

Stoichiometry

The branch of chemistry dealing with mass relationships of elements within compounds and among reactants and products in chemical reactions.

Atomic Mass: The mass in atomic mass units of an element

Molecular Mass: The mass in atomic mass units of a molecule

Formula Mass: The mass in atomic mass units of an ionic compound

Na - $23.0 \times 1 = 23.0$

Cl - $35.5 \times 1 = 35.5$

58.5 amu

C - $12 \times 1 = 12$

O - $16 \times 2 = 32$

44 amu

Moles

- The quantity of matter containing Avogadro's number of particles
- 6.022×10^{23} particles
- Particles may include:
 - subatomic particles
 - ions
 - atoms
 - molecules

Molar Mass: The mass of one mole of a substance in grams

Stoichiometric Calculations

Calculating moles from grams

Divide grams by molar mass

Calculating grams from moles

Multiply moles by molar mass

Solutions: A homogeneous mixture of two or more substances

Components – Two parts consisting of the Solvent and Solute

Concentration – General terms consist of dilute or concentrated. Specific term describing the concentration is molarity (M).

$$M = \text{moles of solute} / \text{L of solution}$$

Example: White vinegar is a solution of acetic acid, $\text{CH}_3\text{CO}_2\text{H}$, in water. Vinegar, with an acidity of 5.00%, contains 50.4 g of acetic acid in 1.00 L of vinegar. Determine the concentration in moles per liter.

First step -- Convert grams of $\text{CH}_3\text{CO}_2\text{H}$ to moles:

$$\text{mol } \text{CH}_3\text{CO}_2\text{H} = 50.4 \text{ g } \text{CH}_3\text{CO}_2\text{H} \times \frac{1 \text{ mol } \text{CH}_3\text{CO}_2\text{H}}{60.0 \text{ g } \text{CH}_3\text{CO}_2\text{H}} = 0.839 \text{ mol } \text{CH}_3\text{CO}_2\text{H}$$

Second step --- Convert moles to molarity

$$M \text{ } \text{CH}_3\text{CO}_2\text{H} = \frac{0.839 \text{ mol } \text{CH}_3\text{CO}_2\text{H}}{1 \text{ L solution}} = 0.839 \text{ M } \text{CH}_3\text{CO}_2\text{H}$$

Titration: A process for determining the concentration of a solution by allowing a carefully measured volume to react with a solution of a second substance whose concentration is known.

Percent Composition

$$\%X = \frac{\text{mass } X}{\text{mass sample}} \times 100\%$$

Empirical Formula

$$\text{mol } X = \frac{\text{mass } X}{\text{molar mass}}$$

Example: CO_2

First step:

$$C: 1 \times 12.0 \text{ amu} = 12.0 \text{ amu}$$

$$\underline{O: 2 \times 16.0 \text{ amu} = 32.0 \text{ amu}}$$

$$44.0 \text{ amu}$$

Second step:

$$C: (12.0 \text{ amu} \div 44.0 \text{ amu}) \times 100\% = 27.3 \%$$

$$O: (32.0 \text{ amu} \div 44.0 \text{ amu}) \times 100\% = 72.7 \%$$

Types of data used in calculating the empirical formula

- Percentage Composition Data -- utilizes data as percentages of substance
- Relative Mass Data -- utilizes data as grams of substance

Determination of Molecular Formula

$$(\text{empirical formula})_x = \text{molecular formula} \quad x = \frac{\text{molecular mass}}{\text{empirical formula mass}}$$

Example 1: A compound of carbon and hydrogen contains 92.3 % C and has a molecular mass of 78.1 amu. Determine its molecular formula.

$$C: 92.3 \% \Rightarrow 92.3 \text{ g} \times \frac{1 \text{ mol}}{12.0 \text{ g}} = 7.69 \text{ mol}$$

$$H: 7.7 \% \Rightarrow 7.7 \text{ g} \times \frac{1 \text{ mol}}{1.01 \text{ g}} = 7.62 \text{ mol}$$

$$\text{Then: } C: 7.69 \text{ mol} \div 7.62 = 1 \quad \text{and} \quad H: 7.62 \text{ mol} \div 7.62 = 1 \quad \text{So... CH}$$

$$\text{But... molecular mass is 78.1 amu} \quad \text{So... } x = \frac{78.1 \text{ amu}}{\text{formula mass}} = \frac{78.1 \text{ amu}}{13.0 \text{ amu}} = 6.00$$

$$\text{Finally... } (\text{CH})_x = (\text{CH})_6 = \text{C}_6\text{H}_6$$

Example 2: Determine the molecular formula of a compound of 43.6% phosphorus and 56.4%.

