

Question	Answer	Marks	Guidance
1	A	1	

Question			Answer	Marks	Guidance
2	(a)		$n(\text{H}_2\text{O}_2) = 2.30 \times \frac{25.0}{1000}$ OR $= 0.0575 \text{ (mol)}$ ✓ $\text{vol O}_2 = \frac{0.0575}{2} \times 24000 = 690 \text{ cm}^3$ ✓ Collect in $1000 \text{ cm}^3/1 \text{ dm}^3$ measuring cylinder ✓	3	ALLOW $0.69(0) \text{ dm}^3$ 2 nd mark subsumes 1 st mark ALLOW $1000 \text{ cm}^3/1 \text{ dm}^3$ syringe Needs a name of actual apparatus, not just 'container' 'measuring cylinder' without volume is insufficient DO NOT ALLOW burette For other possible apparatus, contact Team Leader ALLOW volumes from $700\text{--}1000 \text{ cm}^3$ but should be realistic apparatus, e.g. 700, 750, 800, 850, 900, 950.
	(b)		Measure mass (loss) ✓	1	ALLOW weight for mass ALLOW take samples and titrate (remaining H_2O_2)

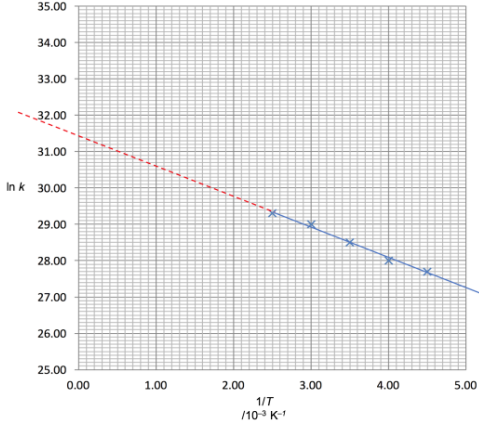
2 Question	Answer	Marks	Guidance
(c)*	<i>Please refer to the marking instructions on page 5 of mark scheme for guidance on marking this question.</i> Level 3 (5–6 marks) A comprehensive conclusion using quantitative data from the graph to correctly determine initial rate AND half lives/gradient with 1st order conclusion for H₂O₂ AND determination of <i>k</i>. <i>There is a well-developed line of reasoning which is clear and logically structured.</i> <i>Clear working for initial rate, half life/gradient and order and <i>k</i>.</i> <i>Units mostly correct throughout.</i> Level 2 (3–4 marks) Attempts to describe all three scientific points but explanations may be incomplete. OR Explains two scientific points thoroughly with few omissions. <i>There is a line of reasoning with some structure and supported by some evidence. The scientific points are supported by evidence from the graph.</i> Level 1 (1–2 marks) Reaches a simple conclusion using at least one piece of quantitative data from the graph. Attempts to calculate initial rate OR half life. <i>There is an attempt at a logical structure with a reasoned conclusion from the evidence.</i> 0 marks No response worthy of credit.	6	Indicative scientific points may include: Initial rate - Tangent shown on graph as line at $t = 0$ s - Gradient determined in range: $1.5 - 2.0 \times 10^{-3}$ e.g. $\frac{2.3}{1300} = 1.77 \times 10^{-3}$ <i>initial rate</i> as gradient value with units: $\text{mol dm}^{-3} \text{s}^{-1}$ <i>For other methods contact TL</i> Evidence for 1st order 2 methods 1st order clearly linked to half-life OR 2 gradients: 1. Half life - Half life shown on graph - Half life range 800–1000 s - Two 'constant' half lives ± 50 s 2. Two gradients → two rates 2 tangents shown on graph at c and $c/2$ - Gradient at $c/2$ is half gradient at c e.g. $c = 2.3 \text{ mol dm}^{-3}$, gradient = 1.6×10^{-3} AND $c = 1.15 \text{ mol dm}^{-3}$, gradient = 0.8×10^{-3} - For chosen method, conclusion: H₂O₂ is 1st order Determination of <i>k</i> 2 methods <i>k</i> clearly linked to rate OR half-life: $k = \frac{\text{rate}}{[\text{H}_2\text{O}_2]}$ e.g. $k = \frac{1.6 \times 10^{-3}}{2.3} = 7 \times 10^{-4} \text{ s}^{-1}$ OR $k = \frac{\ln 2}{t_{1/2}}$ e.g. $k = \frac{0.693}{950} = 7.3 \times 10^{-4} \text{ s}^{-1}$
	Total	10	

