

Questions

Q1.

The progress of the reaction between iodine and propanone with an acid catalyst can be followed in an experiment using a titrimetric method.

Procedure

Step 1 Mix 25 cm³ of 1 mol dm⁻³ aqueous propanone with 25 cm³ of 1 mol dm⁻³ sulfuric acid in a beaker. Both these reactants are in excess.

Step 2 Start the stop clock as 50 cm³ of 0.02 mol dm⁻³ iodine solution is added to the beaker. Mix the reactants thoroughly.

Step 3 Withdraw a 10.0 cm³ sample of the reaction mixture, using a pipette, and transfer it to a conical flask.

Step 4 Add a spatula measure of sodium hydrogencarbonate, noting the exact time.

Step 5 Titrate the iodine present in the 10.0 cm³ sample with 0.01 mol dm⁻³ sodium thiosulfate solution, using starch indicator.

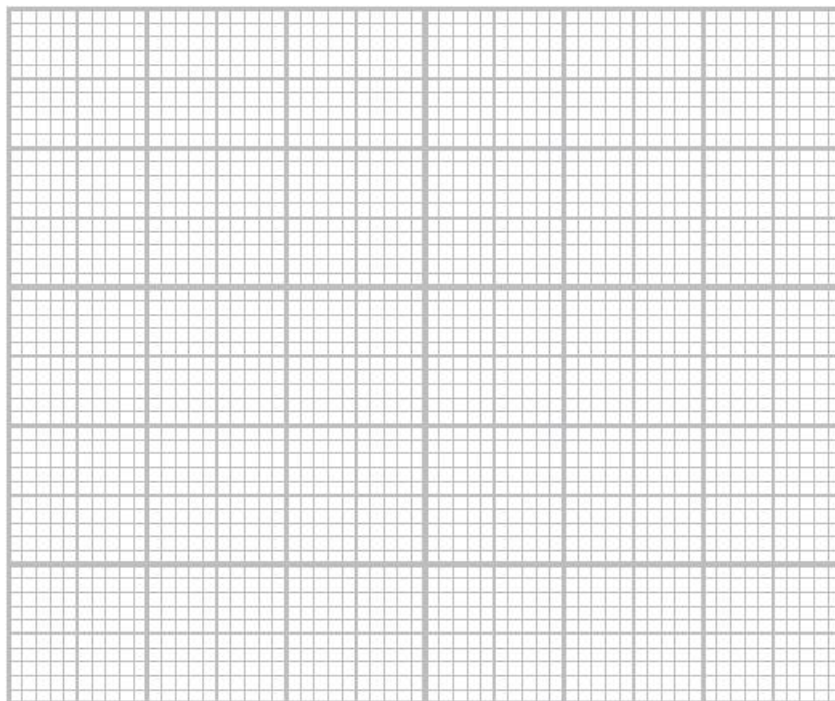
Step 6 Continue to withdraw 10.0 cm³ samples about every two minutes, repeating Steps 4 and 5 with each sample.

Some data from the experiment are shown.

Time sodium hydrogencarbonate is added / min	2.0	5.0	6.5	8.0	10.5	12.0
Volume of sodium thiosulfate / cm ³	19.2	15.5	14.0	12.1	9.5	7.2

(i) Plot a graph of the volume of sodium thiosulfate against the time the sodium hydrogencarbonate is added.

(1)



(ii) Explain how the graph of volume of thiosulfate against time confirms the reaction is zero order with respect to iodine, I_2 .

(3)

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(Total for question = 4 marks)

Q2.

The progress of the reaction between iodine and propanone with an acid catalyst can be followed in an experiment using a titrimetric method.

Procedure

Step 1 Mix 25 cm³ of 1 mol dm⁻³ aqueous propanone with 25 cm³ of 1 mol dm⁻³ sulfuric acid in a beaker. Both these reactants are in excess.

Step 2 Start the stop clock as 50 cm³ of 0.02 mol dm⁻³ iodine solution is added to the beaker. Mix the reactants thoroughly.

Step 3 Withdraw a 10.0 cm³ sample of the reaction mixture, using a pipette, and transfer it to a conical flask.

Step 4 Add a spatula measure of sodium hydrogencarbonate, noting the exact time.

Step 5 Titrate the iodine present in the 10.0 cm³ sample with 0.01 mol dm⁻³ sodium thiosulfate solution, using starch indicator.

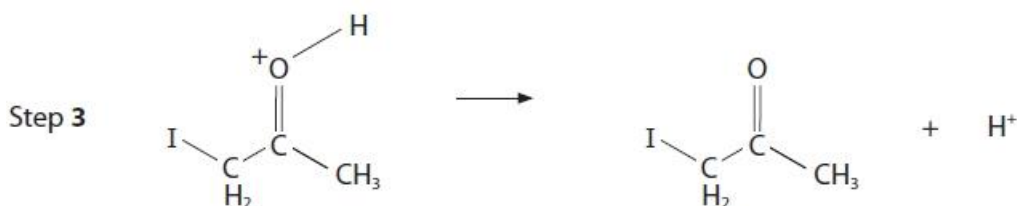
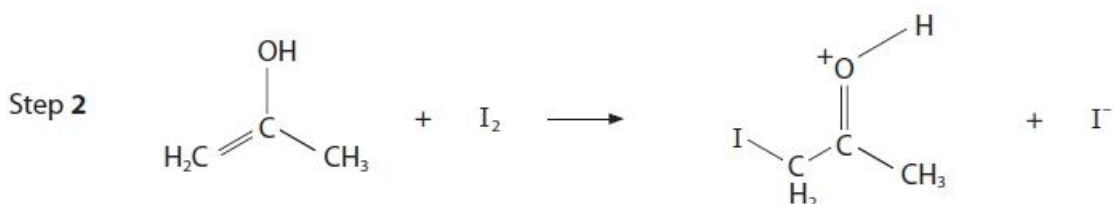
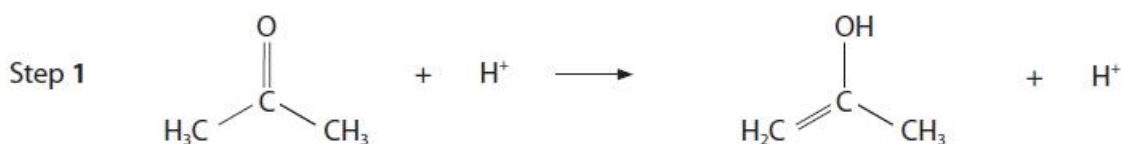
Step 6 Continue to withdraw 10.0 cm³ samples about every two minutes, repeating Steps 4 and 5 with each sample.

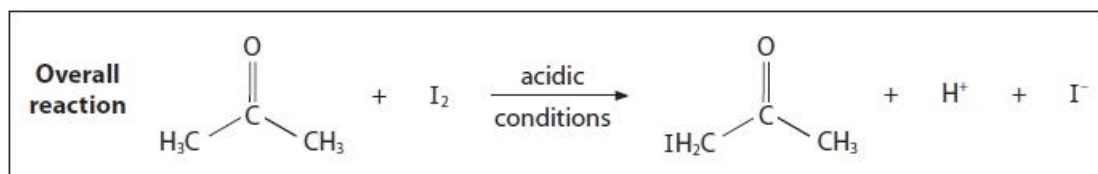
Some data from the experiment are shown.

Time sodium hydrogencarbonate is added / min	2.0	5.0	6.5	8.0	10.5	12.0
Volume of sodium thiosulfate / cm ³	19.2	15.5	14.0	12.1	9.5	7.2

The overall rate equation for the reaction is rate = $k[\text{H}^+(\text{aq})][\text{CH}_3\text{COCH}_3(\text{aq})]$.

