Q1.

Solutions of two compounds, **W** and **X**, react together in the presence of a soluble catalyst, **Y**, as shown in the equation

$$2\mathbf{W} + \mathbf{X} \rightarrow \mathbf{Z}$$

When the concentrations of **W**, **X** and **Y** are all doubled, the rate of reaction increases by a factor of four.

Which is a possible rate equation for this reaction?

A rate = $k\,[\mathbf{W}]^2\,[\mathbf{X}]$ ○

B rate = $k\,[\mathbf{W}]^2\,[\mathbf{Y}]$ ○

C rate = $k\,[\mathbf{X}]\,[\mathbf{Y}]$ ○

D rate = $k\,[\mathbf{X}]\,[\mathbf{Z}]$ ○

(Total 1 mark)

Q2.

This question involves the use of kinetic data to deduce the order of a reaction and calculate a value for a rate constant.

The data in **Table 1** were obtained in a series of experiments on the rate of the reaction between compounds **A** and **B** at a constant temperature.

Table 1

Experiment	Initial concentration of A / mol dm^{-3}	Initial concentration of B / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.12	0.26	2.10×10^{-4}
2	0.36	0.26	1.89×10^{-3}
3	0.72	0.13	3.78×10^{-3}

(a) Show how these data can be used to deduce the rate expression for the reaction between **A** and **B**.

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(3)

The data in **Table 2** were obtained in two experiments on the rate of the reaction between compounds **C** and **D** at a constant temperature.

Table 2

Experiment	**Initial concentration of C / mol dm^{-3}**	**Initial concentration of D / mol dm^{-3}**	**Initial rate / mol dm^{-3} s^{-1}**
4	1.9×10^{-2}	3.5×10^{-2}	7.2×10^{-4}
5	3.6×10^{-2}	5.4×10^{-2}	To be calculated

The rate equation for this reaction is

$$rate = k[\mathbf{C}]^2[\mathbf{D}]$$

(b) Use the data from experiment **4** to calculate a value for the rate constant, *k*, at this temperature. Deduce the units of *k*.

k = ________________ Units = ________________

(3)

(c) Calculate a value for the initial rate in experiment **5**.

Initial rate = _______________ mol dm^{-3} s^{-1}

(1)

(d) The rate equation for a reaction is

$$rate = k[\mathbf{E}]$$

Explain qualitatively why doubling the temperature has a much greater effect on the rate of the reaction than doubling the concentration of **E**.

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(3)

(e) A slow reaction has a rate constant $k = 6.51 \times 10^{-3}$ mol^{-1} dm^3 at 300 K.

Use the equation $\ln k = \ln A - E_a / RT$ to calculate a value, in kJ mol^{-1}, for the activation energy of this reaction.

The constant $A = 2.57 \times 10^{10}$ mol^{-1} dm^3.
The gas constant $R = 8.31$ J K^{-1} mol^{-1}.

Activation energy = _______________

(2)

(Total 12 marks)

Q3.

The rate expression for the reaction between **X** and **Y** is

$$rate = k\,[\mathbf{X}]^2\,[\mathbf{Y}]$$

Which statement is correct?

A The rate constant has units $mol^{-1}\ dm^3\ s^{-1}$

B The rate of the reaction is halved if the concentration of **X** is halved and the concentration of **Y** is doubled.

C The rate increases by a factor of 16 if the concentration of **X** is tripled and the concentration of **Y** is doubled.

D The rate constant is independent of temperature.

(Total 1 mark)

Q4.

The results of an investigation of the reaction between P and Q are shown in this table.

Experiment	**Initial [P] / mol dm^{-3}**	**Initial [Q] / mol dm^{-3}**	**Initial rate / mol dm^{-3} s^{-1}**
1	0.200	0.500	0.400
2	0.600	To be calculated	0.800

The rate equation is: $rate = k\,[\mathbf{P}]\,[\mathbf{Q}]^2$

What is the initial concentration of **Q** in experiment 2?

A 0.167

B 0.333

C 0.408

D 0.612

(Total 1 mark)

Q5.

The rate equation for the acid-catalysed reaction between iodine and propanone is:

$$\text{rate} = k\,[H^+]\,[C_3H_6O]$$

The rate of reaction was measured for a mixture of iodine, propanone and sulfuric acid at pH = 0.70

In a second mixture the concentration of the sulfuric acid was different but the concentrations of iodine and propanone were unchanged. The new rate of reaction was a quarter of the original rate.

What was the pH of the second mixture?

A 1.00 ○

B 1.30 ○

C 1.40 ○

D 2.80 ○

(Total 1 mark)

Q6.

This question is about rates of reaction.
Iodine and propanone react together in an acid-catalysed reaction

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

A student completed a series of experiments to determine the order of reaction with respect to iodine.

