BACKGROUND

Chemical equations are used to represent chemical reactions between chemical substances. A chemical equation shows the chemical formulas and the amounts of the reacting substances (reactants) and the chemical formulas and the amounts of the substances formed (products).

Consider the equation:

$$2H_2 + O_2 \rightarrow 2H_2O.$$

The number written by the side of each substance represents the number of moles of the substance involved in the reaction. Thus, 2 moles of H_2 react with 1mole of O_2 to form 2 moles of H_2O.

Reaction stoichiometry deals with the quantitative relationships between substances in chemical reactions. As a general rule, we make reference to the proportion established in the balanced equation of the reaction.

Let us consider the general requirements for handling calculations based on chemical equations.

MOLAR MASS AND NUMBER OF MOLES

The general method for finding the molar mass of a substance was explained in the first part of this topic **(Get and study STOICHIOMETRY 1: CHEMICAL FORMULAS AND COMPOSITION STOICHIOMETRY by Temple C. Eke)**.

On the other hand, the method of finding the number of moles of a substance depends on the physical state of the substance.

Case 1: Solids and Gases

The number of moles of a pure solid or gas is given by the ratio of its given mass to its molar mass.

$$\text{i.e} \quad \text{Number of moles} = \frac{\text{given mass}}{\text{molar mass}}.$$

In symbols,

$$n = \frac{m}{M}.$$

Case 2: Aqueous Solutions

The number of moles of a substance in an aqueous solution can be found if the molar concentration (C) and the volume (V) of the solution are known.

The molar concentration of a solution is the number of moles of the solute per dm^3 (per unit volume) of the solution.

Mathematically,

Example 11: Solution Stoichiometry: Mole-Mass Relationship

$21.6\ \mathrm{cm^3}$ of H_2SO_4 completely reacted with $25.0\ \mathrm{cm^3}$ of $0.5\ \mathrm{M\ NaOH}$ according to the equation:

$H_2SO_4 \ + \ 2NaOH \ \rightarrow \ Na_2SO_4 \ + \ H_2O$. Calculate the:

(a) molar concentration of H_2SO_4.

(b) mass of Na_2SO_4 produced.

$[\mathrm{O} = 16,\ \mathrm{Na},\ \mathrm{S} = 32]$

Solution:

Volume of $\mathrm{NaOH} = 25\ \mathrm{cm^3} = 0.025\ \mathrm{dm^3}$

Molar concentration of $\mathrm{NaOH} = 0.5\ \mathrm{M}$

$\text{Number of moles} = \text{ molar concentration} \times \text{ volume } (\mathrm{dm^3})$

$\text{Number of moles of NaOH} = \ 0.5 \times 0.025 = 0.0125 \text{ mole}$

Volume of $H_2SO_4 \ = 21.6\ \mathrm{cm^3} = 0.0216\ \mathrm{dm^3}$

Let the molar concentration of $H_2SO_4 \ = x$

$\text{Number of moles} \ = \ \text{molar concentration} \ \times \ \text{volume } (\mathrm{dm^3})$

$\text{Number of moles of } H_2SO_4 = 0.0216x \text{ mole}$

From the equation of the reaction,

$H_2SO_4 \ + \ 2NaOH \ \rightarrow \ Na_2SO_4 \ + \ H_2O$,

$2 \text{ moles of NaOH reacts with 1 mole of } H_2SO_4.$

By simple proportion,

$0.0025 \text{ moles of NaOH will react with } \frac{1}{2} \times 0.0125 \text{ mole of } H_2SO_4.$

$= 0.00625 \text{ mole of } H_2SO_4.$

Since the required number of moles of $H_2SO_4 \ = 0.0216x$, we have

$$0.0216x \ = 0.00625$$

$$\therefore \ x = \frac{0.00625}{0.0216} = 0.289 \text{ mol/dm}^3.$$

(b) The mass of Na_2SO_4 produced.

Molar mass of $Na_2SO_4 = (23 \times 2) + 32 + (16 \times 4) = 142$.

From the equation of the reaction,

$H_2SO_4 \ + \ 2NaOH \ \rightarrow \ Na_2SO_4 \ + \ H_2O$,

$2 \text{ moles of NaOH produce 1 mole of } Na_2SO_4.$

Using the molar mass of Na_2SO_4,

$2 \text{ moles of NaOH produce 142 g of } Na_2SO_4.$

By simple proportion,

1 mole of C_6H_6 produces 1 mole of $C_6H_5NO_2$.

Using the molar masses,

78 g of C_6H_6 produces 123 g of $C_6H_5NO_2$.

By simple proportion,

$$13 \text{ g of } C_6H_6 \text{ will produce } \frac{123}{78} \times 13 \text{ g of } C_6H_5NO_2.$$

$$= 20.5 \text{ g of } C_6H_5NO_2.$$

Now, the theoretical yield $= 20.5$ g.

