1 Hydrogen is produced in industry from methane and steam in a two-stage process.

(a) In the first stage, carbon monoxide and hydrogen are formed.
The equation for this reaction is

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H = +206 \text{ kJ mol}^{-1}$

(i) Use Le Chatelier's principle to state whether a high or low temperature should be used to obtain the highest possible equilibrium yield of hydrogen from this first stage. Explain your answer.

Temperature .....

Explanation .....

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(3)

(ii) Le Chatelier's principle suggests that a high pressure will produce a low yield of hydrogen in this first stage.

Explain, in terms of the behaviour of particles, why a high operating pressure is used in industry.

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(2)

(iii) A nickel catalyst is used in the first stage.

Explain why the catalyst is more effective when coated onto an unreactive honeycomb.

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(2)

(b) The second stage is carried out in a separate reactor. Carbon monoxide is converted into carbon dioxide and more hydrogen is formed.

The equation for this reaction is

$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ $\Delta H = -41$ kJ mol^{-1}

Use Le Chatelier's principle to state the effect, if any, of a **decrease** in the total pressure on the yield of hydrogen in this second stage. Explain your answer.

Effect .....

Explanation .....

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(2)
(Total 9 marks)

2 Calamine lotion can contain a mixture of zinc carbonate and zinc oxide in suspension in water. A manufacturer of calamine lotion claims that a sample contains 15.00 g of zinc carbonate and 5.00 g of zinc oxide made up to 100 cm^3 with distilled water.

(a) A chemist wanted to check the manufacturer's claim. The chemist took a 20.0 cm ^{3} sample of the calamine lotion and added it to an excess of sulfuric acid.
The volume of carbon dioxide evolved was measured over time. The chemist's results are shown in the table.

Time / s	0	15	30	45	60	75	90	105	120	135
Volume / cm^3	0	135	270	380	470	530	560	570	570	570

(i) Plot a graph of the results in the table on the grid. The volume should be on the *y*-axis. Draw a best-fit curve through **all** the points.

(3)

(ii) Estimate the time taken for the reaction to be completed.

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(1)

(b) (i) The volume of carbon dioxide in part (a) was measured at 293 K and at a pressure of 100 kPa.

Use information from your graph to calculate the maximum amount, in moles, of carbon dioxide evolved from the zinc carbonate in this 20.0 cm^3 sample.

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

Show your working.

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(3)

(ii) Use your answer to part (i) to calculate the mass of zinc carbonate in the 20.0 cm^3 sample of calamine lotion.

(If you were unable to complete part (i), you may assume that the amount of carbon dioxide evolved was 0.0225 mol. This is **not** the correct answer.)

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(2)

(iii) Calculate the difference between your answer to part (ii) and the manufacturer's claim that there are 15.00 g of zinc carbonate in 100 cm^3 of the calamine lotion.

Express this difference as a percentage of the manufacturer's claim.

(If you were unable to complete part (ii), you may assume that the mass of zinc carbonate in the 20 cm^3 sample of calamine lotion was 2.87 g. This is **not** the correct answer.)

Difference .....

Percentage .....

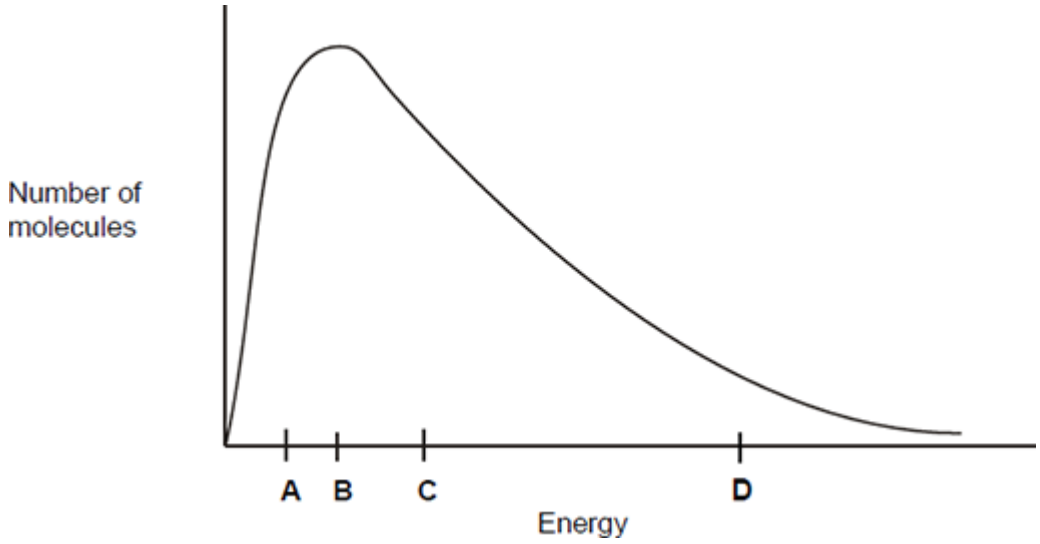
.....

(2)

(c) Draw a diagram of a suitable apparatus needed to perform the experiment outlined in part (a). Include in your diagram a method for collecting and measuring the carbon dioxide. The apparatus should be airtight.

(2)
(Total 13 marks)

3 This question is about the Maxwell–Boltzmann distribution of molecular energies in a sample of a gas shown in the figure below.



Which letter best represents the mean energy of the molecules?

A ⬭

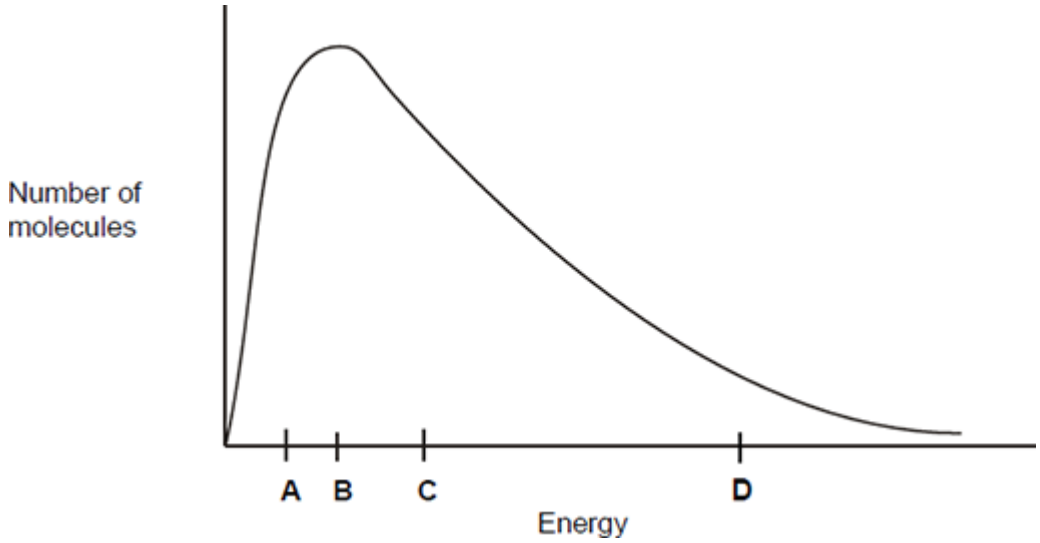
B ⬭

C ⬭

D ⬭

(Total 1 mark)

4 This question is about the Maxwell–Boltzmann distribution of molecular energies in a sample of a gas shown in the following figure.



What does the area under the curve represent?

A The total energy of the particles. ⬭

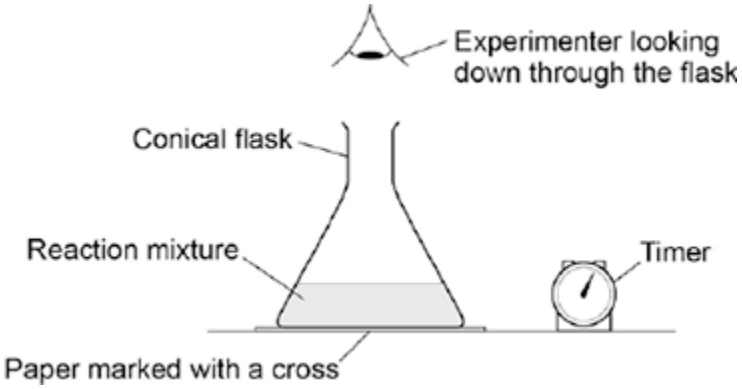
B The total number of particles. ⬭

C The number of particles that can react with each other. ⬭

D The total number of particles that have activation energy. ⬭

(Total 1 mark)

5 The apparatus in the figure below was set up to measure the time taken for 20.0 cm^3 of sodium thiosulfate solution to react with 5.0 cm^3 of hydrochloric acid in a 100 cm^3 conical flask at 20 °C.
The timer was started when the sodium thiosulfate solution was added to the acid in the flask.
The timer was stopped when it was no longer possible to see the cross on the paper.



What is likely to decrease the accuracy of the experiment?

A Rinsing the flask with acid before each new experiment. ⬭

B Stirring the solution throughout each experiment. ⬭

C Using the same piece of paper for each experiment. ⬭

D Using different measuring cylinders to measure the volumes of acid and sodium thiosulfate. ⬭

(Total 1 mark)

6 The experiment was repeated at 20 °C using a 250 cm^3 conical flask.

Which statement is correct about the time taken for the cross to disappear when using the larger conical flask?

A The time taken will **not** be affected by using the larger conical flask. ⬭

B The time taken will be decreased by using the larger conical flask. ⬭

C The time taken will be increased by using the larger conical flask. ⬭

D It is impossible to predict how the time taken will be affected by using the larger conical flask. ⬭

(Total 1 mark)

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

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

Table 1

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

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

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(3)

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

Table 2

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

The rate equation for this reaction is

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

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

k = ... Units = ...

(3)

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

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

(1)

(d) The rate equation for a reaction is

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

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

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(3)

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

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

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

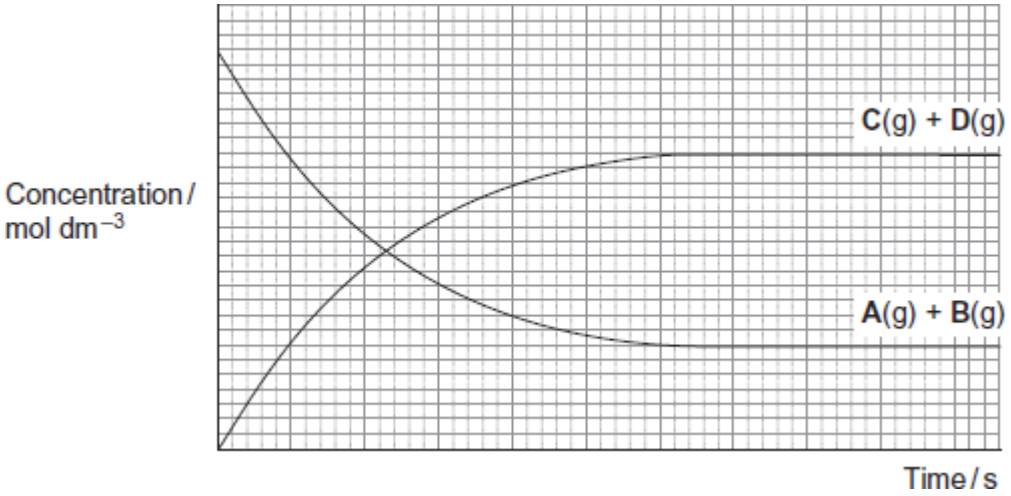
Activation energy = ...

(2)
(Total 12 marks)

8 A dynamic equilibrium is established when gas **A** is mixed with gas **B** at a given temperature.

$$\mathbf{A}(g) + \mathbf{B}(g) \rightleftharpoons \mathbf{C}(g) + \mathbf{D}(g)$$

The figure below shows how the concentrations of reactants and products change with time.



(a) (i) On the appropriate axis of the figure, place an **X** to show the time when equilibrium is first established.

