AQA | Year 12 chemistry

Amount of substance

Questions & answers

51 original questions | 361 marks. Questions start on page 2. Work in the dotted spaces, then check the answers at the back. Use the values supplied in each question.

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Relative masses & moles

Question 1 | AQA | 8 marks

(a) Define relative atomic mass, A_r. (2 marks)

(b) Define relative molecular mass, M_r. (2 marks)

(c) State the relative-mass term used for an ionic compound. (1 mark)

(d) State the unit of A_r, M_r and relative formula mass. (1 mark)

(e) Explain the difference between relative molecular mass and molar mass. (2 marks)

Question 2 | AQA | 6 marks

A mass spectrum of a copper sample gives the following ion counts for its two isotopes.

Relative isotopic mass	62.930	64.928
Number of ions detected	1383	617

(a) Calculate the relative atomic mass of copper. Give your answer to four significant figures. (3 marks)

(b) A student reports 63.929 by taking the unweighted mean of the two masses. Explain why this method is invalid. (2 marks)

(c) State the unit of the relative atomic mass you calculated. (1 mark)

Question 3 | AQA | 5 marks

Use H = 1.0, N = 14.0, O = 16.0, Al = 27.0 and S = 32.1.

(a) Calculate the relative molecular mass of HNO_3. (2 marks)

(b) Calculate the relative formula mass of $Al_2(SO_4)_3$. (3 marks)

Question 4 | AQA | 9 marks

Use $L = 6.022 \times 10^{23}$ mol^{-1}.

(a) Explain the difference between the mole and the Avogadro constant, L. (2 marks)

(b) Name the entity counted in each case: Fe, O_2, NaCl, Cl^- and transferred charge in a half-equation. (5 marks)

(c) Calculate the number of CO_2 molecules in 0.250 mol CO_2. (2 marks)

Question 5 | AQA | 7 marks

A sample contains 0.250 mol H_2SO_4 molecules. Use L = 6.022×10^{23} mol^{-1}.

(a) Calculate the number of H_2SO_4 molecules. (2 marks)

(b) Calculate the number of hydrogen atoms. (2 marks)

(c) Calculate the total number of atoms of all elements. (3 marks)

Mass–mole–particle calculations

Question 6 | AQA | 6 marks

(a) Calculate the number of moles in 11.7 g NaCl. M_r(NaCl) = 58.5. (2 marks)

(b) Calculate the mass of 0.0750 mol CO_2. M_r(CO_2) = 44.0. (2 marks)

(c) A molecular substance has mass 7.30 g and contains 0.125 mol. Calculate its relative molecular mass. (2 marks)

Question 7 | AQA | 2 marks

Use L = 6.022×10^{23} mol^{-1}. Calculate the amount in moles represented by 9.03×10^{22} atoms. (2 marks)

Question 8 | AQA | 7 marks

Use $L = 6.022 \times 10^{23}$ mol^{-1}.

(a) Calculate the amounts in moles of Al^{3+} and SO_4^{2-} ions represented by 0.0800 mol $Al_2(SO_4)_3$. (2 marks)

(b) Calculate the total number of ions represented by this sample. (2 marks)

(c) Sulfur has atomic number 16. Calculate the number of electrons in 0.0150 mol S^{2-} ions. (3 marks)

Question 9 | AQA | 5 marks

Use $L = 6.022 \times 10^{23}$ mol^{-1}.

(a) Calculate the number of H_2O molecules in 9.00 g water. $M_r(H_2O) = 18.0$. (2 marks)

(b) Calculate the number of oxygen atoms in 8.80 g CO_2. $M_r(CO_2) = 44.0$. (3 marks)

Question 10 | AQA | 4 marks

Sample A contains 3.20 g O_2, M_r = 32.0. Sample B contains 4.40 g CO_2, M_r = 44.0. Determine which contains more oxygen atoms. Support your answer with calculations. (4 marks)

Question 11 | AQA | 4 marks

A sample contains 7.525×10^{22} O_2 molecules. $M_r(O_2)$ = 32.0; L = 6.022×10^{23} mol^{-1}.

(a) Calculate the mass of the sample. (3 marks)

(b) State the appropriate number of significant figures for the final answer and justify it. (1 mark)

Question 12 | AQA | 5 marks

A 2.30 g molecular sample contains 3.01×10^{22} molecules. Use $L = 6.022 \times 10^{23}$ mol^{-1}.

(a) Calculate its relative molecular mass. (3 marks)

(b) State the mass of one mole of the substance. (1 mark)

(c) Use an approximate calculation to check that your relative molecular mass is reasonable. (1 mark)

Question 13 | AQA | 7 marks

A student calculates the number of CO_2 molecules in 2.50 g CO_2, M_r = 44.0, using L = 6.022×10^{23} mol^{-1}.

Student working: n = 2.50/44.0 = 0.0568 mol; N = 0.0568/(6.022×10^{23}) = 9.44×10^{-26}.

(a) Identify the error in converting amount to particle number. (1 mark)

(b) Calculate the correct number of CO_2 molecules. (3 marks)

(c) Explain why the unrounded amount should be retained and state the appropriate final precision. (2 marks)

(d) Write 0.004062 mol in standard form. (1 mark)

Equations & reacting masses

Question 14 | AQA | 7 marks

(a) Solid $KClO_3$ decomposes into solid KCl and oxygen gas. Write a balanced equation including state symbols. (2 marks)

(b) Balance $Al(s) + HCl(aq) \rightarrow AlCl_3(aq) + H_2(g)$. (2 marks)

(c) Balance $Ca_3(PO_4)_2(s) + H_2SO_4(aq) \rightarrow CaSO_4(s) + H_3PO_4(aq)$. (2 marks)

(d) Explain why changing a formula subscript is not a valid balancing method. (1 mark)

Question 15 | AQA | 10 marks

$CuSO_4(aq) + 2NaOH(aq) \rightarrow Cu(OH)_2(s) + Na_2SO_4(aq)$.

(a) Write the full ionic equation, including state symbols. (3 marks)

(b) Identify both spectator ions. (2 marks)

(c) Write the net ionic equation, including state symbols. (2 marks)

(d) Explain why $Cu(OH)_2$ is not separated into aqueous ions. (1 mark)

(e) Write the net ionic equation for a strong acid reacting with a strong alkali, including states. (2 marks)

Question 16 | AQA | 4 marks

Sulfur dioxide reacts with oxygen: $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$.

(a) Calculate the amount in moles of SO_3 formed from 0.350 mol SO_2 with O_2 in excess. (1 mark)

(b) Calculate the amount in moles of O_2 needed for 0.350 mol SO_2. (1 mark)

(c) Calculate the amount in moles of SO_3 formed from 0.125 mol O_2 with SO_2 in excess. (1 mark)

(d) Explain why the coefficients cannot be applied directly to masses in grams. (1 mark)

Question 17 | AQA | 4 marks

Titanium is formed in the following reaction: $TiCl_4(g) + Mg(l) \rightarrow Ti(s) + MgCl_2(l)$. A 7.29 g magnesium sample reacts with excess $TiCl_4$. Use $A_r(Mg) = 24.3$ and $A_r(Ti) = 47.9$.

(a) Balance the equation. (1 mark)

(b) Calculate the mass of titanium formed, to three significant figures. (3 marks)

Question 18 | AQA | 3 marks

$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$. Calculate the mass of Fe_2O_3 needed to produce 8.37 g Fe with CO in excess. Use $A_r(Fe) = 55.8$ and $M_r(Fe_2O_3) = 159.6$. (3 marks)

Question 19 | AQA | 5 marks

12.5 g limestone containing $CaCO_3$ and inert impurities reacts with excess HCl, producing 4.40 g CO_2. $CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$. Use $M_r(CO_2) = 44.0$ and $M_r(CaCO_3) = 100.1$.

(a) Calculate the percentage by mass of $CaCO_3$ in the limestone. (4 marks)

(b) Explain why HCl must be in excess. (1 mark)

Limiting reactants & linked reactions

Question 20 | AQA | 7 marks

$3Mg(s) + N_2(g) \rightarrow Mg_3N_2(s)$. A mixture contains 4.86 g Mg and 2.80 g N_2. Use $A_r(Mg) = 24.3$, $M_r(N_2) = 28.0$ and $M_r(Mg_3N_2) = 100.9$.

