Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			**A**	1	**Examiner's Comments** Most candidates were aware that heat increases the number of molecules that have energy greater than the activation energy (A).
			Total	**1**	
2	a		(Over time) concentration decreases **AND** collisions are less frequent ✓	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. **Examiner's Comments** This question proved difficult for candidates to explain well. Collision theory linked to rate requires a quantitative approach, e.g. less particles per unit volume and less collisions per unit time. A lot of candidates wrote vague responses about fewer particles so less collisions and did not gain credit. ? **Misconception** Some candidates described a decrease in energy in the reaction or gave responses related to activation energy for the concentration effect. For example, 'reactants have less

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<td>kinetic energy’ and ‘only a certain number of particles which have enough energy above the activation energy…over time energy will decrease and less particles have enough energy’.

We have produced a delivery guide on rates with some useful resources to help consolidate ideas and avoid misconceptions such as these: Teach Cambridge (ocr.org.uk)</td>
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<td></td>
<td>b</td>
<td></td>
<td>**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*

There is a well-developed line of reasoning which is clear and logically structured.

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

There is a line of reasoning with some structure and supported by some evidence.

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</td>
<td>6</td>
<td>**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) x 10^{-3} s^{-1}</td></tr>
<tr><td>**Units of *k***</td><td>min^{-1}</td><td>s^{-1}</td></tr>
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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.

If time has been measured in minutes
(see below for values using</td>
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			There is an attempt at a logical structure with a reasoned conclusion from the evidence. **0 mark** *No response worthy of credit*		**seconds).** **Indicative scientific points may include:** **Evidence for 1st order** 1st order clearly linked to half-life **OR** 2 gradients: **Half life** Half- life shown on graph Half- life range 2.4 to 2.6 min Two 'constant' half lives **OR Two gradients → two rates** 2 tangents shown on graph at *c* and *c*/2 This could include $c = 0.61 \times 10^{-7}$ mol dm^{-3} (t = 3 min) Gradient at *c*/2 is half gradient at *c* e.g. $c = 0.8 \times 10^{-7}$ mol dm^{-3}, gradient = 2.2×10^{-8} (mol dm^{-3} min^{-1}) **AND** $c = 0.4 \times 10^{-7}$ mol dm^{-3}, gradient = 1.1×10^{-8} (mol dm^{-3} min^{-1}) For chosen method, conclude that the reaction is 1st order wrt CV. **Rate at three minutes** Tangent shown on graph as line at t = 3 min Gradient in range: $(1.5 - 1.8) \times 10^{-8}$ rate as gradient with units: mol dm^{-3} min^{-1} **OR** $k = \frac{\ln 2}{t½} = 0.28\text{min}^{-1}$ And k substituted into rate equation. e.g. Rate = k [CV] Rate = $0.277 \times 0.61 \times 10^{-7}$ = 1.7×10^{-8} mol dm^{-3} min^{-1} **Determination of *k*** *k* clearly linked to rate **OR** half-life:

					e.g. $k = \frac{\text{rate}}{[\text{CV}]} = \frac{1.75 \times 10^{-8}}{0.62 \times 10^{-7}} = 0.28$ k in range: 0.24 - 0.30 min^{-1} **OR** e.g. $k = \frac{\ln 2}{t_{1/2}} = 0.28\ \text{min}^{-1}$ **Units of *k*:** min^{-1} **If time has been measured in seconds:** **Evidence for 1st order** 1st order clearly linked to half-life **OR** 2 gradients: **Half life** Half- life shown on graph Half- life range 144 to 156 s Two 'constant' half lives **OR Two gradients → two rates** 2 tangents shown on graph at *c* and *c*/2 This could include $c = 0.6 \times 10^{-8}\ \text{mol dm}^{-3}$ (t = 3 min) Gradient at *c*/2 is half gradient at *c* e.g. $c = 0.8 \times 10^{-7}\ \text{mol dm}^{-3}$, gradient = $3.7 \times 10^{-10}\ \text{mol dm}^{-3}\ \text{s}^{-1}$ **AND** $c = 0.4 \times 10^{-7}\ \text{mol dm}^{-3}$, gradient = $1.8 \times 10^{-10}\ \text{mol dm}^{-3}\ \text{s}^{-1}$ For chosen method, conclude that the reaction is 1st order wrt CV. **Rate at 180 seconds** Gradient in range (2.5 to 3.0) $\times 10^{-10}$ rate as gradient with units: $\text{mol dm}^{-3}\ \text{s}^{-1}$ **OR** $k = \frac{\ln 2}{t_{1/2}} = 4.6 \times 10^{-3}\ \text{s}^{-1}$ And *k* substituted into rate equation. e.g. Rate = k [CV] Rate = $0.00462 \times 0.61 \times 10^{-7}$ = $2.8 \times 10^{-10}\ \text{mol dm}^{-3}\ \text{s}^{-1}$

