1. 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.

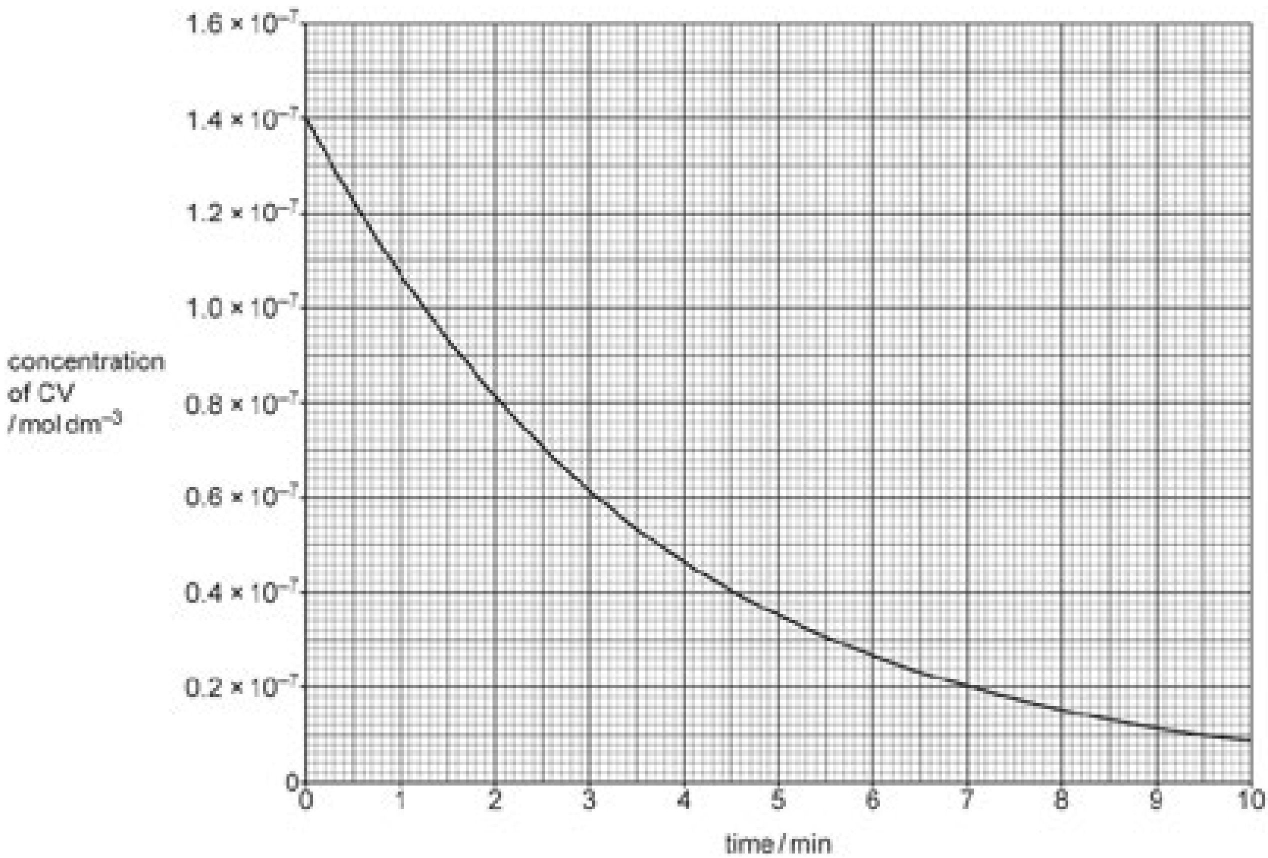
Your answer [1]

2(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]

3. 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]**

4(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.

	ΔH_f°/kJ mol^{1}	S° / 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.

