Formulas, Equations, and Amounts

Objectives

- Provide the names and formulas of commonplace ionic compounds.
- Interpret molecular formulas.
- Interpret chemical reaction equations.
- Employ the mole as a unit of quantity.
- Relate quantities, concentrations, and volumes.
- Quantitatively apply reaction equations to determine equivalent amounts and theoretical yields.

Overview

Matter is not continuous. Every substance on Earth is made of molecules, which in turn are made of atoms interacting in specific ways. Atoms combine to make molecules in specific numbers and proportions. Molecules interact with each other, exchanging and splitting off specific parts to make definite new molecules.

The tendency of substances to react with each other in specific amounts was recognized as a general rule after numerous workers studied countless reactions. This **law of definite proportions** was key evidence that matter is composed of atoms, and allowed chemists to begin to understand the transformations of molecules far too small to see.

To understand and describe the transformations of molecules—**chemical reactions**—chemists use a number of specialized concepts and terms. These allow them to think of the properties of molecules, too small to see or manipulate, in terms of quantities familiar to our ordinary experience. With these tools, chemists rapidly and precisely specify chemical substances, "count" molecules they can't even see, and determine exactly what amount of one substance reacts with another to create how much of something else. You will too.

Chemical names and formulas tell what a substance is, and how much of which elements it contains. Reaction equations tell the definite proportions of the substances that react and are created. Moles and molar masses convert numbers and proportions of invisible molecules into proportions and amounts that we can measure and manipulate. Concentrations allow us to determine how much of a substance exists in a known volume of a solution. These concepts will help you make sense of the chemical transformations you study.

Commonly-Encountered Ions

Monatomic Anions (negative charge): named with "-ide" suffix

Halides (column under F): –1 charge

F^- = fluoride; Cl^- = chloride; Br^- = bromide; I^- = iodide

Chalcides (column under O): –2 charge

O^{-2} = oxide; S^{-2} = sulfide; Se^{-2} = selenide

Hydride: H^- (uncommon, water-reactive)

Monatomic Cations (positive charge): named as elements

Alkali metals (first column): +1 charge

(H^+), Li^+, Na^+, K^+, Rb^+, Cs^+

Alkaline earth metals (second column): +2 charge

Be^{+2}, Mg^{+2}, Ca^{+2}, Sr^{+2}, Ba^{+2}

Group 3 (third main-group column): +3 charge

B^{+3}, Al^{+3}, Ga^{+3}

Metals with more possibilities: Specify charge as "Element(roman numeral charge)"

Fe^{+2} = Iron(II), Fe^{+3} = Iron(III); Pb^{+2} = Lead(II); Pb^{+4} = Lead(IV)

Polyatomic Ions

Cations

NH_4^+ = ammonium

Anions

ClO^-= hypochlorite;	ClO_2^-= chlorite;	ClO_3^-= chlorate;	ClO_4^-= perchlorate
BrO^-= hypobromite;	BrO_2^-= bromite;	BrO_3^-= bromate;	BrO_4^-= perbromate
IO^-= hypoiodite;	IO_2^-= iodite;	IO_3^-= iodate;	IO_4^-= periodate

SO_3^{-2} = sulfite; SO_4^{-2} = sulfate; SeO_4^{-2} = selenate

NO_3^- = nitrate; PO_4^{-3} = phosphate

CO_3^{-2} = carbonate; HCO_3^- = hydrogen carbonate or "bicarbonate"

OH^- = hydroxide; SH^- = hydrosulfide

Formulas

I. Counting atoms and naming

1. Identify and count the atoms in each formula unit.
2. Identify the ions in each formula unit, and name the ionic compound.

Formula	Atoms	Ions	Compound name
NaCl			
BaO			
$CuCl_2$			
H_2SO_4			
$MgSO_4$			
$AgNO_3$			
$Al(NO_3)_3$			
Al_2O_3			
KH_2PO_4			
$Fe_2(SO_4)_3$			

II. Balancing charges

1. Label each ion with its charge.
2. Determine the smallest number of each ion to balance the charges and write the complete formula with subscripts.
3. Name the ionic compound.

Cation	Anion	Formula	Compound name
Ba	HCO_3		
Al	NO_3		
Ca	ClO		
K	Br		
Ca	PO_4		

III. Names to formulas

Find the charge of each ion, determine the number of each ion, and write the complete structural formula.

Compound name	Formula	Compound name	Formula
Copper(I) sulfide		Calcium bicarbonate	
Aluminum hydroxide		Chromium(VI) oxide	

Equations

IV. Is it balanced?

1. Determine the number of atoms of each element in the reactant and product sides of each chemical reaction equation below.
2. Decide if the reaction equations are balanced.

Equation	Reactants	Products	Bal?
$NaHCO_3 + HCl \rightarrow NaCl + CO_2 + H_2O$			**Y N**
$2\ NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$			**Y N**
$Cl_2 + NaOH \rightarrow NaCl + NaOCl$			**Y N**
$CaO + H_2O \rightarrow Ca(OH)_2$			**Y N**

V. Balance it!

Balance the equations below by entering the correct coefficients.

