

A. Definition

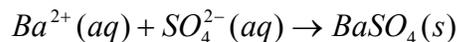
1. An equation that includes only those compounds and ions that undergo a chemical change in a reaction in an aqueous solution

B. Writing a Net Ionic Equation

1. Write a complete ionic equation



2. Generate a net ionic equation by eliminating spectator ions



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 \rightarrow unknown moles

B. Molar Mass

1. Molar mass of compounds and elements is used to convert:
given mass \rightarrow given moles
and
unknown moles \rightarrow unknown mass

II. Calculations Involving Moles and Mass

A. Four problem Types, One Common Solution

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

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

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

$$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$