PEARSON EDEXCEL IAL CHEMISTRY · YCH11

CHEMISTRY



EXAM QUESTION PACK

UNIT 4: KINETICS

SCORE	PERCENTAGE
/127	%

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Q1.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

A series of experiments was carried out to determine the rate constant, k, of the reaction between bromate(V) ions and bromide ions at different temperatures, T.

A graph of ln k was plotted against $\frac{1}{T}$. The gradient of the line was −4670 K.

The Arrhenius equation may be written as

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant} \qquad R = 8.31\,\text{J mol}^{-1}\,\text{K}^{-1}$$

What is the activation energy of this reaction?

(1)

☒ **A** +38.8 kJ mol^{-1}

☒ **B** +38.8 J mol^{-1} K^{-1}

☒ **C** +562 J mol^{-1}

☒ **D** +562 J mol^{-1} K^{-1}

(Total for question = 1 mark)

Q2.

What can be deduced from the position of the activation energy on a Maxwell-Boltzmann distribution curve?

(1)

☒ **A** number of particles in the rate determining step

☒ **B** number of successful collisions per second

☒ **C** order of reaction

☒ **D** proportion of particles with sufficient energy to react

(Total for question = 1 mark)

Q3.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

This question is about chromatography.

(a) A spot caused by an amino acid has moved 42 mm from the baseline of a paper chromatogram.
The R_f value for the amino acid under these conditions is 0.62.

What is the distance moved by the solvent?

(1)

☒ **A** 680 mm

☒ **B** 68 mm

☒ **C** 42 mm

☒ **D** 26 mm

(b) In gas chromatography, GC, which of these would be the most suitable carrier gas?

(1)

☒ **A** argon

☒ **B** hydrogen

☒ **C** methane

☒ **D** oxygen

(Total for question = 2 marks)

Q4.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

The Arrhenius equation can be shown as

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant}$$

A graph is plotted of ln k against $1/T$ for a reaction.
The activation energy, E_a, of this reaction equals

☒ **A** – gradient ÷ R

☒ **B** + gradient ÷ R

☒ **C** – gradient × R

☒ **D** + gradient × R

(Total for question = 1 mark)

Q5.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Bromine oxidises methanoic acid to carbon dioxide.

The equation for the reaction is

$$HCOOH(aq) + Br_2(aq) \rightarrow 2H^+(aq) + 2Br^-(aq) + CO_2(g)$$

Which of the following methods would **not** be suitable for measuring the progress of this reaction?

☒ **A** colorimetry

☒ **B** measuring electrical conductivity

☒ **C** quenching and titrating with acid

☒ **D** measuring the volume of gas

Use this space for any rough working. Anything you write in this space will gain no credit.

(Total for question = 1 mark)

Q6.

A student carried out an experiment to determine the equilibrium constant for the reaction to form ethyl ethanoate from ethanol and ethanoic acid.

$$CH_3COOH + CH_3CH_2OH \rightleftharpoons CH_3COOCH_2CH_3 + H_2O$$

Different amounts of each substance were added to conical flasks, each containing 2.0 cm^3 of 1.0 mol dm^{-3} hydrochloric acid.

Conical flask	Volume added / cm^3				
	HCl (aq)	H_2O (l)	CH_3COOH (l)	$CH_3COOCH_2CH_3$ (l)	CH_3CH_2OH (l)
1	2.0	1.0	0	2.0	0
2	2.0	0	5.0	0	5.0
3	2.0	0	4.0	0	3.0
4	2.0	0	0	3.0	0

The flasks were then stoppered and left for a week to reach equilibrium.

Each mixture was then titrated with 1.0 mol dm^{-3} sodium hydroxide.

(a) In which flask(s) was the equilibrium approached from the right-hand side of the equation?

(1)

☒ **A** flask 1 only

☒ **B** flask 4 only

☒ **C** flasks 1 and 4 only

☒ **D** flasks 2 and 3 only

(b) Which of these statements explains why it is possible to titrate the reaction mixture directly to find the equilibrium concentrations?

(1)

☒ **A** the equilibrium reaction is slow

☒ **B** the sodium hydroxide quickly hydrolyses the ester

☒ **C** all the reactant concentrations remain constant during the titration

☒ **D** a buffer solution forms in the reaction

(Total for question = 2 marks)

Q7.

This question is about some compounds of bromine.

(a) Potassium bromate(V) decomposes to form potassium bromide and oxygen.

$$2KBrO_3(s) \rightarrow 2KBr(s) + 3O_2(g) \qquad \Delta_r H^{\ominus} = -67.2\,kJ\,mol^{-1}$$

The standard molar entropies of these substances are given in the table.

Substance	$KBrO_3(s)$	$KBr(s)$	$O_2(g)$
$S^{\ominus}/JK^{-1}mol^{-1}$	149.2	95.9	205.0

Calculate the total entropy change, ΔS_{total}, for this reaction at 298 K.

(5)

(b) Bromide ions react with bromate(V) ions in acidic solution.

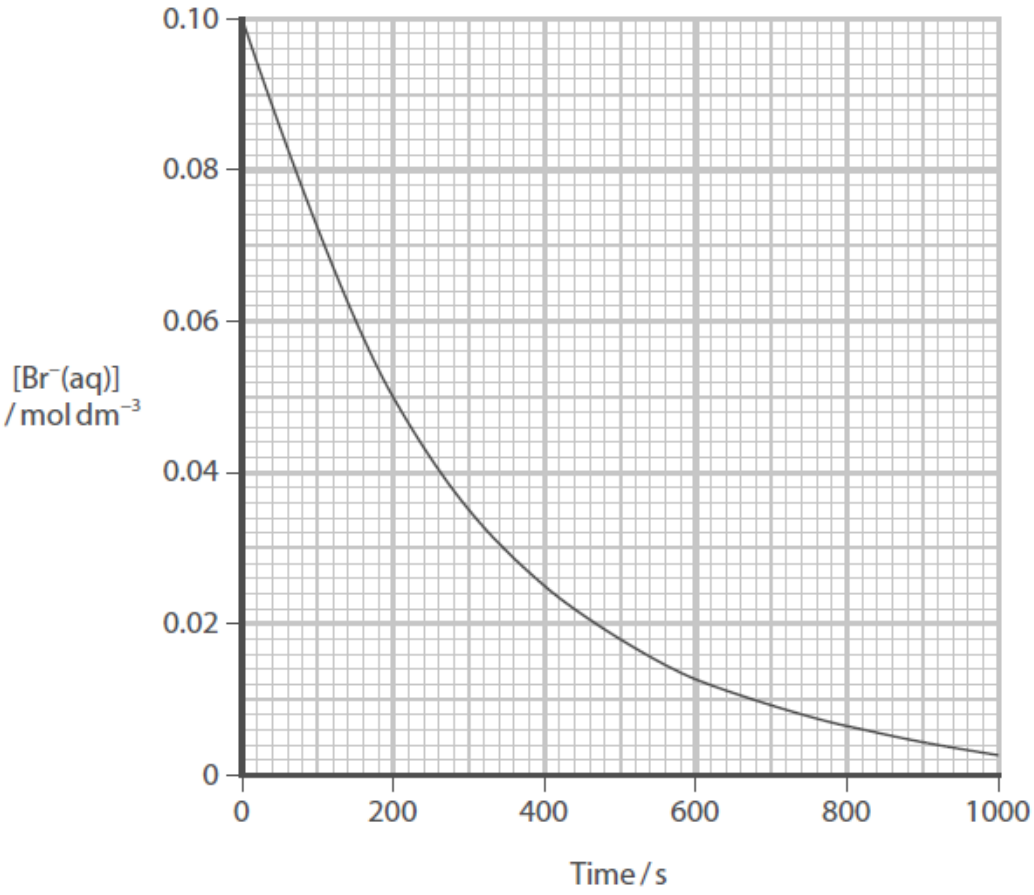
$$5Br^-(aq) + BrO_3^-(aq) + 6H^+(aq) \rightarrow 3Br_2(aq) + 3H_2O(l)$$

Two experiments are carried out.

(i) **Experiment 1**

The concentration of Br^- ions is determined at different times.
The concentrations of BrO_3^- ions and H^+ ions are in large excess and effectively constant.

The graph of concentration of Br^- ions against time is shown.



Determine the order of the reaction with respect to bromide ions.
Show your working on the graph.

(3)

(ii) **Experiment 2**

The initial concentrations of BrO_3^- ions and H^+ ions are changed and the initial rate of reaction is determined.
The initial concentration of Br^- ions is constant and in large excess.

Run	$[BrO_3^-(aq)]$ / mol dm^{-3}	$[H^+(aq)]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.1	0.1	3.6×10^{-3}
2	0.2	0.1	7.2×10^{-3}
3	0.3	0.2	4.3×10^{-2}

Determine the order of reaction with respect to BrO_3^- ions and to H^+ ions.

You must explain your working.

(3)

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(iii) Give the overall rate equation for this reaction.
Include the units for the rate constant.

(2)

(c) The rate constant for the reaction between bromoalkane and cyanide ions is determined at five different temperatures.

The results are given in the table.

Temperature (T) / K	1/Temperature ($1/T$) / K^{-1}	Rate constant (k) / s^{-1}	ln k
300	3.33×10^{-3}	3.72×10^{-5}	−10.20
310	3.23×10^{-3}	1.34×10^{-4}	−8.92
320	3.13×10^{-3}	5.48×10^{-4}	−7.51
330	3.03×10^{-3}	2.01×10^{-3}	−6.21
340	2.93×10^{-3}	7.23×10^{-3}	−4.93

Plot a graph of ln k against $1/T$ and use it to determine the activation energy, E_a .

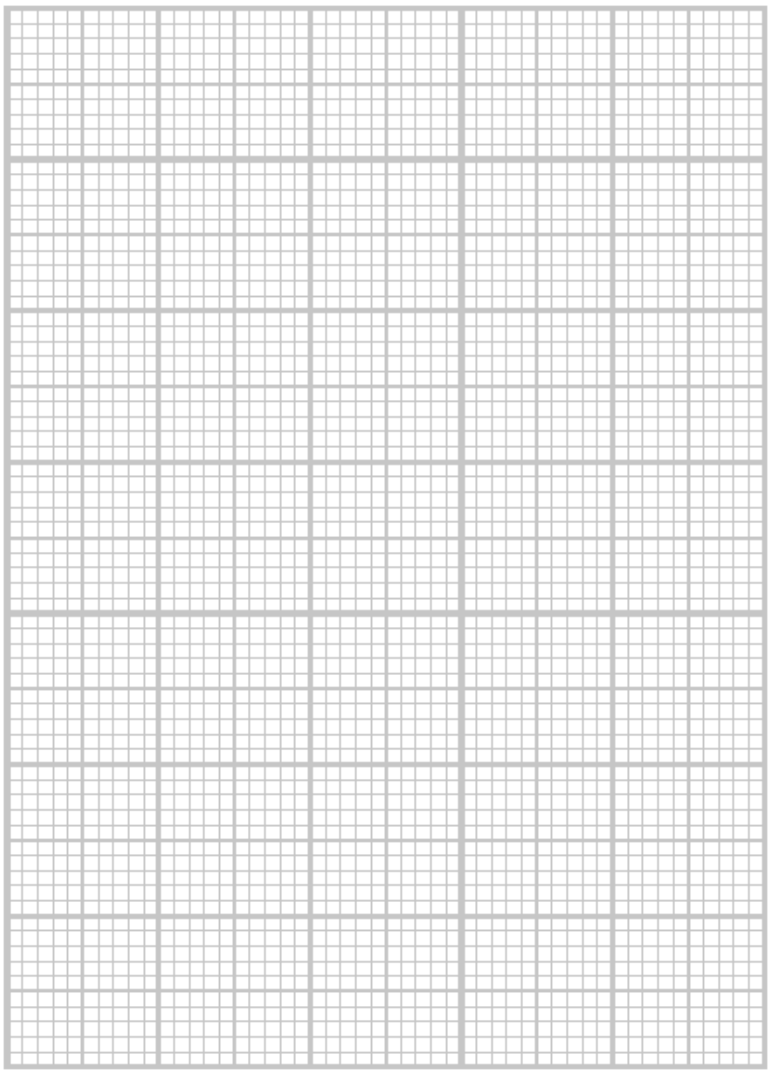
Include the sign and units of the gradient and the activation energy.

(7)

The Arrhenius equation can be expressed as

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant}$$

[R = 8.31 J mol^{-1} K^{-1}]



(Total for question = 20 marks)

Q8.

