CHAPTER 15

Stoichiometry

Student Learning Outcomes

After studying this chapter, students will be able to:

- Use the molar gas volume, 24 dm^3 at room temperature and pressure, in calculations involving gases.
- Define concentration, use both g/dm^3 and mol/dm^3, and convert between them.
- Calculate stoichiometric relationships between substances relationships (specifically:
- reacting masses, limiting reactants,
- volume of gasses at R.T.P.,
- volumes of solution and concentrations of solutions in g/dm^3 or mol/dm^3, including conversion between cm^3 and dm^3)
- Calculate concentration of a solution in a titration using empirical data
- Calculate empirical formula and molecular formula from appropriate data
- Calculate percentage yield, percentage composition by mass and percentage purity from appropriate data.

Subjective Type Questions

Long Questions prepared in the light of new Examination Techniques
(Knowledge, Understanding, Application, Analytical & Conceptual)

15.1 Molar Volume

15.2 Concentration of a Solution

15.3 Calculate the concentration of a solution in titration using empirical data

Q.1: What is molar volume. Why the concept of molar volume is useful for us?

Ans. Molar volume:

It has been found that one mole of all gases occupies a volume of 24 dm^3 at RTP. This is called molar volume.

It is worth nothing that one mole of each gas contains the same number of molecules, occupies the same volume and at the same time has different mass.

In other words the masses and the sizes of the molecules of gases do not change the volume occupied by them.

Variation in volume of a gas:

The volume of a gas varies with changes in pressure and temperature.

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Room temperature and pressure: In order to compare the volumes occupied by different gases, we must adopt a set of standard conditions of temperature and pressure called room temperature and pressure (RTP).

Measurement of volumes of gases at room temperature:

The temperature of 25 °C (298.15k) and one atmosphere (760 torr) are used as standard conditions of temperature and pressure for measurement of volumes of gases at room temperature.

Usefulness of molar volume: The concept of molar volume is useful because it enables us to calculate the number of moles or masses of the gases if we know their volumes.

Q.2: What is concentration of a solution. Identify the specific units used for it.

Ans. Concentration of a solution:

Concentration of a solution is a measure of the amount that has been dissolved in a given amount of solution or solvent.

The amount of solute dissolved is expressed either in grams or in moles.

The quantity of solution is expressed in terms of its volume, dm^3 or cm^3.

Units:
- The units used for the mass /volume concentration is g/dm^3.
- The units used for the molar concentration is mol/dm^3.

Example: Calculate concentration of a solution in g/dm^3 which contains 20 g of sodium chloride dissolved in 0.2 dm^3 of water.

Solution:

Mass of solute in gram = 20 g

Volume of sodium in dm^3 = 0.2

Concentration of solution = ?

$$\text{Concentration} = \frac{\text{Mass of solute in gram}}{\text{Volume of solution in } dm^3}$$

$$= \frac{20}{0.2} = 100 \text{ g/ } dm^3$$

Q.3: How the concentration of a solution in titration is calculated using empirical data?

Ans. Titration:

The concentration of a solution can be determined by titrating it with a solution of known concentration till the end point is reached.

Things to know for titration: For the purpose, you need to know:
- The balanced chemical equation for the reaction between the two solutions.
- The volumes of the two solutions used during the titration.
- The concentration of the other solution.

Example: A titration is performed between NaOH and HCl till the end point is reached. 15 cm^3 of solution of sodium hydroxide having a molar concentration 0.5 mol/dm^3 is used to neutralize 23 cm^3 of HCl. Find out the concentration of HCl in mol/dm^3.

Solution:

- **Balanced chemical equation:**

  Balanced chemical equation for this reaction:

  $NaOH_{(aq)} + HCl_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$

- **Conversion of volume of NaOH:**

  Convert the volume of NaOH used to dm^3. volume of the solution $= \frac{15}{1000} = 0.015\ dm^3$

- **Conversion of volume of HCℓ:**

  Convert the volume of HCl required to neutralize NaOH solution in dm^3.

  Volume of HCl required $= \frac{23}{1000} = 0.023\ dm^3$.

- **No of moles of NaOH:**

  No of moles of NaOH = molar concentration × volume

  $= 0.5\ mol/dm^3 \times 0.015\ dm^3$

  $= 0.0075$

- **According to the balanced chemical equation:**

  1 mol of NaOH has reacted with 1 mol of HCl.

- **No of moles of HCl:**

  No of moles of HCl = 0.0075

- **Concentration of HCl solution:**

  Concentration of HCl solution $= \frac{\text{No.of moles}}{\text{Volume in } dm^3} = \frac{0.0075}{0.023}$

  $= 0.326\ mol/dm^3$

  Therefore, the molar concentration of the HCl solution is $0.326\ mol/dm^3$.

15.4 Percentage Composition by Mass, Empirical formula and Molecular formula

15.5 Empirical formula

15.6 Limiting Reactant

Q.4: What is percentage composition of a compound. How is it useful in Stoichiometry?

Ans. Percentage composition of a compound:

Percentage composition of a compound refers to the percentage mass of each element present in the compound.

Percentage of an Element:

The percentage of an element in a compound is the number of grams of that element present in 100 grams of the compound.

Determining percentage of an Element:

The percentage of an element can be determined by applying the following

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$$\text{Percentage of an element} = \frac{\text{Mass of the element in the compound}}{\text{Formula mass of the compound}} \times 100$$

Usefulness of percentage composition: Percentage composition is useful concept to determine the purity of a compound and its empirical and molecular formula.

Determining percentage composition of a compound:

Percentage composition of a compound can be determined both theoretically as well as by performing quantitative analysis.

Q.5: Write a note on empirical formula.

Ans. Empirical formula:

The formula which shows the simplest whole number ratio of atoms percent in a compound is called empirical formula.

Example: Empirical formula of:

- Hydrogen peroxide (H_2O_2) is HO
- Water (H_2O) is H_2O
- Benzene (C_6H_6) is CH.

Empirical formula of ionic compounds: All the ionic compounds are represented by their empirical formulae. These formulae show the simplest ratio present between their ions.

Sodium chloride (NaCl): The formula of sodium chloride (NaCl) represents the simplest ratio between sodium and chloride ions present in it.

Calcium chloride ($CaCl_2$): Similarly the formula of calcium chloride ($CaCl_2$) shows the ratio present between calcium and chloride ions.

Compounds having same empirical formula:

Since an empirical formula does not tell us about the actual number of atoms present in that compound rather it represents the simplest ratio of minimum ratio between atoms, it is possible that some compounds may have same empirical formula.

Examples:

- Both acetylene (C_2H_2) and benzene (C_6H6) have some empirical formula CH.
- Acetic acid (CH_3COOH) and glucose ($C_6H_{12}O_6$) also have same empirical formula CH_2O.

Q.6: How can the empirical formula of a compound be calculated?

Ans. Empirical formula of a compound can be calculated by following steps:

(i) Determine the percentage composition of the compound.

(ii) Find out the number of moles of each element. This is done by dividing the mass of each element (percentage of element) by its atomic mass.

(iii) Determine the atomic ratio of each element in the compound. This ratio can be found by dividing the number of moles of each element by the smallest number of moles.