(1)

(ii) State how the rate of the forward reaction and the rate of the reverse reaction are related to each other at equilibrium.

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(1)

(b) Give the meaning of the term **dynamic** in the context of a dynamic equilibrium.

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(1)

(c) The total pressure on the system is increased at constant temperature.

(i) State and explain the effect, if any, of this change on the position of this equilibrium.

Effect .....

Explanation .....

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(2)

(ii) State and explain the effect, if any, of this change on the time taken to reach this equilibrium.

Effect .....

Explanation .....

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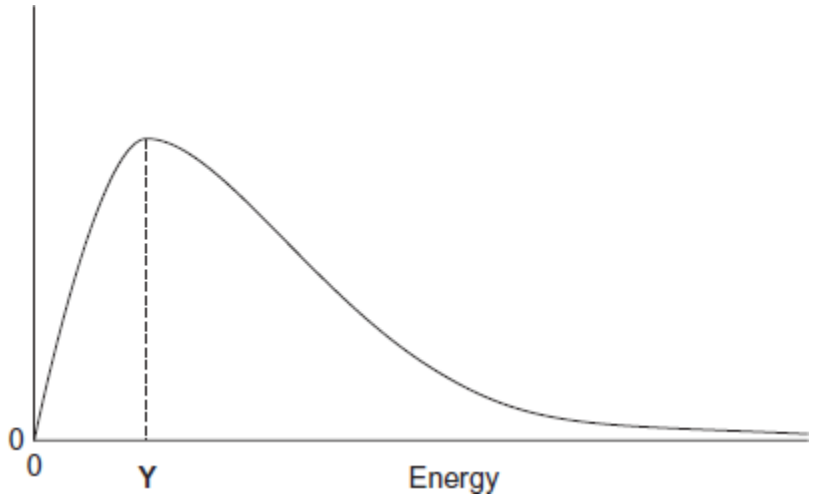
(3)
(Total 8 marks)

9 The following figure shows the Maxwell.Boltzmann distribution of molecular energies in a sample of gas at temperature *T*.



(a) One of the axes is labelled.
Label the other axis.

(1)

(b) State why the curve starts at the origin.

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(1)

(c) Which of the following, **A**, **B** or **C**, describes what the value of **Y** represents in the figure? Write the correct letter, **A**, **B** or **C**, in the box.

A The energy needed for a successful collision
B The minimum energy needed for a reaction to occur
C The most probable energy

(1)

(d) On the figure above, draw a distribution of molecular energies in this sample of gas at a **higher** temperature.

(2)

(e) The pressure of the original sample of gas is doubled at temperature *T*.

State the effect, if any, of this change on the value of **Y**.

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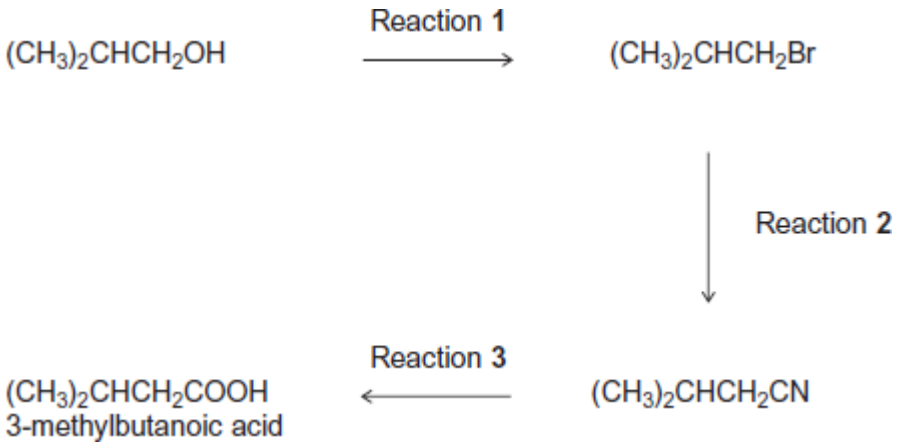
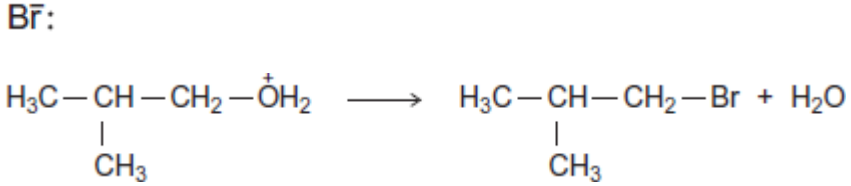
(1)
(Total 6 marks)

10 The carboxylic acid 3-methylbutanoic acid is used to make esters for perfumes.
The following scheme shows some of the reactions in the manufacture of this carboxylic acid.



(a) One of the steps in the mechanism for Reaction **1** involves the replacement of the functional group by bromine.

(i) Use your knowledge of organic reaction mechanisms to complete the mechanism for this step by drawing **two** curly arrows on the following equation.



(2)

(ii) Deduce the name of the mechanism in part (i).

Give the IUPAC name of $(CH_3)_2CHCH_2Br$

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(2)

(b) Reaction **3** is an acid-catalysed reaction in which water is used to break chemical bonds when the CN functional group is converted into the COOH functional group.
Infrared spectroscopy can be used to distinguish between the compounds in this reaction.

Deduce the name of the type of reaction that occurs in Reaction **3**.

Identify **one** bond in $(CH_3)_2CHCH_2CN$ and a **different** bond in $(CH_3)_2CHCH_2COOH$ that can be used with infrared spectroscopy to distinguish between each compound.
For each of these bonds, give the range of wavenumbers at which the bond absorbs.
Use **Table A** on the Data Sheet when answering this question.

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(3)

(c) When 3-methylbutanoic acid reacts with ethanol in the presence of an acid catalyst, an equilibrium is established. The organic product is a pleasant-smelling ester.

$$(CH_3)_2CHCH_2COOH + CH_3CH_2OH \rightleftharpoons \underset{\text{an ester}}{(CH_3)_2CHCH_2COOCH_2CH_3} + H_2O$$

The carboxylic acid is very expensive and ethanol is inexpensive. In the manufacture of this ester, the mole ratio of carboxylic acid to ethanol used is 1 to 10 rather than 1 to 1.

(i) Use Le Chatelier's principle to explain why a 1 to 10 mole ratio is used. In your explanation, you should **not** refer to cost.

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(Extra space) .....

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(3)

(ii) Explain how a catalyst increases the rate of a reaction.

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(Extra space) .....

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(2)

(Total 12 marks)

11 A student investigated how the initial rate of reaction between sulfuric acid and magnesium at 20 °C is affected by the concentration of the acid.

The equation for the reaction is

$$H_2SO_4(aq) + Mg(s) \longrightarrow MgSO_4(aq) + H_2(g)$$

(a) The student made measurements every 20 seconds for 5 minutes. The student then repeated the experiment using double the concentration of sulfuric acid.

State a measurement that the student should make every 20 seconds. Identify the apparatus that the student could use to make this measurement.

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(2)

(b) State **one** condition, other than temperature and pressure, that would need to be kept constant in this investigation.

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(1)

(c) When the student had finished the investigation, an excess of sodium hydroxide solution was added to the reaction mixture. This was to neutralise any unreacted sulfuric acid. The student found that a further reaction took place, producing magnesium hydroxide.

(i) Draw a diagram to show how the student could separate the magnesium hydroxide from the reaction mixture.

(2)

(ii) Suggest **one** method the student could use for removing soluble impurities from the sample of magnesium hydroxide that has been separated.

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(1)

(Total 6 marks)

12 When iodine molecules are dissolved in aqueous solutions containing iodide ions, they react to form triiodide ions (I_3^-).

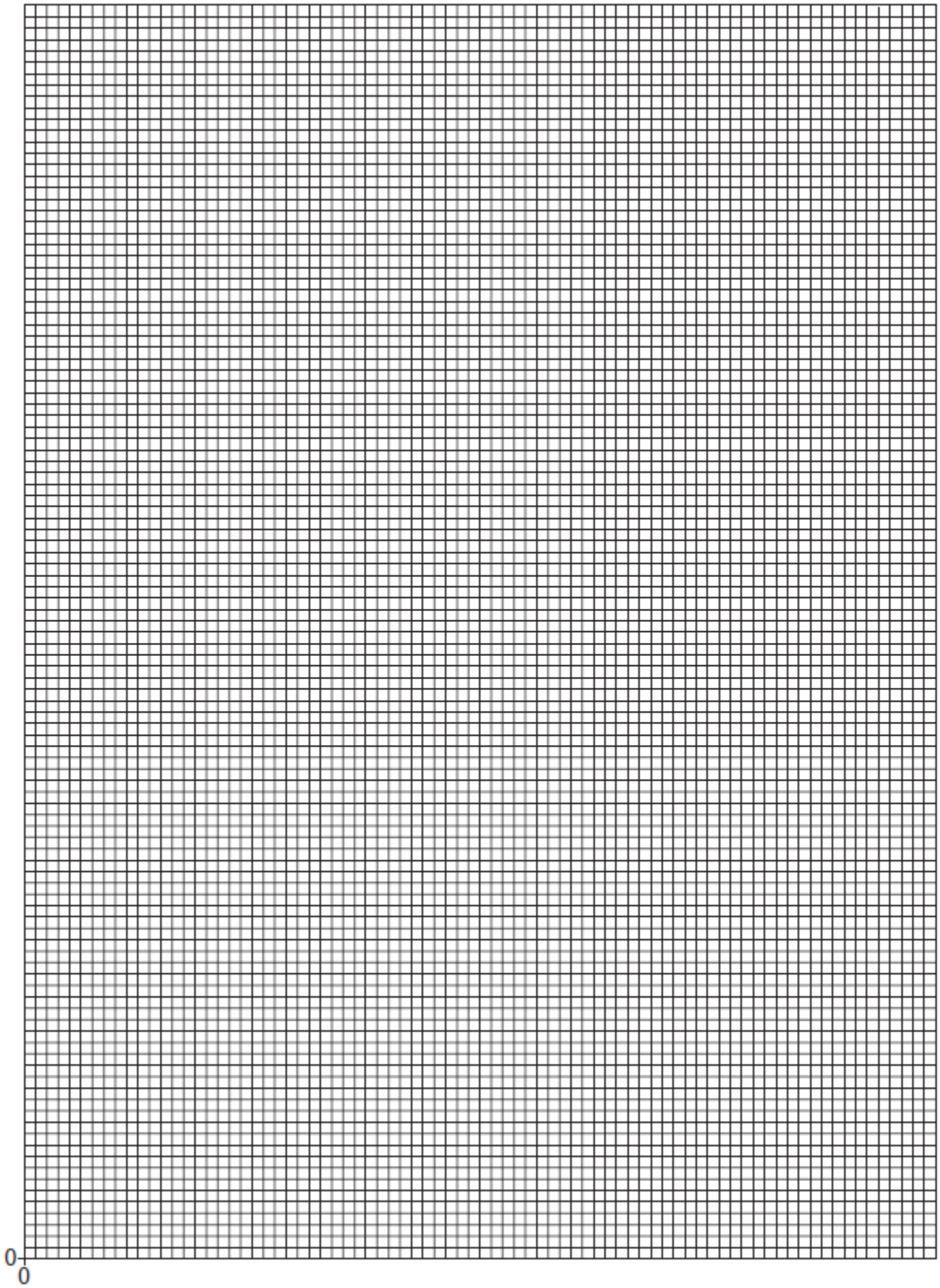
$$I_2 + I^- \longrightarrow I_3^-$$

The rate of the oxidation of iodide ions to iodine by peroxodisulfate(VI) ions ($S_2O_8^{2-}$) was studied by measuring the concentration of the I_3^- ions at different times, starting at time = 0, when the reactants were mixed together. The concentration of the I_3^- ions was determined by measuring the absorption of light using a spectrometer.

The table below shows the results.

