IB · DP · Chemistry

2 hours   11 questions

Structured Questions: Paper 2

16.2 Activation Energy

Easy (3 questions)	/20
Medium (5 questions)	/49
Hard (3 questions)	/26
Total Marks	**/95**

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Easy Questions

1 (a) The Arrhenius equation can be written as:

$$k = Ae^{\frac{-E_a}{RT}}$$

State what each of the following terms represents, including units where applicable.

- A
- E_a
- R
- T

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(5 marks)

(b) Rearrange the Arrhenius equation given in part (a) to make *A* the subject.

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(1 mark)

(c) State how the rate constant, *k* varies with temperature, *T*.

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(1 mark)

(d) State how the activation energy, *Ea*, varies with rate constant, *k*.

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(1 mark)

2 (a) The Arrhenius equation can also be written in natural logarithmic forms.

$$\ln k = \ln A - \frac{Ea}{RT}$$

A plot of ln *k* against $\frac{1}{T}$ gives a straight-line graph of the type y = mx + c.

Complete the table below which relates the terms from the natural logarithmic Arrhenius equation to the equation of a straight line.

Straight-line term	**Arrhenius term**
y	ln *k*
m	
x	
c	

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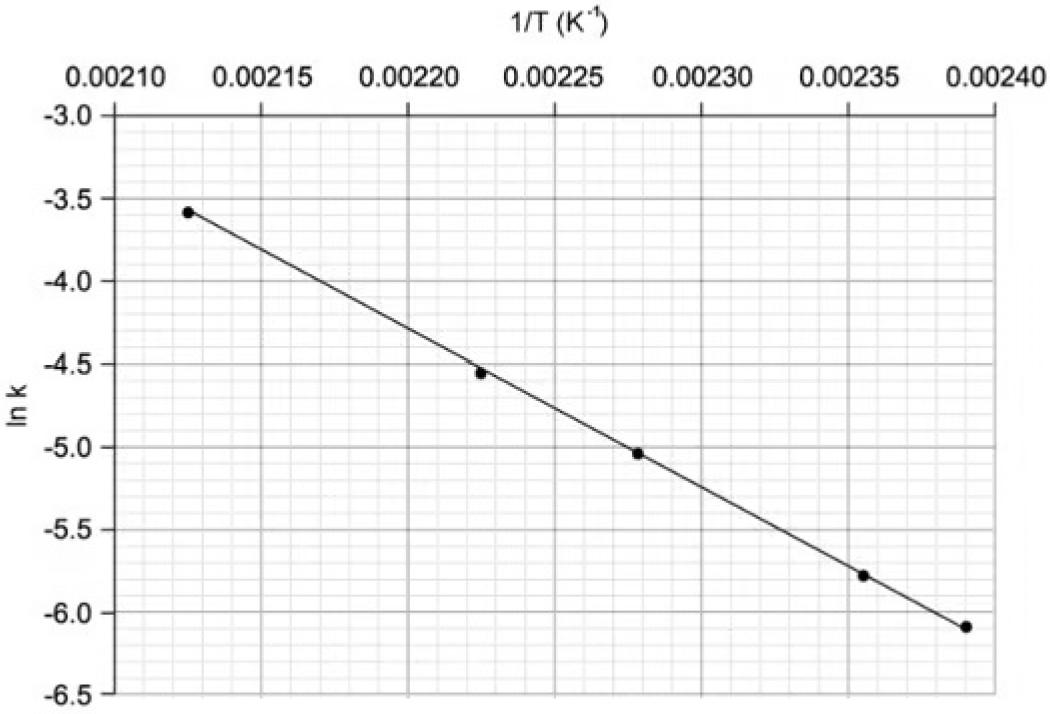
(3 marks)

(b) A graph of ln *k* against $\frac{1}{T}$ is shown below.



Calculate the gradient of the straight line.