(iv) If the atomic ratio obtained is simple whole number, it gives the empirical formula.

otherwise multiply this ratio with suitable digit to get the whole number ratio.

(v) Use this whole number ratio as a subscript for the elements to get the empirical formula.

Example: The percentage composition of a compound shows it to contain 25.26% Mg and 74.74% Chlorine. Find out its empirical formula.

Solution:

Change the percentage of elements to grams:

Mg = 25.26 % = 25.26 g

Cl = 74.74 % = 74.74 g

No. of moles of each element:

$$Mg = \frac{25.26}{24} = 1.05$$

$$Cl = \frac{74.74}{35.5} = 2.10$$

Atomic ratio of each element:

$$Mg = \frac{1.05}{1.05} = 1$$

$$Cl = \frac{2.10}{1.05} = 2$$

The empirical formula of magnesium chloride is $MgCl_2$.

Q.7: Define molecular formula. How is it calculated?

Ans. Molecular formula:

Molecular formula of an element or a compound represents the actual number of atoms present in the molecule of these substances.

Examples: Water, hydrogen peroxide, ethylene and sulphur have molecular formulae H_2O, H_2O_2, C_2H_4 and S_8 respectively.

Calculation of molecular formula: Molecular formula of a compound can be calculated by multiplying a whole number with the empirical formula of that compound.

Molecular formula = n (Empirical formula)

Where $$n = \frac{\text{Molecular Mass}}{\text{Empirical Formula Mass}}$$

Example: Let's find out molecular formula of benzene, if its empirical formula is CH and molecular mass is 78.

Solution:

Empirical formula of benzene = CH

Empirical formula mass of benzene = 12 + 1 = 13

Molecular mass of benzene = 78

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$$n = \frac{78}{13}$$

Therefore the molecular = 6 (Empirical formula)

Formula of benzene $= 6 \times CH = C_6H_6$

So molecular formula of benzene is C_6H_6.

Q.8: How is chemical equation helpful in calculations?

Ans. A complete and balanced chemical equation tells us the mole ratio or mass ratio between the reactants and the products.

With the help of this ratio we can find out:

- The masses of the products from the given masses of the reactants.
- The masses of the reactants from the given masses of the products.

Example: The following equation tells us that one mole (100 g) calcium carbonate reacts with two moles (73 g) of hydrochloric acid to produce one mole (111 g) of $CaCl_2$, one mole (18 g) of water and one mole (44 g) of carbon dioxide.

$$\underset{\substack{1 \text{ mole} \\ 100 \text{ g}}}{CaCO_{3\,(s)}} + \underset{\substack{2 \text{ moles} \\ 73 \text{ g}}}{2HCl_{(aq)}} \longrightarrow \underset{\substack{1 \text{ mole} \\ 111 \text{ g}}}{CaCl_{2\,(aq)}} + \underset{\substack{1 \text{ mole} \\ 18 \text{ g}}}{H_2O_{(l)}} + \underset{\substack{1 \text{ mole} \\ 44 \text{ g}}}{CO_{2\,(g)}}$$

Q.9: What is a limiting reactant? Explain why it is called limiting.

Ans. In a chemical reaction, reactants are not always mixed according to stoichiometric ratio shown in the balanced chemical equation.

The use of excess reactants in experiments: Most often in experimental works, one or more reactants is used in large excess. This is done deliberately to ensure that the other expensive reactant is used completely. In this way the reactant which is used in excess in left behind at the end of the reaction and the other reactant is consumed completely.

Limiting reactant: The reactant which is consumed earlier is called the limiting reactant.

In fact, it is the limiting reactant which controls the amount of the product formed in a chemical reaction.

How to identify a limiting reactant: A limiting reactant present in a chemical reaction can be identified by carrying out the following steps.

(i) Calculate the number of moles of the reactants from the amounts provided.

(ii) Calculate the number of moles of the product which will from with the given moles of reactants.

(iii) Identify the reactant which gives the least amount of the product. This reactant will be the limiting reactant.

15.7 Yield

Q.10: Define actual yield and the theoretical yield. How is percentage yield calculated?

Ans. Actual yield:

The quantity of the product obtained when chemical reaction is performed is called

the actual yield . This yield is always less than the theoretical yield.

Theoretical yield: The theoretical yield is the amount of product which we calculate assuming that all reactants react according to the balanced chemical reaction.

Interest of a chemist: Percentage yield is calculated by applying the following formula:

$$\text{Percentage yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$$

Q.11: What is meant by Percentage purity? Explain with an example.

Ans. Percentage purity:

In chemistry, purity refers to the degree to which a substance is free from impuritites. Percentage purity of compound indicates the amount of pure compound present in an impure sample.

Percentage purity of a sample is calculated by the following formula.

$$\text{Percentage purity} = \frac{\text{Mass of the pure sample}}{\text{Total mass of the impure sample}} \times 100$$

Example: 12.0 g sample of a pharmaceutical product was found to contain 11.57 g of the active drug. Find out the percentage purity of the sample.

Solution:

$$\text{Percentage purity} = \frac{\text{Mass of the pure drug}}{\text{Total mass of sample}}$$

$$= \frac{11.57}{12.0} \times 100 = 96.4\%$$

Examples

15.1 Calculate the number of moles of nitrogen gas present when it occupies a volume of 2.5 dm³ at RTP.

Solution:

24 dm³ is occupied by how many moles of nitrogen = 1 mole

1 dm³ will be occupied by how many moles of nitrogen $= \frac{1}{24}$ mole

2.5 dm³ will be occupied by how many moles of nitrogn $= \frac{1}{24} \times 2.5 = 0.10$ mole

You can use the following equation as well as to solve this problem.

$$\text{No. of moles of a gss} = \frac{\text{Volume of the gas at RTP}}{\text{Molar volume of the gas}} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

15.2 Calculate the volume of 0.5 mol of hydrogen at RTP.

Solution:

Apply the requation (1) $0.5 = \frac{\text{Volume of hydrogen}}{24} = 1$ mole

Volume of hydrogen = $0.5 \times 24 = 12 dm^3$

15.3 Calculate the volume occupied by 200 g carbon dioxide at RTP.

Solution:

$$\text{No. of moles} = \frac{\text{Volume}}{\text{Molar Volume}}$$

$$\text{Volume} = \text{No. of moles} \times \text{Molar volume}$$

$$\text{Since no. of moles} = \frac{\text{Mass}}{\text{Molar Mass}}$$

So,

$$\text{Volume} = \frac{\text{Mass}}{\text{Molar Mass}} \times \text{Molar volume}$$

$$\text{Volume} = \frac{200 g}{44 g} \times 24\ dm^3 = 109\ dm^3$$

15.4 Calculate concentration of a solution in g/dm^3 which contains 20 g of sodium chloride dissolved in 0.2 dm^3 of water.

Solution:

$$\text{Concentration} = \frac{\text{Mass of solute in gram}}{\text{Volume of solution in } dm^3}$$

$$= \frac{20}{0.2} = 100\ g/dm^3$$

15.5 500 cm^3 of hydrochloric acid contains 1.8 g of dissolved hydrogen chloride. Calculate the concentration of the acid in g/dm^3.