(a) Determine the limiting reactant and calculate the mass of Mg_3N_2 formed. (5 marks)

(b) Calculate the mass of the excess reactant remaining. (2 marks)

Question 21 | AQA | 4 marks

All oxygen from stage 1 is used in stage 2; the other reactants are in excess. Stage 1: $2KClO_3 \rightarrow 2KCl + 3O_2$. Stage 2: $4Fe + 3O_2 \rightarrow 2Fe_2O_3$. Calculate the mass of Fe_2O_3 formed from 5.00 g $KClO_3$. Use $M_r(KClO_3) = 122.6$ and $M_r(Fe_2O_3) = 159.6$. (4 marks)

Question 22 | AQA | 9 marks

Sodium made in stage 1 is transferred completely into stage 2. Stage 1: $2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$. Stage 2: $6Na(s) + Fe_2O_3(s) \rightarrow 3Na_2O(s) + 2Fe(s)$. 39.0 g NaN_3 is decomposed, and the sodium reacts with 17.60 g Fe_2O_3. Use $M_r(NaN_3) = 65.0$, $M_r(Fe_2O_3) = 159.6$ and $A_r(Fe) = 55.8$.

(a) Determine the limiting reactant in stage 2 and calculate the mass of iron formed. (6 marks)

(b) Calculate the mass of Fe_2O_3 remaining. (2 marks)

(c) State one assumption underlying the two-stage calculation. (1 mark)

Use A_r: Fe 55.8.

Question 23 | AQA | 7 marks

A hydrate has formula $MCl_2 \cdot xH_2O$ and contains 49.3% water by mass. A 2.22 g sample of the anhydrous chloride contains 0.802 g M. Use A_r: Cl 35.5, Mg 24.3, Ca 40.1, Zn 65.4, Ba 137.3; $M_r(H_2O) = 18.0$.

(a) Determine A_r(M) and identify the metal. (4 marks)

(b) Determine x. (3 marks)

Empirical & molecular formulae

Question 24 | AQA | 7 marks

Use A_r: Mg 24.3; Cl 35.5; P 31.0; O 16.0.

(a) Determine the empirical formula of a compound containing 1.215 g Mg and 3.550 g Cl. (3 marks)

(b) Determine the empirical formula of an oxide containing 43.7% phosphorus and 56.3% oxygen by mass. (3 marks)

(c) Explain why a mass ratio cannot be used directly as an empirical-formula ratio. (1 mark)

Question 25 | AQA | 8 marks

Heating 4.46 g iron in oxygen forms 6.38 g iron oxide. Use A_r(Fe) = 55.8 and A_r(O) = 16.0.

(a) Determine the empirical formula of the oxide. (4 marks)

(b) Explain the purpose of repeated heating, cooling and weighing until constant mass. (1 mark)

(c) Explain why the lid is kept slightly open during heating. (1 mark)

(d) Explain why the crucible must cool before weighing. (1 mark)

(e) State the effect of incomplete oxidation on the calculated oxygen-to-iron ratio. (1 mark)

Question 26 | AQA | 5 marks

A compound has empirical formula C_2H_4O and M_r = 88.0. Use A_r: C 12.0, H 1.0, O 16.0.

(a) Determine the molecular formula. (3 marks)

(b) Distinguish an empirical formula from a molecular formula. (2 marks)

Question 27 | AQA | 10 marks

Complete combustion of 0.880 g of a compound containing only C, H and O gives 1.760 g CO_2 and 0.720 g H_2O. M_r(compound) = 88.0. Use A_r: C 12.0, H 1.0, O 16.0.

(a) Determine the empirical formula, showing how the oxygen in the original sample is found. (6 marks)

(b) Determine the molecular formula. (2 marks)

(c) Explain why not all the oxygen in the combustion products came from the original compound. (1 mark)

(d) Explain why the oxygen-by-mass-difference method would fail if the original compound also contained nitrogen. (1 mark)

Question 28 | AQA | 7 marks

Complete combustion of 1.480 g of a compound containing only C, H and O gives 2.640 g CO_2 and 1.080 g H_2O. M_r(compound) = 148.0. Use A_r: C 12.0, H 1.0, O 16.0. Deduce its molecular formula. (7 marks)

Hydrated salts

Question 29 | AQA | 8 marks

4.76 g $CoCl_2 \cdot xH_2O$ leaves 2.60 g anhydrous $CoCl_2$ after heating to constant mass. Use $M_r(CoCl_2) = 130.0$ and $M_r(H_2O) = 18.0$.

(a) Determine x and write the hydrate formula. (4 marks)

(b) Explain what water of crystallisation means. (1 mark)

(c) State the effect on calculated x if some water remains, and if solid is lost by spitting. (2 marks)

(d) Explain why a separate decomposition of the salt would make this method unreliable. (1 mark)

Question 30 | AQA | 10 marks

A student heats 5.72 g $Na_2CO_3 \cdot xH_2O$. The table shows the mass after each heating. $M_r(Na_2CO_3)$ = 106.0.

Measurement	Mass after subtracting crucible / g
Before heating	5.72
After first heating	2.46
After second heating	2.12
After third heating	2.12

(a) Select the valid final mass and justify your choice. (2 marks)

(b) Determine x and write the formula of the hydrate. (5 marks)

(c) If the first-heating mass were used, explain why the calculated x would be too low. (3 marks)

Use $M_r(H_2O)$ = 18.0.

Concentration & dilution

Question 31 | AQA | 6 marks

(a) Calculate the number of moles in 32.50 cm^3 of 0.1800 mol dm^{-3} KOH. (2 marks)

(b) Calculate the concentration, in mol dm^{-3}, of a solution containing 0.01440 mol in 200.0 cm^3. (2 marks)

(c) Calculate the volume, in cm^3, of 0.1250 mol dm^{-3} solution that contains 0.00750 mol solute. (2 marks)

Question 32 | AQA | 6 marks

(a) A solution is made by dissolving 2.70 g K_2SO_4 and making the solution up to 500.0 cm^3. Calculate its concentration in mol dm^{-3}. $M_r(K_2SO_4)$ = 174.3. (3 marks)

(b) Calculate the mass concentration of this solution in g dm^{-3}. (1 mark)

(c) Calculate the mass of $CaCl_2$ needed to prepare 250.0 cm^3 of 0.0200 mol dm^{-3} solution. $M_r(CaCl_2)$ = 111.0. (2 marks)

Question 33 | AQA | 6 marks

(a) 15.0 cm^3 of 0.8000 mol dm^{-3} NaCl is diluted to a final volume of 250.0 cm^3. Calculate the final concentration in mol dm^{-3}. (3 marks)

(b) Calculate the volume, in cm^3, of 0.500 mol dm^{-3} stock solution needed to prepare 100.0 cm^3 of 0.0650 mol dm^{-3} solution. (2 marks)

(c) Explain why the stock volume from part (b) must not be mixed with 100.0 cm^3 of water. (1 mark)

Question 34 | AQA | 8 marks

Prepare 250.0 cm^3 of 0.0600 mol dm^{-3} Na_2CO_3 from a suitable anhydrous solid. $M_r(Na_2CO_3)$ = 106.0.

(a) Calculate the required mass. (2 marks)

(b) Describe how to prepare the solution accurately, including weighing and transfer. (6 marks)

Titrations & practical technique

Question 35 | AQA | 11 marks

(a) Explain why a burette is rinsed with its titrant before filling. (1 mark)

(b) Explain why a pipette is rinsed with its solution, but the conical flask may be rinsed or its walls washed with deionised water. (2 marks)

(c) Explain why the filling funnel is removed before taking the initial burette reading. (1 mark)

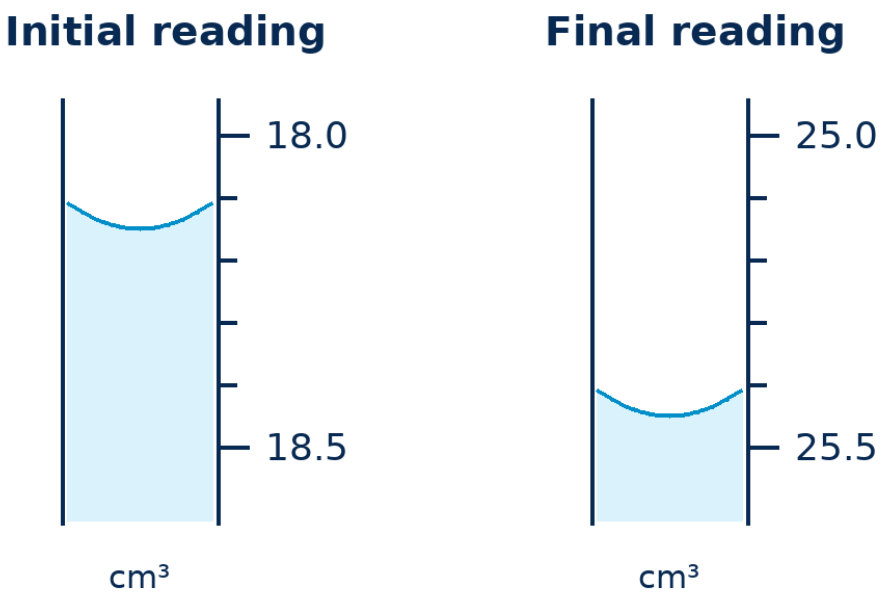
(d) State the purpose of the rough titration and describe how titrant should be added near the end point in accurate repeats. (2 marks)

