



AQA 7405

Amount of Substance III

SOLUTIONS • TITRATIONS • GASES • YIELD • ATOM ECONOMY

ORIGINAL EXAM QUESTIONS | TEST IT → EXAM STYLE → HARDER MIXED → STRETCH

TEST IT	EXAM STYLE	HARDER MIXED	STRETCH
8	8	4	2

22 QUESTIONS MASTERED | 198 TOTAL MARKS

Mapped to AQA Chemistry 7405 sections 3.1.2.2–3.1.2.5 and Required Practical 1

Specification checked 7 October 2026

How to use this pack [START HERE](#)

- 1 Read the command word** State is concise. Explain must link cause to effect. Calculate must show a valid route, unit and sensible precision.
- 2 Choose the equation yourself** The question paper gives data and balanced equations where needed, but no teaching grids. Show the route you selected.
- 3 Keep units beside values** Use dm^3 in $n = cV$; use Pa, m^3 and K in $pV = nRT$. Retain unrounded intermediate values.
- 4 Treat practical data critically** Exclude rough and non-concordant titres, identify error direction and distinguish precision from accuracy.

Specification route

AQA section	Assessed in this pack
3.1.2.2	Concentration, solution volume, mass concentration and dilution.
3.1.2.3	The ideal gas equation in SI units; gas amounts, volumes and molar mass.
3.1.2.5	Solution and gas stoichiometry; percentage yield; atom economy and process comparison.
RP1	Preparation of a volumetric solution; acid–base titration, concordance and uncertainty.

AQA BOUNDARY Empirical and molecular formulae and water of crystallisation are not assessed as new content here. pH, K_a , buffers and redox titrations belong later.

SECTION A TEST IT*Secure the essential routes, units and practical distinctions before the longer questions.***QUESTION 1 | TEST IT**

(a) Calculate the amount, in mol, in 32.50 cm^3 of $0.1800 \text{ mol dm}^{-3}$ KOH. (2 marks)

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

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

QUESTION 2 | TEST IT

(a) A solution is made by dissolving $2.70 \text{ g K}_2\text{SO}_4$ and making the solution up to 500.0 cm^3 . Calculate its concentration in mol dm^{-3} . $M(\text{K}_2\text{SO}_4) = 174.3 \text{ g mol}^{-1}$. (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 $0.0200 \text{ mol dm}^{-3}$ solution. $M(\text{CaCl}_2) = 111.0 \text{ g mol}^{-1}$. (2 marks)

QUESTION 3 | TEST IT

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

(b) Calculate the volume of $0.500 \text{ mol dm}^{-3}$ stock solution needed to prepare 100.0 cm^3 of $0.0650 \text{ mol dm}^{-3}$ 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 4 | TEST IT

A student prepares 250.0 cm^3 of $0.0600 \text{ mol dm}^{-3}$ anhydrous sodium carbonate solution. $M(\text{Na}_2\text{CO}_3) = 106.0 \text{ g mol}^{-1}$.

(a) Calculate the mass of Na_2CO_3 that the student should use. (2 marks)

- (b) Describe how the student should prepare the solution accurately from the weighed solid. (5 marks)
-
-
-
-
-

QUESTION 5 | TEST IT

- (a) Explain why a burette is rinsed with the solution that it will contain. (1 mark)
-
- (b) Explain why a volumetric pipette is rinsed with the solution it will deliver, but a conical flask may be rinsed with deionised water. (2 marks)
-
- (c) State why the filling funnel is removed from the burette before the initial reading is taken. (1 mark)
-
- (d) State the purpose of a rough titration and explain how titrant should be added near the end point in an accurate titration. (2 marks)
-
- (e) Explain why deionised water may be used to wash splashes from the inside wall of the conical flask. (1 mark)
-
- (f) Distinguish between the end point and the equivalence point of an acid–base titration. (2 marks)
-
- (g) Explain why the last drop in a standard transfer pipette is not blown into the conical flask. (1 mark)
-

QUESTION 6 | TEST IT

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 cm³. 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 7 | TEST IT

25.00 cm³ of sulfuric acid reacts exactly with 21.35 cm³ of 0.1200 mol dm⁻³ sodium hydroxide.