A student researching the mechanism for the reaction found this example.





(i) Predict which of the three steps is the rate-determining step. Justify your answer.

(2)

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(ii) The student stated that

'The hydrogen ions cannot be acting as a catalyst.

One hydrogen ion is a reactant in Step 1 but two hydrogen ions are formed as products in Steps 1 and 3.'

Explain whether or not this statement is valid.

(2)

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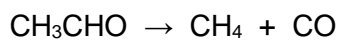
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(Total for question = 4 marks)

Q3.

At high temperatures, ethanal decomposes to form methane and carbon monoxide. The reaction is second order with respect to ethanal and second order overall.



(a) Write the rate equation for this reaction.

(1)

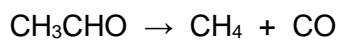
(b) Deduce the units of the rate constant given that the units of rate are $\text{mol dm}^{-3} \text{s}^{-1}$.

(1)

(Total for question = 2 marks)

Q4.

At high temperatures, ethanal decomposes to form methane and carbon monoxide. The reaction is second order with respect to ethanal and second order overall.



(c) The table shows the concentration of ethanal in a sample at different times.

Time / s	Concentration of ethanal / mol dm ⁻³
0	0.72
420	0.36
1260	0.18

Calculate average values for the rate of reaction between 0 and 420 seconds and between 420 and 1260 seconds.

Give your answers to an appropriate number of significant figures.

(2)

0 s – 420 s

420 s – 1260 s

(d) Explain why the data given and your answers in (c) show that the reaction is **neither** zero order **nor** first order.

(2)

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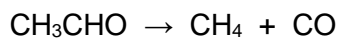
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(Total for question = 4 marks)

Q5.

At high temperatures, ethanal decomposes to form methane and carbon monoxide. The reaction is second order with respect to ethanal and second order overall.



The rate constant for the reaction was determined at five temperatures. The results are given in the table.

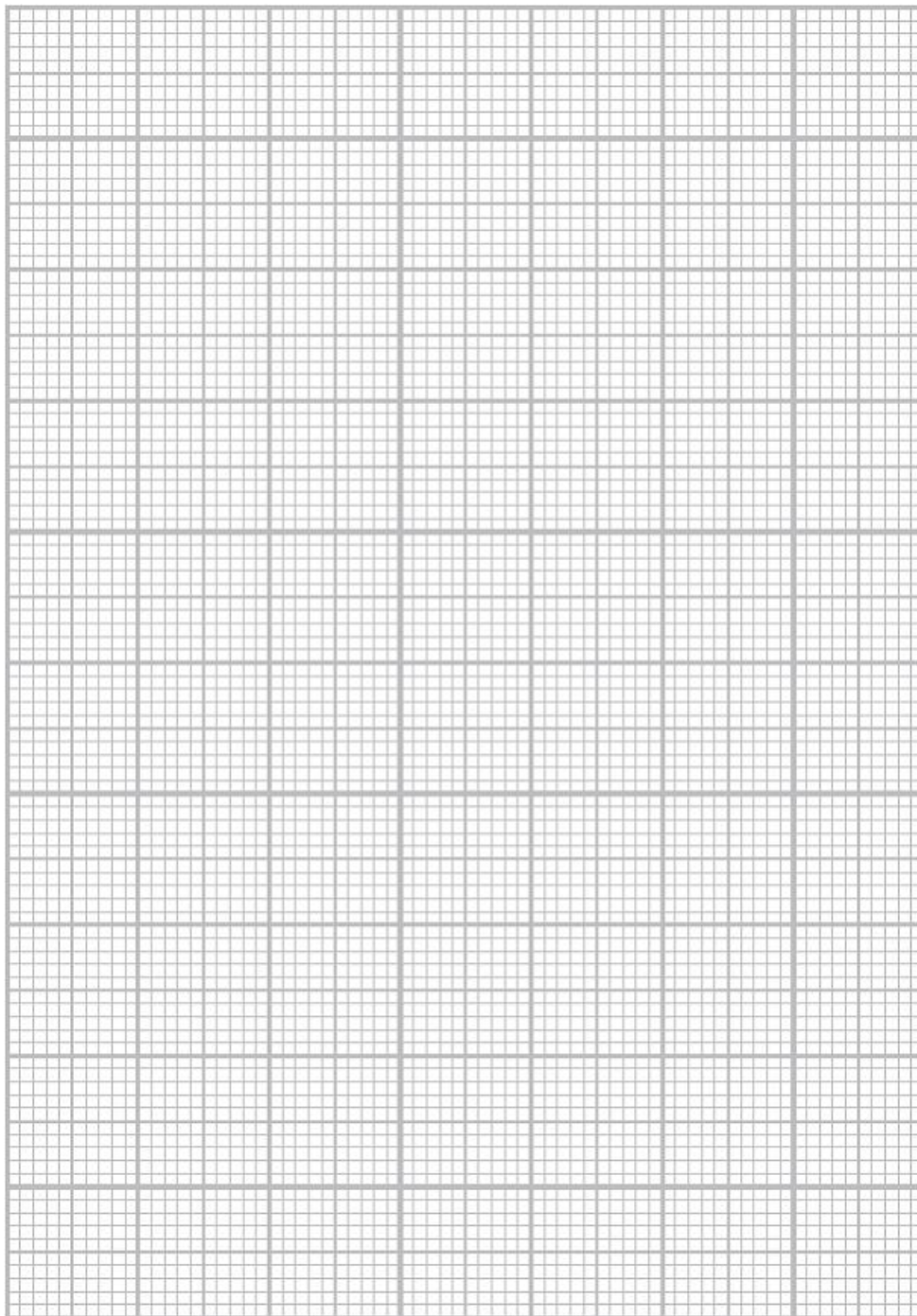
Temperature (T) / K	1/ Temperature ($1/T$) / K^{-1}	Rate constant (k) / units in (b)	$\ln k$
700	1.43×10^{-3}	0.011	-4.51
730	1.37×10^{-3}	0.035	-3.35
760	1.32×10^{-3}	0.105	-2.25
790		0.343	
810	1.23×10^{-3}	0.787	-0.24

Determine the activation energy, E_a , in kJ mol^{-1} , by completing the data in the table and plotting a graph of $\ln k$ against $1/T$.

You should include the value of the gradient of the line and its units.

The Arrhenius equation can be expressed as
$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant}$$

(7)



(Total for question = 7 marks)

Q6.

This question is about reaction kinetics.

Compound **A** decomposes in a first order reaction.

Calculate the time it takes for the mass of **A** to decrease from 600 g to 37.5 g if the decomposition has a constant half-life of 14 minutes.

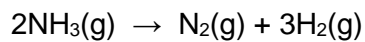
(1)

(Total for question = 1 mark)

Q7.

This question is about transition metals and their ions.

Tungsten wire catalyses the decomposition of ammonia.