Method

- Transfer 25 cm^3 of 1.0 mol dm^{-3} propanone solution into a conical flask.
- Add 10 cm^3 of 1.0 mol dm^{-3} HCl(aq)
- Add 25 cm^3 of 5.0×10^{-3} mol dm^{-3} I_2(aq) and start a timer.
- At intervals of 1 minute, remove a 1.0 cm^3 sample of the mixture and add each sample to a separate beaker containing an excess of $NaHCO_3$(aq)
- Titrate the contents of each beaker with a standard solution of sodium thiosulfate and record the volume of sodium thiosulfate used.

(a) Suggest why the 1.0 cm^3 portions of the reaction mixture are added to an excess of $NaHCO_3$ solution.

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(2)

(b) Suggest why the order of this reaction with respect to propanone can be ignored in this experiment.

(2)

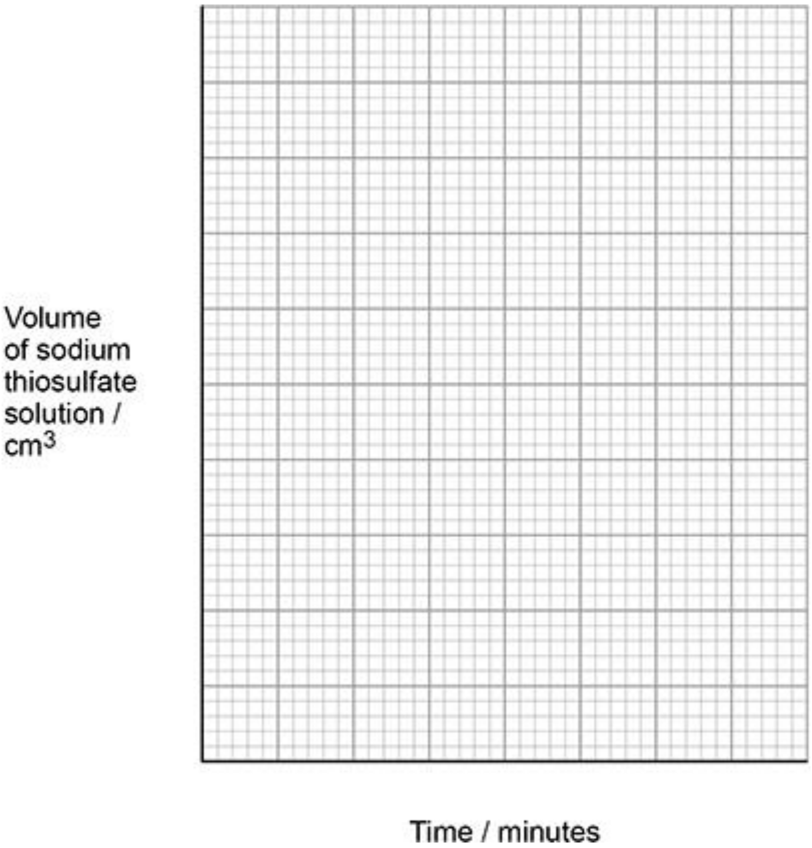
The volume of sodium thiosulfate solution used in each titration is proportional to the concentration of iodine in each beaker.

The table below shows the results of the experiment.

Time / minutes	**Volume of sodium thiosulfate solution / cm^3**
1	41
2	35
3	24
4	22
5	16
6	10

(c) Use the results in the table above to draw a graph of volume of sodium thiosulfate solution against time.

Draw a line of best fit.



(3)

(d) Explain how the graph shows that the reaction is zero-order with respect to iodine in the reaction between propanone and iodine.