- (a) Calculate the concentration of the sulfuric acid. (4 marks)
-
-

- (b) Calculate the mass concentration of the sulfuric acid in g dm⁻³. M(H₂SO₄) = 98.1 g mol⁻¹. (2 marks)
-

- (c) Explain why the moles of H₂SO₄ must not be set equal to the moles of NaOH. (1 mark)
-

QUESTION 8 | TEST IT

A mean titre is 23.40 cm³. Each burette reading has uncertainty ±0.05 cm³.

- (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 cm³. 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)
-

SECTION B EXAM STYLE

Apply the specification in linked AQA-style questions with unscaffolded working space.

QUESTION 9 | EXAM STYLE

A student accurately weighs 1.325 g of anhydrous Na₂CO₃ and makes it up to 250.0 cm³. A 25.00 cm³ aliquot requires 24.80 cm³ of hydrochloric acid for complete reaction.



- (a) Calculate the exact concentration of the sodium carbonate solution. M(Na₂CO₃) = 106.0 g mol⁻¹. (3 marks)
-
-

(b) State two details of the preparation that ensure all solute reaches the flask and the final volume is accurate. (2 marks)

(c) Calculate the concentration of the hydrochloric acid. (4 marks)

(d) Explain why the recorded mass, rather than the intended target mass, must be used in part (a). (1 mark)

(e) Name a suitable indicator for complete neutralisation of Na_2CO_3 by HCl . (1 mark)

QUESTION 10 | EXAM STYLE

10.00 cm³ of household ammonia solution is diluted to 250.0 cm³. A 25.00 cm³ aliquot of the diluted solution requires 18.40 cm³ of 0.1000 mol dm⁻³ HCl.



(a) Calculate the concentration of NH_3 in the original household solution. (5 marks)

(b) Calculate the mass concentration of NH_3 in the original solution. $M(\text{NH}_3) = 17.0 \text{ g mol}^{-1}$. (2 marks)

QUESTION 11 | EXAM STYLE

A 1.80 g sample contains Na_2CO_3 and inert impurities. The sample is dissolved and made up to 250.0 cm³. A 25.00 cm³ aliquot requires 20.40 cm³ of 0.1000 mol dm⁻³ HCl.



(a) Calculate the percentage by mass of Na_2CO_3 in the sample. $M(\text{Na}_2\text{CO}_3) = 106.0 \text{ g mol}^{-1}$. (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 12 | EXAM STYLE

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. (3 marks)
Explain the effect on the titre and on the calculated sodium hydroxide concentration.

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

- (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 13 | EXAM STYLE

A 1.05 g sample vaporises completely. The vapour occupies 425 cm³ at 102 kPa and 298 K. Assume ideal behaviour. $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$.

- (a) Calculate the amount, in mol, of vapour. (4 marks)

- (b) Calculate the molar mass and hence the relative molecular mass of the substance. (2 marks)

- (c) State one experimental condition, other than ideal behaviour, required for the result to be valid. (1 mark)

QUESTION 14 | EXAM STYLE

0.500 g CaCO₃ reacts with 25.0 cm³ of 0.300 mol dm⁻³ HCl. $M(\text{CaCO}_3) = 100.1 \text{ g mol}^{-1}$. The gas is measured at 100 kPa and 298 K. $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$.



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

- (b) Calculate the maximum volume of CO₂, in cm³, at the stated conditions. (5 marks)

QUESTION 15 | EXAM STYLE

80.0 cm³ N₂ is mixed with 180 cm³ H₂. The reaction goes to completion and all volumes are measured at the same temperature and pressure.



- (a) Identify the limiting reactant and justify your answer using gas volumes. (2 marks)

.....

- (b) Calculate the volumes of N₂ left and NH₃ formed, and hence the total final gas volume. (3 marks)

.....

.....

QUESTION 16 | EXAM STYLE

Two routes make ethanol. In each trial, 1.00 mol of the limiting organic reactant is used. Water or NaOH is in excess as shown by the equations.



Route	Actual ethanol / g	Energy demand	Additional information
A	36.8	High	No stoichiometric by-product
B	41.4	Lower	Aqueous NaCl by-product

M_r: C₂H₄ = 28.0, H₂O = 18.0, C₂H₅Cl = 64.5, NaOH = 40.0, C₂H₅OH = 46.0.

- (a) Calculate the atom economy of route A. (2 marks)

.....

- (b) Calculate the atom economy of route B. (3 marks)

.....

.....

- (c) Calculate the percentage yield of ethanol in each route. (4 marks)

.....

.....

- (d) State which route has the higher atom economy and which has the higher yield. (2 marks)

.....