(e) Distinguish end point from equivalence point. (2 marks)

(f) Explain why the final drop in a standard transfer pipette is not blown out. (1 mark)

(g) Name a suitable indicator for HCl added to NaOH and state its end-point colour change. (2 marks)

Question 36 | AQA | 4 marks



(a) Record the initial and final readings. (2 marks)

(b) Calculate the titre. (1 mark)

(c) Explain why the meniscus must be read at eye level. (1 mark)

Question 37 | AQA | 8 marks

The table shows burette readings from one rough titration and four accurate titrations.

Reading / cm^3	Rough	1	2	3	4
Final	25.10	24.80	49.30	24.75	49.60
Initial	0.20	0.15	24.60	0.25	24.90

(a) Calculate the five titres. (2 marks)

(b) Use a concordance limit of 0.10 cm^3. Select the concordant accurate titres and calculate their mean. (3 marks)

(c) Explain why the other two values are excluded and why burette readings are recorded to two decimal places. (3 marks)

Question 38 | AQA | 6 marks

25.00 cm^3 sulfuric acid reacts exactly with 21.35 cm^3 of 0.1200 mol dm^{-3} NaOH. $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$. Use $M_r(H_2SO_4) = 98.1$.

(a) Calculate the sulfuric acid concentration in mol dm^{-3}. (4 marks)

(b) Calculate its mass concentration in g dm^{-3}. (2 marks)

Question 39 | AQA | 7 marks

10.00 cm^3 of household ammonia solution is diluted to 250.0 cm^3. A 25.00 cm^3 aliquot of the diluted solution requires 18.40 cm^3 of 0.1000 mol dm^{-3} HCl solution for complete neutralisation. $NH_3 + HCl \rightarrow NH_4Cl$

(a) Calculate the concentration of NH_3 in the original household solution, in mol dm^{-3}. (5 marks)

(b) Calculate the mass concentration of NH_3 in the original solution, in g dm^{-3}. $M_r(NH_3) = 17.0$. (2 marks)

Question 40 | AQA | 8 marks

A mean titre is 23.40 cm^3. Each burette reading has uncertainty ±0.05 cm^3.

(a) Calculate the percentage uncertainty in the titre due to the two burette readings only. (2 marks)

(b) The end-point judgement adds a further ±0.05 cm^3. Calculate the total percentage uncertainty when this is included. (2 marks)

(c) Known acid is in the burette and unknown alkali is in the conical flask. Explain the effect on the calculated alkali concentration if the burette is left wet with water before filling. (3 marks)

(d) Explain why concordant titres do not prove that the final concentration is accurate. (1 mark)

Question 41 | AQA | 8 marks

Known hydrochloric acid is delivered from a burette to an aliquot of unknown sodium hydroxide in a conical flask.

(a) The pipette is left wet with water before the sodium hydroxide aliquot is measured. Explain the effect on the titre and on the calculated sodium hydroxide concentration. (3 marks)

(b) The conical flask is left wet with deionised water before the aliquot is added. Explain why this does not change the calculated concentration. (2 marks)

(c) An air bubble in the burette jet is present at the initial reading and disappears during the titration. Explain the effect on the titre and on the calculated sodium hydroxide concentration. (3 marks)

Question 42 | AQA | 9 marks

A 1.80 g sample contains Na_2CO_3 and impurities. The sample is dissolved and made up to 250.0 cm^3. A 25.00 cm^3 aliquot of this solution requires 20.40 cm^3 of 0.1000 mol dm^{-3} HCl solution for complete neutralisation. $Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$

(a) Calculate the percentage by mass of Na_2CO_3 in the sample. $M_r(Na_2CO_3) = 106.0$. (6 marks)

(b) State one assumption about the impurities required by this calculation. (1 mark)

(c) A student overshoots the end point in every accurate titration. Explain the effect on the calculated percentage of Na_2CO_3. (2 marks)

Question 43 | AQA | 8 marks

1.590 g anhydrous Na_2CO_3 is made up to 250.0 cm^3. A 25.00 cm^3 aliquot of this solution requires 30.20 cm^3 of HCl solution for complete neutralisation. Then 22.65 cm^3 of this HCl solution completely neutralises 25.00 cm^3 of NaOH solution. $Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$; $HCl + NaOH \rightarrow NaCl + H_2O$. $M_r(Na_2CO_3) = 106.0$.

(a) Calculate the HCl concentration in mol dm^{-3}. (5 marks)

(b) Calculate the NaOH concentration in mol dm^{-3}, retaining the full first answer in your working. (3 marks)

Question 44 | AQA | 8 marks

A 1.25 g antacid tablet containing $CaCO_3$ and inert binder reacts with excess HCl: 50.00 cm^3 of 0.5000 mol dm^{-3}. All the HCl remaining after complete reaction is completely neutralised by 15.00 cm^3 of 0.2000 mol dm^{-3} NaOH solution. $CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$; $HCl + NaOH \rightarrow NaCl + H_2O$. $M_r(CaCO_3) = 100.1$.

(a) Calculate the percentage by mass of $CaCO_3$ in the tablet. (6 marks)

(b) Explain the effect on the calculated percentage if some $CaCO_3$ does not react. (2 marks)

Question 45 | AQA | 16 marks

An industrial feed contains $NaHCO_3$ and inert material. A 1.200 g feed sample is dissolved and made up to 250.0 cm^3. A 25.00 cm^3 aliquot of this solution requires 12.80 cm^3 of 0.1000 mol dm^{-3} HCl solution for complete neutralisation. A production batch uses 50.0 kg of the same feed and obtains 24.6 kg Na_2CO_3. $NaHCO_3 + HCl \rightarrow NaCl + CO_2 + H_2O$ $2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$ M_r: $NaHCO_3$ = 84.0; Na_2CO_3 = 106.0.

(a) Use the titration to calculate the percentage by mass of $NaHCO_3$ in the feed. (5 marks)

(b) Calculate the theoretical mass of Na_2CO_3 obtainable from the 50.0 kg feed batch. (4 marks)

(c) Calculate the percentage yield of Na_2CO_3. (2 marks)

(d) Calculate the atom economy for making Na_2CO_3 by the decomposition reaction. (2 marks)

(e) Explain why the percentage yield and atom economy have different values, and state one further item of information needed to judge the process. (3 marks)

Gas calculations

Question 46 | AQA | 11 marks

A 1.05 g sample vaporises completely. Its vapour occupies 425 cm^3 at 102 kPa and 25 °C. Assume ideal behaviour and use R = 8.31 J mol^{-1} K^{-1}.

(a) Calculate the amount in moles of vapour. (3 marks)

(b) Calculate its relative molecular mass. (2 marks)

(c) State one further experimental condition, other than the assumptions already given, required for this result to be valid. (1 mark)

(d) A gas has density 2.00 g dm^{-3} at 101 kPa and 298 K. Calculate its relative molecular mass. (3 marks)

(e) Explain why ideal-gas behaviour is a better approximation at low pressure and high temperature. (2 marks)

Question 47 | AQA | 7 marks

80.0 cm^3 N_2 and 180 cm^3 H_2 react completely according to $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$. All gas volumes are measured at the same temperature and pressure.

(a) Determine the limiting reactant and calculate the total final gas volume. (4 marks)

(b) Explain why equation coefficients can be used as gas-volume ratios here. (1 mark)

(c) A separate gas sample occupies 360.0 cm^3 where the supplied molar gas volume is 24.0 dm^3 mol^{-1}. Calculate the number of moles of gas in this sample. (2 marks)

Question 48 | AQA | 6 marks

0.500 g $CaCO_3$ reacts with 25.0 cm^3 of 0.300 mol dm^{-3} HCl. $CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$. Use $M_r(CaCO_3) = 100.1$ and $R = 8.31$ J mol^{-1} K^{-1}.