Determination of *k*

k clearly linked to rate **OR** half-life:

e.g. $k = \frac{\text{rate}}{[\text{CV}]} = \frac{2.75 \times 10^{-10}}{0.62 \times 10^{-7}} = 4.4 \times 10^{-3}\ \text{s}^{-1}$

k in range (4.0 to 4.8) x 10^{-3} s^{-1}

OR e.g $k = \frac{\ln 2}{t_{1/2}} = 0.28\ \text{min}^{-1}$

OR 4.6 x 10^{-3} s^{-1}

Units of *k*: s^{-1}

Examiner's Comments

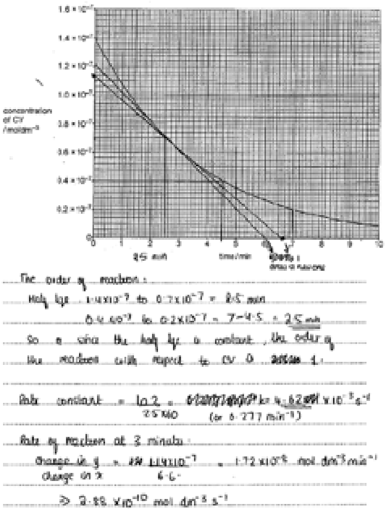
The first Level of Response question in the paper was answered well with the higher-attaining candidates on the paper scoring full marks.

These students started with a nice clear analysis of the half-life, referring to labelled sections of the graph, then went on to calculate the rate from a well-drawn tangent with correct indices and were careful to write down the correct units. Then used the rate equation to calculate K and get the correct units.

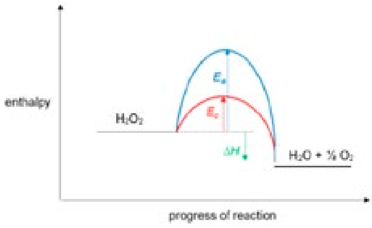
Almost all candidates were able to conclude that it was first order for CV. Most used the half-life approach with others comparing two gradients. Candidates should be advised, especially in LoR questions, that the conclusion needs a clear link to the data.

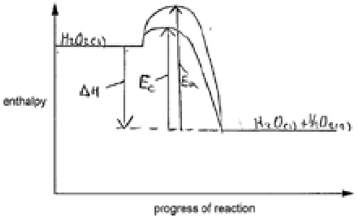
The gradient at 3 minutes was done well and the candidates used the appropriate scale from the graph in their calculations. Clarity of communication does require indication of what is being calculated and how the numbers were obtained. This would allow an initial rate versus a rate at three minutes to be distinguished. Units were particularly important in this question as some candidates used minutes from the graph while others converted time into seconds. A common error was to state the wrong units or leave them out altogether.

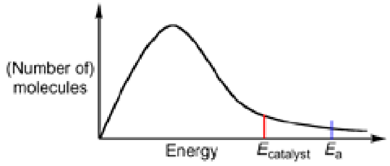
Most candidates used the rate

					equation to calculate K and get the correct units. A few approached the value by using $k = \frac{\ln 2}{t_{1/2}}$. Error carried forward was given for those with incorrect half-lives or rate value. Candidate errors arose from graph readings that caused rate to be wrong, errors in concentrations used in rate or K calculation, and badly drawn tangents causing the rate to be out of tolerance. Some candidates tried to adjust the concentrations as if conducting mole calculations or take the rate from two points on the graph. Exemplar 2  The order of reaction: Half life 1.4×10^{-7} to 0.7×10^{-7} = 2.5 min 0.4×10^{-7} to 0.2×10^{-7} = 7−4.5 = 2.5 min So as the half life is constant, the order of the reaction with respect to CV is 1. Rate constant = $\frac{\ln 2}{2.5\ \text{min}}$ = $4.62 \times 10^{-3}\ s^{-1}$ (or $0.277\ \text{min}^{-1}$) Rate of reaction at 3 minutes: $\frac{\text{change in } y}{\text{change in } x} = \frac{1.14 \times 10^{-7}}{6.6} = 1.72 \times 10^{-8}$ mol dm^{-3} min^{-1} ⇒ 2.88×10^{-10} mol dm^{-3} s^{-1} The candidate scored Level 3. The graph was clearly used to obtain half-lives and gradients. This was communicated on the answer lines, showing calculations and units. **OCR support** M3 section of the Maths Skills handbook contains useful information on use of graphs in chemistry, including M3.5 on drawing and using the slope of the tangent to a curve as a measure of a rate of change: Teach Cambridge (ocr.org.uk)
			Total	**7**	
3			**B**	1	