- (e) State one further factor needed before choosing the better industrial route. (1 mark)

.....

ADDITIONAL WORKING FOR QUESTION 16

.....

.....

.....

.....

.....

.....

.....

SECTION C HARDER MIXED

Select the route yourself and combine solution, titration, gas and process data.

QUESTION 17 | HARDER MIXED

A hydrochloric acid solution is standardised using 1.590 g anhydrous Na_2CO_3 made up to 250.0 cm^3 . A 25.00 cm^3 aliquot requires 30.20 cm^3 HCl. The standardised HCl is then used: 22.65 cm^3 reacts with 25.00 cm^3 NaOH.



- (a) Calculate the concentration of the hydrochloric acid. $M(\text{Na}_2\text{CO}_3) = 106.0 \text{ g mol}^{-1}$. (5 marks)

.....

.....

.....

.....

- (b) Calculate the concentration of the sodium hydroxide. (3 marks)

.....

.....

.....

- (c) Calculate the mass of NaOH needed to prepare 500.0 cm^3 of a solution with the concentration found in part (b). $M(\text{NaOH}) = 40.0 \text{ g mol}^{-1}$. (2 marks)

.....

QUESTION 18 | HARDER MIXED

A 1.25 g antacid tablet contains CaCO_3 and inert binder. The tablet is treated with 50.00 cm^3 of 0.5000 mol dm^{-3} HCl, which is in excess. The remaining HCl requires 15.00 cm^3 of 0.2000 mol dm^{-3} NaOH.



- (a) Explain why titrating the remaining acid allows the amount that reacted with CaCO_3 to be found. (2 marks)

.....

- (b) Calculate the percentage by mass of CaCO_3 in the tablet. $M(\text{CaCO}_3) = 100.1 \text{ g mol}^{-1}$. (7 marks)

.....

.....

.....

.....

.....

- (c) Explain the effect on the calculated percentage if some CaCO_3 remains unreacted. (2 marks)

.....

.....

QUESTION 19 | HARDER MIXED

0.600 g Mg is added to 40.0 cm³ of 0.500 mol dm⁻³ HCl. The reaction produces 220 cm³ H₂ at 98.0 kPa and 298 K. The gas-volume uncertainty is ± 2 cm³. $M(\text{Mg}) = 24.3 \text{ g mol}^{-1}$; $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$.



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

.....

.....

.....

- (b) Calculate the theoretical amount of H₂. (2 marks)

.....

.....

.....

- (c) Use the gas data to calculate the actual amount of H₂ collected. (3 marks)

.....

.....

.....

- (d) Calculate the percentage yield of H₂. (2 marks)

.....

.....

.....

- (e) Calculate the percentage uncertainty in the measured gas volume. (2 marks)

.....

.....

.....

QUESTION 20 | HARDER MIXED

Two proposed routes make the same desired product. Assume that atom economy gives the theoretical desired-product mass as a percentage of total reactant mass, and that the stated yield applies to that theoretical product.

Route	Atom economy	Yield	Energy / GJ t ⁻¹	By-product information
X	92%	74%	8.0	Small amount; low toxicity
Y	68%	96%	4.5	Corrosive; largely recovered

- (a) Calculate the actual mass of desired product obtained from 100 kg total reactants by route X. (2 marks)

.....

.....

.....

- (b) Calculate the corresponding mass for route Y. (2 marks)

.....

.....

.....

- (c) State which route gives more desired product per 100 kg reactants. (1 mark)

.....

.....

.....

- (d) Recommend a route using the full data set. Your answer must recognise why a different priority could change the decision. (3 marks)

.....

.....

.....

- (e) Explain why a high percentage yield does not by itself show that little waste is formed. (2 marks)

.....

.....

.....

SECTION D STRETCH / SYNOPTIC

Deduce what is not stated and audit a complete quantitative chain.

QUESTION 21 | STRETCH / SYNOPTIC

A 2.00 g sample containing Na_2CO_3 and inert material is dissolved and made up to 250.0 cm^3 . A 25.00 cm^3 aliquot is titrated with 0.1500 mol dm^{-3} HCl. The gas from reaction of the entire original sample with excess acid is then collected at 100 kPa and 298 K. $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$.

Titration	Rough	1	2	3
Titre / cm^3	16.95	16.80	16.85	16.75



(a) Using a concordance limit of 0.10 cm^3 , select the accurate titres and calculate the mean. (2 marks)

.....

