



AQA 7405

Amount of Substance II

[EQUATIONS](#) • [REACTING MASSES](#) • [FORMULAE](#) • [HYDRATED SALTS](#)

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

TEST IT	EXAM STYLE	HARDER MIXED	STRETCH
8	8	4	2

22 QUESTIONS MASTERED | 194 TOTAL MARKS

[Mapped to AQA Chemistry 7405 sections 3.1.2.4 and selected 3.1.2.5](#)

Specification checked September 2026

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

- 1 Start with the equation** Balance it first. Formulae stay fixed; only coefficients may change.
- 2 Use the mole route** Known mass ↓ known amount → required amount ↑ required mass. Change substance only through the balanced-equation mole ratio.
- 3 Name every quantity** Write the substance beside each amount and keep unrounded calculator values until the final answer.
- 4 Audit the result** Check the limiting reactant, whole-number formula ratio, unit and appropriate significant figures.

Notation and units

Symbol	Meaning	Unit	Symbol	Meaning	Unit
n	amount of substance	mol	N	number of specified particles	no unit
m	mass	g	N _A	Avogadro constant	mol ⁻¹
M	molar mass	g mol ⁻¹	A _r	relative atomic mass	no unit
M _r	relative molecular or formula mass	no unit	x	whole-number water ratio in a hydrate	no unit

CALCULATION RULE Use $n = m \div M$ and $m = n \times M$. The numerical value of M is obtained from A_r or M_r. A_r and M_r themselves have no unit.

AQA BOUNDARY This pack assesses empirical and molecular formulae plus mass-based equation calculations. Concentration, gas-volume calculations, titrations, percentage yield and atom economy belong to Amount of Substance III.

Useful A_r values: H 1.0; C 12.0; N 14.0; O 16.0; Na 23.0; Mg 24.3; Al 27.0; S 32.1; Cl 35.5; Ca 40.1; Fe 55.8; Zn 65.4.

SECTION A TEST IT

Secure equations, mole ratios and the core calculation methods before the longer problems.

QUESTION 1 | TEST IT

Balance each equation using the smallest whole-number coefficients. Do not alter any formula.

(a) $\text{KClO}_3(\text{s}) \rightarrow \text{KCl}(\text{s}) + \text{O}_2(\text{g})$ (2 marks)

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(b) $\text{Al}(\text{s}) + \text{HCl}(\text{aq}) \rightarrow \text{AlCl}_3(\text{aq}) + \text{H}_2(\text{g})$ (2 marks)

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(c) $\text{Ca}_3(\text{PO}_4)_2(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{CaSO}_4(\text{s}) + \text{H}_3\text{PO}_4(\text{aq})$ (2 marks)

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(d) Explain why changing a subscript is not a valid way to balance an equation. (1 mark)

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QUESTION 2 | TEST IT

Copper(II) sulfate solution reacts with sodium hydroxide solution as shown.



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

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

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

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(d) Explain why $\text{Cu}(\text{OH})_2$ is not separated into ions in the ionic equation. (1 mark)

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QUESTION 3 | TEST IT

Sulfur dioxide reacts with oxygen according to $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})$.

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

(b) Calculate the amount of O_2 needed to react with 0.350 mol SO_2 . (1 mark)

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

(d) A student says the equation means $2 \text{ g SO}_2 + 1 \text{ g O}_2 \rightarrow 2 \text{ g SO}_3$. Explain why this is incorrect. (3 marks)

QUESTION 4 | TEST IT

Sodium burns in excess oxygen: $4\text{Na}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{Na}_2\text{O}(\text{s})$. Calculate the mass of Na_2O formed from 5.75 g Na. Give the final answer to three significant figures.

Show the mole-ratio step and final mass, with units. (6 marks)

QUESTION 5 | TEST IT

Iron is produced according to $\text{Fe}_2\text{O}_3(\text{s}) + 3\text{CO}(\text{g}) \rightarrow 2\text{Fe}(\text{s}) + 3\text{CO}_2(\text{g})$. Calculate the mass of Fe_2O_3 needed to make 8.37 g Fe when CO is in excess. $M_r(\text{Fe}_2\text{O}_3) = 159.6$.

Show your working and give the final mass to three significant figures. (6 marks)

QUESTION 6 | TEST IT

A compound contains 1.215 g Mg and 3.550 g Cl. Determine its empirical formula.

(a) Determine the empirical formula. Show your working. (5 marks)

(b) Explain why the mass ratio cannot be used directly as the formula ratio. (1 mark)

QUESTION 7 | TEST IT

A phosphorus oxide contains 43.7% phosphorus and 56.3% oxygen by mass.

(a) Use a 100 g sample to determine the empirical formula. Show your working.

(6 marks)

(b) State what must be done if the simplest ratio contains 1.5.

