Saman

CHM 101

CHEMICAL EQUATIONS AND STOICHIOMETRY

Chemical formulas: are a way of expressing information about the proportions of atoms that constitute a compound using: element symbols, numerical subscripts, and other symbols (e.g., dishes as in structural formulas and parentheses such as (l) for liquid, (s) for solid, (g) for gases and (aq) for substances dissolved in water or aqueous solutions. Example,

$$2Na_{(s)} + 2H_2O_{(l)} \longrightarrow 2NaOH_{(aq)} + H_{2(g)}$$

Types of Chemical Formulas

Empirical formula– smallest whole number ratio of numbers of the atoms in a molecule

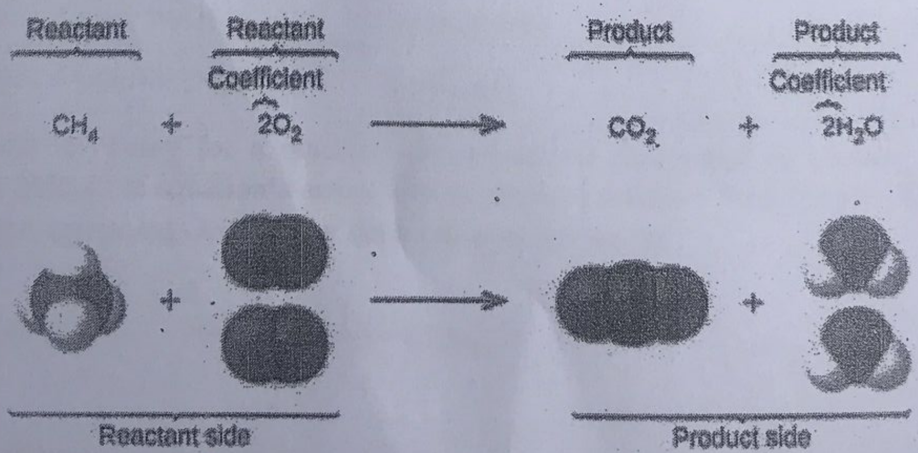
Molecular formula– actual number of atoms in a molecule.

Structural formula– chemical formula showing how atoms are bonded together in a molecule.

Fundamental aspects of any chemical equation.

1. The substances undergoing reaction are called reactants, and their formulas are placed on the left side of the equation.
2. The substances generated by the reaction are called products, and their formulas are placed on the right side of the equation.
3. Plus signs (+) separate individual reactant and product formulas, and an arrow (⟶) separates the reactant and product (left and right) sides of the equation.
4. The relative numbers of reactant and product species are represented by coefficients (numbers placed immediately to the left of each formula). A coefficient of 1 is typically omitted.

The reaction between methane and oxygen to yield carbon dioxide in water may be represented by a chemical equation using formulas as follows:



Writing and Balancing of Chemical Equations

A balanced chemical equation often may be derived from a qualitative description of some chemical reaction by a fairly simple approach known as balancing by inspection. Consider as an example the decomposition of water to yield molecular hydrogen and oxygen. This process is represented qualitatively by an unbalanced chemical equation:

$$H_2O \longrightarrow H_2 + O_2 \qquad \text{(unbalanced or skeletal equation)}$$

Comparing the number of H and O atoms on either side of this equation confirms its imbalance.

The numbers of H atoms on the reactant and product sides of the equation are equal, but the numbers of O atoms are not. To achieve balance, the coefficients of the equation may be changed as needed. Keep in mind, of course, that the formula subscripts define, in part, the identity of the substance, and so these cannot be changed without altering the qualitative meaning of the equation. For example, changing the reactant formula from H_2O to H_2O_2 would yield balance in the number of atoms, but doing so also changes the reactant's identity (it's now hydrogen peroxide and not water). The O atom balance may be achieved by changing the coefficient for H_2O to 2.

$$2H_2O \longrightarrow H_2 + O_2 \qquad \text{(unbalanced)}$$

The H atom balance was upset by this change, but it is easily reestablished by changing the coefficient for the H_2 product to 2.

$$2H_2O \longrightarrow 2H_2 + O_2 \qquad \text{(balanced)}$$

Example 2:

Write a balanced equation for the reaction of molecular nitrogen (N_2) and oxygen (O_2) to form dinitrogen pentoxide.

Solution:

First, write the unbalanced equation, then balance it.

$$N_2 + O_2 \longrightarrow N_2O_5 \qquad \text{(unbalanced)}$$

$$2N_2 + 5O_2 \longrightarrow 2N_2O_5 \qquad \text{(balanced)}$$

Special conditions necessary for a reaction are sometimes designated by writing a word or symbol above or below the equation's arrow. For example, a reaction carried out by heating may be indicated by the uppercase Greek letter delta (Δ) over the arrow.

$$CaCO_{3(s)} \xrightarrow{\Delta} CaO_{(s)} + CO_{2(g)}$$

Exercise

1. Balance the following equations:
   i. $P_{4(s)} + O_{2(g)} \longrightarrow P_4O_{10(s)}$
   ii. $Fe_{(s)} + H_2O_{(l)} \longrightarrow Fe_3O_{4(s)} + H_{2(g)}$
2. Write a balanced molecular equation describing each of the following chemical reactions:

Example 1: A compound is found to contain 56% carbon, 7% hydrogen, and 37% oxygen. What is the empirical formula for this compound? The molecular weight for this compound is 86.14 g/mol. What is the molecular formula? (take, C=12.01 g/mol, H=1.01 g/mol, O=16.00)

Solution:

First, assume exactly 100 g of the compound is present. This allows you to exchange percentages with grams.