(a) Determine the limiting reactant. (3 marks)

(b) Calculate the maximum CO_2 volume at 100 kPa and 298 K, in cm^3. (3 marks)

Yield & atom economy

Question 49 | AQA | 10 marks

0.600 g Mg reacts with 40.0 cm^3 of 0.500 mol dm^{-3} HCl. 220 cm^3 H_2 is collected at 98.0 kPa and 298 K. Gas-volume uncertainty is ±2 cm^3. $Mg + 2HCl \rightarrow MgCl_2 + H_2$. Use $A_r(Mg) = 24.3$ and $R = 8.31$ J mol^{-1} K^{-1}.

(a) Determine the limiting reactant and theoretical number of moles of H_2. (4 marks)

(b) Calculate the actual number of moles of H_2 and percentage yield. (4 marks)

(c) Calculate the percentage uncertainty in the gas volume. (1 mark)

(d) State the effect of a gas leak on the measured yield. (1 mark)

Question 50 | AQA | 9 marks

Two routes make ethanol. Each trial uses 1.00 mol of the limiting organic reactant; the other reactant is in excess. Route A: $C_2H_4 + H_2O \rightarrow C_2H_5OH$. Route B: $C_2H_5Cl + NaOH \rightarrow C_2H_5OH + NaCl$. Actual ethanol masses are 36.8 g for A and 41.4 g for B. Use M_r: C_2H_4 28.0, H_2O 18.0, C_2H_5Cl 64.5, NaOH 40.0, C_2H_5OH 46.0.

(a) Calculate the atom economy for each route. (3 marks)

(b) Calculate the percentage yield for each route. (3 marks)

(c) Explain why catalysts, solvents and arbitrary excess quantities are not included in the atom-economy denominator. (2 marks)

(d) Explain the effect on the calculated ethanol yield if the isolated product contains water. (1 mark)

Question 51 | AQA | 9 marks

Two routes make the same desired product. Each starts with 100.0 kg of a stoichiometric mixture of its reactants, excluding solvents, catalysts and inert material. The stated yield applies to the theoretical product amount.

Route	Atom economy	Yield	Energy / GJ t^{-1}	By-product information
X	92.0%	74.0%	8.0	Small amount; low toxicity
Y	68.0%	96.0%	4.5	Corrosive; largely recovered

(a) Calculate the actual desired-product mass obtained by each route. (4 marks)

(b) Recommend a route using the full data set, recognising how a different priority could alter the decision. (3 marks)

(c) Explain why a high yield alone does not show that little waste forms. (2 marks)

Answers & marking points

Equivalent correct chemistry and working are acceptable. Use the question number to find the matching answer.

Relative masses & moles

Question 1 | AQA | 8 marks

(a) A_r is the weighted mean mass of an atom of an element [1] relative to one-twelfth of the mass of one carbon-12 atom. [1]

(b) M_r is the mean mass of a molecule [1] relative to one-twelfth of the mass of one carbon-12 atom. [1]

(c) Relative formula mass. [1]

(d) A_r, M_r and relative formula mass have no unit. [1]

(e) Molar mass is the mass of one mole of specified entities [1] and has unit g mol^{-1}. [1] Its numerical value is normally the same as the corresponding relative mass.

EXAM TRAP Relative masses are ratios, so they have no unit. Molar mass is a mass per mole and must carry g mol^{-1}.

Question 2 | AQA | 6 marks

(a) A_r = [(62.930 × 1383) + (64.928 × 617)] ÷ (1383 + 617). [1] Total ions = 2000; calculator value = 63.546383. [1] To four significant figures, A_r = 63.55. [1]

(b) The isotope abundances are unequal, so an unweighted mean gives each isotope the same influence. [1] Weight each isotopic mass by its ion count and divide the sum by the total ion count. [1]

(c) No unit. [1]

EXAM TRAP Divide by the total abundance. Here the counts total 2000, so the denominator is 2000. Use 100 only when the given abundances are percentages. Keep the full calculator value until the final rounding step.

Question 3 | AQA | 5 marks

Relative molecular/formula mass = sum of the A_r contributions of every atom

(a) $M_r(HNO_3)$ = 1.0 + 14.0 + 3(16.0) [1] = 63.0. [1]

(b) $Al_2(SO_4)_3$ contains $Al_2S_3O_{12}$. [1] Relative formula mass = 2(27.0) + 3(32.1) + 12(16.0) [1] = 342.3. [1]

Question 4 | AQA | 9 marks

(a) The mole, mol, is the unit of amount of substance. [1] L is the number of specified entities per mole, with unit mol^{-1}. [1]

(b) Atoms; molecules; formula units; ions; electrons, respectively. [1 each]

(c) N = nL = 0.250 × 6.022 × 10^{23} [1] = 1.51 × 10^{23} CO_2 molecules. [1]

Question 5 | AQA | 7 marks

(a) N(H_2SO_4 molecules) = nL
N(H_2SO_4 molecules) = 0.250 × 6.022 × 10^{23} [1] = 1.51 × 10^{23} molecules. [1]

(b) Moles of hydrogen atoms = moles of H_2SO_4 × hydrogen atoms per molecule
n(H atoms) = 2 × 0.250 = 0.500 mol [1], so N = nL
N = 0.500 × 6.022 × 10^{23} = 3.01 × 10^{23} H atoms. [1]

(c) One H_2SO_4 molecule contains 2 + 1 + 4 = 7 atoms. [1] Total moles of atoms = moles of H_2SO_4 × total atoms per molecule
n(total atoms) = 7 × 0.250 = 1.75 mol [1], so N = nL
N = 1.75 × 6.022 × 10^{23} = 1.05 × 10^{24} atoms. [1]

EXAM TRAP For hydrogen atoms, multiply the molecular amount by 2. For all atoms, multiply it by 7.

Mass–mole–particle calculations

Question 6 | AQA | 6 marks

(a) $n = m/M_r$
n = 11.7/58.5 [1] = 0.200 mol. [1]

(b) $m = n \times M_r$
m = 0.0750 × 44.0 [1] = 3.30 g. [1]

(c) $M_r = m/n$
M_r = 7.30/0.125 [1] = 58.4, with no unit. [1]

Question 7 | AQA | 2 marks

n = N/L = (9.03 × 10^{22})/(6.022 × 10^{23}) [1] = 0.150 mol of atoms. [1]

Question 8 | AQA | 7 marks

(a) Moles of aluminium ions = moles of $Al_2(SO_4)_3$ × aluminium ions per formula unit
n(Al^{3+}) = 2 × 0.0800 = 0.160 mol [1]; Moles of sulfate ions = moles of $Al_2(SO_4)_3$ × sulfate ions per formula unit
n(SO_4^{2-}) = 3 × 0.0800 = 0.240 mol. [1]

(b) Total moles of ions = moles of $Al_2(SO_4)_3$ × total ions per formula unit
n(all ions) = (2 + 3) × 0.0800 = 0.400 mol [1]; N = nL
N = 0.400 × 6.022 × 10^{23} = 2.41 × 10^{23} ions. [1]

(c) Each S^{2-} has 16 + 2 = 18 electrons. [1] n(electrons) = electrons per ion × n(ions)
n(electrons) = 18 × 0.0150 = 0.270 mol. [1] N = nL
N = 0.270 × 6.022 × 10^{23} = 1.63 × 10^{23} electrons. [1]

Question 9 | AQA | 5 marks

(a) $n(H_2O) = m/M_r$
$n(H_2O) = 9.00/18.0 = 0.500$ mol [1]; $N = nL$
$N = 0.500 \times 6.022 \times 10^{23} = 3.01 \times 10^{23}$ molecules. [1]

(b) $n(CO_2) = m/M_r$
$n(CO_2) = 8.80/44.0 = 0.200$ mol [1]; Moles of oxygen atoms = moles of CO_2 × oxygen atoms per molecule
$n(O\ atoms) = 2 \times 0.200 = 0.400$ mol [1]; $N = nL$
$N = 0.400 \times 6.022 \times 10^{23} = 2.41 \times 10^{23}$ oxygen atoms. [1]

Question 10 | AQA | 4 marks

A: $n(O_2) = m/M_r$
$n(O_2) = 3.20/32.0 = 0.100$ mol. [1] B: $n(CO_2) = m/M_r$
$n(CO_2) = 4.40/44.0 = 0.100$ mol. [1] Each molecule contains two O atoms, so each sample contains 0.200 mol O atoms. [1] The numbers of oxygen atoms are equal. [1] Multiplication by L is valid but unnecessary for the comparison.