Question	Answer	Marks	AO element	Guidance
3	A	1	AO1.1	

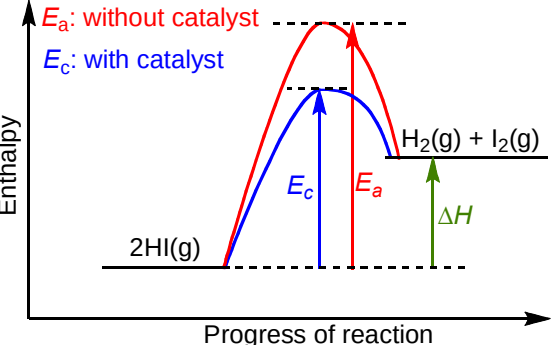
Question	Answer	Marks	AO element	Guidance
4	C	1	AO1.1	

Question		Answer	Marks	Guidance
5	(a)*	<i>Please refer to the marking instructions on page 5 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) A comprehensive conclusion which uses quantitative results for determination of the reaction orders. AND Determines k from correct rate equation. AND Proposes the two-step mechanism which adds up to overall equation <i>with no intermediate electrons</i>. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated. The working for the scientific content is clearly linked to the experimental evidence.</i> Level 2 (3–4 marks) Reaches a sound, but not comprehensive, conclusion based on the quantitative results. AND Correctly identifies the orders and rate equation. AND Calculates the rate constant OR Proposes the two-step mechanism with reactants of first step matching rate equation or matches orders <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence. The working for the scientific content is clearly linked to the experimental evidence.</i>	6	Indicative scientific points may include: Orders and rate equation - Fe³⁺ 1st order AND I[−] 2nd order OR rate = $k[\text{Fe}^{3+}][\text{I}^{-}]^2$ - Supported by experimental results Calculation of k, including units k correctly calculated AND correct units, e.g. $k = \frac{8.10 \times 10^{-4}}{(4.00 \times 10^{-2}) \times (3.00 \times 10^{-2})^2} = 22.5$ - dm⁶ mol^{−2} s^{−1} OR mol^{−2} dm⁶ s^{−1} Two-step mechanism - Two steps add up to give overall equation - Slow step/ rate-determining step matches stoichiometry of rate equation. - Each step balances by species and charge e.g. $\text{Fe}^{3+}(\text{aq}) + 2\text{I}^{-}(\text{aq}) \rightarrow [\text{FeI}_2]^{+}$ SLOW $\text{Fe}^{3+}(\text{aq}) + [\text{FeI}_2]^{+} \rightarrow 2\text{Fe}^{2+}(\text{aq}) + \text{I}_2(\text{aq})$ FAST $\text{Fe}^{3+}(\text{aq}) + 2\text{I}^{-}(\text{aq}) \rightarrow \text{Fe}^{2+}(\text{aq}) + \text{I}_2^{-}(\text{aq})$ SLOW $\text{Fe}^{3+}(\text{aq}) + \text{I}_2^{-}(\text{aq}) \rightarrow \text{Fe}^{2+}(\text{aq}) + \text{I}_2(\text{aq})$ FAST $\text{Fe}^{3+}(\text{aq}) + 2\text{I}^{-}(\text{aq}) \rightarrow \text{Fe}^{+} + \text{I}_2$ SLOW $\text{Fe}^{3+}(\text{aq}) + \text{Fe}^{+} \rightarrow 2\text{Fe}^{2+}(\text{aq})$ FAST There may be other feasible possibilities

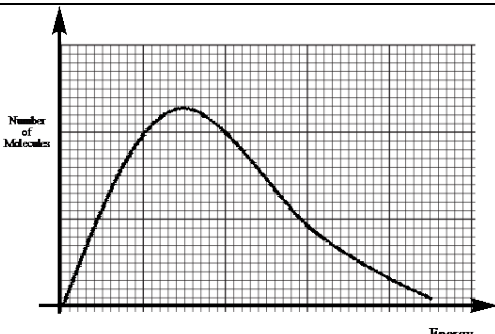
5 Question			Answer	Marks	Guidance
			Level 1 (1–2 marks) Attempts to reach a simple conclusion for orders AND Attempts a relevant rate equation. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant The working for the scientific content is clearly linked to the experimental evidence.</i> 0 marks No response or no response worthy of credit.		

5 Question	Answer	Marks	Guidance
(b) (i)	 Gradient Correct gradient calculated from best-fit straight line drawn within the range $\pm 800 \rightarrow \pm 1040$ ✓ E_a calculation $E_a = (-) \text{gradient} \times 8.314$ ✓ e.g. from ± 820, $E_a = (+)6817.48 \text{ (J mol}^{-1}\text{)}$ E_a to 3 SF AND use of 10^{-3} for gradient ✓ e.g. from ± 820, $E_a = (+)6820 \text{ (J mol}^{-1}\text{)}$	3	ALLOW lines which do not intercept y-axis ALLOW mark for gradient if correct working shown within E_a calculation without gradient being calculated separately ALLOW $\pm 0.8(00) \rightarrow \pm 1.04(0)$ (omission of 10^{-3}) ALLOW ECF for calculated gradient $\times 8.314$ If value of gradient not shown separately, ALLOW E_a in range: $6650 \rightarrow 8650$ OR $6.65 \rightarrow 8.65$ (omission of 10^{-3}) This mark subsumes gradient mark NOTE: Omission of 10^{-3} can get 1st 2 marks

