Exercise walk-through

The mole and the Avogadro constant ▪ 3.3

eXercise

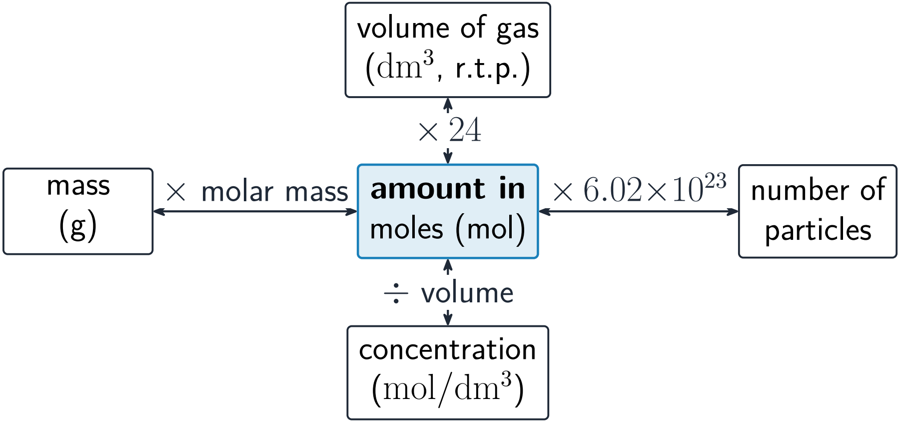
You must be able to

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

Method — Mole calculations

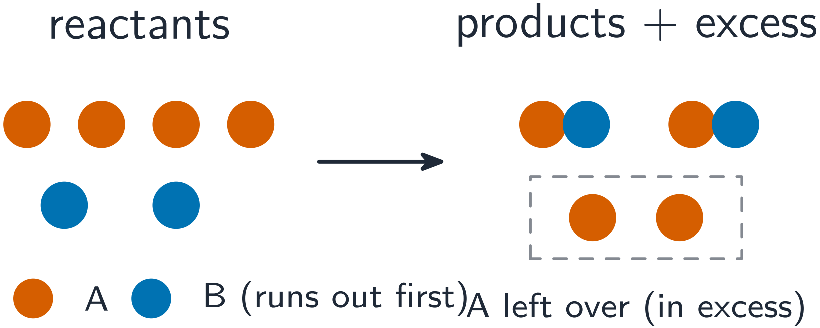
36 **g water:** $n = \dfrac{36}{18} = 2$ mol.

Method — Mole calculations



A mole map: moles in the centre, linked to mass, gas volume and concentration

Method — Mole calculations



Limiting reactant: B runs out, leaving A in excess

Method — 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**.

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

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: $2\mathrm{Mg} + \mathrm{O_2} \rightarrow 2\mathrm{MgO}$.
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. $M_r(\mathrm{MgO}) = 24 + 16 = 40$, so $m = n \times M_r = 0.20 \times 40 = 8.0$ g.

Method — The four calculations, each as a route through the mole

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. $\mathrm{NaOH} + \mathrm{HCl} \rightarrow \mathrm{NaCl} + \mathrm{H_2O}$ is $1:1$, so moles of NaOH $= 2.00 \times 10^{-3}$ mol.
3. $c = \dfrac{n}{V} = \dfrac{2.00 \times 10^{-3}}{0.0250} = 0.0800$ 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. $\mathrm{C} + \mathrm{O_2} \rightarrow \mathrm{CO_2}$; $n(\mathrm{C}) = \dfrac{6.0}{12} = 0.50$; $n(\mathrm{O_2}) = \dfrac{16.0}{32} = 0.50$.

Method — The four calculations, each as a route through the mole

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.

Practice 2.1 ▪ 2 marks

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

Solution 2.1

Method: The four calculations, each as a route through the mole

Worked steps

$$n = \frac{8.0}{40} = 0.20 \text{ mol}$$ **M1** **A1**.

Practice 2.2 ▪ 2 marks

Find the volume of 0.50 mol of a gas at r.t.p.

Solution 2.2

Method: Mole calculations

Worked steps

$V = 0.50 \times 24 = 12\ \mathrm{dm}^3$ M1 A1.

Practice 2.3 ▪ 2 marks

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

Solution 2.3

Method: The four calculations, each as a route through the mole

Worked steps

$$n = \frac{8.8}{44} \quad \textbf{M1} \quad = 0.20\ \text{mol} \quad \textbf{A1}.$$

Practice 2.4 ▪ 2 marks

Calculate the volume, at r.t.p., of 0.25 mol of hydrogen gas.