(1 mark)

QUESTION 8 | TEST IT

A compound has empirical formula C_2H_4O and $M_r = 88.0$.

(a) Determine the molecular formula.

(3 marks)

(b) State the difference between an empirical formula and a molecular formula.

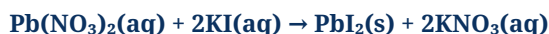
(2 marks)

SECTION B**EXAM STYLE**

Apply the same methods in linked AQA-style questions with unfamiliar substances and practical data.

QUESTION 9 | EXAM STYLE

Lead(II) nitrate solution reacts with potassium iodide solution.



(a) Write the full ionic equation.

(3 marks)

(b) Identify the spectator ions.

(1 mark)

(c) Write the net ionic equation.

(2 marks)

(d) Calculate the mass of PbI_2 formed from 6.62 g $Pb(NO_3)_2$ when KI is in excess. $M_r(Pb(NO_3)_2) = 331.0$ and $M_r(PbI_2) = 461.0$. Show your working.

(5 marks)

QUESTION 10 | EXAM STYLE

Titanium is extracted in the supplied reaction: $TiCl_4(g) + Mg(l) \rightarrow Ti(s) + MgCl_2(l)$. A sample of 7.29 g Mg reacts with excess $TiCl_4$. $A_r(Ti) = 47.9$.

(a) Balance the equation using the smallest whole-number coefficients.

(2 marks)

(b) Calculate the mass of Ti formed. Use your balanced equation and show your working. (6 marks)

(c) State why the coefficient ratio must be applied to amounts in moles rather than directly to masses. (1 mark)

QUESTION 11 | EXAM STYLE

Aluminium reacts with chlorine: $2\text{Al}(\text{s}) + 3\text{Cl}_2(\text{g}) \rightarrow 2\text{AlCl}_3(\text{s})$. A mixture contains 5.40 g Al and 14.2 g Cl_2 . $M_r(\text{Cl}_2) = 71.0$; $M_r(\text{AlCl}_3) = 133.5$.

(a) Calculate the initial amount of each reactant. (2 marks)

(b) Use $n \div \text{coefficient}$ to determine the limiting reactant. (4 marks)

(c) Calculate the mass of AlCl_3 formed. (2 marks)

(d) Calculate the mass of the excess reactant remaining. (3 marks)

QUESTION 12 | EXAM STYLE

A 12.5 g sample of limestone contains CaCO_3 and inert impurities. It reacts with excess hydrochloric acid and produces 4.40 g CO_2 .
 $\text{CaCO}_3 + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{CO}_2 + \text{H}_2\text{O}$. $M_r(\text{CaCO}_3) = 100.1$.

(a) Calculate the percentage by mass of CaCO_3 in the sample. Show your working. (7 marks)

(b) Explain why hydrochloric acid is stated to be in excess. (1 mark)

QUESTION 13 | EXAM STYLE

A student heats 4.46 g iron in oxygen. The mass of iron oxide formed is 6.38 g.

(a) Determine the empirical formula of the oxide. Show your working. (6 marks)

(b) Explain why the crucible is heated, cooled and reweighed until constant mass. (2 marks)

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(c) Suggest why a lid is kept slightly open during heating. (1 mark)

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QUESTION 14 | EXAM STYLE

A 0.880 g compound containing only carbon, hydrogen and oxygen produces 1.760 g CO₂ and 0.720 g H₂O on complete combustion. The compound has $M_r = 88.0$. Determine its molecular formula.

(a) Show clearly how the amounts of C, H and O are obtained and determine the empirical formula. (8 marks)

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(b) Use M_r to determine the molecular formula. (3 marks)

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QUESTION 15 | EXAM STYLE

A 4.76 g sample of CoCl₂·xH₂O is heated to constant mass. The anhydrous CoCl₂ has a mass of 2.60 g. $M_r(\text{CoCl}_2) = 130.0$.

(a) Determine x and write the formula of the hydrated salt. Show your working. (6 marks)

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(b) Explain why the crucible is cooled before it is weighed. (1 mark)

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(c) Explain why heating to constant mass improves the validity of the result. (1 mark)

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(d)(i) State the effect on the calculated value of x if some water remains. (1 mark)

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(d)(ii) State the effect on the calculated value of x if solid spits from the crucible. (1 mark)

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QUESTION 16 | EXAM STYLE

Oxygen made in stage 1 is used completely in stage 2. All other reactants are in excess. Stage 1: $2\text{KClO}_3(\text{s}) \rightarrow 2\text{KCl}(\text{s}) + 3\text{O}_2(\text{g})$. Stage 2: $4\text{Fe}(\text{s}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{Fe}_2\text{O}_3(\text{s})$. Calculate the mass of Fe₂O₃ formed from 5.00 g KClO₃. $M_r(\text{KClO}_3) = 122.6$; $M_r(\text{Fe}_2\text{O}_3) = 159.6$.