					Examiner's Comments The correct answer was B. Candidates had a good knowledge of the Boltzmann distribution and few incorrect responses were seen.
			Total	**1**	
4	a	i	**FIRST CHECK ANSWER ON ANSWER LINE** **If answer = −117 kJ mol^{-1}, award 4 marks.** --- ΔH = −286− (−188) = −98 kJ mol^{-1} ✓ ΔS = 70 + ½(205) − 110 = 62.5 (J K^{-1} mol^{-1}) or 0.0625 (kJ K^{-1} mol^{-1}) ✓ ΔG = ΔH − TΔS = −98 − (298 × 0.0625) ✓ ΔG = −117 kJ mol^{-1} **(3SF)** ✓	4	**ALLOW ECF** throughout **ALLOW** −98000 − (298 × 62.5) **Common Errors for ΔG** ***3 marks*** *−18700 (ΔS not converted to kJ)* −493 (ΔH = −286 + (−188) = −474) *−147 (ΔS = 165: not halving 205)* *− 99.6 (T not converted to K)* *−18.7 (ΔH not converted J but ΔS J K^{-1} mol^{-1})* (+)79.4 (−188 − (−286) = +98) ***2 marks*** *(+) 117 (incorrect signs for ΔH and ΔS)* ***Final Answer MUST BE 3 SF*** **Examiner's Comments** Almost all candidates had a good attempt at this calculation, with many gaining full marks. Most were able to calculate the entropy change. Almost all could reproduce the equation for free energy. Of those who did not get the correct final answer, the most common error was not converting the entropy value into kJ and / or the temperature to K. There were a few candidates who did not manipulate the equation correctly. A few candidates incorrectly calculated ΔS, obtaining the value of 165 J K^{-1} mol^{-1} or ΔH, obtaining -474 kJ mol^{-1}. Candidates were given ECF in these cases.
		ii	(Rate of reaction) slow **OR** Activation energy high ✓	1	**ALLOW** ΔG takes no account of rate of reaction **ALLOW** molecules do not have sufficient energy to equal or exceed the activation energy.

					IGNORE molecules do not have sufficient energy to react. **DO NOT ALLOW** there is not enough activation energy **Examiner's Comments** Lots of good answers from candidates were seen for this question. A few candidates attempted the explanation via a ΔG / ΔS argument and misinterpreted the comment within the question.
	b	i	 H_2O_2 on LHS **AND** H_2O + ½ O_2 on RHS **AND** **Δ*H*** labelled with product line below reactant line **AND** Arrow downwards ✓ ***E*$_a$** correctly labelled ✓ ***E*$_c$** <u>correctly labelled</u> with $E_c < E_a$ ✓	3	**Care** enthalpy profile must match Δ*H* **sign** in16 a) i) – check calculation **ALLOW** endothermic profile as **ECF** from + Δ*H* calculated in 16 a) i) for all three marks State symbols not required **Δ*H* DO NOT ALLOW −**Δ*H* **DO NOT ALLOW** double headed arrow on Δ*H* **ALLOW** Δ*H* arrow even with small gap at the top and bottom, i.e. line does not quite reach reactant or product line. ***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 −Δ*H* value (from16 a) i))

					Examiner's Comments This question proved more difficult for candidates with lots of inaccuracies. The profile was dependent on the calculation for ΔH in Question 16 (a)(i). The arrowhead for ΔH needs to be pointing from the reactants to the products. The activation energies, again, need to start at the reactant line and go to the maximum level of the curve. Those that needed to draw an endothermic profile were far more likely to make an error with the E_a and E_c arrows, often starting from the product line or even from the base line of the graph. A significant number of candidates did not add arrows and instead labelled the curves E_a and E_c. Some candidates drew a Boltzmann distribution curve scoring 0 marks. Exemplar 1  The candidate has the correct exothermic profile but has the incorrect starting point for the activation energy going from the product line.
		ii	(MnO_2) is in different phase/state (to the reactant / H_2O_2) **OR** catalyst is a solid **AND** reactant is liquid ✓	1	**ASSUME** 'it' is MnO_2 **ALLOW** 'species in the reaction' **IGNORE** references to products **Examiner's Comments** This was a well answered question. A few candidates, incorrectly, suggested that it was heterogeneous due to the reactants and products being in different states, and did not mention the catalyst.
		iii	Mn is +2 **AND** +3 **OR**	1	+ required **ALLOW** 2+ and 3+

			Mn is +1 **AND** +6 ✓		**DO NOT ALLOW** Mn^{2+} Mn^{3+} **DO NOT ALLOW** + 4 (this is the oxidation state in MnO_2) **<u>Examiner's Comments</u>** This question proved more challenging for candidates. Candidates stating +4 was the most common error; this is the oxidation state in MnO_2. Some candidates stated fractions, negative values and gave the state symbol instead i.e. solid and liquid.
			Total	**10**	
5	a		 ***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 below E_a on Boltzmann distribution ✓ ***Particles with E > Ea*** More molecules/particles/collisions have energy above activation energy (with catalyst) **OR** more molecules have enough energy to react	4	ANNOTATE ANSWER WITH TICKS AND CROSSES **DO NOT ALLOW** two curves *Confusion with effect of temperature* **IGNORE** a slight inflexion on the curve if less than one small square **DO NOT ALLOW** 'atoms' as y-axis label **DO NOT ALLOW** 'enthalpy' for x-axis label **IF** y axis labelled as 'atoms' **ALLOW ECF** for atoms (instead of molecules/particles) **IGNORE** (more) successful collisions **IGNORE** response implying 'more collisions' *(confusion with effect of greater temperature)* **<u>Examiner's Comments</u>** This is a familiar question with around half of candidates scoring all 4 marks. Common errors included drawing 2 lines, as you would have with different temperatures, but labelling one with catalyst and other without. Some had