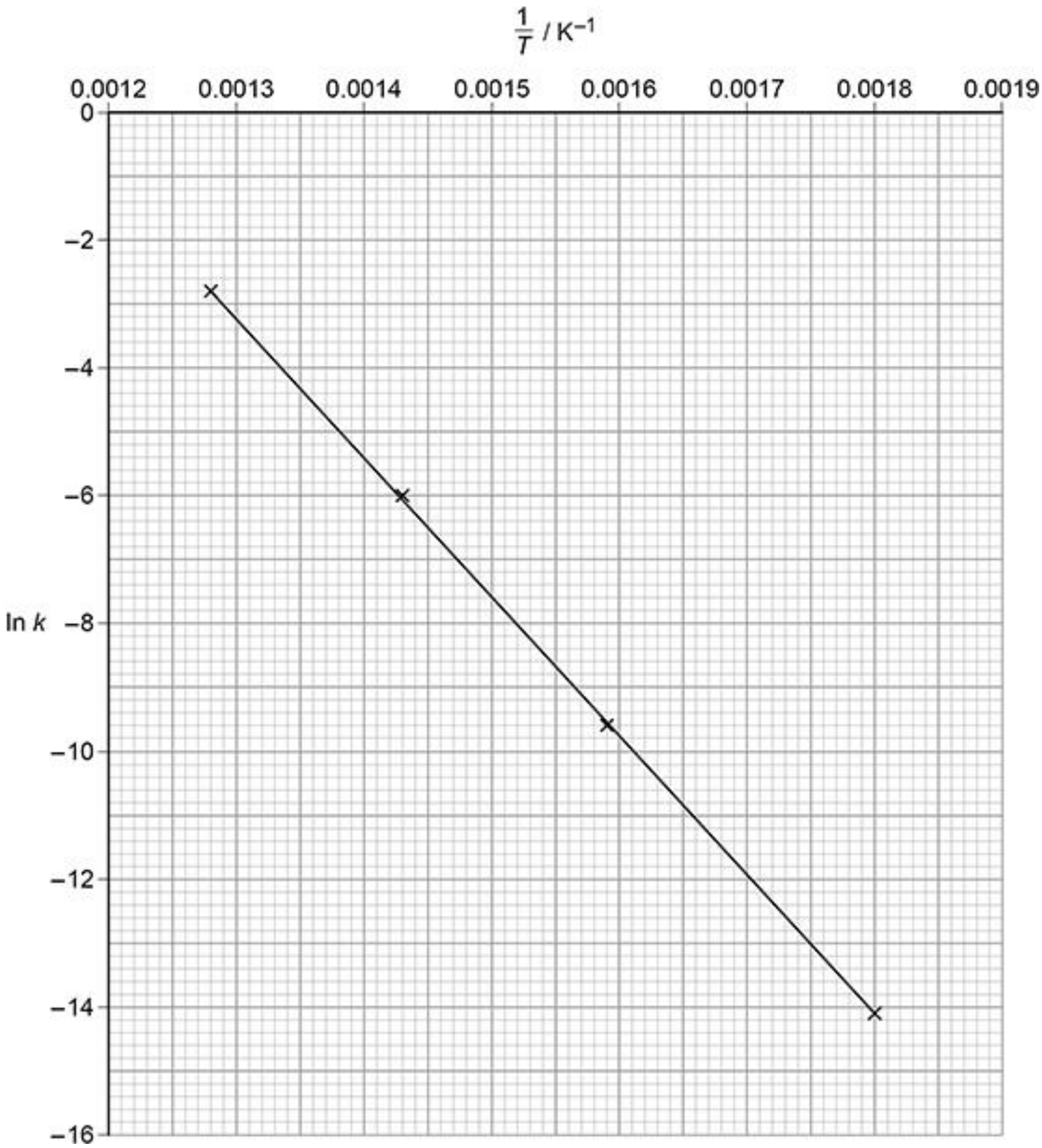
(2)

(e) The Arrhenius equation can be written as

$$\ln k = \frac{-E_a}{RT} + \ln A$$

The figure below shows a graph of ln *k* against $\frac{1}{T}$ for the reaction

$$2\ HI(g) \rightarrow H_2(g) + I_2(g)$$



Use the figure above to calculate a value for the activation energy (E_a), in kJ mol^{-1}, for this reaction.

The gas constant R = 8.31 J K^{-1} mol^{-1}

E_a ____________________ kJ mol^{-1}

(3)

(Total 12 marks)

Q7.

This question is about rates of reaction.

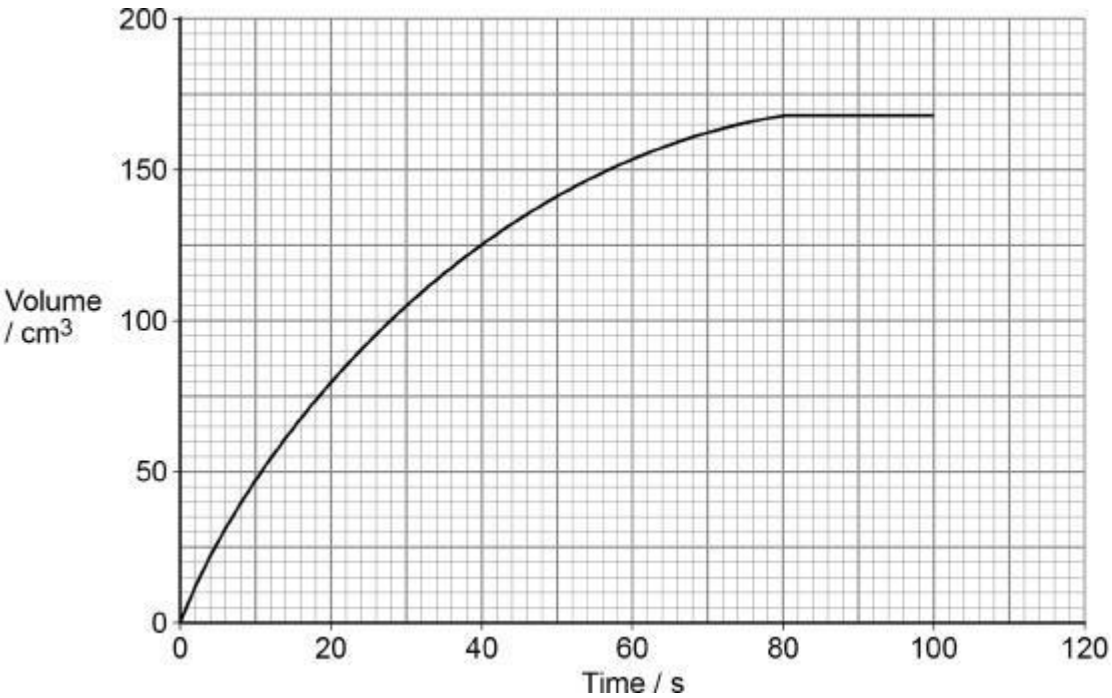
Phosphinate ions ($H_2PO_2^-$) react with hydroxide ions to produce hydrogen gas as shown.

