1. Every year, two million tonnes of ethanol are produced worldwide by hydration of ethene obtained from crude oil.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \qquad \Delta H = -45\ kJ\ mol^{-1}$$

This reaction is typically carried out using a catalyst at 300 °C and 6000 kPa.

The catalyst allows the reaction to reach equilibrium more quickly at the given temperature and pressure.

i. State the catalyst used in this reaction.

[1]

ii. Outline how a catalyst increases the rate of a chemical reaction.

[2]

2. Which statement explains why the rate of a reaction increases when the temperature is increased?

A. The activation energy for the reaction decreases.
B. The activation energy for the reaction increases.
C. The proportion of molecules exceeding the activation energy decreases.
D. The proportion of molecules exceeding the activation energy increases.

Your answer

[1]

3. The following reaction is used in industry to make sulfur trioxide gas, SO_3.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H^{\ominus} = -196\ kJ\ mol^{-1}$$

This preparation is carried out in the presence of a catalyst.

* Explain the conditions of temperature and pressure that could be used to obtain the maximum equilibrium yield of sulfur trioxide.
Discuss the importance of a compromise between equilibrium yield and reaction rate when deciding the operational conditions for this process.

[6]

4. Reaction rates can be increased or decreased by changing the temperature of the reaction. **Fig. 17.1** below shows the energy distribution of the reactant molecules at 25 °C.

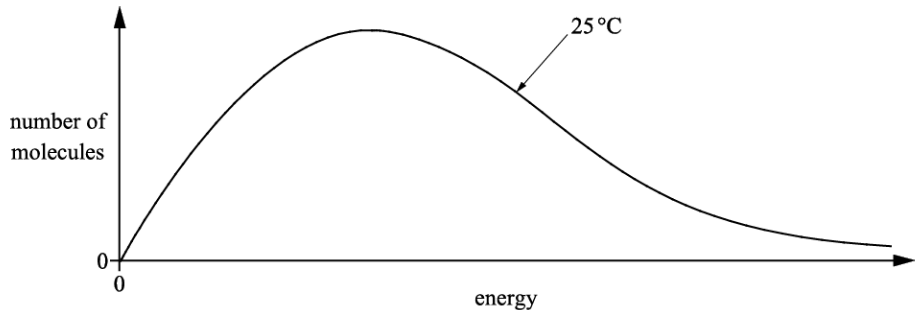


Fig. 17.1

Draw a second curve on **Fig. 17.1**, to represent the distribution of the same number of molecules at a higher temperature.

Use your curve to explain how increasing the temperature increases the rate of reaction.

[2]

5(a). An experiment is carried out to find the rate of this reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

The results of the experiment are given in the table below:

Time / s	0	50	100	150	200	250	300	350
Concentration of SO_3 / mol dm^{-3}	0	0.024	0.034	0.038	0.039	0.040	0.041	0.041

i. Plot a graph from the data provided.
Include a line of best fit.

[3]

ii. Use the graph to determine the **initial** rate of this reaction.
Show your working below and on the graph.

initial rate = ...mol dm^{-3} s^{-1} **[2]**

iii. This experiment is repeated in the presence of a catalyst.
Draw and label a line **on the graph** to show the results of the catalysed experiment over the same time period.

[1]

(b). A solid catalyst, vanadium(V) oxide, V_2O_5, is used in industry to increase the rate of the production of sulfur trioxide, SO_3, in this reaction.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H^{\ominus} = -196 \text{ kJ mol}^{-1}$$

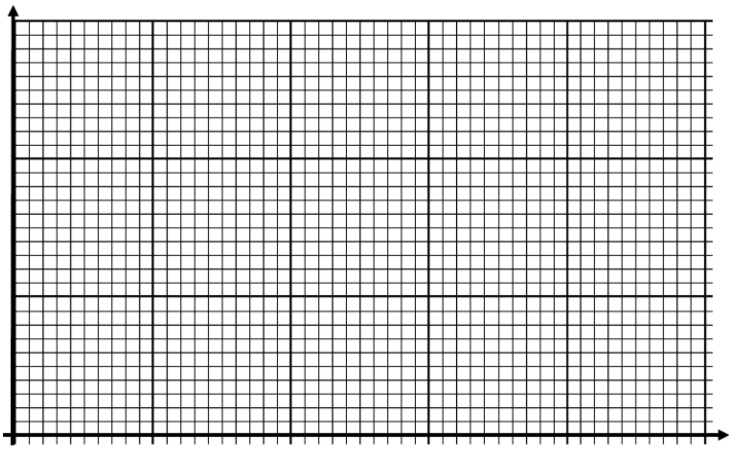
i. Explain, with a reason, whether V_2O_5 is a homogeneous or heterogeneous catalyst.

[1]

ii. The use of catalysts in industrial processes can be beneficial to the environment.
State **one** reason for this.

[1]

iii. Using a fully labelled Boltzmann distribution on the grid below, explain why adding a catalyst increases the rate of a reaction.



[4]

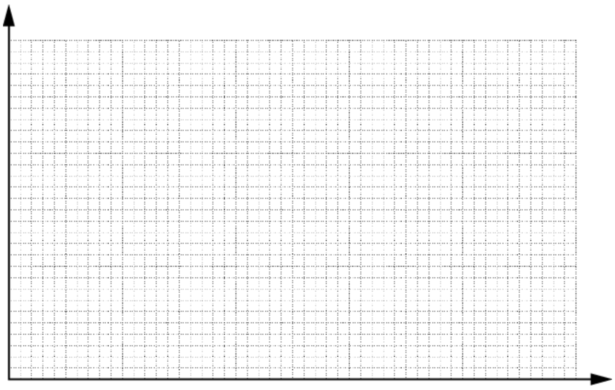
6. Reaction rates can be increased or decreased by changing conditions of temperature and pressure.

i. Explain how increasing the temperature increases the rate of reaction.

Include a labelled sketch of the Boltzmann distribution, on the grid below.

Label the axes.

Your answer needs to be clear and well organised using the correct terminology.



[4]

ii. Describe and explain the effect of decreasing the pressure on the rate of a reaction.

[2]

7(a). Methanol, CH_3OH, is an important feedstock for the chemical industry.

In the manufacture of methanol, carbon dioxide and hydrogen are reacted together in the reversible reaction shown below.

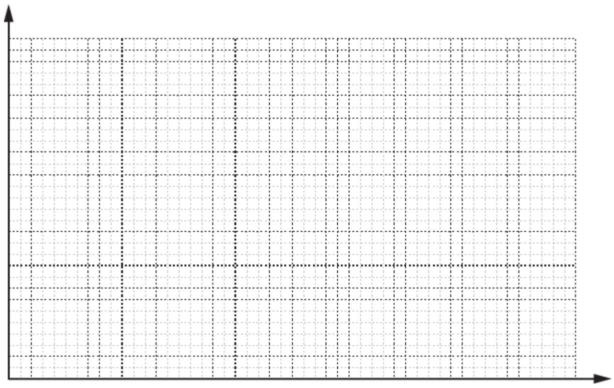
$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \qquad \Delta H = -49\ \text{kJ mol}^{-1}$$

Describe and explain the effect of increasing the pressure on the reaction **rate**.

[2]

(b). The manufacture of methanol uses a catalyst.

- Sketch a labelled diagram of the Boltzmann distribution on the grid provided.
- Label your axes.
- Using your Boltzmann distribution, explain how the catalyst increases the rate of reaction.



[4]

(c). Explain why the use of a catalyst can reduce the demand for energy.

[1]

8(a). Ethyne gas, C_2H_2, is manufactured in large quantities for a variety of uses.

Much of this ethyne is manufactured from methane as shown in the equation below.

$$2CH_4(g) \rightleftharpoons C_2H_2(g) + 3H_2(g) \qquad \Delta H = +377\ \text{kJ mol}^{-1}$$

Write an expression for K_c for this equilibrium.

[1]

(b). A research chemist investigates how to improve the synthesis of ethyne from methane at a high temperature.

- The chemist adds CH_4 to a 4.00 dm^3 container.
- The chemist heats the container and allows equilibrium to be reached at constant temperature. The total gas volume does not change.
- The equilibrium mixture contains 9.36×10^{-2} mol CH_4 and 0.168 mol C_2H_2.

i. Calculate the amount, in mol, of H_2 in the equilibrium mixture.

amount of H_2 = ... mol **[1]**

ii. Calculate the equilibrium constant, K_c, at this temperature, including units.

Give your answer to **three** significant figures.

K_c = ... units ....**[3]**

iii. Calculate the amount, in mol, of CH_4 that the chemist originally added to the container.

amount of CH_4 = ... mol **[1]**

(c). The chemist repeats the experiment three times.
In each experiment the chemist makes **one** change but uses the **same** initial amount of CH_4.

Complete the table to show the predicted effect of each change compared with the original experiment.

Only use the words **greater, smaller** or **same**.

Change	K_c	**Equilibrium amount of C_2H_2(g) / mol**	**Initial rate**
The container is heated at constant pressure			
A smaller container is used			
A catalyst is added to CH_4 at the start			

[3]

9(a). A student investigates the reaction between strontium carbonate and dilute nitric acid.

$$SrCO_3 + 2HNO_3 \rightarrow Sr(NO_3)_2 + CO_2 + H_2O$$

The rate of reaction is determined from the loss in mass over a period of time.

i. Explain why there is a loss in mass during the reaction.

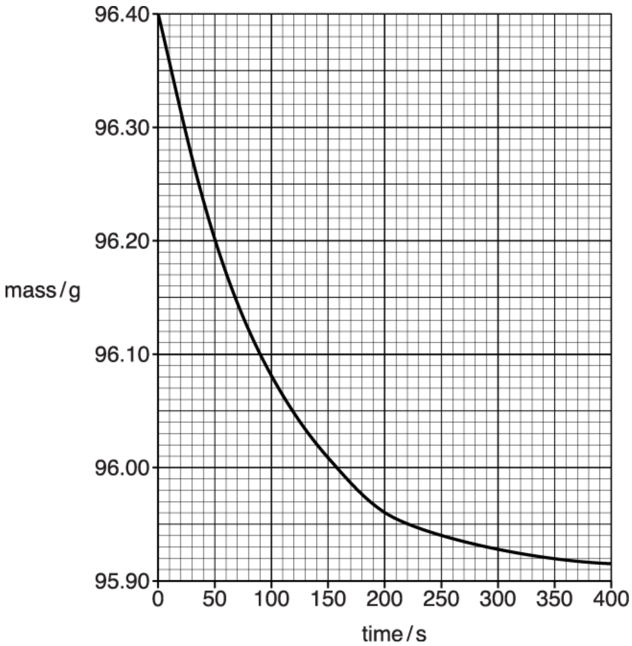
[1]

ii. An excess of strontium carbonate, $SrCO_3$, is mixed with 20.0 cm^3 of 1.25 mol dm^{-3} nitric acid, HNO_3.

Calculate the mass of $SrCO_3$ that reacts with the HNO_3.

mass = ... g **[3]**

(b). The student plots a graph of total mass (reagents + container) against time.



i. Describe and explain the change in the rate of the reaction during the first 200 seconds of the experiment.

[2]

ii. Using the graph, calculate the rate of reaction, in g s^{-1}, at 200 seconds.

Show your working on the graph.

rate of reaction = ... g s^{-1} **[2]**

(c). Outline a method that could be used to obtain the results that are plotted on the graph.

Your answer should include the apparatus required and the procedure for the experiment.

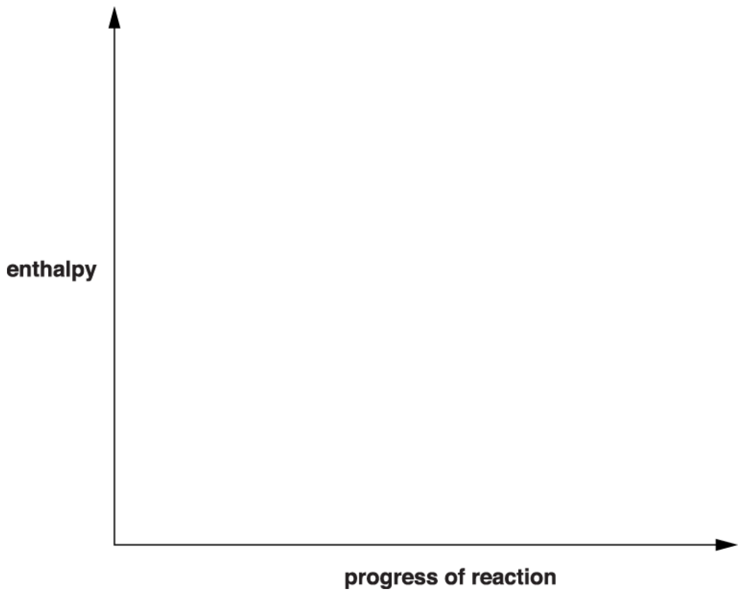
[3]

10(a). Catalysts can be used to change the rate of some chemical reactions.

i. Zinc and sulfuric acid react together to form a solution of zinc sulfate, $ZnSO_4$, and hydrogen gas. The reaction is exothermic.

The rate of the reaction increases when a catalyst is added.

- Complete the enthalpy profile diagram for this reaction using the formulae of the reactants and products.
- Label activation energies, E_a (without catalyst) and E_c (with catalyst).
- Label the enthalpy change of reaction, **Δ***H*.

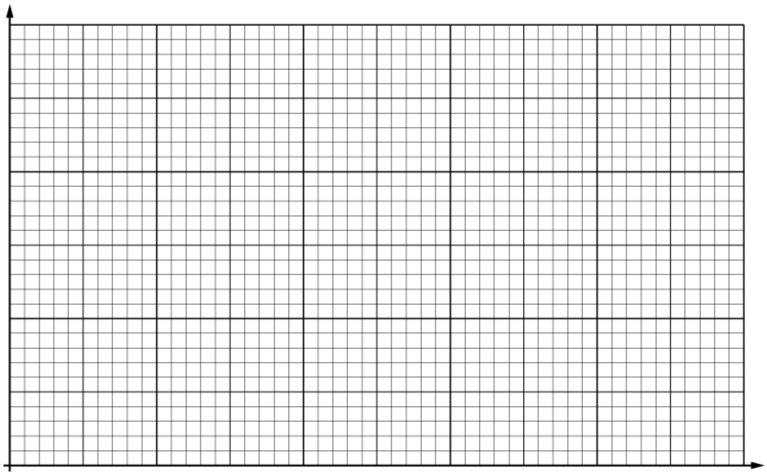


[3]

ii. Using a Boltzmann distribution, explain how a catalyst increases the rate of a chemical reaction.

Include a labelled sketch of your Boltzmann distribution on the grid below. Label the axes and any other important features.

Your answer needs to be clear and well organised using the correct terminology.



[4]

(b). The chemical industry uses catalysts for many of its reactions.

i. State an example of a catalyst used by the chemical industry and write the equation for the reaction that is catalysed.

catalyst ....

equation ....

[1]

ii. State **two** ways that the use of catalysts helps chemical companies to make their processes more sustainable and less harmful to the environment.

[2]

11(a). Hydrogen peroxide reacts with iodide ions in acid conditions, as shown below.

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

A student investigates the rate of this reaction by carrying out four experiments at the same temperature. The student's results are shown below.

Experiment	$[H_2O_2(aq)]$ / mol dm^{-3}	$[I^-(aq)]$ / mol dm^{-3}	$[H^+(aq)]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.0010	0.20	0.10	5.70×10^{-6}
2	0.0020	0.20	0.10	1.14×10^{-5}
3	0.0020	0.20	0.20	1.14×10^{-5}
4	0.0040	0.40	0.10	4.56×10^{-5}

The rate equation is: *rate* = *k* $[H_2O_2(aq)]\ [I^-(aq)]$

- Show that the student's results support this rate equation.
- Calculate the rate constant, *k,* for this reaction.

  Give your answer to **two** significant figures, in standard form and with units.

In your answer you should make clear how the experimental results provide evidence for the rate equation.

[6]

(b). The student concluded that $H^+(aq)$ ions act as a catalyst.

Explain why the student's conclusion is **not** correct.

[1]

(c). A four-step mechanism has been proposed for this reaction.
The rate-determining step is the first step.

i. State what is meant by the term *rate-determining step.*

[1]

ii. The equation for **Step 3** in the four-step mechanism is shown below.

Suggest equations for the other three steps.
State symbols are **not** required.

Step 1: ....

Step 2: ....

Step 3: $HIO + I^- \rightarrow I_2 + OH^-$

Step 4: ....

[3]

12. Methane is an important raw material for manufacturing chemicals. Hydrogen can be manufactured from methane and steam as shown below in **equation 17.1**.

$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ $\Delta H = +210 \text{ kJ mol}^{-1}$ **Equation 17.1**

The rate of reaction is increased by using a catalyst.

*Using the Boltzmann distribution model, explain why the rate of the reaction is increased in the presence of a catalyst and suggest the benefits of using a catalyst for energy demand and the environment.

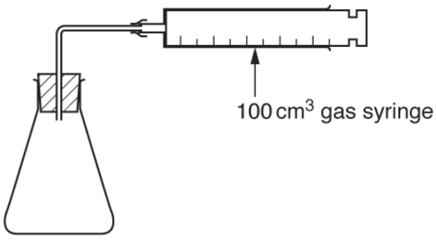
[6]

13. A student was asked to carry out an experiment to determine the initial rate of reaction of zinc and hydrochloric acid.

The student plans to collect a total of about 72 cm^3 of hydrogen at RTP and to use an excess of zinc.

The student selects the following apparatus:

- the apparatus shown in the diagram
- 100 cm^3measuring cylinder
- stop clock
- 2 decimal place balance



Outline how the student could carry out the experiment and explain how the results could be processed graphically.
Show all working in your calculations.

[6]

14. Solutions of hydrogen peroxide decompose slowly into water and oxygen:

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

This reaction is catalysed by manganese dioxide, $MnO_2(s)$.

Standard electrode potentials are shown below.

$O_2(g) + 2H^+(aq) + 2e^-$	⇌	$H_2O_2(aq)$	$E^\theta = +0.70$ V
$MnO_2(s) + 4H^+(aq) + 2e^-$	⇌	$Mn^{2+}(aq) + 2H_2O(l)$	$E^\theta = +1.51$ V
$H_2O_2(g) + 2H^+(aq) + 2e^-$	⇌	$2H_2O(l)$	$E^\theta = +1.78$ V

Using the electrode potentials, explain how MnO_2 is able to act as a catalyst for the decomposition of hydrogen peroxide.

Your answer should include relevant equations.

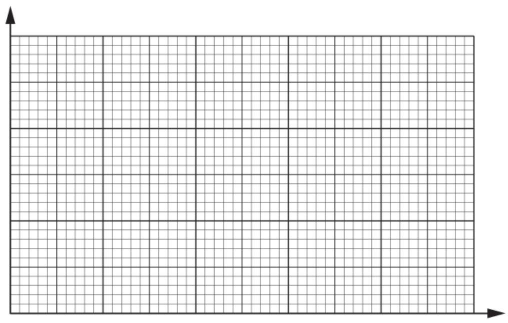
[4]

15(a). Methanol can be prepared industrially by reacting carbon monoxide with hydrogen in the presence of a copper catalyst. This is a reversible reaction.

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH\ (g)$

Using the Boltzmann distribution model, explain why the rate of a reaction increases in the presence of a catalyst.

You are provided with the axes below, which should be labelled.



[4]

(b). The reaction for the production of methanol in the presence of the copper catalyst is carried out at 200–300 °C.

Explain why use of the catalyst reduces energy demand and benefits the environment.

[2]

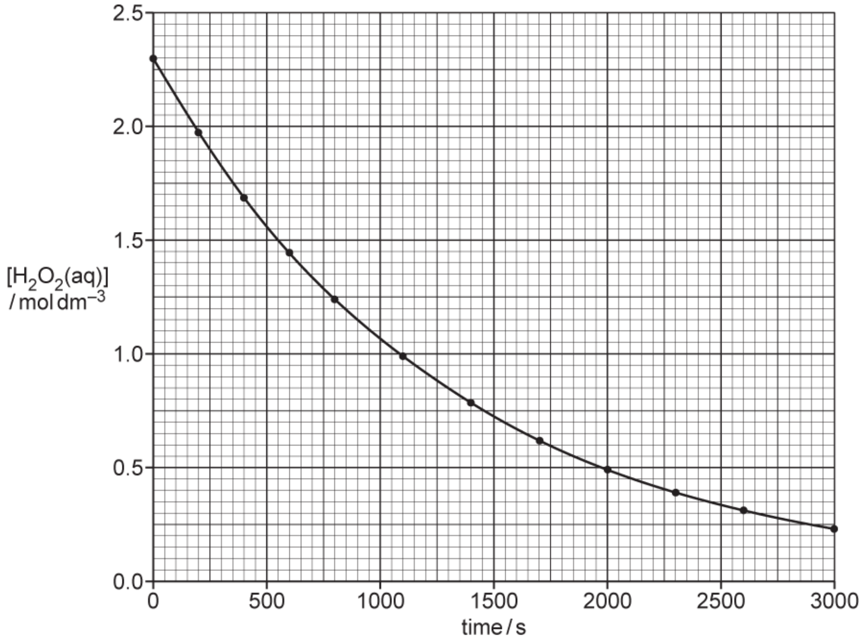
16(a). Aqueous solutions of hydrogen peroxide, $H_2O_2(aq)$, decompose as in the equation below.