(a) Show the two mole-ratio steps and calculate the final mass. (7 marks)

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(b) Explain why the two equations may be linked through O_2 but the masses may not be linked directly. (2 marks)

SECTION C

HARDER MIXED

Select the route yourself, audit flawed methods and combine several specification-valid ideas.

QUESTION 17 | HARDER MIXED

Each student solution contains one fundamental error. For each, identify the error, state the correct rule and give the corrected result.

Student	Working shown
A	$Mg + O_2 \rightarrow MgO_2$, so the equation is balanced.
B	2.70 g Al and 2.40 g O give 2.70 : 2.40, so the empirical formula is AlO.
C	$N_2 + 3H_2 \rightarrow 2NH_3$. From 4.00 g H_2 , mass $NH_3 = 4.00 \times 2/3 = 2.67$ g.

(a) Correct student A. (3 marks)

(b) Correct student B. (3 marks)

(c) Correct student C. (3 marks)

QUESTION 18 | HARDER MIXED

A 7.700 g sample is 85.0% by mass of a metal M. The metal reacts completely with chlorine to form 13.645 g MCl_2 . The remaining material in the original sample is inert.

(a) Determine $A_r(M)$. Show how the purity and the formula MCl_2 are used. (7 marks)

(b) Identify M from Mg, Fe, Zn and Ba. (1 mark)

(c) State one numerical check on your result. (1 mark)

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(c) Calculate the mass of Fe formed.

(3 marks)

(d) Calculate the mass of Fe_2O_3 remaining.

(3 marks)

(e) State one assumption made in this two-stage calculation.

(1 mark)

QUESTION 22 | STRETCH / SYNOPTIC

A hydrated metal chloride has formula $\text{MCl}_2 \cdot x\text{H}_2\text{O}$. Heating 4.38 g of the hydrate to constant mass produces 2.22 g anhydrous MCl_2 . Chemical analysis shows that the 2.22 g sample contains 0.802 g of M.

(a) Use the anhydrous-salt data to determine $A_r(\text{M})$ and identify M.

(5 marks)

(b) Determine x and write the full formula of the hydrated salt. Show your working.

(6 marks)

(c) Explain why constant mass is required before x is calculated.

(2 marks)

Final calculation self-check

Before marking, confirm that you have...	Tick
balanced every equation without changing a formula	☐
written the substance beside each amount in moles	☐
used equation coefficients only between mole amounts	☐
compared $n \div \text{coefficient}$ when two reactant masses were given	☐
scaled every fractional formula ratio to whole numbers	☐
kept unrounded values, then added the correct unit and significant figures	☐

QUESTIONS END HERE • ANSWERS BEGIN ON THE NEXT PAGE



AQA 7405

Amount of Substance II

EQUATIONS • REACTING MASSES • FORMULAE • HYDRATED SALTS

FULLY WORKED. PRECISELY MARKED. BUILT FOR IMPROVEMENT.

TEST IT	EXAM STYLE	HARDER MIXED	STRETCH
8	8	4	2

22 QUESTIONS MASTERED | 194 TOTAL MARKS

Mapped to AQA Chemistry 7405 sections 3.1.2.4 and selected 3.1.2.5

Specification checked September 2026

Specification coverage audit AQA 7405

AQA area	Assessed content	Questions
3.1.2.4	Meaning of empirical and molecular formulae; relationship between them	6–8, 14, 19
3.1.2.4	Empirical formula from mass and percentage composition	6, 7, 13, 17, 19
3.1.2.4	Molecular formula from empirical formula and M_r	8, 14, 19
3.1.2.5	Balanced full and ionic equations with state symbols	1, 2, 9, 10
3.1.2.5	Mole ratios and mass-based reacting-mass calculations	3–5, 9–12, 16–18
3.1.2.5	Limiting reactants, excess and linked reactions	11, 16, 21
3.1.2.4–5	Metal-oxide, combustion and hydrated-salt mass evidence	13–15, 19, 20, 22

BOUNDARY CHECK Every calculation is mass-based. No concentration, gas-volume calculation, titration, percentage yield or atom-economy question is included.

HOW MARKING WORKS Each bracketed point earns one mark unless a different value is shown. Accept chemically equivalent working where the route is valid, values are carried without premature rounding and the final unit is correct.

SECTION A TEST IT — ANSWERS

Short, exact marking points for the foundational questions.