(2 marks)

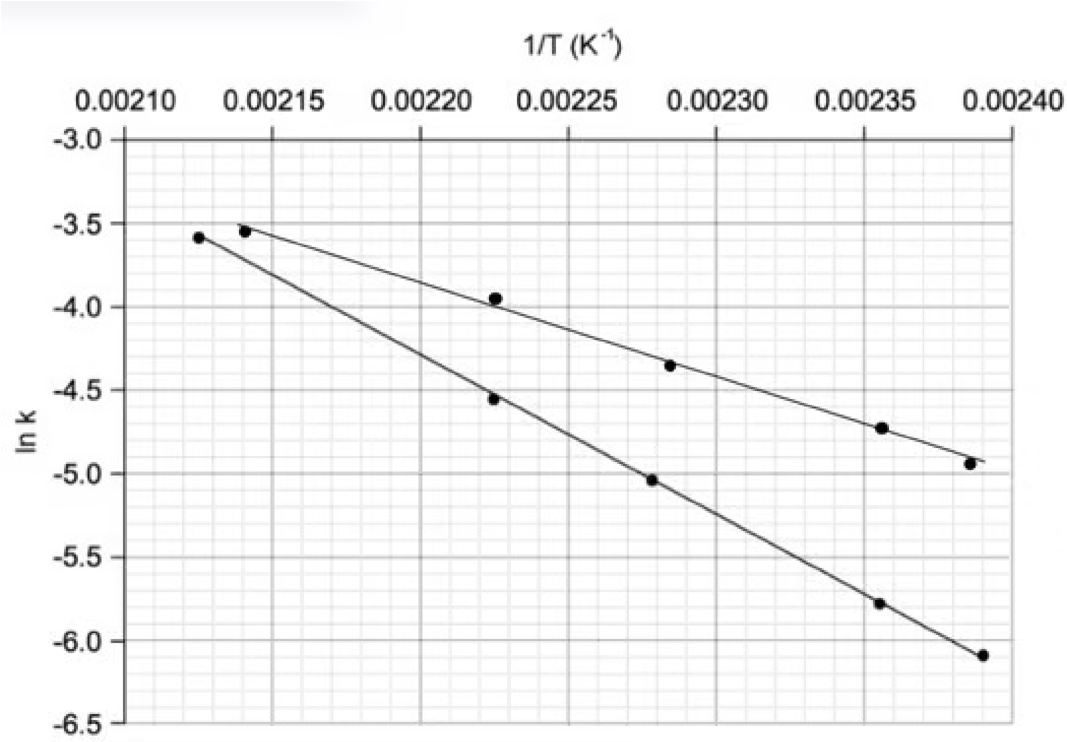
(c) Using section 2 of the data booklet, calculate the activation energy, *Ea* for the graph in part b).

(1 mark)

(d) Calculate the frequency factor, A, for the graph in part b) to 2 decimal places.

(2 marks)

3 (a) Arrhenius plots for two reactions with different activation energies are shown below.



State which plot shows the reaction with the greatest activation energy.

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(1 mark)

(b) The temperature of both reactions from part a) is increased from 20° to 45°.

Using section 1 of the data booklet, determine which of the reactions will experience the largest change in the rate of reaction.

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(1 mark)

(c) The decomposition of hydrogen peroxide into water and oxygen occurs at a slow rate with a rate constant of k = 6.42×10^{-4} mol dm^{-3} s^{-1} and at a temperature of 290 K.

When the temperature is increased to 340 K the rate constant k = 6.47×10^{-2} mol dm^{-3} s^{-1}.

Using sections 1 and 2 of the data booklet, calculate the activation energy for this reaction.

(2 marks)

Medium Questions

1 (a) The decomposition of hydrogen peroxide into water and oxygen occurs at a slow rate with a rate constant of k = 6.62 x 10^{-3} mol dm^{-3} s^{-1} and at a temperature of 290 K.

Using Sections 1 and 2 of the Data Booklet, calculate the activation energy, E_a, correct to three significant figures and state its units.

The constant, A = 3.18 × 10^{11} mol^{-1} dm^{3}.

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(3 marks)

(b) Hydrogen peroxide decomposes to form water and oxygen as shown in the equation below.

$$2H_2O_2\ (aq) \rightarrow 2H_2O\ (l) + O_2\ (g)$$

The table below shows the value of the rate constant at different temperatures for a reaction.

