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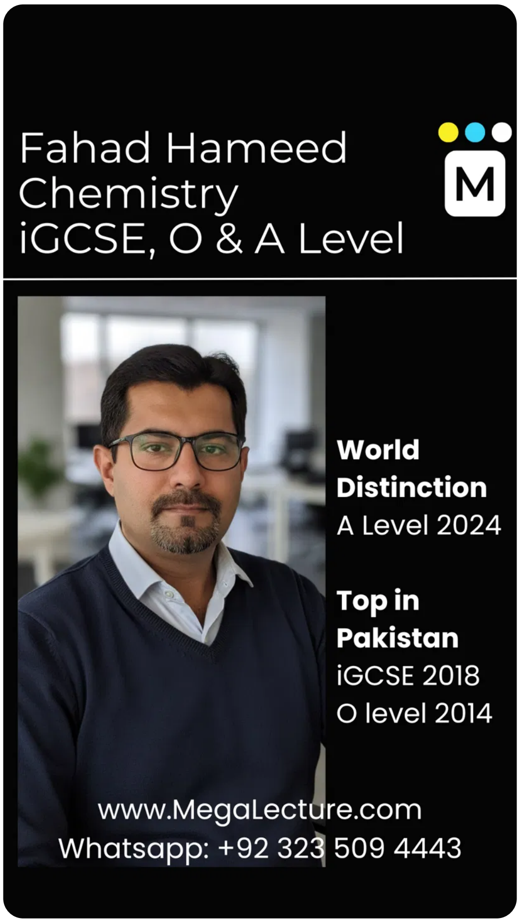
Chapter 3: Amount of Substance

OCR A Level Chemistry A (H432) — Structured Practice Worksheet



SPECIFICATION	TOTAL MARKS	SUGGESTED TIME
2.1.3 Amount of substance: moles, gases, solutions, formulae, yield & atom economy	99	2 hours

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Instructions to candidates

- Answer **all** questions in the spaces provided. Show all working — most marks are for working.
- Take molar gas volume at RTP as 24.0 $dm^3 mol^{-1}$, R = 8.314 J $mol^{-1} K^{-1}$, $N_A = 6.02 \times 10^{23} mol^{-1}$.
- Give answers to 3 significant figures unless told otherwise.
- Marks are shown in brackets [ ] at the end of each part.

Question 1 — Moles, mass and particles

2.1.3

a. Calculate the amount, in mol, of CO_2 in 8.80 g of carbon dioxide. **[2]**

b. Calculate the number of CO_2 molecules in this sample. **[2]**

c. Calculate the number of oxygen atoms in this sample. **[1]**

d. Calculate the mass of 0.250 mol of calcium hydroxide, $Ca(OH)_2$. **[3]**

Question 1 total: 8 marks

Question 2 — Empirical and molecular formulae

2.1.3

a. Define the term *empirical formula*. **[1]**

b. A compound contains 40.0% carbon, 6.7% hydrogen and 53.3% oxygen by mass. Determine its empirical formula. **[3]**

c. The relative molecular mass of the compound in (b) is 180. Determine its molecular formula. **[2]**

d. A hydrocarbon contains 85.7% carbon by mass and has a relative molecular mass of 56. Determine its empirical formula and its molecular formula. **[4]**

Question 2 total: 10 marks

Question 3 — Water of crystallisation

2.1.3 / PAG 1

A student heats 2.86 g of hydrated sodium carbonate, $Na_2CO_3 \cdot xH_2O$, until no further mass change occurs. The mass of the anhydrous residue is 1.06 g.

a. Determine the value of x. **[5]**

b. Explain why the solid is heated *to constant mass*. **[2]**

c. The student's value of x is lower than the true value. Suggest a reason for this and explain the effect on the calculation. **[3]**