TEST IT 1

7 marks

- (a) $2\text{KClO}_3(\text{s}) \rightarrow 2\text{KCl}(\text{s}) + 3\text{O}_2(\text{g})$. Correct $\text{KClO}_3:\text{KCl}$ coefficients [1]; correct O_2 coefficient and smallest whole-number set [1].
 (b) $2\text{Al}(\text{s}) + 6\text{HCl}(\text{aq}) \rightarrow 2\text{AlCl}_3(\text{aq}) + 3\text{H}_2(\text{g})$. Correct Al/AlCl_3 relationship [1]; correct HCl/H_2 coefficients [1].
 (c) $\text{Ca}_3(\text{PO}_4)_2(\text{s}) + 3\text{H}_2\text{SO}_4(\text{aq}) \rightarrow 3\text{CaSO}_4(\text{s}) + 2\text{H}_3\text{PO}_4(\text{aq})$. Correct Ca/S species [1]; correct phosphate/acid coefficients [1].
 (d) A subscript is part of a substance's chemical formula, so changing it changes the substance rather than balancing the stated reaction [1].

COMMON ERROR Do not write KClO_2 , AlCl_2 or a different calcium phosphate to force an atom count to match.

TEST IT 2

8 marks

- (a) $\text{Cu}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) + 2\text{Na}^+(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Cu}(\text{OH})_2(\text{s}) + 2\text{Na}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$. Correct separation of aqueous ionic substances [1]; correct coefficients and species [1]; correct states with atoms and charge conserved [1].
 (b) Na^+ and SO_4^{2-} are the spectator ions [2].
 (c) $\text{Cu}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Cu}(\text{OH})_2(\text{s})$. Correct reacting ions and 1:2 ratio [1]; correct charge and states [1].
 (d) $\text{Cu}(\text{OH})_2$ is an insoluble solid, not freely separated aqueous ions [1].

COMMON ERROR "Aqueous" species may be separated only when they are soluble ionic substances, strong acids or strong alkalis in this context. A precipitate stays intact.

TEST IT 3

6 marks

- (a) $n(\text{SO}_3) = 0.350 \times 2/2 = 0.350 \text{ mol}$ [1].
 (b) $n(\text{O}_2) = 0.350 \times 1/2 = 0.175 \text{ mol}$ [1].
 (c) $n(\text{SO}_3) = 0.125 \times 2/1 = 0.250 \text{ mol}$ [1].
 (d) Equation coefficients give ratios of particles and therefore amounts in moles, not grams [1]. The substances have different molar masses [1]. For one equation amount, $128 \text{ g SO}_2 + 32 \text{ g O}_2 \rightarrow 160 \text{ g SO}_3$, which also conserves mass [1].

TEST IT 4

6 marks

$M_r(\text{Na}_2\text{O}) = (2 \times 23.0) + 16.0 = 62.0$ [1].
 $n(\text{Na}) = 5.75 \div 23.0 = 0.250 \text{ mol}$ [1].
 The equation ratio is 4 mol Na : 2 mol Na_2O [1], so $n(\text{Na}_2\text{O}) = 0.250 \times 2/4 = 0.125 \text{ mol}$ [1].
 $m(\text{Na}_2\text{O}) = 0.125 \times 62.0 = 7.75$ [1] = 7.75 g to three significant figures [1].

GRID METHOD	4Na	+ O ₂	→ 2Na ₂ O
Mass / g	[1] 5.75	In excess	[6] 7.75
M _r / A _r	[2] 23.0	32.0	[5] 62.0
Amount / mol	[3] 0.250	Not needed	[4] 0.125

TEST IT 5

6 marks

$n(\text{Fe}) = 8.37 \div 55.8 = 0.150 \text{ mol}$ [1].

The equation ratio is 1 mol Fe₂O₃ : 2 mol Fe [1], so $n(\text{Fe}_2\text{O}_3) = 0.150 \times 1/2 = 0.0750 \text{ mol}$ [1].

$M_r(\text{Fe}_2\text{O}_3) = 159.6$ [1]. $m(\text{Fe}_2\text{O}_3) = 0.0750 \times 159.6 = 11.97 \text{ g}$ [1] = 12.0 g to three significant figures [1].

GRID METHOD	Fe ₂ O ₃	+ 3CO	→ 2Fe	+ 3CO ₂
Mass / g	[6] 12.0	In excess	[1] 8.37	Not needed
M _r / A _r	[4] 159.6	28.0	55.8	44.0
Amount / mol	[3] 0.0750	Not needed	[1] 0.150	Not needed

TEST IT 6

6 marks

(a) $n(\text{Mg}) = 1.215 \div 24.3 = 0.0500 \text{ mol}$ and $n(\text{Cl}) = 3.550 \div 35.5 = 0.100 \text{ mol}$ [2]. Dividing both by 0.0500 gives Mg : Cl = 1 : 2 [2]. The empirical formula is MgCl₂ [1].

(b) A formula represents a ratio of atoms, and mass depends on the different A_r values. The masses must first be converted to amounts in moles [1].