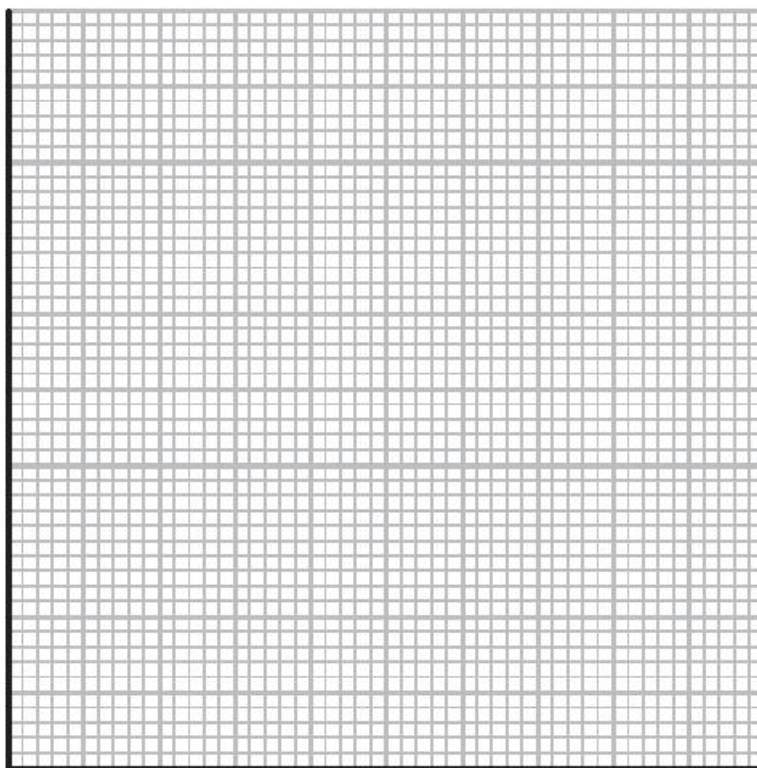


In an experiment, the following results were obtained.

Time /s	Partial pressure of ammonia / kPa
0	0.350
100	0.335
200	0.319
300	0.303
400	0.287
500	0.271

(i) Plot a graph of partial pressure of ammonia against time.

(2)



(ii) Deduce the rate equation for this reaction by using your graph in (i).

Justify your answer.

(2)

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(iii) Use the graph to calculate the rate constant. Include units in your answer.

(2)

(iv) Describe the stages in the catalytic decomposition of ammonia by tungsten.

(3)

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(Total for question = 9 marks)

Q8.

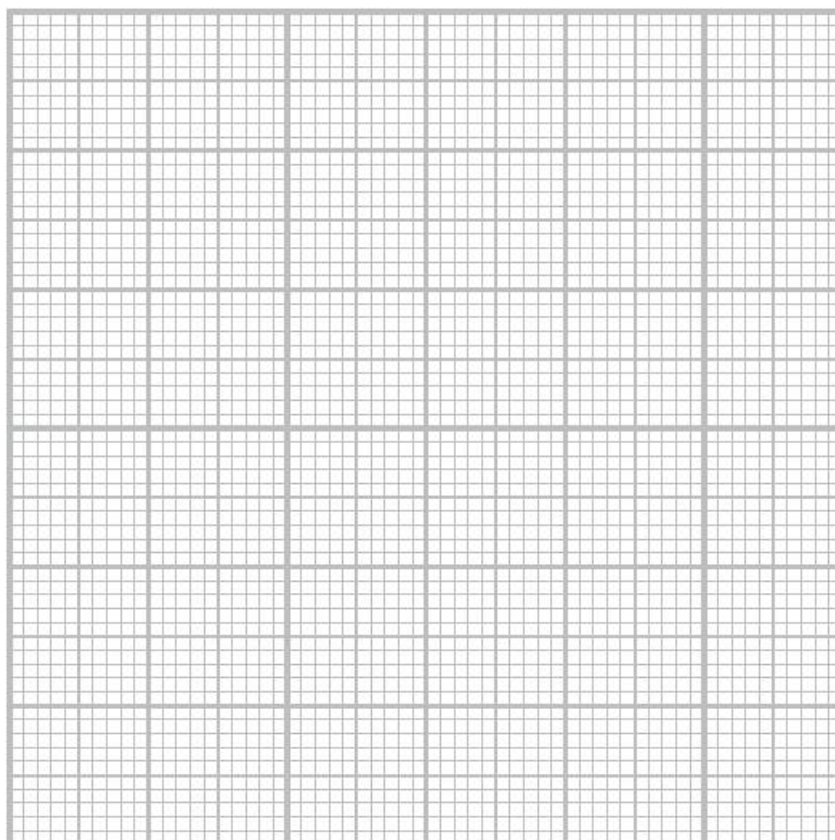
A series of experiments was carried out to determine the kinetics of the reaction between a chloroalkane, RCl, and potassium hydroxide in aqueous solution. A large excess of the chloroalkane was used.

The data obtained are shown.

$[\text{OH}^-] / \text{mol dm}^{-3}$	Time / s
0.00100	39
0.00200	31
0.00300	23
0.00400	16
0.00500	8

(a) Plot a graph of the concentration of the hydroxide ions against time.

(2)



- (b) State the order with respect to hydroxide ions.
Justify your answer by reference to your graph in (a).

(2)

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- (c) Deduce the type of mechanism occurring.
Justify your answer.

(2)

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- (d) Give the classification of the chloroalkane in this reaction.

(1)

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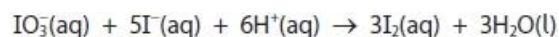
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(Total for question = 7 marks)

Q9.

This question is about the reaction kinetics of an 'iodine clock' reaction.

One example of an 'iodine clock' reaction that involves the iodate(V) ions and iodide ions in acidic solution is



A series of experiments was carried out by a student to determine the order of reaction with respect to iodate(V) ions. The concentrations of the iodide ions and the acid were in large excess and the volume of the iodate(V) solution was varied. The total volume of the reaction mixture was kept constant by the addition of suitable volumes of deionised water.

The following results were obtained:

Experiment Number	1	2	3	4	5	6
Volume of iodate(V) solution / cm ³	10.0	7.0	5.0	3.0	2.0	1.0
Time (t) / s	180	260	357	606	900	800
(1000/t) / s ⁻¹	5.56				1.11	1.25

(i) In experiment 6, the student forgot to add deionised water to keep the total volume the same for each experiment.

State why the total volume should be kept the same.

(1)

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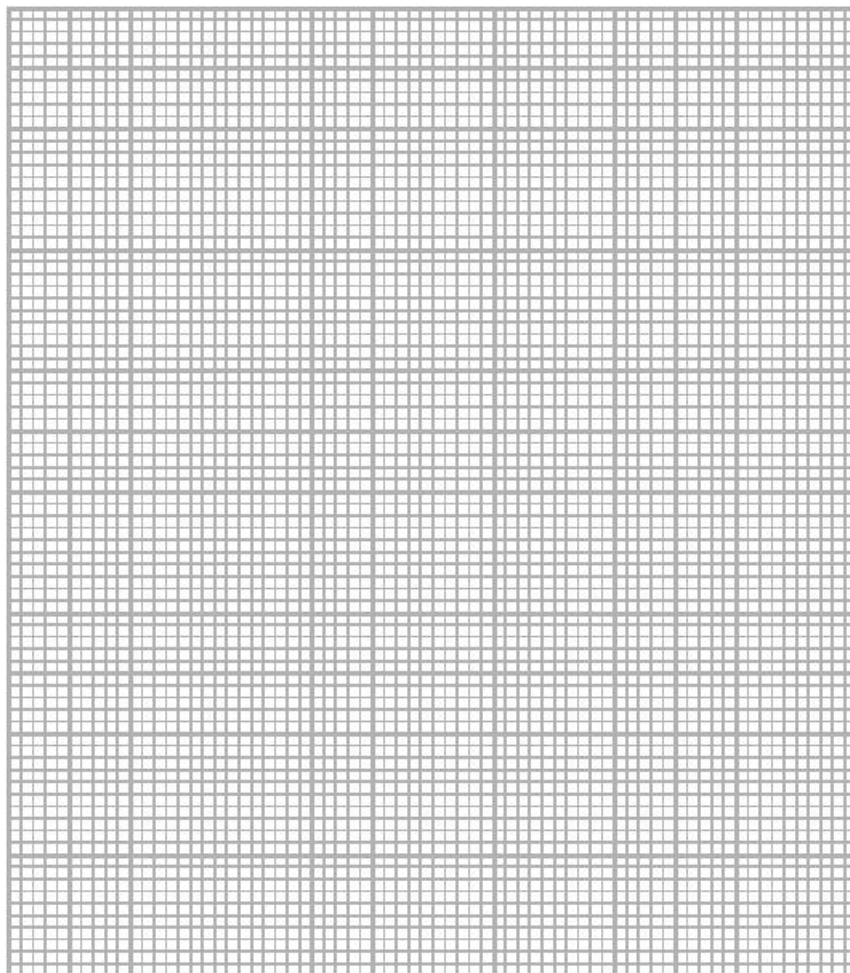
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(ii) Complete the table and use the results from experiments 1, 2, 3, 4 and 5 to plot a graph of $1000/t$ against volume of iodate(V) ions.