$$H_2PO_2^- + OH^- \rightarrow HPO_3^{2-} + H_2$$

A student completed an experiment to determine the initial rate of this reaction. The student used a solution containing phosphinate ions and measured the volume of hydrogen gas collected every 20 seconds at a constant temperature.

Figure 1 shows a graph of the student's results.

Figure 1



(a) Use the graph in **Figure 1** to determine the initial rate of reaction for this experiment. State its units. Show your working on the graph.

Rate ________________ Units ________________

(3)

(b) Another student reacted different initial concentrations of phosphinate ions with an excess of hydroxide ions. The student measured the time (t) taken to collect 15 cm^3 of hydrogen gas. Each experiment was carried out at the same temperature. The table shows the results.

Initial [$H_2PO_2^-$] / mol dm^{-3}	***t* / s**
0.25	64
0.35	32
0.50	16
1.00	4

State the relationship between the initial concentration of phosphinate and time (t).

Deduce the order of the reaction with respect to phosphinate.

Relationship

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Order

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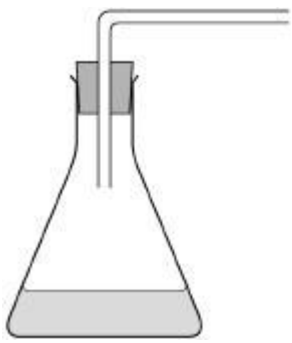
(2)

(c) Complete the diagram in **Figure 2** to show how the hydrogen gas could be collected and measured in the experiments in part (a) and (b).

Figure 2



The rate equation for a different reaction is

$$rate = k\,[L]\,[M]^2$$

(1)

(d) Deduce the overall effect on the rate of reaction when the concentrations of both **L** and **M** are halved.

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(1)

(e) The rate of reaction is 0.0250 mol dm^{-3} s^{-1} when the concentration of **L** is 0.0155 mol dm^{-3}

Calculate the concentration of **M** if the rate constant is 21.3 mol^{-2} dm^{6} s^{-1}

Concentration of **M** ________________ mol dm^{-3}

(3)

(f) Define the term overall order of reaction.

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(1)

(Total 11 marks)

Q8.

Cisplatin, $[Pt(NH_3)_2Cl_2]$, is used as an anti-cancer drug.

(a) Cisplatin works by causing the death of rapidly dividing cells.

Name the process that is prevented by cisplatin during cell division.

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(1)

After cisplatin enters a cell, one of the chloride ligands is replaced by a water molecule to form a complex ion, **B**.

(b) Give the equation for this reaction.

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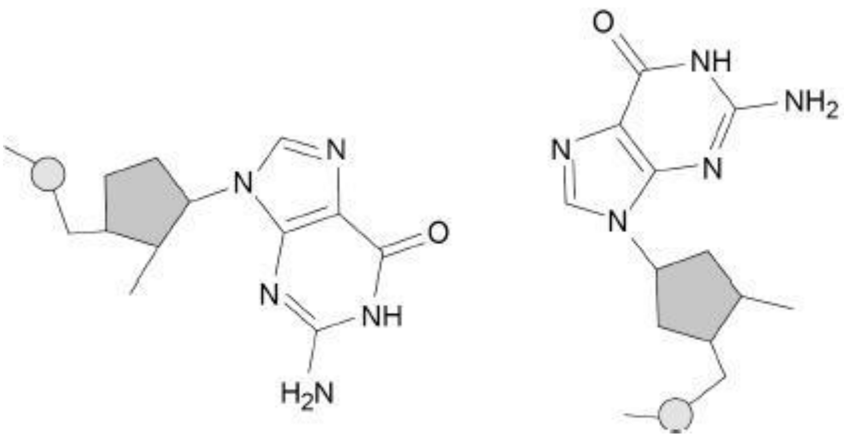
(2)

(c) When the complex ion **B** reacts with DNA, the water molecule is replaced as a bond forms between platinum and a nitrogen atom in a guanine nucleotide.
The remaining chloride ligand is also replaced as a bond forms between platinum and a nitrogen atom in another guanine nucleotide.