$$P: 43.6 \% \Rightarrow 43.6 \text{ g} \times \frac{1 \text{ mol}}{31.0 \text{ g}} = 1.41 \text{ mol}$$

$$O: 56.4 \% \Rightarrow 56.4 \text{ g} \times \frac{1 \text{ mol}}{16.0 \text{ g}} = 3.52 \text{ mol}$$

$$\text{Then: } P: 1.41 \text{ mol} \div 1.41 = 1 \quad \text{and} \quad O: 3.52 \text{ mol} \div 1.41 = 2.5$$

Since the ratios are not integer (almost integers) then they must be multiplied by a common factor that will give an integer.

$$\text{So... } P: 1 \times 2 = 2 \quad \text{and} \quad O: 2.5 \times 2 = 5 \quad \text{Therefore... P}_2\text{O}_5$$

Types of Equation Based Calculations

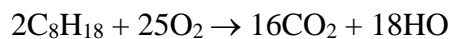
Mole to Mole
Mole to Mass
Mass to Mole
Mass to Mass

Procedure

- Write a balanced chemical equation
- Determine what is given and what is to be determined
- Determine the molar ratios
- Use dimensional analysis to:
 - convert mass to moles
 - compare moles
 - convert moles to mass

An Example: What mass of oxygen gas, O_2 , from the air is consumed in the combustion of 702 g (1 L) of octane, C_8H_{18} , one of the principal components of gasoline?

702 g x g

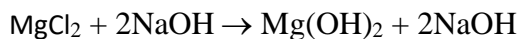


2 mol 25 mol

$$x \text{ g } O_2 = 702 \text{ g } C_8H_{18} \times \frac{1 \text{ mol } C_8H_{18}}{114.23 \text{ g } C_8H_{18}} \times \frac{25 \text{ mol } O_2}{2 \text{ mol } C_8H_{18}} \times \frac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = 2.46 \times 10^3 \text{ g } O_2$$

Another Example: What mass of sodium hydroxide, NaOH, would be required to produce 16 g of the antacid milk of magnesia [magnesium hydroxide, Mg(OH)₂] by the reaction of magnesium chloride, MgCl₂, with NaOH?

$$\boxed{x \text{ g}} \quad \boxed{16 \text{ g}}$$



$$\boxed{2 \text{ mol}} \quad \boxed{1 \text{ mol}}$$

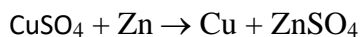
$$x \text{ g NaOH} = 16 \text{ g Mg(OH)}_2 \times \frac{1 \text{ mol Mg(OH)}_2}{58.3 \text{ g Mg(OH)}_2} \times \frac{2 \text{ mol NaOH}}{1 \text{ mol Mg(OH)}_2} \times \frac{40.0 \text{ g NaOH}}{1 \text{ mol NaOH}} = 22 \text{ g NaOH}$$

Percentage Yield

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

A Percent Yield Example: A general chemistry student, preparing copper metal by the reaction of 1.274 g of copper (II) sulfate with zinc metal, obtained a yield of 0.392 g of copper. What was the percent yield?

$$\boxed{1.276 \text{ g}} \quad \boxed{x \text{ g}}$$



$$\boxed{1 \text{ mol}} \quad \boxed{1 \text{ mol}}$$

$$x \text{ g Cu} = 1.274 \text{ g Cu(SO)}_4 \times \frac{1 \text{ mol Cu(SO)}_4}{159.6 \text{ g Cu(SO)}_4} \times \frac{1 \text{ mol Cu}}{1 \text{ mol Cu(SO)}_4} \times \frac{63.54 \text{ g Cu}}{1 \text{ mol Cu}} = 0.5072 \text{ g Cu}$$

Since there are 0.5072 g Cu, % yield can now be calculated from the formula

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% = \frac{0.392 \text{ g}}{0.5072 \text{ g}} \times 100\% = 77.3\%$$

Limiting Reagents

- Calculate a mass to mass stoichiometric problem using one of the two givens.
- Calculate the same problem, but using the second of the two givens.
- Determine which one limits the other
- This is the limiting reagent.

Reactions with Limiting Amounts of Reactants

- Most reactions do not use exactly the right proportions of reactants.
- Many reactions use an excess amount of one reactant.
- Whenever the ratios of reactant molecules used in an experiment are different from those given by the coefficients of the balanced equation, a surplus of one reactant remains.
- The extent to which a chemical reaction takes place depends on the reactant that is present in the limiting amount – The Limiting Reactant

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