(4)



(iii) Deduce the order of reaction with respect to the iodate(V) ions. Justify your answer.

(2)

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(Total for question = 7 marks)

Q10.

This question is about reaction kinetics.

The 'initial rates' method was used to investigate the orders of reaction with respect to reactants **X**, **Y** and **Z**. The table shows the results obtained.

Run	Initial concentration / mol dm ⁻³			Initial rate / mol dm ⁻³ s ⁻¹
	X	Y	Z	
1	0.00100	0.00300	0.00600	2.17×10^{-6}
2	0.00100	0.00600	0.00600	8.68×10^{-6}
3	0.00050	0.00600	0.00600	4.34×10^{-6}
4	0.00300	0.00300	0.00300	6.51×10^{-6}

(i) Calculate the orders with respect to **X**, **Y** and **Z**.

X

Y

Z

(ii) Give the rate equation for the reaction and hence calculate the rate constant, *k*, to an appropriate number of significant figures. Include units in your answer.

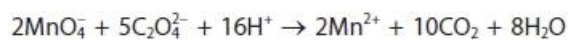
(4)

(Total for question = 4 marks)

Q11.

This question is about transition metals.

Manganate(VII) ions, MnO_4^- , react with ethanedioate ions in acid solution.



The reaction starts slowly, the rate of reaction then increases, before it decreases again.

Explain this sequence.

(3)

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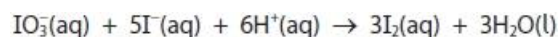
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(Total for question = 3 marks)

Q12.

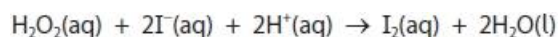
This question is about the reaction kinetics of an 'iodine clock' reaction.

One example of an 'iodine clock' reaction that involves the iodate(V) ions and iodide ions in acidic solution is



A different version of the 'iodine clock' reaction involves mixing hydrogen peroxide with aqueous solutions of potassium iodide, sodium thiosulfate and starch.

The main reaction is



The reaction is first order with respect to hydrogen peroxide and iodide ions but zero order with respect to hydrogen ions.

(i) In one experiment, the following data were obtained:

Reactants	Initial concentration / mol dm ⁻³
H ₂ O ₂ (aq)	1.50 × 10 ⁻³
I ⁻ (aq)	2.10 × 10 ⁻³
H ⁺ (aq)	2.10 × 10 ⁻³

$$\text{Initial rate} = 1.24 \times 10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1}$$

Write the rate equation and hence deduce the value of the rate constant, k , from these data. Include units and give your answer to an appropriate number of significant figures.

(2)

(ii) Explain the purpose of the starch present in the reaction mixture when starch is neither in the rate equation, nor in the reaction equation.

(2)

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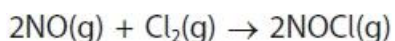
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(Total for question = 4 marks)

Q13.

Nitrogen monoxide and chlorine react together to form nitrosyl chloride.



The rate equation for the formation of nitrosyl chloride is

$$\text{Rate} = k[\text{NO}]^2[\text{Cl}_2]$$

(i) Complete the table by adding the missing values.

Experiment	[NO] / mol dm ⁻³	[Cl ₂] / mol dm ⁻³	Rate / mol dm ⁻³ s ⁻¹
1	0.122	0.241	1.09×10^{-2}
2		0.482	8.72×10^{-2}
3	0.366		4.91×10^{-2}

(2)

(ii) Calculate the rate constant, k , using data from Experiment 1.

Include units with your answer.

(3)

(iii) Explain how using a catalyst increases the rate constant, k .

(2)

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(iv) The heterogeneous catalyst palladium was suggested for use in this reaction.

Explain how impurities in the gaseous reactants could make the catalyst less effective.

(3)

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(Total for question = 10 marks)

Q14.

This question is about carbon monoxide, CO, which is a toxic and colourless gas used widely in the chemical industry.

Haemoglobin (Hb) found in red blood cells reacts almost irreversibly with carbon monoxide. Initial rate experiments were carried out to investigate the effect of the concentrations of Hb and CO on the rate of this reaction.

Experiment	[Hb] / mol dm ⁻³	[CO] / mol dm ⁻³	Rate / mol dm ⁻³ s ⁻¹
1	2.09×10^{-6}	1.40×10^{-6}	8.20×10^{-7}
2	4.18×10^{-6}	1.40×10^{-6}	1.64×10^{-6}
3	3.26×10^{-6}	2.80×10^{-6}	2.56×10^{-6}

(i) Deduce the order of reaction with respect to haemoglobin.

(1)

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(ii) Determine the order with respect to carbon monoxide using your answer to (i) and the data in the table.

Justify your answer.

(2)

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(iii) Write the rate equation for this reaction using your answers to (i) and (ii).

(1)

(iv) Calculate the rate constant, k , for the reaction, using the data from Experiment 1 and the rate equation from (iii).

Include units in your answer.

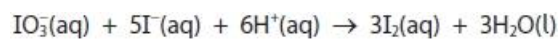
(3)

(Total for question = 7 marks)

Q15.

This question is about the reaction kinetics of an 'iodine clock' reaction.

One example of an 'iodine clock' reaction that involves the iodate(V) ions and iodide ions in acidic solution is



State why the order of reaction with respect to iodide ions cannot be five, even though 5 mol of iodide ions are shown in the equation.

(1)

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(Total for question = 1 mark)

Q16.

This question is about reaction kinetics.

The kinetics of the 'bromine clock' were investigated and the rate equation was found to be

$$\text{Rate} = k[\text{BrO}_3^-][\text{Br}^-][\text{H}^+]^2$$

(i) What is the overall reaction order?

(1)

- A First
- B Second
- C Third
- D Fourth

(ii) Calculate the concentration of bromide ions required to produce a reaction rate of $4.08 \times 10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1}$ at 298 K given that

$$k = 8.00 \text{ dm}^9 \text{ mol}^{-3} \text{ s}^{-1}$$

$$[\text{BrO}_3^-] = 0.200 \text{ mol dm}^{-3}$$

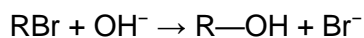
$$[\text{H}^+] = 0.100 \text{ mol dm}^{-3}$$

(2)

(Total for question = 3 marks)

Q17.

A bromoalkane, RBr, reacts with aqueous hydroxide ions in a nucleophilic substitution reaction.



This reaction is first order with respect to the bromoalkane and the rate equation is

$$\text{rate} = k[\text{RBr}]^1[\text{OH}^-]^x$$

where x is the order of the reaction with respect to hydroxide ions.