Solution:

$$\text{Volume of hydrochloric acid in } dm^3 = \frac{500 cm^3}{1000} = 0.5\ dm^3$$

$$\text{Concentration of hydrochloric acid in } dm^3 = \frac{1.8}{0.5} = 3.6\ g/dm^3$$

15.6 Calculate the mass of copper sulphate in grams dissolved in 2 dm^3 of the solution to get a solution with a concentration 15 g/dm^3.

Solution:

Mass of solute in gram = Concentration in g/dm^3 × volume in dm^3

$= 15 \times 2 = 30$ g

15.7 A solution is prepared by dissolving 10 g of NaOH in 1.2 dm^3 of water. Calculate the concentration of the solution in mol/dm^3.

Solution:

Amount of NaOH = 10g

$$\text{No of moles of NaOH} = \frac{10}{40} = 0.25\ mol$$

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$$\text{Concentration of the solution} = \frac{0.25}{1.2}$$

Concentration of the solution = 0.21 mol/dm³

15.9 Find out the percentage composition of $Ca(OH)_2$

Solution:

Formula mass of $Ca(OH)_2 = 40 + 32 + 2 = 74$

Applying the formula given in equation (2)

$$\text{Percentage of an element} = \frac{\text{Mass of the element in the compound}}{\text{Formula mass of the compound}} \times 100$$

$$\text{Percentage of Ca} = \frac{40}{74} \times 100 = 54.05\%$$

$$\text{Percentage of Oxygen} = \frac{32}{74} \times 100 = 43.24\%$$

$$\text{Percentage of Hydrogen} = \frac{2}{74} \times 100 = 2.70\%$$

15.10 8.657 g of a compound were decomposed into its elements. It give 5.217g of carbon, 0.962 g of hydrogen and 2.478 g of oxygen. Find out the percentage composition of the compound.

Solution:

Applying the following formula

$$\text{Percentage of element} = \frac{\text{Mass of element}}{\text{Mass of compound}} \times 100$$

$$\text{Percentage of carbon} = \frac{5.217\,g}{8.657\,g} \times 100 = 60.26\%$$

$$\text{Percentage of hydrogen} = \frac{0.962\,g}{8.657\,g} \times 100 = 11.11\%$$

$$\text{Percentage of oxygen} = \frac{2.478\,g}{8.657\,g} \times 100 = 28.62\%$$

So, 100 g of the compound under study contains 60.26 g of carbon, 11.11 g of hydrogen and 28.62 g of oxygen.

15.11 The percentage composition of a compound shows it to contain 25.26% Mg and 74.74 Chlorine. Find out its empirical formula.

Solution:

1. Change the percentage of elements to gram

   Mg = 25.26 % = 26.26 g Cl = 74.74 = 74.74 g

2. No. of moles of each element

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Mg $= \frac{26.26}{24} = 1.05$ Cl $= \frac{74.74}{35.5} = 2.10$

3. Atomic ratio of each element

Mg $= \frac{1.05}{1.05} = 1$ Cl $= \frac{2.10}{1.05} = 2$

The empirical formula of magnesium chloride is $MgCl_2$

15.12 The percentage composition of an organic compound by mass is 64.8% carbon, 15.62% hydrogen and 21.58% oxygen. Find out its empirical formula.

Solution:

Change the percentage of elements to gram:

C = 64.8 % H = 15.62 % O = 21.58 %

= 64. g = 15.62 g O = 21.58 g

No. of moles of each element:

C $= \frac{64.8}{12} = 5.4$ H $= \frac{15.62}{1.35} = 15.62$ O $= \frac{21.58}{16} = 1.35$

Atomic ratio of each element

C $= \frac{5.4}{1.35} = 4$ H $= \frac{15.62}{1.35} = 10$ O $= \frac{1.35}{1.35} = 1$

The empirical formula of the compound is $C_4H_{10}O$.

15.14 Glucose has an empirical formula CH_2O and its molecular mass is 180g mol. What will be its molecular formula?

Solution:

Empirical formula of glucose = CH_2O

Empirical formula mass of glucose = 12 + 2 + 16 = 30

Molecular mass of glucose = 180

$$n = \frac{180}{30} = 6$$

Molecular formula of glucose = $6(CH_2O) = C_6H_{12}O_6$

So molecular formula of glucose will be $C_6H_{12}O_6$

15.15 25 g of lime stone ($CaCO_3$) react with an excess of hydrochloric acid according to the above equation. How much calcium chloride ($CaCl_2$) will be produced?

Solution:

According to the equation

100 g of lime stone react to produce calcium chloride = 111 g

1 g of lime stone will react to produce calcium chloride = $\frac{111g}{100}$

25 g of lime stone will react to produce calcium chloride = $\frac{111}{100} \times 25 = 27.75$ g

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15.16 Calculate the amount of carbon dioxide in grams produced when 25g of glucose reacts with 40 g of oxygen in the following photosynthesis reaction.

$$C_6H_{12}O_{6(s)} + 6O_{2\,(g)} \longrightarrow 6CO_{2\,(g)} + 6H_2O_{(\ell)}$$

Glucose

Solution:

In order to find out the amount of CO_2 in this reaction, we will have to identify which of the reactants is a limiting reactant

No. of moles of the reactants:

$$\text{No. of moles of glucose} = \frac{25}{180} = 0.138 \text{ mol}$$

$$\text{No of moles of oxygen} = \frac{40}{32} = 1.25 \text{ mol}$$

Calculate the no of moles of CO_2 which will be given by each of the reactants:

1 mole of glucose gives = 6 moles of CO_2

$$0.138 \text{ mol of glucose will give} = \frac{6}{1} \times 0.1385$$

$$= 0.83 \text{ mol}$$

6 moles of oxygen gives = 6 moles of CO_2

$$1.25 \text{ mol of oxygen will give} = \frac{6}{6} \times 1.25$$

$$= 1.25 \text{ mol}$$

Since CO_2 obtained from glucose than that of oxygen, so glucose is the limiting reactant.

Amount of CO_2 produced = $0.83 \times 44 = 36.5$ g

15.17 A chemist reacts 50 g of Zn with excess of nitric acid to get 80.2 g $Zn(NO_3)2$. Calculate the theoretical yield and the percentage yield of this reaction.

Solution:

Balanced chemical equation for the reaction

$$Zn_{(s)} + 2HNO_{3(aq)} \longrightarrow Zn(NO_3)_{2\,aq} + H_2(g)$$

$$\text{No of moles of Zn} = \frac{50}{65.37} = 0.76 \text{ mol}$$

Amount of $Zn(NO_3)_2$ = 80.2 g

Theoretical yield

According to the balanced chemical equation

1 mol of Zinc gives = 1 mol of $Zn(NO_3)_2$

Amount of $Zn(NO_3)$ in grams = $0.76 \times 189.38 = 143.92$ g

Percentage yield:

$$\text{Percentage Yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$$

$$= \frac{80.2}{143.92} \times 100 = 55.7\,\%$$

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15.1 Quick Check!

Calculate the amount CO_2 in 100 dm³ at RTP?

