Cambridge (CIE) A Level Chemistry

Your notes

Reacting Masses & Volumes (of Solutions & Gases)

Contents

Mole Calculations

- The number of moles of a substance can be found by using the following equation:

$$\text{number of moles} = \frac{\text{mass of a substance (g)}}{\text{molar mass (g mol}^{-1})}$$

- It is important to be clear about the type of particle you are referring to when dealing with moles
  - E.g. 1 mole of CaF_2 contains one mole of CaF_2 formula units, but one mole of Ca^{2+} and two moles of F^- **ions**

Reacting masses

- The **masses** of reactants are useful to determine how much of the reactants **exactly** react with each other to prevent waste
- To calculate the reacting masses, the chemical equation is required
- This equation shows the ratio of moles of all the reactants and products, also called the **stoichiometry,** of the equation
- To find the mass of products formed in a reaction the following pieces of information is needed:
  - The mass of the reactants
  - The molar mass of the reactants
  - The balanced equation

Percentage yield

- In a lot of reactions, not all reactants react to form products which can be due to several factors:
  - Other reactions take place simultaneously
  - The reaction does not go to **completion**
  - Reactants or products are **lost** to the atmosphere
- The **percentage yield** shows how much of a particular product you get from the reactants compared to the maximum theoretical amount that you can get:

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{predicted or theoretical yield}} \times 100$$

- Where **actual yield** is the number of moles or mass of product obtained **experimentally**
- The **predicted yield** is the number of moles or mass obtained by calculation

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Worked Example

Mass calculation using moles

Calculate the mass of magnesium oxide that can be produced by completely burning 6 g of magnesium in oxygen.

magnesium + oxygen → magnesium oxide

Answer

- **Step 1:** The symbol equation is:
  - **$2Mg (s) + O_2 (g) \rightarrow 2MgO (s)$**
- **Step 2:** The relative atomic and formula masses are:
  - Magnesium: 24.3
  - Oxygen: 32
  - Magnesium oxide: 40.3
- **Step 3:** Calculate the moles of magnesium used in the reaction:
  - Number of moles = $\frac{6.0 \text{ g}}{24.3 \text{ g mol}^{-1}}$ = **0.2469 moles**
- **Step 4:** Find the ratio of magnesium to magnesium oxide using the balanced chemical equation:

	Magnesium	Magnesium oxide
Moles	2	2
Ratio	1	1
Change in moles	- 0.2469	+ 0.2469

- Therefore, **0.2469 mol of MgO** is formed
- **Step 5:** Find the mass of magnesium oxide
  - mass = mol x M_r
  - mass = 0.2469 mol x 40.3 g mol^{-1}
  - mass = 9.95 g
- Therefore, the mass of magnesium oxide produced is **9.95 g**

Worked Example

Calculate % yield using moles

In an experiment to displace copper from copper(II) sulfate, 6.54 g of zinc was added to an excess of copper(II) sulfate solution.

The copper was filtered off, washed and dried.

The mass of copper obtained was 4.80 g.

Calculate the percentage yield of copper.

Answer

- **Step 1:** The symbol equation is:
  - **Zn (s) + $CuSO_4$ (aq) → $ZnSO_4$ (aq) + Cu (s)**
- **Step 2:** Calculate the amount of zinc reacted in moles
  - Number of moles = $\frac{6.54 \text{ g}}{65.4 \text{ g mol}^{-1}}$ = **0.10 moles**
- **Step 3:** Calculate the maximum amount of copper that could be formed from the molar ratio:
  - Since the ratio of Zn(s) to Cu(s) is 1:1 a maximum of 0.10 moles can be produced
- **Step 4:** Calculate the maximum mass of copper that could be formed (**theoretical yield**)
  - Mass = mol x M_r
  - Mass = 0.10 mol x 63.5 g mol^{-1}
  - Mass = **6.35 g**
- **Step 5:** Calculate the percentage yield of copper
  - Percentage yield = $\frac{4.80 \text{ g}}{6.35 \text{ g}}$ x 100 = **75.6 %**

Excess & limiting reagents

- Sometimes, there is an **excess** of one or more of the reactants (**excess reagent**)
- The reactant which is not in excess is called the **limiting reagent**
- To determine which reactant is limiting:
  - The number of moles of the reactants should be calculated

Worked Example

Excess & limiting reagent

9.2 g of sodium is reacted with 8.0 g of sulfur to produce sodium sulfide, Na_2S.

Which reactant is in excess and which is the limiting reagent?

Answer

- **Step 1:** Calculate the moles of each reactant
  - Number of moles (Na) = $\frac{9.2 \text{ g}}{23.0 \text{ g mol}^{-1}}$ = **0.40 mol**

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- Number of moles (S) = $\frac{8.0 \text{ g}}{32.1 \text{ g mol}^{-1}}$ = **0.25 mol**

- **Step 2:** Write the balanced equation and determine the molar ratio
  - **$2Na + S \rightarrow Na_2S$**
  - The molar ratio of Na: Na_2S is **2:1**
- **Step 3:** Compare the moles and determine the limiting reagent
  - To completely react 0.40 moles of Na requires 0.20 moles of S
  - Since there are 0.25 moles of S, then **S is in excess**
  - Therefore, **Na is the limiting reactant**