Element	Mass / g	A _r	Amount / mol	÷ smallest	Whole-number ratio
Mg	1.215	24.3	0.0500	1.00	1
Cl	3.550	35.5	0.100	2.00	2

TEST IT 7

7 marks

(a) Treat the percentages as masses in a 100 g sample. $n(\text{P}) = 43.7 \div 31.0 = 1.4097 \text{ mol}$ and $n(\text{O}) = 56.3 \div 16.0 = 3.5188 \text{ mol}$ [2]. Divide by 1.4097 to give 1.000 : 2.496 [2]. This is 1 : 2.5; multiply the entire ratio by 2 [1] to give 2 : 5, so the empirical formula is P₂O₅ [1].

(b) Multiply every value in the ratio by 2; do not round 1.5 down or change only one value [1].

Element	Mass / g	A _r	Amount / mol	÷ smallest	Whole-number ratio
P	43.7	31.0	1.4097	1.000	2
O	56.3	16.0	3.5188	2.496 ≈ 2.5	5

TEST IT 8

5 marks

(a) Empirical-formula mass = $(2 \times 12.0) + (4 \times 1.0) + 16.0 = 44.0$ [1]. Multiplier = $88.0 \div 44.0 = 2$ [1]. Molecular formula = C₄H₈O₂ [1].

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

SECTION B

EXAM STYLE — ANSWERS

Full worked routes and AQA-style marking guidance.

EXAM STYLE 9

11 marks

(a) $\text{Pb}^{2+}(\text{aq}) + 2\text{NO}_3^-(\text{aq}) + 2\text{K}^+(\text{aq}) + 2\text{I}^-(\text{aq}) \rightarrow \text{PbI}_2(\text{s}) + 2\text{K}^+(\text{aq}) + 2\text{NO}_3^-(\text{aq})$. Correct aqueous dissociation [1]; PbI₂ kept as a solid [1]; coefficients, states and charge correct [1].

(b) K⁺ and NO₃⁻ are the spectator ions; both are required [1].

(c) $\text{Pb}^{2+}(\text{aq}) + 2\text{I}^-(\text{aq}) \rightarrow \text{PbI}_2(\text{s})$. Correct species and 1:2 ratio [1]; states and charge correct [1].

(d) $n(\text{Pb}(\text{NO}_3)_2) = 6.62 \div 331.0 = 0.0200 \text{ mol}$ [1]. The 1:1 equation ratio [1] gives $n(\text{PbI}_2) = 0.0200 \text{ mol}$ [1]. $m = 0.0200 \times 461.0 = 9.22$ [1] = 9.22 g [1].

GRID METHOD	$\text{Pb}(\text{NO}_3)_2$	+ 2KI	$\rightarrow \text{PbI}_2$	+ 2KNO ₃
Mass / g	6.62	In excess	9.22	Not needed
M_r / A_r	331.0	166.0	461.0	101.0
Amount / mol	0.0200	Not needed	0.0200	Not needed

EXAM STYLE 10

9 marks

- (a) $\text{TiCl}_4(\text{g}) + 2\text{Mg}(\text{l}) \rightarrow \text{Ti}(\text{s}) + 2\text{MgCl}_2(\text{l})$. Coefficient 2 before Mg [1] and MgCl_2 [1].
 (b) $n(\text{Mg}) = 7.29 \div 24.3 = 0.300 \text{ mol}$ [1]. The ratio is 2 mol Mg : 1 mol Ti [1], so $n(\text{Ti}) = 0.150 \text{ mol}$ [1]. $m(\text{Ti}) = 0.150 \times 47.9$ [1] = 7.185 g [1] = 7.19 g to three significant figures [1].
 (c) Coefficients describe numbers of particles and therefore amounts in moles; each substance has a different molar mass [1].

GRID METHOD	TiCl_4	+ 2Mg	$\rightarrow \text{Ti}$	+ 2MgCl ₂
Mass / g	In excess	7.29	7.19	Not needed
M_r / A_r	189.9	24.3	47.9	95.3
Amount / mol	Not needed	0.300	0.150	Not needed

EXAM STYLE 11

11 marks

- (a) $n(\text{Al}) = 5.40 \div 27.0 = 0.200 \text{ mol}$ and $n(\text{Cl}_2) = 14.2 \div 71.0 = 0.200 \text{ mol}$ [2].
 (b) Al: $0.200 \div 2 = 0.100$ [1]. Cl_2 : $0.200 \div 3 = 0.0667$ [1]. The smaller reaction extent is 0.0667 [1], so Cl_2 is limiting [1].
 (c) $n(\text{AlCl}_3) = 0.0667 \times 2 = 0.1333 \text{ mol}$ [1]. $m(\text{AlCl}_3) = 0.1333 \times 133.5 = 17.8 \text{ g}$ [1].
 (d) $n(\text{Al used}) = 0.0667 \times 2 = 0.1333 \text{ mol}$ [1]. $n(\text{Al left}) = 0.200 - 0.1333 = 0.0667 \text{ mol}$ [1]. $m(\text{Al left}) = 0.0667 \times 27.0 = 1.80 \text{ g}$ [1].
COMMON ERROR Comparing 0.200 mol with 0.200 mol alone is insufficient. Divide each amount by its own equation coefficient.