Figure 1 represents two adjacent guanine nucleotides in DNA.

Complete **figure 1** to show how the platinum complex forms a cross-link between the guanine nucleotides.

Figure 1



(2)

An experiment is done to investigate the rate of reaction in part (b).

(d) During the experiment the concentration of cisplatin is measured at one-minute intervals.

Explain how graphical methods can be used to process the measured results, to confirm that the reaction is first order.

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(3)

In another experiment, the effect of temperature on the rate of the reaction in part (b) is investigated.

The table shows the results.

Temperature T **/ K**	$\frac{1}{T}$ / K^{-1}	**Rate constant** k **/** s^{-1}	**ln** k
293	0.00341	1.97×10^{-8}	−17.7
303	0.00330	8.61×10^{-8}	−16.3
313	0.00319	3.43×10^{-7}	−14.9
318		6.63×10^{-7}	
323	0.00310	1.26×10^{-6}	−13.6

(e) Complete the table above.

(2)

(f) The Arrhenius equation can be written in the form

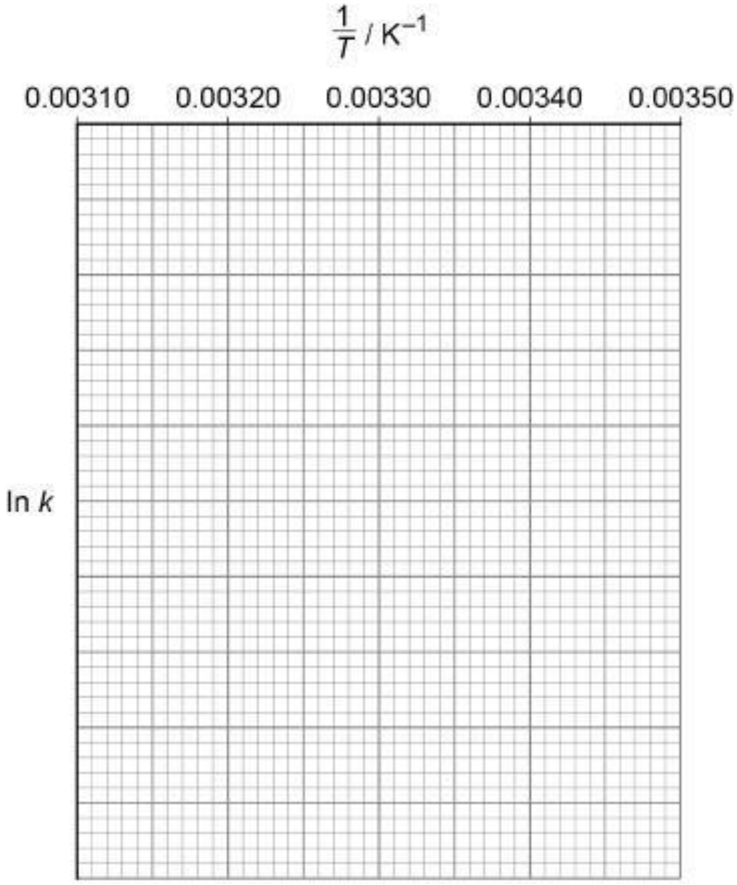
$$\ln k = \frac{-E_a}{RT} + \ln A$$

Use the data in the table above to plot a graph of ln k against $\frac{1}{T}$ on the grid in **Figure 2**.

Calculate the activation energy, E_a, in kJ mol^{-1}

The gas constant, R = 8.31 J K^{-1} mol^{-1}

Figure 2



E_a ________________ kJ mol^{-1}

(5)

(Total 15 marks)

Q9.

The rate constant, k, for a reaction varies with temperature as shown by the equation

$$k = Ae^{-E_a/RT}$$

For this reaction, at 25 °C, $k = 3.46 \times 10^{-8}$ s^{-1}
The activation energy E_a = 96.2 kJ mol^{-1}
The gas constant R = 8.31 J K^{-1} mol^{-1}

Calculate a value for the Arrhenius constant, A, for this reaction.
Give the units for A.

A ________________________ Units ________________________

(Total 4 marks)

Q10.

Bromate(V) ions and bromide ions react in acid conditions according to the equation

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

(a) A series of experiments was carried out at a given temperature. The results were used to deduce the rate equation for the reaction.

$$\textit{rate} = k\,[BrO_3^-][Br^-][H^+]^2$$

Table 1 shows an incomplete set of results.