The decomposition of benzenediazonium chloride is a first order reaction.

$$C_6H_5N_2Cl + H_2O \rightarrow C_6H_5OH + N_2 + HCl$$

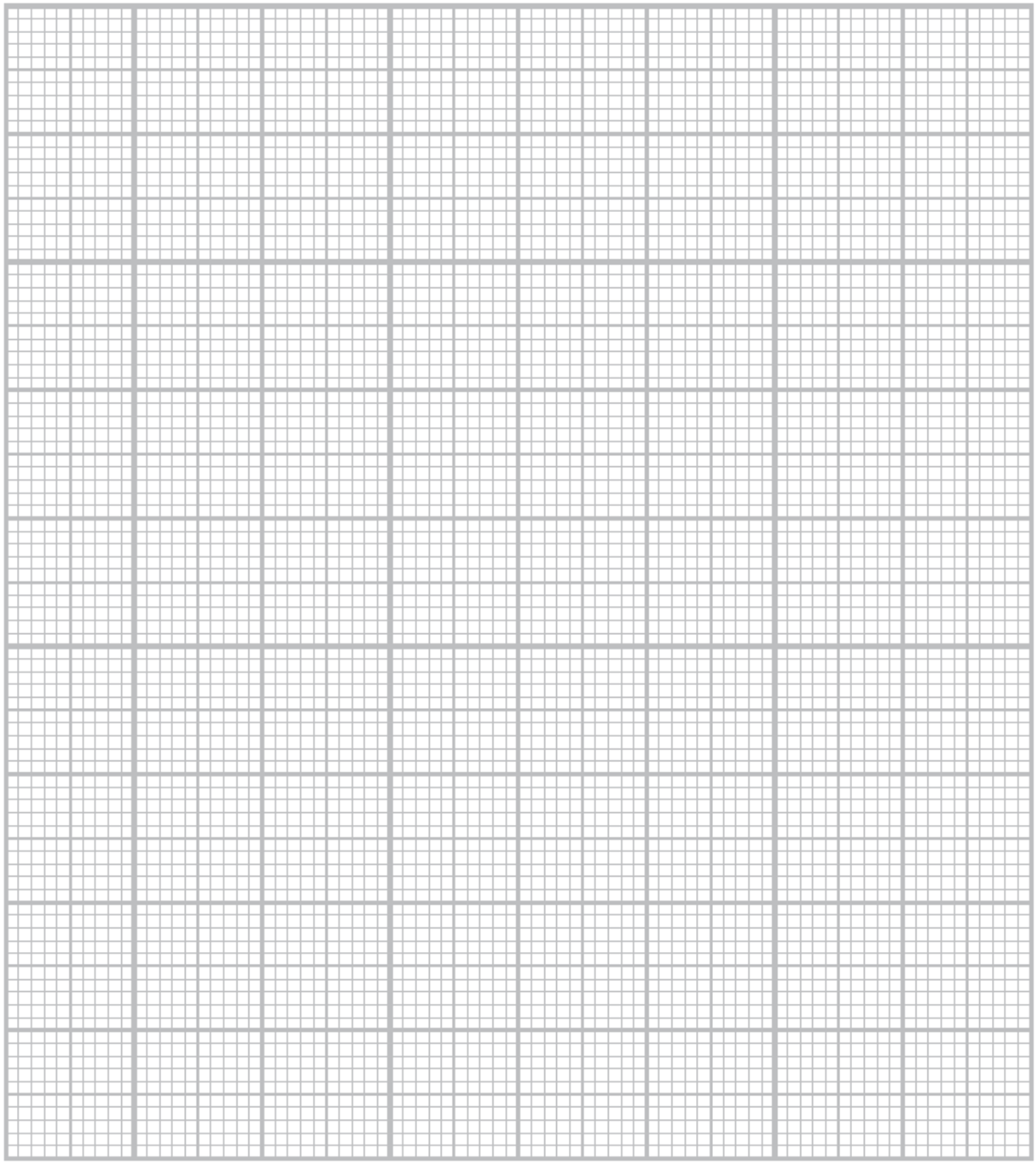
The activation energy of this reaction was determined by measuring the rate constant at various temperatures.

(a) In an experiment at 333 K, the concentration of a sample of benzenediazonium chloride was measured at various times during its decomposition. The results of this experiment are shown.

Time / s	$[C_6H_5N_2Cl]$ / mol dm^{-3}
0.0	0.500
40.0	0.410
100	0.285
200	0.165
280	0.100
350	0.070
400	0.050

(i) Plot a graph of concentration of benzenediazonium chloride against time.

(3)



(ii) Determine a value for the half-life, $t_{1/2}$, of this reaction.

You **must** show your working on the graph.

(1)

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(iii) Calculate the rate constant, *k*, for the reaction at 333 K.

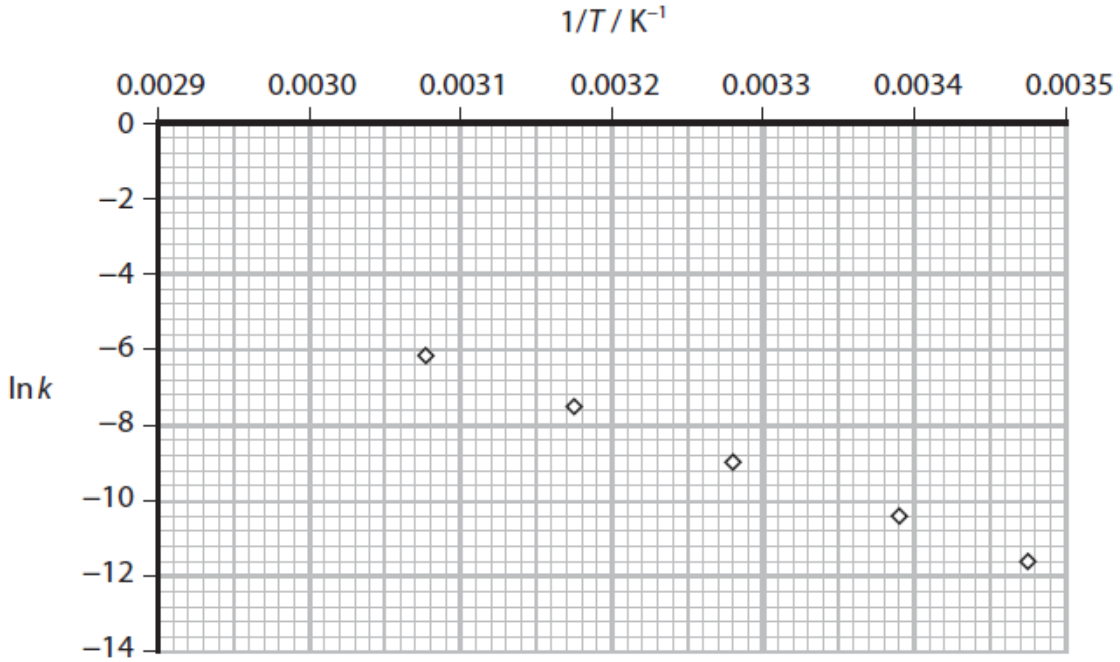
Include units in your answer.

Use the expression $\ln 2 = kt_{1/2}$

(2)

(b) The experiment described in (a) was repeated for five temperatures and the data used to plot a graph for the Arrhenius equation in the form

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant}$$



(i) Use the rate constant that you have calculated in (a)(iii) to obtain data for a point on the graph for 333 K.

(2)

(ii) Plot your data from (b)(i) on the graph.

(1)

(iii) Determine the gradient of the graph by drawing a best-fit line.

Include a sign and units in your answer.

(3)

(iv) Use the gradient determined in (b)(iii) to calculate the activation energy for the

decomposition of benzenediazonium chloride.
Include a sign and units with your answer.

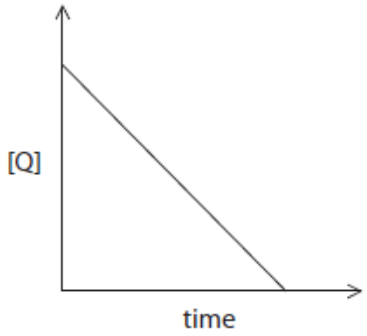
(3)

(Total for question = 15 marks)

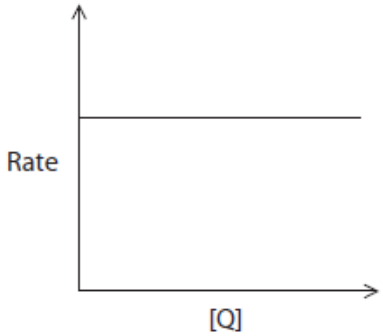
Q9.

A reactant Q is converted into two products. Which of these graphs shows that this reaction is first order with respect to Q?

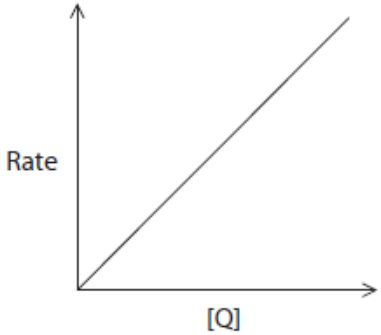
Graph 1



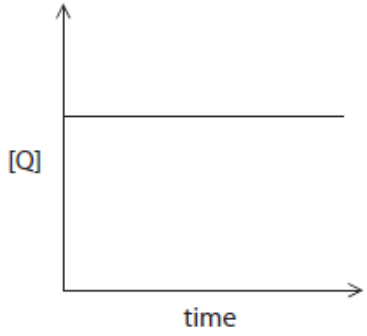
Graph 2



Graph 3



Graph 4



☒ **A** Graph 1

☒ **B** Graph 2

☒ **C** Graph 3

☒ **D** Graph 4

(Total for question = 1 mark)

Q10.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

The halogenoalkane 2-bromo-2-methylbutane was hydrolysed with sodium hydroxide solution, NaOH(aq).
Which suggestion about the mechanism of this reaction is correct?

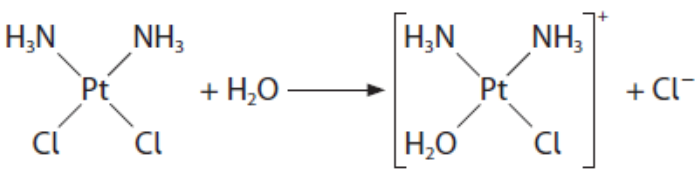
	Type of mechanism	Number of steps in mechanism
☐ **A**	S_N2	one
☐ **B**	S_N2	two
☐ **C**	S_N1	one
☐ **D**	S_N1	two

(Total for question = 1 mark)

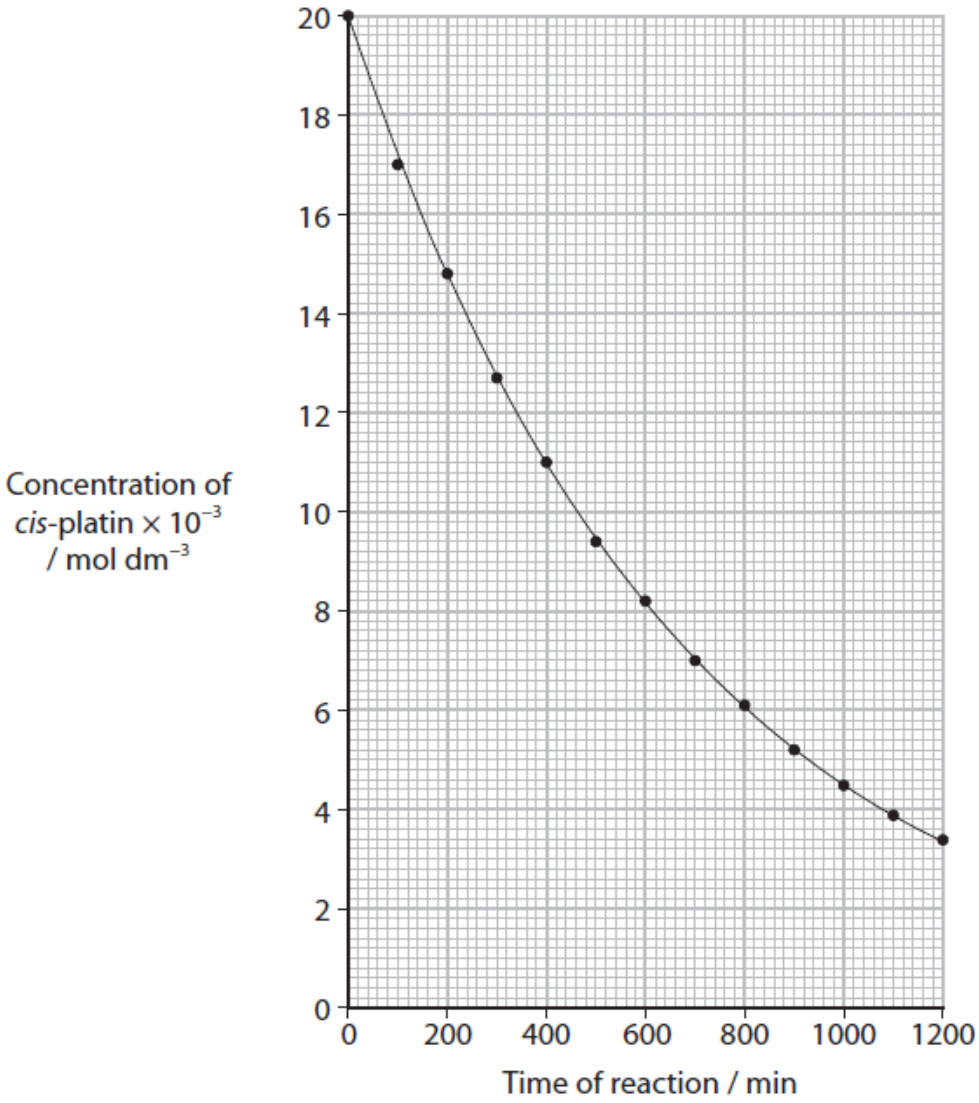
Q11.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The inorganic anti-cancer drug *cis*-platin, $Pt(NH_3)_2Cl_2$, is hydrolysed by water to make it active.
The reaction is



The hydrolysis is first order overall. The half-life can be found from a graph of the concentration of *cis*-platin against time.



The half-life of the reaction is

- ☒ **A** 430 min
- ☒ **B** 460 min
- ☒ **C** 590 min
- ☒ **D** 600 min

(Total for question = 1 mark)

Q12.