Question 11 | AQA | 4 marks

(a) $n = (7.525 \times 10^{22})/(6.022 \times 10^{23}) = 0.124958...$ mol. [1] $m = n \times 32.0$ [1] = 3.99867... g, giving 4.00 g. [1]

(b) Three significant figures, limited by the supplied $M_r = 32.0$. [1]

Question 12 | AQA | 5 marks

(a) $n = (3.01 \times 10^{22})/(6.022 \times 10^{23}) = 0.0499834...$ mol. [1] $M_r = 2.30/n$ [1] = 46.0, with no unit. [1]

(b) 46.0 g. [1]

(c) The sample is approximately 0.0500 mol, one-twentieth of a mole, so one mole should have mass about 20 × 2.30 = 46 g. [1]

Question 13 | AQA | 7 marks

(a) Moving from moles to particle number requires multiplication by L. [1]

(b) $n = m/M_r$
$n = 2.50/44.0 = 0.056818...$ mol [1]; $N = nL$ [1] = 3.42×10^{22} CO_2 molecules. [1]

(c) Retaining the calculator value avoids an extra rounding error. [1] The final answer is to three significant figures, matching the mass and supplied M_r. [1]

(d) 4.062×10^{-3} mol. [1]

Equations & reacting masses

Question 14 | AQA | 7 marks

(a) $2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$: coefficients [1]; states [1].

(b) $2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$: Al/$AlCl_3$ coefficients [1]; HCl/H_2 coefficients [1].

(c) $Ca_3(PO_4)_2(s) + 3H_2SO_4(aq) \rightarrow 3CaSO_4(s) + 2H_3PO_4(aq)$: Ca/S species [1]; phosphate/acid coefficients [1].

(d) The subscript is part of the substance’s formula; changing it changes the substance. [1]

Question 15 | AQA | 10 marks

(a) $Cu^{2+}(aq) + SO_4^{2-}(aq) + 2Na^+(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s) + 2Na^+(aq) + SO_4^{2-}(aq)$. Appropriate dissociation [1]; species/coefficients [1]; states and conserved charge [1].

(b) Na^+ [1] and SO_4^{2-}. [1]

(c) $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$: species/ratio [1]; states and charge [1].

(d) It is an insoluble solid, rather than freely separated aqueous ions. [1]

(e) $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$: species/stoichiometry [1]; states [1].

Question 16 | AQA | 4 marks

(a) 0.350 mol SO_3. [1] (b) 0.350 × 1/2 = 0.175 mol O_2. [1] (c) 0.125 × 2 = 0.250 mol SO_3. [1]

(d) The coefficients give particle/amount ratios; different substances have different masses per mole. [1]

Question 17 | AQA | 4 marks

(a) $TiCl_4(g) + 2Mg(l) \rightarrow Ti(s) + 2MgCl_2(l)$. [1]

(b) $n(Mg) = m/A_r$
n(Mg) = 7.29/24.3 = 0.300 mol. [1] n(Ti) = n(known substance) × coefficient(target)/coefficient(known substance)
n(Ti) = 0.300/2 = 0.150 mol. [1] $m(Ti) = n \times A_r$
m(Ti) = 0.150 × 47.9 = 7.185 g = 7.19 g. [1]

Question 18 | AQA | 3 marks

$n(Fe) = m/A_r$
n(Fe) = 8.37/55.8 = 0.150 mol. [1] $n(Fe_2O_3)$ = n(known substance) × coefficient(target)/coefficient(known substance)
$n(Fe_2O_3)$ = 0.150/2 = 0.0750 mol. [1] $m(Fe_2O_3) = n \times M_r$
$m(Fe_2O_3)$ = 0.0750 × 159.6 = 11.97 g = 12.0 g to three significant figures. [1]

Question 19 | AQA | 5 marks

Percentage purity = (mass of pure substance ÷ mass of sample) × 100
(a) $n(CO_2) = m/M_r$
$n(CO_2)$ = 4.40/44.0 = 0.100 mol. [1] The 1:1 ratio gives 0.100 mol $CaCO_3$. [1] Pure $CaCO_3$ mass = 0.100 × 100.1 = 10.01 g. [1] Purity = 10.01/12.5 × 100 = 80.1%. [1]

(b) Enough HCl must be available to react with all the $CaCO_3$, so the measured CO_2 represents the carbonate rather than a shortage of acid. [1]

Limiting reactants & linked reactions

Question 20 | AQA | 7 marks

(a) $3Mg + N_2 \rightarrow Mg_3N_2$.

Quantity	Mg	N_2	Mg_3N_2
Mass / g	4.86	2.80	$m = n \times M_r$ 0.066666... × 100.9 = **6.73** [1]
A_r or M_r (no unit)	24.3	28.0	100.9
Amount, n / mol	$n = m/A_r$ 4.86/24.3 = 0.200 [1]	$n = m/M_r$ 2.80/28.0 = 0.100 [1]	0.066666... × 1 = 0.066666... [1]
Coefficient	3	1	1
n ÷ coefficient / mol	0.200/3 = **0.066666… (smaller)**	0.100/1 = 0.100	Product: not compared

Mg is limiting because its n ÷ coefficient is smaller. [1]

(b) $n(N_2 \text{ left}) = n(N_2 \text{ initial}) - n(Mg)/3$
$n(N_2 \text{ left}) = 0.100 - 0.200/3 = 0.033333...$ mol. [1] $m(N_2 \text{ left}) = n \times M_r$
$m(N_2 \text{ left}) = 0.033333... \times 28.0 = 0.933$ g. [1]

Question 21 | AQA | 4 marks

$n(KClO_3) = m/M_r$
$n(KClO_3) = 5.00/122.6 = 0.040783...$ mol. [1] $n(O_2) = n(\text{known substance}) \times \text{coefficient(target)/coefficient(known substance)}$
$n(O_2) = 0.040783... \times 3/2 = 0.061174...$ mol. [1] $n(Fe_2O_3) = n(\text{known substance}) \times \text{coefficient(target)/coefficient(known substance)}$
$n(Fe_2O_3) = 0.061174... \times 2/3 = 0.040783...$ mol. [1] $m = n \times M_r$
$m = 0.040783... \times 159.6 = 6.51$ g. [1]

Question 22 | AQA | 9 marks

(a) Stage 1: $n(NaN_3) = m/M_r = 39.0/65.0 = 0.600$ mol. [1] The 1 : 1 NaN_3 : Na ratio gives 0.600 mol Na. [1] For stage 2, $6Na + Fe_2O_3 \rightarrow 3Na_2O + 2Fe$:

Quantity	Na	Fe_2O_3	Fe
Mass / g	Moles known from stage 1	17.60	$m = n \times A_r$ $0.200 \times 55.8 =$ **11.2** [1]
A_r or M_r (no unit)	Not needed	159.6	55.8
Amount, n / mol	0.600	$n = m/M_r$ 17.60/159.6 = 0.110276... [1]	$0.100 \times 2 = 0.200$ [1]
Coefficient	6	1	2
n ÷ coefficient / mol	0.600/6 = **0.100 (smaller)**	0.110276.../1 = 0.110276...	Product: not compared

Na is limiting because its n ÷ coefficient is smaller. [1]

(b) Stage 2 uses $0.600/6 = 0.100$ mol Fe_2O_3, mass 15.96 g. [1] Remaining mass = 17.60 − 15.96 = 1.64 g. [1]

(c) Any one: stage 1 is complete; stage 2 goes to completion; no competing reaction consumes the sodium. [1] Do not credit complete transfer, which is stated in the question.