Table 1

Experiment	**Initial $[BrO_3^-]$ / mol dm^{-3}**	**Initial $[Br^-]$ / mol dm^{-3}**	**Initial $[H^+]$ / mol dm^{-3}**	**Initial rate of reaction / mol dm^{-3} s^{-1}**
1	0.10	0.20	0.30	2.4×10^{-2}
2		0.20	0.30	3.6×10^{-2}
3	0.20	0.40	0.50	
4	0.10	0.10		2.7×10^{-2}

Use the data from Experiment 1 to calculate a value for the rate constant, k, at this temperature and give its units.

Give your answer to an appropriate number of significant figures.

k ____________________ Units ____________________

(3)

(b) Complete **Table 1**.

Space for working

(3)

(c) A second series of experiments was carried out to investigate how the rate of the reaction varies with temperature.
The results were used to obtain a value for the activation energy of the reaction, E_a

Identical amounts of reagents were mixed at different temperatures.
The time taken, *t*, for a fixed amount of bromine to be formed was measured at different temperatures.

The results are shown in **Table 2**.

Table 2

Temperature, *T* / K	$\frac{1}{T}$ / K^{-1}	**Time, t / s**	$\frac{1}{t}$ / s^{-1}	$\ln \frac{1}{t}$
286	3.50×10^{-3}	54	1.85×10^{-2}	−3.99
295	3.39×10^{-3}	27	3.70×10^{-2}	
302		15	6.67×10^{-2}	−2.71
312	3.21×10^{-3}	8	1.25×10^{-1}	−2.08

Complete **Table 2**

(2)

(d) The Arrhenius equation can be written as

$$\ln k = -\frac{E_a}{R}\left(\frac{1}{T}\right) + C_1$$

In this experiment, the rate constant, *k*, is directly proportional to $\frac{1}{t}$

Therefore

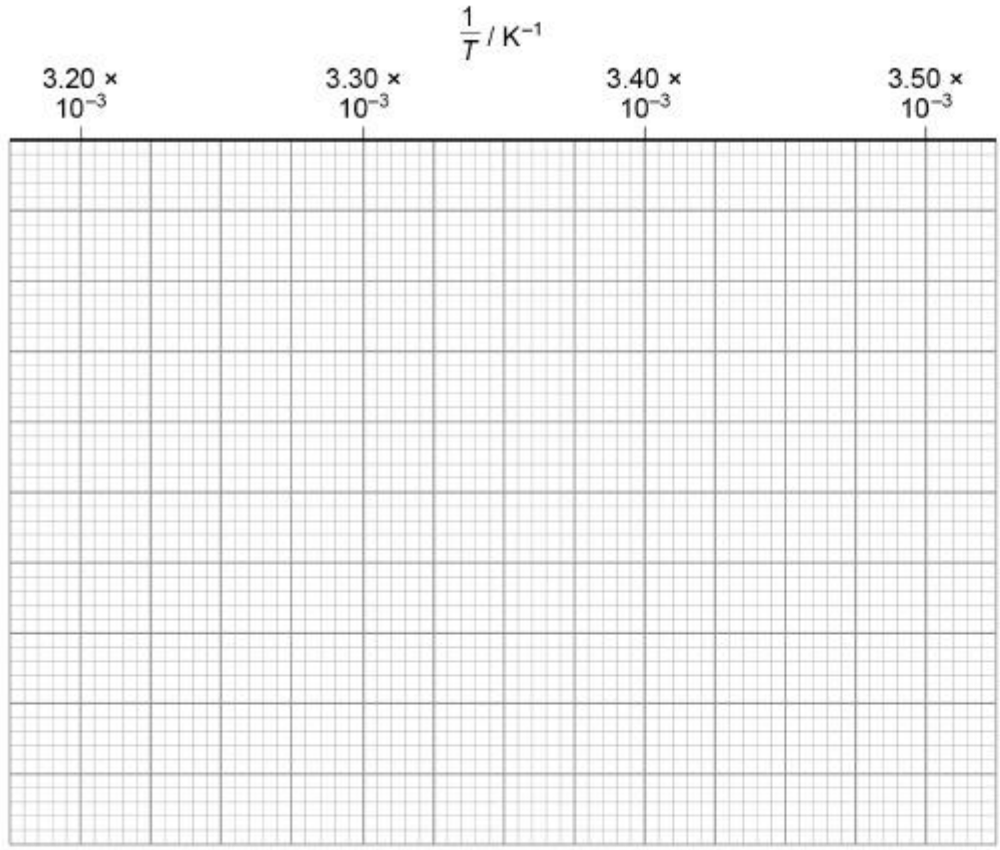
$$\ln \frac{1}{t} = -\frac{E_a}{R}\left(\frac{1}{T}\right) + C_2$$

where C_1 and C_2 are constants.