Question 3 total: 10 marks

Question 4 — Gas calculations 2.1.3

a. State the ideal gas equation and the SI units of each quantity in it. **[2]**

b. Calculate the volume, in dm^3, occupied by 0.150 mol of a gas at RTP. **[2]**

c. 0.230 g of a gaseous compound occupies 112 cm^3 at 100 kPa and 298 K. Calculate the molar mass of the gas. **[4]**

d. The gas contains carbon, hydrogen and chlorine. Suggest its identity. **[1]**

e. Calculate the density of carbon dioxide gas, in $g\ dm^{-3}$, at RTP. **[3]**

Question 4 total: 12 marks

Question 5 — Solutions and concentration 2.1.3

a. 4.00 g of sodium hydroxide is dissolved in water and made up to 250 cm^3 of solution. Calculate the concentration in $mol\ dm^{-3}$. **[3]**

b. Express this concentration in $g\ dm^{-3}$. **[1]**

c. Calculate the volume of 2.00 $mol\ dm^{-3}$ hydrochloric acid needed to prepare 250 cm^3 of 0.100 $mol\ dm^{-3}$ solution by dilution. **[3]**

d. Describe how to prepare a standard solution from a solid, weighed sample. **[3]**

Question 5 total: 10 marks

Question 6 — Titration calculations

2.1.3 / PAG 2

25.0 cm^3 of sodium hydroxide solution of unknown concentration is titrated with 0.100 mol dm^{-3} hydrochloric acid. The mean titre is 22.60 cm^3.

a. Calculate the concentration of the sodium hydroxide solution in mol dm^{-3}. **[4]**

b. State what is meant by *concordant titres* and explain why only concordant titres are used to calculate the mean. **[2]**

c. Each burette reading has an uncertainty of ±0.05 cm^3. Calculate the percentage uncertainty in the titre of 22.60 cm^3. **[3]**

d. Suggest one way of reducing the percentage uncertainty in the titre. **[1]**

e. Explain why the burette is rinsed with the acid solution, not with water, before filling. **[2]**

Question 6 total: 12 marks

Question 7 — Limiting reagent

2.1.3

6.00 g of calcium carbonate is added to 50.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid.
$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

a.

Show, by calculation, that hydrochloric acid is the limiting reagent. **[3]**

b. Calculate the volume of carbon dioxide, in dm^3, produced at RTP. **[3]**

c. Calculate the mass of unreacted calcium carbonate remaining. **[4]**

Question 7 total: 10 marks

Question 8 — Percentage yield and atom economy

2.1.3

a. Define *percentage yield*. **[1]**

b. In an esterification, 0.500 mol of carboxylic acid produces 0.380 mol of ester. Calculate the percentage yield. **[2]**

c. Define *atom economy*. **[1]**

d. Calcium oxide is made by thermal decomposition: $CaCO_3 \rightarrow CaO + CO_2$. Calculate the atom economy for the production of calcium oxide. (A_r: Ca = 40.1, C = 12.0, O = 16.0) **[3]**

e. Explain the difference between percentage yield and atom economy, and explain why processes with high atom economy are important for sustainability. **[3]**

Question 8 total: 10 marks

Question 9 — Identifying a metal 2.1.3

0.486 g of a divalent metal **M** reacts with an excess of dilute hydrochloric acid, releasing 480 cm^3 of hydrogen gas at RTP.
$M(s) + 2HCl(aq) \rightarrow MCl_2(aq) + H_2(g)$

a. Calculate the relative atomic mass of **M** and identify the metal. **[5]**

b. Write the ionic equation for the reaction, with state symbols. **[3]**

Question 9 total: 8 marks

Question 10 — Practical planning PAG 1

A student is asked to determine the formula of hydrated copper(II) sulfate, $CuSO_4 \cdot xH_2O$, by heating. Plan the experiment. Your plan should include the apparatus, the measurements to be recorded, an outline of the calculation, and two precautions or sources of error. **[6]**

This question is marked using a level of response.

a. **[3]**

The blue solid turns black if heated too strongly. Explain what has happened and how this would affect the calculated value of x.

Question 10 total: 9 marks

PAPER TOTAL: 99 MARKS

MARK SCHEME — Chapter 3: Amount of Substance

Award marks independently unless stated. ECF applies throughout. Accept answers within rounding of those given.