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

A student investigates the decomposition of $H_2O_2(aq)$ by measuring the volume of oxygen gas produced over time. All gas volumes are measured at room temperature and pressure.

The student uses 25.0 cm^3 of 2.30 mol dm^{-3} H_2O_2.

From the results, the student determines the concentration of $H_2O_2(aq)$ at each time. The student then plots a concentration–time graph.



Determine the total volume of oxygen, measured at room temperature and pressure, that the student should be prepared to collect in this investigation.

Suggest apparatus that would allow this gas volume to be collected, indicating clearly the scale of working.

[3]

(b). Aqueous solutions of hydrogen peroxide, $H_2O_2(aq)$, decompose as in the equation below.

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

A student investigates the decomposition of $H_2O_2(aq)$ by measuring the volume of oxygen gas produced over time. All gas volumes are measured at room temperature and pressure.

The student uses 25.0 cm^3 of 2.30 mol dm^{-3} H_2O_2.

From the results, the student determines the concentration of H2O2(aq) at each time. The student then plots a concentration–time graph.

Suggest a different experimental method that would allow the rate of this reaction to be followed over time.

[1]

17. Nitrogen can be reacted with hydrogen in the presence of a catalyst to make ammonia in the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92 \text{ kJ mol}^{-1}$$

Describe and explain the effect of increasing the pressure on the rate of this reaction.

[2]

18. Which statement(s) explain(s) why reaction rates increase as temperature increases?

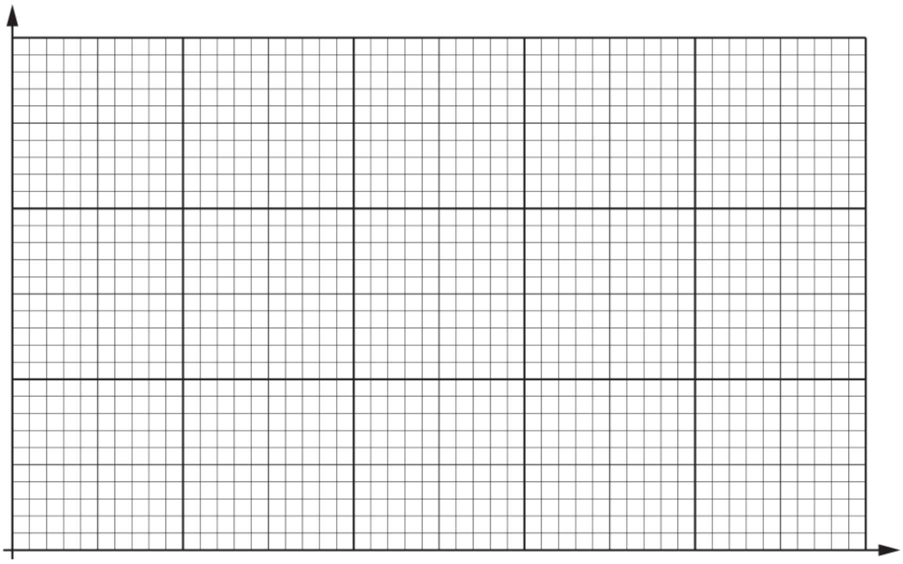
1 The activation energy is less.
2 Collisions between molecules are more frequent.
3 A greater proportion of molecules have energy greater than the activation energy.

A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer **[1]**

19. Using the Boltzmann distribution model, explain how the rate of a reaction is affected by temperature.

You are provided with the axes below, which should be labelled.



[4]

20. What is the **main** reason for the increase in reaction rate with increasing temperature?

A The activation energy decreases.
B The activation energy increases.
C More molecules have an energy greater than the activation energy.
D The molecules collide more frequently.

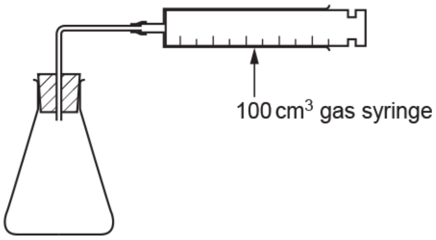
Your answer ☐ **[1]**

21(a). Zinc reacts with hydrochloric acid, HC*l*(aq), as shown in the following equation.

$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

A student investigates the rate of this reaction.

The student uses the apparatus in the diagram.



The student's method is outlined below:

- Pour 50.0 cm^3 of 0.100 mol dm^{-3} HC*l* into the conical flask.
- Add 0.200 g of zinc (an excess), and quickly attach the delivery tube and gas syringe.
- Measure the volume of gas collected every 20 seconds until the reaction stops.

The student obtains the results shown in **Table 4.1**.

Time / s	0	20	40	60	80	100	120	160	200
Volume of gas / cm^3	0	16	27	37	39	50	53	58	58

Table 4.1

(i) On the graph paper in **Fig. 4.1**, label the x axis **and** plot the results in **Table 4.1.** **[1]**

(ii) Circle any anomalous results present in the graph you have drawn in **Fig. 4.1.** **[1]**

(iii) Draw a best-fit smooth curve on the graph you have drawn in **Fig. 4.1.** **[1]**

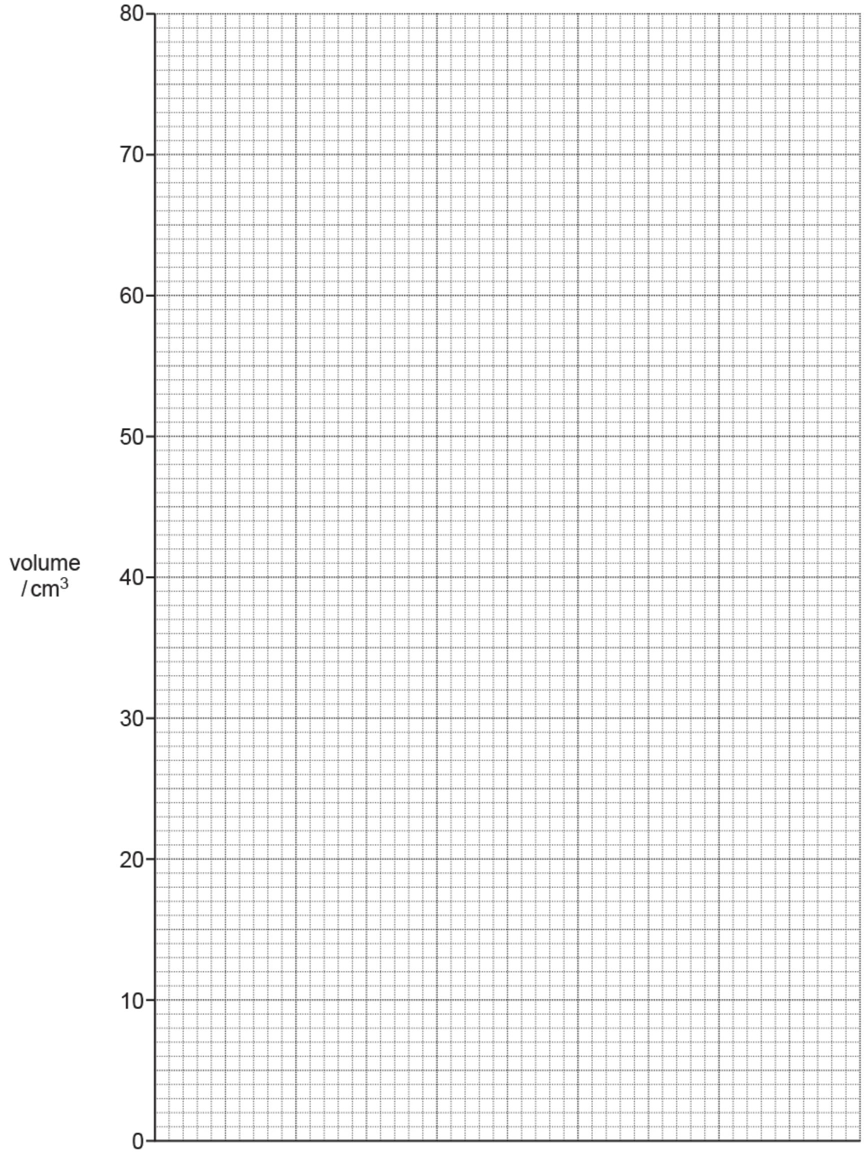


Fig. 4.1

(b). The student repeats the experiment using:

- zinc with the same mass (0.200 g) and same surface area
- the same temperature and pressure
- 40.0 cm^3 of 0.125 mol dm^{-3} HC*l*, instead of 50.0 cm^3 of 0.100 mol dm^{-3} HC*l*.

On your graph in **Fig. 4.1** sketch the curve you would expect in this experiment. **[2]**

(c). The graph shows that rate of reaction decreases over time.

Explain why, in terms of collision theory.

[2]

(d).

i. The rate of the reaction between zinc and hydrochloric acid can be increased using a solution of copper(II) sulfate as a catalyst.

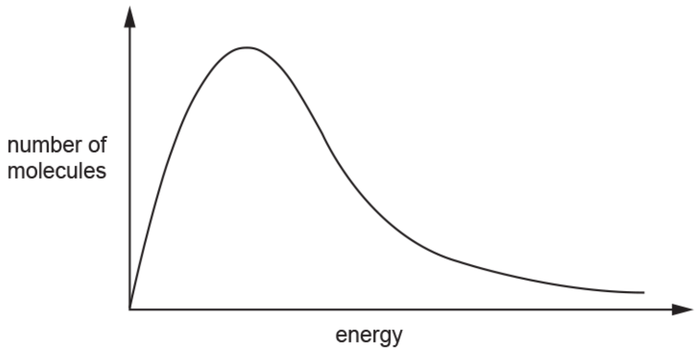
Explain how a catalyst increases the rate of reaction.

[2]

ii. Why is it difficult to classify the solution of copper(II) sulfate as a homogeneous or heterogeneous catalyst in this reaction?

[1]

22. The diagram represents a Boltzmann distribution curve of molecules at a given temperature.



Which statement for this Boltzmann distribution curve is correct at a higher temperature?

A The peak increases in height and moves to the left.
B The peak increases in height and moves to the right.
C The peak decreases in height and moves to the left.
D The peak decreases in height and moves to the right.

Your answer **[1]**

23. Methanol, CH3OH, can be made industrially by the reaction of carbon monoxide with hydrogen, as shown in **equilibrium 1**.

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H = -91 \text{ kJ mol}^{-1}$ **Equilibrium 1**

A catalyst is used in the production of methanol in **equilibrium 1**.

State **two** ways that the use of catalysts helps chemical companies to make their processes more sustainable and less harmful to the environment.

1 ______________________________

____

2 ______________________________

____

[2]

24. A student investigates the reaction between ethanoic acid, $CH_3COOH(l)$ and methanol, $CH_3OH(l)$, in the presence of an acid catalyst. The equation is shown below.

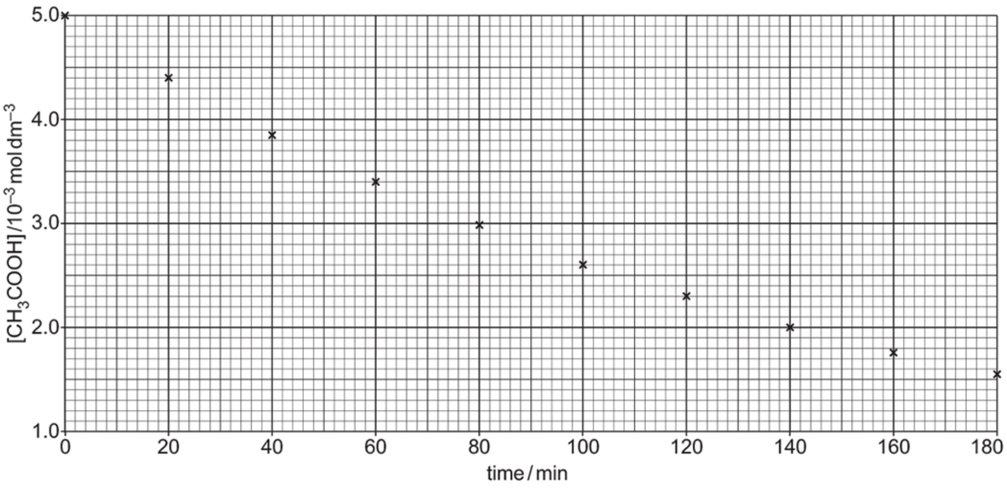
$CH_3COOH(l) + CH_3OH(l) \rightleftharpoons CH_3COOCH_3(l) + H_2O(l)$

The student carries out an experiment to determine the order of reaction with respect to CH_3COOH.

The student uses a large excess of CH_3OH. The temperature is kept constant throughout the experiment.

The student takes a sample from the mixture every 20 minutes, and then determines the concentration of the ethanoic acid in each sample.

From the experimental results, the student plots the graph below.



i. Explain why the student uses a large excess of methanol in this experiment.

[1]

ii. Use the half-life of this reaction to show that the reaction is first order with respect to CH_3COOH.

Show your working on the graph and below.

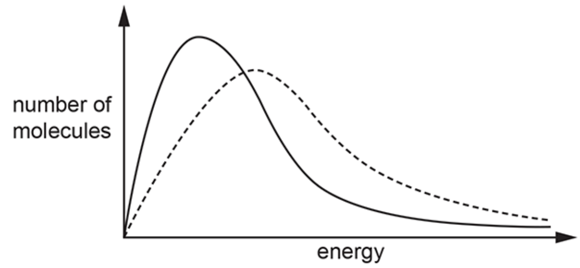
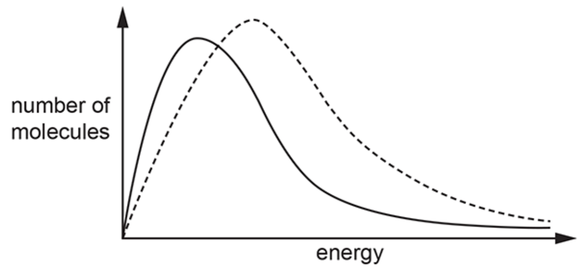
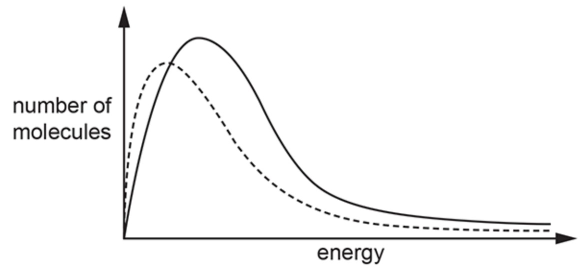
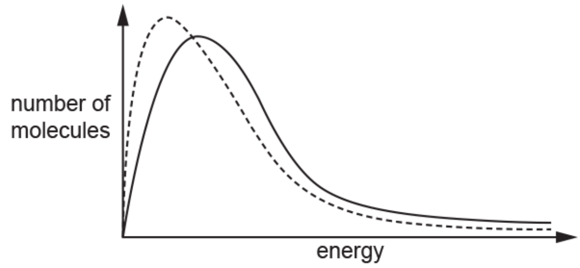
[2]

iii. Determine the initial rate of reaction.

initial rate = ... mol dm^{-3} min^{-1} **[2]**

25. The Boltzmann distributions below show a gas at two different temperatures.

Which Boltzmann distribution shows the dotted curve at a higher temperature?

A	
B	
C	
D	

Your answer ☐ **[1]**

26. Methanol, CH_3OH, is manufactured by the reaction of carbon monoxide, CO, with hydrogen, H_2.

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H = -91\ kJ\ mol^{-1}$

The industrial manufacture of methanol has used a copper-based catalyst.

Chemists have recently developed a new method for making methanol that uses a nickel-gallium catalyst. This allows methanol to be produced at a lower temperature than the old method.

Suggest **two** reasons why using a lower temperature is beneficial to the environment.

1

2

[2]

27(a). A student investigates the rate of reaction between strontium and water.

$Sr(s) + 2H_2O(l) \rightarrow Sr(OH)_2(aq) + H_2(g)$

The student's method is shown below.

- Pour 100 cm^3 of water into a conical flask.
- Add 0.26 g of strontium and quickly connect a 100 cm^3 gas syringe.
- Measure the volume of gas produced every 10 seconds until all the strontium has reacted.

The student plots a graph of volume of gas produced against time as shown in **Fig. 6.1**.

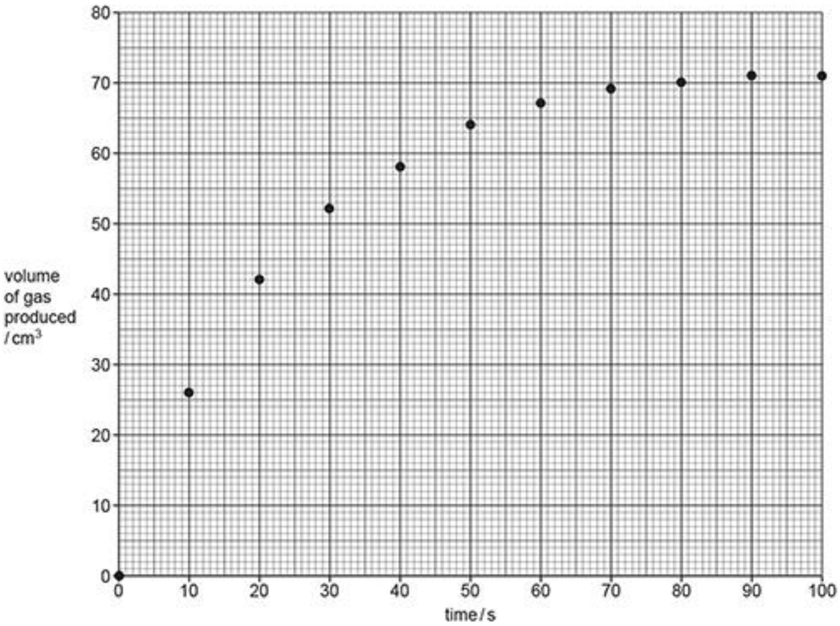


Fig. 6.1

Draw a best fit curve on **Fig. 6.1**.
Use the graph to determine the rate of reaction, in $cm^3\ s^{-1}$, at 50 s.

Show your working below and on the graph.

rate at 50 s .... $cm^3\ s^{-1}$ **[3]**

(b). A second student suggests that the experiment could be improved by measuring the loss in mass in the conical flask over time.

The student places a conical flask containing 100 cm^3 of water on a 2 decimal place balance, and then adds 0.26 g of strontium.

The mass is recorded every 10 seconds.

Suggest **one** advantage and **one** disadvantage of using this method compared to the gas collection method.

Advantage:

Disadvantage:

[2]

(c). A third student repeats the original experiment using the same amount, in moles, of barium as strontium.

i. Calculate the mass of barium that the student uses.
Give your answer to **2** decimal places.

mass of barium = ... g **[2]**

ii. The student observes that the rate of reaction for barium is different from the rate of reaction with strontium.

On **Fig. 6.1** sketch the graph the student would obtain using barium instead of strontium.

[2]

iii. Describe and explain the difference in reactivity of barium and strontium with water.

[4]

28. This question is about chemical equilibrium.

Nitrogen monoxide, NO, and oxygen, O_2, react to form nitrogen dioxide, NO_2, in the reversible reaction shown in **Equilibrium 20.1**.

Equilibrium 20.1 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H = -114\ kJ\ mol^{-1}$
$\Delta S = -147\ J\ mol^{-1}\ K^{-1}$

A chemist investigates the equilibrium shown in **Equilibrium 20.1**.

The chemist mixes together 1.60 mol of NO(g) and 1.50 mol of $O_2(g)$ in a container and the mixture is allowed to reach equilibrium.

At equilibrium:

- 75% of the NO(g) has been converted to NO_2(g)
- the total pressure is 1.21 MPa.

i. Calculate K_p, in MPa^{-1}, for **Equilibrium 20.1**.

Give your answer to 3 significant figures.

K_p = ... MPa^{-1} **[4]**

ii. The chemist then repeats the experiment three times. In each experiment, the chemist makes **one** change but uses the same initial amounts of NO and O_2.

Complete the table to show the predicted effect of each change compared with the original experiment.

Only use the words **greater, smaller** or **same**.

Change	K_p	Equilibrium amount of NO_2(g)	Initial rate
Temperature increase			
Pressure increase			
Catalyst added			

[3]

29. Two students plan to investigate **Equilibrium 4.1**, shown below.

$CoCl_4^{2-}(aq) + 6H_2O(l) \rightleftharpoons [Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq)$ **Equilibrium 4.1**

blue pink

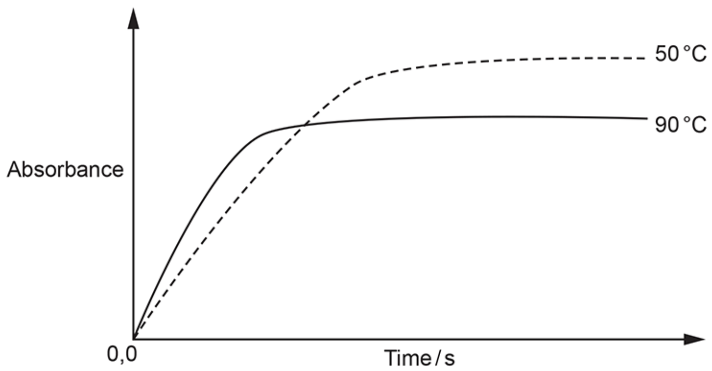
The students are supplied with the equilibrium mixture in **Equilibrium 4.1** at room temperature.