Rate constant k / s^{-1}	***ln k***	**Temperature / K**	$\frac{1}{T}$
0.000493		295	
0.000656		298	
0.001400		305	
0.002360		310	
0.006120		320	

Complete the table by calculating the values of *ln k* and $\frac{1}{T}$ at each temperature.

(2 marks)

(c) The results of the experiment can be used to calculate the activation energy, E_a. Use the results table to plot a graph of *ln k* against $\frac{1}{T}$.

(4 marks)

(d) Using Sections 1 and 2 of the Data Booklet and your graph, calculate a value for the activation energy, E_a, for this reaction. To gain full marks you must show all of your working.

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(4 marks)

2 (a) The Arrhenius equation can be represented as $k = Ae^{-Ea/RT}$ in its exponential form.

State the effect on *k* of an increase in;

i) The constant, *A*, (frequency factor)

ii) Activation energy, E_a

iii) Temperature, *T*

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(3 marks)

(b) Using Sections 1 and 2 of the Data Booklet, calculate the activation energy, E_a, of a reaction at 57°C and a rate constant of 1.30 x 10^{-4} mol dm^{-3} s^{-1}. The constant *A* = 4.55 × 10^{13}.

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(2 marks)

(c) The table below shows how temperature affects the rate of reaction.

Rate constant k/s^{-1}	***ln k***	**Temperature / K**	$\frac{1}{T}$
2.0 x 10^{-5}	-10.8	278	0.00360
4.7 x 10^{-4}	-7.7	298	0.00336
1.7 x 10^{-3}	-6.4	308	0.00325
5.2 x 10^{-3}	-5.3	318	0.00314

Use the results to plot a labelled graph of *ln k* against $\frac{1}{T}$.

(3 marks)

(d) Using Sections 1 and 2 of the Data Booklet and your graph, calculate a value for the activation energy, E_a, for this reaction.

(4 marks)

3 (a) Nitrogen dioxide and ozone react according to the following equation.

$$2NO_2\ (g) + O_3(g) \rightarrow N_2O_5\ (g) + O_2\ (g)$$

Experimental data shows the reaction is first order with respect to NO_2 and first order with respect to O_3.

State the rate expression for the reaction.

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(1 mark)

(b) At 30°C, the initial rate of reaction is 3.46×10^{-3} mol dm^{-3} s^{-1} when the initial concentration of NO_2 is 0.50 mol dm^{-3} and the initial concentration of O_3 is 0.21 mol dm^{-3}.

Calculate a value for the rate constant *k* at this temperature and state its units.

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(3 marks)

(c) Using Sections 1 and 2 of the Data Booklet and your answer from part (b), calculate a value for the activation energy of this reaction at 30 °C.

For this reaction *ln A* = 15.8 mol^{-1} dm^{3}.

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(4 marks)

(d) The relationship between the rate constant and temperature is given by the Arrhenius equation, $k = Ae^{-\frac{Ea}{RT}}$

State how temperature affects activation energy.

(1 mark)

4 (a) A common relationship exists between temperature and rate.

What temperature change is associated with a doubling of rate?