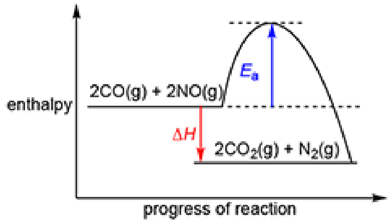
			OR greater area under curve above activation energy ✓		incorrect or missing labels on the axes. The most frequently gained mark was for knowing that the activation energy was lowered by a catalyst; this could be given by correct lines and labelling shown on the distribution, although care needed to be taken as some contradicted their answers with their diagram. Some labelled E_a and E_c lines but didn't have energy on x-axis scale. Some struggled with the final marking point, not recognising that more molecules have the required activation energy. For example, 'more frequent successful collisions' with no reference to the activation energy, i.e. why they are successful.
	b	i	**Line** Smooth curve using all points **EXCEPT** point at 100 s. ✓ **Anomaly** Point at 100 s circled ✓	2	**ALLOW** flexibility around point at 120 s Graph should be seen to level off on or very near to 90 cm^3 **Examiner's Comments** Most scored both marks here. Some didn't circle the anomalous result and some lost a mark for a poorly drawn curve. Candidates must ensure they have a sharp pencil and draw a single line through all the points (except the anomalous point). Some didn't start at the origin or didn't level off at around 90 cm^3.
		ii	**Tangent on graph** drawn at = 50 s (± 10 s)✓ **Calculation of rate** **=** gradient (y/x) of tangent drawn = 0.67 ± 0.2 cm^3 s^{-1} ✓	2	**DO NOT ALLOW** interpolation (taking a direct reading from graph), Answer must be derived from taking a gradient **ALLOW ECF** from incorrectly drawn tangent or a straight line of best fit **Examiner's Comments** More candidates were able to correctly draw a tangent than seen in previous years with similar questions. A generous range was given for both tangent and gradient so many scored both marks. The most common reasons for losing marks was for having a gap between the curve and

					the tangent or calculating the gradient incorrectly, e.g. misreading scales, dx/dy, or by using interpolation rather than a tangent.
		iii	FIRST CHECK ANSWER ON THE ANSWER LINE If answer = 0.15 (mol dm^{-3}) award 3 marks $n(O_2)$ = 90/24000 **OR** 0.09/24 **OR** 0.00375 (mol) ✓ $n(H_2O_2)$ = 2 x 0.00375 **OR** 0.0075 (mol) ✓ $c(H_2O_2)$ = 0.0075 x 1000/50.0 = 0.15 mol dm^{-3} ✓	3	**ALLOW ECF** **COMMON ERRORS** For 2 marks: 0.075 missing x 2 150 missing a cm^3 to dm^3 conversion -- ALLOW use of ideal gas equation using sensible *p* and *T* for first mark. e.g. from 100 kPa and 293 K $n = \frac{pV}{RT}$ $\rightarrow n = \frac{pV}{RT} = \frac{(100 \times 10^3) \times (90 \times 10^{-6})}{8.314 \times 293} = 0.00369...$ (mol) Examples of 'sensible' p and T: p = 100 kPa, 101 kPa, 101,325 Pa T = 273 - 298 K **Examiner's Comments** Over half of candidates scored all 3 marks here. However, around a quarter did not gain any credit at all. Some confused the volume of H_2O_2 for a volume for a gas and attempted to find moles using molar gas volume (i.e. used 50cm^3 rather than 90cm^3). This often lost all 3 marks as they then divided by 2 and to find concentration divided by 90/1000 instead. A few attempted to use the ideal gas equation but this rarely yielded a correct value. Candidates must be encouraged to set out working clearly, showing logical steps and preferably labelling each step with what is being calculated and giving units. Many wrote the calculation as series of steps which all equalled the previous. e.g. 90 ÷ 24000 = 3.75 x 10^{-3} x 2 = 7.5 x 10^{-3} ÷ 0.05 = 0.15