This question is about the hydrolysis of 2-bromobutane with aqueous sodium hydroxide at 298 K.

The equation for the reaction is:

$$CH_3CH_2CHBrCH_3 + OH^- \rightarrow CH_3CH_2CHOHCH_3 + Br^-$$

(a) The data shown were obtained in an experiment to investigate the kinetics of this reaction.

Experiment number	Initial concentration / mol dm^{-3}		Initial rate / mol dm^{-3} s^{-1}
	[$CH_3CH_2CHBrCH_3$]	[OH^-]	
1	0.100	0.100	1.01×10^{-3}
2	0.200	0.100	2.02×10^{-3}
3	0.100	0.200	1.01×10^{-3}

(i) Deduce the order of reaction with respect to 2-bromobutane and with respect to hydroxide ions. Justify your answers.

(2)

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(ii) Write the rate equation for the reaction using your answer to (a)(i).

(1)

(iii) Calculate the rate constant for Experiment 1.

Include units in your answer.

(2)

(b) Draw the mechanism for this reaction that is consistent with your rate equation.

Include curly arrows, and any relevant dipoles and lone pairs of electrons.

(3)

(Total for question = 8 marks)

Q13.

* The hydrolysis of halogenoalkanes by alkali is a nucleophilic substitution reaction.

$$RX + OH^- \rightarrow ROH + X^-$$

The mechanism of this reaction for primary halogenoalkanes is different from the mechanism for tertiary halogenoalkanes.

Describe how knowledge of the rate equations for the hydrolysis of halogenoalkanes provides evidence for the mechanisms of these reactions.

Curly arrow mechanisms are **not** required.

(6)

(Total for question = 6 marks)

Q14.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

Propanone reacts with iodine in the presence of a catalyst of dilute hydrochloric acid. The reaction occurs in aqueous solution.

$$CH_3COCH_3 + I_2 \rightarrow CH_3COCH_2I + HI$$

The rate equation for this reaction is

$$\text{rate} = k[CH_3COCH_3][H^+]$$

Which is a possible mechanism for the reaction?

☒ **A**

$CH_3COCH_3 + H^+ \rightleftharpoons CH_3C(\overset{+}{O}H)CH_3$ fast

$CH_3C(\overset{+}{O}H)CH_3 \rightarrow CH_3C(OH)=CH_2 + H^+$ slow

$CH_3C(OH)=CH_2 + I_2 \rightarrow CH_3COCH_2I + HI$ fast

☒ **B**

$CH_3COCH_3 + H^+ \rightleftharpoons CH_3C(\overset{+}{O}H)CH_3$ fast

$CH_3C(\overset{+}{O}H)CH_3 \rightarrow CH_3C(OH)=CH_2 + H^+$ fast

$CH_3C(OH)=CH_2 + I_2 \rightarrow CH_3COCH_2I + HI$ slow

☒ **C**

$CH_3COCH_3 \rightarrow CH_3COCH_2^- + H^+$ slow

$I_2 \rightarrow I^+ + I^-$ slow

$CH_3COCH_2^- + I^+ \rightarrow CH_3COCH_2I$ fast

☒ **D**

$I_2 \rightarrow I^+ + I^-$ slow

$CH_3COCH_3 + I^- \rightarrow CH_3COCH_2^- + HI$ slow

$CH_3COCH_2^- + I^+ \rightarrow CH_3COCH_2I$ fast

(Total for question = 1 mark)

Q15.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

The rate equation for a reaction is

$$\text{rate} = k[A]^2[B]^0$$

The initial rate of reaction is 9.0×10^{-5} mol dm^{-3} s^{-1} when [A] = 0.30 mol dm^{-3} and [B] = 0.20 mol dm^{-3}.

What is the value of the rate constant in dm^3 mol^{-1} s^{-1}?

☒ **A** 8.1×10^{-6}

☒ **B** 3.0×10^{-4}

☒ **C** 1.0×10^{-3}

☒ **D** 5.0×10^{-3}

(Total for question = 1 mark)

Mark Scheme

Q1.

Question Number	Answer	Mark
	The only correct answer is A (+38.8 kJ mol^{-1}) *B is not correct because the units are incorrect* *C is not correct because the gradient has been divided by R* *D is not correct because the gradient has been divided by R and the units are incorrect*	(1)

Q2.

Question number	Answer	Mark
	D proportion of particles with sufficient energy to react	1

Q3.

Q	Correct Answer	Mark
(a)	**The only correct answer is B** (68 mm) *A is incorrect as it is a factor of 10 to large* *C is incorrect as it is the distance moved by the amino acids* *D is incorrect as it is the expression for R_f has been inverted*	1

Q	Correct Answer	Mark
(b)	**The only correct answer is A** (argon) ***B*** *is incorrect as the carrier gas must be inert* ***C*** *is incorrect as the carrier gas must be inert* ***D*** *is incorrect as the carrier gas must be inert*	**1**

Q4.

Q	Correct Answer	Mark
	The only correct answer is C (– gradient x *R*) ***A*** *is incorrect the Arrhenius equation has been rearranged incorrectly* ***B*** *is incorrect as the gradient of the graph is negative, so this expression would give a negative value for an activation energy* ***D*** *is incorrect as the gradient of the graph is negative, so this expression would give a negative value for an activation energy*	**1**

Q5.

Question Number	Answer	Mark
	The only correct answer is C (quenching and titrating with acid) ***A*** *is incorrect because bromine is coloured* ***B*** *is incorrect because ions are produced during the reaction* ***D*** *is incorrect because carbon dioxide is a gas produced in the reaction*	(1)

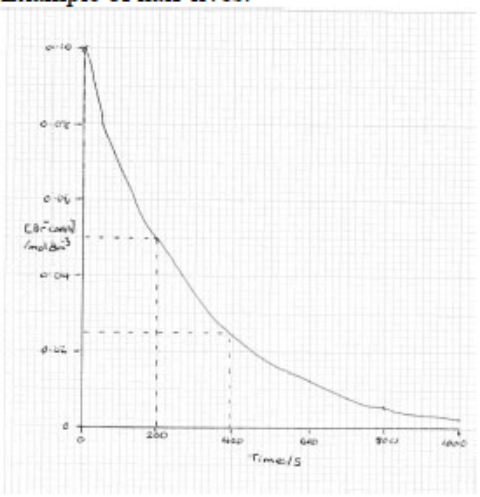
Q6.

Question Number	Answer	Mark
(a)	The only correct answer is **C** (flasks 1 and 4 only) *A is incorrect as flask 4 also contains only substances from the right-hand side of the equilibrium (HCl(aq) includes some water)* *B is incorrect as flask 1 also contains only substances from the right-hand side of the equilibrium* *D is incorrect as flasks 2 and 3 do not contain any ester*	1

Question Number	Answer	Mark
(b)	The only correct answer is **A** (the equilibrium reaction is slow) *B is incorrect as rapid hydrolysis would affect the position of the equilibrium* *C is incorrect as the acid is neutralized* *D is incorrect as although a buffer may form it does not affect the position of the ester equilibrium*	1

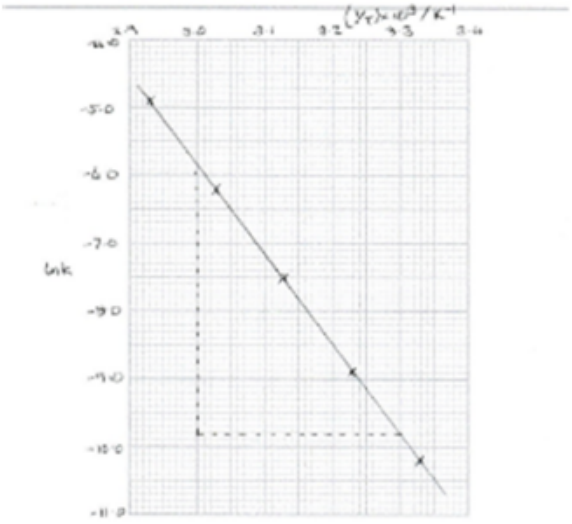
Q7.

Question Number	Ans	Additional Guidance	Mark
(a)	• substitution of values into expression for ΔS_{system} **(1)** • calculation of ΔS_{system} **(1)** • substitution of values into expression for $\Delta S_{surroundings}$ **(1)** • calculation of $\Delta S_{surroundings}$ **(1)** • calculation of ΔS_{total} **(1)**	Example of calculation: $\Delta S_{system} = (2 \times 95.9) + (3 \times 205.0) - (2 \times 149.2)$ Allow $191.8 + 615.0 - 298.4$ / $806.8 - 298.4$ $\Delta S_{system} = (+)508.4$ (J K^{-1} mol^{-1}) $\Delta S_{surroundings} = -\frac{(-67.2)}{298}$ $\Delta S_{surroundings} = (+)0.2255$ (kJ K^{-1} mol^{-1}) or $(+)225.5$ (J K^{-1} mol^{-1}) $\Delta S_{total} = 508.4 + 225.5 = (+)733.9$ (J K^{-1} mol^{-1}) or $(+)0.7339$ (kJ K^{-1} mol^{-1}) TE on calculated values for ΔS_{system} and $\Delta S_{surroundings}$ Do not award ΔS_{system} added to $\Delta S_{surroundings}$ in different units e.g. $508.4 + 0.2255 = 508.6255$ Ignore SF except 1 SF Units are not needed. Units in any order e.g. J mol^{-1} K^{-1} Penalise incorrect / incomplete units in ΔS_{total} but allow: e.g. J / mol/ K or J/mol.K mol^{-} and K^{-} in otherwise correct units Correct answer with no working scores (5)	(5)

Question Number	Answer	Additional Guidance	Mark
(b)(i)	• working for at least one half-life shown on graph (1) • values of two half-lives (1) • first order **and** because the half-lives are constant / the same / similar (1)	Example of half-lives:  half-lives may be written or clearly shown on graph first half-life = 200 s **and** second half-life = 200 s ± 20 s Allow 2nd half-life = 400 – 200 = 200 s Stand alone mark Do not award zero order / second order	(3)

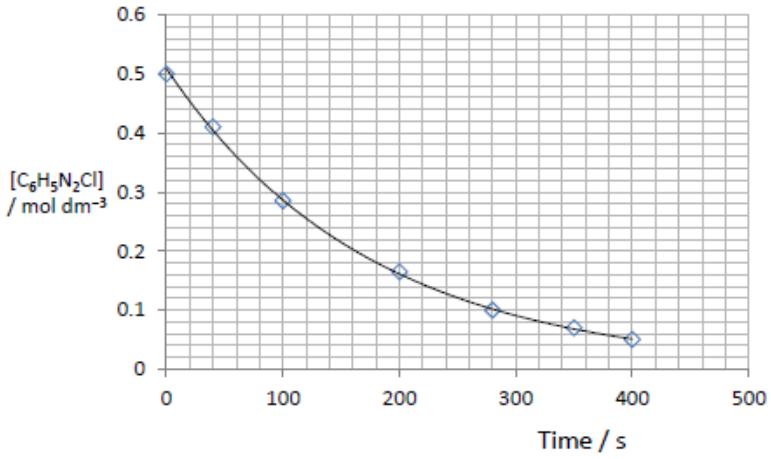
Question Number	Answer	Additional Guidance	Mark
(b)(ii)	An explanation that makes reference to the following points: • first order with respect to BrO_3^- ions **and** because in runs 1 and 2 as $[BrO_3^-]$ doubles (and $[H^+]$ is constant) the rate doubles (1) • in runs 1 and 3, as $[BrO_3^-]$ triples rate should triple (to 1.08×10^{-2}) and $[H^+]$ also doubles and rate increases by a factor of 4 (1) • so reaction is second order with respect to H^+ ions (1)	In M1 and M2, the working may be shown in the table Allow implied runs e.g. as $[BrO_3^-]$ doubles (and $[H^+]$ is constant), the rate doubles Allow correct alternative explanations using runs 2 and 3 and others e.g. $[BrO_3^-]$ triples, $[H^+]$ doubles and rate x 12 Do not award just $[H^+]$ doubles and rate x 4 with no mention of bromate ions Stand alone mark	(3)

Question Number	Answer	Additional Guidance	Mark
(b)(iii)	• rate equation (1) • units of k (1)	rate = $k[Br^-(aq)][BrO_3^-(aq)][H^+(aq)]^2$ TE on orders in (a)(i) and (ii) Allow species in any order / R for rate / K for k Ignore missing state symbols If no order given in (a)(i), allow rate equation with Br^- included or omitted $dm^9\ mol^{-3}\ s^{-1}$ Allow these in any order Allow $dm^9\ mol^{-3}\ s^-$ TE on rate equation	(2)

Question Number	Answer	Additional Guidance	Mark
(c)		Example of graph:  Example of gradient: $\frac{-9.8-(-5.85)}{3.3 \times 10^{-3} - 3.0 \times 10^{-3}} = -13167\ K$	(7)