Q1 (a) [2]

- $M(CO_2) = 44.0 \text{ g mol}^{-1}$; $n = 8.80 \div 44.0$ (1)
- $= 0.200$ mol. (1)

Q1 (b) [2]

- $0.200 \times 6.02 \times 10^{23}$ (1) $= 1.20 \times 10^{23}$ molecules. (1)

Q1 (c) [1]

- $2 \times 1.204 \times 10^{23} = 2.41 \times 10^{23}$ atoms. (1)

Q1 (d) [3]

- $M(Ca(OH)_2) = 40.1 + 2(16.0 + 1.0) = 74.1 \text{ g mol}^{-1}$ (1)
- $m = n \times M = 0.250 \times 74.1$ (1) $= 18.5$ g. (1)

Q2 (a) [1]

- The simplest whole-number ratio of atoms of each element in a compound. (1)

Q2 (b) [3]

- C: 40.0/12 = 3.33; H: 6.7/1 = 6.7; O: 53.3/16 = 3.33 (1)
- Ratio 1 : 2 : 1 (1)
- Empirical formula CH_2O. (1)

Q2 (c) [2]

- Mass of CH_2O = 30; 180 ÷ 30 = 6 (1)
- Molecular formula $C_6H_{12}O_6$. (1)

Q2 (d) [4]

- C: 85.7/12 = 7.14; H: 14.3/1 = 14.3 (1)
- Ratio 1 : 2 → empirical formula CH_2. (1)
- Mass of CH_2 = 14; 56 ÷ 14 = 4 (1)
- Molecular formula C_4H_8. (1)

Q3 (a) [5]

- Mass of water lost = 2.86 − 1.06 = 1.80 g (1)
- $n(Na_2CO_3) = 1.06 \div 106 = 0.0100$ mol (1)
- $n(H_2O) = 1.80 \div 18.0 = 0.100$ mol (1)
- Ratio = 0.100 ÷ 0.0100 = 10 (1)
- x = 10 ($Na_2CO_3 \cdot 10H_2O$). (1)

Q3 (b) [2]

- Repeated heating and weighing until two consecutive masses are the same... (1)
- ...which shows all the water of crystallisation has been removed. (1)

Q3 (c) [3]

- Heating was incomplete — some water of crystallisation remains in the residue. (1)
- The residue mass is too high, so the calculated water loss is too low. (1)
- $n(H_2O) \div n(Na_2CO_3)$ is therefore too small, giving a low x. (1)

Q4 (a) [2]

- $pV = nRT$ (1)
- p in Pa, V in m^3, n in mol, T in K ($R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$). (1)

Q4 (b) [2]

- 0.150×24.0 (1) $= 3.60 \text{ dm}^3$. (1)

Q4 (c) [4]

- $V = 112 \times 10^{-6}$ m^3; $p = 100\,000$ Pa (1)
- $n = pV/RT = (100\,000 \times 1.12 \times 10^{-4}) \div (8.314 \times 298)$ (1)
- $n = 4.52 \times 10^{-3}$ mol (1)
- $M = 0.230 \div 4.52 \times 10^{-3} = 50.9$ g mol^{-1} (accept 50–52). (1)

Q4 (d) [1]

- Chloromethane, CH_3Cl (M = 50.5). (1)

Q4 (e) [3]

- 1 mol (44.0 g) occupies 24.0 dm^3 at RTP (1)
- density = 44.0 ÷ 24.0 (1) = 1.83 g dm^{-3}. (1)

Q5 (a) [3]

- n(NaOH) = 4.00 ÷ 40.0 = 0.100 mol (1)
- V = 0.250 dm^3; c = 0.100 ÷ 0.250 (1) = 0.400 mol dm^{-3}. (1)

Q5 (b) [1]

- 0.400 × 40.0 = 16.0 g dm^{-3}. (1)

Q5 (c) [3]

- n needed = 0.250 × 0.100 = 0.0250 mol (1)
- V = 0.0250 ÷ 2.00 = 0.0125 dm^3 (1) = 12.5 cm^3. (1)

Q5 (d) [3]

- Weigh the solid accurately; dissolve in distilled water in a beaker. (1)
- Transfer with washings to a volumetric flask. (1)
- Make up to the graduation mark with distilled water and invert to mix. (1)

Q6 (a) [4]