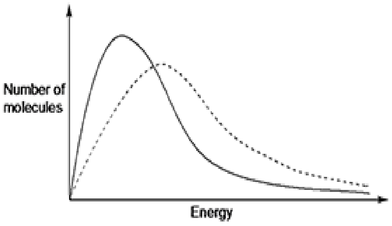
					? **Misconception** Encourage students to assign information in the question to the correct chemical. One way to do this is to write out the equation and then underneath each species put correct volumes as given. It also helps to highlight ratios shown in the equation. It is important here to pay close attention to state symbols as it helps identify correct calculations to use. For example; $2H_2O_2 (aq) \rightarrow 2H_2O (l) + O_2(g)$ 50.0cm^3 90 cm^3 Solution Gas at RTP Conc?
	c		**ANY two** ✓✓ • Amount of catalyst/metal oxide (allow same mass **OR** same moles) • Temperature • Volume of H_2O_2 • Concentration of H_2O_2 • Moles/amount of H_2O_2 • Pressure • Surface area of catalyst	2	**DO NOT ALLOW** concentration/volume of catalyst/metal oxide **<u>Examiner's Comments</u>** More than half of candidates achieved both marks and most scored at least 1. The most common reason for losing marks was for not being specific, by just saying 'concentration' or 'volume', or suggesting volume and concentration for metal oxide. Some suggested use of the same gas syringe without realising that the apparatus used should not affect volume of gas produced, just how easy and accurate it is to measure.
			Total	**13**	
6			**Level 3 (5–6 marks)**	6 (AO 3.1 × 3)	**Indicative scientific points may include** **<u>Orders</u>**

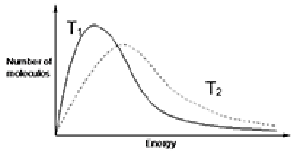
			ALL 3 correct orders linked to explanations **AND** rate equation **AND** rate constant *There is a well-developed line of reasoning which is clear and logically structured.* **Level 2 (3–4 marks)** Three correct orders **AND** two out of: some evidence of an explanation linked to an order rate equation rate constant 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 *There is a line of reasoning with some structure and supported by some evidence.* **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.	(AO 3.2 × 3)	• 1st order wrt Br^- • 1st order wrt BrO_3^- • 2nd order wrt H^+ **Rate equation** • rate = $k[Br^-][BrO_3^-][H^+]^2$ **Calculation of *k* from any row of data, e.g.** $k = \frac{\text{Rate}}{[Br^-][BrO_3^-][H^+]^2}$ $k = \frac{2.52 \times 10^{-4}}{0.020 \times 0.120 \times (0.080)^2} = 16.4(0625)$ -- **Explanations from results e.g.** **Br^-** $[Br^-]$ × 3 rate × 3 Expts 1 and 2 **BrO_3^-** $[Br^-]$ × 2 **AND** $[BrO_3^-]$ ÷ 2 rate: no change Expts 1 and 3 **OR** $[Br^-]$ × 2/3 **AND** $[BrO_3^-]$ ÷ 2 rate: × 1/3 Expts 2 and 3 **H^+** $[BrO_3^-]$ ÷ 2 **AND** $[H^+]$ × 5 rate × 12.5 Expts 1 and 4 **OR** $[Br^-]$ ÷ 3 and $[BrO_3^-]$ ÷ 2 and $[H^+]$ × 5 rate × 4.17 Expts 2 and 4 **OR** $[Br^-]$ ÷ 2 and $[H^+]$ × 5 rate × 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

			There is an attempt at a logical structure with a reasoned conclusion from the evidence. **0 mark** *No response worthy of credit.*		**Units** dm^9 mol^{-3} s^{-1} **ALLOW** any order, e.g. mol^{-3} dm^9 s^{-1} **Examiner's Comments** The first Level of Response question in the paper was answered well. Almost all candidates were able to conclude that the experimental results showed that they were consistent with first order with respect to Br^-. Some candidates were able to use a sequential approach to determine the orders with respect to BrO_3^- and H^+, reaching a Level 3, but others found this more problematic. Some did not notice that more than one concentration had been changed between experiments. This led to many determining the rate to be 0 order with respect to $[BrO_3^-]$ and $[H^+]$. Candidates should focus on the quality of their descriptions when linking data to their conclusions with some candidates creating their own data set to fit their explanations. Having determined orders, nearly all candidates were able to give a corresponding rate equation and could calculate a value for the rate constant, albeit with frequent omission of units. Some candidates confused the rate equation with a K_c expression.
			Total	**6**	
7			**D**	1 (AO 1.2)	**Examiner's Comments** Half of the candidates chose the correct half-life of D and a large proportion of the others chose 8 minutes, halving the time as the concentration was doubled, causing C to be a common error.
			Total	**1**	
8		i	$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$ Correct species ✓ Balanced ✓	2 (AO2.6 ×2)	**ALLOW** multiples **IGNORE** state symbols For heptane formula, **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as