- One student heats 20 cm^3 of the mixture to 50°C.
- The other student heats 20 cm^3 of the mixture to 90°C.

The students use colorimetry to observe how the colour of the equilibrium mixture changes over time.

- The colorimeter is set up so that the greater the absorbance, the greater the concentration of $[Co(H_2O)_6]^{2+}$.
- The initial absorbance is set to zero.
- The absorbance is recorded every 30 seconds.

The students plot the graph below from the results of the experiment.



Use the graph and relevant chemical theory to answer the following. Include all reasoning:

- Explain the different initial rates at 50°C and 90°C.
- Predict the sign of Δ*H* for the forward reaction in **Equilibrium 4.1**.

[4]

30(a). A student investigates some reactions of zinc compounds and zinc metal.

The student investigates the rate of reaction between zinc carbonate, $ZnCO_3(s)$, and dilute hydrochloric acid, $HCl(aq)$.

$ZnCO_3(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + CO_2(g) + H_2O(l)$

The student follows the method outlined below:

- Add 50 cm^3 of dilute $HCl(aq)$ into a conical flask at 20°C.
- Place the flask on a top-pan balance.

- Add an excess of $ZnCO_3(s)$ to the flask.
- Record the mass of the flask and contents on the top-pan balance every 30 seconds.

The student plots a graph of mass against time, shown in **Fig. 3.1** below.

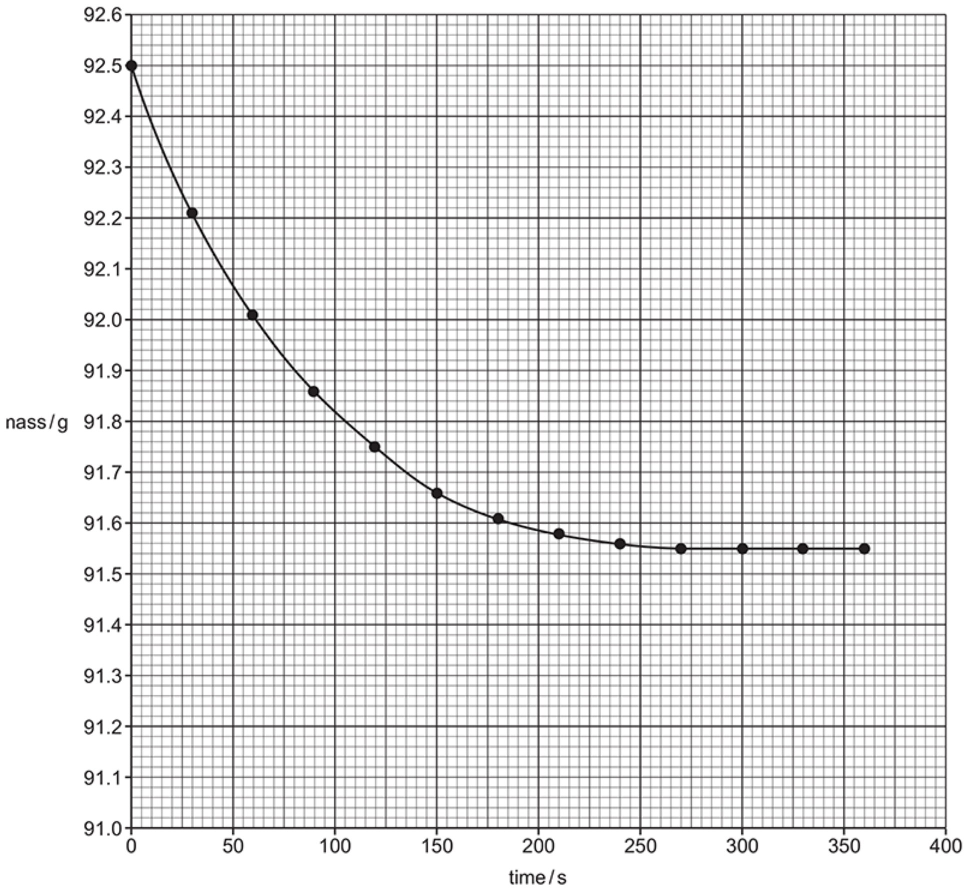


Fig. 3.1

i. The graph shows that the reaction gets slower over time, and eventually stops.

Explain why, in terms of collision theory.

[3]

ii. Using the graph in **Fig. 3.1**, find the rate of reaction, in g s^{-1}, at 50 seconds.

Show your working on the graph and in the space below.

rate of reaction = ... g s^{-1} **[2]**

iii. The student repeats the experiment but heats 50 cm^3 of dilute hydrochloric acid up to 40°C before adding the $ZnCO_3(s)$.

On **Fig. 3.1**, sketch the curve the student would obtain. **[2]**

(b). The student investigates the reaction between zinc and dilute sulfuric acid.

$$Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g) \qquad \Delta H = -140 \text{ kJ mol}^{-1}$$

Copper(II) sulfate is a catalyst for this reaction.

- The student adds a piece of zinc to each of two test tubes.
- The student adds a few drops of aqueous copper(II) sulfate to one of the test tubes, forming a pale blue solution.
- The student adds an excess of dilute sulfuric acid to each test tube.

i. Describe two differences the student would observe between the test tubes.

1

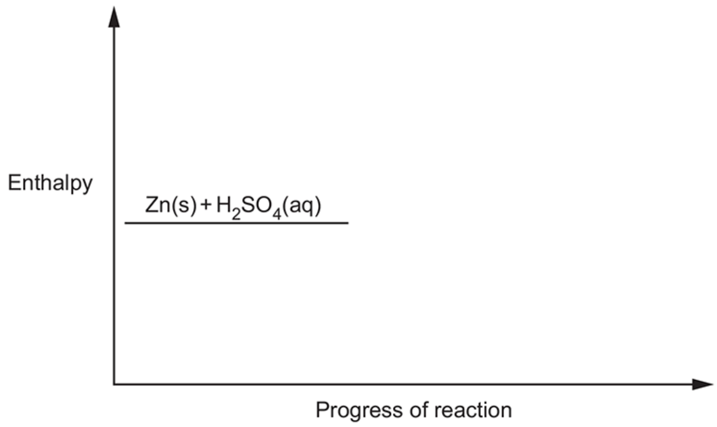
2

[2]

ii. Using the axes below, sketch an enthalpy profile diagram for the reaction with and without the catalyst.

On your diagram, include the following labels:

- ΔH, the enthalpy change
- E_a, the activation energy **without** a catalyst
- E_c, the activation energy **with** a catalyst.



[3]

31. Which prediction can be made using le Chatelier's principle?

A The effect of a catalyst on the reaction rate.
B The effect of a catalyst on the equilibrium position.
C The effect of temperature on the reaction rate.
D The effect of concentration on the equilibrium position.

Your answer ☐ **[1]**

32. A catalytic converter in a car removes nitrogen monoxide, NO, and carbon monoxide, CO, from the exhaust gases.

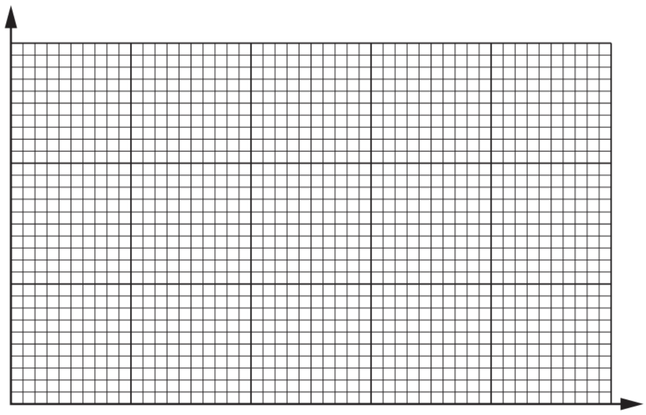
One reaction that happens in a catalytic converter is shown below.

$2CO(g) + 2NO(g) \rightarrow N_2(g) + 2CO_2(g)$ **Reaction 16.1**

i. Explain how increasing the temperature increases the rate of **Reaction 16.1**.

Include a labelled sketch, using Boltzmann distributions, on the grid below.

Label the axes.



[3]

ii. The rate of **Reaction 16.1** is investigated by carrying out three experiments at the same temperature. The results are shown below.

Experiment	[NO(g)]/moldm^{-3}	[CO(g)]/moldm^{-3}	Initial rate/moldm^{-3} s^{-1}
1	2.75×10^{-4}	7.25×10^{-4}	1.85×10^{-4}
2	5.50×10^{-4}	7.25×10^{-4}	7.40×10^{-4}
3	1.10×10^{-3}	2.90×10^{-3}	1.18×10^{-2}

Determine the orders with respect to NO and CO, the rate equation, and the rate constant, *k*, including units.

Explain your reasoning.

k = ... units .... **[5]**

33. The Boltzmann distribution model can be used by chemists to explain how the rate of a reaction is affected by temperature.
Fig. 25.1 shows the Boltzmann distribution for a gas at room temperature.

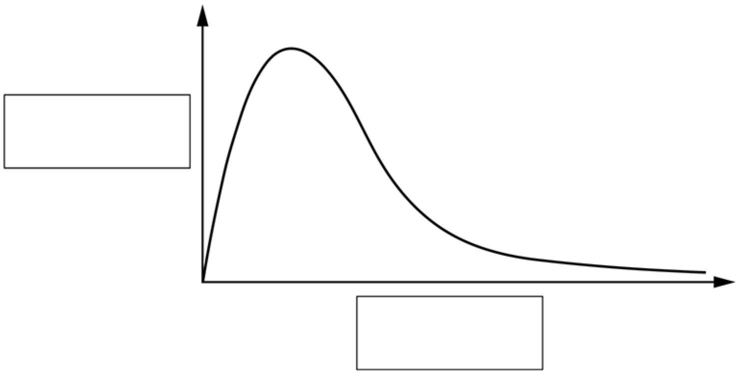
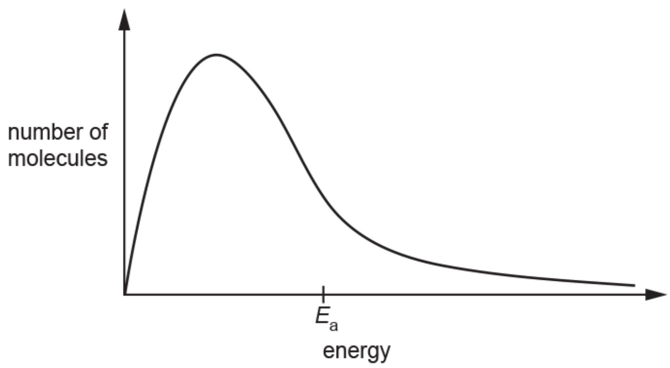


Fig. 25.1

Label the axes on **Fig. 25.1** and add a second curve to show the Boltzmann distribution of the gas at a higher temperature.
Explain why the Boltzmann distribution shows that the rate of a reaction is affected by temperature.

[3]

34. The Boltzmann distribution showing the activation energy, E_a, for an uncatalysed reaction is shown below.



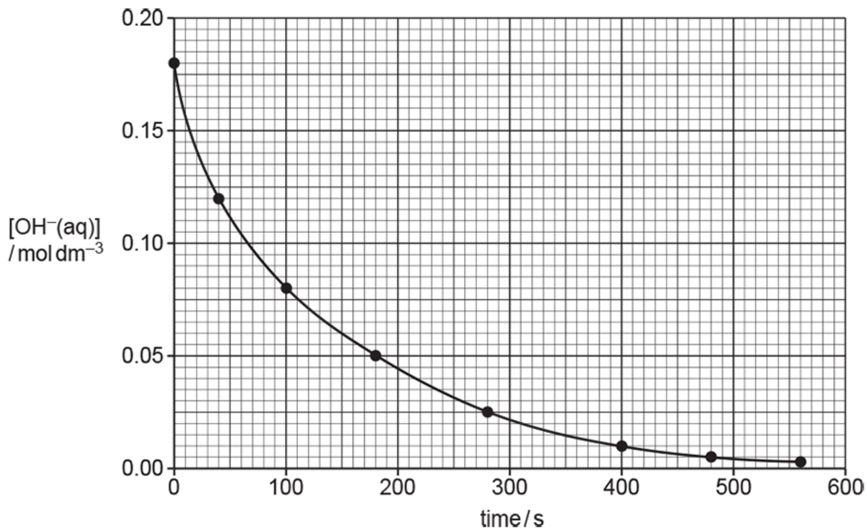
What is the difference for the **catalysed** reaction?

A The activation energy shifts to the left.
B The activation energy shifts to the right.
C The curve flattens.
D The curve shifts to the right.

Your answer [1]

35. A student measures how the OH^- concentration changes over time for a reaction.

The student plots the graph below.



What is the rate of reaction, in mol dm^{-3} s^{-1}, at 200s?

A 2.2×10^{-4}
B 2.8×10^{-4}
C 1.8×10^{-3}
D 4.4×10^{-2}

Your answer [ ] **[1]**

36. This question is about enthalpy changes.

In a petrol engine, alkanes undergo combustion.

i. Heptane is one of the alkanes in petrol.

Write the equation for the complete combustion of heptane.

State symbols are **not** required.

[2]

ii. In a petrol engine, polluting gases such as CO and NO are formed. These are mostly removed before being emitted from the exhaust.

The equation for the removal of CO and NO is shown below.

$2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)$ $\Delta H = -746$ kJ mol^{-1}

Complete the enthalpy profile diagram in **Fig. 23.1** for this reaction.

On your diagram:

- Label the enthalpy change of reaction, ΔH.
- Include the formulae of the reactants and products.
- Label the activation energy, E_a.

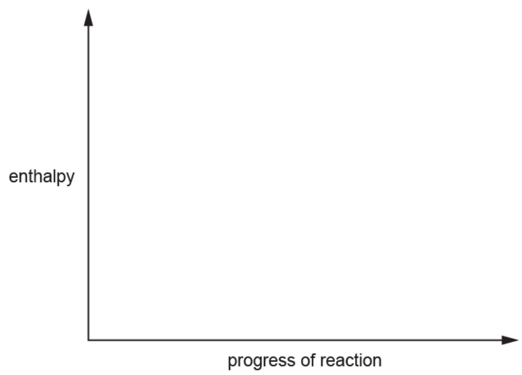


Fig. 23.1

[2]

iii. CO and NO are removed by use of a catalyst.

Explain the role of the catalyst.

Refer to your enthalpy profile diagram in **Fig. 23.1** in your answer.

[2]

37. The reaction below is first order with respect to reactant **X**.

X(aq) → products

When the initial concentration of **X** is 1.0 mol dm^{-3}, the half-life is 16 minutes.

What is the half-life when the initial concentration of **X** is 2.0 mol dm^{-3}?

A 2 minutes
B 4 minutes
C 8 minutes
D 16 minutes

Your answer **[1]**

38. Bromine, Br_2, can be produced by the reaction:

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

A student investigates the rate of this reaction by carrying out four experiments at the same temperature. The student's results are shown below.

Experiment	[Br^-] / mol dm^{-3}	[BrO_3^-] / mol dm^{-3}	[H+] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	2.00×10^{-2}	1.20×10^{-1}	8.00×10^{-2}	2.52×10^{-4}
2	6.00×10^{-2}	1.20×10^{-1}	8.00×10^{-2}	7.56×10^{-4}
3	4.00×10^{-2}	6.00×10^{-2}	8.00×10^{-2}	2.52×10^{-4}
4	2.00×10^{-2}	6.00×10^{-2}	4.00×10^{-1}	3.15×10^{-3}

Explain how the reaction orders can be determined from the student's results, and determine the rate equation and rate constant for this reaction.

[6]

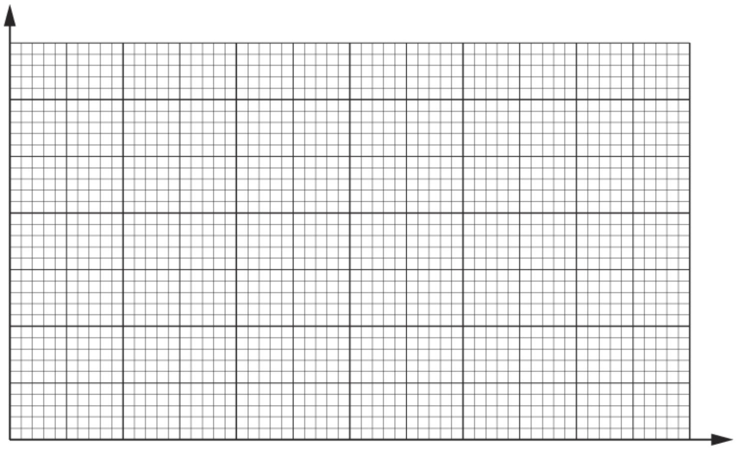
39(a). Aqueous hydrogen peroxide, $H_2O_2(aq)$, gradually decomposes to produce water and oxygen.

$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$ $\Delta H = -196\ kJ\ mol^{-1}$ **Equation 4.1**

The rate of decomposition of H_2O_2 can be increased by adding a small amount of manganese(IV) oxide, MnO_2, which acts as a catalyst.

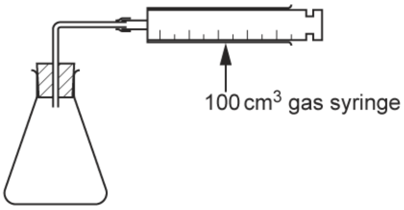
Explain, using a Boltzmann distribution model, why the rate of a reaction increases in the presence of a catalyst.

You are provided with the axes below, which you should label.

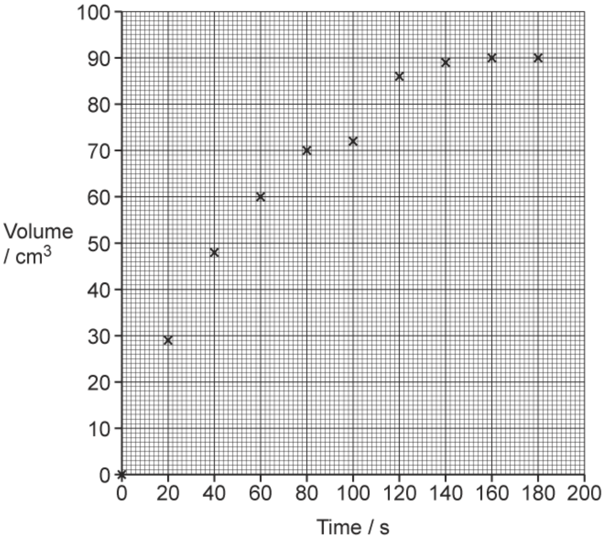


[4]

(b). A student investigates the rate of decomposition of H_2O_2, on addition of MnO_2 catalyst, using a gas syringe.



The student obtains the results shown in **graph 4.1.**



Graph 4.1

i. On **graph 4.1**, draw a best-fit smooth curve of the results **and** circle the anomalous result.

[2]

ii. Use your graph to determine the rate of reaction, in $cm^3\ s^{-1}$, at 50 s.

Show your working below and on the graph.

rate = ... $cm^3\ s^{-1}$ **[2]**

iii. The student uses 50.0 cm^3 of H_2O_2 in the experiment. **Equation 4.1** shows the reaction that takes place.

$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$ **Equation 4.1**

Calculate the concentration of H_2O_2, in mol dm^{-3}, required to produce 90 cm^3 of $O_2(g)$ at RTP.

concentration = ... mol dm^{-3} **[3]**

(c). A student plans to compare the rate of decomposition of H_2O_2 using different metal oxides as the catalyst.

Suggest **two** variables which should be kept constant.

1

2 **[2]**

40. Which row in the table explains how a catalyst affects the activation energy (E_a) and the proportion of molecules with energy > E_a?

	How the activation energy changes	**Proportion of molecules with energy > E_a**
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

Your answer ☐ **[1]**

41(a). This question is about energy changes.

Hydrogen peroxide decomposes as shown in **Reaction 16.1**.

$H_2O_2(l) \rightarrow H_2O(l) + \frac{1}{2}O_2(g)$ **Reaction 16.1**

The table shows enthalpy changes of formation and entropies.

	$\Delta H_f^{\ominus}$/kJ mol^{1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
$H_2O_2(l)$	−188	110
$H_2O(l)$	−286	70.0
$O_2(g)$	0	205

i. Calculate the free-energy change, ΔG, in kJ mol^{-1}, of **Reaction 16.1** at 25 °C.

Give your answer to **3** significant figures.

ΔG = ... kJ mol^{-1} **[4]**

ii. The decomposition of hydrogen peroxide shown in **Reaction 16.1** is feasible.

Suggest why **Reaction 16.1** does **not** take place at 25 °C despite being feasible.

