A-LEVEL CHEMISTRY • EXERCISE SHEET

2.4 Reacting masses and volumes

Name: ____________ Class: ________ Date: __________ **Total: 31 marks**

KEY WORDS limiting reagent 限量试剂 • titration 滴定 • percentage yield 产率 • stoichiometry 化学计量 • ion 离子

Objective

Build the skills to answer exam questions on **reacting masses and volumes** — **stoichiometry** 化学计量, **percentage yield** 产率, **limiting reagent** 限量试剂, gas volumes, and **titration** 滴定 calculations.

You must be able to:

- calculate reacting masses and percentage yield from a balanced equation
- identify the limiting reagent and calculate gas volumes ($n = V/24$)
- calculate solution concentrations from a titration ($n = cV$)

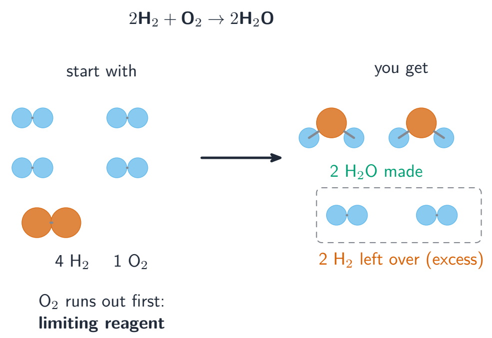
1 Worked examples

Reacting masses and percentage yield

Mole ratio comes from the equation. **Example.** Mass of MgO from 4.8 g Mg: $2Mg + O_2 \rightarrow 2MgO$. Moles Mg = 4.8/24 = 0.20; ratio 1:1 → 0.20 mol MgO; $m = 0.20 \times 40 = 8.0$ g.

$$\text{percentage yield} = \frac{\text{actual product}}{\text{maximum possible}} \times 100\%$$

Limiting reagent

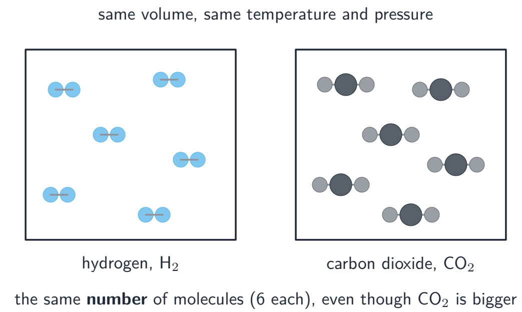


The limiting reagent runs out first and decides the product; the leftover is in excess

Find moles of each reactant, divide by its equation number — the smallest is the **limiting reagent**.

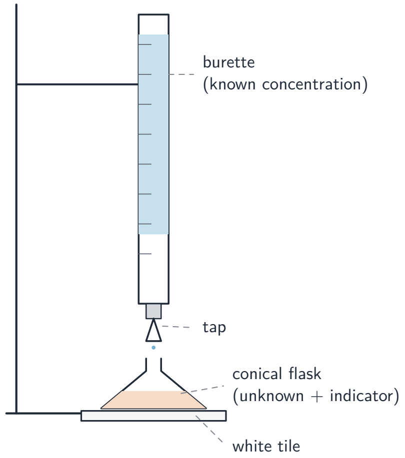
Gas volumes

At r.t.p. one mole of any gas = 24.0 dm^3, so $n = V/24.0$.



Equal gas volumes (same T, p) hold equal numbers of molecules

Titration ($n = cV$)



A titration finds an unknown concentration using a solution of known concentration

Example. 20.0 cm^3 of 0.100 mol dm^{-3} HCl neutralises 25.0 cm^3 NaOH (1:1). Moles HCl $= 0.100 \times 0.0200 = 2.00 \times 10^{-3}$; so NaOH conc $= 2.00 \times 10^{-3}/0.0250 = 0.0800$ mol dm^{-3}.

■ The three routes through a mole calculation

Every quantitative question is the same shape: **convert to moles → use the equation's ratio → convert to the answer's unit.**

$$n = \frac{m}{M_r} \qquad n = c \times V(\text{dm}^3) \qquad n = \frac{V(\text{dm}^3)}{24.0}\ \text{(gas at r.t.p.)} \qquad pV = nRT$$

Gas volumes shortcut. At the same temperature and pressure, equal volumes contain equal numbers of moles (Avogadro), so for gases the equation's coefficients are **volume ratios directly** — no conversion needed. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ burns 24 cm^3 of methane in 48 cm^3 of oxygen and makes 24 cm^3 of carbon dioxide (the water is liquid at r.t.p. and is not counted).

Limiting reactant. Divide each reactant's moles by its coefficient; the **smallest** answer is limiting, and every product amount follows from it. The other reactant is in excess, and the leftover is the difference.

Percentage yield and atom economy are different questions and are often confused:

$$\text{percentage yield} = \frac{\text{actual moles of product}}{\text{theoretical moles}} \times 100 \qquad \text{atom economy} = \frac{M_r(\text{desired product})}{\sum M_r(\text{all products})} \times 100$$

Yield is about how well the reaction *ran*; atom economy is a property of the *equation* and is fixed before you start.

Worked example. 0.30 mol of H_2 reacts with 0.20 mol of O_2: $2H_2 + O_2 \rightarrow 2H_2O$. Find the limiting reactant, the water formed, and the excess left over.

