Lecture Notes: Chemical Equations and Stoichiometry

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Determining Empirical and Molecular Formulas

- **Empirical Formula**: representation that shows the ratio of elements present in a compound as the smallest set of whole number ratios that match elemental analysis.

Problem 1: Determining Molecular Formula From Empirical Formula

The empirical formula of hexane is C_3H_7. Its molecular mass is 86.2 amu. What is the molecular formula of hexane?

- To determine empirical formula from elemental analysis data:

  1) Divide each mass percentage by the molar mass of the element. This gives you the number of moles of each element in a 100g sample (100g is assumed to make the math easier.)
  2) Divide the results of Step 1 by whichever number of moles is the smallest. This maintains the mole ratios from Step 1 but bases them on one mole of the least abundant element.
  3) If some results from Step 2 are far from integers multiply through by a common factor that converts all molar amounts to integers or near-integers.
  4) Round off each molar number to the nearest integer.

Problem 2: Determining Empirical and Molecular Formula From Mass Percents

An unknown compound contains only carbon, hydrogen and oxygen. Elemental analysis reveals that the compound is 38.7% carbon and 9.75% hydrogen. Mass spectroscopy reveals that the molecular mass is 62.07 g/mol. What is the molecular formula for this unknown compound?

Problem 3: Dealing with Non-Integer Ratios

Cadaverine, a foul smelling substance produced by the action of bacteria on meat, contains 58.55% C, 13.81% H, and 27.40% N by mass; its molar mass is 102.2 g/mol. Determine the empirical and molecular formulas of Cadaverine.

Chemical Equations

- **Chemical Equation**: a symbolic representation of a chemical reaction that details the species that are consumed and produced.
  - Reactant: a substance that is consumed in the course of a chemical reaction
  - Product: a substance that is produced in the course of a chemical reaction

$$H_2 + Cl_2 \longrightarrow HCl \tag{1}$$

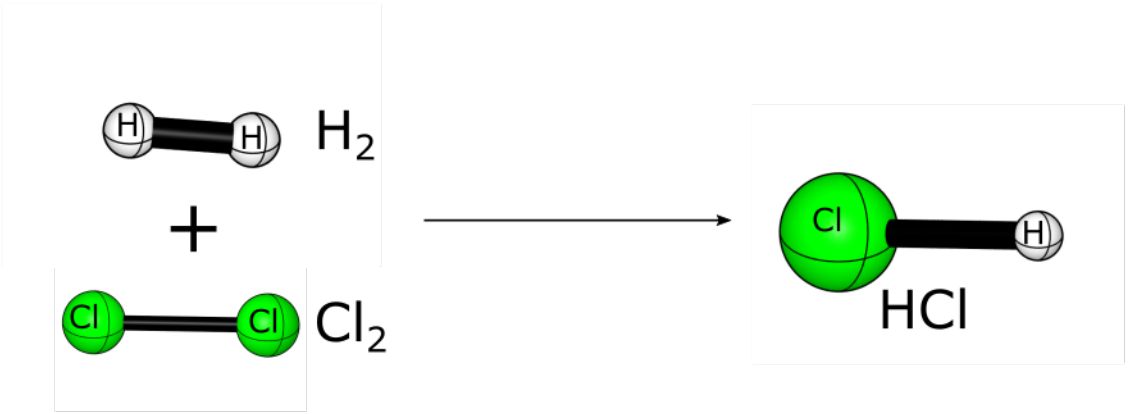

Figure 1: Ball and Stick representation of the chemical reaction in which Cl_2 and H_2 are consumed to form HCl.

Table 1: Number of reactants and products in the above reaction

Reactants	Products
2 Cl	1 Cl
2 H	1 H

Question 1: By now you know and have identified that the above reaction is *unbalanced*...but so what? What fundamental law of chemistry says that we must balance chemical equations?