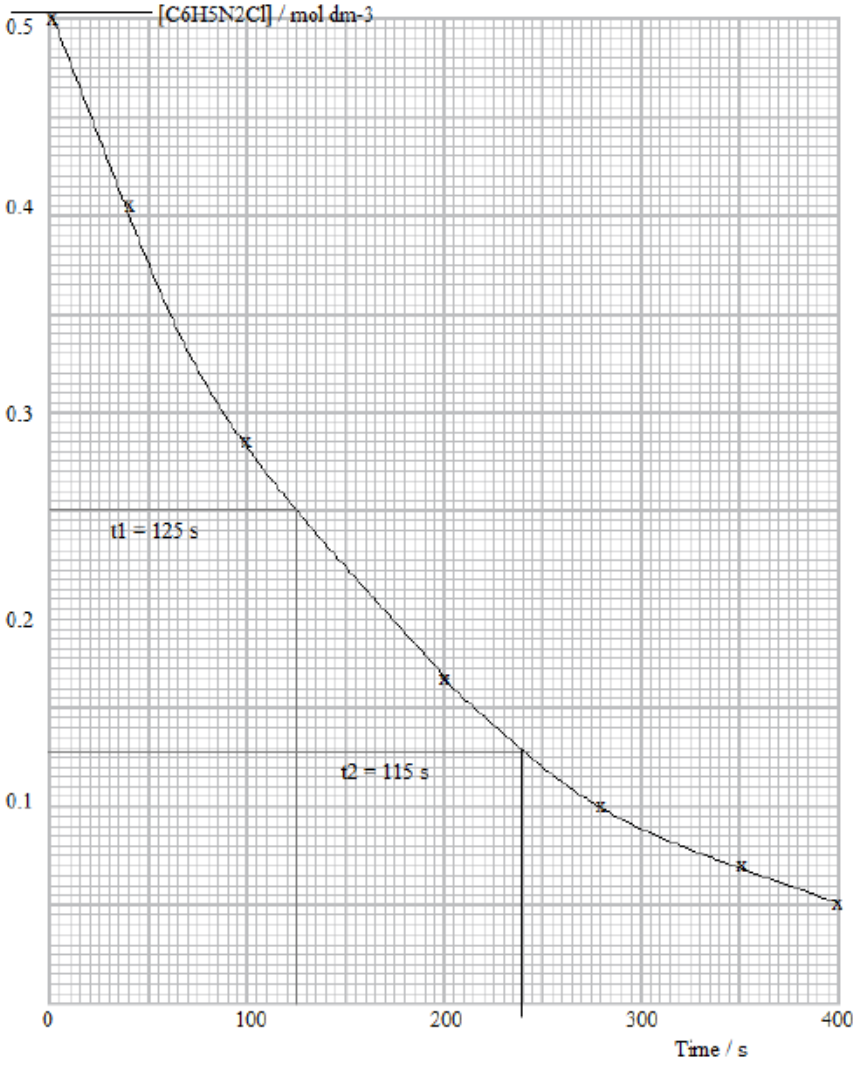
Question Number	Answer	Additional Guidance	Mark
(c)	• axes correct way around **and** suitable scale (1)	Points / line must cover at least half the grid in both directions ln *k* values must become more negative down the axis with negative signs shown Allow horizontal axis shown at bottom of graph	
	• both axes labelled **and** units for x axis (1)	y axis: ln k with no units on y axis **and** x axis: 0.0033 etc with (1/T) / K^{-1} **or** 3.3 etc with (1/T) / 10^{-3} K^{-1} **or** 3.3 x 10^{-3} etc with (1/T) / K^{-1} **or** 3.3 etc with (1/T) x 10^{3} / K^{-1} Brackets are not needed around 1/T	
	• all points plotted correctly **and** best-fit straight line (1)	Allow ± ½ square Allow line covering points provided it is straight Ignore extrapolation in either direction	
	• calculation of gradient (1)	This may be shown on the graph Allow gradient in the range (−)12800 to (−)13800 Allow gradient calculated from data in the table If gradient not evaluated, allow correct working	
	• sign and units of gradient (1)	Negative sign **and** units K Allow $1/K^{-1}$ for units Allow −12.8 to −13.8 kK for M4 and M5	
	• calculation of activation energy (1)	E_a = 13167 x 8.31 / 1000 = 109.418 Expected range 106 to 115 **or** 13167 x 8.31 = 109418 TE on gradient	
	• sign and corresponding units of activation energy (1)	+ 109.418 kJ mol^{-1} or +109418 J mol^{-1} Allow kJ mol^{-} or J mol^{-} Ignore missing + but do not award − sign Penalise 1 SF for gradient and E_a value once only	

Q8.

Q	Answer	Additional guidance	Mark
(a)(i)	An answer that makes reference to the following • sensible choice scale (to cover at least half the grid in both directions) **and** labelled axes with units on both axes (1) • All points given in table correctly plotted TE on **linear** axes used (1)	Example of graph Allow line  Allow any curve with all points within one square of the line Do not award a **clearly** point-to-point line Non-linear scale scores max (1) for M2 only Do not penalise punctuation errors, e.g. (mol dm^{-3}) for / mol dm^{-3} Allow seconds / sec / secs for 's'	3

	• any sensible (reasonably) smooth best fit curve (1)		

Question number	Answer	Additional guidance	Mark
(a)(ii)	• half-life / $t_{½}$ = 120 (s)	Allow 110 – 130 (s) for a correct curve Allow a value in this range given in (a)(iii) Do not award this mark unless there is some evidence of working on the graph in (a)(i) TE on the line drawn in (a)(i)	1

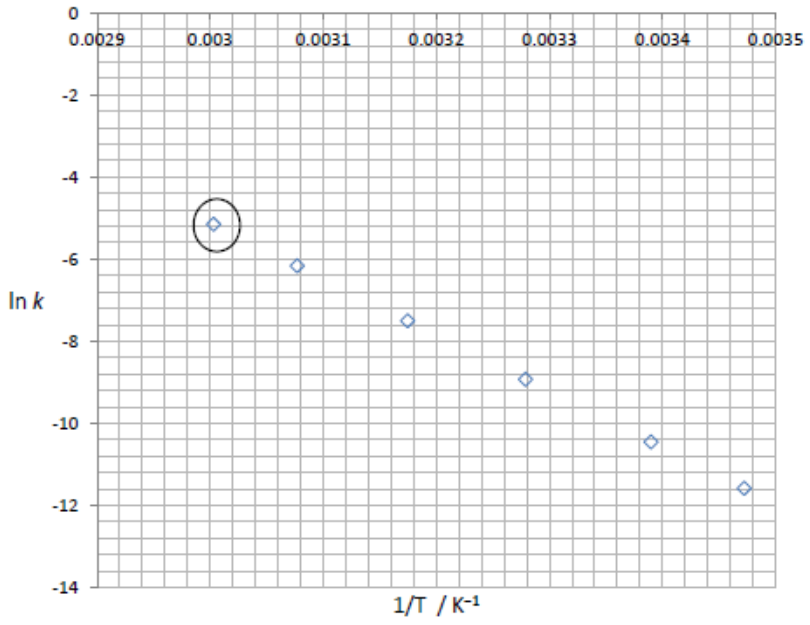


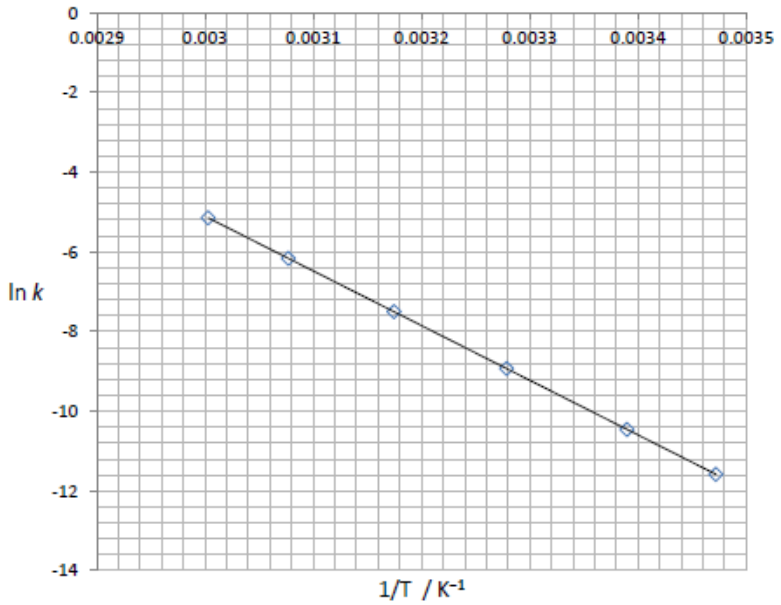
Example of graph using grid on the question paper

Accept use of one value of $t_{½}$

Question number	Answer	Additional guidance	Mark
(a)(iii)	• rearrangement of expression (1) • calculation of value **and** units (1)	Example of calculation $k = \ln 2 \div t_{½}$ $= 0.693 \div 120 = 5.7762 \times 10^{-3}$/ 0.0057762 s^{-1} Ignore SF except 1 SF TE on value from (a)(ii) No TE on incorrectly rearranged expression $t_{½} = 110$ gives k = 6.3013×10^{-3}/ 0.0063013 s^{-1} $t_{½} = 125$ gives k = 5.5452×10^{-3}/ 0.0055452 s^{-1} $t_{½} = 130$ gives k = 5.3319×10^{-3}/ 0.0053319 s^{-1}	2

Question number	Answer	Additional guidance	Mark
(b)(i)	• calculation of ln*k* (1) • calculation of 1/*T* (1)	Example of calculation $\ln 5.776 \times 10^{-3} = -5.154$ $1 \div 333 = 3.003 \times 10^{-3}$/ 0.003003 ($K^{-1}$) TE on (a)(iii) Plotted point can score both calculation marks Ignore incorrect or omitted units Ignore SF	2

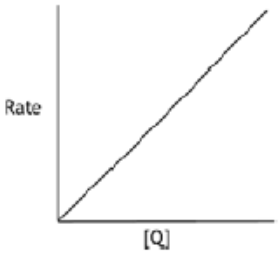
Question number	Answer	Additional guidance	Mark
(b)(ii)	• circled point correctly plotted on graph	Example of graph  TE on (b)(i)	1

Question number	Answer	Additional guidance	Mark
(b)(iii)	An answer that makes reference to the following • best-fit line drawn **(1)**	Example of graph with BFL  Do not award BFL mark unless line goes through **all** the points given in the question.	**3**

	• measures increase in ln*k* and increase in 1/T and used in correct expression **(1)** • final answer with sign **and** units **(1)**	<u>Example of calculation</u> Gradient = $\frac{-10.5-(-6.4)}{0.0034-0.0031}$ −13667 / −13700 / −14000 K ALLOW (−)13200—14200 on correct BFL or no BFL shown TE on BFL drawn No TE on incorrect gradient e.g. inverse grad can score BFL mark only Ignore SF except 1 SF	

Question number	Answer	Additional guidance	Mark
(b)(iv)	• identification and rearrangement of relationship **(1)** • evaluation of activation energy **(1)** • sign and units **(1)**	Example of calculation Grad = $-E_a/R$ and $-E_a$ = Grad x R $-E_a = -13667 \times R = -13667 \times 8.31$ =|113572| E_a = (+)113570 J mol^{-1} / (+)114000 J mol^{-1} Or E_a = (+)113.570 kJ mol^{-1} / (+)114 kJ mol^{-1} Allow (+)110000 J mol^{-1} — 118000 J mol^{-1} (from allowed range in (b)(iii) TE on (b)(iii) Sign on final value must be consistent with sign of gradient Ignore SF except 1 SF	**3**

Q9.

Question Number	Answer	Mark
	The only correct answer is **C**  *A is incorrect as it shows a 0 order reaction* *B is incorrect as it shows a 0 order reaction* *D is incorrect as the concentration of Q remains constant*	**1**

Q10.

Q	Correct Answer	Mark
	The only correct answer is D (S_N1 ; Two steps in mechanism) *A is incorrect as the halogenoalkane is tertiary so mechanism would be S_N1 which has two steps* *B is incorrect as although the mechanism has two steps the halogenoalkane is tertiary so mechanism would be S_N1* *C is incorrect as although the mechanism is S_N1, it would have two steps*	1

Q11.

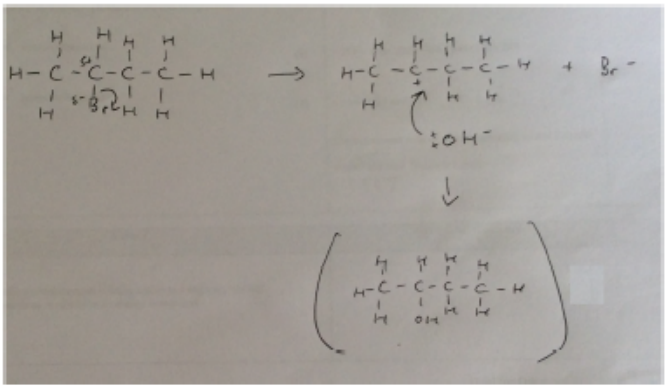
Question Number	Answer	Mark
	The only correct answer is B (460 mins) *A is incorrect because this value would be misreading the scale of the graph* *C is incorrect because this is the time to get half way to the final concentration on the graph* *D is incorrect because this is half the time of the reaction on the graph*	(1)

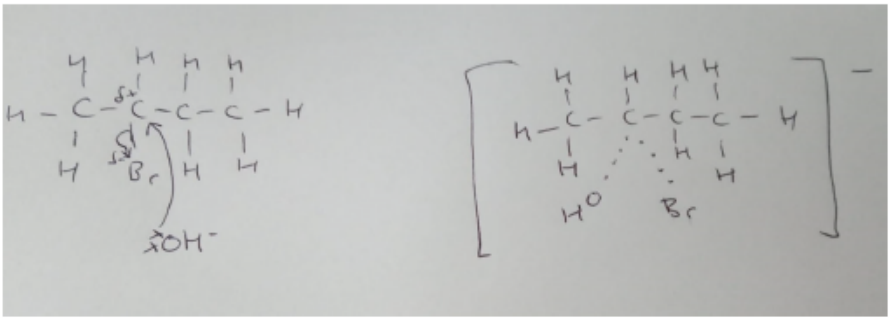
Q12.