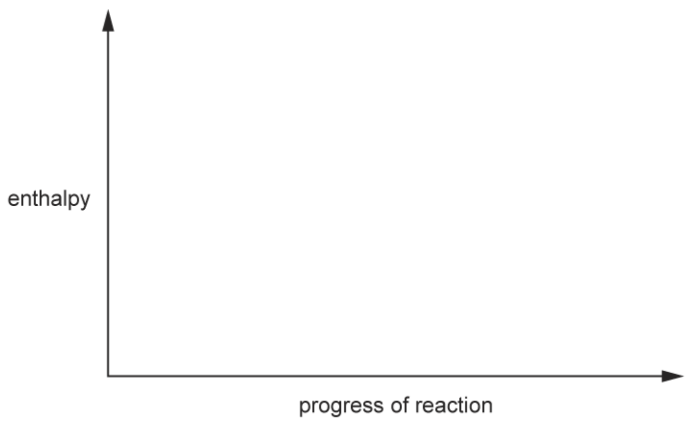
[1]

(b). The rate of decomposition of hydrogen peroxide shown in **Reaction 16.1** can be increased by adding a small amount of powdered manganese(IV) oxide, MnO_2.

The MnO_2 acts as a catalyst.

i. Complete the enthalpy profile diagram for **Reaction 16.1** using formulae for the reactants and products.

- Use E_a to label the activation energy **without** MnO_2.
- Use E_c to label the activation energy **with** MnO_2.
- Use ΔH to label the enthalpy change of reaction.



[3]

ii. Explain why MnO_2 is described as a **heterogeneous** catalyst for this reaction.

[1]

iii. Mn_3O_4 is a compound in which Mn has two different oxidation states. The two oxidation states are different from the Mn in MnO_2.

Suggest the two oxidation states of manganese in Mn_3O_4.

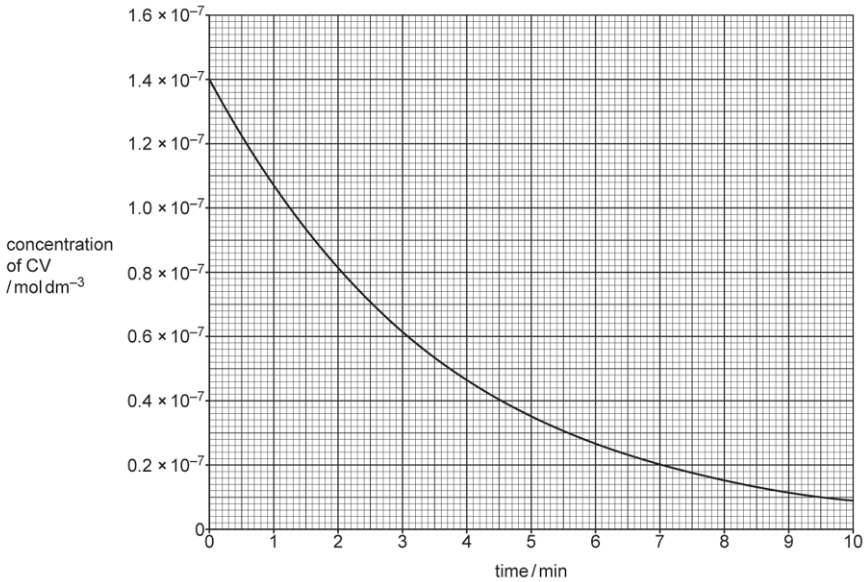
[1]

42(a). Crystal violet (CV) is a purple dye. In the presence of an alkali, CV reacts to form a colourless product.

A student uses a colorimeter to investigate the rate of the reaction between CV and sodium hydroxide, NaOH.

- The student mixes 10.0 cm^3 of 2.8×10^{-7} mol dm^{-3} CV with 10.0 cm^3 of 0.016 mol dm^{-3} NaOH.
- A large excess of NaOH is used, so that the reaction is effectively zero-order with respect to OH^- ions.
- The student places a sample of the reaction mixture in a colorimeter and measures the absorbance over time.

The student uses the absorbance readings to calculate the concentration of CV and plots a graph of concentration of CV against time, as shown below.



Using collision theory, explain why the gradient decreases over time.

[1]

(b). Use the graph to determine the order of reaction with respect to CV, the rate of the reaction at three minutes and the rate constant, *k*.

Your answer must show full working on the graph and on the lines below.

[6]

43. A mixture of gases is heated in a closed container. The reaction rate increases.

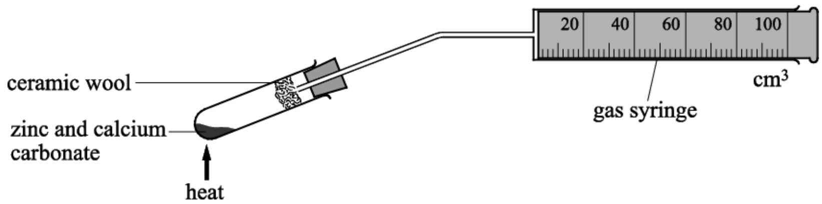
Which statement explains why the rate increases?

A More molecules have an energy greater than the activation energy.
B The activation energy decreases.
C The activation energy increases.
D The concentration of the gases increases.

Your answer ☐ **[1]**

44. Carbon monoxide can be made in the laboratory by heating a mixture of zinc metal and calcium carbonate. An equation for this reaction is shown below.

$$Zn(s) + CaCO_3(s) \rightarrow ZnO(s) + CaO(s) + CO(g)$$



The student repeated the experiment in **(c)** using different quantities of zinc and calcium carbonate.

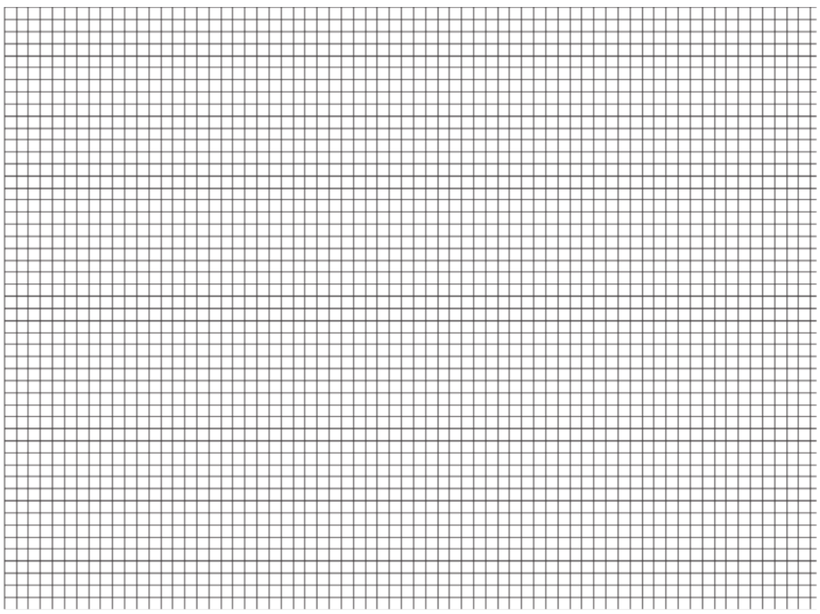
The student measured the total volume of gas collected over time.

The student's results are shown below.

Time / s	**Total volume of gas collected / cm^3**
0	0
20	13
40	42
60	56
80	65
100	72
120	72

i. Plot a graph from the data provided.

Include a line of best fit.



[3]

ii. Using the graph, determine the rate of reaction, in $cm^3\ s^{-1}$, after 50 s.

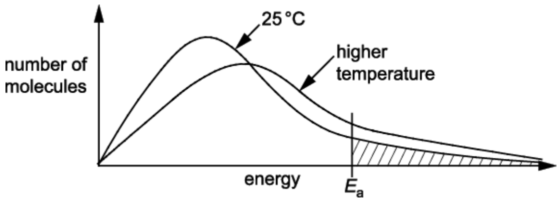
Show your working on your graph.

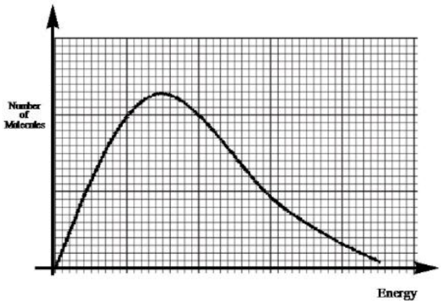
rate after 50 s = ... $cm^3\ s^{-1}$ **[2]**

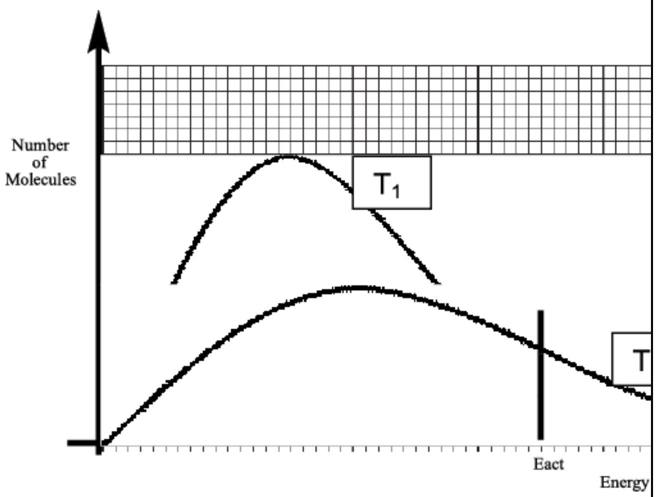
END OF QUESTION PAPER

Mark scheme

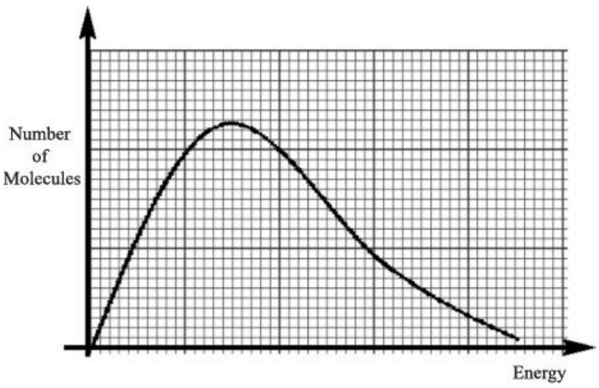
Question			Answer/Indicative content	Marks	Guidance
1		i	phosphoric acid / H_3PO_4	1	if both name and formula are given, the formula must be correct, but **allow** minor errors in an attempt at the name
		ii	(allows the reaction to proceed via a route with) lower activation energy … (1) … so that a greater proportion of molecules exceed the activation energy (1)	2	**allow** a sketch of an energy profile diagram as long as the catalysed and uncatalysed E_a are both labelled **allow** 'more molecules exceed the activation energy' **allow** a sketch of a Boltzmann distribution as long as both axes and both E_a values are labelled
			Total	**3**	
2			D	1	
			Total	**1**	
3			** Please refer to the marking instruction point 10 for guidance on how to mark this question.* **(Level 3)** All/most points covered and clearly linked. Must have points taken across all of the headings in the indicative points for Level 3. *The explanations show a well-developed line of reasoning linked to appropriate suggestions which is clear and logically structured. The compromises are relevant and well thought out and clearly linked to the explanations.* (5–6 marks) **(Level 2)** Suggests correct conditions with explanations **OR** comments on compromises with reference to yield **AND** rate effect. *The explanations are linked to appropriate suggestions and show a line of reasoning with some structure. The compromises are relevant but may not be clearly linked to the explanation.* (3–4 marks)	6	**Indicative scientific points may include** Yield • Increasing pressure increases yield of SO_3 • Decreasing temperature increases yield of SO_3 Explanation • (pressure) more moles / molecules on the reactant side **ORA** • (temp.) the forward reaction is exothermic **ORA** Rate • Increasing pressure increases rate • Increasing temperature increases rate

			(Level 1) Comments on conditions with some explanation **OR** comments on compromise with reference to yield **OR** rate. *The comments about yield / rate with explanation are basic and communicated in an unstructured way. The compromises may not be relevant with lack of reasoning.* (1–2 marks) No response or no response worthy of credit. (0 marks)		Compromise • Choose a higher temperature which creates a reduced yield but in a shorter space of time **ignore** reference to increase pressure leading to safety / cost issues
			Total	**6**	
4			 Correct curve for higher temperature (1) Activation energy shown on diagram **AND** graph shows that at higher temperature *(owtte)* more molecules have energy above activation energy **OR** more molecules have enough energy to react (1)	2	Boltzmann distribution – must start at origin and must not end up at 0 on *y*-axis i.e. must not touch *x*-axis at high energy maximum of curve to right **AND** lower than maximum of lower temperature curve **AND** above lower temp line at higher energy as shown in diagram link to graph required for mark
			Total	**2**	
5	a	i	Time plotted along *x*-axis **AND** sensible scale that uses most of graph paper **AND** both axes labelled (1) Points plotted accurately (1) Correct curve of best fit (1)	3	
		ii	Evidence of tangent drawn correctly on the graph from the origin (1) (0.023/25) = 9.2×10^{-4} (mol dm^{-3} s^{-1}) (1)	2	**allow** answer between 8×10^{-4} and 1×10^{-3} **allow** answer from line drawn through origin and data point at 50 s: 0.024/50 = 4.8×10^{-4}
		iii	(Differ) initial gradient steeper **AND** (Same) curve reaches same height	1	look on graph paper for this answer
	b	i	The catalyst / vanadium(V) oxide / V_2O_5 is solid while the reactants are gases, so the catalyst is in a different state from the reactants.	1	

		ii	Catalysts lower the energy demand for a reaction **OR** Less combustion of fossil fuels and therefore lower carbon dioxide emissions **OR** Allows different reactions to take place with greater atom economy / less waste **OR** Allows less toxic chemicals to be used	1	
		iii	*Boltzmann distribution (2 marks)*  Correct drawing of a Boltzmann distribution i.e. curve must start within the first small square nearest to the origin **AND** must not touch the *x*-axis at high energy (1) Axes labelled (number of) molecules and (kinetic) energy (1) *Explanation (2 marks)* Catalyst (provides an alternative route) **AND** with a lower activation energy (1) (With a catalyst) more molecules have energy above activation energy **OR** greater area under curve above the activation energy	4	candidates do not need E_a on graph **ignore** a slight inflexion on the curve **do not allow** two curves **allow** particles instead of molecules on *y*-axis **do not allow** enthalpy for *x*-axis label **do not allow** atoms instead of particles or molecules **allow ecf** for the subsequent use of atoms (instead of molecules or particles) **allow** annotations on Boltzmann distribution diagram **ignore** more molecules have enough energy to react (as not linked to E_a) **ORA** if states the effect with no catalyst **ignore** (more) successful collisions
			Total	**12**	

6		i	 axes labelled (number of) molecules and (kinetic) energy ✓ Correct drawing of a two Boltzmann distributions i.e. both curves must start within the first small square nearest to the origin **AND** must not touch the x axis at high energy ✓ Drawing of Boltzmann distribution at **two** different temperatures with higher and lower temperature clearly identified (ie $T_2 > T_1$) ✓ **QWC** - (At a higher temperature) more molecules have energy above activation energy **OR** greater area under the curve above the activation energy✓	4	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** Candidates do not need Ea on graph **ALLOW** particles instead of molecules on the y axis **DO NOT ALLOW** atoms instead of particles / molecules **ALLOW ECF** for the incorrect use of atoms (instead of molecules / particles) **DO NOT ALLOW** enthalpy on the x-axis **DO NOT ALLOW** increase of more than one small square at high energy end of curve. Maximum of curve for higher temperature to right **AND** lower than maximum of lower temperature curve **AND** above lower temp line at higher energy Higher temp line should intersect lower temp line once **DO NOT ALLOW lower** activation energy **QWC** requires more molecules have or exceed activation energy / E_a. **IGNORE** more molecules have enough energy to react for the **QWC** mark (as not linked to E_a) **ORA** if states the effect when the temperature is lower **IGNORE** (more) successful collisions **Examiner's Comments** Candidates are very familiar with the Boltzmann distribution curve and there were many examples of excellent diagrams to illustrate the effect of increasing the temperature on the rate

					of reaction. Occasionally curves that did not start at the origin and/or ended up touching the x- axis were seen, but these were less common than in previous sessions. Candidates should be aware that, when two curves are required, each curve should be clearly labelled. Unlabelled curves was a common reason why candidates only scored three marks and not four.
		ii	(Decreasing the pressure) decreases the rate of reaction **AND** Decreased concentration of molecules **OR** Number of molecules remains the same but the volume increases **OR** Less molecules per (unit) volume ✓ Less **frequent** collisions ✓	2	**Correct effect on rate must be linked to reason for the first marking point.** **ALLOW** molecules are further apart **IGNORE** less crowded **ALLOW** particles or atoms for molecules **ALLOW** 'space' for volume **DO NOT ALLOW** area instead of volume **ALLOW** collisions occur less often **OR** decreased rate of collision **IGNORE** less chance of collisions 'less collisions' alone is **not** sufficient **IGNORE** successful **Examiner's Comments** Most candidates recognised that a decrease in pressure would lower the concentration of the particles resulting in a decreased rate of reaction. The examiners were encouraged that a significant proportion of the cohort scored the second mark by relating the decreased rate with the frequency of collisions, rather than vaguer responses just in terms of collisions.
			Total	**6**	
7	a		Increased rate **AND**	2	**ALLOW** particles for molecules **IGNORE** atoms **Response must imply a volume and not area** **ALLOW** more molecules in the **same**

			greater concentration of molecules / more molecules per (unit) volume ✓ More collisions per second / more frequent collisions ✓		**space** **OR** more molecules in the **same volume** **OR** same number of molecules in a **smaller volume** **IGNORE** molecules are closer together (*no idea of volume*) **ALLOW** collisions more often **OR** increased rate of collision **IGNORE** more chance of collisions 'more collisions' alone is **not** sufficient (*no rate*) **IGNORE** 'successful' **Examiner's Comments** The effect of pressure on reaction rate is well known by candidates at this level and many candidates scored one or two marks in this part. The examiners were encouraged that a significant proportion of the cohort scored the first mark by relating the increased rate to the increased concentration of the molecules, rather than vaguer responses in terms of the relative proximity of the molecules. Weaker responses focused on the equilibrium rather than an explanation of how the rate is affected. Candidates are advised to take note of key terms in questions, especially those in bold, as they often give guidance as to what is expected.
	b		 Correct drawing of Boltzmann distribution curve ✓	4	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** Curve must start at origin. The limit of acceptability is that the curve must start within the first small square nearest the origin. Curve must not touch the x-axis at higher energy **IGNORE** a slight inflexion on the curve

			Axes labelled: y axis: (number of) molecules **AND** x axis: energy ✓ Catalyst lowers the activation energy (by providing an alternative route) ✓ (With a catalyst a) greater proportion of molecules with energy greater than activation energy **OR** (With a catalyst a) greater proportion of molecules with energy equal to the activation energy ✓		**DO NOT ALLOW** two curves **DO NOT ALLOW** a curve that bends up at the end by more than one small square **ALLOW** particles instead of molecules on y axis **DO NOT ALLOW** enthalpy for x-axis label **DO NOT ALLOW** atoms instead of particles or molecules **ALLOW ECF** for the subsequent use of atoms (instead of molecules or particles) **ALLOW** annotations on Boltzmann distribution diagram **ALLOW** (with a catalyst) more molecules have sufficient energy to react **IGNORE** (more) successful collisions **Examiner's Comments** Candidates are very familiar with the Boltzmann distribution curve and there were many examples of excellent diagrams. The majority of candidates scored maximum marks in this part. Failure to identify that more molecules have an energy greater than the activation energy when a catalyst is used, was a common reason why only three marks were scored.
	c		Allows reactions to take place at lower temperatures ✓	1	**ALLOW** less heat (required) **IGNORE** references to pressure **IGNORE** references to less energy (*in question*) e.g. lowers E_a **Examiner's Comments** The strongest candidates identified that lower temperatures could be used with a catalyst and hence reduce the energy demand of a reaction.