Time / s	**Concentration of I_3^- / mol dm^{-3}**
10	0.23
20	0.34
30	0.39
40	0.42
50	0.47
60	0.44
70	0.45

(a) Plot the values of the concentration of I_3^- (y-axis) against time on the grid below.



(2)

(b) A graph of these results should include an additional point. On the grid, draw a ring around this additional point.

(1)

(c) Draw a best-fit curve on the grid, **including the extra point from part (b)**.

(2)

(d) Draw a tangent to your curve at time = 30 seconds. Calculate the slope (gradient) of this tangent and hence the rate of reaction at 30 seconds. Include units with your final answer. Show your working.

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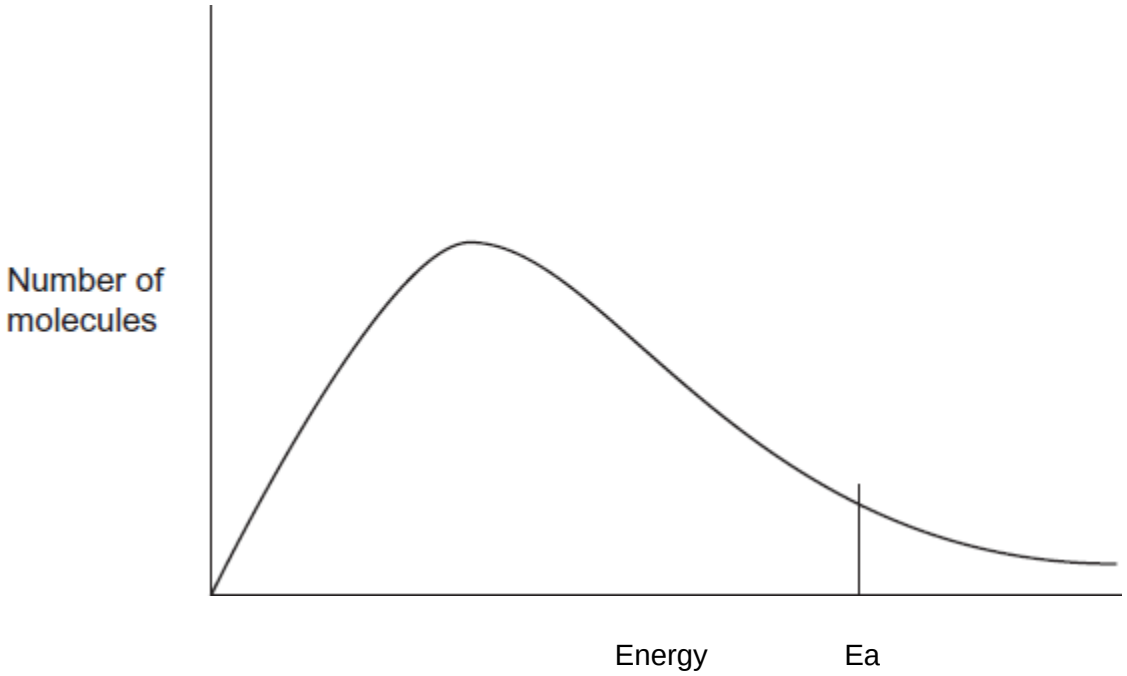
(4)
(Total 9 marks)

13 The diagram shows the Maxwell–Boltzmann distribution for a sample of gas at a fixed temperature.
E_a is the activation energy for the decomposition of this gas.



E_{mp} is the most probable value for the energy of the molecules.

(a) On the appropriate axis of this diagram, mark the value of E_{mp} for **this** distribution.

On this diagram, sketch a new distribution for the same sample of gas at a **lower** temperature.

(3)

(b) With reference to the Maxwell–Boltzmann distribution, explain why a decrease in temperature decreases the rate of decomposition of this gas.

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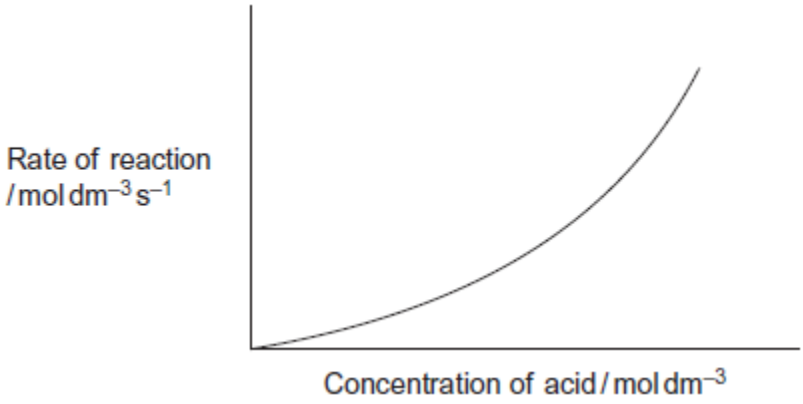
(2)
(Total 5 marks)

14 (a) In an investigation of the rate of reaction between hydrochloric acid and pure magnesium, a student obtained the following curve.



The reaction of magnesium with dilute hydrochloric acid is exothermic.

Use your understanding of collision theory to explain why the student did **not** obtain a straight line.

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(3)

(b) The magnesium used in a laboratory experiment was supplied as a ribbon. The ribbon was stored in an open plastic bag exposed to the air.

Explain why it is important to clean the surface of this magnesium ribbon when investigating the rate of its reaction with hydrochloric acid.

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(2)

(c) Magnesium ribbon reacts with hot water. Heated magnesium ribbon reacts with steam.
State **two** differences between these reactions.

Difference 1 .....

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Difference 2 .....

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(2)

(d) Pure magnesium reacts completely with an excess of dilute sulfuric acid.
The reaction of pure calcium with an excess of dilute sulfuric acid is very rapid initially.
This reaction slows down and stops before all of the calcium has reacted.

Use your knowledge of the solubilities of Group 2 sulfates to explain why these reactions of magnesium and calcium with dilute sulfuric acid are so different.

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(3)
(Total 10 marks)

15 An equation for the decomposition of hydrogen peroxide is

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

(a) The rate of reaction can be determined by collecting the oxygen formed and measuring its volume at regular intervals.

Draw a diagram to show the apparatus that you would use to collect and measure the volume of the oxygen formed.

(2)

(b) Explain how you could use your results from the experiment in part (a) to determine the initial rate of this reaction.

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(2)

(c) The rate of decomposition of hydrogen peroxide is increased by the addition of cobalt(II) ions.

Outline the essential features of an additional experiment to show that the rate of decomposition is increased by the addition of cobalt(II) chloride. Use the same method and the same apparatus as in part (a).

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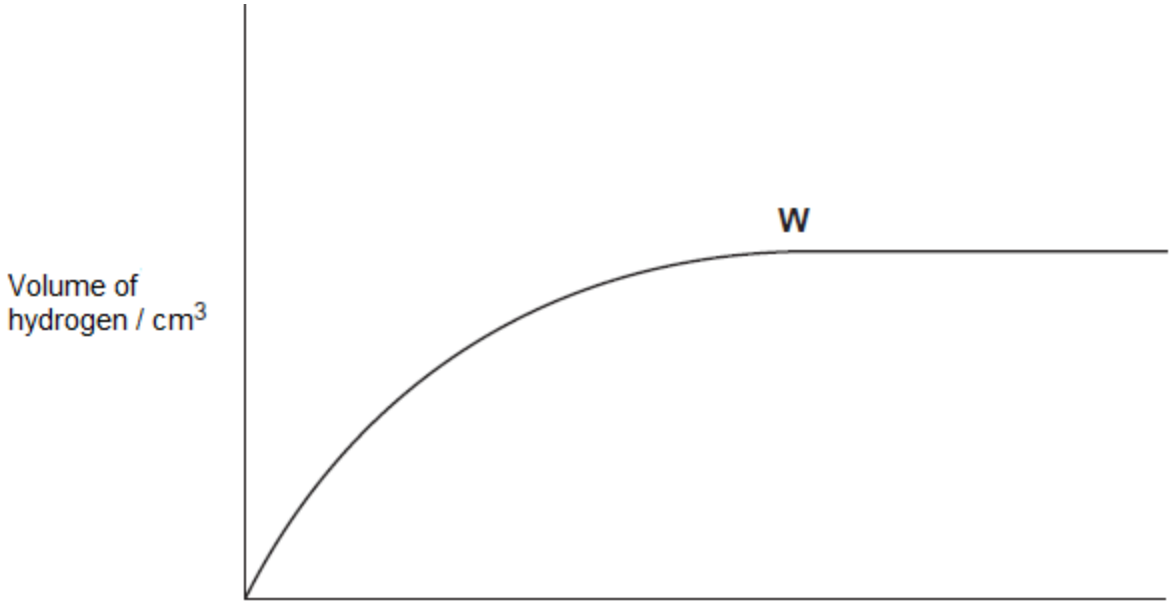
(2)
(Total 6 marks)

16 (a) **Figure 1** shows the volume of hydrogen gas collected when a sample of magnesium reacted with an excess of dilute hydrochloric acid.

The rate of this reaction can be studied by measuring the time it takes for a given volume of hydrogen to be collected.

Figure 1



(i) State the meaning of the term *rate of reaction*.

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(1)

(ii) State and explain what has happened to the rate of this reaction at point **W** in **Figure 1**.

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(2)

(iii) In terms of collision theory explain why, at a fixed temperature, the rate of this reaction doubles when the concentration of the hydrochloric acid doubles.

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(2)

(b) In a study of the reaction in part (a), a student referred to activation energy.

(i) State the meaning of the term *activation energy*.

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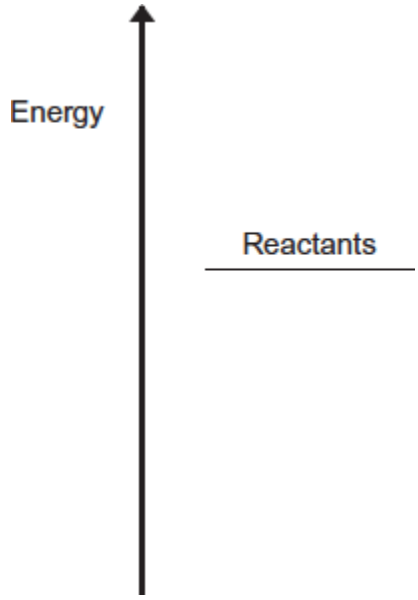
(1)

(ii) Complete **Figure 2** by drawing the shape of the reaction profile from reactants to products for an exothermic reaction.
Show the position of the products. Show and label the activation energy.

Figure 2



(2)

(c) Barium metal reacts very quickly with dilute hydrochloric acid, but it reacts more slowly with water.

(i) Write an equation for the reaction of barium with water.

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(1)

(ii) A solution containing barium ions can be used to show the presence of sulfate ions in an aqueous solution of sodium sulfate.

Write the **simplest ionic** equation for the reaction that occurs and state what is observed.

Simplest ionic equation

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Observation

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(2)

(iii) State **one** use of barium sulfate in medicine.
Explain why this use is possible, given that solutions containing barium ions are poisonous.

Use .....

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Explanation .....

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(2)
(Total 13 marks)

17 A study of equilibrium is important for understanding chemical reactions.

(a) State le Chatelier's principle.

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(Extra space) .....

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(1)

(b) Catalysts play an important role in many reactions.

(i) State the meaning of the term *catalyst*.
Explain, in general terms, how catalysts work.

Meaning of the term *catalyst* .....

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How catalysts work .....

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(3)

(Extra space) .....

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(ii) State the effect, if any, of a catalyst on the time taken to reach equilibrium.

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(1)

(iii) State the effect, if any, of a catalyst on the position of an equilibrium.

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(1)

(c) Consider the following equilibrium reactions.