Solution. Given data

Gas = carbon dioxide (CO_2)

Given volume (v) = 100 dm³

Molar volume at RTP = 24 dm³/mole

Number of moles = ?

$$\text{No. of moles (n)} = \frac{\text{Volume of the gas at RTP}}{\text{Molar volume of the gas}}$$

$$= \frac{100\ dm^3}{24\ dm^3/mol}$$

$$= 4.17 \text{ moles}$$

15.2 Quick Check!

What mass of $CuSO_4$ is present in 5- cm³ of a 5×10^{-2} mol/dm³ aqueous solution?

Solution. Given data

$$\text{Volume of solution} = \frac{50 cm^3}{1000} = 15.2$$

Concentration of solution = 5 × 10-2 mol/dm³ (0.05mol/dm³)

Molar mass of $CuSO_4$ = 159.5 g/mol

Number of moles = Concentration in mol/dm³ (0.05 mol/dm³)

= 0.05 mol/dm³ × 0.05 dm³

= 0.0025 moles

Mass of in $CuSO_4$solution = No. of moles × Molar Mass

= 0.0025 × 159.5

= 0.39875 g

= 0.40 g

15.3 Quick Check!

Calculate the volume of 0.1mol/ dm³ oxlic acid ($C_2O_4H_2$) solution to exactly neutralize 25 cm³ of 0.1 mol/dm³ KOH solution.

Solution. 1. Balanced chemical equation:

$$C_2O_4H_2 + 2KOH \longrightarrow K_2C_2O_4 + 2H_2O$$

The ratio of Acid : Bare is 1 : 2

2. Calculate moles of KOH:

Volume of KOH = 25 cm³

Concentration of KOH = 0.1 mol/dm³

$$\text{Moles of KOH} = \text{Concentration} \times \frac{\text{Volume}}{1000}$$

$$= 0.1 \times \frac{25}{1000} = 0.0025 \text{ moles}$$

3. Calculate moles of oxalic acid needed:

Using the 1 : 2 ratio from the balanced equation

$$\text{Moles of acid} = \frac{\text{Moles of Bare}}{2}$$

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Moles of acid = $\frac{0.0025}{2}$ = 0.00125 moles

4. Calculate volume of oxalic acid:

Moles of oxalic acid = 0.00125 moles

Concentration of oxalic = 0.1 mol/dm³

$$\text{Volume} = \frac{\text{Moles}}{\text{Concentration}} \times 1000$$

$$= \frac{0.00125}{0.1} \times 1000$$

$$= 0.0125 \times 1000 = 12.5 \text{ cm}^3$$

Therefor the volume of 0.1 mol/dm³ oxalic acid required is 12.5 cm³

15.4 Quick Check!

Calculate the percentage of sulphate ions (SO_4^{-2}) in $Al_2(SO_4)_3$.

Solution. Atomic mass of Al = 27

Atomic mass of S = 32

Atomic mass of O = 16

Molar mass of one sulphate ion (SO_4):

Molar mass of SO_4 = 32 + (4 × 16)

= 32 (64) = 96

Molar mass of aluminium shulphate ($Al_2(SO_4)_3$):

Mass of Al = 2 × 27 = 54

Mass of 3 (SO_4) = 3 × 96 = 288

Total molar mass = 54 + 288

= 342 g/m

Applying the percentage composition formula:

$$\text{Percentage of an element } (SO_4^{-2}) = \frac{\text{Mass of the element in the compound}}{\text{Molar mass of the compound}} \times 100$$

$$= \frac{288}{342} \times 100$$

$$= 0.8421 \times 100 = 84.21\ \%$$

The percentage of sulphate ions (SO_4^{-2}) in $Al_2(SO_4)_3$ is 84.21 %

15.5 Quick Check!

A 0.5 g sample of compound contains 0.418 g of antimony (Sb) and 0.082 g of oxygen. What is the empirical formula of the compound?

Solution. Molar Masses

Antimony (Sb) = 121.8 g / mol

Oxygen (O) = 16.0 g3 / mol

No. of moles of each element

Moles of Sb

$$Sb = \frac{0.418 \text{ g}}{121.08 \text{ g / mol}} = 0.00343 \text{ mol}$$

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Moles of O

$$O = \frac{0.082\ g}{16.0\ g/mol} = 0.005125\ mol$$

Atomic ratio of each element

$$Sb = \frac{0.00343}{0.00343} = 1$$

$$O = \frac{0.005125}{0.00343} = 1.494 \text{ (close to 1.5)}$$

Conevert to whole number

Since we cannot have a fraction in a formula (1.5), we multiply both numbers by 2 to get the simplest whole number ratio:

$Sb = 1 \times 2 = 2$

$O = 1.5 \times 2 = 3$

The empirical formula of the compound is Sb_4O_3.

15.6 Quick Check!

An unknown hydrocarbon contains 85.71 carbon. its molar mass is 84g/mol. What is its molecular formula?

Solution.

Carbon = 85.71 %

Molar mass = 84 g / mol

Molecular formula = ?

Finding the empirical formula:

A hydrocarbon contains only carbon (C) and hydrogen (H).

- Carbon = 85.71 %
- Hydrogen = 100 % – 85.71 % = 14.129 %

Assume a 100 g sample:

- Moles of C = 85.71 g / 12.0 = 7.14 mol
- Moles of H = 14.29 g / 1.0 = 14.29 mol

Mole ratio

- $C = \frac{7.14}{7.14} = 1$
- $H = \frac{14.29}{7.14} = 2$

The empirical formula is CH_2

- **Finding the molecular formula:**

1. Calculate empirical formula mass:

$CH_2 = 12 + (2 \times 1) = 14$ g/mol

2. Find the n:

$$n = \frac{\text{Molecular mass}}{\text{Empirical formula mass}}$$

3. Multiply the empirical formula by n:

Molecular formula = $6\ (CH_2)$

$= C_6H_{12}$

Therefore, the molecular formula of the hydrocarbon is C_6H_{12}

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15.7 Quick Check!

Why it is necessary for a chemical equation to be balanced before it can be used in calculation?

Ans. It is necessary for a chemical equation to be balanced before it can be used in calculation because a complete and balanced chemical equation tells us the mole ratio or mass ratio between the reactants and the products. With the help of this ratio we can find out the masses of the products from the given masses of the reactants or the masses of the reactants from the given masses of the products.

15.8 Quick Check!

If you react 100 g of chlorine gas with 500 g of KI, which reactant will be the limiting reactant?

$$Cl_{2\,(q)} + 2KI_{(aq)} \longrightarrow KCl_{(aq)} + I_{2\,(g4)}$$

Solution. Given data

Chlorine gas = 100 g

KI = 500 g

Calculating available moles:

Moles of Cl_2:

$$\text{No. of moles} = \frac{\text{Volume}}{\text{Molar mass}}$$

$$n = \frac{100\ g}{71 g/mol}$$

$$= 1.41 \text{ moles}$$

Moles of KI

$$\text{No. of moles} = \frac{\text{Volume}}{\text{Molar mass}}$$

$$n = \frac{50\ g}{166 g/mol}$$

$$= 3.01 \text{ moles}$$

Determine the limiting reactant

$$Cl_{2\,(g)} + 2KI \longrightarrow 2Cl_{(aq)} + I_{2\,(g)}$$

The mole ration of Cl_2 : KI is 1 : 2

Moles of KI required for 1.41 moles of Cl_2:

$1.41 \times 2 = 2.82$ moles

We have 3.01 moles of kJ, which is more than the 2.82 moles needed.