5 Question			Answer	Marks	Guidance
		(ii)	Intercept shown on graph <i>could be by extrapolation of line, or label on y axis</i> AND $\ln A$ linked to intercept value <i>e.g. $\ln A = 31.4$ ✓</i> Calculation of $A = e^{\text{intercept}}$ ✓ <i>e.g. $A = e^{31.4} = 4.33 \times 10^{13}$</i>	2	ALLOW $y = 31.4$ ALLOW substitution of correct values of $\ln k$ and $1/T$ into $\ln k = -E_a/R \times 1/T + \ln A$ to give a value of $\ln A$ which approximately matches the intercept if given $\ln A = \ln k + (E_a/R \times 1/T)$ Calculation of $A = e^{\ln A}$ OR $e^{\ln k + (E_a/R \times 1/T)}$ ALLOW ECF from incorrect $\ln A$ $e^{31.2} = 3.55 \times 10^{13}$ $e^{31.3} = 3.92 \times 10^{13}$ $e^{31.35} = 4.12 \times 10^{13}$ $e^{31.45} = 4.56 \times 10^{13}$ $e^{31.5} = 4.79 \times 10^{13}$ $e^{31.6} = 5.29 \times 10^{13}$ $e^{31.7} = 5.85 \times 10^{13}$ $e^{31.8} = 6.46 \times 10^{13}$ $e^{31.9} = 7.14 \times 10^{13}$ $e^{32.0} = 7.9(0) \times 10^{13}$ $e^{32.1} = 8.73 \times 10^{13}$ IF 2 DP answer given, check rounding from calculator value, not 3 DP values given Eg $e^{31.7} = 5.8497 \times 10^{13}$ and $= 5.8 \times 10^{13}$ (2SF)
			Total	11	

6 Question	Answer	Marks	Guidance
(a)	 2HI(g) on LHS AND H₂(g) + I₂(g) on RHS ✓ ΔH labelled with product above reactant AND arrow upwards ✓ E_a AND E_c correctly labelled with E_c below E_a ✓	3	FULL ANNOTATIONS MUST BE USED Mark each point independently IGNORE state symbols. ΔH: DO NOT ALLOW -ΔH. ALLOW ΔH arrow even with a gap at the top and bottom, i.e. does not quite reach reactant or product line E_a: ALLOW no arrowhead or arrowheads at both ends of E_a line E_a line must reach (near or not too far beyond) maximums regardless of position ALLOW AE or EA for E_a Exothermic diagram can access the first and third marks

Question	Answer	Marks	AO	Guidance
7	C	1	AO2.6	

Question			Answer	Marks	AO element	Guidance
8	(a)	(i)	 Correct drawing of Boltzmann distribution Curve starts within one small square of origin AND not touching the x axis at high energy ✓ Axes labels: y: (number of) molecules/particles AND x: (kinetic) energy ✓ Catalyst and activation energy Catalyst provides a lower activation energy OR E_c shown to the left of E_a on Boltzmann distribution ✓ Particles with $E > E_a$ more or a greater proportion of molecules / particles / collisions have (energy above) activation energy (with catalyst) OR more molecules have enough energy to react OR greater area under curve above activation energy ✓	4	1.1 ×4	DO NOT ALLOW two curves <i>Confusion with effect of temperature</i> DO NOT ALLOW 'enthalpy' for x-axis label DO NOT ALLOW 'atoms' as y-axis label ALLOW ECF for atoms (instead of molecules/particles) if y axis labelled as 'atoms' IGNORE (more) successful collisions IGNORE response implying 'more collisions' (<i>confusion with effect of greater temperature</i>)
		(ii)	heterogeneous (catalyst) AND catalyst in a different phase/state (from other substances) ✓	1	1.2	ALLOW catalyst is a solid AND not a gas / everything else is a gas
			Total	23		