				$\Delta H^{\ominus}$ / kJ mol^{-1}
P	$H_2(g) + I_2(g)$	$\rightleftharpoons$	$2HI(g)$	−10
Q	$CO_2(g) + 3H_2(g)$	$\rightleftharpoons$	$CH_3OH(g) + H_2O(g)$	−49
R	$N_2O_4(g)$	$\rightleftharpoons$	$2NO_2(g)$	+58
S	$N_2(g) + 3H_2(g)$	$\rightleftharpoons$	$2NH_3(g)$	−92
T	$C_2H_4(g) + H_2O(g)$	$\rightleftharpoons$	$CH_3CH_2OH(g)$	−42

In each of parts (c)(i) to (c)(v), you should record in the box one of the letters, **P, Q, R, S** or **T**, that corresponds to the equilibrium that best fits the information provided.
You may use each letter once, more than once or not at all.

(i) A decrease in temperature at constant pressure shifts the position of this equilibrium from right to left.

☐

(1)

(ii) This equilibrium uses concentrated phosphoric acid as a catalyst in a hydration reaction.

☐

(1)

(iii) A decrease in pressure at constant temperature shifts the position of this equilibrium from left to right.

☐

(1)

(iv) There is no change in the position of this equilibrium when the pressure is increased at constant temperature.

☐

(1)

(v) An increase in the concentration of steam at constant temperature and constant pressure shifts the position of this equilibrium from right to left.

☐

(1)
(Total 11 marks)

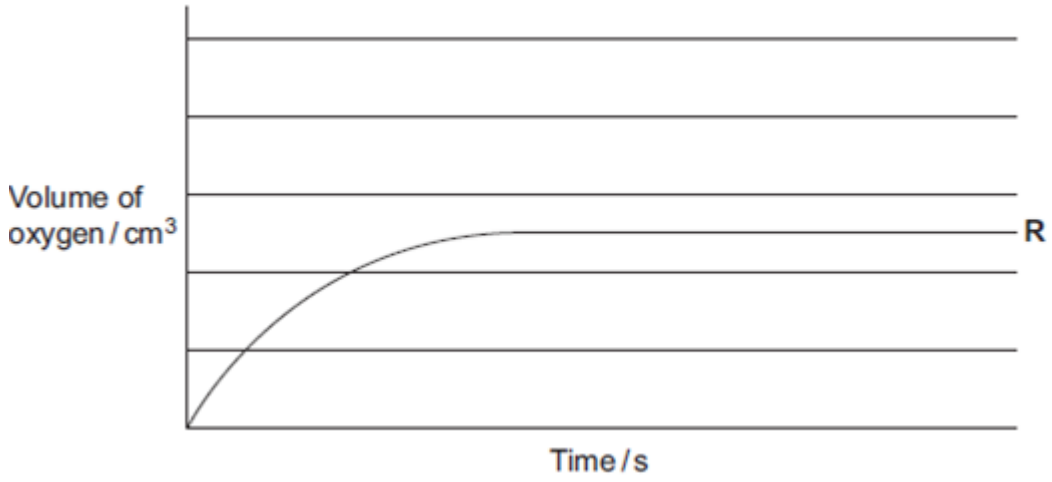
18 A student carried out an experiment to determine the rate of decomposition of hydrogen peroxide into water and oxygen gas.

The student used 100 cm^3 of a 1.0 mol dm^{-3} solution of hydrogen peroxide at 298 K and measured the volume of oxygen collected.

Curve **R**, in each of **Figures 1**, **2** and **3**, shows how the total volume of oxygen collected changed with time under these conditions.

(a) Draw a curve on **Figure 1** to show how the total volume of oxygen collected will change with time if the experiment is repeated at 298 K using 100 cm^3 of a 2.0 mol dm^{-3} solution of hydrogen peroxide.

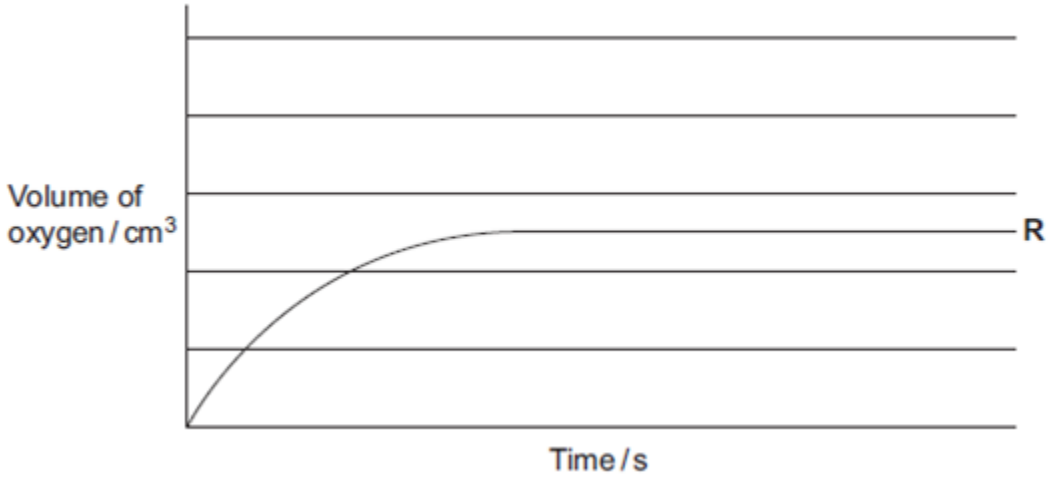
Figure 1



(2)

(b) Draw a curve on **Figure 2** to show how the total volume of oxygen collected will change with time if the experiment is repeated at 298 K using 100 cm^3 of a 0.4 mol dm^{-3} solution of hydrogen peroxide.

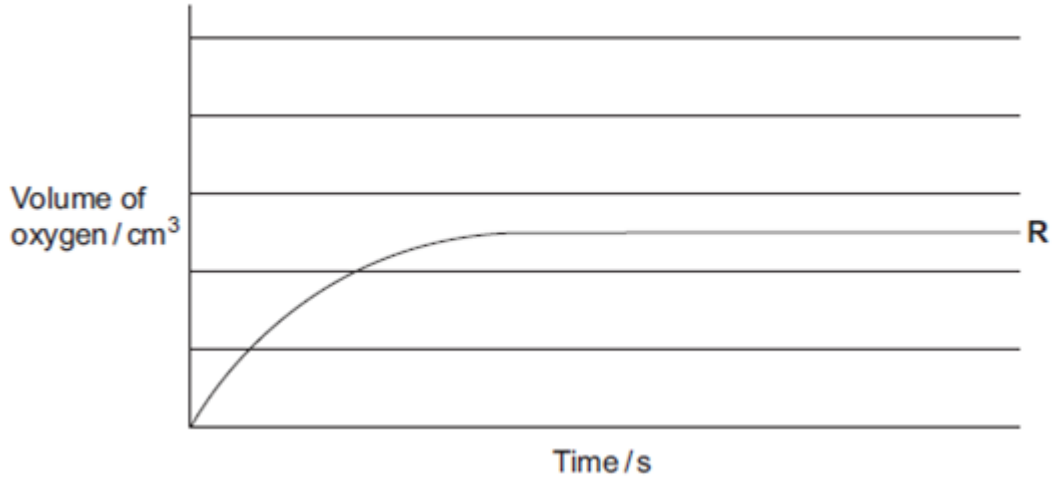
Figure 2



(2)

(c) Draw a curve on **Figure 3** to show how the total volume of oxygen collected will change with time if the **original** experiment is repeated at a temperature higher than 298 K. You should assume that the gas is collected at a temperature of 298 K.

Figure 3



(2)

(d) Explain why the slope (gradient) of curve **R** decreases as time increases.

.....

.....

.....

.....

(Extra space) .....

.....

(e) The student discovered that hydrogen peroxide decomposes at a faster rate when a few drops of aqueous hydrogen bromide are added to the solution.
The student found on the Internet that this decomposition is thought to proceed in two steps as shown by the following equations.

Step **1** $H_2O_2 + HBr \longrightarrow HBrO + H_2O$

Step **2** $HBrO + H_2O_2 \longrightarrow H_2O + O_2 + HBr$

(i) Write an equation for the overall reaction.

.....

(1)

(ii) Give **one** reason, other than the increase in rate of reaction, why the student was able to deduce that hydrogen bromide behaves as a catalyst in this two-step reaction.

.....

.....

.....

(1)

19 A student calculated that a value for the enthalpy change of neutralisation is –51.2 kJ mol^{-1}.

The design of a possible hand-warmer using hydrochloric acid and sodium hydroxide was discussed. It was proposed that 500 cm^3 of hydrochloric acid should be used in a flexible, sealed plastic container with a breakable tube of solid sodium hydroxide also in the container. On breaking the tube, the sodium hydroxide would be released, react with the acid and produce heat.
A 40 °C temperature rise was thought to be suitable.

(a) Calculate the heat energy, in J, required to raise the temperature of the reaction mixture by 40 °C. Assume that the reaction mixture has a density of 1.00 g cm^{-3} and a specific heat capacity of 4.18 J K^{-1} g^{-1}.
Assume that all of the heat energy given out is used to heat the reaction mixture.

.....

.....

.....

.....

(2)

(b) Use your answer from part (a) and the value for the enthalpy change of neutralisation of –51.2 kJ mol^{-1} to calculate the minimum amount, in moles, and hence the minimum mass of sodium hydroxide required in the breakable tube.
(If you could not complete the calculation in part (a) assume that the heat energy required was 77 400 J. This is **not** the correct answer).

Show your working.

Moles of NaOH .....

.....

Mass of NaOH .....

.....

(3)

(c) Use the amount, in moles, of sodium hydroxide from part (b) to calculate the minimum concentration, in mol dm^{-3}, of hydrochloric acid required in the 500 cm^3 of solution used in the sealed container.

.....

.....

.....

(1)

(d) Suggest **one** possible risk to a person who uses a hand-warmer containing sodium hydroxide and hydrochloric acid.

.....

.....

(1)

(e) A commercial hand-warmer uses powdered iron sealed in a plastic container.
A valve allows air to enter the container, and oxygen in the air reacts slowly with the iron to form solid iron(lll) oxide. The heat released warms the container.

(i) Write an equation for this reaction between iron and oxygen to form iron(lll) oxide.

.....

(1)

(ii) One version of an iron-oxygen hand-warmer advertises that it is designed to stay warm for up to four hours.
Other than by increasing the amount of iron in the container, state **one** change to the iron in the hand-warmer that would increase this time.
Explain why this change to the iron might **not** be an advantage.

Change to the iron .....

.....

Explanation .....

.....

.....

(3)

(f) Another type of hand-warmer uses sodium thiosulfate. Sodium thiosulfate is very soluble in water at 80 °C but is much less soluble at room temperature.
When a hot, concentrated solution of sodium thiosulfate is cooled it does not immediately crystallise. The sodium thiosulfate stays dissolved as a stable 'super-saturated' solution until crystallisation is triggered.
Heat energy is then released when the sodium thiosulfate crystallises.

(i) This type of hand-warmer is re-usable.
Suggest **one** environmental advantage that a sodium thiosulfate hand-warmer has over the other two types.

.....

(1)

(ii) Describe the **two** steps that you would take to make the sodium thiosulfate hand-warmer ready for re-use.

Step 1 .....

.....

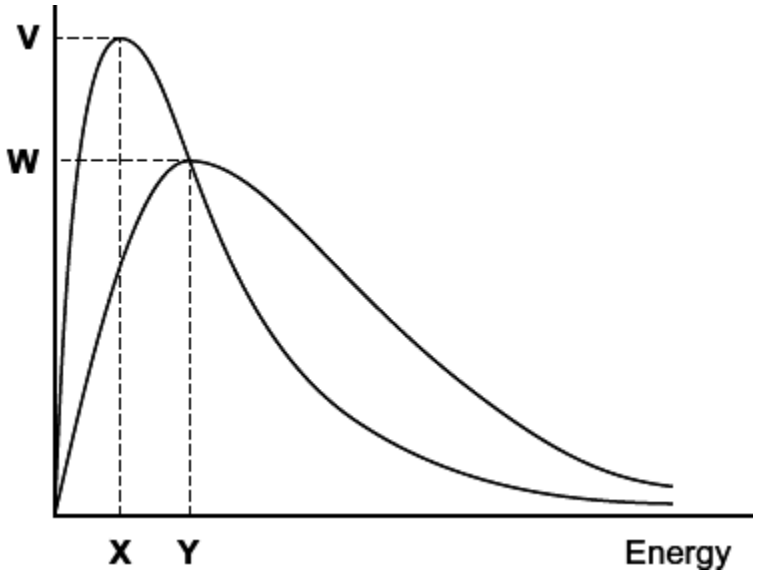
Step 2 .....