Question Number	Answer	Additional Guidance	Mark
(a)(i)	An answer that makes reference to two of the following points: • 2-bromobutane: first order as doubling the concentration (in experiments 1 and 2 where OH^- is constant) the rate doubles **(1)** • hydroxide ions: zero order as doubling the concentration (in experiments 1 and 3 where 2-bromobutane is constant) the rate does not change **OR** hydroxide ions: zero order as doubling the concentration (in experiments 2 and 3) where the concentration of 2-bromobutane is halved the rate halves. **(1)**	Two correct orders with no or incorrect reasoning scores 1 Note the reasoning can be shown on the table	**(2)**

Question Number	Answer	Additional Guidance	Mark
(a)(ii)	• rate / r = k [C_4H_9Br]	TE on (i) Allow displayed or structural formulae Allow rate = k [C_4H_9Br]^1[OH^-]^0 Allow upper case K Allow reactants in any order Do not award round brackets	(1)

Question Number	Answer	Additional Guidance	Mark
(a)(iii)	An answer that makes reference to the following points: • correct calculation (1) • correct units (1)	Allow the calculation from any experiment Example of calculation from experiment 1 $1.01 \times 10^{-3} / 0.100 = 0.0101 / 1.01 \times 10^{-2}$ TE on (ii) Ignore SF s^{-1} Allow s^- TE on (ii)	(2)

Question Number	Answer	Additional Guidance	Mark
(b)	An answer that makes reference to the following points: • M1 dipole on C-Br **and** curly arrow from bond to Br (1) • M2 correct intermediate **and** Br^- (1) • M3 curly arrow going from the lone pair on OH^- to the C^+ (1) 	If mechanism is inconsistent with rate equation in (a)(ii) then 2 max (for fully correct mechanism) Allow skeletal formula Ignore final product	(3)

	Note if the calculated order is 2 or over allow full marks for S_N2 mechanism • M1 dipole on C-Br **and** curly arrow from bond to Br $^{\delta-}$ **(1)** • M2 curly arrow going from lone pair on OH^- to $C^{\delta+}$ **(1)** • M3 correct intermediate with both Br and OH attached with ------ and negative charge **(1)** 	Ignore final product	

Q13.

<table>
<tr><th>Question number</th><th>Answer</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td>*</td><td>This question assesses the student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><th></th><th>Number of marks awarded for structure of answer and sustained lines of reasoning</th></tr>
<tr><td>Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr>
</table></td><td>Guidance on how the mark scheme should be applied.

The mark for indicative content should be added to the mark for lines of reasoning. For example, a response with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).

If there were no linkages between the points, then the same indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

In general it would be expected that
5 or 6 indicative points would get 2 reasoning marks
3 or 4 indicative points would get 1 reasoning mark
0, 1 or 2 indicative points would get zero reasoning marks

If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).

Comment: Look for the indicative marking points first, then consider the mark for the structure of the answer and sustained line of reasoning</td><td>6</td></tr>
</table>

* cont	Indicative content		
	• **IP1**the rate equation for primary halogenoalkanes • **IP2** the rate equation for tertiary halogenoalkanes • **IP3** primary halogenoalkanes react by S_N2 • **IP4** and tertiary halogenoalkanes react by S_N1 • **IP5** for primary halogenoalkanes the slow step / RDS is when the compound reacts with hydroxide ions via a transition state • **IP6** for tertiary halogenoalkanes the slow step / RDS is when the compound forms a carbocation (in a step that only involves the halogenoalkane) Rate equations 2 IPs Identifying mechanism types 2 IPs Identifying rate determining / slow steps with transition state and carbocation 2 IPs	Rate = $k[RX][OH^-]$ for primary Rate = k[RX] for tertiary Allow other symbols for the halogenoalkanes Rate equations are required for IP1 and IP2 Allow equation indicating slow step $RX + OH^- \longrightarrow [HO\text{---}R\text{---}X]^-$ **and** slow /rate determining step ($\longrightarrow ROH + X^-$) Allow equation indicating slow step $RX \longrightarrow R^+ + X^-$ **and** slow /rate determining step Ignore curly arrows even if incorrect Ignore detailed mechanisms even if incorrect If S_N2 and S_N1 given the wrong way round deduct one indicative point	

Q14.

Question Number	Answer	Mark
	The only correct answer is A ($CH_3COCH_3 + H^+ \rightleftharpoons CH_3C(O^+H)CH_3$ fast, $CH_3C(O^+H)CH_3 \rightarrow CH_3C(OH)=CH_2 + H^+$ slow, $CH_3C(OH)=CH_2 + I_2 \rightarrow CH_3COCH_2I + HI$ fast) ***B** is not correct because the steps up to and including the slow step must include CH_3COCH_3 and H^+ ions and I_2 must only be involved in a fast step* ***C** is not correct because the steps up to and including the slow step must include CH_3COCH_3 and H^+ ions and I_2 must only be involved in a fast step* ***D** is not correct because the steps up to and including the slow step must include CH_3COCH_3 and H^+ ions and I_2 must only be involved in a fast step*	(1)

Q15.

Question Number	Answer	Mark
	The only correct answer is C (1.0×10^{-3}) ***A*** *is not correct because the initial rate and the rate constant have been mixed up* ***B*** *is not correct because [A] has not been squared* ***D*** *is not correct because [B] has been included*	**(1)**

Q1.

A student investigated the kinetics of the reaction between bromate(V) ions and bromide ions in acidic conditions.

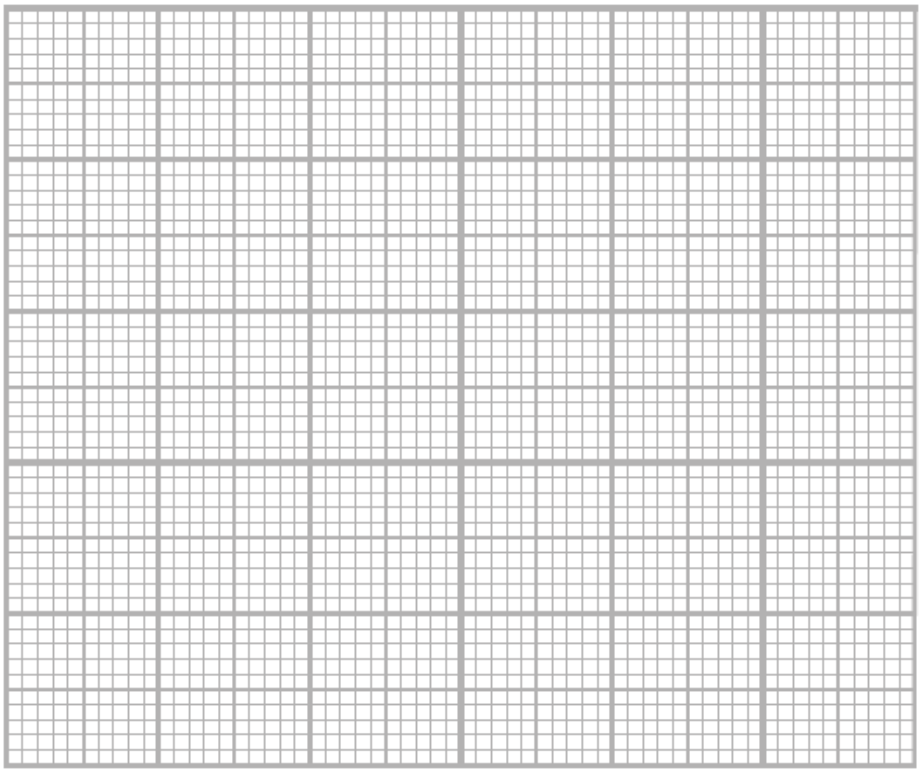
$$BrO_3^-(aq) + 5Br^-(aq) + 6H^+(aq) \rightarrow 3Br_2(aq) + 3H_2O(l)$$

(a) In the first experiment, the student measured the initial rate of the reaction at five different concentrations of bromate(V) ions, BrO_3^-. In each case, the initial concentrations of bromide ions and hydrogen ions were constant and in large excess. The results obtained are shown.

Initial concentration of bromate(V) ions / mol dm^{-3}	Initial rate of reaction / mol dm^{-3} s^{-1}
0.030	4.17×10^{-7}
0.060	8.34×10^{-7}
0.090	1.25×10^{-6}
0.120	1.67×10^{-6}
0.150	2.09×10^{-6}

(i) Use the results to plot a suitable graph that can be used to show that the reaction is first order with respect to bromate(V) ions.

(3)



(ii) State how your graph shows that the reaction is first order with respect to bromate(V) ions.

(1)

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(b) In the second experiment, the student determined the initial rates of the same reaction starting with different concentrations of the reactants.

Run	$[BrO_3^-]$ / mol dm^{-3}	$[Br^-]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	Initial rate of reaction / mol dm^{-3} s^{-1}
1	0.062	0.21	0.40	1.52×10^{-5}
2	0.31	0.21	0.20	1.90×10^{-5}
3	0.062	0.63	0.40	4.56×10^{-5}

(i) Use these results and your answer to (a) to deduce the orders with respect to Br^- ions and H^+ ions.

(2)

Br^- ions

.....

H^+ ions

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(ii) Write the rate equation for the reaction.

(1)

(iii) Use the results for Run 1 and your rate equation from (b)(ii) to calculate the value for the rate constant, k. Include units in your answer.

(3)

(c) The presence of bromate(V) ions in drinking water is harmful to humans. Bromate(V) ions can be converted to less harmful bromide ions by passing the water through palladium with a reducing agent.

Describe how a heterogeneous catalyst, such as palladium, increases the rate of a reaction.

(3)

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(Total for question = 13 marks)

Q2.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The rate of the reaction between two compounds, **Y** and **Z**, was investigated.
The results are shown.

Experiment	Initial concentration of **Y** / mol dm^{-3}	Initial concentration of **Z** / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.64	0.24	8.00×10^{-3}
2	0.64	0.48	3.20×10^{-2}
3	0.32	0.48	3.20×10^{-2}

What are the orders of reaction with respect to **Y** and **Z**?

	Order with respect to **Y**	Order with respect to **Z**
☒ **A**	0	1
☒ **B**	0	2
☒ **C**	1	1
☒ **D**	1	2

Use this space for any rough working. Anything you write in this space will gain no credit.

(Total for question = 1 mark)

Q3.

This question is about the kinetics of the reaction between nitrogen monoxide and oxygen.

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

The rate equation for the reaction is rate = $k[NO]^2[O_2]$

(a) Which statement is **not** correct?

(1)

☒ **A** the reaction is third order overall

☒ **B** the units of the rate of the reaction are mol dm^{-3} s^{-1}

☒ **C** the rate of the reaction increases when the pressure is increased

☒ **D** when the concentration of nitrogen monoxide doubles and the concentration of oxygen quadruples, the rate increases by a factor of 8

(b) What are the units of the rate constant, k, for this reaction?

(1)

☒ **A** dm^9 mol^{-3} s^{-1}

☒ **B** mol^3 dm^{-9} s^{-1}

☒ **C** mol^2 dm^{-6} s^{-1}

☒ **D** dm^6 mol^{-2} s^{-1}

(c) An experiment was carried out using 1.10×10^{-2} mol dm^{-3} of oxygen and some nitrogen monoxide.

The numerical value of the initial rate and rate constant were:

- initial rate = 3.20×10^{-3}
- rate constant, $k = 1.70 \times 10^3$

What was the initial concentration, in mol dm^{-3}, of the nitrogen monoxide used in the experiment?

(1)

☒ **A** 1.31×10^{-2}

☒ **B** 1.71×10^{-4}

☒ **C** 2.02×10^{-3}

☒ **D** 4.50×10^{-2}

(Total for question = 3 marks)

Q4.

The rate constant for the reaction to convert cyclopropane to propene was determined at five different temperatures.



The results are shown in the table.