The actual yield $= 16.5$ g (given in the question).

$$\text{Percent yield} = \frac{\text{actual yield of product}}{\text{theoretical yield of product}} \times 100$$

$$\therefore \text{ Percent yield of } C_6H_5NO_2 = \frac{16.5}{20.5} \times 100$$

$$= 80.49\ \%$$

The significance of this is that the laboratory procedure used to produce Nitrobenzene according to the given reaction is $80.49\ \%$ efficient.

Example 18: Actual Yield from Percent Yield

Phosphorus (III) chloride reacts with Chlorine to form Phosphorus (V) chloride according to the equation:

$PCl_3 \ + \ Cl_2 \ \rightarrow \ PCl_5$.

If the percent yield of the reaction is $85.6\ \%$, calculate the mass of PCl_5 expected from the reaction of 20.0 g of PCl_3 with excess Chlorine.

[P $=31$, Cl $= 35.5$]

Solution:

The mass of PCl_5 expected is the actual yield.

Molar mass of PCl_3 $= 31 + (35.5 \times 3) = 137.5$.

Molar mass of PCl_5 $= 31 + (35.5 \times 5) = 208.5$.We calculate the mass of PCl_5 formed when 20.0 g of PCl_3 completely reacts with Chlorine, using the balanced equation of the reaction. This gives the theoretical yield.

From the balanced equation of the reaction:

$PCl_3 \ + \ Cl_2 \ \rightarrow \ PCl_5$,

1 mole of PCl_3 produces 1 mole of PCl_5.

Using the molar masses,

137.5 g of PCl_3 produces 208.5 g of PCl_5.

By simple proportion,

1 mole of CaO produces 1 mole of $Ca(OH)_2$.

Using the molar mass of $Ca(OH)_2$,

1 mole of CaO produces 74 g of $Ca(OH)_2$.

By simple proportion,

10 moles of CaO would produce (74×10) g of $Ca(OH)_2$.

$$= 740 \text{ g of } Ca(OH)_2$$

Example 22: Sequential Reactions: Double Evolution of CO_2

Carbon (IV)oxide, CO_2 is liberated on strong heating of Potassium trioxocarbonate (IV), $KHCO_3$ according to the equation:

$$2KHCO_3 \rightarrow K_2CO_3 + H_2O + CO_2.$$

The residue, K_2CO_3 reacts with Hydrochloric acid to liberate more CO_2 according to the equation:

$$K_2CO_3 + 2HCl \rightarrow 2KCl + H_2O + CO_2.$$

Using the given sequence of reactions, calculate the total volume of CO_2, measured at STP that can be obtained from 25 g of $KHCO_3$.

[H = 1, C = 12, O = 16, Cl = 35.5, K = 39, molar volume at STP = 22.4 dm^3]

Solution:

First, we find the volume of CO_2 liberated in the first reaction.

Given mass of $KHCO_3$ = 25 g.

Molar mass of $KHCO_3 = 39 + 1 + 12 + (16 \times 3) = 100.$

Molar mass of $K_2CO_3 = (39 \times 2) + 12 + (16 \times 3) = 138.$

The equation of the reaction is:

$$2KHCO_3 \rightarrow K_2CO_3 + H_2O + CO_2.$$

2 moles of $KHCO_3$ produces 1 mole of CO_2.

Using the molar mass of $KHCO_3$, and the molar volume,

(2×100) g of $KHCO_3$ produces 22.4 dm^3 of CO_2.

$\therefore$ (2×100) g of $KHCO_3$ produces 22.4 dm^3 of CO_2.

By simple proportion,

$$25 \text{ g of } KHCO_3 \text{ would produce } \frac{22.4}{200} \times 25 \text{ dm}^3 \text{ of } CO_2.$$

$$= 2.8 \text{ dm}^3 \text{ of } CO_2.$$

To calculate the volume of CO_2 produced in the second reaction, we must know the mass of K_2CO_3 formed from the first reaction.

Taking the first equation:

$$2KHCO_3 \rightarrow K_2CO_3 + H_2O + CO_2,$$

2 moles of $KHCO_3$ produced 1 mole of K_2CO_3.

SUMMARY OF PRINCIPLES.

You have learned:

1. The method of finding the number of moles of a substance depends on its physical state. The given mass, molar mass, molar concentration, and volume of a solution are usual parameters.

2. $1\ \mathrm{mole}$ of any gas at STP occupies a volume of $22.4\ \mathrm{dm}^3$ or $22400\mathrm{cm}^3$. This is known as the molar volume, V_m.

3. Calculations based on chemical reactions begin with the establishment of a stoichiometric relationship between the substance whose amount is given and the substance whose amount is to be found. The required amount is found by using a simple proportion.

4. The extent of any chemical reaction is dictated by the limiting reactant. Stoichiometric calculations are based on the limiting reactant.

5. The term percent yield is used to indicate how much of a desired product is obtained when a chemical reaction is carried out in the laboratory.

6. For stoichiometric calculations involving sequential reactions, the substance common to the given reactions forms the basis of such calculations. It serves to link the reactions.