3.3 The mole and the Avogadro constant

Name: _____ Class: _____ Date: _____ **Total: 32 marks**

KEY WORDS volume • concentration • solution • the mole • titration

Objective

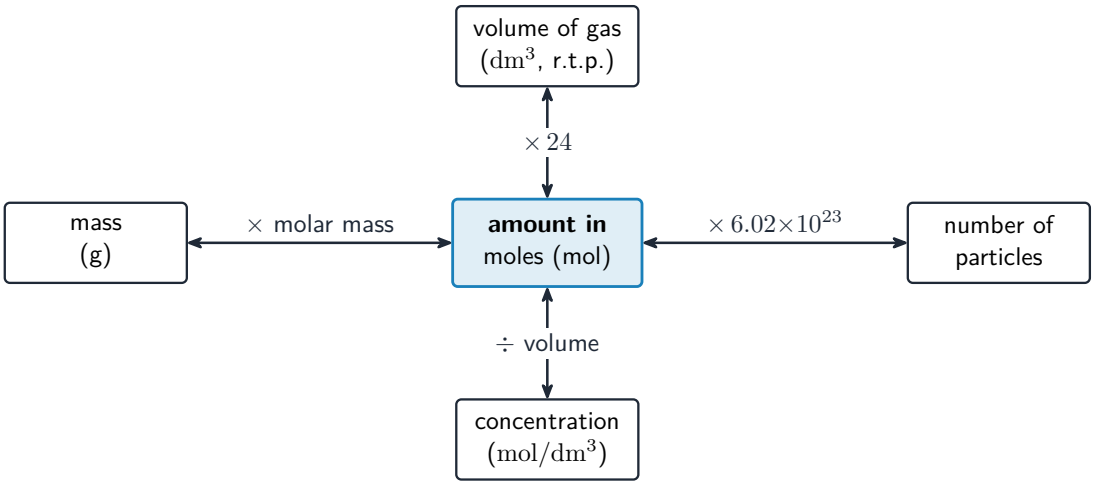
Build the skills to answer exam questions on **the mole** – $n = \frac{\text{mass}}{M_r}$, gas volumes, **concentration**, reaction calculations, and the **limiting reactant**.

You must be able to:

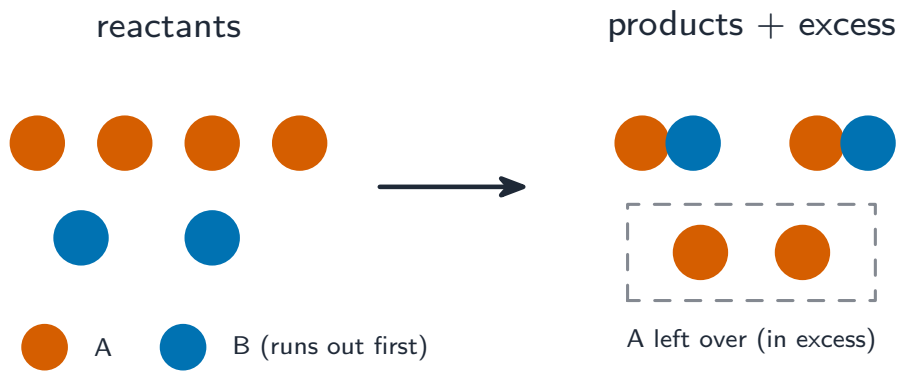
- use $n = \frac{\text{mass}}{M_r}$ and the molar gas volume (24 dm^3)
- use $c = \frac{n}{V}$ and do reacting-mass / titration calculations
- find the limiting reactant and an empirical formula

1 Key knowledge and worked examples

Mole calculations



$$n = \frac{mass}{M_r};\ volume\ of\ gas = n \times 24\ dm^3;\ c = \frac{n}{V}$$



The limiting reactant runs out first and sets how much product forms

36 g water: $n = \dfrac{36}{18} = 2$ mol.

■ The four calculations, each as a route through the mole

Every quantitative question is the same three steps: **convert what you are given into moles**, **use the balanced equation to get the moles of what you want**, then **convert those moles into the answer's unit**.

$$n = \frac{m}{M_r} \qquad n = \frac{V(\text{cm}^3)}{24\,000}\ \text{(gas at r.t.p.)} \qquad n = c \times V(\text{dm}^3)$$

Worked example 1 (mass to mass). Calculate the mass of magnesium oxide formed when 4.8 g of magnesium burns completely. (A_r: Mg 24, O 16.)