Question	Answer	Marks	AO element	Guidance
9	Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question. Level 3 (5–6 marks) Most evidence used to determine the correct orders AND rate equation AND rate constant. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some evidence used to determine two orders correctly AND rate equation AND rate constant consistent with orders. OR Little evidence used to determine all three orders correctly AND rate equation AND rate constant. <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Little evidence used to determine two orders correctly OR One order correct, with attempt to determine the rate equation AND rate constant. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	6	3.1 $\times 4$ 3.2 $\times 2$	Indicative scientific points may include: Orders Student 1 - zero order wrt Br_2 Student 2 1st order wrt CH_3COCH_3 Student 3 1st order wrt H^+ Explanations Student 1 - constant gradient OR linear negative gradient OR constant rate OR rate independent of concentration OR decreasing half-life Student 2 - straight line through 0,0 OR rate directly proportional to $[\text{CH}_3\text{COCH}_3]$ OR $[\text{CH}_3\text{COCH}_3] \times 2$, rate $\times 2$ Student 3 $[\text{H}^+] \times 2$, rate $\times 2$ Rate equation, rate constant and units - rate = $k [\text{CH}_3\text{COCH}_3] [\text{H}^+]$ ALLOW rate = $k [\text{Br}_2]^0 [\text{CH}_3\text{COCH}_3]^1 [\text{H}^+]^1$ $k = \frac{\text{rate}}{[\text{CH}_3\text{COCH}_3] [\text{H}^+]}$ OR $\frac{1.25 \times 10^{-5}}{1.6 \times 0.2}$ $k = 3.9 \dots \times 10^{-5}$ - units: $\text{dm}^3 \text{mol}^{-1} \text{s}^{-1}$ (Any order, e.g. $\text{mol}^{-1} \text{dm}^3 \text{s}^{-1}$)
	Total	6		

Question	Answer	Marks	AO	Guidance
10	D	1	1.1	

Question	Answer	Marks	AO	Guidance
11	D	1	2.6	

Question	Answer	Marks	AO	Guidance
12	C	1	1.2	ALLOW 2 in the answer box

Question			Answer	Marks	AO	Guidance
13	(a)		(Reaction can be carried out at) lower temperatures / lower energy demand ✓ Less (fossil) fuels burnt / less CO ₂ emissions ✓	2	1.1×2	ALLOW lower pressures as alternative to lower temperature ALLOW reduced carbon footprint as alternative to less fuels burnt ALLOW different reactions can be used with greater atom economy / less waste

Question			Answer	Marks	AO element	Guidance
14	(a)	(i)	To keep $[\text{CH}_3\text{OH}]$ (effectively) constant OR Zero order with respect to CH_3OH	1	3.3	ALLOW Change in $[\text{CH}_3\text{OH}]$ is negligible ALLOW rate is independent of $[\text{CH}_3\text{OH}]$ IGNORE Methanol doesn't run out/is not limiting reagent.
		(ii)	One half-life $t_{1/2}$ between 102 and 110 (mins) Two half-lives calculated OR evidence on the graph of two half-lives AND constant half-life/values (means first order) ✓	2	3.1 3.2	ALLOW any two combinations of positions, e.g. 5 and 2.5 AND 4 and 2 AND 3 and 1.5
		(iii)	Using gradients Evidence of tangent at $t = 0$ and intercept between 100 -140 (min) ✓ Correctly calculated gradient in the range of 2.9×10^{-5} to 4.0×10^{-5} ($\text{mol dm}^{-3} \text{min}^{-1}$) ✓ OR	2	3.1×1 3.2×1	

Question			Answer	Marks	AO element	Guidance
15	(a)	(i)	(Expt 1 and 2) $[S_2O_3^{2-}]$ halves, $[H^+]$ constant, AND rate halves AND first order (with respect to $[S_2O_3^{2-}]$) ✓ (Expt 2 and 3) $[S_2O_3^{2-}]$ quarter AND $[H^+]$ halves, AND rate quarters AND zero order (with respect to $[H^+]$) ✓	2	AO3.1 ×2	ALLOW ORA i.e. (Expt 2 and 1) $[S_2O_3^{2-}]$ doubles, $[H^+]$ constant, AND rate doubles AND first order with respect to $[S_2O_3^{2-}]$ ALLOW comparison of Expt 1 and 3: $[S_2O_3^{2-}] \times 1/8$ AND $[H^+]$ halves, AND rate $\times 1/8$ AND zero order with respect to $[H^+]$
	(a)	(ii)	$S_2O_3^{2-}$ as only reactant species in step 1 ✓ Rest of mechanism correct ✓	2	AO3.2 ×2	Step 1: $S_2O_3^{2-} \rightarrow S + SO_3^{2-}$ Step 2: $SO_3^{2-} + 2H^+ \rightarrow SO_2 + H_2O$ OR Step 1: $S_2O_3^{2-} \rightarrow SO_2 + SO^{2-}$ Step 2: $SO^{2-} + 2H^+ \rightarrow S + H_2O$ Check with Team Leader for other equations
	(b)	(i)	Gradient gradient in range of -5700 to -6100 ✓ E_a calculation $E_a = (-) \text{gradient} \times 8.314$ e.g. from -5900, $E_a = (+) 49052.6 \text{ (J mol}^{-1}\text{)}$ ✓ E_a to 3SF and in kJ mol^{-1} ✓ e.g. $49.1 \text{ (kJ mol}^{-1}\text{)}$	3	AO2.8 ×3	FULL ANNOTATIONS MUST BE USED ----- Marks are for intermediate calculations ALLOW ECF from an incorrect gradient ALLOW ECF on missing $\times 10^{-3}$, e.g. ALLOW 2 marks for: gradient = -5.9, leading to $E_a = 49.0526 \text{ (J mol}^{-1}\text{)}$ AND $0.0491 \text{ (kJ mol}^{-1}\text{)}$ DO NOT ALLOW a negative E_a