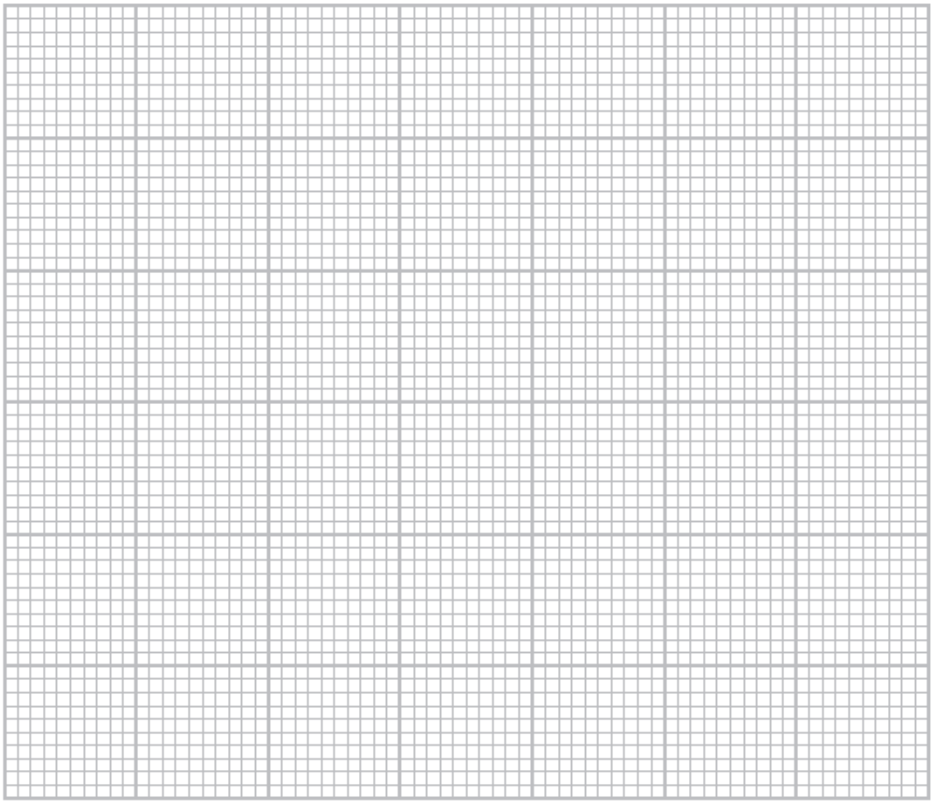
Temperature (T) / K	1 / Temperature ($1/T$) / K^{-1}	Rate constant (k) / s^{-1}	ln k
719	1.39×10^{-3}	2.49×10^{-5}	−10.60
746	1.34×10^{-3}	1.23×10^{-4}	−9.00
791	1.26×10^{-3}	1.66×10^{-3}	
840		1.83×10^{-2}	−4.00
889	1.12×10^{-3}	1.65×10^{-1}	−1.80

(a) (i) Complete the table.

(1)

(ii) Plot a graph of ln k against $1 / T$.

(3)



(iii) Use your graph to determine the activation energy, E_a, in kJ mol^{-1}.

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

The Arrhenius equation is

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant}$$

(3)

(b) The activation energy for many reactions is around +50 kJ mol^{-1}.

Given this information, comment on your value for E_a.

(2)

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(c) Explain the trend in the value of the rate constant k as the temperature increases.

(3)

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(Total for question = 12 marks)

Q5.

Which diagram shows the mechanism for the second order reaction between 1-bromoethane and potassium hydroxide in aqueous solution?

Diagram 1

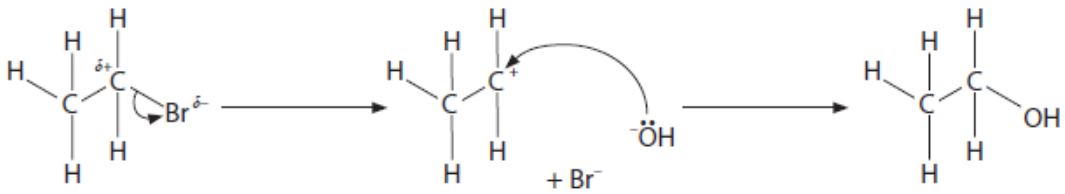


Diagram 2

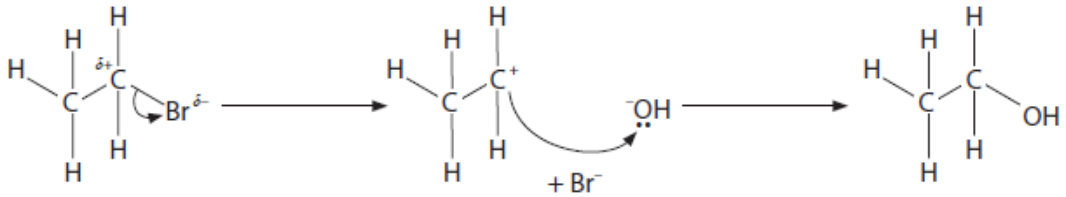


Diagram 3

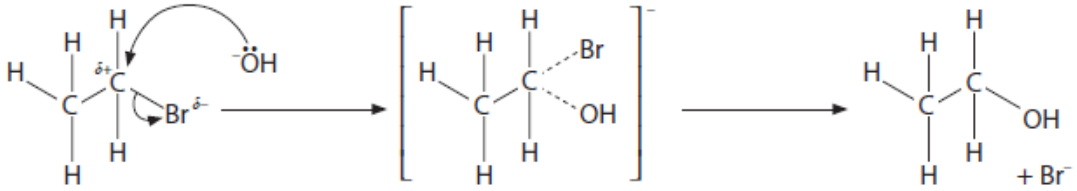
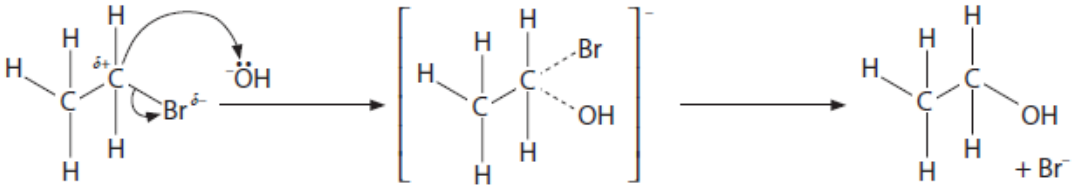


Diagram 4



☒ **A** Diagram 1

☒ **B** Diagram 2

☒ **C** Diagram 3

☒ **D** Diagram 4

(Total for question = 1 mark)

Q6.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

Nitrogen monoxide and hydrogen react together to form nitrogen and water.

$$2NO + 2H_2 \rightarrow N_2 + 2H_2O$$

The steps in the mechanism of the reaction are

Step 1	$2NO \rightleftharpoons N_2O_2$	fast
Step 2	$N_2O_2 + H_2 \rightarrow N_2O + H_2O$	slow
Step 3	$N_2O + H_2 \rightarrow N_2 + H_2O$	fast

Which statement about the reaction is correct?

☒ **A** Step 3 is the rate determining step and the overall order is 2

☒ **B** Step 3 is the rate determining step and the overall order is 4

☒ **C** Step 2 is the rate determining step and the overall order is 2

☒ **D** Step 2 is the rate determining step and the overall order is 3

(Total for question = 1 mark)

Q7.

Answer the questions with a cross in the boxes you think are correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Propanone reacts with iodine in acidic solution.

$$CH_3COCH_3(aq) + I_2(aq) \rightarrow CH_3COCH_2I(aq) + H^+(aq) + I^-(aq)$$

The rate equation for the formation of iodopropanone is found to be

$$\text{rate} = k[CH_3COCH_3(aq)][H^+(aq)]$$

(a) Which of the following is true?

(1)

☒ **A** the units for the rate constant are $dm^3\,mol^{-1}\,s^{-1}$

☒ **B** the reaction is a first order reaction overall

☒ **C** the units for the rate are $dm^3\,mol^{-1}\,s^{-1}$

☒ **D** doubling the concentrations of propanone and of iodine quadruples the rate

(b) Which of the following is **not** true?

(1)

☒ **A** the reaction rate increases if the temperature is raised

☒ **B** the rate constant increases if the temperature is raised

☒ **C** the addition of a small amount of sodium hydroxide decreases the reaction rate

☒ **D** the rate is unchanged when the hydrogen ion concentration is doubled

Use this space for any rough working. Anything you write in this space will gain no credit.

(Total for question = 2 marks)

Q8.

The mechanism for the rapid decomposition of hydrogen peroxide, H_2O_2, in the presence of iodide ions, is:

$$H_2O_2 + I^- \rightarrow IO^- + H_2O \qquad \text{equation 1}$$

$$H_2O_2 + IO^- \rightarrow I^- + H_2O + O_2 \qquad \text{equation 2}$$

(a) Write the overall equation for the reaction and hence state the role of the iodide ions.

(2)

.....

.....

(b) In further experiments, a student calculated the rate constant for the decomposition of hydrogen peroxide at two different temperatures.

Temperature/°C	Rate constant (k) / $dm^3\ mol^{-1}\ s^{-1}$
22.0	4.90×10^{-4}
47.0	2.92×10^{-3}

The rate constant (k) is related to the temperature, T, (in Kelvin) by the following equation:

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant} \qquad R = 8.31\,J\,K^{-1}\,mol^{-1}$$

Use the data in the table to calculate the activation energy, E_a, for the reaction by a non-graphical method.
Give your answer in kJ mol^{-1} and to an appropriate number of significant figures.
Include a sign in your answer.

(4)

(c) If acid conditions are used, the decomposition of hydrogen peroxide proceeds by a different mechanism. The equation for this reaction is:

$$H_2O_2 + 2I^- + 2H^+ \rightarrow I_2 + 2H_2O$$

This reaction is first order with respect to both iodide ions and hydrogen peroxide.

The progress of this reaction is usually followed by adding a fixed quantity of sodium thiosulfate

solution and a little starch solution to the reaction mixture, then timing the appearance of a blue-black colour. This is known as a clock reaction.

(i) Explain the formation of the blue-black colour and why its appearance is delayed.

(3)

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(ii) Although the oxidation of thiosulfate ions ($S_2O_3^{2-}$) by hydrogen peroxide is thermodynamically favourable, it does not take place in this clock reaction.
Suggest a reason for this.

(1)

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(Total for question = 10 marks)

Q9.

Answer the questions with a cross in the boxes you think are correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The decomposition of ammonia is catalysed by tungsten metal.

$$2NH_3(g) \xrightarrow{\text{tungsten}} N_2(g) + 3H_2(g)$$

This reaction has zero order kinetics.

(a) What is the rate equation for this reaction?

(1)

☒ **A** rate = k

☒ **B** rate = $k[NH_3]$

☒ **C** rate = $k[NH_3]^2$

☒ **D** rate = $k[N_2][H_2]^3$

(b) What are the units of the rate constant, k, for this zero order reaction?

(1)

☒ **A** no units

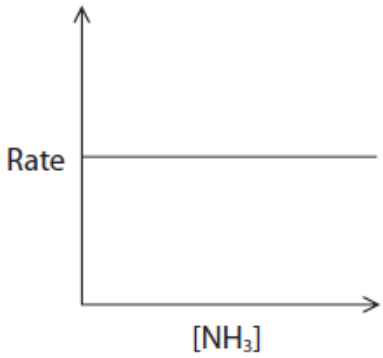
☒ **B** s^{-1}

☒ **C** mol dm^{-3} s^{-1}

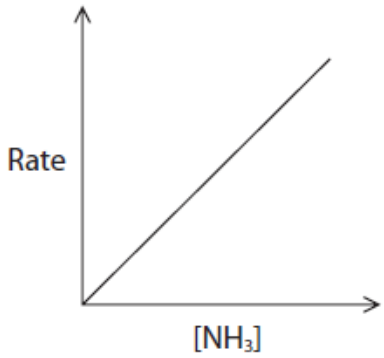
☒ **D** dm^3 mol^{-1} s^{-1}

(c) Which of these graphs represents this zero order reaction?

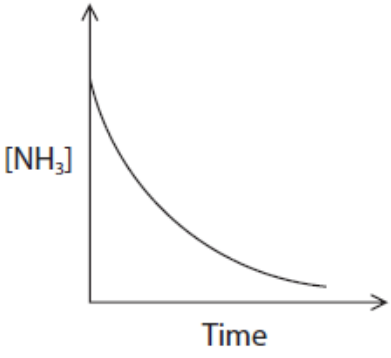
(1)



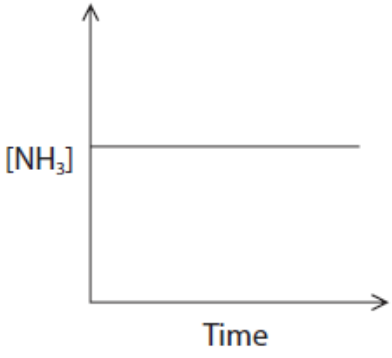
☒ **A**



☒ **B**



☒ **C**



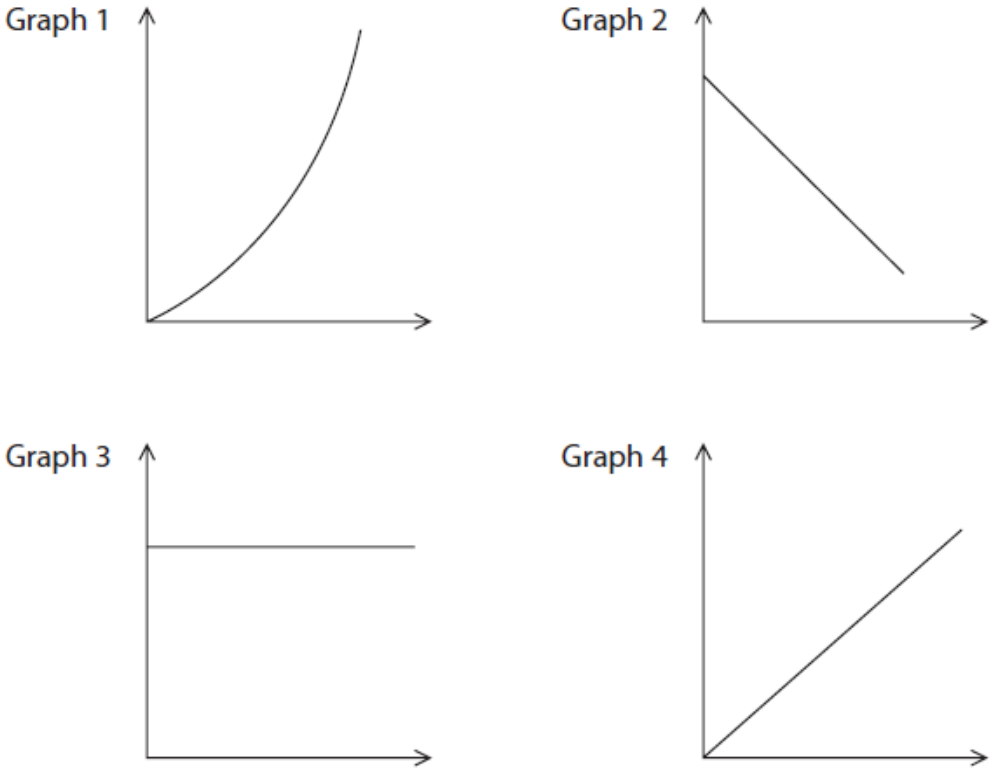
☒ **D**

(Total for question = 3 marks)

Q10.