(b) Calculate the percentage by mass of Na_2CO_3 in the original sample. $M(\text{Na}_2\text{CO}_3) = 106.0 \text{ g mol}^{-1}$. (6 marks)

.....

.....

.....

.....

.....

.....

(c) Calculate the theoretical CO_2 volume, in cm^3 , from the entire sample at the stated conditions. (3 marks)

.....

.....

.....

(d) The actual CO_2 volume collected is 285 cm^3 at the same conditions. Calculate the gas yield. (2 marks)

.....

(e) Suggest one experimental reason why the gas yield may be below 100%. (1 mark)

.....

QUESTION 22 | STRETCH / SYNOPTIC

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 requires 12.80 cm^3 of 0.1000 mol dm^{-3} HCl. A production batch uses 50.0 kg of the same feed and obtains 24.6 kg Na_2CO_3 .



M_r : $\text{NaHCO}_3 = 84.0$; $\text{Na}_2\text{CO}_3 = 106.0$.

(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)

BEFORE YOU TURN OVER — FINAL CHECK

1	Solution volumes converted to dm^3 ; gas volumes converted to m^3 for $pV = nRT$.
2	Pressure is in Pa and temperature is in K where the ideal gas equation is used.
3	Balanced-equation ratios have been applied once and to the correct substances.
4	Rough and anomalous titres are excluded; any mean uses justified concordant titres.
5	Actual and theoretical quantities are kept separate in yield calculations.
6	Every final answer has an appropriate unit, precision and quick sense-check.

ADDITIONAL WORKING — LABEL THE QUESTION NUMBER CLEARLY

QUESTIONS END HERE • ANSWERS BEGIN ON THE NEXT PAGE

Amount of Substance III

SOLUTIONS • TITRATIONS • GASES • YIELD • ATOM ECONOMY

ANSWERS & MARK SCHEME | FULLY WORKED • PRECISELY MARKED • BUILT FOR IMPROVEMENT

TEST IT	EXAM STYLE	HARDER MIXED	STRETCH
8	8	4	2

22 QUESTIONS MASTERED | 198 TOTAL MARKS

Mapped to AQA Chemistry 7405 sections 3.1.2.2–3.1.2.5 and Required Practical 1

Specification checked 7 October 2026

SECTION A TEST IT ANSWERS

Mark each chemically valid stage; units and the stated precision form part of the final answer.

QUESTION 1 | TEST IT 6 marks

(a) $V = 32.50/1000 = 0.03250 \text{ dm}^3$ [1]; $n = cV = 0.1800 \times 0.03250 = 0.005850 \text{ mol}$ [1].

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

(c) $V = n/c = 0.00750/0.1250 = 0.0600 \text{ dm}^3$ [1] = 60.0 cm^3 [1].

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

QUESTION 2 | TEST IT 6 marks

(a) $n(\text{K}_2\text{SO}_4) = 2.70/174.3 = 0.01549 \text{ mol}$ [1]; $V = 0.5000 \text{ dm}^3$ [1]; $c = 0.01549/0.5000 = 0.03098 \text{ mol dm}^{-3}$, or $0.0310 \text{ mol dm}^{-3}$ [1].

(b) Mass concentration = $2.70/0.5000 = 5.40 \text{ g dm}^{-3}$ [1].

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

QUESTION 3 | TEST IT 6 marks

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

(b) $c_1V_1 = c_2V_2$, so $V_1 = (0.0650 \times 100.0)/0.500$ [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 4 | TEST IT 7 marks

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

(b) Dissolve the accurately weighed solid completely in deionised water in a beaker [1]. Transfer the solution to a 250.0 cm^3 volumetric flask [1]. Rinse the beaker, stirring rod and funnel into the flask to achieve quantitative transfer [1]. Add water to the calibration mark, using a dropper near the mark and reading the bottom of the meniscus at eye level [1]. Stopper and invert repeatedly to mix [1].

COMMON ERROR The instruction is to make the solution up to 250.0 cm^3 , not to add 250.0 cm^3 of water.

QUESTION 5 | TEST IT 10 marks

(a) Rinsing with titrant prevents residual water from diluting the solution in the burette [1].

(b) The pipette rinse prevents the measured aliquot from being diluted [1]. Water in the conical flask changes only the total volume, not the moles delivered by the pipette [1].

(c) Drops from the funnel could enter after the reading and change the burette volume without being recorded correctly [1].