Since we have more KI than required, KI is the excess reactant and Cl_2 is the limiting reactant.

15.9 Quick Check!

Find out the theoretical yield and percent yield of oxygen generated by heating 40 g of $KClO_3$ (M = 122.5). The mass of oxygen gas produced is 14.9 g

$$2KClO_{3\,(s)} \longrightarrow 2KCl_{(s)} + 3O_{2\,(g)}$$

Solution. Given data

Mass of $KClO_3$ = 40 g

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Molar mass (M) = 122.5 g / mol

Mass of oxygen = 14.9 g

Theoretical yield of oxygen = ?

Percentage yield of oxygen = ?

Calculate theoretical yield of oxygen:

Find the moles of reactant

$$n = \frac{\text{Volume}}{\text{Molar mass}}$$

$$n = \frac{40\ g}{122.5\ g / mol}$$

$$= 0.3265\ mol$$

- **Use the mole ratio from the balanced equation**

$2KClO_3 \longrightarrow 2KCl + 3O_2$

The ratio of $KClO_3 : O_2$ is 2 : 3

$$\text{Moles of } O_2 = 0.3265 \times \frac{3}{2} = 0.4898\ mol$$

- **Convert moles of to mass (Theoretical yield)**

Molar mass of O_2 : $16 \times 2 = 32$ g / mol

Theoretical yield = 0.4898 mol × 32 g / mol

= 15.67 g

Calculate percentage yield

$$\text{Percentage yield} = \frac{\text{Actual yield}}{\text{Theoretical yieldc}} \times 100$$

$$= \frac{14.9}{15.67} \times 100$$

$$= 95.1\ \%$$

INTERESTING INFORMATION

- The composition of all the chemical products which are in our daily use, such as shampoos, cleaners, soaps, perfumes and fertilizers are formed using stoichiometric calculations.

INTERESTING INFORMATION

- Stoichiometry is essential for optimizing chemical reactions in many industries.

INTERESTING INFORMATION

- Stoichiometry is used to determine the optimal dosages of medications for patients based on their weight, age and other factors.

POINT TO NOTE

- Molar concentration and molarity both refer to the concentration of a solute in a solution.

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Objective Type Questions

Additional MCQ's

Multiple Choice Questions prepared in the light of new Examination Techniques
(Knowledge, Understanding, Application, Analytical & Conceptual)

15.1 Molar Volume

15.2 Concentration of a Solution

15.3 Calculate the concentration of a solution in titration using empirical data

1. What is the room temperatrue for standard conditions:
(a) 0 °C (b) 25 °C (c) 75 °C (d) 100 °C

2. At RTP, one mole of any gas occupies a volume of:
(a) 22 dm^3 (b) 23 dm^3 (c) 24 dm^3 (d) 25 dm^3

3. Which factor does NOT change the volume occupied by one mole of a gas at RTP?
(a) Temperature (b) Pressure
(c) Size of the molecules (d) Number of moles

4. The pressure value used for standard RTP conditions is:
(a) 100 kpa (b) 1 atmosphere (760 torr)
(c) 273 torr (d) 24 atmosphere

5. Concentration of a solution is a measure of the amount of solute dissolved in a given amount of:
(a) Solution or solvent (b) Only solute
(c) Solid crystals (d) Catalyst

6. What is the standard unit for the mass/volume concentration?
(a) mol /kg (b) g /cm^3 (c) mg /ℓ (d) g / dm^3

7. Molar concenttration is expressed in which of the following units?
(a) g / dm^3 (b) mol / g (c) mol / dm^3 (d) dm^3 / mol

8. If 20 g of sodium is dissolved in 0.2 dm^3 of water, the concentration is:
(a) 10 g / dm^3 (b) 40 g / dm^3 (c) 80 g / dm^3 (d) 100 g / dm^3

9. In a titration, the solution is added until the _____ point is reached.
(a) Starting (b) Boiling (c) End (d) Freezing

10. To determine the concentration of a solution via titration, you must know the:
(a) Density of the flask (b) Room humidity
(c) Colours of the solute (d) Balanced chemical equation

11. Empirical data required for titration calculations includes:
(a) Volumes of two solutions used (b) The atmpospheric pressure only
(c) The weight of the burette (d) None of these

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12. **Titration is a techinque used to find the concentration of a solution by reacting it with:**
(a) Water only (b) Solution of known concentration
(c) Insoluble salt (d) Gaseous catalyst

13. **In the formula for concentration, what is the denominator?**
(a) Mass of solute in grams (b) Mass of solvent in kg
(c) Volume of solution in dm^3 (d) Temperature of the solution

14. **for titration purposes, you need to know the concentration of:**
(a) Both solutions beforehand (b) The other (known) solution
(c) indicator (d) Both a and b.

15. **It is esential for optimizing chemical reactions in many industires.**
(a) Stoichiometry (b) Biochemistry
(c) Organic chemistry (d) Electrochemistry

15.4 Percentage Composition by Mass, Empirical formula and Molecular formula

15.5 Empirical formula

15.6 Limiting reactant

15.7 Yield

16. **The percentage mass of each element present in a compound is known as:**
(a) Molecular mass (b) Percentage composition
(c) Empirical ratio (d) Molar volume

17. **What is formula mass of $Ca(OH)_2$?**
(a) 58 (b) 62 (c) 74 (d) 85

18. **The formula that represents the simplest whole number ratio of atoms in a compound is the:**
(a) Emirical formula (b) Molecular formula
(c) Molar volume (d) Percentage composition

19. **Benzene (C_6H_6) and acetylne (C_2H_2) both have the same empirical formula, which is:**
(a) CH_2 (b) C_2H (c) CH (d) CH_4

20. **To find the molecular formula from an 'empirical formula, the multiplier 'n' is calculated by:**
(a) Empricial mass / Molecular mass
(b) Molecular mass / Empirical formula mass
(c) Atomic mass × moles (d) Actual yield × Theoretical yield

21. **The reactant that is consumed earlier in a reaction and controls the amount of product formed is the:**
(a) Excess reactant (b) Catalyst
(c) Limitng reactant (d) Theoretical reactant

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22. How many moles of HCl are needed to react with 1 mole of $CaCO_3$ in the given reaction?