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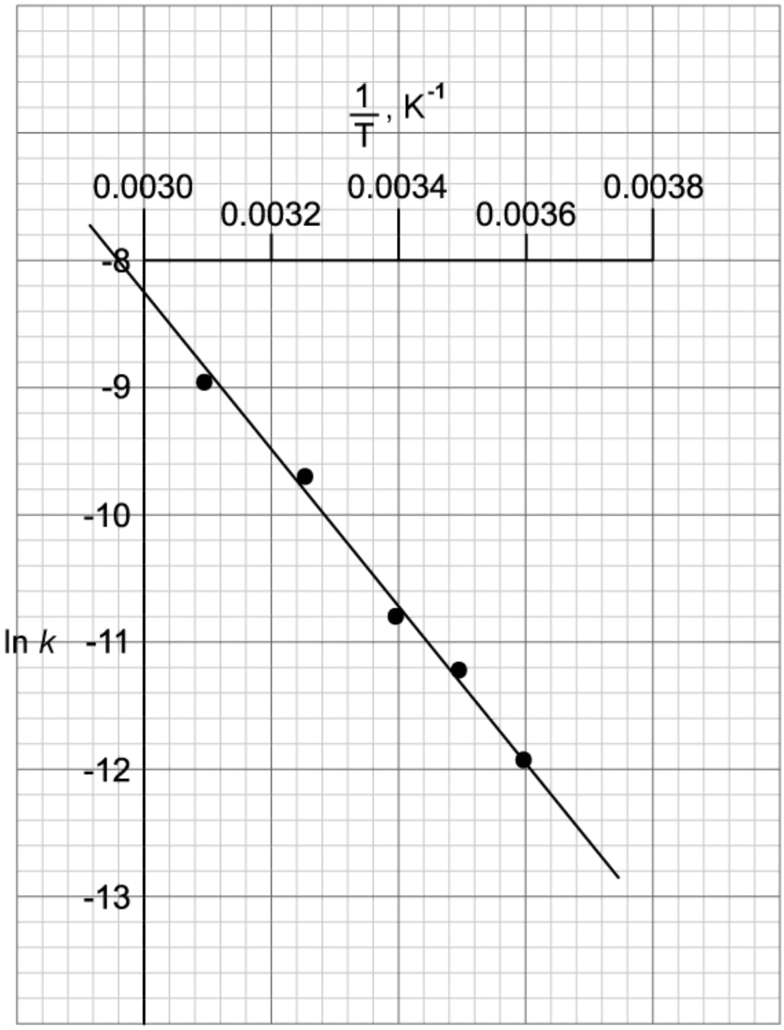
(1 mark)

(b) An Arrhenius plot of ln k against $\frac{1}{T}$ for the reaction between A (g) and B (g) at different temperatures is shown in **Figure 1** below.



The equation of the line of best fit was found to be:

$$\ln k = -6154\left(\frac{1}{T}\right) - 8.2$$

Calculate the activation energy, E_a, for the reaction between A (g) and B (g).

(2 marks)

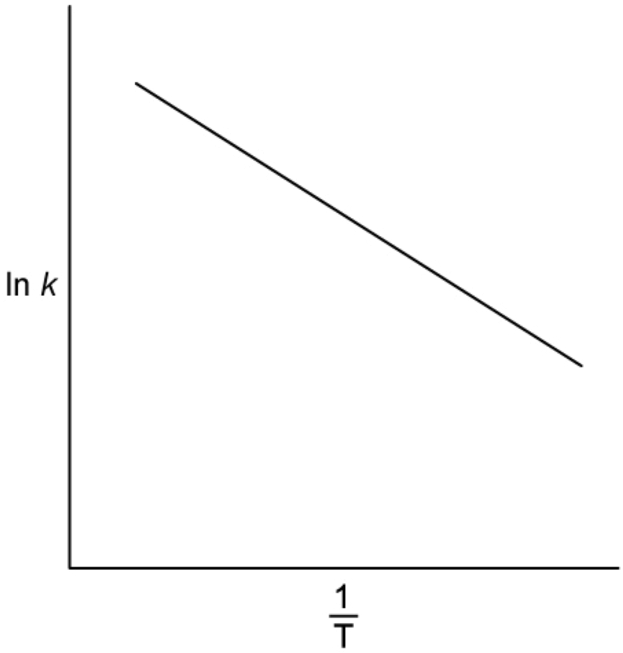
(c) Define the Arrhenius constant, *A*.

(2 marks)

(d) Using the Arrhenius plot, calculate an approximate value for the constant, *A*.

(2 marks)

5 (a) The graph of ln *k* against $\frac{1}{T}$ for a general reaction is shown.



Sketch the expected line for a **different** reaction with a higher activation energy.