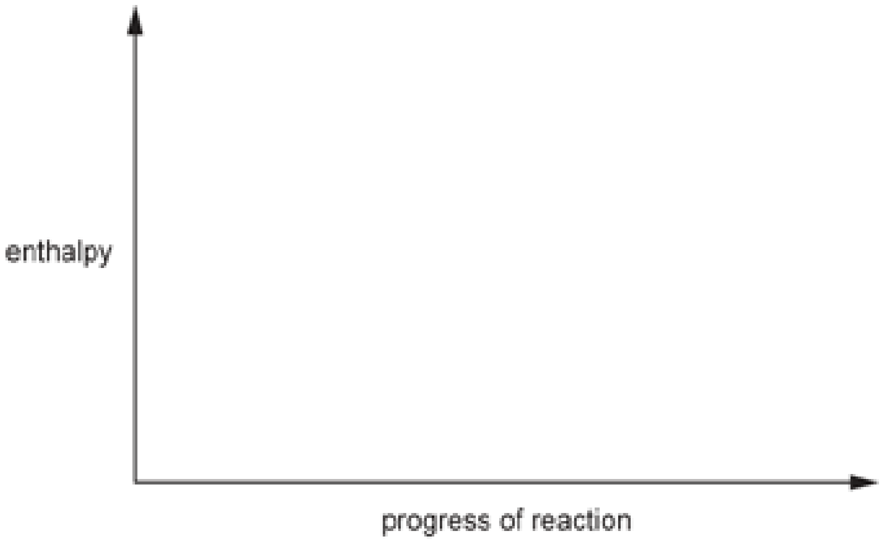
[1]

(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]**

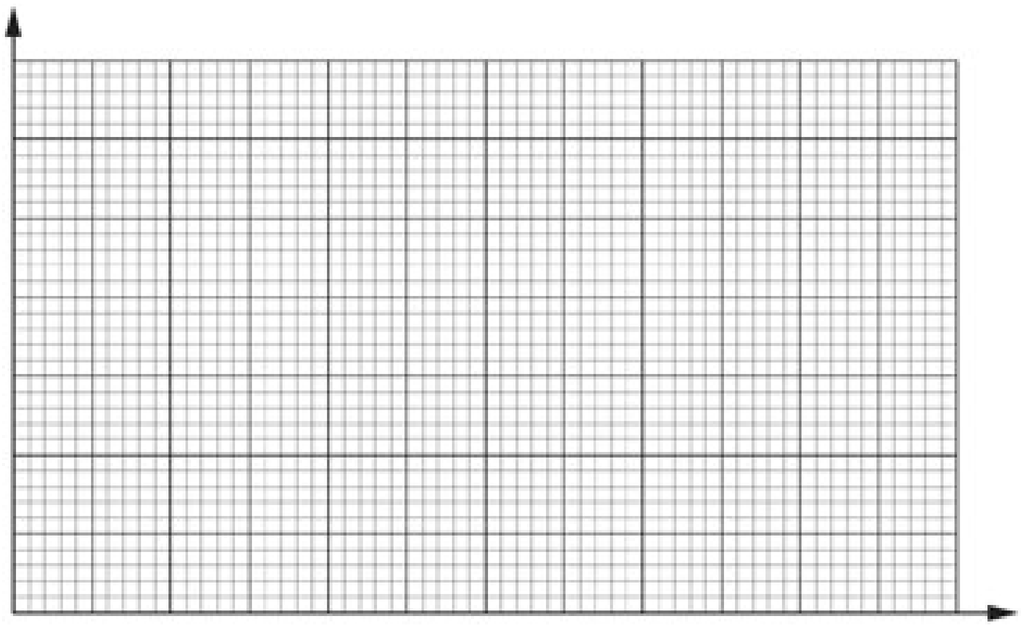
5(a). Aqueous hydrogen peroxide, $H_2O_2(aq)$, gradually decomposes to produce water and oxygen.

$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$ ΔH=-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.