Question 23 | AQA | 7 marks

(a) $m(Cl) = 2.22 - 0.802 = 1.418$ g. [1] $n(Cl) = m/A_r$
$n(Cl) = 1.418/35.5 = 0.0399437...$ mol. [1] $n(M) = n(Cl)/2 = 0.0199718...$ mol. [1] $A_r(M) = m/n$
$A_r(M) = 0.802/0.0199718... = 40.2$ to three significant figures, consistent with Ca. [1]

(b) In 100 g hydrate: $n(water) = m/M_r$
$n(water) = 49.3/18.0 = 2.73889...$ mol. [1] $n(CaCl_2) = m/M_r$
$n(CaCl_2) = 50.7/111.1 = 0.456346...$ mol. [1] $x = n(H_2O)/n(\text{anhydrous salt})$
$x = 2.73889.../0.456346... = 6.001... \approx 6$. [1]

Empirical & molecular formulae

Question 24 | AQA | 7 marks

(a) $n(Mg) = m/A_r$
$n(Mg) = 1.215/24.3 = 0.0500$ mol and $n(Cl) = m/A_r$
$n(Cl) = 3.550/35.5 = 0.100$ mol. [1] Ratio 1:2. [1] $MgCl_2$. [1]

(b) For 100 g, $n(P) = m/A_r$
$n(P) = 43.7/31.0 = 1.40968...$ and $n(O) = m/A_r$
$n(O) = 56.3/16.0 = 3.51875$ mol. [1] Ratio 1:2.496... is close to 1:2.5; multiply both by 2. [1] P_2O_5. [1]

(c) Formula subscripts give numbers of atoms; the elements have different atomic masses, so first convert masses to amounts. [1]

Question 25 | AQA | 8 marks

(a) Oxygen gained = 6.38 − 4.46 = 1.92 g. [1] n(Fe) = m/A_r
n(Fe) = 4.46/55.8 = 0.079928...; n(O) = m/A_r
n(O) = 1.92/16.0 = 0.120 mol. [1] Fe:O = 1:1.501... ≈ 2:3. [1] Fe_2O_3. [1]

(b) Unchanged consecutive masses show no further measurable change under those conditions and support completion of oxidation. [1] They do not alone prove the solid's identity or purity.

(c) It lets oxygen enter while reducing loss of solid. [1]

(d) Hot apparatus causes an unreliable balance reading, for example through convection. [1]

(e) The apparent oxygen-to-iron ratio is too low because oxygen gain is too small. [1]

Question 26 | AQA | 5 marks

Multiplier = M_r/empirical-formula mass

(a) Empirical-formula mass = 2(12.0) + 4(1.0) + 16.0 = 44.0. [1] Multiplier = 88.0/44.0 = 2. [1] $C_4H_8O_2$. [1]

(b) The empirical formula gives the simplest whole-number atom ratio. [1] The molecular formula gives the actual numbers of atoms of each element in one molecule. [1]

Question 27 | AQA | 10 marks

(a) n(C) = n(CO_2) = m/M_r
n(CO_2) = 1.760/44.0 = 0.0400 mol. [1] n(H) = 2m(H_2O)/M_r(H_2O)
n(H) = 2(0.720/18.0) = 0.0800 mol. [1] m(C) = 0.480 g and m(H) = 0.0800 g. [1] Oxygen in sample = 0.880 − 0.480 − 0.0800 = 0.320 g, so n(O) = 0.0200 mol. [1] Ratio C:H:O = 2:4:1 [1]; C_2H_4O. [1]

(b) Empirical-formula mass = 44.0; multiplier = 88.0/44.0 = 2. [1] Molecular formula $C_4H_8O_2$. [1]

(c) Oxygen gas supplied for combustion also contributes oxygen atoms to the products. [1]

(d) The remaining sample mass would include nitrogen as well as oxygen, so it could not all be assigned to oxygen. [1]

Question 28 | AQA | 7 marks

n(C) = m(CO_2)/M_r(CO_2)
n(C) = 2.640/44.0 = 0.0600 mol. [1] n(H) = 2m(H_2O)/M_r(H_2O)
n(H) = 2(1.080/18.0) = 0.120 mol. [1] m(C) = 0.720 g, m(H) = 0.120 g, so m(O in sample) = 1.480 − 0.720 − 0.120 = 0.640 g. [1] n(O) = m/A_r
n(O) = 0.640/16.0 = 0.0400 mol. [1] Ratio 1.5:3:1 becomes 3:6:2, empirical formula $C_3H_6O_2$. [1] Empirical-formula mass = 74.0; multiplier = 148.0/74.0 = 2. [1] $C_6H_{12}O_4$. [1]

Hydrated salts

Question 29 | AQA | 8 marks

(a) Water lost = 4.76 − 2.60 = 2.16 g. [1] n(water) = m/M_r
n(water) = 2.16/18.0 = 0.120 mol and n($CoCl_2$) = m/M_r
n($CoCl_2$) = 2.60/130.0 = 0.0200 mol. [1] x = n(H_2O)/n(anhydrous salt)
x = 0.120/0.0200 = 6. [1] $CoCl_2 \cdot 6H_2O$. [1]

(b) Water molecules incorporated in a fixed ratio in the salt's crystal structure. [1]

(c) Water remaining: x too low. [1] Solid lost: x too high under the assumed-residue calculation. [1]

(d) The mass loss would not all be water and/or the residue would not be the assumed anhydrous salt. [1]

Question 30 | AQA | 10 marks

(a) Use 2.12 g [1] because the second and third heating values agree, showing constant mass [1].

(b) m(H_2O) = 5.72 − 2.12 = 3.60 g [1]. n(H_2O) = m/M_r
n(H_2O) = 3.60 ÷ 18.0 = 0.200 mol [1]. n(Na_2CO_3) = m/M_r
n(Na_2CO_3) = 2.12 ÷ 106.0 = 0.0200 mol [1]. Ratio = 0.200 : 0.0200 = 10 : 1, so x = 10 [1]. Formula = $Na_2CO_3 \cdot 10H_2O$ [1].

(c) After the first heating, some water remains in the sample [1]. The recorded residue is therefore too heavy and the apparent water loss is too small [1], making n(H_2O) ÷ n(Na_2CO_3), and hence x, too low [1].

Quantity	Na_2CO_3	H_2O lost
Mass / g	2.12	3.60
A_r or M_r (no unit)	106.0	18.0
Amount / mol	n = m/M_r n = 2.12/106.0 = 0.0200	n = m/M_r n = 3.60/18.0 = 0.200

Concentration & dilution

Question 31 | AQA | 6 marks

(a) V(dm³) = V(cm³)/1000
V = 32.50/1000 = 0.03250 dm^3 [1]; n = cV = 0.1800 × 0.03250 = 0.005850 mol [1].

(b) V = 0.2000 dm^3 [1]; c = n/V = 0.01440/0.2000 = 0.07200 mol dm^{-3} [1].

(c) V = n/c = 0.00750/0.1250 = 0.0600 dm^3 [1] = 60.0 cm^3 [1].

EXAM TRAP Convert cm^3 to dm^3 before using n = cV; convert the final volume back only if the question asks for cm^3.

Question 32 | AQA | 6 marks

(a) $n(K_2SO_4) = m/M_r$
$n(K_2SO_4) = 2.70/174.3 = 0.01549$ mol [1]; $V = 0.5000$ dm^3 [1]; $c = n/V$
$c = 0.01549/0.5000 = 0.03098$ mol dm^{-3}, or 0.0310 mol dm^{-3} [1].

Mass concentration = mass of solute ÷ solution volume
(b) Mass concentration = $2.70/0.5000 = 5.40$ g dm^{-3} [1].

(c) $n = cV = 0.0200 \times 0.2500 = 0.00500$ mol [1]; $m = nM_r = 0.00500 \times 111.0 = 0.555$ g [1].

Question 33 | AQA | 6 marks

(a) n before $= 0.8000 \times 0.0150 = 0.0120$ mol [1]; final $V = 0.2500$ dm^3 [1]; $c = n/V$
$c = 0.0120/0.2500 = 0.0480$ mol dm^{-3} [1].

(b) $c_1V_1 = c_2V_2$, so $V_1 = c_2V_2/c_1$
$V_1 = (0.0650 \times 100.0)/0.500$ [1] = 13.0 cm^3 [1].

(c) 100.0 cm^3 is the final solution volume; adding 100.0 cm^3 of water would make the final volume greater than 100.0 cm^3 and the solution too dilute [1].