Use values from **Table 2** to plot a graph of $\ln \frac{1}{t}$ (y axis) against $\frac{1}{T}$ on the grid.

Use your graph to calculate a value for the activation energy, in kJ mol^{-1}, for this reaction.

The value of the gas constant, R = 8.31 J K^{-1} mol^{-1}



Activation energy ____________________ $kJ\ mol^{-1}$

(6)

(Total 14 marks)

Q11.

Iodide ions are oxidised to iodine by hydrogen peroxide in acidic conditions.

$$H_2O_2(aq) + 2H^+(aq) + 2I^-(aq) \rightarrow I_2(aq) + 2H_2O(l)$$

The rate equation for this reaction can be written as

$$rate = k\,[H_2O_2]^a\,[I^-]^b\,[H^+]^c$$

In an experiment to determine the order with respect to $H^+(aq)$, a reaction mixture is made containing $H^+(aq)$ with a concentration of 0.500 $mol\ dm^{-3}$

A large excess of both H_2O_2 and I^- is used in this reaction mixture so that the rate equation can be simplified to

$$rate = k_1\,[H^+]^c$$

(a) Explain why the use of a large excess of H_2O_2 and I^- means that the rate of reaction at a fixed temperature depends only on the concentration of $H^+(aq)$.

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(2)

(b) Samples of the reaction mixture are removed at timed intervals and titrated with alkali to determine the concentration of $H^+(aq)$.

State and explain what must be done to each sample before it is titrated with alkali.

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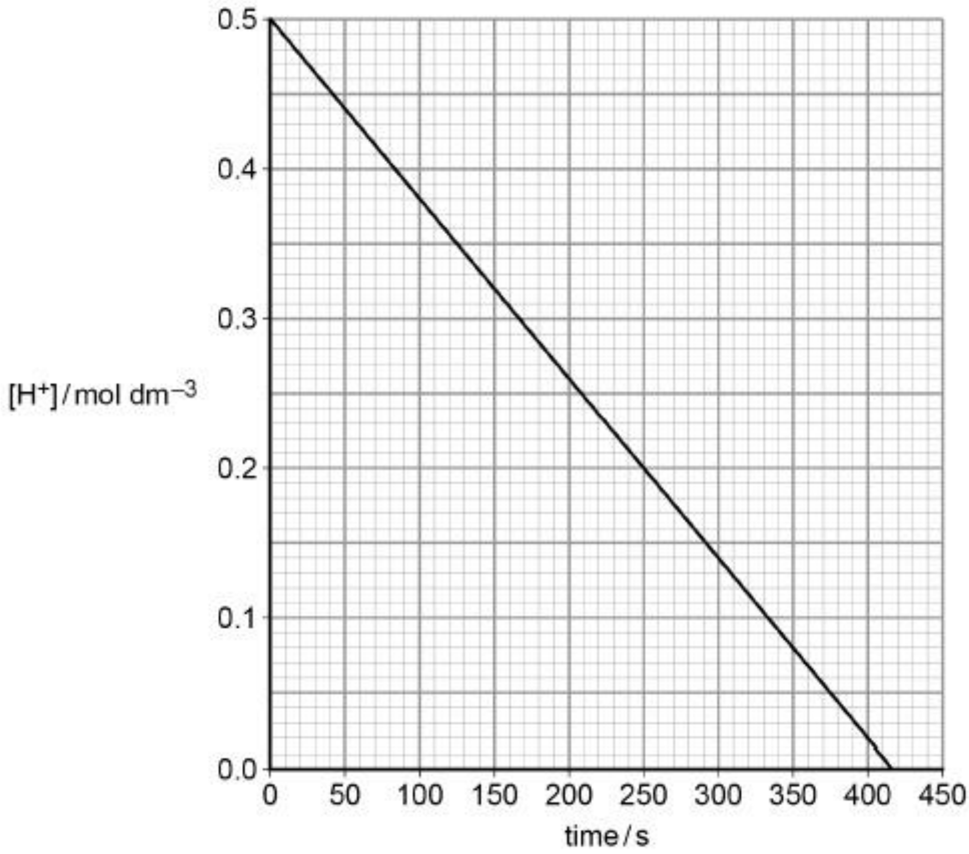
(2)

(c) A graph of the results is shown in **Figure 1**.

Figure 1



Explain how the graph shows that the order with respect to H^+(aq) is zero.