			Total	7	
8	a		$(K_c =) \frac{[C_2H_2]\,[H_2]^3}{[CH_4]^2}$ ✓	1	Square brackets are **essential** State symbols **not** required. **IGNORE** incorrect state symbols **Examiner's Comments** The K_c expression was shown correctly by almost all candidates, the only mistakes being the very occasional inverted expression or use of "+' within the denominator.
	b	i	amount of H_2 = 3 × 0.168 = 0.504 (mol) ✓	1	**Examiner's Comments** The correct answer of 0.504 mol was seen in the majority of scripts but examiners were also presented with many other responses. The key was use of the 1:3 molar ratio of C_2H_2 and H_2 formed in the equilibrium mixture, with simple multiplication of 0.168 by 3 giving the correct answer. The commonest incorrect answer was 0.1404 from 3/2 × 9.36 × 10^{-2}: from use the molar ratio of moles CH_4 formed and H_2 formed. Answer: 0.504 mol
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 0.153 mol^2 dm^{-6}, award **3 marks** **IF** answer = 0.153 with incorrect units, award **2 marks** .... **IF answer from 3(b)(i) for *n*(H_2) ≠ 0.504, mark by ECF.** **Equilibrium concentrations** (from *n*(H_2) = 0.504 mol dm^{-3}) $[CH_4]$ = 2.34 × 10^{-2} (mol dm^{-3}) **AND** $[C_2H_2]$ = 4.20 × 10^{-2} (mol dm^{-3}) **AND** $[H_2]$ = 0.126 (mol dm^{-3}) ✓ **Calculation of K_c and units** $K_c = \frac{4.20 \times 10^{-2} \times (0.126)^3}{(2.34 \times 10^{-2})^2}$ = 0.153 ✓ mol^2	3	*FULL ANNOTATIONS MUST BE USED* .... **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below .... **ALLOW** ÷ by 4 of equilibrium amounts in all expressions, i.e. **ALLOW** $[CH_4] = \frac{9.36 \times 10^{-2}}{4}$ mol dm^{-3} **AND** $[C_2H_2] = \frac{0.168}{4}$ mol dm^{-3} **AND** $[H_2] = \frac{0.504}{4}$ mol dm^{-3} ✓ **ALLOW ECF** from incorrect concentrations or from moles From moles: 9.36 × 10^{-2}, 0.168 and 0.504, K_c = 2.45 by **ECF**

			dm^{-6} ✓ **3 significant figures** are required		**ALLOW** dm^{-6} mol^2 **DO NOT ALLOW** mol^2/dm^6 **ALLOW ECF** from incorrect K_c expression for both calculation and units .... **COMMON ECF** From **3(b)(i)** answer of 0.1404, K_c = 3.32 x 10^{-3} 2 marks + units K_c = 0.0531 No ÷ 4 throughout 1 mark + units **Examiner's Comments** Many candidates are well-rehearsed for this type of question. Candidates were expected to use the equilibrium amounts, convert to concentrations by dividing by 4 and to use these values to obtain the K_c value. A common mistake was omission of the concentration stage, leading to a value of 2.45. More calculator errors were seen than in the past, perhaps caused by the cubed power within the numerator. Candidates without a cubed function key on the calculator can simply multiply a value with itself three times. Few candidates failed to express their numerical value for K_c to three significant figures. The units caused few problems although some inverted units were seen. Answer: 0.153 mol^2 dm^{-6}
		iii	**Initial amount of CH_4** amount of CH_4 = 9.36 × 10^{-2} + 2 x 0.168 = 0.4296 **OR** 0.43(0) (mol) ✓	1	**NO ECF** possible (all data given in question) **Examiner's Comments** Although this part was more challenging than the initial molar ratio in (b)(i), many candidates were able to work out the amount of CH_4 that had reacted as 2 × 9.36 × 10^{-2} and to then add this to the remaining amount of CH_4: 9.36 × 10^{-2}. This part did cause a lot of difficult for weaker candidates with a range of

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>incorrect numerical answers being seen.

Answer: 0.4296 mol</td></tr>
<tr><td></td><td>c</td><td></td><td>
<table>
<tr><th>Change</th><th>K_c</th><th>Equilibrium amount of C_2H_2 / mol</th><th>Initial rate</th></tr>
<tr><td>temperature increased</td><td>greater</td><td>greater</td><td>greater</td></tr>
<tr><td>smaller container</td><td>same</td><td>smaller</td><td>greater</td></tr>
<tr><td>catalyst added</td><td>same</td><td>same</td><td>greater</td></tr>
<tr><td></td><td>✓</td><td>✓</td><td>✓</td></tr>
</table>
</td><td>3</td><td>Mark by COLUMN

ALLOW obvious alternatives for greater / smaller / same, e.g.
increases / decreases;
more / less

Examiner's Comments

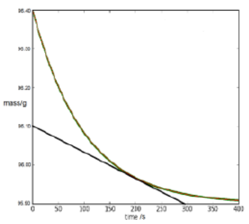
This part tested candidates understanding of how three quantities would change from changes to experimental conditions. This was marked by column.
Of the three quantities, K_c and rate were correct more often than the equilibrium amount of C_2H_2. This question discriminated extremely well. Strangely, some candidates chose to use their own words instead of those provided and examiners often saw words such as ‘increases’ and ‘decreases’. As the meaning was clear, such responses were still credited.</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>9</td><td></td></tr>
<tr><td>9</td><td>a</td><td>i</td><td>carbon dioxide lost/evolved/given off/or produced as a gas ✓</td><td>1</td><td>DO NOT ALLOW water or steam or CO_2 evaporates

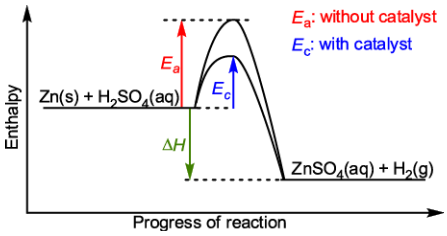
Examiner's Comments

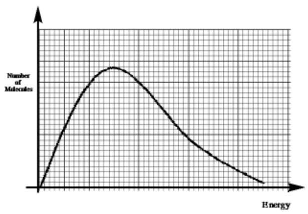
Candidates who failed to state that the gas being lost was CO_2 could not access the mark for this question. Vague answers relating to water being produced, products being gases, products being lost or a gas evolved were often given by Candidates.</td></tr>
<tr><td></td><td></td><td>ii</td><td>FIRST CHECK ANSWER ON THE ANSWER LINE
IF answer = 1.85 OR 1.845 g award 3 marks
……………………………………………………
$n(HNO_3)$

$= 1.25 \times \frac{20.0}{1000} = 0.0250$ mol ✓</td><td>3</td><td>If there is an alternative answer, check to see if there is any ECF credit possible</td></tr>
</table>

			$n(SrCO_3)$ $= \frac{0.0250}{2} = 0.0125$ mol ✓ $m(SrCO_3)$ = 0.0125 × 147.6 = 1.845 g **OR** 1.85 g ✓		**ALLOW ECF** from incorrect $n(HNO_3)$ molar mass of $SrCO_3$ = 147.6 (g mol^{-1}) **ALLOW ECF** from incorrect $n(SrCO_3)$ **Examiner's Comments** The vast majority of candidates were able to complete this calculation arriving at the correct answer to score all three available marks. The most common error was in calculating the amount, in moles, of the $SrCO_3$ from the stoichiometry given in the equation. This resulted in an answer which was twice that expected however two marks could still be obtained by applying error carried forward. Answer = 1.845 g or 1.85 g
	b	i	rate of reaction decreases **AND** concentration decreases / reactants are used up ✓	1	**ALLOW** reaction slows down **ALLOW** concentration of reactants decreases.
		i	less frequent collisions ✓	1	**ALLOW** fewer collisions per unit time **OR** collisions less often **OR** decreased rate of collision **IGNORE** less successful collisions / less collisions less chance of collisions **Examiner's Comments** Very few candidates were able to explain the change in the rate of the reaction during the first 200 seconds of the experiment. This relatively straightforward question required a statement that the rate decreases as the concentration of the reactants decreases due to there being less frequent collisions. Although a large number of candidates were able to state

					that the rate decreases few were able to explain why. This was possibly due to candidates having to apply their understanding in an unfamiliar context rather than from a lack of knowledge
		ii	Attempted tangent on graph drawn to line at approximately *t* = 200 s ✓	1	
		ii	Gradient (*y*/*x*) e.g. $\frac{0.20}{290}$ = 6.9×10^{-4} ✓ 	1	**ALLOW** 1 SF up to calculator value, in range 5×10^{-4} to 8×10^{-4} **IGNORE** units **IGNORE** sign **Examiner's Comments** This was the first time AS level candidates have been required to calculate a rate of reaction from a graph and many found this quite testing. Although many knew that a tangent was required only the most able candidates were able to arrive at a value for the gradient that was within the expected range. Candidates sometimes took as their values the point at which their tangent cut the axes rather than calculating the change in mass or change in time. Acceptable range 5×10^{-4} to 8×10^{-4}
	c		Flask **OR** beaker **AND** balance **AND** stopwatch **OR** stop clock **OR** other timing device ✓	1	**DO NOT ALLOW** round-bottomed flask. **IGNORE** weighing scales
			Records **mass** at time intervals ✓	1	**ALLOW** ‘weigh at time intervals’
			Time interval quoted between 10-50s ✓	1	**Examiner's Comments** This was the second question that required candidates to describe an experiment that they could have carried out as part of their course. Even if this experiment had not been completed in class, candidates should be able to recognise that mass needs to be

					measured over a period of time. As the reaction was between an acid and a carbonate a suitable named reaction vessel such as a beaker or flask was required. A balance was needed for mass measurement and a timing device to monitor time. A simple statement that mass should be recorded at a given time interval scored two marks with one mark being allocated to suitable apparatus. At this level it is expected that candidates will be familiar with the correct names for the apparatus required to carry out an investigation.
			Total	**11**	
10	a	i	 Zn and H_2SO_4 on LHS **AND** $ZnSO_4 + H_2$ on RHS ✓ ΔH labelled with product below reactant **AND** arrow downwards ✓ E_a **AND** E_c correctly labelled with E_c below E_a ✓	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **IGNORE** state symbols. ΔH: **DO NOT ALLOW** $-\Delta H$ **ALLOW** this arrow even if it has a small gap at the top and bottom i.e. does not quite reach reactant or product line E_a: **ALLOW** no arrowhead or arrowheads at both ends of activation energy line The E_a line must point to maximum (or near to the maximum) on the curve **OR** span approximately 80% of the distance between reactants and maximum regardless of position **ALLOW** AE or A_E for E_a **Examiner's Comments** Many candidates are well-prepared for this type of question however there are still some issues regarding the use of

					double headed arrows to indicate an enthalpy change. Whilst allowed by the examiners for showing activation energies, a correct single headed arrow was required to illustrate Δ*H*. A small proportion of candidates omitted hydrogen as a product, despite it being stated in the question.
		ii	 Correct drawing of a Boltzmann distribution curve ✓ Axes labelled y axis: (number of) molecules **AND** x axis: (kinetic) energy ✓ Catalyst lowers the activation energy (by providing an alternative route) ✓ **QWC** - (With a catalyst a) greater proportion of molecules with energy greater than activation energy **OR** (With a catalyst a) greater proportion of molecules with energy equal to the activation energy **OR** (With a catalyst there is a) greater area under curve above the activation energy ✓	4	**ANNOTATE ANSWER WITH TICKS AND CROSSES** Curve must start at origin. The limit of acceptability is that the curve must start within the first small square nearest the origin. Curve must not touch the x-axis at higher energy **IGNORE** a slight inflexion on the curve **DO NOT ALLOW** two curves **DO NOT ALLOW** a curve that bends up at the end by more than one small square **ALLOW** particles instead of molecules on y axis **DO NOT ALLOW** enthalpy for x-axis label **DO NOT ALLOW** atoms instead of particles or molecules **ALLOW ECF** for the subsequent use of atoms (instead of molecules or particles) **ALLOW** annotations on Boltzmann distribution diagram **QWC** requires more molecules have / exceed activation energy / E_a. **IGNORE** more molecules have enough energy to react for the **QWC** mark (as

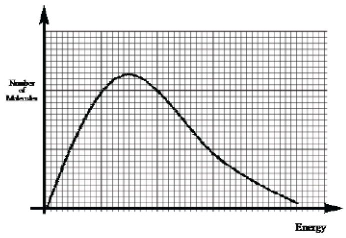
					not linked to E_a) **ORA** if states the effect with no catalyst **IGNORE** (more) successful collisions **Examiner's Comments** Candidates are very familiar with the Boltzmann distribution curve and there were many examples of excellent diagrams. The majority of candidates scored maximum marks in this part. Failure to identify that more molecules have an energy greater than the activaction energy when a catalyst is used, was a common reason why only three marks were scored.
	b	i	Catalyst (name or correct formula) **AND** balanced equation for the reaction catalysed ✓	1	Many possible responses but in practice it is likely that examples will be few, e.g. Fe **AND** $N_2 + 3H_2 \rightarrow 2NH_3$ V_2O_5/Pt **AND** $2SO_2 + O_2 \rightarrow 2SO_3$ H_2SO_4/H_3PO_4 **AND** $C_2H_4 + H_2O \rightarrow C_2H_5OH$ Hydrogenation of an alkene: e.g. Ni **AND** $C_2H_4 + H_2 \rightarrow C_2H_6$ Esterification: e.g. H_2SO_4 **AND** $CH_3COOH + C_2H_5OH \rightarrow CH_3COOC_2H_5 + H_2O$ **ALLOW** multiples for equation **Note:** the reaction chosen must be a feasible industrial reaction. If you see an alternative from the list above please contact your TL **Examiner's Comments** Most candidates were able to provide an equation for an industrial process with a suitable catalyst. The most frequent correct response was the use of Fe in the Haber process. Other common responses included the use of an acid catalyst for the preparation ethanol from ethene and Ni for the hydrogenation of an alkene.

		ii	**Any two from:** lower temperatures / lower pressures (can be used) ✓ lower energy demand **OR** uses less fuel **OR** reduces CO_2 emissions ✓ (different reactions can be used with) greater atom economy **OR** less waste **OR** can reduce use of toxic solvents **OR** can reduce use of toxic reactants ✓ (catalysts are often enzymes) generating specific products ✓	2	**IGNORE** catalyst not used up in reaction **IGNORE** catalyst can be re-used **IGNORE** lower activation energy **IGNORE** cheaper **IGNORE** less greenhouse gases **OR** reduces global warming **ALLOW** increases atom economy **ALLOW** reduce use of hazardous / toxic / harmful / poisonous chemicals **Examiner's Comments** The majority of candidates were able to provide two suitable examples of how catalysts increase the sustainability of chemical processes. The mark scheme allowed a variety of different responses that reflected the specification statements being assessed. The strongest responses focussed on the use of lower temperatures and reduced CO_2 emissions. Reference to alternative processes with a better atom economy was also frequently seen.
			Total	**10**	
11	a		**initial rates data (3 marks)** **NOTE**: Each comparison **MUST** relate to the **actual** change in concentration / rate in the experiments	3	**FULL ANNOTATIONS MUST BE USED** .... **THROUGHOUT**, • Square brackets **NOT REQUIRED** around H_2O_2, H^+ and I^-

			EXPTS **H_2O_2:** $[H_2O_2] \times 2$ rate × 2 (1 & 2) **AND** 1st order ✓ **H^+:** $[H^+] \times 2$ rate does not change (2 & 3) **AND** Zero order ✓ **I^-:** $[I^-] \times 2$ **AND** $[H_2O_2] \times 2$ rate × 4 (2 & 4) **OR** $[I^-] \times 2$ **AND** $[H_2O_2] \times 4$ rate × 8 (1 & 4) **OR** $[I^-] \times 2$ **AND** $[H_2O_2] \times 2$ rate × 4 (3 & 4) **AND** 1st order ✓		• **ALLOW** 'doubles' for × 2; quadruples for × 4 **ALLOW** direct comparison of concentrations and rate, e.g. $[H_2O_2]$ changes by $\frac{0.0020}{0.0010}$ = 2, rate changes by $\frac{1.14 \times}{5.70 \times}$ **AND 1**st order (Expts 1 & 2) **DO NOT ALLOW** I_2 for I^- **IGNORE** $[H^+]$ for Expts 3 & 4
			Calculation of rate constant (3 marks), EITHER $k = \frac{5.70 \times 10^{-6}}{0.0010 \times 0.20}$ **OR** 2.85×10^{-2} **OR** 0.0285 **OR** 0.029 ✓ $k = 2.9 \times 10^{-2}$ ✓ (2 SF in standard form) *Subsumes previous mark if no working shown* $dm^3\ mol^{-1}\ s^{-1}$ ✓	3	**IGNORE working** **DO NOT ALLOW** 0.03 **ALLOW ECF** from error in powers of 10 **ONLY** e.g. 2.9×10^{-3} by use of 0.010 instead of 0.0010 **DO NOT ALLOW 2.90** $\times 10^{-2}$ **(3 SF)** **OR 29** $\times 10^{-3}$ (Not standard form) **ALLOW** mol^{-1}, dm^3 and s^{-1} in any order, e.g. $mol^{-1}\ dm^3\ s^{-1}$ **Examiner's Comments** This question assessed different aspects of reaction rates, based around the reaction of hydrogen peroxide with hydrogen and iodide ions. This part required candidates to show that the experimental results provided evidence for a provided rate equation. Most candidates were able to link concentration changes within the experiments with rate for H_2O_2 and H^+. For I^-, there were two concentration changes but weaker candidates often ignored the H_2O_2 change. The best answers were well-structured and succinct. Many longer, less focussed responses were seen which often

					omitted important detail. The rate constant was usually calculated correctly but many candidates did not show their calculated answer in standard form or to two significant figures. Candidates are advised to look carefully at the requirements of the question. Answer: $k = 2.9 \times 10^{-2}$ dm^3 mol^{-1} s^{-1}.
	b		H^+ ions are consumed / used up **OR** H^+ ions are in the (overall) equation ✓	1	**ALLOW** H^+ is **not** regenerated / reformed **ALLOW** H^+ is a reactant but not a product **ALLOW** 'it' for H^+ **IGNORE** H^+ is not in the rate equation / does not affect rate **IGNORE** does not take part in rate-determining step **Examiner's Comments** This question assessed different aspects of reaction rates, based around the reaction of hydrogen peroxide with hydrogen and iodide ions. This part was answered well, with most candidates recognising that H^+ was used up in the overall equation. Some candidates were distracted by the absence of H^+ in the rate equation.
	c	i	The slowest / slow step ✓	1	**ALLOW** step that takes the longest time **Examiner's Comments** This question assessed different aspects of reaction rates, based around the reaction of hydrogen peroxide with hydrogen and iodide ions. Almost all candidates were aware that the rate-determining step is the slowest step in a multi-step mechanism.
		ii	**NO ECF from incorrect rate equation** **Principles**	3	**IGNORE state symbols**

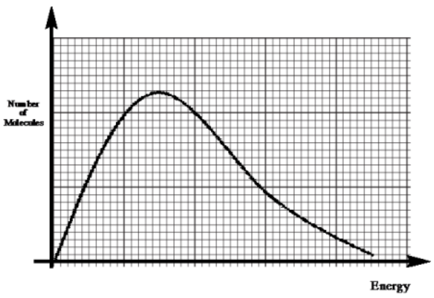
			• H_2O_2 and I^- **must be** the reactants in **1st step** • 2nd mark **only to be awarded** if 1st mark scored • Step 4 is independent **Reactants of Step 1 as H_2O_2 + I^-** **1 mark** **Step 1**: $H_2O_2 + I^-$ ✓ **Products of Step 1 AND all of Step 2** **1 mark** **Step 1** → $IO^- + H_2O$ **AND Step 2**: $H^+ + IO^- \rightarrow HIO$ ✓ **Step 4 (Independent mark)** **1 mark** $H^+ + OH^- \rightarrow H_2O$ ✓		Elements can be in any order in formulae **Alternatives for 2nd mark** **Step 1**: → $HIO + OH^-$ **AND Step 2**: $H^+ + OH^- \rightarrow H_2O$ ✓ **Step 1**: → $H_2O_2I^-$ **AND Step 2**: $H^+ + H_2O_2I^- \rightarrow HIO + H_2O$ ✓ Other possibilities, contact TL **ALLOW** $2H^+ + 2OH^- \rightarrow 2H_2O$ $H_3O^+ + OH^- \rightarrow 2H_2O$ **Examiner's Comments** This question assessed different aspects of reaction rates, based around the reaction of hydrogen peroxide with hydrogen and iodide ions. This part was attempted very well, the majority identifying that the reactants of the rate-determining step (Step 1) are obtained from the rate equation. Various possible equations were allowed for the remaining steps. Some otherwise correct equations could not be credited as charges had been omitted. Candidates are advised to check that charges, as well as species, balance on each side of any equation.