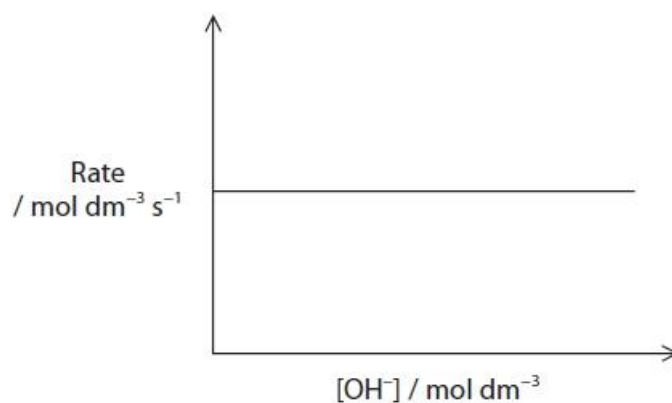
In an experiment, a sample of the bromoalkane was added to a large excess of aqueous sodium hydroxide and the concentration of the bromoalkane was determined at regular time intervals.

Results

Time / s	[RBr] / mol dm ⁻³
0	0.100
30	0.065
60	0.042
90	0.028
120	0.019
150	0.014

The experiment was repeated using equal concentrations of RBr and varying the concentration of hydroxide ions.

A graph was plotted of the results.



- (i) Deduce the value of x in the rate equation.

$$\text{rate} = k[\text{RBr}]^1[\text{OH}^-]^x \quad (1)$$

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(ii) Give the mechanism for the reaction that is consistent with the orders of reaction with respect to R—Br and hydroxide ions.

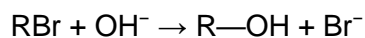
Include curly arrows and relevant lone pairs.

(3)

(Total for question = 4 marks)

Q18.

A bromoalkane, RBr, reacts with aqueous hydroxide ions in a nucleophilic substitution reaction.



This reaction is first order with respect to the bromoalkane and the rate equation is

$$\text{rate} = k[\text{RBr}]^1[\text{OH}^-]^x$$

where x is the order of the reaction with respect to hydroxide ions.

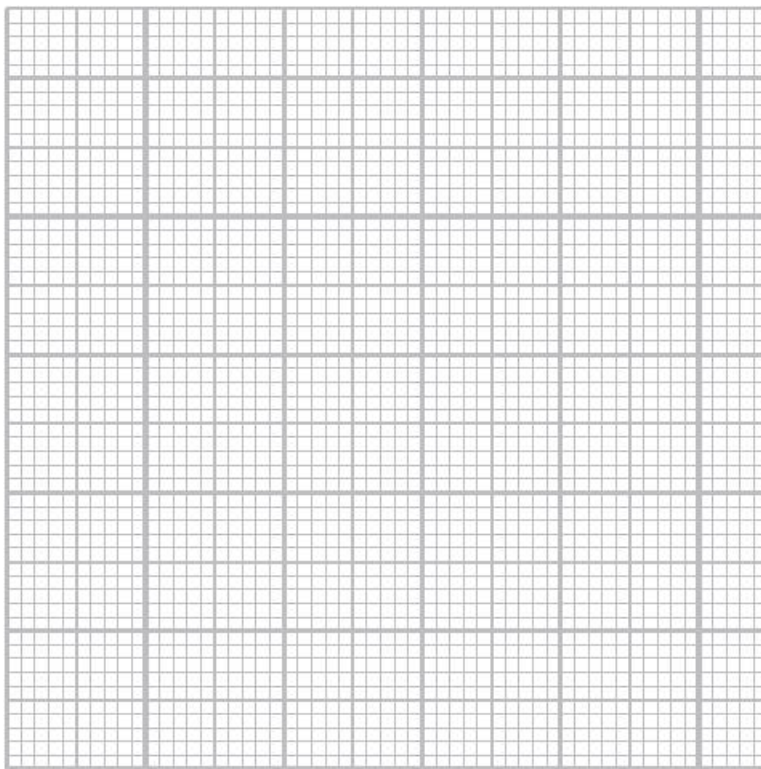
In an experiment, a sample of the bromoalkane was added to a large excess of aqueous sodium hydroxide and the concentration of the bromoalkane was determined at regular time intervals.

Results

Time / s	[RBr] / mol dm ⁻³
0	0.100
30	0.065
60	0.042
90	0.028
120	0.019
150	0.014

- (i) Plot a graph of $[RBr]$ against time.

(3)



- (ii) Explain how the graph shows that the reaction is first order with respect to RBr .
Include the values of two consecutive half-lives.

You **must** show your working for the half-lives on the graph.

(2)

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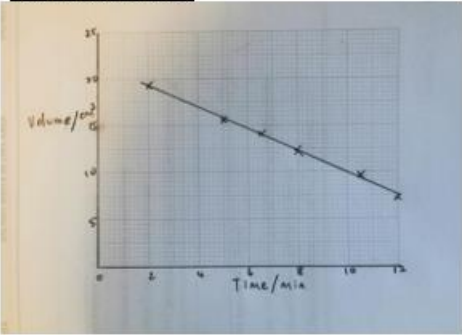
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(Total for question = 5 marks)

Mark Scheme

Q1.

Question Number	Answer	Additional Guidance	Mark
(i)	<p>y axis labelled with volume and cm^3 and</p> <p>x axis</p> <ul style="list-style-type: none"> labelled with time and min and suitable scale (1) all points plotted correctly and line of best fit (1) 	<p>Example of graph</p>  <p>Do not award time in seconds</p> <p>Suitable scale so that points cover at least half the available space along the x axis and at least 2 large squares on y axis (as shown)</p> <p>$\pm \frac{1}{2}$ a small square</p> <p>Allow M2 as TE if axes wrong way around</p> <p>Ignore extrapolations</p>	(2)
Question Number	Answer	Additional Guidance	Mark
(ii)	<p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> $[\text{I}_2]$ is proportional to the volume (of sodium thiosulfate) (1) gradient does not change / is constant / the graph shows a straight line / is linear (as $[\text{I}_2]$ decreases) (1) which means the rate doesn't change / increase or decrease (as $[\text{I}_2]$ increases or decreases) (1) 	<p>Ignore references to half-life</p> <p>Allow description of proportional</p> <p>Allow decreases at a constant rate</p> <p>Ignore volume (of sodium thiosulfate) / $[\text{I}_2]$ is proportional to time</p> <p>Allow $[\text{I}_2]$ does not affect the rate (of reaction) / rate is independent of $[\text{I}_2]$</p>	(3)

Q2.

Question Number	Answer	Additional Guidance	Mark
(i)	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> • Step 1 is the rate determining step (1) • as it involves (1 mol of) both propanone and hydrogen ions (which matches the rate equation) (1) 	<p>Stand alone Allow RDS / slow step</p> <p>Conditional on M1 Allow it does not involve I₂ (which is zero order) Allow it involves both species in the rate equation Allow I₂ is not involved in the RDS so RDS must be before Step 2</p>	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	<p>An explanation that makes reference to the following points:</p> <p>(The statement is not valid because)</p> <ul style="list-style-type: none"> • one hydrogen ion is regenerated / reformed (so is acting as a catalyst) (1) • the other hydrogen ion is lost from the propanone (when replaced by iodine) / is a (by-)product of the reaction / is used to form HI (1) 	<p>Ignore reference to specific steps.</p> <p>Do not award M1 if candidate states that it is valid Ignore it is an autocatalyst</p>	(2)

Q3.