1. Balanced equation: $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$.
2. Moles of Mg: $n = \dfrac{4.8}{24} = 0.20$ mol.
3. The ratio Mg : MgO is 2 : 2, so moles of MgO = 0.20 mol.
4. $M_r(\text{MgO}) = 24 + 16 = 40$, so $m = n \times M_r = 0.20 \times 40 = 8.0$ g.

Worked example 2 (titration, concentration). 25.0 cm^3 of sodium hydroxide needs 20.0 cm^3 of 0.100 mol/dm^3 hydrochloric acid. Find the concentration of the alkali.

1. Moles of HCl $= c \times V = 0.100 \times \dfrac{20.0}{1000} = 2.00 \times 10^{-3}$ mol.
2. $\text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O}$ is 1 : 1, so moles of NaOH $= 2.00 \times 10^{-3}$ mol.
3. $c = \dfrac{n}{V} = \dfrac{2.00 \times 10^{-3}}{0.0250} = 0.0800\ \text{mol/dm}^3$.

Worked example 3 (limiting reactant, then percentage yield). 6.0 g of carbon reacts with 16.0 g of oxygen. Determine the limiting reactant, the maximum mass of carbon dioxide, and the percentage yield if 19.8 g is collected.

1. $C + O_2 \rightarrow CO_2$; $n(C) = \dfrac{6.0}{12} = 0.50$; $n(O_2) = \dfrac{16.0}{32} = 0.50$.
2. The ratio is 1 : 1 and the moles are equal, so neither is in excess; had one been smaller, that one would be **limiting** because it runs out first and sets how much product forms.
3. Maximum $CO_2 = 0.50 \times 44 = 22.0$ g.
4. percentage yield $= \dfrac{\text{actual}}{\text{theoretical}} \times 100\% = \dfrac{19.8}{22.0} \times 100\% = 90.0\%$.

Percentage composition and empirical formula. Divide each percentage by the element's A_r, then divide every answer by the smallest of them to get the whole-number ratio: 40.0% C, 6.7% H, 53.3% O gives $\frac{40.0}{12} = 3.33$, $\frac{6.7}{1} = 6.7$, $\frac{53.3}{16} = 3.33$, which is 1 : 2 : 1, so CH_2O.

2 Practice

2.1 Find the amount (in mol) in 8.0 g of NaOH ($M_r = 40$). [2]

2.2 Find the volume of 0.50 mol of a gas at r.t.p. [2]

2.3 Calculate the number of moles in 8.8 g of carbon dioxide. ($M_r = 44$.) [2]

2.4 Calculate the volume, at r.t.p., of 0.25 mol of hydrogen gas. [2]

2.5 Determine the empirical formula of a compound containing 52.2% carbon, 13.0% hydrogen and 34.8% oxygen. (A_r: C 12, H 1, O 16.) [3]

3 Exam-style questions

3.1 The number of moles in 22 g of CO_2 ($M_r = 44$) is: [1]

- ☐ **A** 0.25
- **B** 0.50
- **C** 1.0
- **D** 2.0

3.2 Magnesium burns: $2Mg + O_2 \rightarrow 2MgO$ (A_r: Mg = 24, O = 16).

(a) Find the moles in 12 g of magnesium. [1]

(b) Find the mass of magnesium oxide formed. [3]

3.3 25.0 cm^3 of sodium hydroxide is neutralised by 20.0 cm^3 of 0.10 mol/dm^3 HCl. $NaOH + HCl \rightarrow NaCl + H_2O$.

(a) Find the moles of HCl. [2]

(b) Find the concentration of the sodium hydroxide. [2]

3.4 Calcium carbonate decomposes when heated: $CaCO_3 \rightarrow CaO + CO_2$. A student heats 25.0 g of calcium carbonate until there is no further change. (A_r: Ca 40, C 12, O 16.)

(a) Calculate the number of moles of calcium carbonate used. [2]

(b) Determine the maximum mass of calcium oxide that can be formed. [3]

(c) The student collects 12.6 g of calcium oxide. Calculate the percentage yield. [2]

(d) Calculate the volume of carbon dioxide, at r.t.p., released in the reaction. [2]

(e) The carbon dioxide is bubbled through 50.0 cm^3 of limewater of concentration 0.0200 mol/dm^3. Calculate the number of moles of calcium hydroxide present, and state whether it is enough to react with all the gas. [3]