					unambiguous **ALLOW 1 mark** for balanced combustion equation for a different alkane (**ECF**) e.g. $C_6H_{14} + 9½O_2 \rightarrow 6CO_2 + 7H_2O$ **<u>Examiner's Comments</u>** Most candidates were able to construct a balanced equation for the combustion of heptane. Most were aware that CO_2 and H_2O would be the products although some generated CO, C_6H_{12} or unusual compounds such as $C_7H_{14}O$. The hardest part was the formula of heptane itself with use of hexane instead being a common error; candidates who made this error were given 1 mark, provided that their equation was balanced.
		ii	 **Reactants, products and Δ*H*** **2CO + 2NO** on LHS **AND** **$2CO_2$ + N_2** on RHS **AND** Δ*H* labelled with products **below** reactants **AND** **Arrow downwards** ✓ ***E_a* (independent of Δ*H*)** curve with arrow from reactants to top of curve **AND** E_a labelled ✓	2 (AO2.1) (AO1.2)	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **IGNORE** state symbols Δ***H*** **DO NOT ALLOW** –Δ*H* **DO NOT ALLOW** double headed arrow on Δ*H* **ALLOW** Δ*H* arrow even with small gap at the top and bottom, i.e. line does not quite reach reactant or product line. **ALLOW** –746 for Δ*H* E_a **ALLOW** AE **OR** A_E **ALLOW 2** arrowheads at **each** end of E_a line **OR** no arrowhead **BUT DO NOT ALLOW** arrowhead down E_a line must reach maximum (or near to maximum) on curve

			IF endothermic diagram shown, **ALLOW ECF** for E_a using MS criteria		**Examiner's Comments** Most candidates obtained 1 or 2 of the available marks, the commonest errors being use of a doubleheaded arrow for Δ*H* or a –Δ*H* label. Some candidates showed endothermic profiles and these could create issues with positioning of the Δ*H* and E_a arrows. Generally, positioning of Δ*H* and E_a arrows was imprecise and candidates are advised to start and finish the positions of their arrows accurately. The mark scheme did allow for some leeway but positioning of arrows could generally be improved.
		iii	Catalyst lowers activation energy **OR** Catalyst increases rate without itself changing ✓ Reaction proceeds via a different route/pathway **OR** More molecules/particles exceed activation energy ✓	2 (AO1.2 ×2)	**ALLOW** 2nd labelled curve on profile diagram in **23(a)(ii)** with lower activation energy/E_c with catalyst **ALLOW** E_c needs less energy to start reaction **ALLOW** E_c curve is lower than E_a curve **IGNORE** 'shorter route' for alternative route **IGNORE** more successful collisions **Examiner's Comments** Almost all candidates knew that a catalyst lowered activation energy and most were aware that an alternative pathway was made possible by a catalyst.
			Total	**6**	
9			**A**	1 (AO 1.1)	**Examiner's Comments** The behaviour of the Boltzmann distribution under different conditions is well known with most candidates making the correct choice of A.
			Total	**1**	

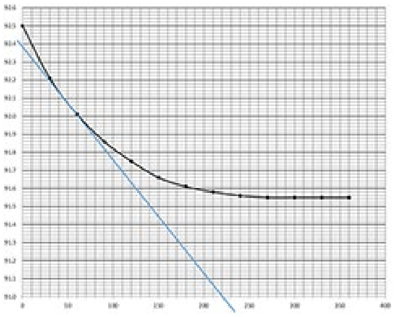
10			**B**	1 (AO 2.8)	**Examiner's Comments** This question discriminated well, rewarding those candidates with a good understanding of the link between concentration, time and rate. Many candidates drew a tangent to the curve at 200 s, measuring its gradient to get the correct choice of B. Common errors focused on reading of the concentration at 200 s. This was then either matched to option D directly or divided by 200 to give option A.
			Total	**1**	
11			 ***Curve at higher temperature 1 mark*** Curve starts close to zero **AND** does not touch x axis at high energy **AND** maximum to right **AND** lower than provided curve **AND** finishing higher than provided curve ✓ ***Labels 1 mark*** Axes labels correct: • Number of molecules **AND** Energy ✓ ***Explanation 1 mark*** More molecules have energy greater **than E_a** **OR** Greater area under curve **above E_a** ✓ *Could be in diagram* *If not stated, assume higher temperature*	3 (AO1.2) (AO1.1) (AO1.1)	**ANNOTATE ANSWER WITH TICKS AND CROSSES NOTE**: Look for marking criteria within annotations on Boltzmann distribution diagram **IGNORE** slight inflexion on the curve **For labels ALLOW** number of particles **ALLOW** amount of molecules/particles **IGNORE** number of atoms **ALLOW** kinetic energy **IGNORE** enthalpy for energy **ORA at lower temperature ALLOW** more molecules have the energy to react more molecules can overcome/reach E_a **IGNORE** atoms **IGNORE** more successful collisions **OR** collide more frequently **DO NOT ALLOW** explanation is in terms of two activation energies (i.e. 'catalyst explanation) **Examiner's Comments** Most candidates answered this question well. Most graphs were drawn with care but some peaks were shown at the same height as the provided curve or meeting this curve at high energy. Some candidates labelled what should have been 'energy' on the x axis as 'progress of reaction', or used 'atoms' rather than molecules for the y axis label. Many candidates were able to explain that more molecules exceed the activation energy at a higher temperature.
			Total	**3**	

