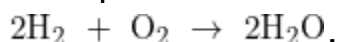


BACKGROUND

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:



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 1 mole 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.

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

In symbols,

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

Case 2: Aqueous Solutions

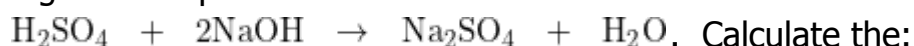
The number of moles of a substance in an aqueous solution can be found if the molar concentration (C) and the volume (V) of the solution are known.

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 cm³ of H₂SO₄ completely reacted with 25.0 cm³ of 0.5 M NaOH according to the equation:



(a) molar concentration of H₂SO₄.

(b) mass of Na₂SO₄ produced.

[O = 16, Na, S = 32]

Solution:

Volume of NaOH = 25 cm³ = 0.025 dm³

Molar concentration of NaOH = 0.5 M

Number of moles = molar concentration × volume (dm³)

Number of moles of NaOH = 0.5 × 0.025 = 0.0125 mole

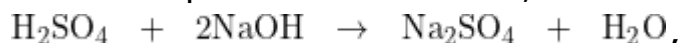
Volume of H₂SO₄ = 21.6 cm³ = 0.0216 dm³

Let the molar concentration of H₂SO₄ = x

Number of moles = molar concentration × volume (dm³)

Number of moles of H₂SO₄ = 0.0216 x mole

From the equation of the reaction,



2 moles of NaOH reacts with 1 mole of H₂SO₄.

By simple proportion,

0.0025 moles of NaOH will react with $\frac{1}{2} \times 0.0125$ mole of H₂SO₄.
= 0.00625 mole of H₂SO₄.

Since the required number of moles of H₂SO₄ = 0.0216 x , we have

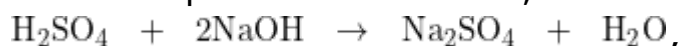
$$0.0216x = 0.00625$$

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

(b) The mass of Na₂SO₄ produced.

Molar mass of Na₂SO₄ = (23 × 2) + 32 + (16 × 4) = 142.

From the equation of the reaction,



2 moles of NaOH produce 1 mole of Na₂SO₄.

Using the molar mass of Na₂SO₄,

2 moles of NaOH produce 142 g of Na₂SO₄.

By simple proportion,

1 mole of C_6H_6 produces 1 mole of $\text{C}_6\text{H}_5\text{NO}_2$.

Using the molar masses,

78 g of C_6H_6 produces 123 g of $\text{C}_6\text{H}_5\text{NO}_2$.

By simple proportion,

$$\begin{aligned} 13 \text{ g of } \text{C}_6\text{H}_6 \text{ will produce } & \frac{123}{78} \times 13 \text{ g of } \text{C}_6\text{H}_5\text{NO}_2. \\ & = 20.5 \text{ g of } \text{C}_6\text{H}_5\text{NO}_2. \end{aligned}$$

Now, the theoretical yield = 20.5 g.

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

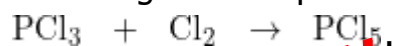
$$\text{Percent yield} = \frac{\text{actual yield of product}}{\text{theoretical yield of product}} \times 100$$

$$\begin{aligned} \therefore \text{Percent yield of } \text{C}_6\text{H}_5\text{NO}_2 &= \frac{16.5}{20.5} \times 100 \\ &= 80.49 \% \end{aligned}$$

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:



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]

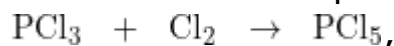
Solution:

The mass of PCl_5 expected is the actual yield.

Molar mass of $\text{PCl}_3 = 31 + (35.5 \times 3) = 137.5$.

Molar mass of $\text{PCl}_5 = 31 + (35.5 \times 5) = 208.5$. 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:



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.

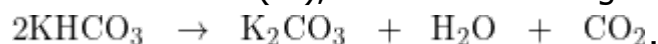
By simple proportion,

10 moles of CaO would produce (74 × 10) g of Ca(OH)₂.

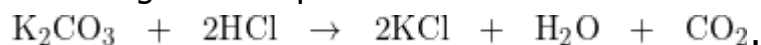
$$= 740 \text{ g of Ca(OH)}_2$$

Example 22: Sequential Reactions: Double Evolution of CO₂

Carbon (IV)oxide, CO₂ is liberated on strong heating of Potassium trioxocarbonate (IV), KHCO₃ according to the equation:



The residue, K₂CO₃ reacts with Hydrochloric acid to liberate more CO₂ according to the equation:



Using the given sequence of reactions, calculate the total volume of CO₂, measured at STP that can be obtained from 25 g of KHCO₃.

[H = 1, C = 12, O = 16, Cl = 35.5, K = 39, molar volume at STP = 22.4 dm³]

Solution:

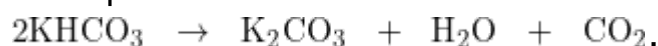
First, we find the volume of CO₂ liberated in the first reaction.

Given mass of KHCO₃ = 25 g

Molar mass of KHCO₃ = 39 + 1 + 12 + (16 × 3) = 100.

Molar mass of K₂CO₃ = 39 × 2 + 12 + (16 × 3) = 138.

The equation of the reaction is:



2 moles of KHCO₃ produces 1 mole of CO₂.

Using the molar mass of KHCO₃, and the molar volume,

(2 × 100) g of KHCO₃ produces 22.4 dm³ of CO₂.

∴ (2 × 100) g of KHCO₃ produces 22.4 dm³ of CO₂.

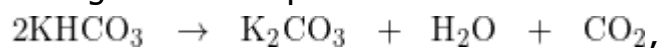
By simple proportion,

25 g of KHCO₃ would produce $\frac{22.4}{200} \times 25$ dm³ of CO₂.

$$= 2.8 \text{ dm}^3 \text{ of CO}_2.$$

To calculate the volume of CO₂ produced in the second reaction, we must know the mass of K₂CO₃ formed from the first reaction.

Taking the first equation:



2 moles of KHCO₃ produced 1 mole of K₂CO₃.

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 mole of any gas at STP occupies a volume of 22.4 dm^3 or 22400 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.