			Total	11	
1 2			**Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** All three scientific points are covered in detail and explained thoroughly. *There is a well-developed explanation which is clear and logically structured, with correct labels for the distribution, E_a in distribution linked to areas and benefits clearly linked to energy demand and the environment.* **Level 2 (3–4 marks)** All three scientific points are covered but explanations may be incomplete. **OR** Two of the scientific points are described thoroughly with no omissions. *The explanation has a line of reasoning presented with some structure, and linked to the distribution; attempts to link benefits for energy demand or the environment.* **Level 1 (1–2 marks)** There is a description based on at least two of the main scientific points **OR** One scientific point explained thoroughly with few omissions. *Explanation is communicated in an unstructured way with some links to the Boltzmann distribution or energy demand/the environment.*	6	**Indicative scientific points may include:** **BOLTZMANN DISTRIBUTION**  ***Curve*** • Curve starts at origin (**ALLOW** some leeway) • Curve does not touch the x axis at high energy ***Axes labels*** • y axis: Number of molecules/particles • x axis: Energy (**IGNORE** enthalpy) **ACTIVATION ENERGY** ***Catalyst on distribution*** • Two activation energies labelled • Activation energy with catalyst at lower energy ***Explanation*** • More molecules have more energy than E_a • Greater area under curve above E_a

			0 marks No response worthy of credit.		**CATALYST** ***Lower energy demand*** • Reactions take place at lower temperatures ***Environment*** • Reduced CO_2 emissions/burning fossil fuel • Different reactions possible with better atom economy/less waste/less hazardous chemicals (**IGNORE**' less global warming')
			Total	**6**	
1 3			*Please refer to marking instructions on page 5 of mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** All three scientific points are covered in detail and explained thoroughly. *The method is logically structured and clear calculations are shown for an appropriate mass of metal and suitable volume of acid. The drawing of a tangent and determination of the gradient is communicated well.* **Level 2 (3–4 marks)** Candidates cover all three scientific points but explanations may be incomplete. **OR** Two of the scientific points are described thoroughly with no omissions. *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence. e.g. there are clear calculations to justify mass and acid volume supported by some working and units; a simple description for determining initial rate related to tangent but no detail of how to measure gradient..*	**6**	**Indicative scientific points** **<u>1. Method</u>** • measure mass of (excess) zinc (using 2 decimal place balance) • measure volume of hydrochloric acid (using measuring cylinder) • mix zinc and acid in flask • measure gas volume at time intervals **<u>2. Calculations</u>** • moles of hydrogen 72/24000 = 0.00300 mol • minimum mass of zinc 0.003 × 65.4 = 0.20 g • moles of hydrochloric acid $Zn + 2HCl \rightarrow ZnCl_2 + H_2$ 0.00300 × 2 = 0.00600 mol • volume / concentration of acid If [HCl(aq)] = 0.1 mol dm^{-3} appropriate volume of acid = 0.006 × 1000/0.1 = 60 cm^3 If [HCl(aq)] ≥ 0.3 mol dm^{-3}, too low (≤ 20 cm^3) If [HCl(aq)] ≤ 0.03 mol dm^{-3} too

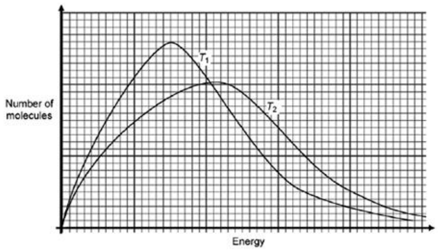
			Level 1 (1–2 marks) There is a description based on at least two of the main scientific points **OR** The candidate explains one scientific point thoroughly with few omissions. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* *e.g. 'add zinc and acid and measure volume (no mass, volume or time intervals); calculations that have little structure, absent units and little working.* **0 marks** *No response or no response worthy of credit.*		high (≥ 200 cm^3) **3. Processing results** • Plot a graph of volume against time • Draw a tangent at t = 0 • Gradient of tangent = initial rate • Gradient = volume / time **Examiner's Comment:** This question was marked using a level of response mark scheme and relatively few candidates were able to achieve Level 3. Many vague and rambling responses failed to mention the basic requirement to measure the volume of gas at regular time intervals. Some preferred to record the change in mass and ignored the diagram with a labelled gas syringe, while some carried out the experiment in a measuring cylinder. The question advises candidates to show working in their calculations but many omitted calculations from their answer. The question asked for an explanation of how the results could be processed graphically but this section was often lacking detail. Level 1 responses usually included the measurement and mixing of reactants and an attempt at processing the results by plotting a graph but further detail was missing.

					Candidates achieving Level 2 usually included a calculation of the moles of reactants and a more detailed description of how to process the results. Some excellent Level 3 responses included a full calculation of the mass of zinc and volume of hydrochloric acid required for the experiment.
			Total	**6**	
14			**ALLOW** equilibrium sign in equations provided reactants on left **Reaction of H_2O_2 with MnO_2:** $H_2O_2 + MnO_2 + 2H^+ \rightarrow O_2 + Mn^{2+} + 2H_2O$ ✓ **Reaction of H_2O_2 with Mn^{2+}:** $H_2O_2 + Mn^{2+} \rightarrow MnO_2 + 2H^+$ ✓ **Use of *E* data** Use of *E* data to support equation(s) above or half direction of provided half equations (one including MnO_2) ✓ *Also look for evidence around half equations* MnO_2 regenerated / reformed ✓ *Must be linked to an equation showing MnO_2 as reactant and an equation showing MnO_2 as product*	**4**	**ALLOW** correct multiples **IGNORE** state symbols .... **ALLOW** uncancelled H_2O and H^+ $H_2O_2 + MnO_2 + \mathbf{4}H^+ \rightarrow O_2 + Mn^{2+} + 2H_2O$ $\mathbf{+ 2H^+}$ $H_2O_2 + Mn^{2+}$ $\mathbf{+ 2H_2O + 2H^+}$ $\rightarrow MnO_2 + \mathbf{4}H^+$ $\mathbf{+ 2H_2O}$ *Examples* • More negative *E* moves to left **ORA** • Reduction half equation to the right **ORA** • Most positive *E* is reduced **ORA** • Calculated *E* cell = +0.81 V (*from top* 2) **OR** *+0.27 V (from bottom 2)* **ALLOW** combining of equations above to show that MnO_2 is used and reformed **Examiner's Comment:** Many candidates found this part challenging and there was a wide

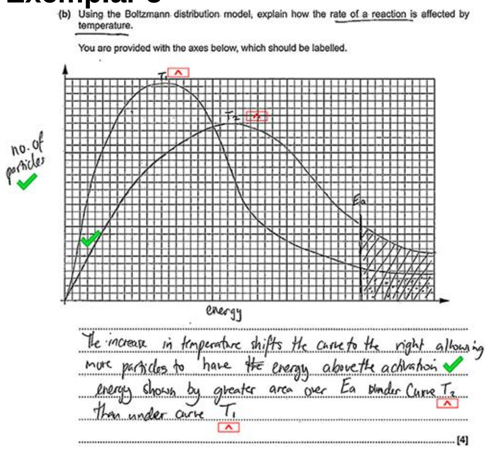
					variety of answers and marks awarded. There were two equations to construct showing how MnO_2, and Mn^{2+} react with H_2O_2. Many combined the two equations involving H_2O_2 to obtain the overall equation for the decomposition of H_2O_2 which was given at the top of the paper. Of the equations seen, many had species uncancelled. Many candidates only tackled one of the equations. Candidates were expected to provide evidence for their equations based on the electrode potentials provided. Use of this data was patchy and only the best candidates linked the relative *E* values to the direction of movement or redox details. A significant number gave cell potentials. Regeneration of MnO_2 was well understood but often just stated with no reference to the equations. This part discriminated very well.
			Total	**4**	
15	a		 *Correct drawing of Boltzmann distribution* Curve starts within **two** small squares of origin **AND** **not** touching the × axis at high energy ✓ *axes labels:* y: (number of) molecules/particles **AND** x: (kinetic) energy ✓	**4**	**FULL ANNOTATIONS WITH TICKS, CROSSES, CON, etc MUST BE USED** **IGNORE** a slight inflexion on the curve **DO NOT ALLOW** two curves *Confusion with effect of temperature* **DO NOT ALLOW** 'atoms' as y-axis label

			Catalyst and activation energy Catalyst provides a lower activation energy **OR** E_c shown below E_a on Boltzmann distribution ✓ More molecules/particles/collisions have energy above activation energy (with catalyst) **OR** greater area under curve above activation energy ✓		**DO NOT ALLOW** 'enthalpy' for x-axis label **ALLOW** 'more molecules have enough energy to react' **IF** y axis labelled as 'atoms' **ALLOW ECF** for atoms (instead of molecules/particles) **IGNORE** (more) successful collisions **IGNORE** response implying 'more collisions' *(confusion with effect of greater temperature)* **Examiner's Comments** This was a well answered question showing that the majority of candidates were well-acquainted with the Boltzmann distribution. Labelling of the axes was a common cause of error. Some candidates showed two curves, confusing the effect of a catalyst with temperature. Most candidates knew that the activation energy was lower with a catalyst than without. A significant number of candidates limited their explanations to 'successful collisions' without referring to more molecules exceeding the lower activation energy in the presence of catalyst. The best responses secured all four marks from a well-drawn and annotated graph.
	b		*Two max ✓✓from:* • Lower temperatures / less heat / less **thermal** energy	**2**	**IGNORE** lower pressures **OR** less energy *(in question)*

			• Less fossil fuels / oil / coal / gas / non-renewable fuels • Reduces CO_2 emissions		**IGNORE** just 'less fuel' **IGNORE** less global warming **IGNORE** less greenhouse gases, less CO, less NO *CO_2 required* **Examiner's Comments** There were many excellent responses in terms of lower temperature, use of less fossil fuels and a reduction in emission of carbon dioxide as a contributor to global warming. Weaker responses lacked precision and often repeated information supplied in the question about less energy demand.
			Total	**6**	
16	a		$n(H_2O_2) = 2.30 \times \frac{25.0}{1000}$ **OR** = 0.0575 (mol) ✓ vol $O_2 = \frac{0.0575}{2} \times 24000 = 690$ **cm³** ✓ Collect in 1000 cm³/1 dm³ measuring cylinder ✓	3	**ALLOW** 0.69(0) **dm³** 2nd mark subsumes 1st mark **ALLOW** 1000 cm³/1 dm³ syringe Needs a **name** of actual apparatus, not just 'container' 'measuring cylinder' without volume is insufficient **DO NOT ALLOW** burette For other possible apparatus, contact Team Leader **ALLOW** volumes from 700−1000 cm³ but should be realistic apparatus, e.g. 700, 750, 800, 850, 900, 950. **Examiner's Comments** The majority of candidates were able to score the two marks for determining the volume of oxygen to be 690 cm³ (or 0.690 dm³). Only a very small proportion of candidates were able to suggest a suitably sized piece of apparatus.

	b		Measure mass (loss) ✓	1	**ALLOW** weight for mass **ALLOW** take samples and titrate (remaining H_2O_2) **Examiner's Comments** The idea of measuring mass loss (over time) was frequently given as a correct response. The idea of titrating samples to determine the concentration of hydrogen peroxide during the course of the reaction was occasionally seen and given credit.
			Total	**4**	
17			(Increase in pressure) increases the rate **and** because molecules are closer together… (1) … so there are more collisions per unit time (1)	2	**allow** more particles per unit volume **not** molecules move faster or have more energy
			Total	**2**	
18			**C**	**1 (AO 1.1)**	**Examiner's Comments** This was almost universally correct.
			Total	**1**	
19			*Boltzmann distribution 3 marks*  **Curve** Curve starts within one small square of origin **AND** curve does not touch x axis at high energy **AND** curve does not increase by more than one small square at higher energy ✓ **Labels** Axes labels correct:	**4**	**FULL ANNOTATIONS MUST BE USED THROUGHOUT** -- **NOTE:** Look for marking criteria within annotations on Boltzmann distribution diagram **IGNORE** slight inflexion on the curve **For labels**, **ALLOW** number of particles **ALLOW** amount of molecules/particles **IGNORE** number of atoms **ALLOW** kinetic energy **IGNORE** enthalpy for energy

			• Number of molecules **AND** Energy ✓ **Curves for two temperatures** Drawing of **two** curves with higher and lower temperature clearly identified in diagram or text **AND** higher *T* maximum to right **AND** at least one small square lower than lower *T* max ✓ **Explanation** **1 mark** **More** molecules have energy greater than E_a **OR** Greater area under curve above E_a ✓ *Could be in diagram*		**IGNORE** curves meeting at higher energy **BUT** **DO NOT ALLOW** crossing over by **more than** one small square **ALLOW** more molecules have the energy to react **IGNORE** more successful collisions **OR** collide more frequently **DO NOT ALLOW** explanation is in terms of two activation energies (i.e. 'catalyst explanation) **<u>Examiner's Comments</u>** Overall, this question was answered well. Most candidates showed two Boltzmann distribution curves at different temperatures. Labelling of the axes was usually correct, although the labels were sometimes seen the wrong way around. Most candidates were aware that more molecules possessed the required activation energy at a higher temperature, although lower ability candidates discussed frequency of collisions instead. Strangely, many good responses were spoilt by not labelling which of the two curves was at higher temperature. This is shown in the otherwise excellent response in the exemplar.

					Exemplar 5 
			Total	**4**	
2 0			**C**	1 (AO1.1)	**Examiner's Comments** The role of activation energy in the rate of a reaction with increasing temperature was well-known and most candidates chose the correct option C. From the annotations on candidate scripts, many had ruled out options A and B entirely. D was anticipated as being the main distractor and this proved to be the case. Activation energy has a much greater effect than increasing collision frequency.
			Total	**1**	
2 1	a	i	**Use of graph paper** linear numerical scale chosen for x axis **AND** Time / s added as label **AND** ALL points plotted correctly ✓	1(AO2.4 ×1)	**ALLOW** Time (s) **OR** Time in s **ALLOW** seconds **OR** sec **OR** secs Tolerance ± 1 small square Point at 0,0 **NOT** required **ALLOW** up to 3 plotting errors **Examiner's Comments** Most candidates obtained this mark, some lost the mark because they did not use a linear scale or provide units.
		ii	**Anomaly** point at 80 s circled ✓	1(AO2.4x 1)	**ALLOW** one more anomalous point **NOT** on the curve drawn in (iii) **Examiner's Comments**

					Nearly all the candidates obtained this mark
		iii	**Line** smooth curve using all points **EXCEPT** point at 80 s ✓	1(AO3.1)	**Examiner's Comments** Nearly all the candidates obtained this mark
	b		Initial slope is steeper **AND** curve levels off at an earlier time ✓ **Same** volume of gas produced (58 cm^3) ✓	2(AO2.8 ×2)	Tolerance ± 1 small square **Examiner's Comments** Many students did not sketch this curve or sketched a curved that was less steep and did not finish at 58cm^3.
	c		**Rate** (Acid) **concentration** decreases. ✓ **Collisions** Fewer collisions per second **OR** less frequent collisions ✓	2(AO 1.1×2)	**IGNORE** amount of acid decreases, response must imply a volume and **NOT** area, e.g. fewer particles/molecules/ions in same space /volume 'fewer collisions' alone is not sufficient (no rate) **Examiner's Comments** Many responses detailed why the graph was steep at the beginning, rather than answering the question. Those that did explain the decrease often omitted the words concentration and frequency so the majority did not gain 2 marks. A large number of candidates discussed particles "losing energy" and "less successful collisions" so were not given any marks.
	d	i	Catalyst lowers the activation energy (by providing an alternative route) ✓ A greater proportion of molecules have more energy greater than/equal to activation energy ✓	2(AO1.2 ×2)	**ALLOW** 'more' for 'greater proportion' **ALLOW** more molecules have sufficient energy to react **IGNORE** (more) successful collisions

					Examiner's Comments Most candidates scored the first marking point but many did not achieve the second marking point as their explanations were too vague.
		ii	Reactants have different physical states ✓	1(AO2.1)	**ALLOW** idea that copper(II) sulfate solution is homogeneous in relation to the acid, but heterogeneous in relation to the zinc **Examiner's Comments** Almost half of the candidates answered this question correctly, the remainder did not realise that the question gave them the answer to the state that the copper sulphate solution was in. Many answers stated that it could be solid or aqueous, so difficult to classify.
			Total	**10**	
22			**D**	1 (AO 1.1)	
			Total	**1**	
23			(Reaction can be carried out at) lower temperatures / lower energy demand ✓ Less (fossil) fuels burnt / less CO_2 emissions ✓	2 (AO 1.1×2)	**ALLOW** lower pressures as alternative to lower temperature **ALLOW** reduced carbon footprint as alternative to less fuels burnt **ALLOW** different reactions can be used with greater atom economy / less waste **ALLOW** can reduce use of toxic substances
			Total	**2**	
24		i	To keep [CH_3OH] (effectively) constant **OR** Zero order with respect to CH_3OH **OR** To ensure equilibrium is far to the right ✓	1 (AO 3.3)	**ALLOW** Change in [CH_3OH] is negligible **ALLOW** rate is independent of [CH_3OH] **IGNORE** Methanol doesn't run out/is not limiting reagent. **Examiner's Comments**

					Most candidates used incorrect ideas about reaction going to completion or the methanol not being limiting.
		ii	One half-life *t*½ between 102 and 110 (mins) Two half-lives calculated **OR** evidence on the graph of two half-lives **AND** constant half-life/values (means first order) ✓	2 (AO 3.1) (AO 3.1)	**ALLOW** any two combinations of positions, e.g. 5 and 2.5 **AND** 4 and 2 **AND** 3 and 1.5 **<u>Examiner's Comments</u>** Very few candidates were given full marks. Higher-attaining students calculated one half life in range but very few could come up with a second half life as the graph did not allow another successive half life to be obtained. Higher-attaining candidates chose alternative half lives from the data given. **Misconception** Candidates are advised that half lives can be calculated from any numerical values on the graph. Further guidance on rates of reaction can be found at: https:/www.ocr.org.uk/Images/371956-experiments-on-rates-of-reaction.doc
		iii	**Using gradients** Evidence of tangent at *t* = 0 and intercept between 100 -140 (min) ✓ Correctly calculated gradient in the range of 2.9×10^{-5} to 4.0×10^{-5} (mol dm^{-3} min^{-1}) ✓ **OR** **Using half-life**	2 (AO 3.1×1) (AO 3.2×1)	**ALLOW ECF** from value of t½ in **(ii)** **<u>Examiner's Comments</u>** This question required the candidate to draw a line of best fit and then draw a

			For t½ = 106 min, $k = \frac{\ln 2}{t_{½}}$ = 0.00654 (min^{-1}) ✓ rate = 0.00654 × 5 × 10^{-3} = 3.27 × 10^{-5} (mol dm^{-3} min^{-1}) ✓		tangent at t=0. Many candidates did not draw a line of best fit, and many did not get a tangent in the acceptable range. Very few candidates processed the gradient by using the correct subtraction on the y axis (scale was from 1 to 5) or by using the 10^{-3} on the axis label.
			Total	**5**	
25			**A**	1 AO1.1	
			Total	**1**	
26			Less fossil fuel used ✓ Reduction in CO_2 (emissions) ✓	2 (AO3.2 × 2)	**ALLOW** Less energy used
			Total	**2**	
27	a		Best fit curve ✓ Tangent drawn at approximately *t* = 50 s ✓ Gradient calculated: 0.44 ± 0.2 (cm^3 s^{-1}) ✓	3 (AO1.2) (AO2.4 × 2)	**DO NOT ALLOW** interpolation (taking a direct reading from graph), answer must be derived from taking a gradient **ALLOW** ECF from incorrectly drawn tangent
	b		Advantage: no loss of gas ✓ Disadvantage: small loss in mass ✓	2 (AO3.4 × 2)	**IGNORE** easier to set up
	c	i	**FIRST CHECK THE ANSWER ON ANSWER LINE** If answer = 0.41 (g) award 2 marks --------------------------------- n(Ba) = $\frac{0.26}{87.6}$ **OR** 2.9…….. × 10^{-3} **OR** 3 × 10^{-3} ✓ mass Ba = 137.3 × 2.9……… × 10^{-3} = 0.41 g ✓ **2 DP required**	2 (AO3.3 × 2)	**ALLOW** ECF from incorrect moles of Ba Calculator: 2.96803653 × 10^{-3} **NOTE** 3 × 10^{-3} also gives 0.41 g
		ii	Steeper initial gradient **AND** levels off earlier ✓ Same volume of gas produced ✓	2 (AO3.1 × 2)	
		iii	**Reactivity** Ba is more reactive (than Sr) ✓ **Atomic radius**	4 (AO1.1 × 4)	Comparison required throughout **ORA** throughout For **more** shells, **ALLOW** higher energy level **IGNORE** more orbitals **OR** more sub-shells

			Ba has a **greater** atomic radius (than Sr) **OR** Ba has **more** shells **OR** Ba has **more** shielding ✓ **Attraction** Nuclear attraction is less in Ba **OR** (outer) electrons in Ba are less attracted (to nucleus) OR Increased distance / shielding in Ba outweighs increased nuclear charge ✓ **Ionisation energy** Ionisation energy of Ba is less **OR** easier to remove (outer) electrons in Ba✓		**IGNORE** 'different shell' or 'new shell' **ALLOW** Ba has less nuclear pull' **OR** 'Ba electrons are less tightly held' **IGNORE** less effective nuclear charge' **IGNORE** 'nuclear charge' for 'nuclear attraction' **ALLOW** easier to oxidise Ba
			Total	**13**	
28		i	**FIRST, CHECK FOR VALUE OF K_p.** **IF** answer = 20.7 (MPa^{-1}), award **4 marks** -- *Equilibrium amounts* *n*(NO) = 0.4 (mol) **AND** $n(O_2)$ = 0.9 (mol) **AND** $n(NO_2)$ = 1.2 (mol) ✓ *Total moles at equilibrium* n_{tot} = 2.5(mol) ✓ *Partial pressures* $p(NO) = \frac{0.4}{2.5} \times 1.21 = 0.1936$ (MPa) **AND** $p(O_2) = \frac{0.9}{2.5} \times 1.21 = 0.4356$ (MPa) **AND** $p(NO_2) = \frac{1.2}{2.5} \times 1.21 = 0.5808$ (MPa) ✓ K_p value $Kp = \frac{0.5808^2}{0.1936^2 \times 0.4356} = 20.7$ **to 3** **SF** (MPa^{-1}) ✓	4 (AO2.4× 4)	**FULL ANNOTATIONS MUST BE USED** -- **ALLOW ECF throughout** **ALLOW** 20.6 from 3 SF partial pressures, 0.194, 0.436 and 0.581 **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below -- **Look for values to 3 SF here: 0.194, 0.436 and 0.581** **ALLOW** **25.0 as ECF (**from omission of partial pressures for **3 marks)** **Examiner's Comments** This question asked the candidate to calculate K_p. Some candidates made full use of tables which allowed for credit to be given through error carried forward. Some candidates did not successfully calculate the number of moles at equilibrium but completed the

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>subsequential steps.