Question 34 | AQA | 8 marks

(a) $n = cV$
$n = 0.0600 \times 0.2500 = 0.0150$ mol [1]; $m = n \times M_r$
$m = 0.0150 \times 106.0 = 1.59$ g. [1]

(b) Weigh accurately, for example by difference, and record the actual mass. [1] Dissolve fully in deionised water in a beaker. [1] Transfer through a funnel to the volumetric flask and add the beaker/rod/funnel washings. [1] Let a warm solution cool to the flask's calibration temperature. [1] Make up to the mark dropwise, with the bottom of the meniscus at eye level. [1] Stopper and invert repeatedly to mix. [1]

Titrations & practical technique

Question 35 | AQA | 11 marks

(a) To avoid residual water diluting the titrant. [1]

(b) The pipette rinse prevents dilution of the aliquot. [1] Deionised water in the flask changes volume, but not the moles already delivered; washing the walls returns reacting droplets to the mixture. [1]

(c) Unmeasured drops could fall into the burette after the initial reading, making the delivered volume unreliable. [1]

(d) The rough trial locates the approximate end point. [1] Add dropwise while swirling near that volume. [1]

(e) End point: observed indicator colour change. [1] Equivalence point: reactants mixed in their stoichiometric ratio. [1]

(f) The pipette is calibrated to deliver the stated volume while leaving that drop behind. [1]

(g) Phenolphthalein [1], pink to just colourless. [1] Accept methyl orange with yellow to the first persistent orange end point; other suitable indicators with correct observations are acceptable.

Question 36 | AQA | 4 marks

(a) Initial 18.15 cm^3 [1]; final 25.45 cm^3. [1]

(b) Titre = 25.45 − 18.15 = 7.30 cm^3. [1]

(c) To avoid parallax: the meniscus can appear above or below its true position when viewed at an angle. [1]

Question 37 | AQA | 8 marks

(a) Titres are rough 24.90; run 1 24.65; run 2 24.70; run 3 24.50; run 4 24.70 cm^3. Award [1] for at least three correct and [1] for all five correct.

(b) Use runs 1, 2 and 4 [1]. Mean = (24.65 + 24.70 + 24.70)/3 = 24.683... cm^3 [1] = 24.68 cm^3 [1].

(c) Exclude the rough titre because it was used only to locate the end point [1]. Exclude run 3 because 24.50 cm^3 is not within 0.10 cm^3 of the selected concordant set [1]. Two decimal places retain the resolution of a burette read to the nearest 0.05 cm^3, including a trailing zero where needed [1].

EXAM TRAP Compare calculated titres, not final burette readings.

Question 38 | AQA | 6 marks

(a) $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$: acid : alkali = 1 : 2. [1]

Quantity	H_2SO_4	NaOH
Concentration, c / mol dm^{-3}	c = n/V 0.001281/0.02500 = **0.05124** [1]	0.1200
Volume, V / dm^3	25.00/1000 = 0.02500	21.35/1000 = 0.02135
Amount, n / mol	0.002562/2 = 0.001281 [1]	n = cV 0.1200 × 0.02135 = 0.002562 [1]
Coefficient (mole ratio)	1	2

(b) Mass concentration = c × M_r. [1] 0.05124 × 98.1 = **5.03 g dm^{-3}**. [1]

Question 39 | AQA | 7 marks

(a) $NH_3 + HCl \rightarrow NH_4Cl$; use the 25.00 cm^3 aliquot of diluted ammonia in the grid.

Quantity	NH_3 (diluted)	HCl
Concentration, c / mol dm^{-3}	c = n/V 0.001840/0.02500 = 0.07360 [1]	0.1000
Volume, V / dm^3	25.00/1000 = 0.02500	18.40/1000 = 0.01840
Amount, n / mol	0.001840 (1 : 1 ratio) [1]	n = cV 0.1000 × 0.01840 = 0.001840 [1]
Coefficient (mole ratio)	1	1

Dilution factor = final dilution volume/original sample volume = 250.0/10.00 = 25.0. [1] Original concentration = 0.07360 × 25.0 = **1.840 mol dm^{-3}**. [1]

(b) Mass concentration = c × M_r. [1] 1.840 × 17.0 = **31.3 g dm^{-3}**. [1]

The 25.00 cm^3 aliquot is a portion of the diluted solution; 10.00 cm^3 is the original sample volume.

Question 40 | AQA | 8 marks

Percentage uncertainty = (absolute uncertainty ÷ measured value) × 100
(a) Absolute uncertainty = 0.05 + 0.05 = 0.10 cm^3 [1]. Percentage uncertainty = 0.10/23.40 × 100 = 0.43% [1].

Percentage uncertainty = (absolute uncertainty ÷ measured value) × 100
(b) Total absolute uncertainty = 0.10 + 0.05 = 0.15 cm^3 [1]. Percentage uncertainty = 0.15/23.40 × 100 = 0.64% [1].

(c) Residual water dilutes the known acid [1], so a larger titre is needed to neutralise the alkali [1]. Using the stated undiluted acid concentration then overestimates acid moles and therefore overestimates the calculated alkali concentration [1].

(d) Concordance indicates precision; the same systematic error could shift every titre in one direction [1].

Question 41 | AQA | 8 marks

(a) Water dilutes the NaOH aliquot, so it contains fewer moles of NaOH [1]. A smaller acid titre is required [1], giving a calculated NaOH concentration that is too low [1].

(b) The pipette has already fixed the moles of NaOH delivered [1]. Water in the flask changes concentration during the titration but not those moles or the equivalence-point amount of acid [1].

(c) Some of the measured volume fills the jet instead of reaching the flask, so the apparent titre is too large [1]. The calculation treats all that volume as reacted acid [1], so the calculated NaOH concentration is too high [1].

Question 42 | AQA | 9 marks

(a) Na_2CO_3 : HCl = 1 : 2.

Quantity	Na_2CO_3 aliquot	HCl
Concentration, c / mol dm⁻³	Not needed for purity	0.1000
Volume, V / dm³	25.00/1000 = 0.02500	20.40/1000 = 0.02040
Amount, n / mol	0.002040/2 = 0.001020 [1]	n = cV 0.1000 × 0.02040 = 0.002040 [1]
Coefficient (mole ratio)	1	2

Moles in full flask = moles in aliquot × flask volume/aliquot volume = 0.001020 × 250.0/25.00 = 0.01020 mol. [1]

Pure mass = n × M_r = 0.01020 × 106.0 = 1.0812 g. [1] Percentage purity = pure mass/sample mass × 100. [1] Purity = 1.0812/1.80 × 100 = **60.1%**. [1]

(b) The impurities do not react with HCl / do not affect the titration [1].

(c) The recorded titre is too large [1], so the calculated moles and percentage of Na_2CO_3 are too high [1].

Question 43 | AQA | 8 marks

(a) Moles of Na_2CO_3 in full flask = m/M_r = 1.590/106.0 = 0.01500 mol. [1]

Quantity	Na_2CO_3 aliquot	HCl
Concentration, c / mol dm⁻³	0.01500/0.2500 = 0.06000	c = n/V 0.003000/0.03020 = **0.09934** [1]
Volume, V / dm³	25.00/1000 = 0.02500	30.20/1000 = 0.03020 [1]
Amount, n / mol	0.01500 × 25.00/250.0 = 0.001500 [1]	0.001500 × 2 = 0.003000 [1]
Coefficient (mole ratio)	1	2

(b) Retain the full HCl concentration, 0.003000/0.03020, for the second titration. HCl + NaOH → NaCl + H_2O.

Quantity	HCl	NaOH
Concentration, c / mol dm⁻³	0.003000/0.03020 = 0.0993377...	c = n/V 0.002250/0.02500 = **0.09000** [1]
Volume, V / dm³	22.65/1000 = 0.02265	25.00/1000 = 0.02500
Amount, n / mol	n = cV (0.003000/0.03020) × 0.02265 = 0.002250 [1]	0.002250 (1 : 1 ratio) [1]
Coefficient (mole ratio)	1	1

Question 44 | AQA | 8 marks

(a) The remaining HCl reacts with NaOH in a 1 : 1 ratio.

Quantity	HCl added	NaOH titre	HCl left
Concentration, c / mol dm⁻³	0.5000	0.2000	Not needed
Volume, V / dm³	50.00/1000 = 0.05000	15.00/1000 = 0.01500	Not needed
Amount, n / mol	n = cV 0.5000 × 0.05000 = 0.02500 [1]	n = cV 0.2000 × 0.01500 = 0.003000	Same moles as NaOH 0.003000 [1]
Coefficient (mole ratio)	Not compared	1	1

Moles of HCl consumed = initial − remaining = 0.02500 − 0.003000 = 0.02200 mol. [1] $CaCO_3$: HCl = 1 : 2, so moles of $CaCO_3$ = 0.02200/2 = 0.01100 mol. [1]

Pure mass = n × M_r = 0.01100 × 100.1 = 1.1011 g. [1] Percentage purity = pure mass/sample mass × 100 = 1.1011/1.25 × 100 = **88.1%**. [1]

(b) More HCl is measured as left over, so less is inferred to have reacted. [1] The calculated carbonate amount and purity are too low. [1]

Question 45 | AQA | 16 marks

(a) $NaHCO_3 + HCl \rightarrow NaCl + CO_2 + H_2O$.