(d) The rough titration locates the approximate end point [1]; in accurate repeats add titrant dropwise near that volume while swirling [1].

QUESTION 5 | TEST IT**10 marks**

- (e) The water returns all reacting solution to the mixture but adds no moles of either reactant [1].
- (f) The end point is the observed indicator colour change [1]. The equivalence point is where reactants have been mixed in their exact stoichiometric ratio [1].
- (g) A standard transfer pipette is calibrated to deliver its stated volume while leaving that drop behind; blowing it out would deliver too much solution [1].

QUESTION 6 | TEST IT**8 marks**

- (a) Titres are rough 24.90; run 1 24.65; run 2 24.70; run 3 24.50; run 4 24.70 cm³. Award [1] for at least three correct and [1] for all five correct.
- (b) Use runs 1, 2 and 4 [1]. Mean = $(24.65 + 24.70 + 24.70)/3 = 24.683... \text{ cm}^3$ [1] = 24.68 cm³ [1].
- (c) Exclude the rough titre because it was used only to locate the end point [1]. Exclude run 3 because 24.50 cm³ is not within 0.10 cm³ of the selected concordant set [1]. Two decimal places retain the resolution of a burette read to the nearest 0.05 cm³, including a trailing zero where needed [1].

COMMON ERROR Compare calculated titres, not final burette readings.**QUESTION 7 | TEST IT****7 marks**

- (a) $n(\text{NaOH}) = 0.1200 \times 0.02135 = 0.002562 \text{ mol}$ [1]. The equation ratio $\text{H}_2\text{SO}_4:\text{NaOH}$ is 1:2 [1], so $n(\text{H}_2\text{SO}_4) = 0.001281 \text{ mol}$ [1]. $c(\text{H}_2\text{SO}_4) = 0.001281/0.02500 = 0.05124 \text{ mol dm}^{-3}$ [1].
- (b) Mass concentration = cM [1] = $0.05124 \times 98.1 = 5.03 \text{ g dm}^{-3}$ [1].
- (c) One mole of H_2SO_4 reacts with two moles of NaOH, so the stoichiometric ratio is not 1:1 [1].

QUESTION 8 | TEST IT**8 marks**

- (a) Absolute uncertainty = $0.05 + 0.05 = 0.10 \text{ cm}^3$ [1]. Percentage uncertainty = $0.10/23.40 \times 100 = 0.43\%$ [1].
- (b) Total absolute uncertainty = $0.10 + 0.05 = 0.15 \text{ cm}^3$ [1]. Percentage uncertainty = $0.15/23.40 \times 100 = 0.64\%$ [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].

SECTION B**EXAM STYLE ANSWERS***The marking points expose the chain of reasoning expected in a complete AQA-style response.***QUESTION 9 | EXAM STYLE****11 marks**

- (a) $n(\text{Na}_2\text{CO}_3) = 1.325/106.0 = 0.01250 \text{ mol}$ [1]; $V = 0.2500 \text{ dm}^3$ [1]; $c = 0.01250/0.2500 = 0.05000 \text{ mol dm}^{-3}$ [1].
- (b) Add beaker/rod/funnel washings to the volumetric flask to make a quantitative transfer [1]. Make the bottom of the meniscus coincide with the mark at eye level, adding water dropwise near the mark [1]. Accept inversion for uniform concentration as an alternative second detail only if the final-volume detail is also addressed elsewhere.
- (c) $n(\text{Na}_2\text{CO}_3)$ in aliquot = $0.05000 \times 0.02500 = 0.001250 \text{ mol}$ [1]. $n(\text{HCl}) = 2 \times 0.001250 = 0.002500 \text{ mol}$ [1]. $V(\text{HCl}) = 0.02480 \text{ dm}^3$ [1]. $c(\text{HCl}) = 0.002500/0.02480 = 0.1008 \text{ mol dm}^{-3}$ [1].
- (d) The exact moles, and therefore the true solution concentration, depend on the mass actually transferred [1].
- (e) Methyl orange [1].

QUESTION 10 | EXAM STYLE**7 marks**

- (a) $n(\text{HCl}) = 0.1000 \times 0.01840 = 0.001840 \text{ mol}$ [1]. The 1:1 equation gives 0.001840 mol NH_3 in the aliquot [1]. $c(\text{diluted } \text{NH}_3) = 0.001840/0.02500 = 0.07360 \text{ mol dm}^{-3}$ [1]. Dilution factor = $250.0/10.00 = 25.00$ [1]. Original c = $0.07360 \times 25.00 = 1.840 \text{ mol dm}^{-3}$ [1].
- (b) Mass concentration = cM [1] = $1.840 \times 17.0 = 31.3 \text{ g dm}^{-3}$ [1].