15 Question			Answer	Marks	AO element	Guidance
	(b)	(ii)	ln A is intercept at 0 when $1/T$ OR x axis is 0 ✓	1	AO3.2	
		(iii)	<i>ln k</i> $\ln k = -2.59$ ✓ <i>Temperature</i> $1/T = 3.10 \times 10^{-3} \text{ (s}^{-1}\text{)}$ $T = 49.6 \text{ }^{\circ}\text{C}$ ✓	2	AO3.1 AO3.2	Correct T scores 2 marks ALLOW ECF for $1/T$ from incorrect lnK shown on the graph ALLOW in the range $1/T = 3.09 - 3.11 \text{ (} \times 10^{-3} \text{ s}^{-1}\text{)}$ $T = 48.5 \text{ to } 50.6 \text{ }^{\circ}\text{C}$ ALLOW $T = 50 \text{ }^{\circ}\text{C}$
			Total	10		

Question	Answer	Marks	AO	Guidance
16	A	1	1.2	

Question		Answer	Marks	AO element	Guidance
17	(a)	(i) Axes labelled (number of) molecules AND (kinetic) energy AND correct drawing of a Boltzmann distribution i.e. curve must start within the first small square nearest to the origin AND must not touch the x-axis at high energy ✓ Drawing of correct Boltzmann distributions at two different temperatures with one temperature identified. ✓ (At higher temperature) more molecules/particles have energy above activation energy ✓	3	AO1.1 ×3	ALLOW particles on the y-axis DO NOT ALLOW atoms on y-axis DO NOT ALLOW enthalpy on x-axis DO NOT ALLOW an increase of more than one small square at the high energy end of the curve i.e. allow a small inflection ALLOW T2 as 'higher temperature' Maximum of curve for higher temperature must be to the right AND lower than the maximum of the curve for lower temperature Lines can only cross once ALLOW ORA if states the effect when the temperature is lower ALLOW has enough energy to react ALLOW E_a shown on graph AND greater area under the curve to the right of E_a DO NOT ALLOW lowers E_a DO NOT ALLOW atoms for molecules IGNORE (more) successful collisions

17 Question			Answer	Marks	AO element	Guidance
	(a)	(ii)	Orders (Expt 1+2) When [NO] $\times 2$, rate $\times 4$ AND 2nd order with respect to NO ✓ (Expt 2+3) When [NO] $\times 2$ AND [CO] $\times 4$, rate $\times 16$ AND 1st order with respect to CO ✓ Rate Equation rate = k [NO]²[CO] ✓ Value of k $(k = \frac{1.85 \times 10^{-4}}{(2.75 \times 10^{-4})^2 \times 7.25 \times 10^{-4}})$ $= 3.37 \times 10^6 \text{ ✓}$ Units of k $\text{dm}^6 \text{ mol}^{-2} \text{ s}^{-1} \text{ ✓}$	5	AO3.1 AO3.2 AO2.6 AO1.2 $\times 2$	ALLOW ORA throughout e.g. expt 2+1 [NO] halves, rate quarters etc. IGNORE [CO] constant ALLOW if working shown with the table. ALLOW if seen in 2 steps i.e. When [NO] $\times 2$, rate $\times 4$ AND [CO] $\times 4$, intermediate rate $\times 4$. ALLOW comparing Expt 1+3 When [NO] $\times 4$ AND [CO] $\times 4$, rate $\times 64$ AND 1st order with respect to CO ALLOW ECF from incorrect orders ALLOW rate = k [NO]²[CO]¹ ALLOW rate equation with correct numbers substituted ALLOW 3.36×10^6 from the use of Expt 3 IGNORE errors in working out – the mark is for the value ALLOW 3 SF upto the calculator value 3374180.678 OR 3.374180678×10^6 IGNORE rounding errors past 3SF ALLOW units in any order e.g. $\text{mol}^{-2} \text{ dm}^6 \text{ s}^{-1}$ ALLOW ECF from incorrect rate equation.