GRID METHOD	2Al	+ 3Cl ₂	$\rightarrow 2\text{AlCl}_3$
Mass / g	5.40; 1.80 left	14.2; limiting	17.8
M_r / A_r	27.0	71.0	133.5
Amount / mol	0.200	0.200	0.1333

EXAM STYLE 12

8 marks

- (a) $n(\text{CO}_2) = 4.40 \div 44.0 = 0.100 \text{ mol}$ [1]. The 1:1 ratio gives $n(\text{CaCO}_3) = 0.100 \text{ mol}$ [1]. $m(\text{pure CaCO}_3) = 0.100 \times 100.1 = 10.01 \text{ g}$ [1].
 Purity = pure mass $\div$ sample mass $\times 100$ [1] = $10.01 \div 12.5 \times 100 = 80.08$ [1] = 80.1 [1] % [1].
 (b) Excess HCl ensures all the CaCO_3 can react, so the CO_2 amount is controlled by the CaCO_3 rather than by a shortage of acid [1].

GRID METHOD	CaCO_3	+ 2HCl	$\rightarrow \text{CaCl}_2$	+ CO ₂ + H ₂ O
Mass / g	10.01 pure	In excess	Not needed	4.40 CO ₂
M_r / A_r	100.1	36.5	111.1	44.0 CO ₂
Amount / mol	0.100	Not needed	Not needed	0.100 CO ₂

EXAM STYLE 13

9 marks

- (a) $m(\text{O}) = 6.38 - 4.46 = 1.92 \text{ g}$ [1]. $n(\text{Fe}) = 4.46 \div 55.8 = 0.0799 \text{ mol}$ [1]. $n(\text{O}) = 1.92 \div 16.0 = 0.120 \text{ mol}$ [1]. Divide by 0.0799 to give 1.000 : 1.501 [1]. Multiply the whole ratio by 2 to give 2 : 3 [1], so the empirical formula is Fe_2O_3 [1].
 (b) Reheating until two consecutive masses agree shows that oxidation is complete [1] and that no further mass change occurs [1].
 (c) A slightly open lid lets oxygen enter while helping to reduce loss of solid by spitting [1].

Element	Mass / g	A _r	Amount / mol	÷ smallest	Whole-number ratio
Fe	4.46	55.8	0.0799	1.000	2
O	1.92	16.0	0.120	1.501	3

EXAM STYLE 14**11 marks**

(a) $n(\text{CO}_2) = 1.760 \div 44.0 = 0.0400 \text{ mol}$, so $n(\text{C}) = 0.0400 \text{ mol}$ [1].

$n(\text{H}_2\text{O}) = 0.720 \div 18.0 = 0.0400 \text{ mol}$ [1], so $n(\text{H}) = 2 \times 0.0400 = 0.0800 \text{ mol}$ [1].

$m(\text{C}) = 0.0400 \times 12.0 = 0.480 \text{ g}$ and $m(\text{H}) = 0.0800 \times 1.0 = 0.0800 \text{ g}$ [1].

$m(\text{O}) = 0.880 - 0.480 - 0.080 = 0.320 \text{ g}$ [1], so $n(\text{O}) = 0.320 \div 16.0 = 0.0200 \text{ mol}$ [1].

C : H : O = $0.0400 : 0.0800 : 0.0200 = 2 : 4 : 1$ [1], giving empirical formula $\text{C}_2\text{H}_4\text{O}$ [1].

(b) Empirical-formula mass = 44.0 [1]. Multiplier = $88.0 \div 44.0 = 2$ [1]. Molecular formula = $\text{C}_4\text{H}_8\text{O}_2$ [1].

Element	Mass / g	A _r	Amount / mol	÷ smallest	Whole-number ratio
C	0.480	12.0	0.0400	2.00	2
H	0.0800	1.0	0.0800	4.00	4
O	0.320	16.0	0.0200	1.00	1

EXAM STYLE 15**10 marks**

(a) $m(\text{H}_2\text{O}) = 4.76 - 2.60 = 2.16 \text{ g}$ [1]. $n(\text{H}_2\text{O}) = 2.16 \div 18.0 = 0.120 \text{ mol}$ [1]. $n(\text{CoCl}_2) = 2.60 \div 130.0 = 0.0200 \text{ mol}$ [1]. Ratio $\text{CoCl}_2 : \text{H}_2\text{O} = 0.0200 : 0.120 = 1 : 6$ [1]. Therefore $x = 6$ [1] and the formula is $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ [1].

(b) A hot crucible creates convection currents and gives an unreliable balance reading, so it is cooled before weighing [1].

(c) Constant mass indicates that no further water is being removed [1].