- **Stoichiometry**: chemical arithmetic, dealing with the quantities of materials consumed and produced in chemical reactions.
  - Stoichiometric Coefficient: indication of the relative number of reactants and products in a balanced chemical reaction.

$$H_2 + Cl_2 \longrightarrow HCl \tag{2}$$

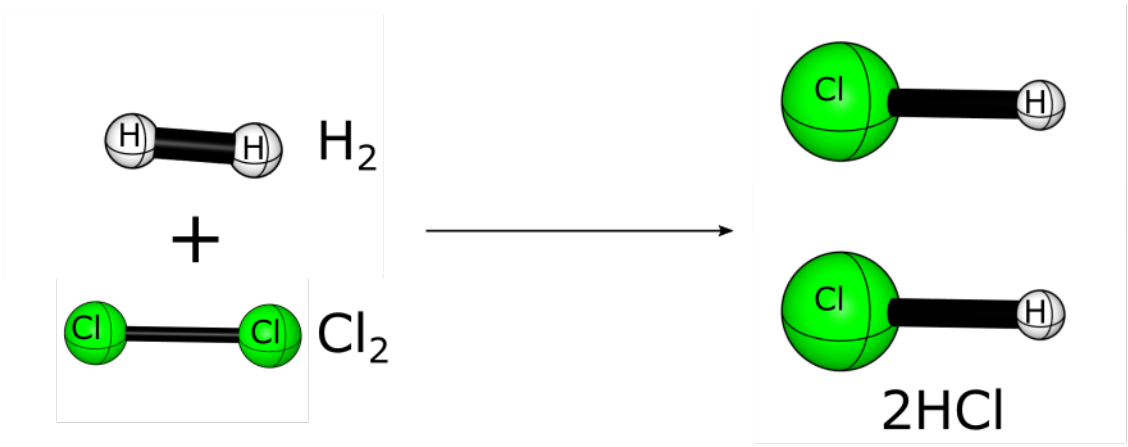

Figure 2: Ball and Stick representation of the chemical reaction in which Cl_2 and H_2 are consumed to form HCl. A second HCl molecule is added to the reactants to represent a balanced chemical reaction. The stoichiometric coefficient 2 is added to denote this balance.

Example Chemical Equation:

$$CH_4(g) + 2\,O_2(g) \longrightarrow CO_2(g) + 2\,H_2O(g) \tag{3}$$

The above chemical equation is a balanced representation of the gas phase reaction between methane and oxygen gas. The equation is balanced and the physical states of the species are indicated in parenthesis.

Table 2: Physical states often denoted in chemical equations

State	Symbol
Solid	(s)
Liquid	(l)
Gas	(g)
Dissolved in water (in aqueous solution)	(aq)

Problem 4: Introductory Example to Balancing Chemical Equations

Lead hydrogen arsenate, an inorganic insecticide used against the potato beetle, is a product of the following reaction:

$$Pb(NO_3)_2(aq) + H_3AsO_4(aq) \longrightarrow PbHAsO_4(s) + HNO_3(aq) \tag{4}$$

Problem 5: An Algebriac Approach to Balancing Chemical Equations

At 1000°C, ammonia gas, $NH_3(g)$, reacts with oxygen gas (O_2) to form gaseous nitric oxide, $NO(g)$, and water vapor (H_2O). This reaction is the first step in the commercial production of nitric acid by the Ostwald process. Balance the equation for this reaction.

Stoichiometric Calculations

- Stoichiometric calculations concern the use of BALANCED chemical equations in order to determine the masses of reacting species.
- **Mole Ratio**: ratio between the amount of moles of any two compounds invloved in a chemical reaction. Used as a conversion factor between different compounds in the reaction process.

Problem 6: Making Use of Stoichiometry

Phosphorus trichloride is produced from the reaction solid phosphorus and chlorine gas:

$$P_4 + Cl_2 \longrightarrow PCl_3 \tag{5}$$

a) Balance the chemical equation?

b) What mass of phosphorus trichloride can be prepared from 75.0 g of phosphorus?

c) What mass of chlorine will be consumed in the reaction?