(a) 1 mole (b) 2 moles (c) 3 moles (d) 4 moles

23. The quantity of product actually obtained when a chemical raetion is performed is called:

(a) Theoretical yield (b) Actual yield

(c) Percent purity (d) Stoichiometric yield

24. What is the empirical formula of a compund containing 25.26% Mg and 74.74 % chlorine (At . mass : Mg = 24, Cl = 35.5)

(a) MgCl (b) $MgCl_2$ (c) Mg_2Cl (d) $MgCl_3$

25. Empirical formula of magnesium chloride is:

(a) $MgCl_2$ (b) 2 MgCl (c) Mg_2Cl_2 (d) $2\,MgCl_2$

26. Glucose has an empirical formula of CH_2O and a molecular mass of 180. What is its molecular formula?

(a) $C_2H_4O_2$ (b) $C_4H_8O_4$ (c) $C_6H_{12}O_6$ (d) $C_4H_8O_4$

27. Empirical formula of glucose is:

(a) $C_3H_6O_3$ (b) CH_2O (c) C_6H_6 (d) CHO

28. Empirical formula of water is:

(a) H_2O (b) $2H_2O$ (c) H_2O_2 (d) HO

29. Which of the following is an empirical formula of benzene?

(a) C_6H_6 (b) $C_6H_{12}O_6$ (c) CH (d) 6CH

Answers

1.	(b)	2.	(c)	3.	(c)	4.	(b)	5.	(a)	6.	(d)	7.	(c)
8.	(c)	9.	(d)	10.	(d)	11.	(a)	12.	(b)	13.	(a)	14.	(b)
15.	(a)	16.	(b)	17.	(b)	18.	(a)	19.	(c)	20.	(b)	21.	(c)
22.	(b)	23.	(b)	24.	(b)	25.	(b)	26.	(c)	27.	(b)	28.	(a)
29.	(c)												

Additional Short Questions

Short Answer Questions prepared in the light of new Examination Techniques
(Knowledge, Understanding, Application, Analytical & Conceptual)

15.1 Molar Volume

15.2 Concentration of a Solution

15.3 Calculate the concentration of a solution in titration using empirical data

1. Define molar volume.

Ans. Molar volume: One mole of all gases occupies a volume of 24 dm^3 at RTP. This is called molar volume.

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2. What is the value for room temperature and pressure (RTP) at standard conditions?

Ans. The standard conditions for RTP is; temperature of 25 °C(298.15 k) and a pressure of one atmosphere (760 torr).

3. What is the numerical value of molar volume at RTP?

Ans. At RTP, one mole of any gas occupies a volume of 24 dm^3.

4. Do the size and mass of gas molecules affect the molar volume?

Ans. No. one mole of different gasses will contain the same number of molecules and occupy the same volume (24 d m^3 at RTP), even though they have different masses and molecular sizes.

5. Define concentration of a solution.

Ans. Concentration of a solution: Concentration of a solution is a measure of the amount of solute that has been dissolved in a given amount of solution or solvent.

6. In what units is the mass/volume concentration typically expressed?

Ans. It is expressed in g /d m^3.

7. What is the unit for molar concentration?

Ans. The unit for molar concentration is mol / dm^3.

8. Give the formula for calculating concentration in g / dm^3.

Ans. $$\text{Concentration} = \frac{\text{Mass of solute in gram}}{\text{Volume of solution in } dm^3}$$

9. How can the concentration of a solution be determined?

Ans. The concentration of a solution can be determined by titrating it with a solution of known concentration till the end point is reached.

10. What is titration?

Ans. Titration: Titration is a technique where the concentration of an unknown solution is determined by reacting it with a solution of known concentration until the end point is reached.

11. What three pieces of empirical data are needed to calculate concentration via titration?

Ans. (i) The balanced chemical equation for the reaction between the two solutions.
(ii) The volumes of the two solutions used during the titration.
(iii) The concentration of the other solution.

12. How is the number of moles or masses of gases calculated using molar volume?

Ans. It is calculated by knowing the volume of the gas and using the relationship that 1 mole = 24 d m^3 at RTP.

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15.4 Percentage Composition by Mass, Empirical formula and Molecular formula

15.5 Empirical formula

15.6 + 15.7 Limiting Reactant + Yield

13. Define percentage composition of a compound.

Ans. Percentage composition of a compound: Percentage composition of a compound refers to the percentage mass of each element present in the compound.

14. What is the percentage of an element in a compound?

Ans. The percentage of an element in a compound is the number of grams of that element present in 100 grams of the compound.

15. What is the formula to calculate the percentage of an element in a compound.?

Ans. The percentage of an element in a compound can be determined by applying the following formula:

$$\text{Percentage of an element} = \frac{\text{Mass of the element in compound}}{\text{Formula mass of the compound}} \times 100$$

16. Define empirical formula.

Ans. Empirical Formula: The formula which shows the simplest whole number ratio of atoms present in a compound is called empirical formula.

Example: Empirical formula of:

- Hydrogen peroide (H_2O_2) is HO
- Water (H_2O) is H_2O
- Benzene (C_6H_6) is CH.

17. How can the percentage composition of a compound be determined?

Ans. Percentage composition of a compound can be determined both theoretically as well as by performing quantitative analysis.

18. What is a useful concept to determine the purity of a compound and its empirical and molecular formula?

Ans. Percentage composition is a useful concept to determine the purity of a compound and its empirical and molecular formula.

19. Give two examples of compounds having the same empirical formula.

Ans. Acetic acid (CH_3COOH) and Glucose ($C_6H_{12}O_6$) have the same empirical formula CH_2O.

20. Define molecular formula.

Ans. Molecular formula: Molecular formula of an element or a compound represents the actual numbers of present in the molecule of these substances.

Examples: Water, hydrogen, peroxide, ethylene and sulphur have molecular formula H_2O, H_2O_2, C_2H_4 and S_8 respectively.

21. What is relationship between molecular formula and empirical formula?

Ans. Molecular formula of a compound can be calculated by multiplying a whole number with the empirical formula of that compound.

Molecular formula = n (Empirical formula)

Where $n = \frac{\text{Molecular mass}}{\text{Empirical formula mass}}$

22. What information does a balanced chemical equation provide for stoichiometry?

Ans. A complete and balanced chemical equation tell us the mole ratio or mass ratio between the reactants and the products.

23. Define limiting reactant.

Ans. Limiting Reactant: The reactant which is consumed earlier in a chemical reaction is called limiting reactant. In fact, it controls the amount of the product formed in a chemical reaction.

24. Differentiate between theoretical yield and actual yield.

Ans. Theoretical Yield: It is the amount of product which we calculate assuming that all the reactants react according to the balanced chemical equation.

Actual Yield: The quantity of the product determined when chemical reaction is performed is called the actual yield.

25. Why is the actual yield often less than the theoretical yield?

Ans. It can be due to side reactions, reversible reactions, less of product during filtration crystallization, or mechanical errors during the experiment.

26. How do you calculate, percentage yield?

Ans. Percentage yield is calculated by applying the following formula

$$\text{Percentage yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$$

27. Define percentage purity.

Ans. Percentage Purity: It refers to the degree to which a substances is free from impurities.

28. What does percentage purity of compound indicate?

Ans. Percentage purity of compound indicates the amount of pure compound present in an impure sample.

29. How is the percentage purity of a sample calculated?

Ans. Percentage purity of a sample is calculated by the following formula:

$$\text{Percentage Purity} = \frac{\text{Mass of the pure sample}}{\text{Total mass of the impure sample}} \times 100$$

30. In stoichiometry what must be done before calculating the mass of products?

Ans. In stoichiometry, before calculating the mass of products you must have a balanced chemical equation.

31. How do you find the "Atomic Ratio" of elements?

Ans. Divide the number of moles of each element by the smallest number of moles obtained.