- n(HCl) = 0.02260 × 0.100 = 2.26×10^{-3} mol (1)
- 1 : 1 ratio, so n(NaOH) = 2.26×10^{-3} mol (1)
- c = 2.26×10^{-3} ÷ 0.0250 (1)
- = 0.0904 mol dm^{-3}. (1)

Q6 (b) [2]

- Titres within 0.10 cm^3 of each other. (1)
- Excludes anomalous results, making the mean more reliable. (1)

Q6 (c) [3]

- Total uncertainty = 2 × 0.05 = 0.10 cm^3 (initial and final reading). (1)
- % = (0.10 ÷ 22.60) × 100 (1) = 0.44%. (1)

Q6 (d) [1]

- Use a larger titre — e.g. dilute the acid or use a larger volume of alkali (larger denominator lowers %). (1)

Q6 (e) [2]

- Water left in the burette would dilute the acid. (1)
- Its concentration would then be lower than 0.100 mol dm^{-3}, making the titre too large. (1)

Q7 (a) [3]

- n($CaCO_3$) = 6.00 ÷ 100.1 = 0.0599 mol (1)
- n(HCl) = 0.0500 × 2.00 = 0.100 mol (1)
- 0.0599 mol $CaCO_3$ requires 0.120 mol HCl > 0.100 mol available, so HCl is limiting. (1)

Q7 (b) [3]

- n(CO_2) = 0.100 ÷ 2 = 0.0500 mol (1)
- V = 0.0500 × 24.0 (1) = 1.20 dm^3. (1)

Q7 (c) [4]

- $n(CaCO_3)$ reacted = 0.100 ÷ 2 = 0.0500 mol (1)
- n unreacted = 0.0599 − 0.0500 = 0.0099 mol (1)
- m = 0.0099 × 100.1 (1) = 0.99 g. (1)

Q8 (a) [1]

- % yield = (actual amount of product ÷ theoretical amount) × 100. (1)

Q8 (b) [2]

- (0.380 ÷ 0.500) × 100 (1) = 76.0%. (1)

Q8 (c) [1]

- Atom economy = (M of desired product ÷ sum of M of all products) × 100. (1)

Q8 (d) [3]

- M(CaO) = 56.1; $M(CaCO_3)$ = 100.1 (total products = 56.1 + 44.0) (1)
- (56.1 ÷ 100.1) × 100 (1) = 56.0%. (1)

Q8 (e) [3]

- Yield measures how much product is actually obtained; atom economy is fixed by the equation and measures what fraction of reactant mass ends up in the desired product. (1)
- A reaction can have a high yield but low atom economy (or vice versa). (1)
- High atom economy means less waste / better use of raw materials — more sustainable and economical. (1)

Q9 (a) [5]

- $n(H_2)$ = 480 ÷ 24 000 = 0.0200 mol (1)
- 1 : 1 ratio, so n(M) = 0.0200 mol (1)
- A_r = 0.486 ÷ 0.0200 (1) = 24.3 (1)
- M is magnesium. (1)

Q9 (b) [3]

- $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$ (1 species, 1 balancing/charges, 1 state symbols)

Q10 (a) [6] — Level of response

- **Level 3 (5–6):** Complete plan: apparatus, all measurements, correct calculation outline, two valid precautions/errors.
- **Level 2 (3–4):** Workable plan with most measurements and a correct calculation outline; one precaution.
- **Level 1 (1–2):** Partial plan; key measurements or the calculation outline missing.

Indicative content: *weigh crucible empty, with hydrated salt, and after heating (crucible + residue); heat gently, cool (in a desiccator), reweigh; repeat to constant mass. Calculation: mass of anhydrous $CuSO_4$ → n = m/159.6; mass of water lost → n = m/18.0; x = $n(H_2O)/n(CuSO_4)$. Precautions/errors: avoid overheating (decomposition), spitting/loss of solid, incomplete dehydration, absorbing moisture while cooling in open air.*

Q10 (b) [3]

- $CuSO_4$ has decomposed to black copper(II) oxide (CuO), losing SO_3. (1)
- The residue mass is now too low, so the apparent mass of "water lost" is too high. (1)
- The calculated x would be too large. (1)

END OF MARK SCHEME · 99 marks