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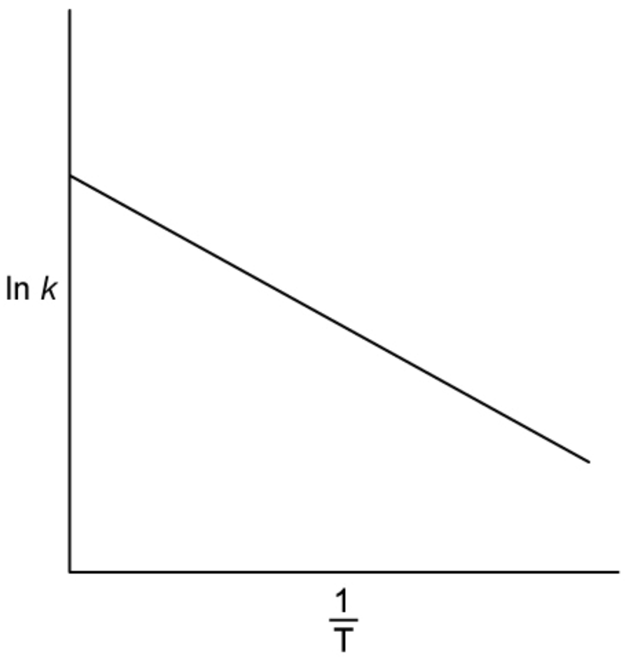
(1 mark)

(b) A graph of ln *k* against $\frac{1}{T}$ for another general reaction is shown.



Sketch the expected line for the **same** reaction with an added catalyst.

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(2 marks)

(c) Rate constant data for the reaction of hydrogen and iodine at two different temperatures is shown in the table below.

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

Table 1

Experiment	**Temperature / K**	**Rate constant, *k* / mol dm^{-3} s^{-1}**
1	599	5.40×10^{-4}
2	683	2.80×10^{-2}

Using Sections 1 and 2 of the Data Booklet, calculate the activation energy, in kJ mol^{-1}, for the reaction.

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(3 marks)

(d) Using the data from experiment 1 and Sections 1 and 2 in the Data Booklet, calculate a value for the constant, *A*.

Table 2

Experiment	Temperature / K	Rate constant, *k* / mol dm^{-3} s^{-1}
1	599	5.40×10^{-4}
2	683	2.80×10^{-2}

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(2 marks)

Hard Questions

1 (a) A series of experiments were carried out to investigate how the rate of the reaction of bromate and bromide in acidic conditions varies with temperature.

The time taken, *t*, was measured for a fixed amount of bromine to form at different temperatures. The results are shown below.

Temperature (T) / K	$\frac{1}{T}$ **x 10^{-3} / K^{-1}**	**Time (t) / s**	$\frac{1}{t}$ **/ s^{-1}**	**ln** $\frac{1}{t}$
408	2.451	21.14	0.0473	-3.051
428	2.336	10.57		
448		5.54	0.1805	-1.712
468	2.137	3.02	0.3311	-1.106
488	2.049			-0.536

Complete the table above.

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(3 marks)

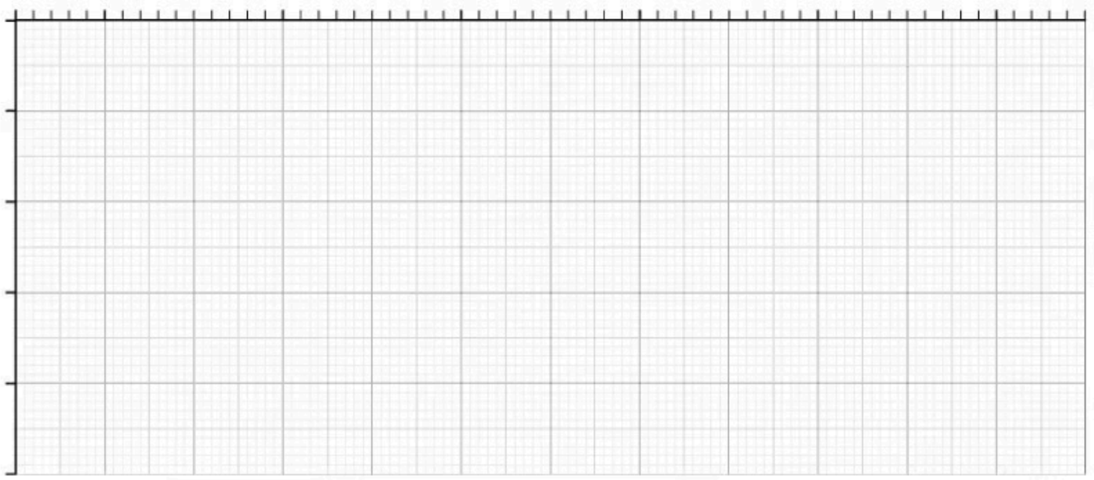
(b) The Arrhenius equation relates the rate constant, k, to the activation energy, E_a, and temperature, T.