Answer the questions with a cross in the boxes you think are correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Four graphs are shown.



(a) Which graph shows the rate of reaction on the vertical axis plotted against concentration of the reactant on the horizontal axis for a **zero** order reaction?

(1)

☒ **A** Graph 1

☒ **B** Graph 2

☒ **C** Graph 3

☒ **D** Graph 4

(b) Which graph shows the rate of reaction on the vertical axis plotted against concentration of the reactant on the horizontal axis for a **first** order reaction?

(1)

☒ **A** Graph 1

☒ **B** Graph 2

☒ **C** Graph 3

☒ **D** Graph 4

(Total for question = 2 marks)

Q11.

For each question, select one answer from A to D and put a cross in the box ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Propanone reacts with iodine in both acidic and alkaline conditions.

(a) The products of the reactions under the stated conditions include

(1)

	Acidic conditions	Alkaline conditions
☒ **A**	CH_3I	CH_3COO^-
☒ **B**	CH_3COCI_3	CH_3COO^-
☒ **C**	CH_3COCH_2I	CH_3I
☒ **D**	CH_3COCH_2I	CHI_3

(b) The rate equation for the reaction between propanone and iodine in acidic conditions is

$$\text{rate} = k[H^+][CH_3COCH_3]$$

The reaction was carried out at two different pH values, all other conditions remaining unchanged.

In the first reaction pH = 2.0

In the second reaction the rate was found to be $\frac{1}{3}$ of the original value.

What was the pH of the second reaction, to 1 decimal place?

(1)

☒ **A** 0.7

☒ **B** 1.5

☒ **C** 2.5

☒ **D** 2.7

(Total for question = 2 marks)

Q12.

Answer the questions with a cross in the boxes you think are correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Propanone reacts with iodine in the presence of a sulfuric acid catalyst.

$$CH_3COCH_3(aq) + I_2(aq) \rightarrow CH_3COCH_2I(aq) + HI(aq)$$

(a) Which method would be most suitable for following this reaction?

(1)

☒ **A** colorimetry

☒ **B** timing how long the solution takes to go cloudy

☒ **C** quenching and titrating with an acid

☒ **D** quenching and titrating with starch solution

(b) The rate equation for this reaction is:

$$\text{rate} = k[H^+][CH_3COCH_3]$$

Two experiments were carried out. In both experiments the concentration of propanone and iodine remained the same but the concentration of the sulfuric acid was changed.

The initial rate in the first experiment was three times faster than the initial rate in the second experiment.

In the first experiment the initial pH was 1.50

What is the initial pH in the second experiment?

(1)

☒ **A** 1.02

☒ **B** 1.98

☒ **C** 2.28

☒ **D** 4.50

Use this space for any rough working. Anything you write in this space will gain no credit.

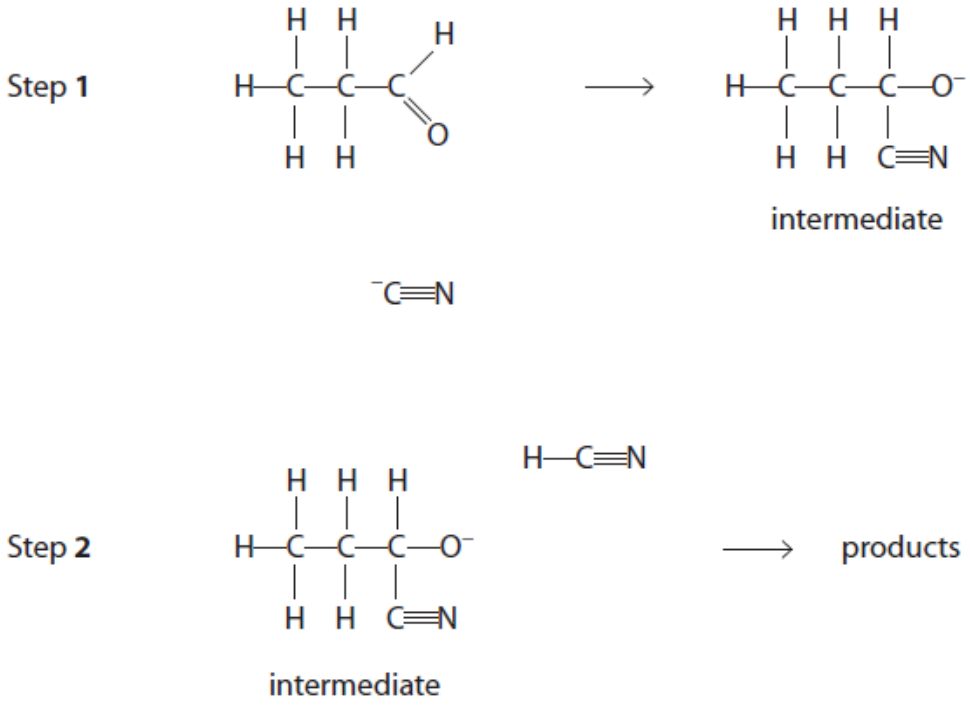
(Total for question = 2 marks)

Q13.

Propanal reacts very slowly with HCN at 298 K. To increase the rate of reaction potassium cyanide, KCN, is added.

(a)(i) Complete the mechanism for this reaction by adding curly arrows, and relevant lone pairs and dipoles to Step **1** and Step **2**.

(4)



(ii) Explain why the reaction between propanal and HCN in the absence of KCN is very slow, referring to the value of K_a. No calculation is required.

[For HCN, $K_a = 4.9 \times 10^{-10}$ mol dm^{-3}]

(2)

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(iii) KCN is a **homogeneous catalyst** in this reaction.

Justify this description by referring to the mechanism.

(2)

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(b) The organic products of this reaction are enantiomers.

Draw the three-dimensional structures of these enantiomers.

(2)

(Total for question = 10 marks)

Q14.

Solid vanadium(V) oxide catalyses the equilibrium shown.

$$2SO_2(g) + O_2(g) \leftrightarrow 2SO3(g) \qquad \Delta H = -196 \text{ kJ mol}^{-1}$$

Which statement is correct?

☒ **A** vanadium(V) oxide is a homogeneous catalyst

☒ **B** decreasing the pressure would increase the equilibrium yield of sulfur trioxide

☒ **C** increasing the surface area of the catalyst would increase the equilibrium yield of sulfur trioxide

☒ **D** decreasing the temperature would increase the equilibrium yield of sulfur trioxide

(Total for question = 1 mark)

Q15.

The halogenoalkane, 2-bromobutane, can be hydrolysed using aqueous sodium hydroxide.

Which technique can be used to follow the progress of this reaction?

(1)

☒ **A** colorimetry

☒ **B** measurement of gas volume change

☒ **C** measurement of mass change

☒ **D** titration of quenched samples

(Total for question = 1 mark)

Q16.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The equation shows the hydrolysis of a bromoalkane.

$$RBr + OH^- \rightarrow ROH + Br^-$$

The rate equation is rate = k[RBr]

RBr is most likely to be

☒ **A** bromomethane

☒ **B** 2-bromopropane

☒ **C** 1-bromo-2-methylpropane

☒ **D** 2-bromo-2-methylpropane

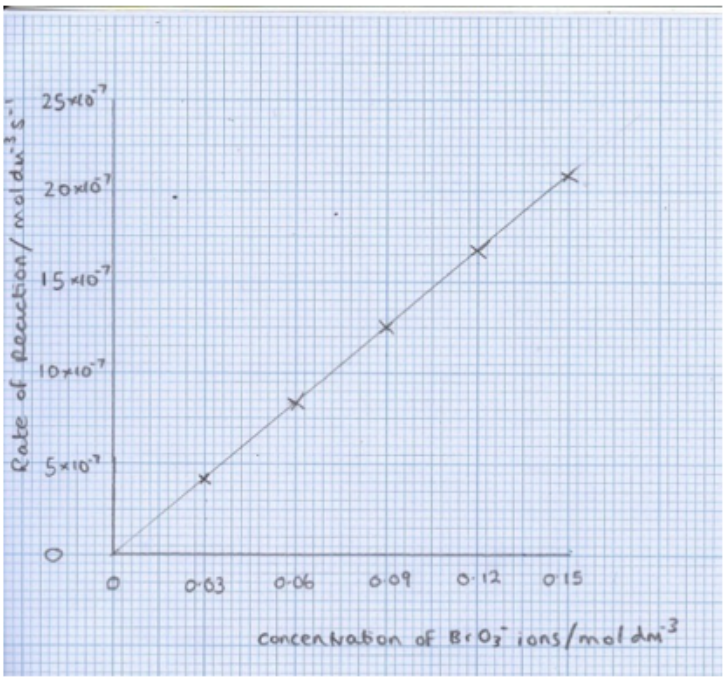
(Total for question = 1 mark)

Mark Scheme

Q1.

Q	Acceptable Answers	Additional Guidance	Mark
(a)(i)	• rate against concentration graph with axes labelled, inc. units **(1)** • suitable scale chosen including the origin **(1)** • all points plotted correctly and straight line of best fit. **(1)**	Do not award M1 if axes are the other way around Points cover at least half available space in both directions Allow ±½ a square Allow if line does not extend to the origin Do not award M3 if scale is non-linear	3

Allow $[BrO_3^-]$ / mol dm^{-3}
Ignore 'initial'



Q	Acceptable Answers	Additional Guidance	Mark
(a)(ii)	• justification of first order	(First order with respect to BrO_3^-) as straight line (through origin / 0,0) Allow line with constant gradient Allow rate is (directly) proportional to concentration Allow use of data from graph to justify order Do not award 'constant half life'	1

Q	Acceptable Answers	Additional Guidance	Mark
(b)(i)	• deduce order wrt Br^- ions **(1)** • deduce order wrt H^+ ions **(1)**	1st order 2nd order	2

Q	Acceptable Answers	Additional Guidance	Mark
(b)(ii)	• rate equation shown	rate = $k[BrO_3^-][Br^-][H^+]^2$ Allow TE from (b)(i)	1

Q	Acceptable Answers	Additional Guidance	Mark
(b)(iii)	• rearrangement of rate equation **(1)** • evaluation of k **(1)** • units for k **(1)**	Example of calculation k = rate/$[BrO_3^-][Br^-][H^+]^2$ / $k = 1.52 \times 10^{-5} \div (0.062 \times 0.21 \times 0.4^2)$ 7.2965×10^{-3} ignore SF except 1SF M1 can be subsumed within award of M2 $dm^9\ mol^{-3}\ s^{-1}$ allow in any order Correct answer with no working scores (3) TE on (b)(ii) Allow use of data from Run 2 or Run 3	3

Q	Acceptable Answers	Additional Guidance	Mark
(c)	An answer that makes reference to: • reactants **ad**sorb onto palladium/catalyst surface **(1)** • this weakens bonds in reactants **(1)** • products then desorb (from catalyst surface) **(1)**	Allow bromate ((V)) ions for reactants Allow 'bond/bind onto catalyst surface' Do not award a**b**sorb Ignore comments related to orientation Allow 'products de-adsorb' / products released (from catalyst surface) If no other mark is awarded allow one for: reaction follows an alternative pathway / route / mechanism of lower activation energy	**3**
(Total for Question = 13 marks)			

Q2.

Question Number	Answer	Mark
	The only correct answer is B (0 2) *A is incorrect because experiments 1 and 2 show the order for Z is 2* *C is incorrect because in experiments 3 and 2 doubling the concentration of Y results in no change in the rate, so Y is order 0.* *D is incorrect because in experiments 1 and 3 doubling the concentration of Z results in 4x the rate, so halving the concentration of Y makes no difference to rate so is order 0.*	(1)

Q3.