.....

(2)

(Total 14 marks)

20 The diagram shows the Maxwell-Boltzmann distribution of molecular energies in a gas at two different temperatures.



(a) One of the axes is labelled. Complete the diagram by labelling the other axis.

(1)

(b) State the effect, if any, of a solid catalyst on the shape of either of these distributions.

.....

.....

(1)

(c) In the box, write the letter, **V**, **W**, **X** or **Y**, that represents the most probable energy of the molecules at the lower temperature.

(1)

(d) Explain what must happen for a reaction to occur between molecules of two different gases.

.....

.....

.....

.....

(2)

(e) Explain why a small increase in temperature has a large effect on the initial rate of a reaction.

.....

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.....

(1)
(Total 6 marks)

21 The rate of a chemical reaction is influenced by the size of the activation energy. Catalysts are used to increase the rates of chemical reactions but are not used up in the reactions.

(a) Give the meaning of the term *activation energy*.

.....

.....

.....

.....

(2)

(b) Explain how a catalyst increases the rate of a reaction.

.....

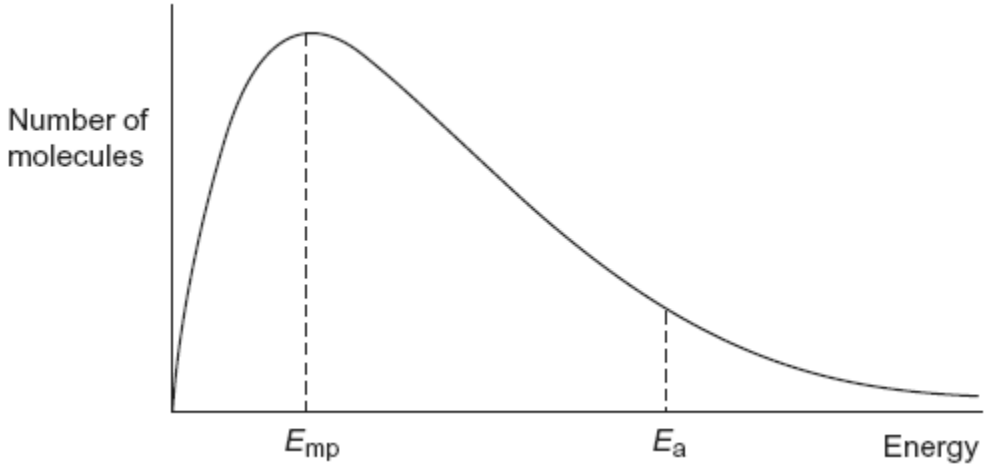
.....

.....

.....

(2)

(c) The diagram below shows the Maxwell–Boltzmann distribution of molecular energies, at a constant temperature, in a gas at the start of a reaction.
On this diagram the most probable molecular energy at this temperature is shown by the symbol E_{mp}
The activation energy is shown by the symbol E_a



To answer the questions (c)(i) to (c)(iv), you should use the words **increases**, **decreases** or **stays the same**. You may use each of these answers once, more than once or not at all.

(i) State how, if at all, the value of the most probable energy (E_{mp}) changes as the total number of molecules is increased at constant temperature.

.....

(1)

(ii) State how, if at all, the number of molecules with the most probable energy (E_{mp}) changes as the temperature is decreased without changing the total number of molecules.

.....

(1)

(iii) State how, if at all, the number of molecules with energy greater than the activation energy (E_a) changes as the temperature is increased without c hanging the total number of molecules.

.....

(1)

(iv) State how, if at all, the area under the molecular energy distribution curve changes as a catalyst is introduced without changing the temperature or the total number of molecules.

.....

(1)

(d) For each of the following reactions, identify a catalyst and name the organic product of the reaction.

(i) The fermentation of an aqueous solution of glucose.

Catalyst .....

Name of organic product .....

.....

(2)

(ii) The hydration of but-2-ene.

Catalyst .....

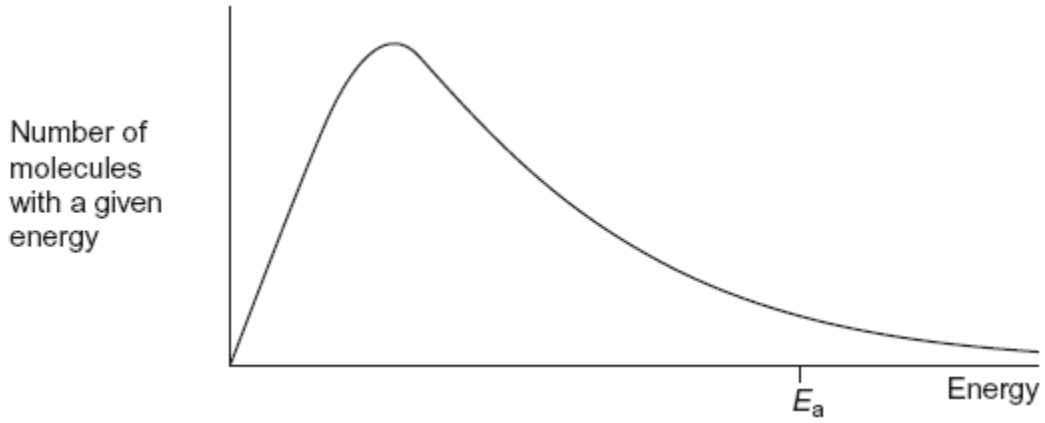
Name of organic product .....

.....

(2)

(Total 12 marks)

22 The diagram below shows a Maxwell–Boltzmann distribution for a sample of gas at a fixed temperature.
E_a is the activation energy for the decomposition of this gas.



(a) (i) On this diagram, sketch the distribution for the same sample of gas at a higher temperature.

(2)

(ii) With reference to the Maxwell–Boltzmann distribution, explain why an increase in temperature increases the rate of a chemical reaction.

.....

.....

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.....

.....

(2)

(b) Dinitrogen oxide (N_2O) is used as a rocket fuel. The data in the table below show how the activation energy for the decomposition of dinitrogen oxide differs with different catalysts.

$$2N_2O(g) \longrightarrow 2N_2(g) + O_2(g)$$

	Ea / kJ mol^{-1}
Without a catalyst	245
With a gold catalyst	121
With an iron catalyst	116
With a platinum catalyst	136

(i) Use the data in the table to deduce which is the most effective catalyst for this decomposition.

.....

(1)

(ii) Explain how a catalyst increases the rate of a reaction.

.....

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.....

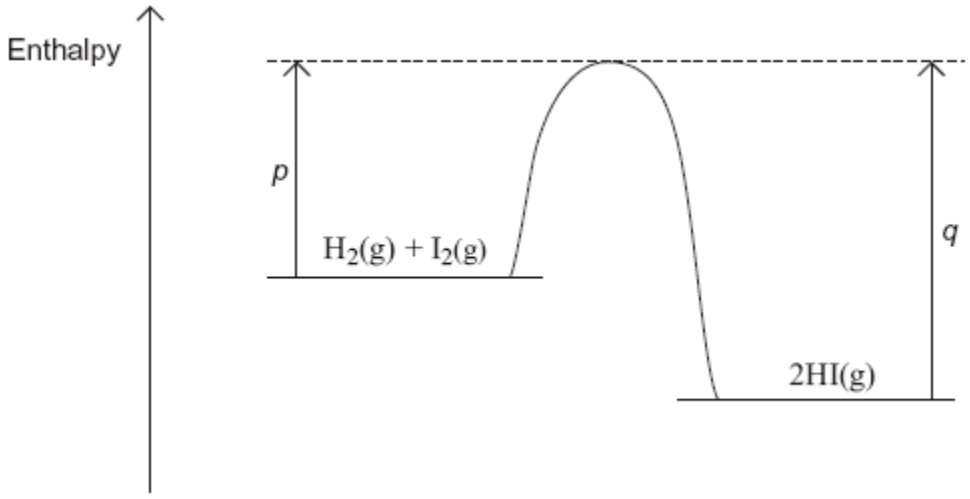
.....

(2)
(Total 7 marks)

23 An equation for the equilibrium reaction between hydrogen, iodine and hydrogen iodide is shown below.

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

(a) The curve in the diagram below illustrates the reaction profile for this equilibrium reaction without a catalyst.



(i) Draw on the diagram a curve to illustrate the reaction profile for this equilibrium reaction **with** a catalyst.

(2)

(ii) Use the diagram to deduce whether the formation of hydrogen iodide from hydrogen and iodine is exothermic or endothermic.

.....

(1)

(iii) State what the diagram suggests about the sum of the bond enthalpies for the reactant molecules compared with the product molecules.

.....

.....

(1)

(iv) In terms of *p* and *q*, identify the following for this equilibrium without a catalyst.

A value for the activation energy for the forward reaction .....

A value for the overall enthalpy change for the forward reaction

.....

(2)

(b) A mixture of $H_2(g)$ and $I_2(g)$ was allowed to reach equilibrium.

(i) State the effect of a catalyst on the rate of attainment of this equilibrium.

.....

(1)

(ii) State and explain the effect of an increase in total pressure on the rate of attainment of this equilibrium.

Effect of an increase in pressure on rate .....

Explanation .....

.....

.....

.....

.....

(3)
(Total 10 marks)

24 An equation for the decomposition of hydrogen peroxide is shown below.

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

State the measurements you would take in order to investigate the rate of this reaction.

.....

.....

.....

.....

(Total 2 marks)

25 Group 2 metals and their compounds are used commercially in a variety of processes and applications.

(a) State a use of magnesium hydroxide in medicine.

.....

(1)

(b) Calcium carbonate is an insoluble solid that can be used in a reaction to lower the acidity of the water in a lake.

Explain why the rate of this reaction decreases when the temperature of the water in the lake falls.

.....

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.....

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.....

(3)

(c) Strontium metal is used in the manufacture of alloys.

(i) Explain why strontium has a higher melting point than barium.

.....

.....

.....

.....

(2)

(ii) Write an equation for the reaction of strontium with water.

.....

(1)

(d) Magnesium can be used in the extraction of titanium.

(i) Write an equation for the reaction of magnesium with titanium(IV) chloride.

.....

(1)

(ii) The excess of magnesium used in this extraction can be removed by reacting it with dilute sulfuric acid to form magnesium sulfate.

Use your knowledge of Group 2 sulfates to explain why the magnesium sulfate formed is easy to separate from the titanium.

.....

.....

.....

(1)

(Total 9 marks)

26 Nitric acid is manufactured from ammonia in a process that involves several stages.

(a) In the first stage, ammonia is converted into nitrogen monoxide and the following equilibrium is established.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H = -905 \text{ kJ mol}^{-1}$$

The catalyst for this equilibrium reaction is a platinum–rhodium alloy in the form of a gauze. This catalyst gauze is heated initially but then remains hot during the reaction.

(i) In terms of redox, state what happens to the ammonia in the forward reaction.

.....

(1)

(ii) Suggest a reason why the catalyst must be hot.

.....

(1)

(iii) Suggest a reason why the catalyst remains hot during the reaction.

.....

(1)

(iv) State how a catalyst increases the rate of a reaction.

.....

.....

.....

.....

(2)

(b) In the second stage, nitrogen monoxide is converted into nitrogen dioxide. The equation for the equilibrium that is established is shown below.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H = -113 \text{ kJ mol}^{-1}$$

Explain why the equilibrium mixture is cooled during this stage of the process.