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

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

$$\ln \frac{1}{t} = \ln A + \frac{-E_a}{RT}$$

Use your answers from part (a) to plot a graph of ln $\frac{1}{t}$ against $\frac{1}{T}$ x 10^{-3} on the graph below.



(4 marks)

(c) Use section 2 of the data booklet along with your graph and information from part (b) to calculate a value for the activation energy, in kJ mol^{-1}, for this reaction.

To gain full marks you must show all of your working.

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(4 marks)

2 (a) Three experiments were carried out at a temperature, T_1, to investigate the rate of the reaction between compounds **F** and **G**. The results are shown in the table below:

	Experiment 1	**Experiment 2**	**Experiment 3**
Initial concentration of **F** / mol dm^{-3}	1.71 x 10^{-2}	5.34 x 10^{-2}	7.62 x 10^{-2}
Initial concentration of **G** / mol dm^{-3}	3.95 x 10^{-2}	6.24 x 10^{-2}	3.95 x 10^{-2}
Initial rate / mol dm^{-3} s^{-1}	3.76 x 10^{-3}	1.85 x 10^{-2}	1.68 x 10^{-2}

Use the data in the table to deduce the rate equation for the reaction between compounds **F** and **G**.

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(3 marks)

(b) Use the information in the table in part (a) to calculate a value for the rate constant, *k*, for this reaction between 0.0534 mol dm^{-3} **F** and 0.0624 mol dm^{-3} **G**.

Give your answer to the appropriate number of significant figures.

State the units for *k*.

(If you did not get an answer for (a), you may assume that $rate = k$ [**F**]^2 [**G**]^2. This is **not** the correct answer)

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(2 marks)

(c) The Arrhenius equation shows how the rate constant, *k*, for a reaction varies with temperature, *T*.

$$k = Ae^{\frac{-E_a}{RT}}$$

For the reaction between 0.0534 mol dm^{-3} **F** and 0.0624 mol dm^{-3} **G** at 25 °C, the activation energy, E_a, is 16.7 kJ mol^{-1}.

Use section 2 of the data booklet and your answer to part (b) to calculate a value for the Arrhenius constant, *A*, for this reaction.

Give your answer to the appropriate number of significant figures.

(If you did not get an answer for (b), you may assume that *k* has a value of 4.97. This is **not** the correct answer)

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(2 marks)

(d) The temperature of the reaction is increased to twice the original temperature, T_1. The value of k increases to 0.28 mol^{-1} dm^3 s^{-1} at this new temperature.

Using sections 1 and 2 of the data booklet and your answer to part (b), determine the original temperature, T_1.

(If you did not get an answer for (b), you may assume that k = 16700 mol^{-1} dm^3 s^{-1} This is **not the correct answer)**

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(2 marks)

3 (a) The rate constant for a reaction doubles when the temperature is increased from 25.0 °C to 35 °C.

Calculate the activation energy, E_a, in kJ mol^{-1} for the reaction using section 1 and 2 of the data booklet.

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(2 marks)

(b) The rate constant is 6.2 x 10^3 s^{-1} when the temperature is reduced by a factor of a fifth from the original starting temperature, 25 °C.

Calculate the rate constant, in min^{-1}, using sections 1 and 2 of the data booklet.

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(2 marks)

(c) A different reaction route is used which reduces the activation energy of the reaction.

Explain how the rate constant calculated in part(b) would differ.

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(2 marks)