(d)(i) If water remains, the apparent water loss and calculated x are too low [1].

(d)(ii) If solid spits out, the final mass is too low, so the apparent water loss and calculated x are too high [1].

GRID METHOD	CoCl_2	$+ 6\text{H}_2\text{O}$
Mass / g	2.60	2.16 lost
M _r / A _r	130.0	18.0
Amount / mol	0.0200	0.120

EXAM STYLE 16**9 marks**

(a) $n(\text{KClO}_3) = 5.00 \div 122.6 = 0.04078 \text{ mol}$ [1]. Stage 1 gives $n(\text{O}_2) = 0.04078 \times 3/2 = 0.06117 \text{ mol}$ [1]. Stage 2 gives $n(\text{Fe}_2\text{O}_3) = 0.06117 \times 2/3 = 0.04078 \text{ mol}$ [1]. The two ratios therefore give an overall 1:1 amount relationship here [1]. $M_r(\text{Fe}_2\text{O}_3) = 159.6$ [1]. $m = 0.04078 \times 159.6 = 6.509 \text{ g}$ [1] = 6.51 g [1].

(b) The amount of O_2 produced in stage 1 is the same amount consumed in stage 2 [1]. Masses cannot be linked by equation coefficients because KClO_3 , O_2 and Fe_2O_3 have different molar masses [1].

GRID METHOD	2KClO_3	3O_2	$2\text{Fe}_2\text{O}_3$
Mass / g	5.00	Intermediate	6.51
M _r / A _r	122.6	32.0	159.6
Amount / mol	0.04078	0.06117	0.04078

SECTION C**HARDER MIXED — ANSWERS**

Marks reward correct selection and diagnosis, not merely a final number.

HARDER MIXED 17**9 marks**

(a) Student A changed the product formula by adding a subscript [1]. Formulae must stay fixed and only coefficients may change [1]. Correct equation: $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$ [1].

(b) Student B used a mass ratio instead of an amount ratio [1]. $n(\text{Al}) = 2.70 \div 27.0 = 0.100 \text{ mol}$ and $n(\text{O}) = 2.40 \div 16.0 = 0.150 \text{ mol}$ [1]. The ratio is 2 : 3, so the formula is Al_2O_3 [1].

(c) Student C applied a coefficient ratio directly to mass [1]. $n(\text{H}_2) = 4.00 \div 2.00 = 2.00 \text{ mol}$ and $n(\text{NH}_3) = 2.00 \times 2/3 = 1.333 \text{ mol}$ [1].
 $m(\text{NH}_3) = 1.333 \times 17.0 = 22.7 \text{ g}$ [1].

HARDER MIXED 18**9 marks**

(a) Pure metal mass = $7.700 \times 0.850 = 6.545 \text{ g}$ [1]. Chlorine mass in the product = $13.645 - 6.545 = 7.100 \text{ g}$ [1]. $n(\text{Cl atoms}) = 7.100 \div 35.5 = 0.200 \text{ mol}$ [1]. MCl_2 contains two Cl atoms per M, so $n(\text{M}) = 0.200 \div 2 = 0.100 \text{ mol}$ [1]. $A_r(\text{M}) = 6.545 \div 0.100$ [1] = 65.45 [1] = 65.4 to three significant figures [1].

(b) M is Zn [1].

(c) Numerical check: $6.545 \text{ g metal} + 7.100 \text{ g chlorine} = 13.645 \text{ g product}$ [1].

ACCEPT A check that 0.100 mol Zn plus 0.200 mol Cl atoms gives the MCl_2 ratio is also valid.

HARDER MIXED 19**11 marks**

$n(\text{CO}_2) = n(\text{C}) = 2.640 \div 44.0 = 0.0600 \text{ mol}$ [1].

$n(\text{H}_2\text{O}) = 1.080 \div 18.0 = 0.0600 \text{ mol}$ [1], so $n(\text{H}) = 0.120 \text{ mol}$ [1].

$m(\text{C}) = 0.0600 \times 12.0 = 0.720 \text{ g}$ and $m(\text{H}) = 0.120 \times 1.0 = 0.120 \text{ g}$ [1].

$m(\text{O}) = 1.480 - 0.720 - 0.120 = 0.640 \text{ g}$ [1], so $n(\text{O}) = 0.640 \div 16.0 = 0.0400 \text{ mol}$ [1].

Divide by 0.0400 to give C : H : O = 1.5 : 3 : 1 [1]. Multiply the whole ratio by 2 to give 3 : 6 : 2 [1], so the empirical formula is $\text{C}_3\text{H}_6\text{O}_2$ [1].

Empirical-formula mass = 74.0, so $148.0 \div 74.0 = 2$ [1]. Molecular formula = $\text{C}_6\text{H}_{12}\text{O}_4$ [1].

COMMON ERROR Do not round 1.5 to 2. Scale the complete ratio to whole numbers.