17 Question			Answer	Marks	AO element	Guidance
						Common errors 4 marks (including units) $4.65 \times 10^9 \text{ mol}^{-3} \text{ dm}^3 \text{ s}^{-1}$ (use of 2 nd order with respect to CO) $2446 \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$ (use of zero order wrt CO)
	(b)		2NO_2 only on LHS of step 1 ✓ Rest of mechanism ✓	2	AO3.1 ×2	M2 dependent on M1 Examples: <i>Step 1 :</i> $2\text{NO}_2 \rightarrow \text{NO} + \text{NO}_3$ <i>Step 2 :</i> $\text{NO}_3 + \text{CO} \rightarrow \text{NO}_2 + \text{CO}_2$ OR <i>Step 1 :</i> $2\text{NO}_2 \rightarrow \text{N}_2\text{O}_4$ <i>Step 2 :</i> $\text{N}_2\text{O}_4 + \text{CO} \rightarrow \text{NO} + \text{NO}_2 + \text{CO}_2$ OR <i>Step 1 :</i> $2\text{NO}_2 \rightarrow \text{N}_2 + 2\text{O}_2$ <i>Step 2 :</i> $\text{N}_2 + 2\text{O}_2 + \text{CO} \rightarrow \text{NO} + \text{NO}_2 + \text{CO}_2$ OR <i>Step 1 :</i> $2\text{NO}_2 \rightarrow 2\text{NO} + \text{O}_2$ <i>Step 2 :</i> $\text{NO} + \text{O}_2 + \text{CO} \rightarrow \text{NO}_2 + \text{CO}_2$
			Total	10		

Question	Answer	Marks	AO element	Guidance
18	D	1	AO1.2	

Question			Answer	Marks	AO element	Guidance
19			<i>Please refer to the marking instructions on page 5 of this mark scheme for guidance on marking this question.</i> Level 3 (5–6 marks) ALL 3 correct orders linked to explanations AND rate equation AND rate constant <i>There is a well-developed line of reasoning which is clear and logically structured.</i> Level 2 (3–4 marks) Three correct orders AND two out of: some evidence of an explanation linked to an order rate equation rate constant	6	AO3.1 ×3 AO3.2 ×3	Indicative scientific points may include Orders • 1st order wrt Br⁻ • 1st order wrt BrO₃⁻ • 2nd order wrt H⁺ Rate equation • rate = $k [\text{Br}^-] [\text{BrO}_3^-] [\text{H}^+]^2$ Calculation of k from any row of data, e.g. $k = \frac{\text{Rate}}{[\text{Br}^-][\text{BrO}_3^-][\text{H}^+]^2}$ $k = \frac{2.52 \times 10^{-4}}{0.020 \times 0.120 \times (0.080)^2} = 16.4(0625)$

Question	Answer	Marks	AO element	Guidance
19	OR Three correct orders with an attempt at: Some evidence of an explanation link to an order rate equation rate constant OR Two correct orders linked to explanations AND rate equation AND rate constant consistent with the candidate's orders <i>There is a line of reasoning with some structure and supported by some evidence.</i> Level 1 (1–2 marks) Two correct orders OR One correct order AND attempts to determine rate equation OR rate constant. OR One correct order AND attempts an explanation. <i>There is an attempt at a logical structure with a reasoned conclusion from the evidence.</i> 0 marks No response worthy of credit.			----- Explanations from results e.g. Br⁻ $[\text{Br}^-] \times 3$ rate $\times 3$ Expts 1 and 2 BrO₃⁻ $[\text{Br}^-] \times 2$ AND $[\text{BrO}_3^-] \div 2$ rate: no change Expts 1 and 3 OR $[\text{Br}^-] \times 2/3$ AND $[\text{BrO}_3^-] \div 2$ rate: $\times 1/3$ Expts 2 and 3 H⁺ $[\text{BrO}_3^-] \div 2$ AND $[\text{H}^+] \times 5$ rate $\times 12.5$ Expts 1 and 4 OR $[\text{Br}^-] \div 3$ and $[\text{BrO}_3^-] \div 2$ and $[\text{H}^+] \times 5$ rate $\times 4.17$ Expts 2 and 4 OR $[\text{Br}^-] \div 2$ and $[\text{H}^+] \times 5$ rate $\times 12.5$ Expts 3 and 4 ALLOW a sequential approach where they apply known orders first ALLOW minor slips as we are looking for an holistic approach to LoR marking NOTE: A clear and logically structured response would link orders to the experiment and experimental results provided. They could provide units Units $\text{dm}^9 \text{mol}^{-3} \text{s}^{-1}$ ALLOW any order, e.g. $\text{mol}^{-3} \text{dm}^9 \text{s}^{-1}$

Question	Answer	Marks	Guidance
20	B	1	

Question	Answer	Marks	Guidance
21	B	1	ALLOW +133 (correct numerical answer)

Question	Answer	Marks	Guidance
22	D	1	

Question		Answer	Marks	Guidance
23	(a)	(i) H₂O₂ on LHS AND H₂O + ½ O₂ on RHS AND ΔH labelled with product line below reactant line AND Arrow downwards ✓	3	For this booklet: enthalpy change = -98 kJ mol⁻¹. Use an exothermic profile. State symbols not required ΔH DO NOT ALLOW -ΔH DO NOT ALLOW double headed arrow on ΔH ALLOW ΔH arrow even with small gap at the top and bottom, i.e. line does not quite reach reactant or product line.