Question Number	Answer	Additional Guidance	Mark
(a)	<ul style="list-style-type: none">rate equation	Rate = $k[\text{CH}_3\text{CHO}]^2$ Allow K for k Allow r or R for Rate Allow displayed, semi-structural or skeletal formula for ethanal Do not allow rounded brackets Do not allow missing rate Do not allow "rate equation = "	(1)

Question Number	Answer	Additional Guidance	Mark
(b)	<ul style="list-style-type: none">rate constant units	$\text{dm}^3 \text{mol}^{-1} \text{s}^{-1}$ Allow units in any order Do not penalise use of $\text{mol}^- / \text{s}^-$ No TE on incorrect equation in (a)	(1)

Q4.

Question Number	Answer	Additional Guidance	Mark
(c)	<ul style="list-style-type: none"> calculation of average rate between 0 – 420 s to 1/2 SF (1) calculation of average rate between 420 – 1260 s to 1/2 SF (1) 	<p><u>Example of calculation</u> Rate = $((0.72 - 0.36) \div (420 - 0)) = 8.5714 \times 10^{-4}$ $= 9 \times 10^{-4} / 8.6 \times 10^{-4} \text{ (mol dm}^{-3} \text{ s}^{-1}\text{)}$</p> <p>Rate = $((0.36 - 0.18) \div (1260 - 420)) = 2.1429 \times 10^{-4}$ $= 2 \times 10^{-4} / 2.1 \times 10^{-4} \text{ (mol dm}^{-3} \text{ s}^{-1}\text{)}$</p> <p>Penalise lack of 1/2 SF once only</p> <p>Ignore units even if incorrect Ignore negative sign in front of rate</p>	(2)

Question Number	Answer	Additional Guidance	Mark
(d)	<p>An explanation that makes reference to</p> <ul style="list-style-type: none"> not zero order because the rate is not constant (1) not first order because the time taken for the concentration to halve is not equal/ half lives are not constant or not first order because the rate change is not (directly) proportional to the concentration change (1) 	<p>Allow the rates calculated in (c) are not the same</p> <p>Allow different times are taken for the concentration to halve</p> <p>Allow the concentration is halved but the rate decreases by a quarter</p> <p>If no other mark awarded allow (1) for reference to justification of second order due to concentration decreasing by $\frac{1}{2}$ but rate decreasing by $\frac{1}{4}$ or due to rate change proportional to concentration squared/ exponential change</p>	(2)

Q5.

Question Number	Answer	Additional Guidance	Mark
		<p>Example of suitable graph:</p> <p> $\text{Gradient} = \frac{-4.25}{2.00 \times 10^{-4} \text{ K}^{-1}} = -21,250 \text{ K}$ $-\frac{E_a}{R} = -21,250 \quad \text{so} \quad E_a = 21,250 \times R = 176587.5 \text{ J mol}^{-1}$ $= 177 \text{ kJ mol}^{-1}$ </p>	(7)

Question Number	Answer	Additional Guidance	Mark
	<ul style="list-style-type: none"> • calculation of $1/T$ value (1) • calculation of $\ln k$ value (1) • axes: correct way round and in the correct direction, labelled with units, suitable scale (1) • all points plotted correctly, with best-fit straight line (1) • calculation of gradient (1) • sign and units of gradient (1) • use of gradient to calculate activation energy (1) 	<p>1.27×10^{-3}</p> <p>-1.07 Penalise values not to 3 SF once only in M1 and M2</p> <p>Accept use of 1×10^3 or 1×10^{-3} on x axis Do not award 1/t for 1/T Plotted points must cover at least $\frac{1}{2}$ the graph paper on each axis</p> <p>Allow ± 1 square</p> <p>Gradient = (-) 21250 Allow ± 900</p> <p>- and K</p> <p>$E_a = -(-21250 \times 8.31) / 1000$ = (+) 177 (kJ mol⁻¹) Allow ± 7</p> <p>Allow 177000 J mol⁻¹ ± 7000 Ignore SF except 1 SF Do not penalise mol⁻¹ TE on numerical value of gradient Final answer must be positive</p>	

Q6.

Question Number	Answer	Additional Guidance	Mark
	Correct answer to 2 SF	<p><u>Example of calculation:</u></p> <p>(Four half-lives to decrease 600 g to 37.5 g so 4 x 14 mins) = 56 (mins)</p> <p>Penalise wrong units, e.g. "m"</p>	(1)

Q7.

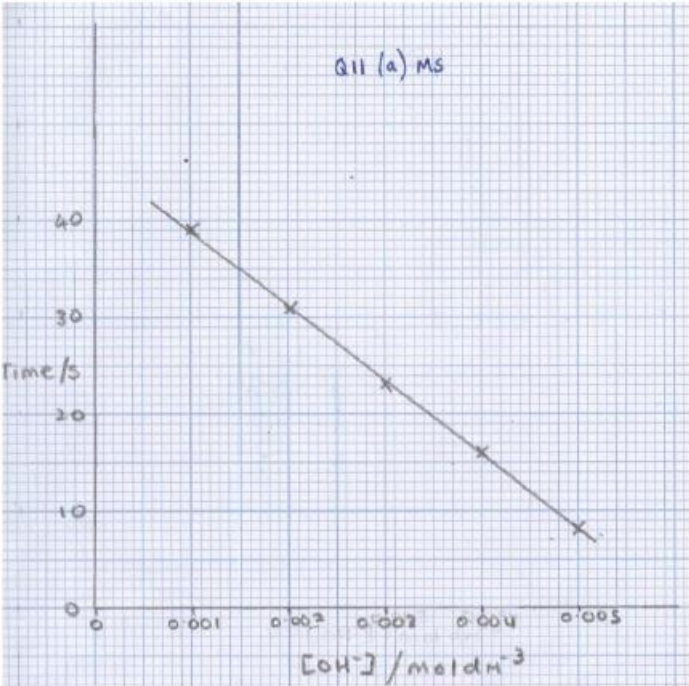
Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> axes with time on x axis and labelled, including units and suitable scale (1) all points plotted correctly and best fit line (1) 	<p>Example of graph</p> <p>Allow y axis labelled with partial pressure / pressure and unit</p> <p>Do not allow partial pressure axis starting at 0</p> <p>Both axes must cover at least half the graph paper</p> <p>Allow $\pm \frac{1}{2}$ square</p> <p>M2 can be awarded if axes the wrong way around in M1</p>	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> rate = k / rate = $k \times p(\text{NH}_3)^0$ (1) (zero / 0 order) because the rate is independent of the partial pressure of ammonia / rate is constant or because the graph is a straight line / (1) linear 	<p>Allow r for rate</p> <p>Allow $-\text{rate} = k$ / rate = $k[\text{NH}_3]^0$</p> <p>Ignore $[\text{H}_2]^0$ or $[\text{N}_2]^0$</p> <p>Conditional on M1</p> <p>Allow because the gradient is constant</p>	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(iii)	<ul style="list-style-type: none"> calculation of gradient of graph / rate/ rate constant (1) corresponding units for rate constant (1) 	<p>Example of calculation $\frac{0.271 - 0.350}{500} = (-) \frac{0.079}{500}$ $k = 1.58 \times 10^{-4} / 0.000158$ Allow any value in the range 1.50 to 1.65×10^{-4}</p> <p>$1.58 \times 10^{-4} / 0.000158 \text{ kPa s}^{-1}$ Allow $158 \times 10^{-6} \text{ kPa s}^{-1} / 0.158 \text{ Pa s}^{-1} / 1.58 \times 10^{-1} \text{ Pa s}^{-1}$</p> <p>Do not award units of $\text{mol dm}^{-3} \text{ s}^{-1}$</p> <p>Ignore SF except 1 SF Ignore negative value for k</p> <p>Correct answer with corresponding units and no working scores (2)</p>	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(iv)	<p>A description that makes reference to the following points:</p> <ul style="list-style-type: none"> adsorption of ammonia / reactant onto surface of tungsten / catalyst (1) breaking bonds in ammonia / reactant or breaking N-H bonds (1) desorption of nitrogen and hydrogen / products / gases from surface of tungsten / catalyst (1) 	<p>Ignore reference to heterogeneous / homogeneous / active sites</p> <p>Allow gas for ammonia Allow adsorb / adsorp for adsorption Ignore "stick" Do not award absorption</p> <p>Allow bonds weaken instead of break Ignore mention of atoms / radicals</p> <p>Allow products released / detached from catalyst surface Allow de-adsorbed / desorped for desorption Do not award desorption of ammonia</p>	(3)

Q8.