Quantity	$NaHCO_3$ aliquot	HCl
Concentration, c / mol dm⁻³	Not needed for purity	0.1000
Volume, V / dm³	25.00/1000 = 0.02500	12.80/1000 = 0.01280
Amount, n / mol	0.001280 (1 : 1 ratio) [1]	n = cV 0.1000 × 0.01280 = 0.001280 [1]
Coefficient (mole ratio)	1	1

Moles in full flask = moles in aliquot × flask volume/aliquot volume = 0.001280 × 250.0/25.00 = 0.01280 mol. [1]

Pure mass = n × M_r = 0.01280 × 84.0 = 1.0752 g. [1] Percentage purity = pure mass/sample mass × 100 = 1.0752/1.200 × 100 = **89.6%**. [1]

(b) Pure $NaHCO_3$ in the batch = 50.0 × 0.896 = 44.8 kg [1]. Amount = 44 800/84.0 = 533.333… mol [1]. The 2:1 ratio gives 266.666… mol Na_2CO_3 [1]. Theoretical mass = 266.666… × 106.0 = 28 266.666… g = 28.3 kg [1].

Percentage yield = (actual yield ÷ theoretical yield) × 100
(c) Percentage yield = 24.6/28.2667 × 100 [1] = 87.0% [1].

Atom economy = (total relative mass of desired product ÷ total relative mass of reactants) × 100
(d) Atom economy = 106.0/(2 × 84.0) × 100 [1] = 63.1% [1].

(e) Yield measures the actual Na_2CO_3 obtained relative to its theoretical maximum [1], whereas atom economy measures the fraction of reactant mass that can enter Na_2CO_3 according to the equation, with CO_2 and H_2O as by-products [1]. One further factor such as energy demand, feedstock cost, hazards, emissions or use of the by-products is needed [1].

EXAM TRAP The inert fraction affects how much pure $NaHCO_3$ enters the batch, but it is not included in the equation-based atom-economy denominator.

Gas calculations

Question 46 | AQA | 11 marks

(a) p = 102000 Pa, V = 4.25 × 10^{-4} m^3 and T(K) = temperature(°C) + 273
T = 25 + 273 = 298 K. [1] n = pV/RT [1] = 0.017505... mol = 0.0175 mol. [1] Accept the use of 298.15 K with consistent working.

(b) M_r = m/n
M_r = 1.05/0.017505... [1] = 60.0, with no unit. [1]

(c) Any one: no vapour is lost; volume contains only sample vapour; temperature and pressure are measured correctly. [1] Do not credit complete vaporisation or ideal behaviour, which are stated in the question.

(d) Consider 1.00 dm^3 gas: mass 2.00 g and volume 1.00 × 10^{-3} m^3. [1] n = pV/(RT)
n = (101000 × 0.00100)/(8.31 × 298) = 0.040785... mol. [1] M_r = 2.00/n = 49.0. [1]

(e) At low pressure the particles are far apart, so their own volume is a small fraction of the gas volume. [1] At high temperature their kinetic energy is larger relative to the effect of attractions. [1]

Question 47 | AQA | 7 marks

(a) N_2 + 3H_2 → 2NH_3. Compare starting volume ÷ coefficient, since all volumes are at the same temperature and pressure.

Quantity	N_2	H_2	NH_3
Initial volume / cm^3	80.0	180	0
Coefficient	1	3	2
Volume ÷ coefficient / cm^3	80.0/1 = 80.0	180/3 = **60.0 (smaller)**	Product: not compared
Volume used or formed / cm^3	60.0 × 1 = 60.0 used	60.0 × 3 = 180 used	60.0 × 2 = 120 formed
Final volume / cm^3	80.0 − 60.0 = **20.0** [1]	0	**120** [1]

H_2 is limiting because its volume ÷ coefficient is smaller. [1] Total final gas volume = 20.0 + 120 = **140 cm^3**. [1]

(b) At matching temperature and pressure, gas volume is proportional to amount, so the mole ratios are volume ratios. [1]

(c) 360.0 cm^3 = 0.3600 dm^3. [1] n = V/V_m
n = 0.3600/24.0 = 0.0150 mol. [1]

Question 48 | AQA | 6 marks

(a) Compare the starting moles divided by the coefficient.

Quantity	$CaCO_3$	HCl
Mass / g	0.500	Not needed
A_r or M_r (no unit)	100.1	Not needed
Concentration, c / mol dm^{-3}	Solid	0.300
Volume, V / dm^3	Solid	25.0/1000 = 0.0250
Amount, n / mol	$n = m/M_r$ 0.500/100.1 = 0.004995… [1]	$n = cV$ 0.300 × 0.0250 = 0.00750 [1]
Coefficient	1	2
n ÷ coefficient / mol	0.004995…/1	0.00750/2 = **0.00375 (smaller)**

HCl has the smaller n ÷ coefficient value, so **HCl is limiting**. [1]

(b) $n(CO_2)$ = n(known substance) × coefficient(target)/coefficient(known substance)
$n(CO_2) = 0.00750/2 = 0.00375$ mol. [1] V = nRT/p
$V = (0.00375 \times 8.31 \times 298)/100000 = 9.286425 \times 10^{-5}$ m^3. [1] V = 92.9 cm^3. [1]

Yield & atom economy

Question 49 | AQA | 10 marks

(a) Compare the starting moles divided by the coefficient.

Quantity	Mg	HCl
Mass / g	0.600	Not needed
A_r or M_r (no unit)	24.3	Not needed
Concentration, c / mol dm^{-3}	Solid	0.500
Volume, V / dm^3	Solid	40.0/1000 = 0.0400
Amount, n / mol	$n = m/A_r$ 0.600/24.3 = 0.024691… [1]	$n = cV$ 0.500 × 0.0400 = 0.0200 [1]
Coefficient	1	2
n ÷ coefficient / mol	0.024691…/1	0.0200/2 = **0.0100 (smaller)**

HCl has the smaller n ÷ coefficient value, so **HCl is limiting**. [1] HCl : H_2 = 2 : 1; theoretical $n(H_2)$ = 0.0200/2 = **0.0100 mol**. [1]

Percentage yield = (actual yield ÷ theoretical yield) × 100
(b) p = 98000 Pa and $V = 2.20 \times 10^{-4}$ m^3. [1] n(actual) = pV/RT [1] = 0.008706… mol. [1] Yield = 0.008706…/0.0100 × 100 = 87.1%. [1]

(c) 2/220 × 100 = 0.91%. [1] (d) It lowers the collected gas amount and the measured yield. [1]

Question 50 | AQA | 9 marks

Atom economy = (total relative mass of desired product ÷ total relative mass of reactants) × 100
(a) A: 46.0/(28.0 + 18.0) × 100 = 100%. [1] B: total reactant formula mass = 64.5 + 40.0 = 104.5 [1]; atom economy = 46.0/104.5 × 100 = 44.0%. [1]

(b) Theoretical ethanol mass = 46.0 g in each case. [1] A: 36.8/46.0 × 100 = 80.0%. [1] B: 41.4/46.0 × 100 = 90.0%. [1]

(c) Catalysts are regenerated and solvents are not consumed as stoichiometric reactants in these equations. [1] Atom economy uses the balanced-equation quantities that react, rather than any excess left over. [1]

(d) Water increases the apparent product mass, giving an overestimated yield, possibly above 100%. [1]

Question 51 | AQA | 9 marks

(a) X: theoretical desired mass = 100.0 × 0.920 = 92.0 kg [1]; actual = 92.0 × 0.740 = 68.1 kg. [1] Y: theoretical = 100.0 × 0.680 = 68.0 kg [1]; actual = 68.0 × 0.960 = 65.3 kg. [1]

(b) A supported choice [1], relevant comparison using output/energy/by-product data [1], and recognition that a different priority could change the choice [1]. For example X gives more product per feed mass and less hazardous waste; Y uses less energy and recovers much of its corrosive by-product.

(c) Yield compares actual product with its theoretical maximum. [1] A route can still have poor atom economy and large stoichiometric by-products even if it gives a high yield. [1]