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(2)

(d) Use the graph in **Figure 1** to calculate the value of k_1

Give the units of k_1

k_1 ______________________

Units ______________________

(3)

(e) A second reaction mixture is made at the same temperature. The initial concentrations of H^+(aq) and I^-(aq) in this mixture are both 0.500 mol dm^{-3}

There is a large excess of H_2O_2

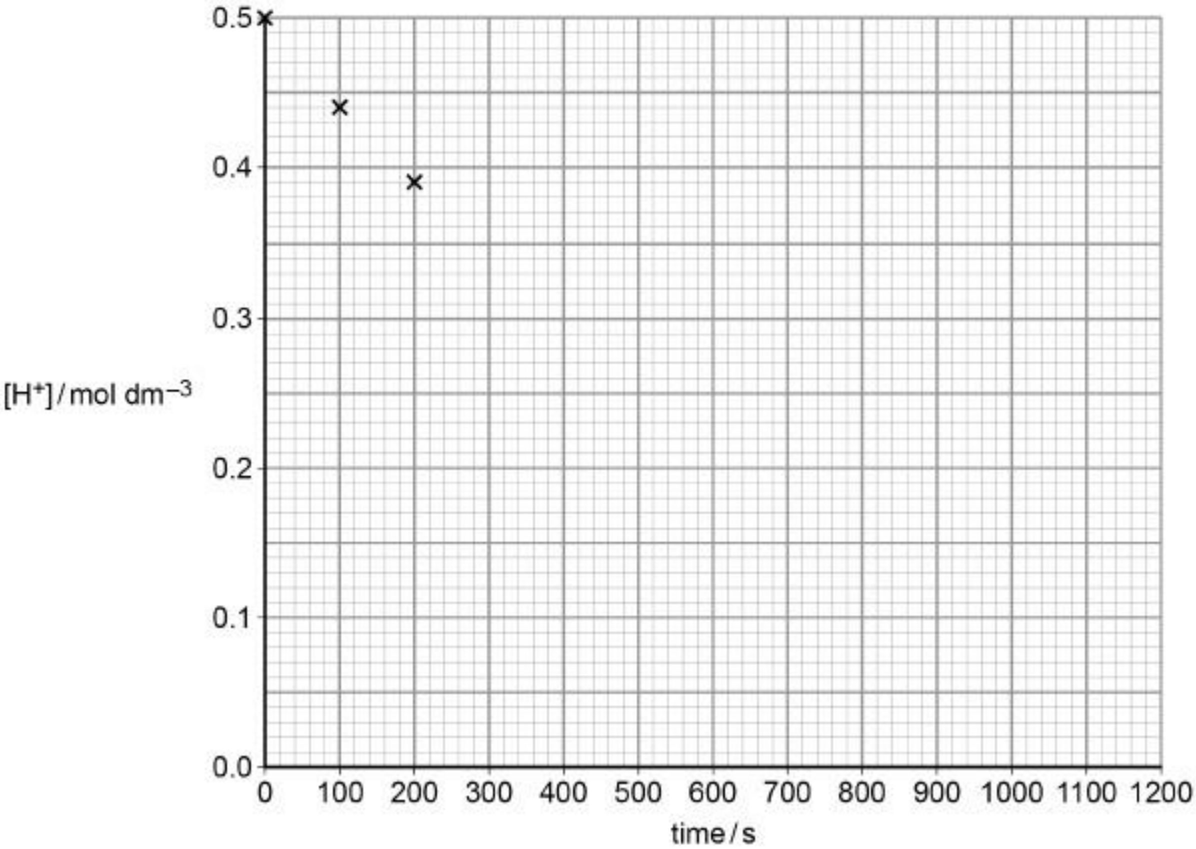
In this reaction mixture, the rate depends only on the concentration of I^-(aq).

The results are shown in the table.

Time / s	0	100	200	400	600	800	1000	1200
[H^+] / mol dm^{-3}	0.50	0.44	0.39	0.31	0.24	0.19	0.15	0.12

Plot these results on the grid in **Figure 2**. The first three points have been plotted.

Figure 2



(1)

(f) Draw a line of best fit on the grid in **Figure 2**.

(1)

(g) Calculate the rate of reaction when $[H^+] = 0.35$ mol dm^{-3}
Show your working using a suitable construction on the graph in **Figure 2**.

Rate ____________________ mol dm^{-3} s^{-1}

(2)

(h) A general equation for a reaction is shown.

A(aq) + **B**(aq) + **C**(aq) → **D**(aq) + **E**(aq)

In aqueous solution, **A**, **B**, **C** and **D** are all colourless but **E** is dark blue.

A reagent (**X**) is available that reacts rapidly with **E**. This means that, if a small amount of **X** is included in the initial reaction mixture, it will react with any **E** produced until all of the **X** has been used up.

Explain, giving brief experimental details, how you could use a series of experiments to determine the order of this reaction with respect to **A**. In each experiment you should obtain a measure of the initial rate of reaction.

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(6)

(Total 19 marks)