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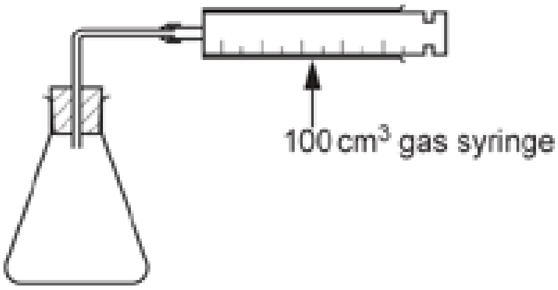
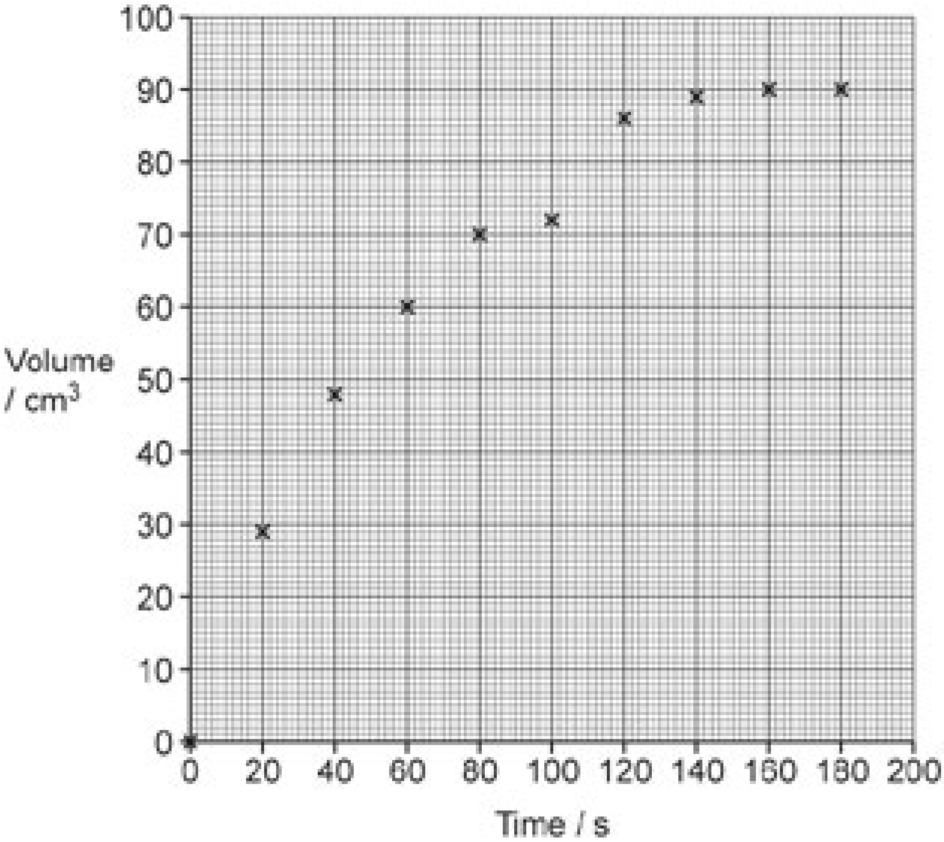
____ **[4]**

(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]**

6. 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.

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[6]

7. 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]**

8. 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.

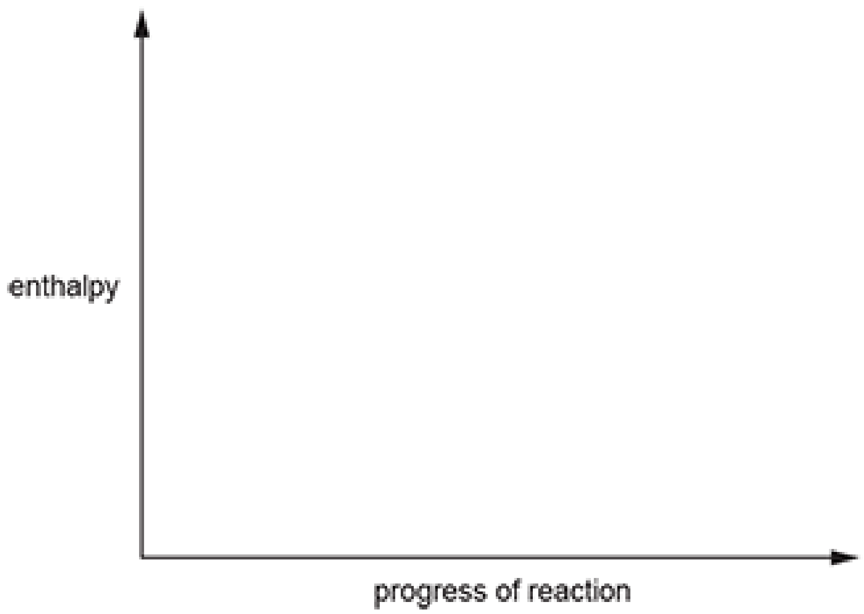


Fig. 23.1

[2]