COMMON ERROR The 25.00 cm³ titrated aliquot and the original 10.00 cm³ sample perform different roles in the calculation.**QUESTION 11 | EXAM STYLE****9 marks**

- (a) $n(\text{HCl}) = 0.1000 \times 0.02040 = 0.002040 \text{ mol}$ [1]. $n(\text{Na}_2\text{CO}_3)$ in aliquot = $0.002040/2 = 0.001020 \text{ mol}$ [1]. Moles in 250.0 cm³ = $0.001020 \times 10 = 0.01020 \text{ mol}$ [1]. Mass of pure $\text{Na}_2\text{CO}_3 = 0.01020 \times 106.0 = 1.0812 \text{ g}$ [1]. Percentage = $1.0812/1.80 \times 100$ [1] = 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 12 | EXAM STYLE**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

QUESTION 12 | EXAM STYLE**8 marks**

calculation treats all that volume as reacted acid [1], so the calculated NaOH concentration is too high [1].

QUESTION 13 | EXAM STYLE**7 marks**

(a) $p = 102\,000\text{ Pa}$ [1]; $V = 425 \times 10^{-6} = 4.25 \times 10^{-4}\text{ m}^3$ [1]. $n = pV/RT$ [1] = $(102\,000 \times 4.25 \times 10^{-4})/(8.31 \times 298) = 0.0175\text{ mol}$ [1].

(b) $M = m/n = 1.05/0.017505\dots = 60.0\text{ g mol}^{-1}$ [1], so $M_r = 60.0$ with no unit [1].

(c) Any one: all the sample vaporises; no vapour is lost; the recorded volume contains only the sample vapour; temperature and pressure are measured correctly [1].

COMMON ERROR Use grams when reporting M in g mol^{-1} , and do not attach a unit to M_r .

QUESTION 14 | EXAM STYLE**8 marks**

(a) $n(\text{CaCO}_3) = 0.500/100.1 = 0.004995\text{ mol}$ [1]. $n(\text{HCl}) = 0.300 \times 0.0250 = 0.00750\text{ mol}$ [1]. $0.004995\text{ mol CaCO}_3$ would require 0.00999 mol HCl , so HCl is limiting [1].

(b) The 2:1 ratio gives $n(\text{CO}_2) = 0.00750/2 = 0.00375\text{ mol}$ [1]. $p = 100\,000\text{ Pa}$ and $T = 298\text{ K}$ [1]. $V = nRT/p$ [1] = $(0.00375 \times 8.31 \times 298)/100\,000 = 9.286 \times 10^{-5}\text{ m}^3$ [1] = 92.9 cm^3 [1].

QUESTION 15 | EXAM STYLE**5 marks**

(a) $80.0\text{ cm}^3\text{ N}_2$ would require $240\text{ cm}^3\text{ H}_2$ [1], but only 180 cm^3 is available, so H_2 is limiting [1].

(b) $180\text{ cm}^3\text{ H}_2$ reacts with $60.0\text{ cm}^3\text{ N}_2$, leaving $20.0\text{ cm}^3\text{ N}_2$ [1]. NH_3 formed = $180 \times 2/3 = 120\text{ cm}^3$ [1]. Total final gas volume = $20.0 + 120 = 140\text{ cm}^3$ [1].

QUESTION 16 | EXAM STYLE**12 marks**

(a) Reactant formula mass = $28.0 + 18.0 = 46.0$ [1]. Atom economy = $46.0/46.0 \times 100 = 100\%$ [1].

(b) Total reactant formula mass = $64.5 + 40.0 = 104.5$ [1]. Atom economy = $46.0/104.5 \times 100$ [1] = 44.0% [1].

(c) The theoretical ethanol mass from 1.00 mol limiting reactant is 46.0 g in each route [1]. Route A yield = $36.8/46.0 \times 100 = 80.0\%$ [1]. Route B yield = $41.4/46.0 \times 100$ [1] = 90.0% [1].

(d) Route A has the higher atom economy [1]; route B has the higher experimental yield [1].