32. What is importance of stoichiometry in the field of medical?

Ans. Stoichiometry is used to determine the optimal dosages of medications for patients

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based on their weight, age and other factors.

33. How are the composition of all the chemical products which are in our daily use such as shampoos, cleaners, perfumes and fertilizers formed?

Ans. The composition of all the chemical products which are in our daily use such as shampoos, cleaners, perfumes and fertilizers are formed using stoichiometric calculations.

Exercise Questions (Solved)

A. Multiple Choice Questions

☆ **Choose and tick the correct answer from the given choices.**

1. Volume occupied by 15 moles of ammonia gas at RTP:

(a) 224 dm^3 (b) 160 dm^3 (c) 360 dm^3 (d) 265 dm^3

2. How many moles of natural gas CH_4 will be present in a cylinder if its volume is 18 dm^3 at RTP?

(a) 0.75 mol (b) 0.67 mol (c) 0.85 mol (d) 0.56 mol

3. What will the molar concentration of potassium hydroxide solution if 2.0 g of it are dissolved in 100 cm^3 of solution?

(a) 0.36 mol/dm^3 (b) 0.53mol/dm^3 (c) 0.70mol/dm^3 (d) 0.45mol/dm^3

4. What will be the mass of NaCl needed to make up 15 dm^3 of its solution with a concentration of 0.7 g/dm^3?

(a) 21 g (b) 10.5 g (c) 31.5 g (d) 5.4 g

5. Find out the concentration of H_2SO_4 in mol/dm^3 if its 10 cm^3 react with 20 cm^3 of NaOH solution having concentration 0.1 mol/dm^3.

(a) 0.01 mol/dm^3 (b) 0.001 mol/dm^3 (c) 0.1 mol/dm^3 (d) 0.15 mol/dm^3

6. If the molar mass of a compound is 178 g/mol and its empirical formula is $C_3H_5O_3$. What is its molecular formula?

(a) $C_3H_5O_3$ (b) $C_6H_{10}O_6$ (c) $C_9H_{15}O_9$ (d) $C_8H_{10}O_8$

7. When natural gas burns in air, which component is the limiting reactant?

(a) Both components (b) Neither component is a limiting reactant

(c) Air (d) Natural gas

8. If the actual yield of a compound is 0.198 g while the theoretical yield is 0.217g. What will be the percentage yield?

(a) 50% (b) 91.2% (c) 80% (d) 90

Answers

1. (c) 2. (a) 3. (a) 4. (b) 5. (c) 6. (b) 7. (d) 8. (b)

B. Short Answer Questions

15.1 What is the molar volume of a gas at RTP?

Ans. The molar volume of any gas at room temperature and pressure (RTP) is 24 dm^3. This means that one mole of each gas contains the same number of molecules.

occupies the same volume under these specific conditions (25 °C or 298.15 K) and 1 atmosphere (760 torr) pressure.

15.2 How does the concept of molar volume useful for us?

Ans. The concept of molar volume is useful for us because it enables us to calculate the number of moles or masses of the gases if we know their volumes.

15.3 How does the molar volume relate to the Avogadro's law?

Ans. Molar volume is a direct practical application of Avogadro's Law. Which states that equal volumes of different gases must contain an equal number of molecules if the temperature and pressure are kept constant. It is because:

1 mole of any substance always contain 6.02×10^{23} particles (Avogadro's number).

Avogadro's Law implies that 1 mole of any gas must occupy the same volume.

Molar volume (24 dm^3) is simply the specific volume that this "Avogadro's number" of gas particles occupies at RTP.

15.4. Why two different compounds may show the same empirical formula?

Ans. Two different compounds may have the same empirical formula because an empirical formula does not tell us about the actual number of atoms present in that compound rather it represents the simplest ratio between atoms.

Example:

Both acetylene (C_2H_2) and benzene (C_6H_6) have same empirical formula CH, because both have a 1 : 1 ratio of carbon to Hydrogen atoms.

Similarly both acetic acid (CH_3COOH) and glucose ($C_2H_{12}O_6$) have same empirical formula CH_2O, because both have a 1 : 2 ratio of carbon and Hydrogen atoms.

15.5 Why is percentage yield important?

Ans. Percentage yield is the efficiency of the chemical reaction. It is important in both laboratory and industrial fields.

Efficiency Measurement:

It tells a chemist how much of the theoretical maximum product was actually obtained.

Economic Viablity:

In industrial manufacturing (like producing medicines or fertilizers), a high percentage yield is essential to keep costs low and maximize profit.

Resource Managment:

It helps in identifying the waste of raw materials by improving the yield, companies can reduce the amount of starting materials needed, which is more sustainable.

15.6 What is the concentration of a solution in mol/dm^3 if it contains 49 g of H_2SO_4 in one dm^3 of solution?

Ans. To find the concentration in mol/dm^3, we first need to convert the mass of H_2SO_4 into moles.

(i) Calculate the molar mass of H_2SO_4

Using the atomic masses : H = 1, S = 32 , O = 16

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Molar mass = $(2 \times 1) + 32 + (4 \times 16)$

Molar mass = $2 + 32 + 64 = 98$ g/mol.

(ii) Calculate the number of moles

$$\text{Moles} = \frac{\text{Given mass}}{\text{Molar mass}}$$

$$\text{Moles} = \frac{49\text{ g}}{98\text{ g/mol}} = 0.5 \text{ moles}$$

(iii) Calculate the concentration:

Since the volume of the solution is 1 dm^3, the concentration is simply the number of moles per dm^3.

$$\text{Concenration} = \frac{\text{Moles}}{\text{Volume in } dm^3}$$

$$= \frac{0.5\text{ mol}}{1\text{ dm}^3} = 0.5 \text{ mol/dm}^3$$

So the concentration of a solution is 0.5 mol/dm^3.

C. Constructed Response Questions

15.1 How would you identify the limiting reactant in a chemical reaction?

Ans. For answer see Q.9

15.2 Why is it important to find the purity of a compound which is used as a medicine?

Ans. Purity: Purity refers to the degree to which a substance is free from impurities.

Importance of finding the purity of a conmpound: It is important to find the purity of a compound which is used as a medicines for three main reasons.

Toxicological safety: During the synthesis of a drug, harmful by-products or impurities can be created. Even in trace amounts, these can cause severe allergic reactions, organ damage or long term toxicity.

Precise Dosage: Medicine must have a specific concentration of the active ingredient. If a compound is only 80 % pure, a patient taking a 100 mg pill is only receiving 80 m g of the drug, which may fail to treat the illness.

Stability and shelf life: Impurities can act as catalysts that speed up the decomposition of the medicine, making it expire faster.

15.3 Will there be a limiting reactant in a reversible reaction?

Ans. Generally no. In a reversible reaction, the concept of a limiting reactant is not typically applicable in the same way it is for irreversible (one-way) reactions.

Reason:

In an irreversible reaction, the limiting reactant is used up until it reaches to zero. However, in a reversible reaction, a state of chemical equilibrium is reached where both reactants and products coexist.

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Outcome:

Since the reaction never goes to 100 % completion in one direction, no reactant is ever "completely consumed". Therefore, technically, there is no "limiting" factor that stops the reaction by disappearing entirely, instead, the reaction is limited by the equilibrium constant (Kc).