12			**D**	1(AO1.1)	**Examiner's Comments** Candidates produced a variety of responses with just over half choosing the correct option D. Option C was the main distractor.
			Total	**1**	
13		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 termperature 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 termperature' 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 **<u>Examiner's Comments</u>** Almost all candidates produced a graph which showed the correct shape curve, although they sometimes incorrectly identified the quantities on the axes, e.g. rate versus time. Those who produced an incorrect diagram were able to discuss 'more' particles reaching the activation energy threshold. A few limited their answer to discussing successful collisions. Candidates needed to identify which curve was the higher temperature and to make sure that the curves did intersect more than once.
		ii	**Orders** **(Expt 1+2)** When [NO] × 2, rate × 4 **AND** 2nd order with respect to NO ✓ **(Expt 2+3)** When [NO] × 2 **AND** [CO] × 4, rate × 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 × 10^6** ✓	5 (AO3.1) (AO3.2) (AO2.6) (AO1.2×2)	**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] × 2, rate x 4 AND [CO] × 4, intermediate rate × 4. **ALLOW** comparing **Expt 1+3** When [NO] × 4 AND [CO] × 4, rate × 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 x 10^6 from the use of Expt 3

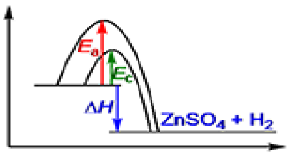
			Units of *k* dm^6 mol^{-2} s^{-1} ✓		**IGNORE** errors in working out –the mark is for the value **ALLOW** 3 SF upto the calculator value 3374180.678 OR 3.374180678 x10^6 **IGNORE** rounding errors past **3SF** **ALLOW** units in any order e.g. mol^{-2} dm^6 s^{-1} **ALLOW ECF** from incorrect rate equation. **Common errors** **4 marks (including units)** 4.65 x 10^9 mol $^{-3}$ dm^9 s^{-1} (use of 2nd order with respect to CO) 2446 mol^{-1} dm^3 s^{-1} (use of zero order wrt CO) **Examiner's Comments** Many candidates were able to explain clearly the second order dependence on [NO] but many found it more challenging to identify and explain the first order relationship for [CO], where the candidate had to consider the second order dependence on [NO] to work out the effect on rate for the change in [CO]. Most gave a rate equation of the correct format based on the orders they had stated, and worked out a value for k. Although some did not determine the correct units, there was an encouraging number who managed this either from memory or by cancelling. The most common error was not including s^{-1}
			Total	**8**	
14		i	**Rate** (Acid) **concentration** decreases ✓ **Collisions**	3 (AO 1.1) (AO 1.1) (AO 2.3)	**IGNORE** amount of acid decreases Response **MUST** imply a volume and **NOT** area, e.g. fewer particles/molecules/ions in **same space /volume**

			Fewer collisions per second **OR** less frequent collisions ✓ **Reaction stops** (Acid/reactant/limiting reagent) has reacted/been used up ✓		**IGNORE** responses not linked to rate, e.g. • 'fewer collisions' • fewer successful collisions • fewer collisions, less chance of collisions *No link to rate.* **AW** **<u>Examiner's Comments</u>** Only a small number of candidates managed to score all 3 marks for this question. Lots began their response describing why the rate is high at the start. This often filled the space available with marks being gained only in the last sentence. Very few gave descriptions with this specific reaction in mind, such as recognising that the HCl was the limiting reagent so gets used up, leaving some $MgCO_3$ remaining. Common errors included referring to "fewer collisions" but without any indication of time, or "less reactant" without considering the volume of the reaction. ? **Misconception** Many candidates described a decrease in energy in the reaction or gave responses related to activation energy. For example: "lose energy and start to collide less often", "reactants have less kinetic energy" and "only a certain number of particles which have enough energy above the activation energy…over time energy will decrease and less particles have enough energy". We have produced a delivery guide on rates with some useful resources to help consolidate ideas and avoid misconceptions such as these:

					https:/www.ocr.org.uk/Images/231742-rates-delivery-guide.pdf
		ii	**Tangent on graph** drawn at approximately *t* = 50 s (± 10 s) ✓ **Calculation of rate** = Gradient (*y*/*x*) of tangent drawn e.g. $\frac{92.4 - 91.0}{220} = \frac{1.4}{220} = 6.36 \times 10^{-3}$ (g s^{-1}) ✓ 	2 (AO 3.1) (AO 3.2)	**DO NOT ALLOW** interpolation (taking a direct reading from graph), answer must be derived from taking a gradient **ALLOW ECF from incorrectly drawn tangent** **ALLOW** range of 5.7 x 10^{-3} to 6.9 x 10^{-3} in calculation of tangent (rounded to 1 d.p.) **IGNORE** units **IGNORE** sign **Tolerance of readings:** y axis should be ± 0.02 g (i.e. within 1 square) x axis should be ± 5 min (i.e. within 1 of a square) **<u>Examiner's Comments</u>** Most candidates recognised that they needed to draw a tangent. Candidates need to be instructed to draw their line clearly and make sure that it covers several large squares on the graph – preferably extending to the axes. The range given for the calculated rate from the gradient of the tangent was generous, however some did not realise that the y-axis started at 91.0 so incorrectly calculated their gradient. Some candidates used interpolation so gained no marks. **OCR support** M3 section of the Maths Skills handbook contains useful information on use of graphs in chemistry,