Element	Mass / g	A_r	Amount / mol	$\div$ smallest	Whole-number ratio
C	0.720	12.0	0.0600	1.5	3
H	0.120	1.0	0.120	3.0	6
O	0.640	16.0	0.0400	1.0	2

HARDER MIXED 20**10 marks**

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

(b) $m(\text{H}_2\text{O}) = 5.72 - 2.12 = 3.60 \text{ g}$ [1]. $n(\text{H}_2\text{O}) = 3.60 \div 18.0 = 0.200 \text{ mol}$ [1]. $n(\text{Na}_2\text{CO}_3) = 2.12 \div 106.0 = 0.0200 \text{ mol}$ [1]. Ratio = 0.200 : 0.0200 = 10 : 1, so $x = 10$ [1]. Formula = $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ [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 $n(\text{H}_2\text{O}) \div n(\text{Na}_2\text{CO}_3)$, and hence x , too low [1].

GRID METHOD	Na_2CO_3	+ 10 H_2O
Mass / g	2.12	3.60 lost
M_r / A_r	106.0	18.0
Amount / mol	0.0200	0.200

SECTION D**STRETCH / SYNOPTIC — ANSWERS**

Complete linked reasoning with no later-topic shortcuts.

STRETCH 21**13 marks**

(a) $n(\text{NaN}_3) = 39.0 \div 65.0 = 0.600 \text{ mol}$ [1]. Stage 1 is 2:2, so $n(\text{Na}) = 0.600 \text{ mol}$ [1].

(b) $n(\text{Fe}_2\text{O}_3) = 17.6 \div 159.6 = 0.1103 \text{ mol}$ [1]. For stage 2, Na gives $0.600 \div 6 = 0.100$ reaction amounts [1], while Fe_2O_3 gives $0.1103 \div 1 = 0.1103$ [1]. The smaller value is from Na, so Na is limiting [1].

(c) $n(\text{Fe}) = 0.100 \times 2 = 0.200 \text{ mol}$ [1]. $m(\text{Fe}) = 0.200 \times 55.8 = 11.16 \text{ g}$ [1] = 11.2 g to three significant figures [1].

(d) $n(\text{Fe}_2\text{O}_3 \text{ used}) = 0.100 \text{ mol}$ [1], so mass used = $0.100 \times 159.6 = 15.96 \text{ g}$ [1]. Mass remaining = $17.6 - 15.96 = 1.64 \text{ g}$ [1].

(e) Assume stage 1 is complete and all sodium is transferred without loss to stage 2 [1].

ACCEPT Assuming stage 2 goes to completion is also valid.

GRID METHOD	6NaN ₃	6Na	+ Fe ₂ O ₃	→ 2Fe
Mass / g	39.0	Intermediate	17.6; 1.64 left	11.2
M _r / A _r	65.0	23.0	159.6	55.8
Amount / mol	0.600	0.600	0.1103	0.200

STRETCH 22

13 marks

(a) Mass of Cl in MCl₂ = 2.22 – 0.802 = 1.418 g [1]. n(Cl atoms) = 1.418 ÷ 35.5 = 0.03994 mol [1]. n(M) = 0.03994 ÷ 2 = 0.01997 mol [1]. A_r(M) = 0.802 ÷ 0.01997 = 40.16 [1], so M is Ca [1].

(b) m(H₂O) = 4.38 – 2.22 = 2.16 g [1]. n(H₂O) = 2.16 ÷ 18.0 = 0.120 mol [1]. M_r(CaCl₂) = 40.1 + (2 × 35.5) = 111.1 [1]. n(CaCl₂) = 2.22 ÷ 111.1 = 0.01998 mol [1]. Ratio H₂O : CaCl₂ = 0.120 : 0.01998 = 6.01 : 1, so x = 6 [1]. Formula = CaCl₂·6H₂O [1].

(c) Constant mass shows that water removal is complete [1]. If water remained, the residue would be too heavy and the calculated x would be too low [1].

GRID METHOD	CaCl ₂	+ 6H ₂ O
Mass / g	2.22	2.16 lost
M _r / A _r	111.1	18.0
Amount / mol	0.01998	0.120

Post-marking diagnosis [REWORK WITH PURPOSE](#)

If marks were lost on...	Revisit	Check first
balancing or ionic equations	1, 2, 9, 10	formulae fixed; atoms, charge and states conserved
reacting-mass grids	4, 5, 9, 10, 12, 16	mass ↓ amount → amount ↑ mass
limiting reactants or excess	11, 21	compare n ÷ coefficient for every reactant
empirical or molecular formulae	6–8, 13, 14, 19	divide masses by A _r before simplifying
hydrated salts or constant mass	15, 20, 22	water lost and anhydrous salt need separate amounts
method selection and error spotting	17, 18	identify the invalid step before recalculating