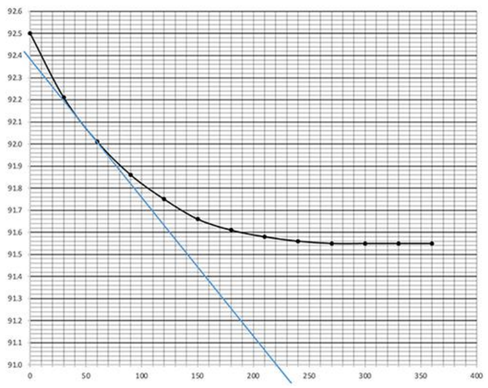
Lower-attaining candidates divided the mole fraction by the partial pressure rather than performing a multiplication and omitted the square relationship within the K_p expression. Candidates should remember to provide written indications of what it is they are working out – presenting the calculations without any annotations and structure can make it harder for error carried forward marks to be given.</td></tr>
<tr><td></td><td></td><td>ii</td><td>
<table>
<tr><th>Change</th><th>K_p</th><th>Equilibrium amount of NO_2</th><th>Initial rate</th></tr>
<tr><td>Temperature increased</td><td>smaller</td><td>smaller</td><td>greater</td></tr>
<tr><td>Pressure increase</td><td>same</td><td>greater</td><td>greater</td></tr>
<tr><td>Catalyst added</td><td>same</td><td>same</td><td>greater</td></tr>
<tr><td></td><td>✓</td><td>✓</td><td>✓</td></tr>
</table>
</td><td>3
(AO1.2×3)</td><td>Mark by COLUMN

ALLOW obvious alternatives for greater/smaller/same,
e.g.
increases/decreases/
more/less</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>7</td><td></td></tr>
<tr><td>29</td><td></td><td></td><td>At 90 °C/higher temperature
Faster rate AND more frequent collisions ✓
More particles have the activation energy/E_a or greater ✓
$[Co(H_2O)_6]^{2+}$ is lower ✓
(forward reaction) ΔH -ve OR exothermic ✓</td><td>4
(1 ×AO2.7)
(1 ×AO1.2)
(1 ×AO2.3)
(1 ×AO1.2)</td><td>ORA for 50 °C
IGNORE more successful collisions
ALLOW more molecules have enough energy to react
ALLOW atoms/molecules/ions
ALLOW decreases

<u>Examiner's Comments</u>

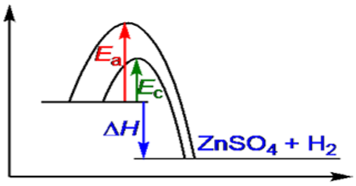
This question asked candidates to explain the different rates from a novel experiment carried out at 50°C and 90°C, and to predict the ΔH sign for the forward reaction. Candidate explanations for the rates were often superficial, solely in terms of greater energy at 90°C. Many responses referred neither to the different frequency of collisions nor the greater number of particles exceeding the activation energy at 90°C. Most candidates predicted that ΔH would have a negative sign.</td></tr>
</table>

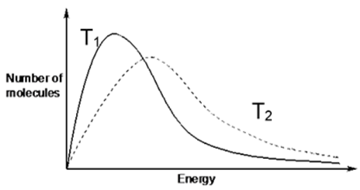
					Candidates were expected to link the evidence from the absorbance data in the graph to less $[Co(H_2O)_6]^{2+}$ being present at 90°C. When experimental information has been presented, candidates are advised to look for the evidence responsible in their explanations.
			Total	**4**	
3 0	a	i	**Rate** (Acid) **concentration** decreases ✓ **Collisions** Fewer collisions per second **OR** less frequent collisions ✓ **Reaction stops** (Acid/reactant/limiting reagent) has reacted/been used up ✓	3 (AO 1.1) (AO 1.1) (AO 2.3)	**IGNORE** amount of acid decreases Response **MUST** imply a volume and **NOT** area, e.g. fewer particles/molecules/ions in **same space /volume** **IGNORE** responses not linked to rate, e.g. • 'fewer collisions' • fewer successful collisions • fewer collisions, less chance of collisions *No link to rate.* **AW** **Examiner's Comments** Only a small number of candidates managed to score all 3 marks for this question. Lots began their response describing why the rate is high at the start. This often filled the space available with marks being gained only in the last sentence. Very few gave descriptions with this specific reaction in mind, such as recognising that the HCl was the limiting reagent so gets used up, leaving some $MgCO_3$ remaining. Common errors included referring to "fewer collisions" but without any indication of time, or "less reactant"

					without considering the volume of the reaction. **Misconception** Many candidates described a decrease in energy in the reaction or gave responses related to activation energy. For example: “lose energy and start to collide less often”, “reactants have less kinetic energy” and “only a certain number of particles which have enough energy above the activation energy…over time energy will decrease and less particles have enough energy”. We have produced a delivery guide on rates with some useful resources to help consolidate ideas and avoid misconceptions such as these: https:/www.ocr.org.uk/Images/231742-rates-delivery-guide.pdf
		ii	**Tangent on graph** drawn at approximately t = 50 s (± 10 s) ✓ **Calculation of rate** = Gradient (y/x) of tangent drawn e.g. $\frac{92.4 - 91.0}{220} = \frac{1.4}{220} = 6.36 \times 10^{-3}$ (g s^{-1}) ✓ 	2 (AO 3.1) (AO 3.2)	**DO NOT ALLOW** interpolation (taking a direct reading from graph), answer must be derived from taking a gradient **ALLOW ECF from incorrectly drawn tangent** **ALLOW** range of 5.7×10^{-3} to 6.9×10^{-3} in calculation of tangent (rounded to 1 d.p.) **IGNORE** units **IGNORE** sign **Tolerance of readings:** y axis should be ± 0.02 g (i.e. within 1 square) x axis should be ± 5 min (i.e. within 1 of a square)

					Examiner's Comments Most candidates recognised that they needed to draw a tangent. Candidates need to be instructed to draw their line clearly and make sure that it covers several large squares on the graph – preferably extending to the axes. The range given for the calculated rate from the gradient of the tangent was generous, however some did not realise that the y-axis started at 91.0 so incorrectly calculated their gradient. Some candidates used interpolation so gained no marks. **OCR support** M3 section of the Maths Skills handbook contains useful information on use of graphs in chemistry, including M3.5 on drawing and using the slope of the tangent to a curve as a measure of a rate of change: https:/www.ocr.org.uk/Images/295468-chemistry-mathematicalskills-handbook.pdf
		iii	Slope is steeper **AND** levels off earlier ✓ **Same** loss in mass, i.e. levels off at ~ 91.55 g ✓	2 (AO 3.2 × 2)	Tolerance ± 1 small square **Examiner's Comments** About a third of candidates didn't score any marks here. Some did not follow the instructions to add their curve to the previous graph. The sketches produced in the blank space then usually lacked any scales on the axes so could not be

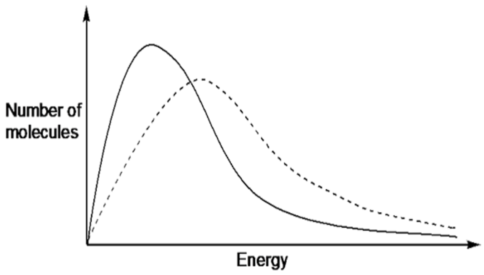
					given marks. Lines added were often inaccurately drawn with lines often extending below 91.55g before returning to this mass at the end. It was often difficult to interpret if a graph levelled off before the original with lots tracking the same curve with a very slightly steeper slope. Some gave a slower rate but did manage to gain marks for finishing at 91.55g.
	b	i	More vigorous bubbling ✓ Zinc dissolves/disappears more quickly ✓	2 (AO 2.7 × 2)	**AW**, e.g. bubbles/fizzes more quickly For 1 alternative marking point **ALLOW** responses related to displacement of Cu from $CuSO_4$ by Zn: **EITHER** red/brown/black precipitate/solid formed **OR** (blue solution) turns colourless **<u>Examiner's Comments</u>** Candidates found this question very challenging. Most recognised that the addition of the catalyst would speed up the reaction but could not translate this into observations for this specific practical. For example, "reacts faster", "releases more hydrogen" or "stops reacting quicker". Giving candidates the opportunity to observe a range of both familiar and unfamiliar reactions, noting qualitative observations can help to improve their skills here. Many just noted that one tube would be blue and the other colourless rather than considering the reaction taking place. Some indicated that only 1 tube would react and the other would not. A few candidates recognised that a competing displacement reaction would take place between Zn and $CuSO_4$ so were given marks for this.
		ii		3 (AO 2.1) (AO 1.1) (AO 1.1)	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC**

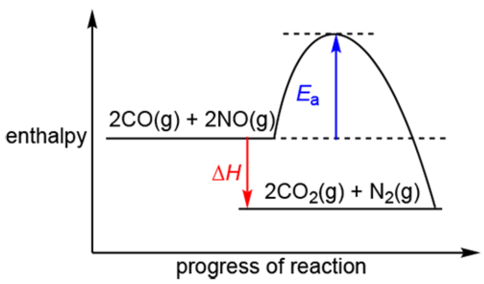
			 ΔH — ΔH labelled with product ($ZnSO_4 + H_2$) below reactant **AND** Arrow downwards ✓ E_a — E_a correctly labelled ✓ E_c — E_c correctly labelled with $E_c < E_a$ ✓		**IGNORE** state symbols ΔH **DO NOT ALLOW** $-\Delta H$ **DO NOT ALLOW** double headed arrow on ΔH **ALLOW** ΔH arrow even with small gap at the top and bottom, i .e. line does not quite reach reactant or product line. ***E*a and *E*c** — E_a **and** E_c **ALLOW** no arrowhead or arrowheads at both end of E_a or E_c lines E_a or E_c lines must reach maximum (or near to maximum) on curve For E_a, **ALLOW** AE **OR** A_E **ALLOW** marks for E_a **and** E_c for correctly labelled endothermic diagram (i.e. **ECF** from ΔH) **<u>Examiner's Comments</u>** Less than half of all candidates managed to gain all 3 marks giving the correct enthalpy profile diagram. Many demonstrated a lack of understanding about what an enthalpy profile diagram shows as seen by labelling of curves for E_a/E_c rather than the enthalpy change or arrows for ΔH extending to the x-axis. Other errors also seen included, -ΔH, double headed ΔH arrow, activation energy lines starting at products, endothermic profiles, E_a and E_c the wrong way round and missing or incorrect labels. Some candidates found it tricky to give activation lines for both catalysed and uncatalysed reactions on the same diagram, these often overlapped or did

					not extend to the top of the energy barrier.
			Total	**12**	
3 1			**D**	1(AO1.1)	**Examiner's Comments** Candidates produced a variety of responses with just over half choosing the correct option D. Option C was the main distractor.
			Total	**1**	
3 2		i	 Axes labelled (number of) molecules **AND** (kinetic) energy **AND** correct drawing of a Boltzmann distribution i.e. curve must start within the first small square nearest to the origin **AND** must not touch the x-axis at high energy ✓ Drawing of correct Boltzmann distributions at **two** different temperatures with one termperature identified. ✓ (At higher temperature) **more** molecules/particles have energy above activation energy ✓	3 (AO1.1×3)	**ALLOW** particles on the y-axis **DO NOT ALLOW** atoms on y-axis **DO NOT ALLOW** enthalpy on x-axis **DO NOT ALLOW** an increase of more than one small square at the high energy end of the curve i.e. allow a small inflection **ALLOW** T2 as 'higher termperature' Maximum of curve for higher temperature must be to the right **AND** lower than the maximum of the curve for lower temperature Lines can only cross once **ALLOW ORA** if states the effect when the temperature is lower **ALLOW** has enough energy to react **ALLOW** E_a shown on graph **AND**

					greater area under the curve to the right of E_a **DO NOT ALLOW** lowers E_a **DO NOT ALLOW** atoms for molecules **IGNORE** (more) successful collisions **<u>Examiner's Comments</u>** Almost all candidates produced a graph which showed the correct shape curve, although they sometimes incorrectly identified the quantities on the axes, e.g. rate versus time. Those who produced an incorrect diagram were able to discuss 'more' particles reaching the activation energy threshold. A few limited their answer to discussing successful collisions. Candidates needed to identify which curve was the higher temperature and to make sure that the curves did intersect more than once.
		ii	**Orders** **(Expt 1+2)** When [NO] × 2, rate × 4 **AND** 2nd order with respect to NO ✓ **(Expt 2+3)** When [NO] × 2 **AND** [CO] × 4, rate × 16 **AND** 1st order with respect to CO ✓	5 (AO3.1) (AO3.2) (AO2.6) (AO1.2×2)	**ALLOW ORA** throughout e.g. expt 2+1 [NO] halves, rate quarters etc. **IGNORE** [CO] constant **ALLOW** if working shown with the table. **ALLOW** if seen in 2 steps i.e. When [NO] × 2, rate x 4 AND [CO] × 4, intermediate rate × 4. **ALLOW** comparing **Expt 1+3** When [NO] × 4 AND [CO] × 4, rate × 64 **AND** 1st order with respect to CO **ALLOW ECF** from incorrect orders

			Rate Equation rate = k $[NO]^2[CO]$ ✓ **Value of k** $(k = \frac{1.85 \times 10^{-4}}{(2.75 \times 10^{-4})^2 \times 7.25 \times 10^{-4}})$ **= 3.37×10^6** ✓ **Units of k** $dm^6\ mol^{-2}\ s^{-1}$ ✓		**ALLOW** rate = k $[NO]^2[CO]^1$ **ALLOW** rate equation with correct numbers substituted **ALLOW** 3.36×10^6 from the use of Expt 3 **IGNORE** errors in working out –the mark is for the value **ALLOW** 3 SF upto the calculator value 3374180.678 OR 3.374180678×10^6 **IGNORE** rounding errors past **3SF** **ALLOW** units in any order e.g. $mol^{-2}\ dm^6\ s^{-1}$ **ALLOW ECF** from incorrect rate equation. **Common errors** **4 marks (including units)** $4.65 \times 10^9\ mol^{-3}\ dm^9\ s^{-1}$ (use of 2nd order with respect to CO) $2446\ mol^{-1}\ dm^3\ s^{-1}$ (use of zero order wrt CO) **<u>Examiner's Comments</u>** Many candidates were able to explain clearly the second order dependence on [NO] but many found it more challenging to identify and explain the first order relationship for [CO], where the candidate had to consider the second order dependence on [NO] to work out the effect on rate for the change in [CO]. Most gave a rate equation of the correct format based on the orders they had stated, and worked out a value for k. Although some did not determine the correct units, there was an encouraging number who managed this either from memory or by cancelling. The most common error was not including s^{-1}

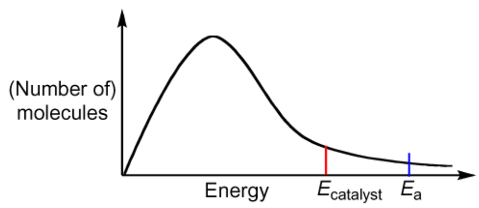
			Total	**8**	
33			 *Curve at higher temperature 1 mark* Curve starts close to zero **AND** does not touch x axis at high energy **AND** maximum to right **AND** lower than provided curve **AND** finishing higher than provided curve ✓ *Labels 1 mark* Axes labels correct: • Number of molecules **AND** Energy ✓ *Explanation 1 mark* More molecules have energy greater **than** E_a **OR** Greater area under curve **above** E_a ✓ *Could be in diagram* *If not stated, assume higher temperature*	3 (AO1.2) (AO1.1) (AO1.1)	**ANNOTATE ANSWER WITH TICKS AND CROSSES NOTE**: Look for marking criteria within annotations on Boltzmann distribution diagram **IGNORE** slight inflexion on the curve **For labels ALLOW** number of particles **ALLOW** amount of molecules/particles **IGNORE** number of atoms **ALLOW** kinetic energy **IGNORE** enthalpy for energy **ORA at lower temperature ALLOW** more molecules have the energy to react more molecules can overcome/reach E_a **IGNORE** atoms **IGNORE** more successful collisions **OR** collide more frequently **DO NOT ALLOW** explanation is in terms of two activation energies (i.e. 'catalyst explanation) **<u>Examiner's Comments</u>** Most candidates answered this question well. Most graphs were drawn with care but some peaks were shown at the same height as the provided curve or meeting this curve at high energy. Some candidates labelled what should have been 'energy' on the x axis as 'progress of reaction', or used 'atoms' rather than molecules for the y axis label. Many candidates were able to explain that more molecules exceed the activation energy at a higher temperature.
			Total	**3**	
34			**A**	1 (AO 1.1)	**<u>Examiner's Comments</u>** The behaviour of the Boltzmann distribution under different conditions is well known with most candidates making the correct choice of A.
			Total	**1**	
35			**B**	1 (AO 2.8)	**<u>Examiner's Comments</u>** This question discriminated well, rewarding those candidates with a good understanding of the link between

					concentration, time and rate. Many candidates drew a tangent to the curve at 200 s, measuring its gradient to get the correct choice of B. Common errors focused on reading of the concentration at 200 s. This was then either matched to option D directly or divided by 200 to give option A.
			Total	**1**	
36		i	$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$ Correct species ✓ Balanced ✓	2 (AO2.6 ×2)	**ALLOW** multiples **IGNORE** state symbols For heptane formula, **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW 1 mark** for balanced combustion equation for a different alkane (**ECF**) e.g. $C_6H_{14} + 9½O_2 \rightarrow 6CO_2 + 7H_2O$ **<u>Examiner's Comments</u>** Most candidates were able to construct a balanced equation for the combustion of heptane. Most were aware that CO_2 and H_2O would be the products although some generated CO, C_6H_{12} or unusual compounds such as $C_7H_{14}O$. The hardest part was the formula of heptane itself with use of hexane instead being a common error; candidates who made this error were given 1 mark, provided that their equation was balanced.
		ii	 **Reactants, products and Δ*H***	2 (AO2.1) (AO1.2)	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **IGNORE** state symbols Δ*H* **DO NOT ALLOW –**Δ*H*

			2CO + 2NO on LHS **AND** **$2CO_2$ + N_2** on RHS **AND** Δ*H* labelled with products **below** reactants **AND** **Arrow downwards** ✓ *E_a (independent of* **Δ***H***)** curve with arrow from reactants to top of curve **AND** *E_a* labelled ✓ **IF** endothermic diagram shown, **ALLOW ECF** for E_a using MS criteria		**DO NOT ALLOW** double headed arrow on Δ*H* **ALLOW** Δ*H* arrow even with small gap at the top and bottom, i.e. line does not quite reach reactant or product line. **ALLOW** –746 for Δ*H* E_a **ALLOW** AE **OR** A_E **ALLOW 2** arrowheads at **each** end of E_a line **OR** no arrowhead **BUT DO NOT ALLOW** arrowhead down E_a line must reach maximum (or near to maximum) on curve **<u>Examiner's Comments</u>** Most candidates obtained 1 or 2 of the available marks, the commonest errors being use of a doubleheaded arrow for Δ*H* or a –Δ*H* label. Some candidates showed endothermic profiles and these could create issues with positioning of the Δ*H* and E_a arrows. Generally, positioning of Δ*H* and E_a arrows was imprecise and candidates are advised to start and finish the positions of their arrows accurately. The mark scheme did allow for some leeway but positioning of arrows could generally be improved.
		iii	Catalyst lowers activation energy **OR** Catalyst increases rate without itself changing ✓ Reaction proceeds via a different route/pathway **OR**	2 (AO1.2 ×2)	**ALLOW** 2nd labelled curve on profile diagram in **23(a)(ii)** with lower activation energy/E_c with catalyst **ALLOW** E_c needs less energy to start reaction **ALLOW** E_c curve is lower than E_a curve