1. H_2: $\frac{0.30}{2} = 0.15$; O_2: $\frac{0.20}{1} = 0.20$.
2. The smaller is hydrogen, so **hydrogen is limiting**.
3. Ratio $H_2 : H_2O = 2 : 2$, so 0.30 mol of water forms, which is $0.30 \times 18 = 5.4$ g.
4. Oxygen used = 0.15 mol, so $0.20 - 0.15 = 0.05$ mol of oxygen remains.

2 Practice

2.1 Calculate the mass of carbon dioxide made when 10 g of calcium carbonate decomposes: $CaCO_3 \rightarrow CaO + CO_2$ (M_r: $CaCO_3$ 100, CO_2 44). [2]

2.2 Calculate the volume of 0.50 mol of gas at r.t.p. [1]

2.3 Calculate the volume of oxygen, at r.t.p., needed to burn 50 cm^3 of propane completely. [2]

2.4 State the difference between percentage yield and atom economy. [2]

2.5 0.40 mol of N_2 reacts with 0.90 mol of H_2 to make ammonia. Identify the limiting reactant. [2]

3 Exam-style questions

3.1 24 cm^3 of methane is burned completely in oxygen: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. What volume of CO_2 is made (same conditions)? [1]

- **A** 12 cm^3
- **B** 24 cm^3
- **C** 48 cm^3
- **D** 96 cm^3

3.2 0.30 mol of H_2 reacts with 0.20 mol of O_2: $2H_2 + O_2 \rightarrow 2H_2O$. The limiting reagent is: [1]

- **A** hydrogen
- **B** oxygen
- **C** water
- **D** neither — they react exactly

3.3 In a titration, 25.0 cm^3 of sulfuric acid is exactly neutralised by 20.0 cm^3 of 0.100 mol dm^{-3} NaOH: $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$.

(a) Calculate the moles of NaOH used. [1]

(b) Calculate the concentration of the sulfuric acid. [3]

3.4 8.0 g of methanol is made from a reaction whose maximum possible yield is 12.8 g. Calculate the percentage yield. [2]

3.5 Ammonia is manufactured by the Haber process: $N_2 + 3H_2 \rightleftharpoons 2NH_3$. In one run, 2.80 kg of nitrogen is mixed with 0.750 kg of hydrogen. (A_r: N 14.0, H 1.0.)

(a) Calculate the amount, in mol, of each reactant. [2]

(b) Determine which reactant is limiting, showing your reasoning. [2]

(c) Calculate the maximum mass of ammonia that could be formed. [3]

(d) The plant actually collects 1.02 kg of ammonia. Calculate the percentage yield. [2]

(e) Calculate the atom economy of this reaction for ammonia, and explain why it takes that value. [3]

(f) Calculate the volume that the unreacted excess reactant would occupy at r.t.p. [2]

Solutions

2.1 moles $CaCO_3 = 10/100 = 0.10$; ratio 1:1 $\rightarrow$ 0.10 mol CO_2; $m = 0.10 \times 44 = 4.4$ g.

2.2 $V = 0.50 \times 24.0 = 12$ dm^3.

2.3 $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$, so the volume ratio is $1:5$; $50 \times 5 = 250$ cm^3.

2.4 Percentage yield compares the product actually obtained with the theoretical maximum, so it measures how well the reaction ran; atom economy compares the mass of the desired product with the total mass of all products, and is fixed by the equation itself.

2.5 N_2: $\dfrac{0.40}{1} = 0.40$; H_2: $\dfrac{0.90}{3} = 0.30$; the smaller value is hydrogen, so hydrogen is limiting.

3.1 B. Ratio $CH_4 : CO_2$ is 1:1, so 24 cm^3 of CO_2.

3.2 A. $0.30/2 = 0.15$ for H_2 vs $0.20/1 = 0.20$ for O_2; H_2 gives the smaller value, so hydrogen is limiting.

3.3 (a) $n = 0.100 \times 0.0200 = 2.00 \times 10^{-3}$ mol.
(b) ratio H_2SO_4 : NaOH is 1:2, so moles $H_2SO_4 = 1.00 \times 10^{-3}$; $c = n/V = 1.00 \times 10^{-3}/0.0250 = 0.0400$ mol dm^{-3}.

3.4 $\dfrac{8.0}{12.8} \times 100 = 62.5\%$.

3.5 (a) $n(N_2) = \dfrac{2800}{28.0} = 100$ mol; $n(H_2) = \dfrac{750}{2.0} = 375$ mol.
(b) N_2: $\dfrac{100}{1} = 100$; H_2: $\dfrac{375}{3} = 125$; nitrogen gives the smaller value, so nitrogen is limiting.
(c) Ratio $N_2 : NH_3 = 1:2$, so $n(NH_3) = 200$ mol; $M_r(NH_3) = 17.0$; $m = 200 \times 17.0 = 3400$ g $= 3.40$ kg.
(d) $\dfrac{1.02}{3.40} \times 100 = 30.0\%$.
(e) Ammonia is the only product, so the atom economy is 100%; every atom of both reactants ends up in the desired product, which is characteristic of an addition or combination reaction.
(f) Hydrogen used $= 3 \times 100 = 300$ mol, so $375 - 300 = 75$ mol remains; $V = 75 \times 24.0 = 1800$ dm^3.