Question Number	Answer	Mark
(a)	The only correct answer is **D** (when the concentration of nitrogen monoxide doubles and the concentration of oxygen quadruples, the rate increases by a factor of 8) *A is not an incorrect statement as the overall order is 3* *B is not an incorrect statement as the rate can be measured in units of mol dm^{-3} s^{-1}* *C is not an incorrect statement as increasing the pressure does increase the rate of the reaction*	1

Question Number	Answer	Mark
(b)	The only correct answer is **D** (dm^6 mol^{-2} s^{-1}) *A is incorrect as these are the units for a fourth overall order rate equation* *B is incorrect as the exponent values are incorrect* *C is incorrect as the signs on the exponent values for mol and dm are incorrect.*	1

Question Number	Answer	Mark
(c)	The only correct answer is **A** (1.31×10^{-2}) *B is incorrect as it is the value for $[NO]^2$* *C is incorrect as the values for $[O_2]$ and rate are the wrong way around in the calculation, and the square root of the calculated value has not been determined* *D is incorrect as the values for $[O_2]$ and rate are the wrong way around in the calculation*	1

Q4.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a) (i)	• Calculation of $1/T$ value 1.19×10^{-3} **and** • Calculation $\ln k$ value -6.40 (1)	Both values must be given to 3sf.	1

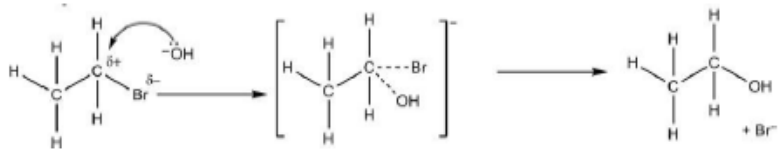
Question Number	Acceptable Answers	Additional Guidance	Mark
18(a)(ii)	**M1** Axes correct way round and labelled (1) **M2** Suitable scale with points covering at least half the axes in both directions (1) **M3** All points plotted (± ½ square), **and** straight line of best fit (1)	If numbers used on x-axis are without the power of ten allow x 10^3 or 10^{-3} on the axis. Do not award M1 if units given for ln k on y-axis Do not award small "t" for "T" Ignore y-axis with increasing negative values going upwards. COMMENT: If wrong columns plotted allow M2 only	3

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)(iii)	M1 Calculation of gradient with sign, in the range -34200 to -31200 (1) M2 Units of gradient is K (1) M3 Calculation of activation energy (1)	Do not award positive gradient. Allow gradient as a fraction Example of calculation: (32700 x 8.31) / 1000 = (+)272 (kJ mol^{-1}) Allow any answer between (+)259 and 284 Allow answer in J mol^{-1} if units given Allow TE from M1 if Ea is positive. Ignore SF other than 1SF Do not award negative Ea	3

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)	The value is large, **Either** as a lot of energy is required (1) so the reactant is kinetically stable / rate of reaction is low (1) **Or** as a lot of energy is required (1) to break the strong C-C bonds in cyclopropane (1) **Or** as a lot of energy is required to break the strong C-C bonds in cyclopropane (1) so the reaction requires very high temperatures (1)	Comment – alternative approach Allow TE from (a)(iii) for a small positive value (less than 50); the value is small so not much energy is required (1) the bonds in cyclopropane are strained/ C-C-C bond angle is 60◦ rather than 109.5◦ (1) Ignore any references to catalysts	2

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)	As T increases k increases (rapidly) (1) As the (average) energy of molecules / particles increases (1) So a greater proportion of / more collisions have energy ≥ activation energy / (1)	Ignore any reference to equilibrium constant Ignore so a greater proportion of collisions are successful	3

Q5.

Question Number	Answer	Mark
	The only correct answer is **C** Diagram 3  *A is incorrect as it shows a primary halogenoalkane forming a carbocation* *B is incorrect as it shows a primary halogenoalkane forming a carbocation and the electrons are moving to a lone pair in the second step* *D is incorrect as the electrons are moving to a lone pair in the first step*	1

Q6.

Q	Correct Answer	Mark
	The only correct answer is D (Step 2 is the rate determining step, the overall order is 3) ***A** is incorrect as Step 3 is fast* ***B** is incorrect as Step 3 is fast* ***C** is incorrect as the overall order is 3*	1

Q7.

Question Number	Answer	Mark
(a)	**The only correct answer is A (the units for the rate constant are $dm^3\ mol^{-1}\ s^{-1}$)** *B is incorrect because the reaction is second order overall* *C is not correct because the units of rate are always mol dm^{-3} s^{-1}* *D is not correct because the rate would double as iodine is zero order*	(1)

Question Number	Answer	Mark
(b)	**The only correct answer is D** (the rate is unchanged when the hydrogen ion concentration is doubled) *A is incorrect because the rate of reaction does increase with temperature* *B is incorrect because the rate constant depends on the temperature and increases as temperature rises* *C is not correct because sodium hydroxide would neutralise some of the $[H^+]$ catalyst so change rate*	(1)

Q8.

Question number	Answer		Additional guidance	Mark
(a)	• $2H_2O_2 \rightarrow 2H_2O + O_2$ • iodide ions act as a catalyst (as they don't appear in the overall equation)	(1) (1)	Ignore state symbols even if incorrect	2

Question number	Answer		Additional guidance	Mark
(b)			Example of calculation:	4
	• converts both temperatures from °C to K	(1)	22.0 °C = 295.0 K 47.0 °C = 320.0 K	
	• correct subtraction	(1)	$\ln\left(\frac{K_1}{K_2}\right) = -\frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$	
	• substitute numbers in equation correctly	(1)	$\ln\left(\frac{4.90 \times 10^{-4}}{1.07 \times 10^{-3}}\right) = -\frac{E_a}{8.31}\left(\frac{1}{295} - \frac{1}{320}\right)$	
	• correct value of E_a	(1)	(+)56.(0) (kJ mol^{-1}) Sign and final answer to 2 or 3 SF Incorrect units loses MP4 Correct answer with no working scores 4	

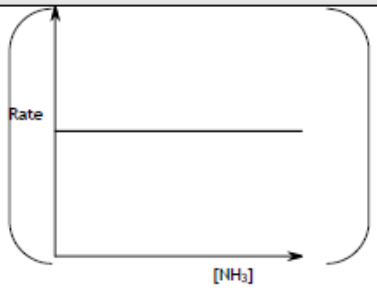
Question number	Answer	Additional guidance	Mark
(c)(i)	An explanation that makes reference to the following points: • (blue-black colour is) product of starch-iodine reaction (1) • the iodine produced reacts (rapidly) with the thiosulfate ions (to reform iodide ions) (1) • when all of the thiosulfate has reacted, the blue-black colour appears. (1)		3

Question number	Answer	Additional guidance	Mark
(c)(ii)	• the reaction (between thiosulfate and hydrogen peroxide) is slow	Allow reaction has high E_a	1

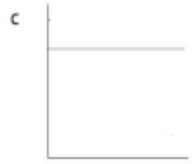
Q9.

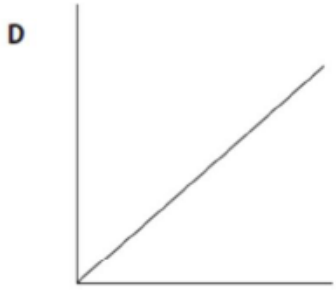
Question number	Answer	Mark
(a)	**The only correct answer is A** (rate = k) *B* *is incorrect because this is a first order rate equation* *C* *is incorrect because this is a second order rate equation* *D* *is incorrect because this shows overall order four and refers to the reverse reaction*	(1)

Question number	Answer	Mark
(b)	**The only correct answer is C** (mol dm^{-3} s^{-1}) *A* *is incorrect because rate constants always have units* *B* *is incorrect because these are the units of a first order rate constant* *D* *is incorrect because these are the units of a second order rate constant*	(1)

Question number	Answer	Mark
(c)	**The only correct answer is A**  *B* *is incorrect because this graph shows a first order reaction* *C* *is incorrect because this graph shows a first order reaction* *D* *is incorrect because this graph shows no reaction occurring*	(1)

Q10.

Question Number	Answer	Mark
(a)	**The only correct answer is C** (Graph 3)  *A is not correct because it is a rate v concentration graph for a second order reaction* *B is not correct because it is a concentration v time graph for a zero order reaction* *D is not correct because it is a rate v concentration graph for a first order reaction*	(1)

Question Number	Answer	Mark
(b)	**The only correct answer is D** (Graph 4)  *A is not correct because it is a graph of rate against concentration for a second order reaction* *B is not correct because it is a graph of concentration against time for a zero order reaction* *C is not correct because it is a graph of rate of reaction against concentration of the reactant for a zero order reaction*	(1)

Q11.

Question Number	Correct Answer	Mark
(a)	**The only correct answer is D** (CH_3COCH_2I CHI_3) ***A*** *is incorrect because* CH_3I *is not formed in acidic conditions* ***B*** *is incorrect because* CH_3COCI_3 *is not formed in acidic conditions* ***C*** *is incorrect because* CH_3I *is not formed in alkaline conditions*	(1)

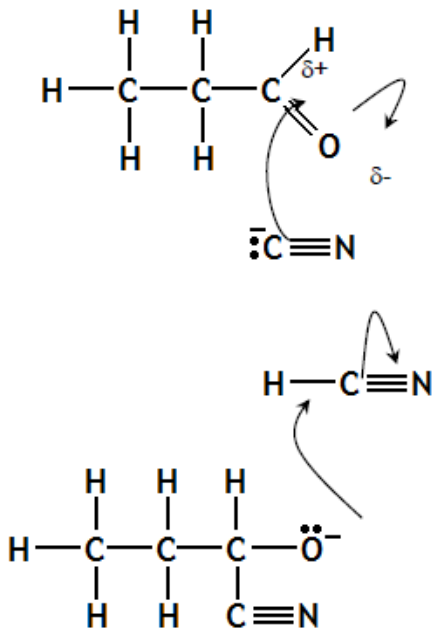
Question Number	Correct Answer	Mark
(b)	**The only correct answer is C** (2.5) ***A*** *is incorrect because the value of the pH has been divided by 3* ***B*** *is incorrect because the concentration of H^+ ions has been multiplied by 3 rather than divided* ***D*** *is incorrect because this value is adding 1/3 of 2 onto 2*	(1)

Q12.

Question Number	Answer	Mark
(a)	**The only correct answer is A** (colorimetry) ***B*** *is not correct because the solution would not go cloudy* ***C*** *is not correct because there is no base to titrate against* ***D*** *is not correct because starch is an indicator and would immediately turn blue-black*	(1)

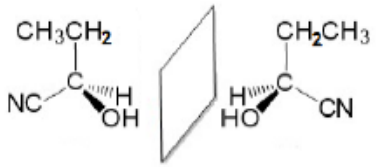
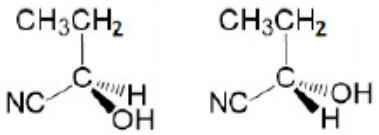
Question Number	Answer	Mark
(b)	**The only correct answer is B** (1.98) ***A*** *is not correct because the concentration of the acid has been increased three times* ***C*** *is not correct because the concentration of the acid has been decreased six times* ***D*** *is not correct because the pH has been multiplied by three*	(1)

Q13.

Question Number	Answer	Additional Guidance	Mark
(a)(i)	An answer that makes reference to the following points: Step 1 • lone pair of electrons on C of C≡N • curly arrow from anywhere on the C of C≡N to C in propanal including the charge • curly arrow from C=O bond to or just beyond O • dipole on C=O Step 2 • lone pair on O in intermediate Step 1 or Step 2 • curly arrow from the O (or minus charge) of intermediate to H of H-C≡N • curly arrow from H-C bond to C of H-C≡N	 All 7 points scores 4 marks 5 or 6 points scores 3 marks 3 or 4 points scores 2 marks 2 points scores 1 mark Ignore formula of products even if incorrect Ignore all dipoles on HCN Penalise dipoles on C-O in the intermediate	**(4)**

Question Number	Answer		Additional Guidance	Mark
(a)(ii)	An explanation that makes reference to the following points:			**(2)**
	• the value of K_a / dissociation is (very) small / the equilibrium lies (very) well to the left	**(1)**	Allow it is a (very) weak acid Allow it is partially dissociated	
	• so the concentration of CN^- ions is (very) low / there is a lack of CN^- ions	**(1)**	Allow a comment that all / most CN^- in the reaction come from KCN Ignore references to K_a of KCN Ignore references to rate of dissociation	

Question Number	Answer	Additional Guidance	Mark
(a)(iii)	An answer that makes reference to the following points: • (it increases the rate of reaction by) providing **CN^- ions** in the same phase/state **(1)** • and it / KCN / CN^- ion is regenerated in Step 2 (so overall is not used up in the reaction) **(1)**	Ignore incorrect phases Allow it is regenerated at the end (of the reaction) Ignore references to adsorbing and desorbing If no other mark is scored for it is in the same phase/state **and** is not used up (1) OR A homogeneous catalyst / KCN is in the same phase/state **and** speeds up the reaction/provides an alternative pathway with lower activation energy (1)	**(2)**

Question Number	Answer	Additional Guidance	Mark
(b)	• a three-dimensional diagram of 2-hydroxybutanenitrile showing at least one dotted bond **(1)** **and** at least one wedged bond which are next to each other **(1)** • the mirror image of the first structure	Allow just a three dimensional diagram of 2-hydroxybutanenitrile showing at least one dotted and one wedged bond Diagrams may show a mirror / plane of symmetry though this is not necessary  Allow diagrams that swap two of the four substituents e.g.  If not other marks are scored allow two tetrahedral structures which are mirror images that do not have wedged and dotted bonds scores (1) Ignore connectivity errors Allow TE in M2 for incorrect compounds	**(2)**

Q14.

Question Number	**Answer**	**Mark**
	The only correct answer is D (decreasing the temperature would increase the equilibrium yield of sulfur trioxide) ***A*** *is not correct because vanadium oxide is a heterogeneous catalyst* ***B*** *is not correct because decreasing pressure would decrease the equilibrium yield of sulfur trioxide* ***C*** *is not correct because increasing the surface area of the catalyst will affect the rate not the equilibrium yield of sulfur trioxide*	(1)

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Q15.

Question number	Answer	Mark
	D titration of quenched samples	1

Q16.

Question Number	Answer	Mark
	The only correct answer is D (2-bromo-2-methylpropane) *A is incorrect because this is a primary bromoalkane and RBr is most likely to be tertiary* *B is incorrect because this is a secondary bromoalkane and RBr is most likely to be tertiary* *C is incorrect because this is a primary bromoalkane and RBr is most likely to be tertiary*	(1)