23	Question		Answer	Marks	Guidance
			E_a correctly labelled ✓ E_c <u>correctly</u> <u>labelled</u> with $E_c < E_a$ ✓		E_a and E_c ALLOW no arrowhead or arrowheads at both end of E_a or E_c lines E_a or E_c lines must reach maximum (or near to maximum) on curve ALLOW overlapping lines OR lines on side reaching maximum For E_a, ALLOW AE OR A_E OR Eact OR suitable alternatives ALLOW ECF marks for E_a and E_c for correctly labelled endothermic diagram from a $-\Delta H$ value (from 16 a) i))
		(ii)	(MnO₂) is in different phase/state (to the reactant / H₂O₂) OR	1	ASSUME 'it' is MnO₂ ALLOW 'species in the reaction'

Question			Answer	Marks	Guidance
Question			Answer	Marks	Guidance
24	(a)		(Over time) concentration decreases AND collisions are less <u>frequent</u> ✓	1	ALLOW less moles/particles per unit volume. ALLOW fewer collisions per second/per unit time IGNORE (over time) fewer reacting particles IGNORE ...chance of.. IGNORE amount decreases IGNORE successful IGNORE particles more spread out/further apart DO NOT ALLOW particles have less energy in terms of energy distribution.

24Question	Answer	Marks	Guidance															
(b)*	Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question. Level 3 (5–6 marks) A comprehensive conclusion using quantitative data from graph to correctly determine 1st order conclusion for CV using half lives/gradients AND rate at 3 minutes AND determination of k <i>There is a well-developed line of reasoning which is clear and logically structured.</i> Level 2 (3–4 marks) Reaches a conclusion using quantitative data from graph to correctly determine rate at 3 minutes AND determination of k. OR Half- lives/gradient with 1st order conclusion for CV AND determination of k OR determined rate AND half-life/first order for CV OR Attempts to determine rate, k and order for CV <i>There is a line of reasoning with some structure and supported by some evidence.</i> Level 1 (1–2 marks) Reaches a simple conclusion using at least one piece of quantitative data from the graph, i.e. Attempts to calculate rate at three minutes OR k OR links half lives to 1st order.³ <i>There is an attempt at a logical structure with a reasoned conclusion from the evidence.</i>	6	Indicative scientific points may include: Care: ALLOW the use of ECF for values obtained from a previously, incorrectly, calculated value. ALLOW minor slips as we are looking for a holistic approach to LoR marking. <table><tr><th></th><th>Minutes</th><th>Seconds</th></tr><tr><td>Half life values</td><td>2.4 to 2.6 min</td><td>144 to 156 s</td></tr><tr><td>Rate at three minutes</td><td>(-) (1.5 to 1.8) $\times 10^{-8}$ mol dm⁻³ min⁻¹</td><td>(-) (2.5 to 3.0)$\times 10^{-10}$ mol dm⁻³ s⁻¹</td></tr><tr><td>Value of k</td><td>0.24 to 0.30 min⁻¹</td><td>(4.0 to 5.0) $\times 10^{-3}$ s⁻¹</td></tr><tr><td>Units of k</td><td>min⁻¹</td><td>s⁻¹</td></tr></table> Examples of the communication statement being met would typically include: - For L1 and L2: full working on the graph and/or appropriate units for calculated values. - For L3: full working on the graph and appropriate units for calculated values.		Minutes	Seconds	Half life values	2.4 to 2.6 min	144 to 156 s	Rate at three minutes	(-) (1.5 to 1.8) $\times 10^{-8}$ mol dm ⁻³ min ⁻¹	(-) (2.5 to 3.0) $\times 10^{-10}$ mol dm ⁻³ s ⁻¹	Value of k	0.24 to 0.30 min ⁻¹	(4.0 to 5.0) $\times 10^{-3}$ s ⁻¹	Units of k	min ⁻¹	s ⁻¹
	Minutes	Seconds																
Half life values	2.4 to 2.6 min	144 to 156 s																
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Value of k	0.24 to 0.30 min ⁻¹	(4.0 to 5.0) $\times 10^{-3}$ s ⁻¹																
Units of k	min ⁻¹	s ⁻¹																

Question			Answer	Marks	Guidance
25	(a)		Equation for Step 1 $\text{F}_2 + \text{NO}_2 \rightarrow \text{F} + \text{NO}_2\text{F}$ ✓ Rate Equation Rate = $k [\text{F}_2][\text{NO}_2]$ ✓	2	Mark independently ALLOW rate = $k [\text{NO}_2][\text{F}_2]$ Care – k must be included.