(e) Any one relevant factor, such as energy cost, feedstock cost/availability, hazards, separation costs, waste treatment or whether the by-product can be used [1].

COMMON ERROR Percentage yield is experimental. Atom economy is fixed by the balanced equation and the chosen desired product.

SECTION C HARDER MIXED ANSWERS

These answers show the selected route, cross-checks and linked calculations.

QUESTION 17 | HARDER MIXED**10 marks**

(a) $n(\text{Na}_2\text{CO}_3) = 1.590/106.0 = 0.01500\text{ mol}$ [1], so $c = 0.01500/0.2500 = 0.06000\text{ mol dm}^{-3}$ [1]. The aliquot contains $0.06000 \times 0.02500 = 0.001500\text{ mol Na}_2\text{CO}_3$ [1], requiring 0.003000 mol HCl [1]. $c(\text{HCl}) = 0.003000/0.03020 = 0.09934\text{ mol dm}^{-3}$ [1].

(b) $n(\text{HCl}) = 0.0993377\dots \times 0.02265 = 0.002250\text{ mol}$ [1]. The 1:1 equation gives the same NaOH amount [1]. $c(\text{NaOH}) = 0.002250/0.02500 = 0.0900\text{ mol dm}^{-3}$ [1].

(c) $n = 0.0900 \times 0.5000 = 0.0450\text{ mol}$ [1]; $m = 0.0450 \times 40.0 = 1.80\text{ g}$ [1].

QUESTION 18 | HARDER MIXED**11 marks**

(a) The NaOH titration measures the HCl left after the tablet reaction [1]. Subtracting this from the HCl initially added gives the HCl that reacted with CaCO_3 [1].

(b) Initial $n(\text{HCl}) = 0.5000 \times 0.05000 = 0.02500\text{ mol}$ [1]. $n(\text{NaOH}) = 0.2000 \times 0.01500 = 0.003000\text{ mol}$ [1], so 0.003000 mol HCl remained [1]. HCl reacted = $0.02500 - 0.003000 = 0.02200\text{ mol}$ [1]. $n(\text{CaCO}_3) = 0.02200/2 = 0.01100\text{ mol}$ [1]. Mass $\text{CaCO}_3 = 0.01100 \times 100.1 = 1.1011\text{ g}$ [1]. Percentage = $1.1011/1.25 \times 100 = 88.1\%$ [1].

(c) Less HCl reacts, so more HCl is measured as remaining [1]. The calculated amount and percentage of CaCO_3 are therefore too low [1].

QUESTION 19 | HARDER MIXED**12 marks**

(a) $n(\text{Mg}) = 0.600/24.3 = 0.02469\text{ mol}$ [1]. $n(\text{HCl}) = 0.500 \times 0.0400 = 0.0200\text{ mol}$ [1]. The acid can react with only 0.0100 mol Mg , so HCl is limiting [1].

(b) The $2\text{HCl}:1\text{H}_2$ ratio gives $n(\text{H}_2) = 0.0200/2$ [1] = 0.0100 mol [1].

(c) $p = 98\,000\text{ Pa}$ and $V = 220 \times 10^{-6} = 2.20 \times 10^{-4}\text{ m}^3$ [1]. $n = pV/RT$ [1] = $(98\,000 \times 2.20 \times 10^{-4})/(8.31 \times 298) = 0.00871\text{ mol}$ [1].

(d) Percentage yield = $\text{actual/theoretical} \times 100$ [1] = $0.008706\dots/0.0100 \times 100 = 87.1\%$ [1].

(e) Percentage uncertainty = $2/220 \times 100$ [1] = 0.91% [1].

COMMON ERROR Use the limiting reactant to obtain the theoretical amount; use the measured gas data to obtain the actual amount.

QUESTION 20 | HARDER MIXED**10 marks**

(a) Theoretical desired mass = $100 \times 0.92 = 92\text{ kg}$ [1]. Actual desired mass = $92 \times 0.74 = 68.08\text{ kg}$, or 68.1 kg [1].

QUESTION 20 | HARDER MIXED**10 marks**

- (b) Theoretical desired mass = $100 \times 0.68 = 68$ kg [1]. Actual desired mass = $68 \times 0.96 = 65.28$ kg, or 65.3 kg [1].
- (c) Route X gives slightly more desired product per 100 kg reactants [1].
- (d) A supported recommendation earns [1]. Relevant evidence earns [1] each, to a maximum of two: X has higher usable mass per reactant and less inherently hazardous waste; Y has lower energy demand, higher yield and a by-product that is largely recovered. The preferred route depends on the weighting of raw materials, energy, hazards and recovery [1].
- (e) Yield compares actual product with the theoretical amount [1]. A reaction may still have poor atom economy and produce a large stoichiometric by-product even when conversion/recovery is efficient [1].

