

1.1.2 Experimental formulae and molar gas volume

Name: _____ Class: _____ Date: _____

Total: 26 marks

KEY WORDS empirical formula • molar volume • constant mass

Objective

Use experimental masses and gas volumes to test formulae and equations. Evaluate a specific error direction rather than saying only that the result is inaccurate.

1 Key knowledge and worked examples

■ Separate the container from the chemical mass

A crucible weighs 18.00 g, with metal 18.48 g, and with its oxide after repeated heating 18.80 g. Metal mass = 0.48 g; oxygen mass = 0.32 g. For Mg = 24.0 and O = 16.0:

$$n(\text{Mg}) = 0.48/24.0 = 0.0200 \text{ mol}; \quad n(\text{O}) = 0.32/16.0 = 0.0200 \text{ mol}$$

The ratio is 1:1, giving MgO. Cool before weighing and repeat heat-cool-weigh until constant mass. A lid limits loss while admitting oxygen.

■ Gas volume tests a mole ratio

For a known limiting amount, molar volume = measured gas volume/amount of gas. A leak lowers the measured volume. To test a proposed reaction equation, predict gas amount from its coefficients and compare with evidence.

2 Practice

2.1 A metal oxide contains 1.08 g aluminium and 0.960 g oxygen. Use Al = 27.0, O = 16.0. Find its empirical formula. [3]

2.2 A 0.120 g magnesium sample reacts with excess acid and gives 118 cm³ hydrogen at the measured room conditions. Use $M_r = 24.0$ and $\text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$. Calculate the experimental molar gas volume in dm³ mol⁻¹. [3]

2.3 For the experiment in 2.2, explain the effect of a gas leak on the calculated molar volume and on a molar mass inferred from the same gas measurement. [3]

3 Exam-style questions

3.1 A heated sample of copper oxide loses 0.160 g when completely reduced to 0.635 g copper. Use $M_r = 63.5$, $O = 16.0$. Find the oxide formula. Explain why incomplete reduction would give an oxygen-to-copper ratio that is too low when final residue is assumed to be pure copper. [5]

3.2 A student proposes $\text{Ca} + 2\text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2 + \text{H}_2$. At a stated molar volume of $24.0 \text{ dm}^3 \text{ mol}^{-1}$, 0.200 g calcium gives 120 cm^3 hydrogen. Use $\text{Ca} = 40.0$. Test whether these data support the equation. State one limitation of concluding that it is proven. [4]

3.3 A magnesium oxidation experiment ends with a high calculated Mg:O ratio. Two possible causes are incomplete oxidation and loss of oxide smoke. Explain how each can produce this result. Suggest a distinct procedural control for each. [4]

3.4 A hydrocarbon contains 3.60 g carbon and 0.600 g hydrogen. Its relative molecular mass is 56.0. Use $\text{C} = 12.0$ and $\text{H} = 1.00$. Find its empirical and molecular formulae. [4]

Solutions

Original authored guidance; these tasks are not official past-paper questions.

2.1 $n(\text{Al}) = 1.08/27.0 = 0.0400 \text{ mol}$ and $n(\text{O}) = 0.960/16.0 = 0.0600 \text{ mol}$. Ratio = 1:1.5 = 2:3, giving Al_2O_3 .

2.2 $n(\text{Mg}) = 0.120/24.0 = 0.00500 \text{ mol}$; the 1:1 ratio gives the same hydrogen amount. $V = 0.118 \text{ dm}^3$.

$$V_m = V/n = 0.118/0.00500 = 23.6 \text{ dm}^3 \text{ mol}^{-1}$$

This value belongs to the actual measurement conditions, not every temperature and pressure.

2.3 A leak lowers recorded gas volume, so V/n and calculated molar volume are too low when n is fixed by the known magnesium amount. If instead gas volume determines n for an unknown substance, inferred n is too low and $M = m/n$ is too high.

3.1 Oxygen removed = 0.160 g. $n(\text{O}) = 0.160/16.0 = 0.0100 \text{ mol}$ and $n(\text{Cu}) = 0.635/63.5 = 0.0100 \text{ mol}$. Ratio 1:1 gives CuO . Incomplete reduction leaves oxygen in the residue, so recorded oxygen loss is too low; treating the heavier residue as all copper also overestimates copper amount, further lowering the inferred O:Cu ratio.

3.2 $n(\text{Ca}) = 0.200/40.0 = 0.00500 \text{ mol}$. The proposed equation predicts $n(\text{H}_2) = 0.00500 \text{ mol}$ and $V = nV_m = 0.00500 \times 24.0 = 0.120 \text{ dm}^3 = 120 \text{ cm}^3$. The measured value agrees, but one volume cannot establish every product identity or exclude compensating measurement errors. Agreement supports the proposed ratio rather than proving the complete equation alone.

3.3 Incomplete oxidation leaves a smaller oxygen mass gain, so oxygen amount is underestimated and Mg:O is too high; repeat heat-cool-weigh until constant mass with oxygen access. Escaping oxide lowers final mass and the inferred oxygen gain while the initial magnesium mass is still used; use a lid slightly open for oxygen and control heating to retain smoke.

3.4 $n(\text{C}) = 3.60/12.0 = 0.300 \text{ mol}$ and $n(\text{H}) = 0.600/1.00 = 0.600 \text{ mol}$. C:H = 1:2 gives CH_2 . Empirical-formula mass = 14.0; factor = $56.0/14.0 = 4$. Multiply every subscript by four to obtain C_4H_8 . This formula does not alone identify connectivity.