15.4 How do you know if a formula is empirical or not?

Ans. Empirical Formula: The formula which shows the simplest whole number ratio of atoms present in a compound is called empirical formula.

Determining if a formula is empirical or not: You can determine if a formula is empirical or not by checking the mathematical ratio of the atoms.

A formula is empirical if the subscripts of the elements are in their simplest whole number ratio and cannot be divided further by a common factor.

Example 1 : H_2O(Ratio 2 : 1)

The formula of water (H_2O) represents the simplest ratio (2 : 1) between Hydrogen and Oxygen atoms present in it. You cannot simplify this further. So, H_2O is an empirical formula of water.

15.5 Write down one method to find out the molecular mass of a compound without knowing its molecular formula.

Ans. The effective way to find out the molecular mass of a compound without knowing its molecular formula is using the molar volume of a gas, which is the volume occupied by one mole of any substance at a specific temperature and pressure.

At standard temperature (25 °C or 298.15 k) and one atmosphere (760 torr), one mole of any gas occupies a volume of 24 dm^3.

Here is how molar volume is used to calculate molecular mass:

The Fundamental Principle:

The molar mass (M) of a substance is the mass of one mole of its particles, measured in grams per mole (g / mol). If you can determine the mass of a gas sample (m) and determine how many moles (n) that sample contains, you can calculate the molar mass:

$$n = \frac{m}{M} = \frac{V}{Vm}$$

By rearranging this formula, you can find out the molar mass (M).

$$M = \frac{m.Vm}{V}$$

Where

- n = Number of moles
- m = Known mass (measured in grams (g))
- M = Molecular mass (Expressed in g/mol)
- V = Volume (Actual volume of gas)
- Vm = Molar volume (24 dm^3)

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D. Numerical Problems

15.1 Calculate the number of moles, volume and number of molecules in 4.0 g of CH_4 at RTP.

Sol. Molar mass of $CH_4 = 12 + (1 \times 4) = 16$ g/mol

$$\text{No. of moles} = \frac{\text{Mass}}{\text{Molar mass}} = \frac{4.0\,\text{g}}{16\,\text{g/mol}} = 0.25 \text{ moles}$$

Molar volume = 24 dm^3

Volume = No. of moles × Molar volume:

$= 0.25 \times 24 = 6.0\ dm^3$

Number of molecules = Moles × 6.02×10^{23}

$= 1.505 \times 10^{23}$ molecules.

15.2 What mass of NaCl need to be dissolved in 150 cm^3 of a solution if the concentration of the solution is 0.4 mol/dm^3?

Sol. Volume = 150 cm^3 = 0.15 dm^3

Concentration = 0.4 mol/dm^3

Finding moles = ?

Moles = Concentration × Volume

$= 0.4 \times 0.15 = 0.06$ moles

Finding mass (Molar mass of NaCl = 58.5 g/mol)

Mass = Moles × Molar mass

$= 0.06 \times 58.5$

$= 3.51$ g.

15.3 Find out the percentage of sodium in $NaHCO_3$.

Sol. Molar Mass of $NaHCO_3$:

23(Na) + 1(H) + 12 (C) + 48 (O_3) = 84 g/mol

Percentage of Na = ?

$$\text{Percentage of Na} = \frac{\text{Mass of Na}}{\text{Molar mass of } NaHCO_3} \times 100$$

$$= \frac{23}{84} \times 100$$

$$= 27.38\ \%$$

15.4 A sulphide of iron contains 1.926 g of sulphur and 2.333 g of iron. Find out the empirical formula of this compound.

Sol. Moles of iron (Fe) = 2.333 g/56 = 0.0416 moles

Moles of sulphur (s) = 1.926 g/32 = 0.0602 moles

Molar ratio = ?

$$\text{Fe} = \frac{0.0416}{0.0416} = 1$$

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$$S = \frac{0.0602}{0.0416} = 1.44 = 1.5$$

Whole number ratio:

Multiply by 2 = Fe_2S_3

Empirical formula of iron sulphide = Fe_2S_3

15.5 A compound contains by mass, 40.0% C, 6.71 % H and 53.3 % oxygen. A 0.320 mole of this compound weighs 28.8 g. What is the molecular formula of this compound?

Sol. Molecular formula of the compound = ?

Empirical formula calculation = ?

$$\text{Carbon (C)} = \frac{40.0}{12} = 3.33$$

$$\text{Hydrogen (H)} = \frac{6.71}{1} = 6.71$$

$$\text{Oxygen (O)} = \frac{53.3}{16} = 3.33$$

Ratio C : H : O = 1 : 2 : 1

Empirical formula = CH_2O

(Mass = 30 g/mol)

Molar mass of compound = ?

$$\text{Molar mass} = \frac{\text{Mass}}{\text{Moles}} = \frac{28.8\text{g}}{0.320\text{mol}} = 90 \text{ g/mol}$$

Molecular formula of compound = ?

$$n = \frac{\text{Molecular mass}}{\text{Empirical formula mass}}$$

$$n = \frac{90}{30}$$

$$= 3$$

Multiply CH_2O by 3 = $C_3H_6O_3$

15.6 The formation of ammonia gas is given by the following equation:

$$3H_{2\,(g)} + N_{2\,(g)} \longrightarrow 2NH_{3\,(g)}$$

If you start reacting 12 g of H_2 with 64 g of N_2, which will be the limiting reactant?

Sol.

$$\text{Moles of } H_2 = \frac{12}{2} = 6 \text{ moles}$$

$$\text{Moles of } N_2 = \frac{64\text{g}}{28} = 2.28 \text{ moles}$$

1 mole of N_2 needs 3 moles of H_2.

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2.28 moles of N_2 should need = 2.28×3

= 6.84 moles of H_2

Since we have only 6 moles of H_2, So H_2 is the limiting reactant.

15.7 When 305 g of $AgNO_3$ is reacted with excess of $MgCl_2$ it produces 23.7 g of $Mg(NO_3)$. What is the percentage yield of the reaction?

$$2AgNO_{3\,(aq)} + MgCl_{2\,(aq)} \longrightarrow Mg(NO_3)_{2\,(aq)} + 2AgCl_{(s)}$$

Sol. Percentage yield of $Mg(NO_3)_2$ = ?

1. Equation Ratio:
2. Moles $AgNO_3$ produce 1 mole $Mg(NO_3)_2$
3. Moles of $AgNO_3 = \dfrac{305\text{ g}}{170\text{ g/mol}} = 1.794$ moles
4. Theoretical mass = 0.897 moles × 148.3 g/mol = 133 g
5. Percentage yield $= \dfrac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$

$$= \left(\frac{23.7}{133}\right) \times 100$$

$$= 17.8\ \%$$

15.8 A sample of metal has a total mass of 3.66 kg and contains 2.45 kg of gold. What is the percentage purity of gold in this sample?

Sol. Percentage purity of gold = ?

Total mass = 3.66 kg

Pure gold mass = 2.45 kg

$$\text{Percentage purity} = \frac{\text{Mass of the pure sample}}{\text{Total mass of the impure sample}}$$

$$= \frac{2.45}{3.66} \times 100$$

$$= 66.94\ \%$$

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