Question Number	Answer	Additional Guidance	Mark
(a)	<ul style="list-style-type: none"> M1 axes labelled with units on axes, suitable uniform scale with points covering at least half the available space in both directions (1) M2 all points plotted correctly with straight line of best fit (1) 	<p>Example of graph</p>  <p>Allow variables on either axis</p>	(2)

Question Number	Answer	Additional Guidance	Mark
(b)	<p>An answer that makes reference to the following points</p> <ul style="list-style-type: none"> zero order with respect to hydroxide ions (1) The graph is a straight line so the rate of reaction is independent of the concentration of the hydroxide ions (1) 	M2 dependent on M1	(2)

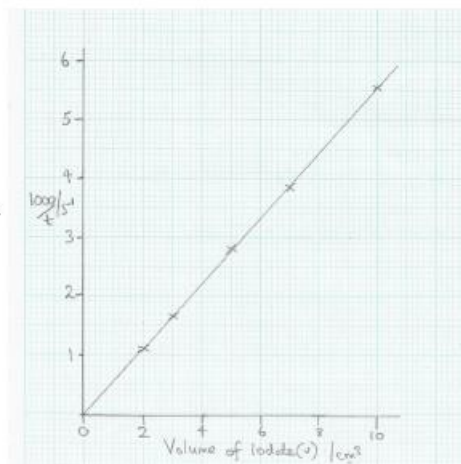
Question Number	Answer	Additional Guidance	Mark
(c)	<p>An answer that makes reference to the following points</p> <ul style="list-style-type: none"> S_N1 (1) as there is only one reactant in the rate determining step / as the hydroxide ions do not affect the rate (1) 	<p>Mark consequentially on order</p> <p>Allow TE from (b) e.g. if first order in (b) allow S_N2</p>	(2)

Question Number	Answer	Additional Guidance	Mark
(d)	<ul style="list-style-type: none"> the chloroalkane is tertiary 	Allow TE from first order in (b) and/or S_N2 in (c) e.g. if S_N2 in (c) allow primary NOTE if first order wrt hydroxide ions in (b) but S_N1 given in (c) can score 1 mark in (d) for tertiary	(1)

Q9.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	A statement that makes reference to the following: <ul style="list-style-type: none"> So that the volume of iodate(V) ions is proportional to the concentration. 	Allow the volume of iodate(V) ions can be used instead of the concentration in plotting the graph. Ignore reference to "fair tests".	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> calculation of all three $1000/t$ values (1) axes: correct way round, labelled and including units (1) suitable scale (1) all points plotted correctly, with best-fit straight line through the origin (1) 	(5.56) 3.85, 2.80, 1.65, (1.11) Do not award 2.8 or $\geq 3SF$ Do not award use of T for t Plotted points must cover at least $\frac{1}{2}$ the graph paper on each axis Allow $\pm \frac{1}{2}$ square Ignore plotting of experiment 6 Exemplar graph	(4)



Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	An answer that makes reference to the following: <ul style="list-style-type: none"> • first order (with respect to iodate(V) ions) (1) • because straight line goes through the origin / rate is (directly) proportional to concentration (1) 	Mark independently Allow "volume" for "concentration" Do not award references of proportionality to time Ignore references to half life	(2)

Q10.

Question Number	Answer	Additional Guidance	Mark
(i)	Reaction Orders: <ul style="list-style-type: none"> • X First/1 (1) • Y Second/2 (1) • Z Zero/0 (1) 	Allow "none"/"no order"	(3)

Question Number	Answer	Additional Guidance	Mark
(ii)	<p>Marking point 1</p> <ul style="list-style-type: none"> • Rate = $k[X][Y]^2[Z]^0$ (1) <p>Marking point 2</p> <ul style="list-style-type: none"> • rearrangement of rate expression (1) <p>Marking point 3</p> <ul style="list-style-type: none"> • calculation of value for k to 2/3 SF (1) <p>Marking point 4</p> <ul style="list-style-type: none"> • units $\text{dm}^6 \text{mol}^{-2} \text{s}^{-1}$ (1) 	<p>Reactants can be in any order Z does not have to be included in the rate equation TE from (b)(i) which will apply for all four marking points</p> <p><u>Example of calculation:</u> $k = \text{rate} / [X][Y]^2$</p> $k = \frac{2.17 \times 10^{-6}}{0.00100 \times 0.00300^2}$ $= 241.11$ $= 241/240$ <p>Any 'run' can be used</p> <p>No TE on incorrect rearrangement</p> <p>Allow units in any order Correct answer without working and with correct units to 2/3 SF scores marking points 2, 3 and 4</p>	(4)

Q11.

Question Number	Acceptable Answer	Additional Guidance	Mark
	<p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> (the initial rate of reaction is slow) because both reacting species are negatively charged / repel each other or the reaction has a high activation energy / few particles have energy greater than (or equal to) the activation energy (1) (the rate of reaction increases) because Mn²⁺ ions (are formed) and they act as a catalyst / are autocatalytic / provide an alternative route with a lower activation energy (1) (the rate decreases) because the concentrations / amounts of the reactants decrease / the reactants are used up (1) 	<p>Allow because there is no catalyst / no Mn²⁺ ions present at the start</p> <p>Allow a description of how the Mn²⁺ ions are acting as a catalyst e.g. the idea of Mn²⁺ ions reacting and being regenerated</p> <p>Do not award 'enzyme'</p> <p>Allow example of one of the reagents used up / becoming a limiting factor</p> <p>Do not award 'the Mn²⁺ ions are used up'</p>	(3)

Q12.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> value of rate constant to 2 or 3 SF (1) units of rate constant (1) 	<p><u>Example of calculation:</u></p> <p>(Rate=$k[\text{H}_2\text{O}_2][\text{I}^-]$ so $k = \text{rate} \div ([\text{H}_2\text{O}_2][\text{I}^-])$ $= 1.24 \times 10^{-3} \div (1.50 \times 10^{-3} \times 2.10 \times 10^{-3})$ $= 393.65\dots)$ $= 390/394$</p> <p>$\text{dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$ Accept units in any order No TE on incorrect rate equation</p>	(2)

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	<p>An explanation that makes reference to</p> <ul style="list-style-type: none"> starch is an indicator (to react with the iodine) <p>(1)</p> <ul style="list-style-type: none"> the time taken for the formation of the blue-black complex (can be used to calculate the reaction rate) <p>(1)</p>	<p>Do not award references to iodide/I⁻</p> <p>Allow</p> <p>Reacts with iodine/produces a blue-black colour when the reaction is complete.</p> <p>Allow</p> <p>Changes colour when all the thiosulfate is used up.</p> <p>Allow indication of 'time taken'</p>	(2)

Q13.