.....

.....

.....

.....

(2)

(c) In the final stage, nitrogen dioxide reacts with water as shown by the following equation.

$$2NO_2(g) + H_2O(l) \rightarrow H^+(aq) + NO_3^-(aq) + HNO_2(aq)$$

Give the oxidation state of nitrogen in each of the following.

NO_2 .....

NO_3^- .....

HNO_2 .....

(3)

(Total 10 marks)

27 Sodium thiosulfate solution ($Na_2S_2O_3$) reacts slowly with dilute hydrochloric acid to form a precipitate. The rate of this reaction can be studied by measuring the time (*t*) that it takes for a small fixed amount of precipitate to form under different conditions. The fixed amount of precipitate is taken as the amount needed to obscure a cross on paper.

The equation for this reaction is shown below.

$$Na_2S_2O_3 + 2HCl \rightarrow 2NaCl + S + SO_2 + H_2O$$

(a) Identify the insoluble product of this reaction which forms the precipitate.

.....

(1)

(b) When this reaction takes place, the collision between the reacting particles requires an activation energy. State what is meant by the term *activation energy*.

.....

.....

(2)

(c) In terms of particles, explain why, at a fixed temperature, you might expect the rate of this reaction to double when the concentration of sodium thiosulfate is doubled and the concentration of hydrochloric acid remains the same.

.....

.....

.....

.....

(2)

(d) (i) State what is meant by the term *rate of reaction*.

.....

.....

(1)

(ii) Consider the description of the way in which this experiment is carried out. Use your understanding of the term *rate of reaction* to explain why it is possible to use a simplified formula $\frac{1}{t}$ as a measure of the rate of **this** reaction.

.....

.....

(1)

(Total 7 marks)

28 In an experiment to determine the rate of a reaction, the volume of gas produced in the reaction was measured at regular intervals for several minutes.

(a) State **one** experimental condition that must be kept constant during the experiment.

.....

.....

(1)

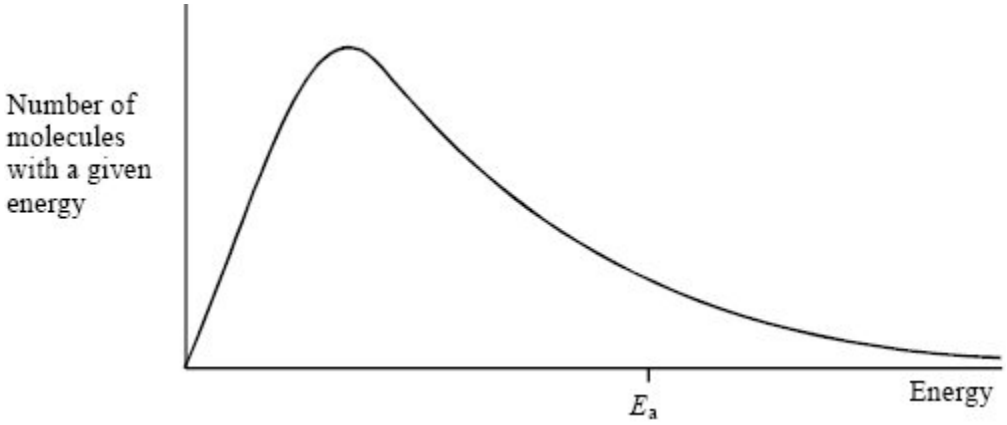
(b) Describe how the initial rate of this reaction can be determined from a graph of volume of gas produced against time.

.....

.....

(1)
(Total 2 marks)

29 The diagram below shows the Maxwell–Boltzmann energy distribution curve for a sample of gas at a fixed temperature. E_a is the activation energy for the decomposition of this gas.



(a) On this diagram sketch the distribution curve for the same sample of gas at a higher temperature.

(3)

(b) (i) What is the effect of an increase in temperature on the rate of a chemical reaction? Explain your answer with reference to the Maxwell–Boltzmann distribution.

Effect .....

Explanation .....

.....

.....

(ii) What is the effect of the addition of a catalyst on the rate of a chemical reaction? Explain your answer with reference to the Maxwell–Boltzmann distribution.

Effect .....

Explanation .....

.....

.....

(6)
(Total 9 marks)

30 A method of synthesising ammonia directly from nitrogen and hydrogen was developed by Fritz Haber. On an industrial scale, this synthesis requires a high temperature, a high pressure and a catalyst and is very expensive to operate.

(a) Use the data given below to calculate a value for the enthalpy of formation of ammonia

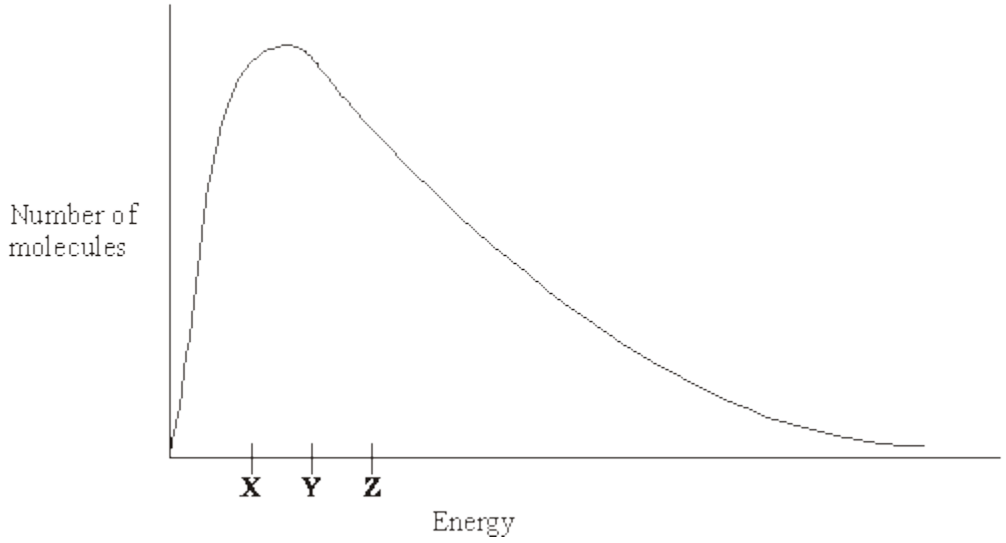
Bond	N ≡N	H – H	N – H
Mean bond enthalpy/kJ mol^{-1}	945	436	391

(3)

(b) A manager in charge of ammonia production wished to increase the daily production of ammonia and reduce the production costs. How would a chemist explain the factors that would influence the commercial efficiency of this production process?

(8)
(Total 11 marks)

31 The diagram below shows the Maxwell–Boltzmann distribution of molecular energies in a sample of a gas.



(a) (i) State which one of **X**, **Y** or **Z** best represents the mean energy of the molecules.

.....

(ii) Explain the process that causes some molecules in this sample to have very low energies.

.....

.....

(3)

(b) On the diagram above, sketch a curve to show the distribution of molecular energies in the same sample of gas at a higher temperature.

(2)

(c) (i) Explain why, even in a fast reaction, a very small percentage of collisions leads to a reaction.

.....

.....

(ii) Other than by changing the temperature, state how the proportion of successful collisions between molecules can be increased. Explain why this method causes an increase in the proportion of successful collisions.

Method for increasing the proportion of successful collisions .....

.....

Explanation .....

.....

(4)
(Total 9 marks)

32 The gas-phase reaction between hydrogen and chlorine is very slow at room temperature.

$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$

(a) Define the term *activation energy*.

.....

.....

(2)

(b) Give **one** reason why the reaction between hydrogen and chlorine is very slow at room temperature.

.....

.....

(1)

(c) Explain why an increase in pressure, at constant temperature, increases the rate of reaction between hydrogen and chlorine.

.....

.....

(2)

(d) Explain why a small increase in temperature can lead to a large increase in the rate of reaction between hydrogen and chlorine.

.....

.....

(2)

(e) Give the meaning of the term *catalyst*.

.....

.....

(1)

(f) Suggest **one** reason why a solid catalyst for a gas-phase reaction is often in the form of a powder.

.....

(1)
(Total 9 marks)

33 (a) Define the term *activation energy* for a chemical reaction.

(2)

(b) Draw, with labelled axes, a curve to represent the Maxwell–Boltzmann distribution of molecular energies in a gas. Label this curve $\mathbf{T}_1$. On the same axes, draw a second curve to represent the same sample of gas at a lower temperature. Label this curve $\mathbf{T}_2$.

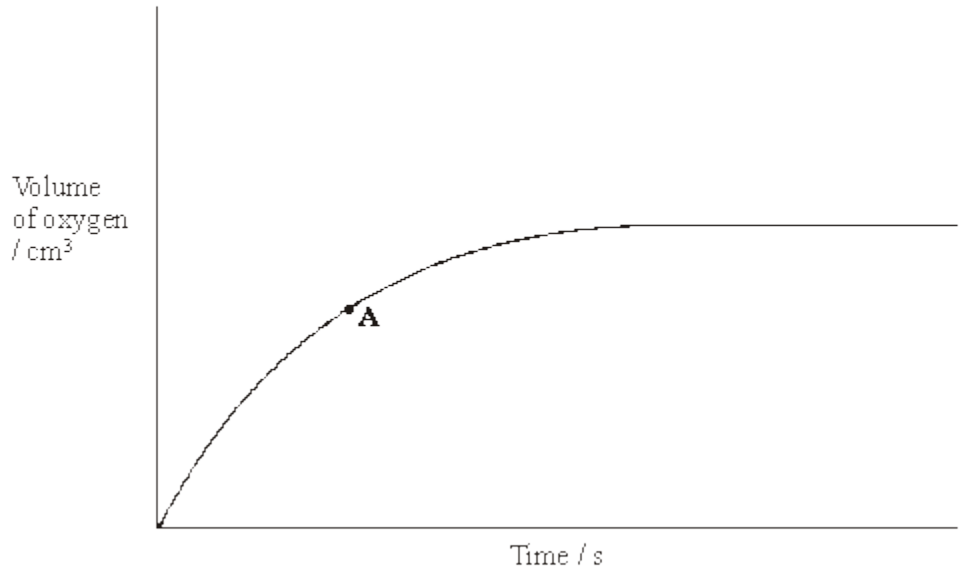
Use these curves to explain why a small decrease in temperature can lead to a large decrease in the rate of a reaction.

(8)

(c) Give **one** reason why most collisions between gas-phase reactants do not lead to a reaction. State and explain **two** ways of speeding up a gas-phase reaction other than by changing the temperature.

(5)
(Total 15 marks)

34 The curve below shows how the volume of oxygen evolved varies with time when 50 cm^3 of a 2.0 mol dm^{-3} solution of hydrogen peroxide, H_2O_2, decomposes at 298 K.



(a) State how you could use the curve to find the rate of reaction at point **A**.

.....

(1)

(b) Sketch curves, on the above axes, to illustrate how the volume of oxygen evolved would change with time if the experiment was repeated at 298 K using the following.

(i) 100 cm^3 of a 1.0 mol dm^{-3} solution of H_2O_2. Label this curve **X**.

(ii) 25 cm^3 of a 2.0 mol dm^{-3} solution of H_2O_2 in the presence of a catalyst. Label this curve **Y**.

(4)

(c) Hydrogen peroxide decomposes more rapidly in the presence of aqueous hydrogen bromide. The decomposition proceeds as shown by the following equations.

$$H_2O_2 + HBr \rightarrow HBrO + H_2O$$

$$HBrO + H_2O_2 \rightarrow H_2O + O_2 + HBr$$

(i) Write an equation for the overall reaction.

.....

(ii) Define the term *catalyst*.

.....

.....

(iii) Give **two** reasons, other than an increase in the reaction rate, why these equations suggest that hydrogen bromide is behaving as a catalyst.

Reason 1 .....

Reason 2 .....

(5)
(Total 10 marks)

35 This question is about the reaction given below.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

Enthalpy data for the reacting species are given in the table below.