					including M3.5 on drawing and using the slope of the tangent to a curve as a measure of a rate of change: https:/www.ocr.org.uk/Images/295468-chemistry-mathematicalskills-handbook.pdf
		iii	Slope is steeper **AND** levels off earlier ✓ **Same** loss in mass, i.e. levels off at ~ 91.55 g ✓	2 (AO 3.2 × 2)	Tolerance ± 1 small square **Examiner's Comments** About a third of candidates didn't score any marks here. Some did not follow the instructions to add their curve to the previous graph. The sketches produced in the blank space then usually lacked any scales on the axes so could not be given marks. Lines added were often inaccurately drawn with lines often extending below 91.55g before returning to this mass at the end. It was often difficult to interpret if a graph levelled off before the original with lots tracking the same curve with a very slightly steeper slope. Some gave a slower rate but did manage to gain marks for finishing at 91.55g.
			Total	**7**	
15			**At 90 °C**/higher temperature • Faster rate **AND** more frequent collisions ✓ • More particles have the activation energy/E_a or greater ✓ • $[Co(H_2O)_6]^{2+}$ is lower ✓ • (forward reaction) ΔH -ve **OR** exothermic ✓	4 (1 ×AO2.7) (1 ×AO1.2) (1 ×AO2.3) (1 ×AO1.2)	**ORA for 50 °C** **IGNORE** more successful collisions **ALLOW** more molecules have enough energy to react **ALLOW** atoms/molecules/ions **ALLOW** decreases **Examiner's Comments** This question asked candidates to explain the different rates from a novel experiment carried out at 50°C and 90°C, and to predict the ΔH sign for the forward reaction. Candidate explanations for the rates were often superficial, solely in terms of greater

					energy at 90°C. Many responses referred neither to the different frequency of collisions nor the greater number of particles exceeding the activation energy at 90°C. Most candidates predicted that Δ*H* would have a negative sign. Candidates were expected to link the evidence from the absorbance data in the graph to less $[Co(H_2O)_6]^{2+}$ being present at 90°C. When experimental information has been presented, candidates are advised to look for the evidence responsible in their explanations.
			Total	**4**	
16		i	More vigorous bubbling ✓ Zinc dissolves/disappears more quickly ✓	2 (AO 2.7 × 2)	**AW**, e.g. bubbles/fizzes more quickly For 1 alternative marking point **ALLOW** responses related to displacement of Cu from $CuSO_4$ by Zn: **EITHER** red/brown/black precipitate/solid formed **OR** (blue solution) turns colourless **<u>Examiner's Comments</u>** Candidates found this question very challenging. Most recognised that the addition of the catalyst would speed up the reaction but could not translate this into observations for this specific practical. For example, "reacts faster", "releases more hydrogen" or "stops reacting quicker". Giving candidates the opportunity to observe a range of both familiar and unfamiliar reactions, noting qualitative observations can help to improve their skills here. Many just noted that one tube would be blue and the other colourless rather than considering the reaction taking place. Some indicated that only 1 tube would react and the other would not. A few candidates recognised that a competing displacement reaction

					would take place between Zn and $CuSO_4$ so were given marks for this.
		ii	 ΔH ΔH labelled with product ($ZnSO_4 + H_2$) below reactant **AND** Arrow downwards ✓ E_a E_a correctly labelled ✓ E_c E_c correctly labelled with $E_c < E_a$ ✓	3 (AO 2.1) (AO 1.1) (AO 1.1)	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **IGNORE** state symbols ΔH **DO NOT ALLOW** $-\Delta H$ **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. ***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 For E_a, **ALLOW** AE **OR** A_E **ALLOW** marks for ***E_a* and *E_c*** for correctly labelled endothermic diagram (i.e. **ECF** from ΔH) **<u>Examiner's Comments</u>** Less than half of all candidates managed to gain all 3 marks giving the correct enthalpy profile diagram. Many demonstrated a lack of understanding about what an enthalpy profile diagram shows as seen by labelling of curves for E_a/E_c rather than the enthalpy change or arrows for ΔH extending to the x-axis. Other errors also seen included, -ΔH, double headed ΔH arrow, activation energy lines starting at products, endothermic profiles, E_a and E_c the wrong way round and missing or incorrect labels. Some candidates found it tricky to give

					activation lines for both catalysed and uncatalysed reactions on the same diagram, these often overlapped or did not extend to the top of the energy barrier.
			Total	**5**	