Solution 2.4

Method: Mole calculations

Worked steps

$V = 0.25 \times 24 = 6.0$ dm^3 M1 A1, which is 6000 cm^3.

Practice 2.5 ▪ 3 marks

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.)

Solution 2.5

Method: The four calculations, each as a route through the mole

Worked steps

$\frac{52.2}{12} = 4.35$, $\frac{13.0}{1} = 13.0$, $\frac{34.8}{16} = 2.175$ **M1**; dividing by the smallest, $2 : 6 : 1$ **M1**; the empirical formula is C_2H_6O **A1**.

Exam-style 3.1 ▪ 1 mark

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

A 0.25

B 0.50

C 1.0

D 2.0

Solution 3.1

Method: The four calculations, each as a route through the mole

A 0.25

B 0.50 ✓

C 1.0

D 2.0

Worked steps

B. $n = \dfrac{22}{44} = 0.50$ mol.

Exam-style 3.2 ▪ 1 mark

Magnesium burns: $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$ (A_r: Mg $= 24$, O $= 16$).
(a) Find the moles in 12 g of magnesium.
(b) Find the mass of magnesium oxide formed.

Solution 3.2

Method: The four calculations, each as a route through the mole

Worked steps

(a) $n = \dfrac{12}{24} = 0.50$ mol **B1**.
(b) ratio Mg : MgO is $1 : 1$, so 0.50 mol MgO **M1**; $M_r(\text{MgO}) = 40$ **M1**; mass $= 0.50 \times 40 = 20$ g **A1**.

Exam-style 3.3 ▪ 2 marks

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.
(b) Find the concentration of the sodium hydroxide.

Solution 3.3

Method: The four calculations, each as a route through the mole

Worked steps

(a) $M_r(\text{CaCO}_3) = 40 + 12 + 48 = 100$ **B1**; $n = \dfrac{25.0}{100} = 0.250$ mol **A1**.

(b) The ratio $\text{CaCO}_3 : \text{CaO}$ is $1 : 1$, so $n(\text{CaO}) = 0.250$ mol **B1**; $M_r(\text{CaO}) = 56$ **B1**; $m = 0.250 \times 56 = 14.0$ g **A1**.

(c) $\dfrac{12.6}{14.0} \times 100\%$ **M1** $= 90.0\%$ **A1**.

(d) $n(\text{CO}_2) = 0.250$ mol; $V = 0.250 \times 24$ **M1** $= 6.0\ \text{dm}^3$ **A1**.

(e) $n = c \times V = 0.0200 \times \dfrac{50.0}{1000}$ **M1** $= 1.00 \times 10^{-3}$ mol **A1**; this is far less than the 0.250 mol of carbon dioxide, so the limewater is not enough to react with all of it **B1**.

Exam-style 3.3 ▪ 2 marks

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.
(b) Determine the maximum mass of calcium oxide that can be formed.
(c) The student collects 12.6 g of calcium oxide. Calculate the percentage yield.
(d) Calculate the volume of carbon dioxide, at r.t.p., released in the reaction.
(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.

Solution 3.3

Method: The four calculations, each as a route through the mole

Worked steps

(a) $M_r(\mathrm{CaCO_3}) = 40 + 12 + 48 = 100$ **B1**; $n = \dfrac{25.0}{100} = 0.250$ mol **A1**.

(b) The ratio $\mathrm{CaCO_3}$: CaO is $1 : 1$, so $n(\mathrm{CaO}) = 0.250$ mol **B1**; $M_r(\mathrm{CaO}) = 56$ **B1**; $m = 0.250 \times 56 = 14.0$ g **A1**.

(c) $\dfrac{12.6}{14.0} \times 100\%$ **M1** $= 90.0\%$ **A1**.

(d) $n(\mathrm{CO_2}) = 0.250$ mol; $V = 0.250 \times 24$ **M1** $= 6.0\ \mathrm{dm^3}$ **A1**.

(e) $n = c \times V = 0.0200 \times \dfrac{50.0}{1000}$ **M1** $= 1.00 \times 10^{-3}$ mol **A1**; this is far less than the 0.250 mol of carbon dioxide, so the limewater is not enough to react with all of it **B1**.