Substance	CO(g)	$H_2O(g)$	$CO_2(g)$	$H_2(g)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	−110	−242	−394	0

Which one of the following statements is **not** correct?

A The value of K_p changes when the temperature changes.

B The activation energy decreases when the temperature is increased.

C The entropy change is more positive when the water is liquid rather than gaseous.

D The enthalpy change is more positive when the water is liquid rather than gaseous.

(Total 1 mark)

36 Gas **G** decomposes as shown in the equation below.

$$G(g) \rightarrow X(g) + Y(g)$$

(a) Draw, on the axes below, a Maxwell–Boltzmann distribution curve for a sample of **G** in which only a small proportion of molecules has energy greater than the activation energy, E_a.

(3)

(b) Define the term *activation energy*.

.....

.....

(2)

(c) At any time, most of the molecules of **G** have energy less than the activation energy. Suggest why, at a constant temperature, most of **G** eventually decomposes.

.....

.....

(2)

(d) State the effect, if any, of adding a catalyst on the time required for **G** to decompose, compared with a similar sample without a catalyst. Explain in general terms how the catalyst has this effect.

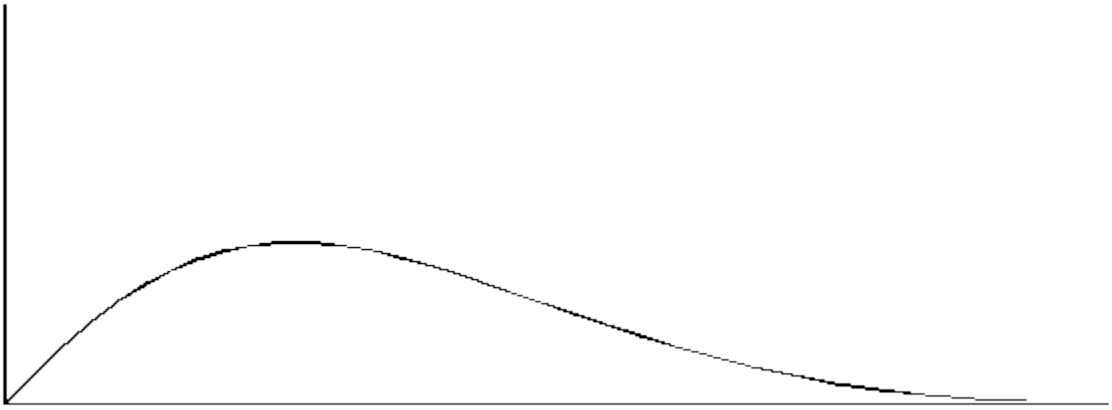
Time for decomposition .....

Explanation .....

.....

(3)
(Total 10 marks)

37 The diagram below represents a Maxwell–Boltzmann distribution curve for the particles in a sample of a gas at a given temperature. The questions below refer to this sample of particles.



(a) Label the axes on the diagram.

(2)

(b) On the diagram draw a curve to show the distribution for this sample at a **lower** temperature.

(2)

(c) In order for two particles to react they must collide. Explain why most collisions do not result in a reaction.

.....

(1)

(d) State one way in which the collision frequency between particles in a gas can be increased without changing the temperature.

.....

(1)

(e) Suggest why a small increase in temperature can lead to a large increase in the reaction rate between colliding particles.

.....

.....

.....

(2)

(f) Explain in general terms how a catalyst works.

.....

.....

.....

(2)
(Total 10 marks)

38 (a) Define the term *activation energy* for a reaction.

.....

.....

(2)

(b) Give the meaning of the term *catalyst.*

.....

.....

(2)

(c) Explain in general terms how a catalyst works.

.....

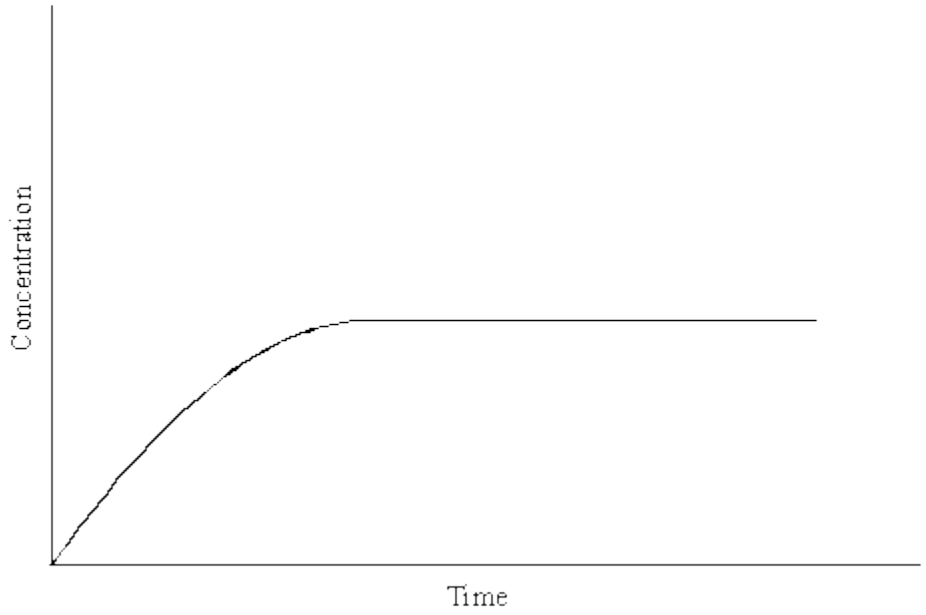
.....

(2)

(d) In an experiment, two moles of gas **W** reacted completely with solid **Y** to form one mole of gas **Z** as shown in the equation below.

$2W(g) + Y(s) \rightarrow Z(g)$

The graph below shows how the concentration of **Z** varied with time at constant temperature.



(i) On the axes above, sketch a curve to show how the concentration of **W** would change with time in the same experiment. Label this curve **W**.

(ii) On the axes above, sketch a curve to show how the concentration of **Z** would change with time if the reaction were to be repeated under the same conditions but in the presence of a catalyst. Label this curve **Z.**

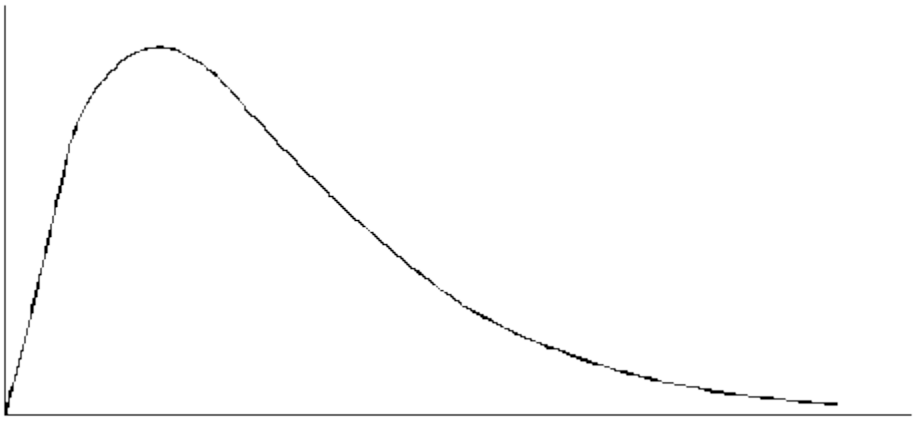
(iii) In terms of the behaviour of particles, explain why the rate of this reaction decreases with time.

.....

.....

(6)
(Total 12 marks)

39 (a) Below is a Maxwell–Boltzmann curve showing the distribution of molecular energies for a sample of gas at a temperature *T*.



(i) Label the axes on the diagram above.

(ii) What does the area under the curve represent?

.....

(iii) State why this curve starts at the origin.

.....

(4)

(b) (i) State what is meant by the term *activation energy*.

.....

.....

(ii) The rate of a chemical reaction may be increased by an increase in reactant concentration, by an increase in temperature and by the addition of a catalyst.

State which, if any, of these changes involves a different activation energy. Explain your answer.

Change(s) .....

Explanation .....

.....

(5)
(Total 9 marks)

40 Hydrogen is produced by the reaction between steam and methane when the following dynamic equilibrium is established.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

(a) Use Le Chatelier's principle to predict the separate effects of an increase in temperature and of an increase in pressure on the yield of hydrogen obtained in the above reaction. In each case, explain your answer.

(6)

(b) State how, and explain why, the use of a catalyst might or might not change the equilibrium yield of hydrogen, and also the amount of hydrogen produced, in a given time.

(4)

(Total 10 marks)

41 The compound lithium tetrahydridoaluminate(III), $LiAlH_4$, is a useful reducing agent. It behaves in a similar fashion to $NaBH_4$. Carbonyl compounds and carboxylic acids are reduced to alcohols. However, $LiAlH_4$ also reduces water in a violent reaction so that it must be used in an organic solvent.

Which one of the following concerning the violent reaction between $LiAlH_4$ and water is **false**?

A A gas is produced.

B The activation energy for the reaction is relatively high.

C The reaction has a negative free-energy change.

D Aqueous lithium ions are formed.

(Total 1 mark)

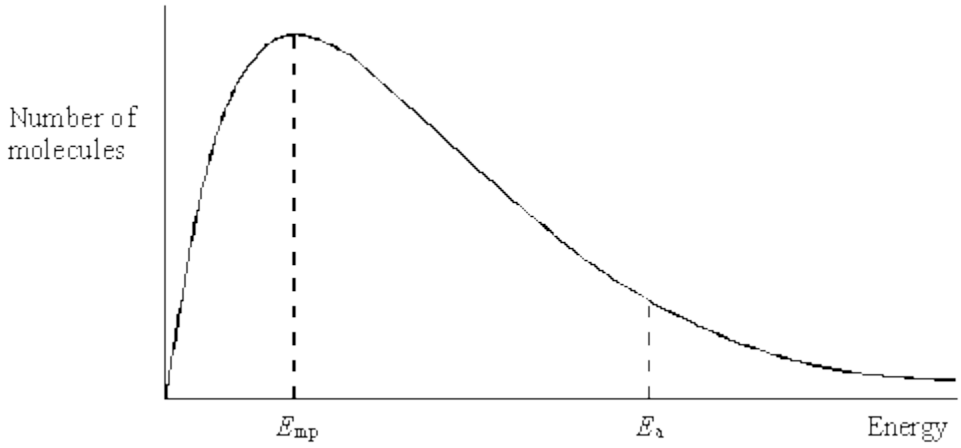
42 (a) State what is meant by the term *activation energy* of a reaction.

(1)

(b) State in general terms how a catalyst increases the rate of a chemical reaction.

(2)

(c) The curve below shows the Maxwell–Boltzmann distribution of molecular energies, at a constant temperature, in a gas at the start of a reaction. On this diagram the most probable molecular energy at this temperature is indicated by the symbol E_{mp} and the activation energy by the symbol E_a.



Consider the following changes.

(i) The number of molecules is increased at constant temperature.

(ii) The temperature is decreased without changing the number of molecules.

(iii) A catalyst is introduced without changing the temperature or the number of molecules.

For **each** of these changes state how, if at all, the following would vary:

- the value of the most probable energy, E_{mp}
- the number of molecules with the most probable energy, E_{mp}
- the area under the molecular energy distribution curve
- the number of molecules with energy greater than the activation energy, E_a

(12)
(Total 15 marks)

43

Summarised directions for recording responses to multiple completion questions			
A (i), (ii) and (iii) only	**B** (i) and (iii) only	**C** (ii) and (iv) only	**D** (iv) alone

Which of the following statements about a catalyst is / are true?

(i) It speeds up the forward reaction and slows down the reversere action.