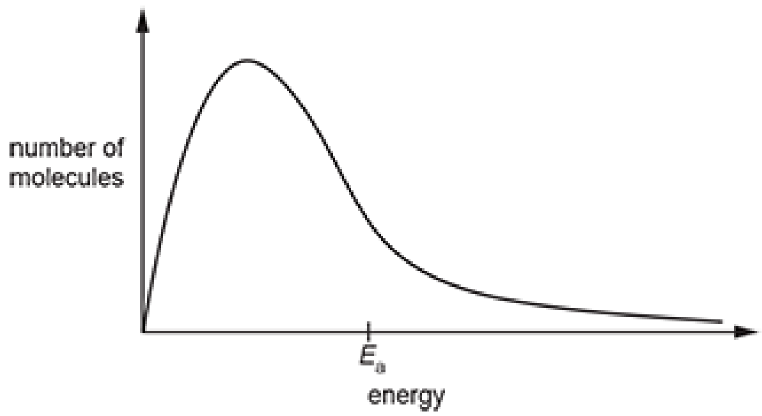
iii. CO and NO are removed by use of a catalyst.

Explain the role of the catalyst.

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

[2]

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



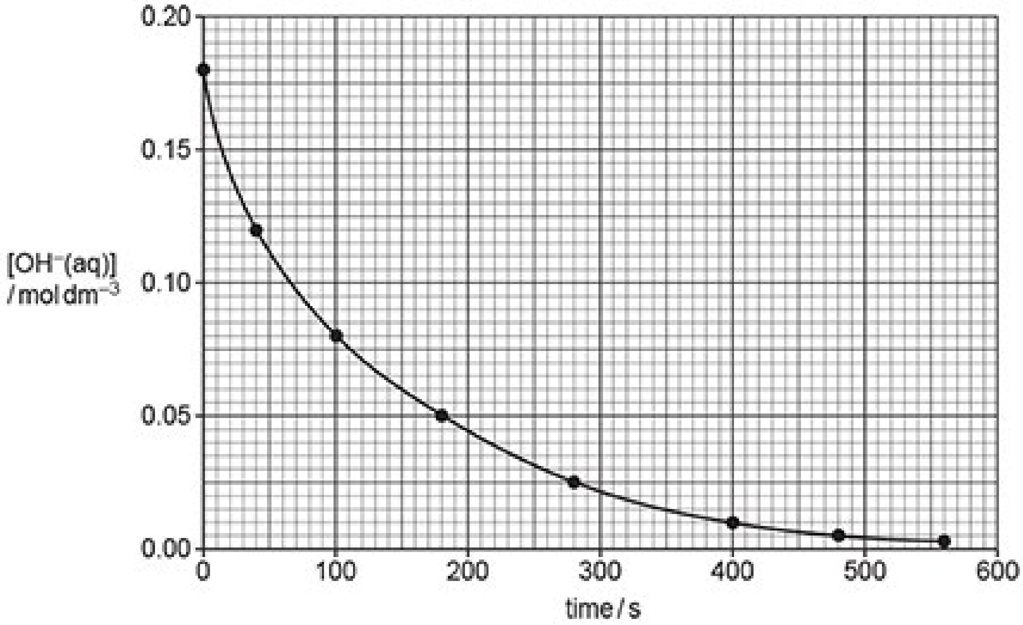
What is the difference for the **catalysed** reaction?

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]**

10. 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]**

11. 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.