C	–	56%	$\rightarrow$	56	g
H	–	7%	$\rightarrow$	7	g
O	–	37%	$\rightarrow$	37	g

Second, convert masses to moles

C	–	(56/12.01)	=	4.66 moles
H	–	(7/1.01)	=	6.93 moles
O	–	(37/16.00)	=	2.31 moles

Third, determine the lowest whole-number ratios; divide the moles of each element by the lowest mole amount

C	–	(4.66/2.31)	=	2.02	$\rightarrow$	2
H	–	(6.93/2.31)	=	3.00	$\rightarrow$	3
O	–	(2.31/2.31)	=	1.00	$\rightarrow$	1

Write the empirical formula from the results: C_2H_3O

To determine the molecular formula from the empirical formula, follow these steps:

Calculate the weight from the empirical formula (multiply atoms of each element with the elements molar mass and add them up)

2 carbon atoms x 12.01 g = 24.02 g

3 hydrogen atoms x 1.01 g = 3.03 g

1 oxygen atom x 16.00 g = 16.00 g

Total: $24.02\ g + 3.03\ g + 16.00\ g = 43.05\ g$

Divide the molecular weight by the weight determined from the empirical formula to find the scaling factor.

$86.14/43.05 = 2.00$ Scaling factor is 2

Using the scaling factor determine the molecular formula. $C_4H_6O_2$

Using this stoichiometric factor, the provided molar amount of propane, and Avogadro's number,

$$\frac{0.75 \text{ mol } C_3H_8 \times 3 \text{ mol } CO_2}{1 \text{ mol } C_3H_8} = 2.25 \text{ mol } CO_2 \times 6.022\times10^{23} = \quad \mathbf{1.4\times10^{24}\ CO_2\ molecules}$$

Stoichiometric Mass-Mass Problems

Example 4:

What mass of sodium hydroxide, NaOH, would be required to produce 16 g of the antacid milk of magnesium hydroxide, $Mg(OH)_2$ by the following reaction?

$$MgCl_{2(aq)} + 2NaOH_{(aq)} \longrightarrow Mg(OH)_{2(s)} + 2NaCl_{(aq)}$$

(Take NaOH = 40 g/mol, $Mg(OH)_2$ = 58.3 g/mol)

Solution:

40×2 g/mol $\longrightarrow$ 58.3 g/mol

X g $\longrightarrow$ 16 g

Cross-multiply,

$$X = \frac{16 \times 80}{58.3} = \mathbf{22\ g}$$

Exercise:

4.0 g of magnesium ribbon was burnt in excess of oxygen. What is the mass what is the mass of magnesium oxide that will be formed? (take Mg =24 g/mol, O = 16 g/mol)

Stoichiometric Mass-Volume Problems

Example 5:

What volume of oxygen at S.T.P. can be produced by 6.125 g of potassium chlorate according to the reaction: $2KClO_3 \longrightarrow 2KCl + 3O_2$? ($KClO_3$ = 122.5 g/mol)

Solution:

$2KClO_3$	$\longrightarrow$	$2KCl$ +	$3O_2$
2 mol		2 mol	3 mol
2 x 122.5 g/mol	$\longrightarrow$		3 x 22.4 L
6.125 g	$\longrightarrow$		?

Therefore, volume of oxygen = $\frac{6.125 \times 3 \times 22.4}{2 \times 122.5}$ = 1.68 L at S.T.P.

Determination of Empirical and Molecular Formulas from Percentage Composition

ii. Gaseous butane, C_4H_{10}, reacts with diatomic oxygen gas to yield gaseous carbon dioxide and water vapor.

iii. Water vapor reacts with sodium metal to produce solid sodium hydroxide and hydrogen gas.

Stoichiometry

Stoichiometry involves using relationships between elements, compounds, chemical formulas, and chemical reactions to acquire quantitative data. Some categories of stoichiometry problems are as follows:

Stoichiometric Mole–Mole Problems

Example 1: How many moles of HCl are needed to react with 0.82 moles of Al according to the equation below?

$Al + HCl \rightarrow AlCl_3 + H_2$ (Take RAM of Al=26.98, H=1.01 and Cl=35.45)

Solution:

Step 1: Balance the chemical equation

$$2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$$

Step 2: Calculate the moles of the substance you are told to find using mole ratios.

If 6 moles of HCl are needed to react with 2 moles Al, then,

X moles of HCl will be needed to react with 0.82 moles of Al.

$$X = \frac{6 \times 0.82}{2} = \mathbf{2.46\ moles}$$

Example 2:
How many moles of I_2 are required to react with 0.429 mol of Al according to the following equation? $2Al + 3I_2 \longrightarrow 2AlI_3$

Number of Product Molecules Generated by a Reaction

Example 3:

How many carbon dioxide molecules are produced when 0.75 mol of propane is combusted according to this equation?

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

Solution:

The approach here is the same as for Example 1, though the absolute number of molecules is requested, not the number of moles of molecules. This will simply require use of the moles-to-numbers conversion factor, Avogadro's number.

The balanced equation shows that carbon dioxide is produced from propane in a 3:1 ratio.