1. _____ H_2 + _____ $O_2 \rightarrow$ _____ H_2O
2. _____ $AlCl_3$ + _____ $H_2O \rightarrow$ _____ $Al(OH)_3$ + _____ HCl
3. _____ $KClO_3 \rightarrow$ _____ KCl + _____ O_2
4. _____ CH_4 + _____ $O_2 \rightarrow$ _____ CO_2 + _____ H_2O
5. _____ $FeCl_3$ + _____ $NaOH \rightarrow$ _____ $Fe(OH)_3$ + _____ $NaCl$
6. _____ H_2 + _____ $N_2 \rightarrow$ _____ NH_3
7. _____ $(NH_4)_2CO_3 \rightarrow$ _____ $CO(NH_2)_2$ + _____ H_2O
8. _____ NaH + _____ $NH_3 \rightarrow$ _____ $NaNH_2$ + _____ H_2
9. _____ Fe_2O_3 + _____ $C \rightarrow$ _____ Fe + _____ CO
10. _____ $FeSO_4$ + _____ H_2O_2 + _____ $H_2O \rightarrow$ _____ $Fe(OH)_3$ + _____ H_2SO_4

VI. Names to equations

Below are chemical equations in words. Convert to formulas and balance.

1. strontium chloride + ammonium sulfate → strontium sulfate + ammonium chloride

2. iron + oxygen → iron(III) oxide

3. lead + lead(IV) oxide + hydrogen sulfate → lead (II) sulfate + water

Moles

VII. Atomic masses

What is the mass in grams of:

1. 1 mol of sulfur (S)?
2. 1 mol of lithium (Li)?
3. 1 mol of xenon (Xe)?
4. 1 mol of molybdenum (Mo)?
5. 1 mol of calcium (Ca)?

VIII. Moles to masses (of elements)

What is the mass in grams of:

1. 0.5 mol of carbon (C)?
2. 2.0 mol of sodium (Na)?
3. 5.5 mol of cobalt (Co)?

IX. Masses to moles (of elements)

How many moles of each element are in:

1. 2.0 g aluminum (Al)?
2. 250 g selenium (Se)?
3. 1 tonne (= 1000 kg) carbon (C)?

X. Formula masses

What is the mass in grams of:

1. 1 mol Na_2S?
2. 1 mol H_2SO_4?
3. 1 mol CO_2?

XI. Masses to moles (of compounds)

How many moles of each compound are in:

1. 454 g $C_{12}H_{22}O_{11}$?

2. 1 kg H_2O?

3. 3.67 tonnes CO_2?

XII. Equivalent Molar Amounts

Given the reaction and number of moles of one species, find the equivalent numbers of moles of the other species.

1. $C_6H_6 + HNO_3 \rightarrow C_6H_5NO_2 + H_2O$
   Start with 0.20 mol HNO_3.

2. $2\ Fe + 3\ CuCl_2 \rightarrow 2\ FeCl_3 + 3\ Cu$
   Start with 1.25 mol Fe.

3. $CaCl_2 + 2\ AgNO_3 \rightarrow Ca(NO_3)_2 + 2\ AgCl$
   End with 5.5 mol AgCl.

XIII. Equivalent Molar Amounts and Masses

Given the reaction and the number of moles of one species, find the equivalent numbers of moles of the other species and the equivalent masses of all species.

1. $Sr + 2\ HCl \rightarrow SrCl_2 + H_2$
   Start with 1.0 mol HCl.

2. $2\ Al + 3\ CuCl_2 \rightarrow 2\ AlCl_3 + 3\ Cu$
   End with 1.5 mol Cu.

XIV. Equivalent Masses

Given the reaction and the mass of one species, find the equivalent masses of all other species.

1. $Zn + 2HCl \rightarrow ZnCl_2 + H_2$
   Start with 4.00 g Zn.

2. $AgNO_3 + NaI \rightarrow AgI + NaNO_3$
   End with 2.00 g AgI.

XV. Limiting Reagent

Find the limiting reagents of the following reactions.

1. $2\ C_6H_6 + 15\ O_2 \rightarrow 12\ CO_2 + 6\ H_2O$
   Start with 0.8 mol C_6H_6 and 4.0 mol O_2.

2. $SrCl_2 + 2\ NaF \rightarrow SrF_2 + 2\ NaCl$
   Start with 2.5 mol $SrCl_2$ and 2.0 mol NaF.

XVI. Limiting Molar Amounts

Find the limiting reagent and determine the masses of all components consumed or produced in the reaction

$$CaC_2 + 2\ H_2O \rightarrow C_2H_2 + Ca(OH)_2$$

starting with 2.0 mol CaC_2 and 11.0 mol H_2O.

XVII. Limiting Reagent Mass

Find the limiting reagent and calculate the product yields for the reaction

$$2\ C_2H_2 + 5\ O_2 \rightarrow 4\ CO_2 + 2\ H_2O$$

starting with 500 g C_2H_2 and 1000 g O_2.