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Volumes of gases

- **Avogadro** suggested that:

equal volumes of gases contain the same number of molecules

- This is also called **Avogadro's hypothesis**
- At room temperature and pressure **one mole** of any gas has a volume of 24.0 dm^3
  - Room temperature is 20 °C
  - Room pressure is 1 atmosphere
- This **molar gas volume** of 24.0 dm^3 can be used to find:
  - The volume of a given mass or number of moles of gas:

volume of gas (dm^3) = amount of gas (mol) x 24.0

- The mass or number of moles of a given volume of gas:

$$\text{amount of gas (mol)} = \frac{\text{volume of gas } (dm^3)}{24.0}$$

Worked Example

Calculating the volume of gas using excess & limiting reagents

Calculate the volume that the following gases occupy:

1. Hydrogen (3 mol)
2. Carbon dioxide (0.25 mol)
3. Oxygen (5.4 mol)
4. Ammonia (0.02 mol)

Calculate the moles in the following volumes of gases:

1. Methane (225.6 dm^3)
2. Carbon monoxide (7.2 dm^3)
3. Sulfur dioxide (960 dm^3)

Answer

Gas	Amount of gas (mol)	Volume of gas (dm^3)
Hydrogen	3.0	**3.0 x 24.0 = 72.0**
Carbon dioxide	0.25	**0.25 x 24.0 = 6.0**
Oxygen	5.4	**5.4 x 24.0 = 129.6**
Ammonia	0.02	**0.02 x 24.0 = 0.48**
Methane	$\frac{225.6}{24.0}$ = 9.4	225.6
Carbon monoxide	$\frac{7.2}{24.0}$ = 0.30	7.2
Sulfur dioxide	$\frac{960}{24.0}$ = 40	960

Volumes & concentrations of solutions

- The **concentration** of a solution is the amount of **solute** dissolved in a **solvent** to make 1 dm^3 of **solution**
  - The solute is the substance that dissolves in a solvent to form a solution
  - The solvent is often water

$$\text{concentration } (\text{mol dm}^{-3}) = \frac{\text{number of moles of solute (mol)}}{\text{volume of solution } (\text{dm}^3)}$$

- A **concentrated** solution is a solution that has a **high** concentration of solute
- A **dilute** solution is a solution with a **low** concentration of solute
- When carrying out calculations involve concentrations in mol dm^{-3} the following points need to be considered:
  - Change mass in grams to **moles**
  - Change cm^3 to dm^3
- To calculate the **mass** of a substance present in solution of known **concentration and volume**:
  - Rearrange the concentration equation

number of moles (mol) = concentration (mol dm^{-3}) x volume (dm^3)

- Multiply the moles of solute by its molar mass

mass of solute (g) = number of moles (mol) x molar mass (g mol^{-1})

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Worked Example

Calculating volume from concentration

Calculate the volume of 1.0 mol dm^{-3} hydrochloric acid required to completely react with 2.5 g of calcium carbonate.

Answer

- **Step 1:** Write the balanced symbol equation
  - $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$
- **Step 2:** Calculate the amount, in moles, of calcium carbonate:
  - Number of moles ($CaCO_3$) = $\frac{2.5 \text{ g}}{100 \text{ g mol}^{-1}}$ = **0.025 mol**
- **Step 3:** Calculate the moles of hydrochloric acid required using the reaction's stoichiometry:
  - 1 mol of $CaCO_3$ requires 2 mol of HCl
  - So 0.025 mol of $CaCO_3$ requires **0.05 mol of HCl**
- **Step 4:** Calculate the volume of HCl required:
  - Volume (HCl) = $\frac{\text{amount (mol)}}{\text{concentration (mol dm}^{-3})} = \frac{0.05 \text{ mol}}{1.0 \text{ mol dm}^{-3}}$ = **0.05 dm^3**
  - So, the volume of hydrochloric acid required is **0.05 dm^3**

Worked Example

Neutralisation calculation

25.0 cm^3 of 0.050 mol dm^{-3} sodium carbonate solution was completely neutralised by 20.0 cm^3 of dilute hydrochloric acid.

Calculate the concentration, in mol dm^{-3}, of the hydrochloric acid.

Answer

- **Step 1:** Write the balanced symbol equation:
  - $Na_2CO_3 + 2HCl \rightarrow Na_2Cl_2 + H_2O + CO_2$
- **Step 2:** Calculate the amount, in moles, of sodium carbonate reacted
  - Rearrange the equation for the amount of substance (mol) and divide the volume by 1000 to convert cm^3 to dm^3
  - Number of moles (Na_2CO_3) = 0.025 dm^3 x 0.050 mol dm^{-3} = **0.00125 mol**
- **Step 3:** Calculate the moles of hydrochloric acid required using the reaction's stoichiometry:
  - 1 mol of Na_2CO_3 reacts with 2 mol of HCl, so the molar ratio is 1 : 2
  - Therefore, 0.00125 moles of Na_2CO_3 react with **0.00250 moles of HCl**
- **Step 4:** Calculate the concentration, in mol dm^{-3} of hydrochloric acid:

- Concentration (HCl) = $\frac{\text{amount (mol)}}{\text{volume (dm}^3\text{)}}$ = $\frac{0.00250}{0.0200}$ = **0.125 mol dm^{-3}**

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Stoichiometric relationships

- The stoichiometry of a reaction can be found if the **exact amounts** of reactants and products formed are known
- The **amounts** can be found by using the following equation:

$$\text{number of moles} = \frac{\text{mass of a substance (g)}}{\text{molar mass (g mol}^{-1}\text{)}}$$

- The gas volumes can be used to deduce the **stoichiometry** of a reaction
  - E.g. in the **combustion** of 50 cm^3 of propane reacting with 250 cm^3 of oxygen, 150 cm^3 of carbon dioxide is formed suggesting that the ratio of propane: oxygen : carbon dioxide is 1 : 5 : 3

C_3H_8 (g) + 5O_2 (g) → 3CO_2 (g) + H_2O (l)