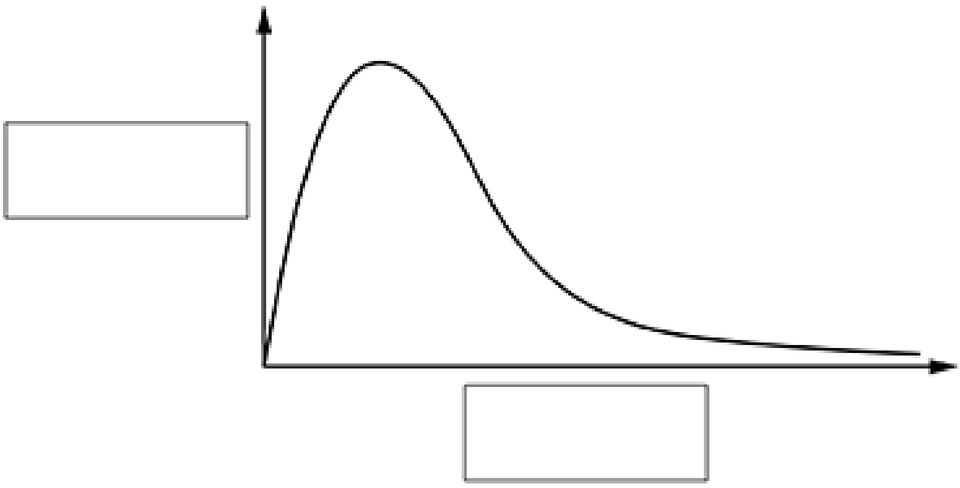


Fig. 25.1

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.

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____ **[3]**

12. 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]**

13. 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.

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____ **[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]**

14. 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.