Question Number	Answer	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> concentration of NO in experiment 2 (1) concentration of Cl₂ in experiment 3 (1) 	<p><u>Example of calculation</u></p> <p>0.244</p> <p>0.121</p> <p>Do not award 0.1205</p> <p>Both values must be to 3SF</p>	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	<p>M1 rearrangement of rate equation to find k (1)</p> <p>M2 calculation of k (1)</p> <p>M3 correct units for k (1)</p>	<p><u>Example of calculation</u></p> <p>$k = \frac{\text{rate}}{[\text{NO}]^2[\text{Cl}_2]}$</p> <p>$\frac{1.09 \times 10^{-2}}{(0.122 \times 0.122 \times 0.241)}$</p> <p>$= 3.03871 = 3.04$</p> <p>Ignore SF</p> <p>Correct numerical answer for k scores both M1 and M2</p> <p>$\text{dm}^3 \text{mol}^{-2} \text{s}^{-1}$</p> <p>Allow units in any order</p> <p>M3 stand alone mark</p>	(3)

Question Number	Answer	Additional Guidance	Mark
(iii)	<p>An explanation that makes reference to the following points:</p> <p>k increases because</p> <ul style="list-style-type: none"> the catalyst provides an alternative pathway of lower activation energy (1) so a greater proportion of molecules / more molecules have energy greater than the activation energy (so faster reaction) (1) 	<p>Award 'particles' instead of 'molecules'</p> <p>Do not award "atoms" instead of 'molecules'</p>	(2)

Question Number	Answer	Additional Guidance	Mark
(iv)	<p>An explanation that makes reference to the following points:</p> <p>Catalysts will be less effective because</p> <ul style="list-style-type: none"> M1 impurities adsorb onto (catalyst) surface or impurities occupy active sites or impurities bond / bind to (catalyst) surface (1) M2 impurities prevent bond weakening in the reactants or less surface area (of catalyst) / fewer active sites available for reaction (1) M3 impurities form strong bonds (to surface) or impurities less likely to desorb (from surface) (1) 	<p>Do not award "absorb" for M1</p> <p>Ignore impurities "react"</p> <p>Allow 'no active sites available'</p> <p>Allow 'impurities remain on surface'</p>	(3)

Q14.

Question Number	Answer	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> order with respect to Hb = 1 		(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> order with respect to CO = 1 (1) justification (1) 	standalone mark Either using experiments 1 and 3 the concentration of Hb goes up by a factor of 1.56 and the concentration of CO doubles and the rate goes up by a factor of 3.12 Or using experiments 2 and 3 the concentration of Hb goes down by a factor of 0.78 but the rate increases by a factor of 1.56 so doubling the concentration of CO means doubling the rate M2 dependent on M1	(2)

Question Number	Answer	Additional Guidance	Mark
(iii)	<ul style="list-style-type: none"> rate equation 	<u>Example of rate equation</u> $\text{rate} = k[\text{Hb}][\text{CO}]$ allow e.g R / r for rate and K for k Allow expressed in terms of k Allow TE from 6(d)(i) and 6(d)(ii) Note – must be consistent with 6(d)(i) and 6(d)(ii)	(1)

Question Number	Answer	Additional Guidance	Mark
(iv)	<ul style="list-style-type: none"> rearrangement of rate equation to find k (1) calculation of k (1) correct units of k (1) 	<p><u>Example of calculation</u> $k = \text{rate} / [\text{Hb}][\text{CO}]$</p> <p>$8.20 \times 10^{-7} / (2.09 \times 10^{-6} \times 1.40 \times 10^{-6})$ $= 280246 = 280000$ Ignore SF except 1 SF</p> <p>$\text{dm}^3 \text{mol}^{-1} \text{s}^{-1}$</p> <p>Allow units in any order</p> <p>Allow use of data from experiments 2 or 3 Correct answer including units with no working scores 3 marks</p> <p>Allow TE on rate equation from (d)(iii) No TE for mistake with rate equation within (d)(iv) e.g. rearrangement error</p>	(3)

Q15.

Question Number	Acceptable Answer	Additional Guidance	Mark
	A statement that makes reference to the following: <ul style="list-style-type: none"> The chance of five or more ions colliding in the rate determining step is negligible 	Allow 'at the same time' for the RDS	(1)

Q16.

Question Number	Answer	Mark
(i)	<p>The only correct answer is D (Fourth)</p> <p>A is not correct because this is the individual reaction order with respect to bromate(V) ions and with respect to bromide ions but is not the overall reaction order</p> <p>B is not correct because this is the reaction order with respect to hydrogen ions but is not the overall reaction order</p> <p>C is not correct because this is the number of species in the rate equation but is not the overall reaction order</p>	(1)

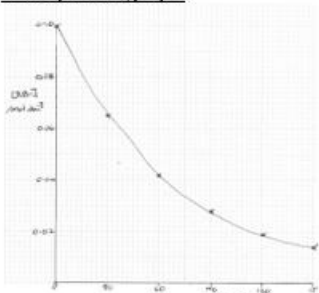
Question Number	Answer	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> rearrange rate equation so $[Br^-] =$ (1) calculation of value to 2/3 SF (1) 	<p>Example of calculation:</p> $[Br^-] = \frac{\text{rate}}{k [BrO_3^-][H^+]^2}$ $= 0.255/0.26 \text{ (mol dm}^{-3}\text{)}$ <p>Correct answer without working to 2/3 SF scores 2 marks</p> <p>If units given then must be correct</p> <p>No TE on incorrect rearrangement</p>	(2)

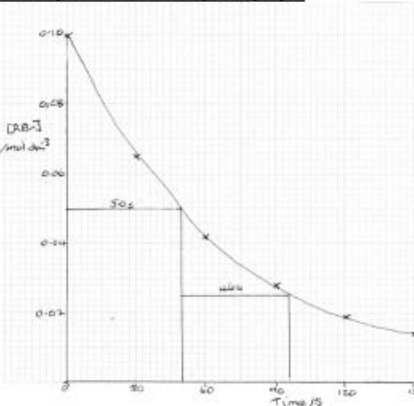
Q17.

Question Number	Answer	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> zero (order 0 / 0 (order) 	<p>Allow $x = 0$ / rate is proportional to $[OH^-]^0$ / rate = $k[R-Br][OH^-]^0$</p>	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> curly arrow from R-Br bond to, or just beyond, Br (1) R^+ and Br^- (1) lone pair on O of OH^- and curly arrow from lone pair to R^+ (1) 	<p>Example of mechanism</p> $R-Br \longrightarrow R^+ + Br^-$ $R^+ + \overset{\cdot\cdot}{O}H^- \longrightarrow R-OH$ <p>Ignore dipole on RBr</p>	(3)

Q18.

Question Number	Answer	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> both axes labelled, including units (1) suitable scales and points taking up at least half the graph paper in both directions (1) points plotted correctly and smooth curve through the points (1) 	<p><u>Example of graph</u></p>  <p>Allow T / t for time with units Allow just 'concentration' with units Do not award RBr without square brackets</p> <p>Allow \pm half square</p> <p>Do not award point-to-point straight lines</p>	(3)

Question Number	Answer	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> first half-life 50 s and second half-life 50 s (1) reaction is first order because the half-lives are (almost) the same (1) 	<p><u>Example of working on graph</u></p>  <p>Allow \pm 6 s for both half-lives Do not award M1 if no working is shown on the graph</p> <p>Allow $\text{rate} \propto [\text{RBr}]$ / $\text{rate} = k[\text{RBr}]$ for first order Conditional on 2 half-lives within 12 s or the second half-life is (about) twice the first half-life</p>	(2)