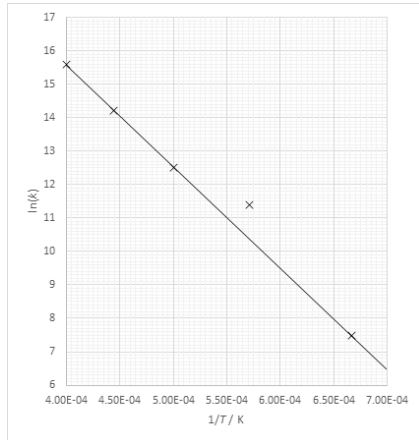
Question	Answer	Marks	Guidance
26	B	1	

Question	Answer	Marks	Guidance
27	B	1	

Question	Answer	Marks	Guidance
28	C	1	

Question			Answer	Mark	Guidance
29	(a)	(i)	(Pt has) different state / phase (to reactants) ✓	1	ALLOW Pt is a solid but reactants are gases IGNORE products
18		(ii)	Correct drawing of a Boltzmann distribution curve must start within the first small square nearest to the origin AND must not touch the x-axis at high energy AND not be horizontal for more than 1 large square ✓ Catalyst (provides a reaction pathway with) lower activation energy OR E_a to the right of $E_{c/cat}$ marked on graph AND A greater proportion / more of molecules / particles have energy greater or equal to the activation energy / $E \geq E_a$ ✓	2	DO NOT ALLOW multiple curves IGNORE a slight inflexion at the end of the curve less than one <u>small</u> square ALLOW shading on the graph if linked to the idea of more molecules ALLOW more molecules have (sufficient) energy to react for $E \geq E_a$ IGNORE more (frequent) successful collisions BUT DO NOT ALLOW more frequent collisions IGNORE more molecules have / meet / reach activation energy DO NOT ALLOW molecules have more energy (confusion with temperature)
		(iii)	Lower temperature can be used (for the same yield) OR less energy demand / required to heat reaction OR less fossil fuels need to be burnt OR reduction in CO₂ OR catalyst can be reused ✓	1	

Question			Answer	Mark	Guidance
29	(b)		(Experiments 1 & 2) As $[O_2] \times 2$, rate $\times 2$ AND 1st order with respect to O_2 ✓ (Experiments 1 & 3) As $[NO] \times 1.5$, rate $\times 2.25$ AND 2nd order with respect to NO OR (Experiments 2 & 3) As $[NO] \times 1.5$ and $[O_2] \div 2$, rate $\times 1.13$ ($1.13 = 1.5^2 \div 2$) AND 2nd order with respect to NO ✓ rate = $k [NO]^2 [O_2]$ ✓ $k = \frac{7.45 \times 10^{-4}}{0.04^2 \times 0.035} = 13(.30357...$ OR $k = \frac{1.49 \times 10^{-3}}{0.04^2 \times 0.070} = 13(.30357...$ OR $k = \frac{1.68 \times 10^{-3}}{0.06^2 \times 0.035} = 13(.33333... ✓$ Units: $dm^6 mol^{-2} s^{-1}$ ✓	5	ALLOW ORA throughout Check table for working if none shown ALLOW 2 SF up to calculator value ALLOW ECF from incorrect orders ALLOW in any order ALLOW ECF from incorrect rate equation e.g. 1st order wrt NO units $mol^{-1} dm^3 s^{-1}$ zero order wrt NO units: s^{-1}

Question			Answer	Mark	Guidance				
29	(c)	(i)	11.4 / 11.35 ✓	1					
		(ii)	Straight line of best fit ✓  Gradient Gradient from a straight line in range of (–)28300 to (–)31300 ✓ CHECK THE ANSWER ON ANSWER LINE If answer = 240 to 260 (kJ mol^{–1}) award last two marks ----- E_a calculation E_a = (–) gradient × R (8.314) ✓ e.g. from –30000, E_a = (+)249420 (J mol^{–1}) E_a to 2 SF and in kJ mol^{–1} ✓ e.g. 250(kJ mol^{–1})	4	FULL ANNOTATIONS MUST BE USED Mark first two marking points independently ALLOW rounding to 2SF Best fit line judged from their points using the following guidance: Line should go through ranges: <table><tr><td>Top left</td><td>15.3 – 15.7</td></tr><tr><td>Bottom right</td><td>6.3 – 6.8</td></tr></table> and exclude anomalous point at ln(k) = 11.4 Consider using ruler tool on RM Marks are for intermediate calculations ALLOW ECF from an incorrect gradient IGNORE signs for both E_a calculation and gradient DO NOT ALLOW a negative E_a	Top left	15.3 – 15.7	Bottom right	6.3 – 6.8
Top left	15.3 – 15.7								
Bottom right	6.3 – 6.8								