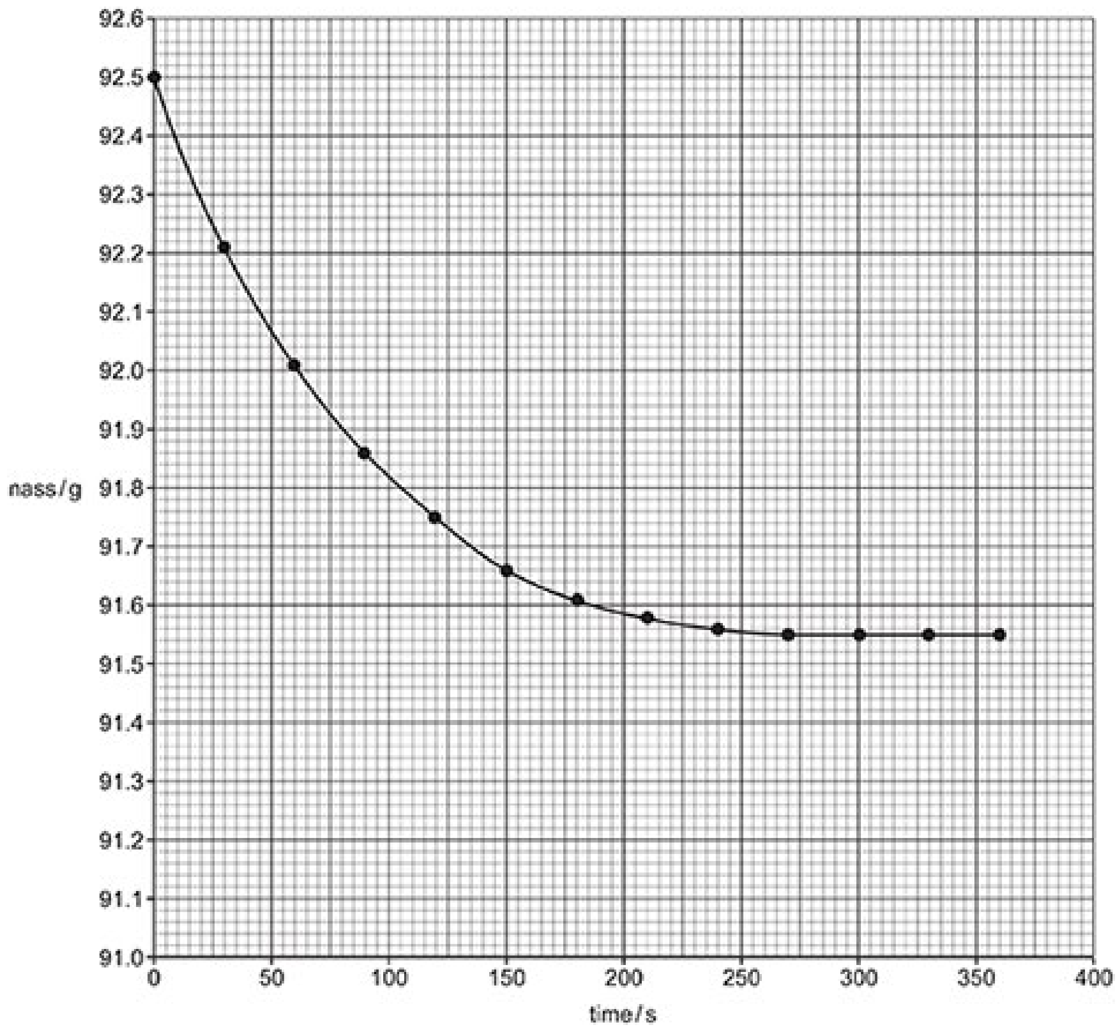


Fig. 3.1

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]**

15. 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

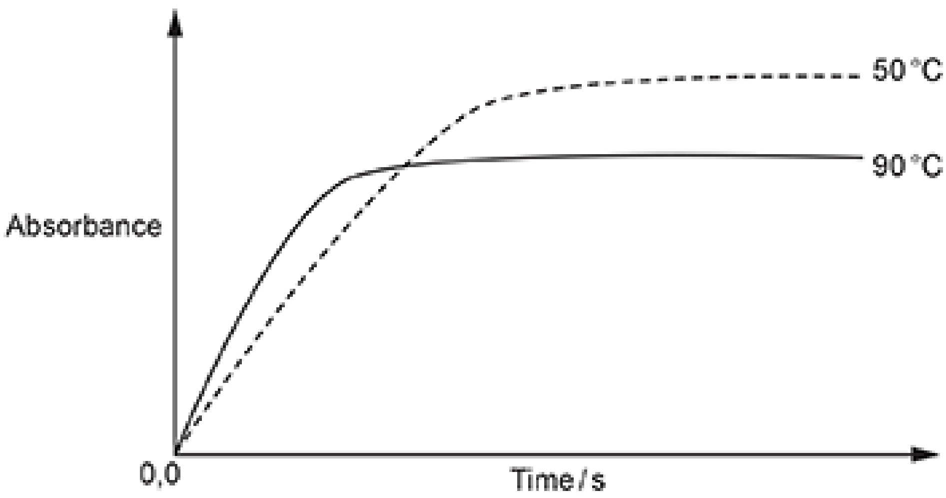
The students are supplied with the equilibrium mixture in **Equilibrium 4.1** at room temperature.

- 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]**

16. A student investigates some reactions of zinc compounds and zinc metal.

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 ____

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2 ____

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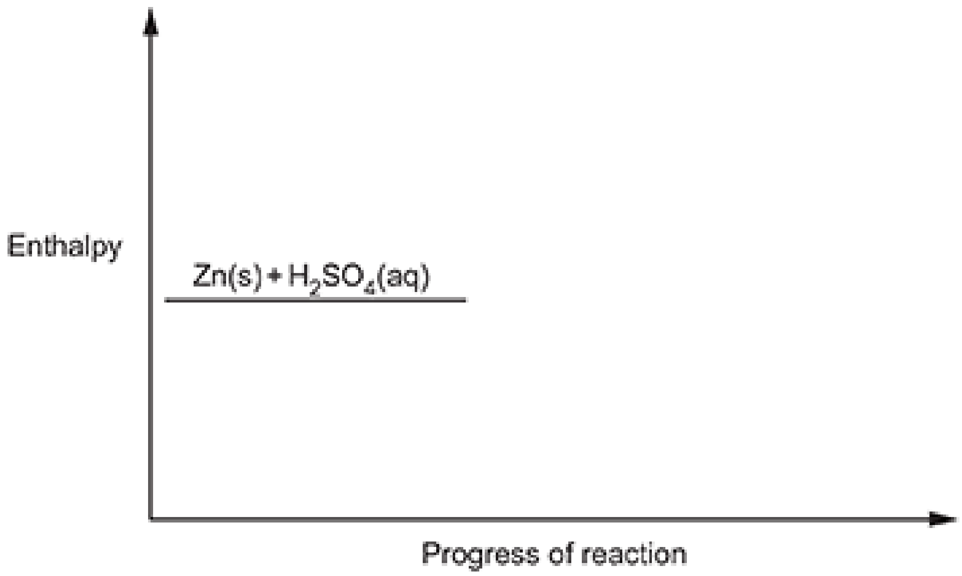
[2]

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:

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



[3]

END OF QUESTION PAPER