SECTION D STRETCH / SYNOPTIC ANSWERS

Full-credit routes combine several specification strands without hidden teaching steps.

QUESTION 21 | STRETCH / SYNOPTIC**14 marks**

- (a) Use 16.80, 16.85 and 16.75 cm³; their range is 0.10 cm³ [1]. Mean = $(16.80 + 16.85 + 16.75)/3 = 16.80$ cm³ [1].
- (b) $n(\text{HCl}) = 0.1500 \times 0.01680 = 0.002520$ mol [1]. $n(\text{Na}_2\text{CO}_3)$ in aliquot = $0.002520/2 = 0.001260$ mol [1]. Whole-flask amount = $0.001260 \times 250.0/25.00 = 0.01260$ mol [1]. Mass $\text{Na}_2\text{CO}_3 = 0.01260 \times 106.0 = 1.3356$ g [1]. Percentage = $1.3356/2.00 \times 100$ [1] = 66.8% [1].
- (c) The 1:1 $\text{Na}_2\text{CO}_3:\text{CO}_2$ ratio gives $n(\text{CO}_2) = 0.01260$ mol [1]. $V = nRT/p = (0.01260 \times 8.31 \times 298)/100\,000 = 3.120 \times 10^{-4}$ m³ [1] = 312 cm³ [1].
- (d) Gas yield = $285/312.024... \times 100$ [1] = 91.3% [1].
- (e) Any one: gas escaped through a leak; some gas remained dissolved; the carbonate did not react completely; gas was lost before the apparatus was sealed [1].

QUESTION 22 | STRETCH / SYNOPTIC**16 marks**

- (a) $n(\text{HCl}) = 0.1000 \times 0.01280 = 0.001280$ mol [1]. The 1:1 ratio gives 0.001280 mol NaHCO_3 in the aliquot [1]. Whole-flask amount = $0.001280 \times 10 = 0.01280$ mol [1]. Mass $\text{NaHCO}_3 = 0.01280 \times 84.0 = 1.0752$ g [1]. Percentage = $1.0752/1.200 \times 100 = 89.6\%$ [1].
- (b) Pure NaHCO_3 in the batch = $50.0 \times 0.896 = 44.8$ kg [1]. Amount = $44\,800/84.0 = 533.3$ mol [1]. The 2:1 ratio gives 266.7 mol Na_2CO_3 [1]. Theoretical mass = $266.7 \times 106.0 = 28\,267$ g = 28.3 kg [1].
- (c) Percentage yield = $24.6/28.2667 \times 100$ [1] = 87.0% [1].
- (d) Atom economy = $106.0/(2 \times 84.0) \times 100$ [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].

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

FINAL SPECIFICATION COVERAGE AUDIT

AQA strand	Question coverage
3.1.2.2	Q1–3, 7, 9–12, 17, 21–22: concentration, dilution, aliquots and solution stoichiometry.
3.1.2.3	Q13–15, 19, 21: $pV = nRT$, SI units, molar mass and gas volumes.
3.1.2.5	Q7–22: equation ratios, limiting reactants, titrations, yield and atom economy.
Required practical 1	Q4–6, 8–12, 17–18, 21–22: preparation, titration, concordance, uncertainty and evaluation.
Boundary check	No pH, K_a , buffers or redox titrations; Amount II appears only as prior stoichiometry.

IF YOU LOST MARKS — CHECK THE ROUTE

Symptom	Most likely check
Factor-of-1000 error	Recheck $\text{cm}^3 \leftrightarrow \text{dm}^3$, $\text{cm}^3 \leftrightarrow \text{m}^3$ or $\text{kPa} \leftrightarrow \text{Pa}$ conversions.
Correct first amount, wrong final value	Recheck the equation ratio, aliquot factor or dilution factor.
All titres shifted in one direction	Audit rinsing, the burette jet, meniscus reading and end-point control.
Yield above 100%	Recheck the limiting reactant and the order actual/theoretical $\times 100$.
Weak process recommendation	Quote the calculated output and weigh it against energy, hazards and waste.