			More molecules/particles exceed activation energy ✓		**IGNORE** 'shorter route' for alternative route **IGNORE** more successful collisions **Examiner's Comments** Almost all candidates knew that a catalyst lowered activation energy and most were aware that an alternative pathway was made possible by a catalyst.
			Total	**6**	
37			**D**	1 (AO 1.2)	**Examiner's Comments** Half of the candidates chose the correct half-life of D and a large proportion of the others chose 8 minutes, halving the time as the concentration was doubled, causing C to be a common error.
			Total	**1**	
38			**Level 3 (5–6 marks)** ALL 3 correct orders linked to explanations **AND** rate equation **AND** rate constant *There is a well-developed line of reasoning which is clear and logically structured.* **Level 2 (3–4 marks)** Three correct orders **AND** two out of: some evidence of an explanation linked to an order rate equation rate constant OR Three correct orders **with an attempt at:** Some evidence of an explanation link to an order rate equation rate constant	6 (AO 3.1 × 3) (AO 3.2 × 3)	**Indicative scientific points may include** **Orders** • 1st order wrt Br^- • 1st order wrt BrO_3^- • 2nd order wrt H^+ **Rate equation** • rate = $k[Br^-][BrO_3^-][H^+]^2$ **Calculation of *k* from any row of data, e.g.** $k = \frac{\text{Rate}}{[Br^-][BrO_3^-][H^+]^2}$ $k = \frac{2.52 \times 10^{-4}}{0.020 \times 0.120 \times (0.080)^2} = 16.4(0625)$ --- **Explanations from results e.g.** **Br^-** $[Br^-] \times 3$ rate × 3 Expts 1 and 2 **BrO_3^-** $[Br^-] \times 2$ **AND** $[BrO_3^-] \div 2$ rate: no change Expts 1 and 3

			OR Two correct orders linked to explanations **AND** rate equation **AND** rate constant consistent with the candidate's orders *There is a line of reasoning with some structure and supported by some evidence.* **Level 1 (1–2 marks)** Two correct orders **OR** One correct order **AND** attempts to determine rate equation **OR** rate constant. **OR** One correct order AND attempts an explanation. *There is an attempt at a logical structure with a reasoned conclusion from the evidence.* **0 mark** *No response worthy of credit.*		**OR** $[Br^-]$ × 2/3 **AND** $[BrO_3^-]$ ÷ 2 rate: × 1/3 — Expts 2 and 3 **H^+** $[BrO_3^-]$ ÷ 2 **AND** $[H^+]$ × 5 rate × 12.5 — Expts 1 and 4 **OR** $[Br^-]$ ÷ 3 and $[BrO_3^-]$ ÷ 2 and $[H^+]$ × 5 rate × 4.17 — Expts 2 and 4 **OR** $[Br^-]$ ÷ 2 and $[H^+]$ × 5 rate × 12.5 — Expts 3 and 4 **ALLOW** a sequential approach where they apply known orders first **ALLOW** minor slips as we are looking for an holistic approach to LoR marking **NOTE**: A clear and logically structured response would link orders to the experiment and experimental results provided. They could provide units **<u>Units</u>** $dm^9\ mol^{-3}\ s^{-1}$ **ALLOW** any order, e.g. $mol^{-3}\ dm^9\ s^{-1}$ **<u>Examiner's Comments</u>** The first Level of Response question in the paper was answered well. Almost all candidates were able to conclude that the experimental results showed that they were consistent with first order with respect to Br^-. Some candidates were able to use a sequential approach to determine the orders with respect to BrO_3^- and H^+, reaching a Level 3, but others found this more problematic. Some did not notice that more than one concentration had been changed between experiments. This led to many determining the rate to be 0 order with

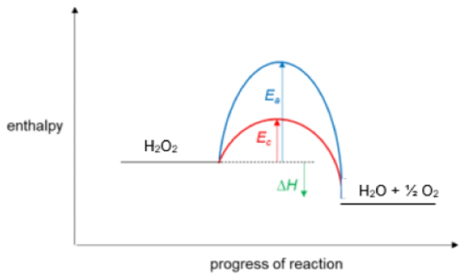
					respect to [BrO_3^-] and [H^+]. Candidates should focus on the quality of their descriptions when linking data to their conclusions with some candidates creating their own data set to fit their explanations. Having determined orders, nearly all candidates were able to give a corresponding rate equation and could calculate a value for the rate constant, albeit with frequent omission of units. Some candidates confused the rate equation with a K_c expression.
			Total	**6**	
3 9	a		 **Correct drawing of Boltzmann distribution** Curve starts within **one** small square of origin **AND** **not** touching the x axis at high energy✓ **Axes labels** y: (number of) molecules/particles **AND** x: (kinetic) energy ✓ **Catalyst and activation energy** Catalyst provides a lower activation energy **OR** E_c shown below E_a on Boltzmann distribution ✓ **Particles with E > Ea** More molecules/particles/collisions have energy above activation energy (with catalyst) **OR** more molecules have enough energy to react **OR** greater area under curve above activation energy ✓	4	ANNOTATE ANSWER WITH TICKS AND CROSSES **DO NOT ALLOW** two curves *Confusion with effect of temperature* **IGNORE** a slight inflexion on the curve if less than one small square **DO NOT ALLOW** 'atoms' as y-axis label **DO NOT ALLOW** 'enthalpy' for x-axis label **IF** y axis labelled as 'atoms' **ALLOW ECF** for atoms (instead of molecules/particles) **IGNORE** (more) successful collisions **IGNORE** response implying 'more collisions' *(confusion with effect of greater temperature)* **<u>Examiner's Comments</u>** This is a familiar question with around half of candidates scoring all 4 marks. Common errors included drawing 2 lines, as you would have with different temperatures, but labelling one with catalyst and other without. Some had incorrect or missing labels on the axes. The most frequently gained mark was

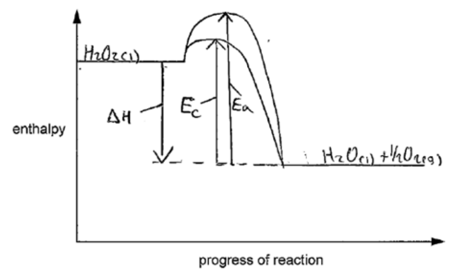
					for knowing that the activation energy was lowered by a catalyst; this could be given by correct lines and labelling shown on the distribution, although care needed to be taken as some contradicted their answers with their diagram. Some labelled E_a and E_c lines but didn't have energy on x-axis scale.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

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

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

40			**B**	1	**Examiner's Comments** The correct answer was B. Candidates had a good knowledge of the Boltzmann distribution and few incorrect responses were seen.
			Total	**1**	
41	a	i	**FIRST CHECK ANSWER ON ANSWER LINE** **If answer = −117 kJ mol^{-1}, award 4 marks.** -- ΔH = −286− (−188) = −98 kJ mol^{-1} ✓ ΔS = 70 + ½(205) − 110 = 62.5 (J K^{-1} mol^{-1}) or 0.0625 (kJ K^{-1} mol^{-1}) ✓ ΔG = ΔH − TΔS = −98 − (298 × 0.0625) ✓ ΔG = −117 kJ mol^{-1} **(3SF)** ✓	4	**ALLOW ECF** throughout **ALLOW** −98000 − (298 × 62.5) **Common Errors for Δ*G*** *3 marks* *−18700 (ΔS not converted to kJ)* −493 (Δ*H* = −286 + (−188) = −474) *−147 (ΔS = 165: not halving 205)* *− 99.6 (T not converted to K)* *−18.7 (ΔH not converted J but ΔS* J K^{-1} mol^{-1} *)* (+)79.4 (−188 − (−286) = +98) *2 marks* *(+) 117 (incorrect signs for ΔH and ΔS)* *Final Answer MUST BE 3 SF* **Examiner's Comments** Almost all candidates had a good attempt at this calculation, with many gaining full marks. Most were able to calculate the entropy change. Almost all could reproduce the equation for free energy. Of those who did not get the correct final answer, the most common error was not converting the entropy value into kJ and / or the temperature to K. There were a few candidates who did not manipulate the equation correctly. A few candidates incorrectly calculated ΔS, obtaining the value of 165 J K^{-1} mol^{-1} or ΔH, obtaining -474 kJ mol^{-1}. Candidates were given ECF in these cases.

		ii	(Rate of reaction) slow **OR** Activation energy high ✓	1	**ALLOW** Δ*G* takes no account of rate of reaction **ALLOW** molecules do not have sufficient energy to equal or exceed the activation energy. **IGNORE** molecules do not have sufficient energy to react. **DO NOT ALLOW** there is not enough activation energy **<u>Examiner's Comments</u>** Lots of good answers from candidates were seen for this question. A few candidates attempted the explanation via a ΔG / ΔS argument and misinterpreted the comment within the question.
	b	i	 H_2O_2 on LHS **AND** $H_2O + ½ O_2$ on RHS **AND** **Δ*H*** labelled with product line below reactant line **AND** Arrow downwards ✓ E_a correctly labelled ✓ E_c <u>correctly labelled</u> with $E_c < E_a$ ✓	3	**Care** enthalpy profile must match Δ*H* **sign** in16 a) i) – check calculation **ALLOW** endothermic profile as **ECF** from + Δ*H* calculated in 16 a) i) for all three marks State symbols not required **Δ*H* DO NOT ALLOW −Δ*H*** **DO NOT ALLOW** double headed arrow on Δ*H* **ALLOW** Δ*H* arrow even with small gap at the top and bottom, i.e. line does not quite reach reactant or product line. **E_a and E_c** **ALLOW** no arrowhead or arrowheads at both end of E_a or E_c lines E_a or E_c lines must reach maximum (**or near to maximum**) on curve **ALLOW** overlapping lines **OR** lines on side reaching maximum

					For E_a, **ALLOW** AE **OR** A_E **OR** Eact **OR** suitable alternatives **ALLOW ECF** marks for E_a **and** E_c for correctly labelled endothermic diagram from a $-\Delta H$ value (from16 a) i)) **Examiner's Comments** This question proved more difficult for candidates with lots of inaccuracies. The profile was dependent on the calculation for ΔH in Question 16 (a) (i). The arrowhead for ΔH needs to be pointing from the reactants to the products. The activation energies, again, need to start at the reactant line and go to the maximum level of the curve. Those that needed to draw an endothermic profile were far more likely to make an error with the E_a and E_c arrows, often starting from the product line or even from the base line of the graph. A significant number of candidates did not add arrows and instead labelled the curves E_a and E_c. Some candidates drew a Boltzmann distribution curve scoring 0 marks. Exemplar 1  The candidate has the correct exothermic profile but has the incorrect starting point for the activation energy going from the product line.
		ii	(MnO_2) is in different phase/state (to the reactant / H_2O_2) **OR**	1	**ASSUME** 'it' is MnO_2 **ALLOW** 'species in the reaction' **IGNORE** references to products

			catalyst is a solid **AND** reactant is liquid ✓		**Examiner's Comments** This was a well answered question. A few candidates, incorrectly, suggested that it was heterogeneous due to the reactants and products being in different states, and did not mention the catalyst.
		iii	Mn is +2 **AND** +3 **OR** Mn is +1 **AND** +6 ✓	1	+ required **ALLOW** 2+ and 3+ **DO NOT ALLOW** Mn^{2+} Mn^{3+} **DO NOT ALLOW** + 4 (this is the oxidation state in MnO_2) **Examiner's Comments** This question proved more challenging for candidates. Candidates stating +4 was the most common error; this is the oxidation state in MnO_2. Some candidates stated fractions, negative values and gave the state symbol instead i.e. solid and liquid.
			Total	**10**	
42	a		(Over time) concentration decreases **AND** collisions are less frequent ✓	1	**ALLOW** less moles/particles per unit volume. **ALLOW** fewer collisions per second/per unit time **IGNORE** (over time) fewer reacting particles **IGNORE** …chance of.. **IGNORE** amount decreases **IGNORE** successful **IGNORE** particles more spread out/further apart **DO NOT ALLOW** particles have less energy in terms of energy distribution. **Examiner's Comments** This question proved difficult for candidates to explain well. Collision theory linked to rate requires a

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>quantitative approach, e.g. less particles per unit volume and less collisions per unit time. A lot of candidates wrote vague responses about fewer particles so less collisions and did not gain credit.

?
Misconception
Some candidates described a decrease in energy in the reaction or gave responses related to activation energy for the concentration effect. For example, ‘reactants have less kinetic energy’ and ‘only a certain number of particles which have enough energy above the activation energy…over time energy will decrease and less particles have enough energy’.

We have produced a delivery guide on rates with some useful resources to help consolidate ideas and avoid misconceptions such as these: Teach Cambridge (ocr.org.uk)</td></tr>
<tr><td></td><td>b</td><td></td><td>Level 3 (5–6 marks)
A comprehensive conclusion using quantitative data from graph to correctly determine
1st order conclusion for CV using half lives/gradients
AND rate at 3 minutes
AND determination of k

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

Level 2 (3–4 marks)
Reaches a conclusion using quantitative data from graph to correctly determine rate at 3 minutes AND determination of k.
OR
Half- lives/gradient with 1st order conclusion for CV
AND determination of k
OR
determined rate AND half-life/first order for CV
OR
Attempts to determine rate, k and order for CV</td><td>6</td><td>Indicative scientific points may include:

Care: ALLOW the use of ECF for values obtained from a previously, incorrectly, calculated value.

ALLOW minor slips as we are looking for a holistic approach to LoR marking.

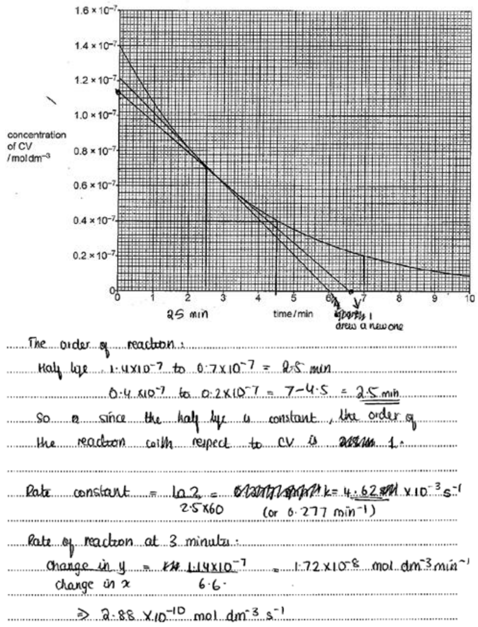
<table>
<tr><th></th><th>Minutes</th><th>Seconds</th></tr>
<tr><td>Half life values</td><td>2.4 to 2.6 min</td><td>144 to 156 s</td></tr>
<tr><td>Rate at three minutes</td><td>(-) (1.5 to 1.8) $\times 10^{-8}$ mol dm^{-3} min^{-1}</td><td>(-) (2.5 to 3.0)$\times 10^{-10}$ mol dm^{-3} s^{-1}</td></tr>
<tr><td>Value of k</td><td>0.24 to 0.30 min^{-1}</td><td>(4.0 to 5.0) x 10^{-3} s^{-1}</td></tr>
<tr><td>Units of k</td><td>min^{-1}</td><td>s^{-1}</td></tr>
</table></td></tr>
</table>

			There is a line of reasoning with some structure and supported by some evidence. **Level 1 (1–2 marks)** Reaches a simple conclusion using at least one piece of quantitative data from the graph, i.e. Attempts to calculate rate at three minutes **OR** *k* **OR** links half lives to 1st order.3 *There is an attempt at a logical structure with a reasoned conclusion from the evidence*. **0 mark** *No response worthy of credit*		Examples of the communication statement being met would typically include: • For L1 and L2: full working on the graph and/or appropriate units for calculated values. • For L3: full working on the graph and appropriate units for calculated values. **If time has been measured in minutes** **(see below for values using seconds).** **Indicative scientific points may include:** **Evidence for 1st order** 1st order clearly linked to half-life **OR** 2 gradients: **Half life** Half- life shown on graph Half- life range 2.4 to 2.6 min Two 'constant' half lives **OR Two gradients → two rates** 2 tangents shown on graph at *c* and *c*/2 This could include $c = 0.61 \times 10^{-7}$ mol dm^{-3} ($t = 3$ min) Gradient at *c*/2 is half gradient at *c* e.g. $c = 0.8 \times 10^{-7}$ mol dm^{-3}, gradient = 2.2×10^{-8} (mol dm^{-3} min^{-1}) **AND** $c = 0.4 \times 10^{-7}$ mol dm^{-3}, gradient = 1.1×10^{-8} (mol dm^{-3} min^{-1}) For chosen method, conclude that the reaction is 1st order wrt CV.

					Rate at three minutes Tangent shown on graph as line at *t* = 3 min Gradient in range: (1.5 − 1.8) × 10^{-8} rate as gradient with units: mol dm^{-3} min^{-1} **OR** $k = \frac{\ln 2}{t_{½}} = 0.28 min^{-1}$ And k substituted into rate equation. e.g. Rate = *k* [CV] Rate = 0.277 x 0.61 x10^{-7} = 1.7 x10^{-8} mol dm^{-3} min^{-1} **Determination of *k*** *k* clearly linked to rate **OR** half-life: e.g. $k = \frac{rate}{[CV]} = \frac{1.75 \times 10^{-8}}{0.62 \times 10^{-7}} = 0.28$ *k* in range: 0.24 - 0.30 min^{-1} **OR** e.g. $k = \frac{\ln 2}{t_{½}} = 0.28\ min^{-1}$ **Units of *k*:** min^{-1} **If time has been measured in seconds:** **Evidence for 1st order** 1st order clearly linked to half-life **OR** 2 gradients: **Half life** Half- life shown on graph Half- life range 144 to 156 s Two 'constant' half lives **OR Two gradients → two rates** 2 tangents shown on graph at *c* and *c*/2 This could include *c* = 0.6 × 10^{-8} mol dm^{-3} (*t* = 3 min) Gradient at *c*/2 is half gradient at *c* e.g. *c* = 0.8 x 10^{-7} mol dm^{-3}, gradient = 3.7 × 10^{-10} mol dm^{-3} s^{-1}

					AND c = 0.4 x 10^{-7} mol dm^{-3}, gradient = 1.8 × 10^{-10} mol dm^{-3} s^{-1} For chosen method, conclude that the reaction is 1st order wrt CV. **Rate at 180 seconds** Gradient in range (2.5 to 3.0) ×10^{-10} rate as gradient with units: mol dm^{-3} s^{-1} **OR** $k = \frac{\ln 2}{t_{1/2}} = 4.6 \times 10^{-3}\ s^{-1}$ And k substituted into rate equation. e.g. Rate = k [CV] Rate = 0.00462 x 0.61 x10^{-7} = 2.8 x 10^{-10} mol dm^{-3} s^{-1} **Determination of *k*** k clearly linked to rate **OR** half-life: e.g. $k = \frac{\text{rate}}{[\text{CV}]} = \frac{2.75 \times 10^{-10}}{0.62 \times 10^{-7}} = 4.4 \times 10^{-3}\ s^{-1}$ k in range (4.0 to 4.8) x 10^{-3} s^{-1} **OR** e.g $k = \frac{\ln 2}{t_{1/2}} = 0.28\ \text{min}^{-1}$ **OR** 4.6 x 10^{-3} s^{-1} **Units of *k*:** s^{-1} **Examiner's Comments** The first Level of Response question in the paper was answered well with the higher-attaining candidates on the paper scoring full marks. These students started with a nice clear analysis of the half-life, referring to labelled sections of the graph, then went on to calculate the rate from a well-drawn tangent with correct indices and were careful to write down the correct units. Then used the rate equation to calculate K and get the correct units. Almost all candidates were able to conclude that it was first order for CV.

					Most used the half-life approach with others comparing two gradients. Candidates should be advised, especially in LoR questions, that the conclusion needs a clear link to the data. The gradient at 3 minutes was done well and the candidates used the appropriate scale from the graph in their calculations. Clarity of communication does require indication of what is being calculated and how the numbers were obtained. This would allow an initial rate versus a rate at three minutes to be distinguished. Units were particularly important in this question as some candidates used minutes from the graph while others converted time into seconds. A common error was to state the wrong units or leave them out altogether. Most candidates used the rate equation to calculate K and get the correct units. A few approached the value by using $k = \frac{\ln 2}{t_{1/2}}$. Error carried forward was given for those with incorrect half-lives or rate value. Candidate errors arose from graph readings that caused rate to be wrong, errors in concentrations used in rate or K calculation, and badly drawn tangents causing the rate to be out of tolerance. Some candidates tried to adjust the concentrations as if conducting mole calculations or take the rate from two points on the graph. Exemplar 2

					 The candidate scored Level 3. The graph was clearly used to obtain half-lives and gradients. This was communicated on the answer lines, showing calculations and units. **OCR support** M3 section of the Maths Skills handbook contains useful information on use of graphs in chemistry, including M3.5 on drawing and using the slope of the tangent to a curve as a measure of a rate of change: Teach Cambridge (ocr.org.uk)
			Total	**7**	
43			**A**	1	**Examiner's Comments** Most candidates were aware that heat increases the number of molecules that have energy greater than the activation energy (A).
			Total	**1**	
44		i	axes: labels correct, **AND** units **AND** scales chosen so that the plotted points	3	

			occupy at least half the graph grid in both the *x* and *y* directions (1) **ALL** points plotted correctly (1) Best curve drawn through points **AND** ignoring point at 20 s (1)		
		ii	*Tangent* tangent drawn to curve at *t* = 50 s (1) *Calculation of rate from the gradient of tangent drawn* e.g. rate = $\frac{64}{94}$= 0.68 (cm^3 s^{-1}) (1)	2	Annotate tangent on graph **Note**: This mark can only be awarded from a tangent **allow ecf** for tangent drawn at different time from 50 s **allow** ±10% of gradient of tangent drawn **allow** 2 sig figs up to calculator value **allow** trailing zeroes, e.g. 0.7 for 0.070 **ignore** '−' sign for rate **Note:** if candidate calculates rate via ln 2 method, consult with TL
			Total	**5**	