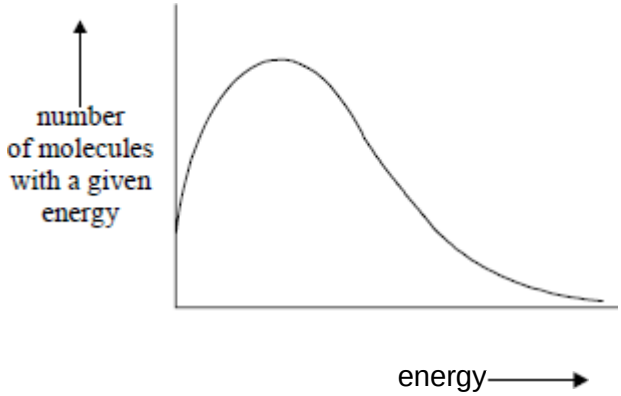
(iii) It increases the proportion of molecules with higher energies.

(iii) A homogeneous catalyst usually acts in the solid state.

(iv) It does not alter the value of the equilibrium constant.

(Total 1 mark)

44



The total area under the distribution curve represents

A total energy.

B activation energy.

C total number of reacting molecules.

D total number of molecules present.

(Total 1 mark)

1 (a) (i) **M1**

High (temperature) OR Increase (the temperature)

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

M2

The (forward) reaction / to the right is endothermic or takes in / absorbs heat

OR

The reverse reaction / to the left is exothermic or gives out / releases heat

M3 depends on correct M2 and must refer to temperature / heat

M3** depends on a correct statement for **M2

At high temperature, the (position of) equilibrium shifts / moves left to right to oppose the increase in temperature

*For **M3**, the position of equilibrium shifts / moves*

to absorb heat OR

to lower the temperature OR

to cool down the reaction

3

(ii) **M1**

The reaction gets to equilibrium faster / in less time

OR

Produces a small yield faster / in less time

OR

Increases the rate (of reaction / of attainment of equilibrium)

Mark independently

M2

High pressure leads to **one** of the following

- more particles / molecules in a given volume
- particles / they are closer together
- higher concentration of particles / molecules

AND

- more collisions in a given time / increased collision frequency

*Penalise **M2** for reference to increased energy of the particles*

2

(iii) **M1** Increase in / more / large(r) / big(ger) surface area / surface sites

Mark independently

*For **M1** accept "an increase in surface"*

M2 increase in / more successful / productive / effective collisions (in a given time) (on the surface of the catalyst / with the nickel)

*For **M2** not simply "more collisions"*

Ignore "the chance or likelihood" of collisions

2

(b) **M1**

No effect / None

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

M2 requires a correct M1

Equal / same number / amount of moles / molecules / particles on either side of the equation

OR

2 moles / molecules / particles on the left and 2 moles / molecules / particles on the right

M2** depends on a correct statement for **M1

*In **M2 not** "atoms"*

2

[9]

2 (a) (i) Uses sensible scales.

*Lose this mark if the **plotted points** do not cover half of the paper.*

Lose this mark if the graph plot goes off the squared paper

Lose this mark if volume is plotted on the x-axis

1

All points plotted correctly

Allow ± one small square.

1

Smooth curve from 0 seconds to at least 135 seconds − the line must pass through or close to all points (± one small square).

Make some allowance for the difficulties of drawing a curve but do not allow very thick or doubled lines.

1

(ii) Any value in the range 91 to 105 s

Allow a range of times within this but not if 90 quoted.

1

(b) (i) Using pV = nRT

This mark can be gained in a correctly substituted equation.

1

$100\,000 \times 570 \times 10^{-6} = n \times 8.31 \times 293$

Correct answer with no working scores one mark only.

1

n = 0.0234 mol

Do not penalise precision of answer but must have a minimum of 2 significant figures.

1

(ii) Mol of $ZnCO_3$ = 0.0234

Mark consequentially on Q6

M1

1

Mass of $ZnCO_3$ = M1 × 125.4 = 2.9(3) or 2.9(4) g

If 0.0225 used then mass = 2.8(2) g

M2

1

(iii) Difference = (15.00 / 5) − Ans to b

If 2.87 g used then percentage is 4.3

M1

1

Percentage = (M1 / 3.00) × 100

Ignore precision beyond 2 significant figures in the final answer

If 2.82 g used from (ii) then percentage = 6.0

M2

1

(c) A reaction vessel which is clearly airtight round the bung

1

Gas collection over water or in a syringe

Collection vessel must be graduated by label or markings

Ignore any numbered volume markings.

1

[13]

3 C

[1]

4 B

[1]

5 A

[1]

6 C

[1]

7 (a) Consider experiments 1 and 2: [B constant]

[A] increases × 3: rate increases by 3^2 therefore 2nd order with respect to A

1

Consider experiments 2 and 3:

[A] increases × 2: rate should increase × 2^2 but only increases × 2

Therefore, halving [B] halves rate and so 1st order with respect to B

1

Rate equation: rate = $k[A]^2[B]$

1

(b) rate = k $[C]^2[D]$ therefore k = rate / $[C]^2[D]$

1

$$k = \frac{7.2\times10^{-4}}{\left(1.9\times10^{-2}\right)^2 \times \left(3.5\times10^{-2}\right)} = 57.0$$

Allow consequential marking on incorrect transcription

1

$mol^{-2}\ dm^{+6}\ s^{-1}$

Any order

1

(c) rate = $57.0 \times (3.6 \times 10^{-2})^2 \times 5.4 \times 10^{-2} = 3.99 \times 10^{-3}$ (mol dm^{-3} s^{-1})

OR

Their $k \times (3.6 \times 10^{-2})^2 \times 5.4 \times 10^{-2}$

1

(d) Reaction occurs when molecules have $E \geq E_a$

1

Doubling T by 10 °C causes <u>many</u> more molecules to have this E

1

Whereas doubling [**E**] only doubles the number with this E

1

(e) $E_a = RT(\ln A - \ln k) / 1000$

Mark is for rearrangement of equation and factor of 1000 used correctly to convert J into kJ

1

E_a = 8.31 × 300 (23.97 – (–5.03)) / 1000 = 72.3 (kJ mol^{-1})

1

[12]

8

(a) (i) Award mark for **X on the time axis** at the point where the lines just become **horizontal**

*Allow this mark if **X** is above the letters "sh" in the word "show" in part(ii) - in the range of lines 31 to 33.*

1

(ii) They are equal / the same

OR

Forward (rate) = Reverse / backward (rate)

Allow the word 'speed' in this context.

Ignore reference to concentration.

1

(b) Both **OR** forward and reverse reactions occur at the same time

OR both are occurring at once

OR both occur all of the time

OR both are ongoing

OR both never stop

Ignore 'at equal rates'.

Ignore reference to concentration or equilibrium.

The idea that both reactions occur simultaneously is essential.

The simple idea of 'both reactions occurring' is insufficient for the mark.

1

(c) (i) **M1** No effect / no change / none / stays the same

M2 requires correct **M1**

*In **M2**, ignore reference to particles or atoms.*

M2 Equal (number of) moles / molecules on both sides

2

(ii) **M1** Less time or it decreases or (equilibrium) reached faster (ie **M1** is a reference to time taken)

*If **M1** is 'more time / it increases' or 'no effect', then **CE=0** for the clip.*

*Reference to faster / increased rate / increased speed alone penalises **M1**, but mark on **M2** and **M3**.*

M2 More particles / molecules in a given volume / space

OR the particles / molecules are closer together

*If **M1** is blank, then look for all three marks in the text.*

M3 More successful / productive collisions in a given time

OR more collisions with $E>E_{Act}$ in a given time

OR more frequent successful / productive collisions

OR increased / greater successful / productive collision frequency / rate

Ignore reference to reactants / products.

*Penalise **M3** if an increase / decrease in the value of E_{Act} is stated.*

3

[8]

9

(a) Amount / number / proportion / percentage / fraction / moles of molecules / particles

Penalise an incorrect qualification of the number eg NOT number of molecules with E greater than Ea.

Not 'atoms'.

1

(b) There are no molecules / particles with zero energy

OR

All of the molecules / particles are moving / have some energy

Not 'atoms'.

The answer should relate the energy to the molecules.

1

(c) **C** (The most probable energy)

1

(d) **M1** The peak of the new curve is <u>displaced to the right</u> and <u>lower</u> than the original

M2 All of the following needed

- The new curve starts at the origin and should begin to separate from the original almost immediately
- <u>and</u> the new curve only crosses the original curve once
- <u>and</u> the total area under the new curve is <u>approximately</u> the same as the original
- <u>and</u> an attempt has been made to draw the new curve correctly towards the axis <u>above the original curve</u> but not to touch the original curve

2

(e) None / no effect / stays the same

1

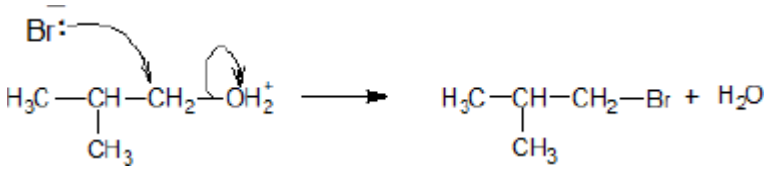
[6]

10 (a) (i) **M1** double-headed curly arrow from the lone pair of the bromide ion to the C atom of the CH_2

Penalise additional arrows.

M2 double-headed arrow from the bond to the O atom

As follows



2

(ii) **M1** <u>nucleophilic substitution</u>

M1 *both words needed (allow phonetic spelling).*

M2 1-bromo(-2-)methylpropane

M2 *Require correct spelling in the name but ignore any hyphens or commas.*

2

(b) **M1** hydrolysis

*For **M1** give credit for 'hydration' on this occasion only.*

M2 C≡N with absorption range 2220–2260 (cm^{-1})

*Credit 1 mark from **M2** and **M3** for identifying C≡N **and** either O–H(acids) **or** C=O **or** C–O without reference to wavenumbers or with incorrect wavenumbers.*

M3 O–H(acids) with absorption range 2500–3000 (cm^{-1})

OR

C=O with absorption range 1680–1750 (cm^{-1})

OR

C–O with absorption range 1000–1300 (cm^{-1})

*Apply the list principle to **M3***

3

(c) (i) **M1** Yield / product **OR** ester increases / goes up / gets more

M2 (By Le Chatelier's principle) the position of equilibrium is driven / shifts / moves to the right / L to R / in the forward direction / to the product(s)

M3 – requires a correct statement in M2

(The position of equilibrium moves)

to oppose the increased concentration of ethanol

to oppose the increased moles of ethanol

to lower the concentration of ethanol

to oppose the change and decrease the ethanol

*If no reference to **M1**, marks **M2** and **M3** can still score BUT if **M1** is incorrect CE=0*

*If there is reference to 'pressure' award **M1** ONLY.*

3

(ii) **M1**

Catalysts provide an alternative route / pathway / mechanism

OR

surface adsorption / surface reaction occurs

*For **M1**, not simply 'provides a surface' as the only statement.*

__M1__ may be scored by reference to a specific example.

M2

that has a lower / reduced activation energy

OR

lowers / reduces the activation energy

*Penalise **M2** for reference to an increase in the energy of the molecules.*

*For **M2**, the student may use a definition of activation energy without referring to the term.*

*Reference to an increase in successful collisions in unit time alone is not sufficient for **M2** since it does not explain why this has occurred.*

2

[12]

11 (a) (Measure the) volume of gas / mass of the container + contents

1

Suitable named piece of equipment

Gas syringe (or inverted burette or measuring cylinder, as long as student has referred to the cylinder being filled with water) / balance.

Equipment must be correct for the measurement stated.

1

(b) Any **one** of:

- Mass of magnesium

  Allow amount of magnesium.

- Surface area of magnesium

1

(c) (i) Gravity: Conical flask or beaker and funnel /

Vacuum: Sealed container with a side arm and Buchner or Hirsch funnel

Must be either gravity filtration (with a V-shaped funnel) or vacuum filtration (with a side-arm conical flask) appropriately drawn.

1

Filter paper

Must show filter paper as at least two sides of a triangle (V-shaped) for gravity filtration or horizontal filter paper for vacuum filtration.

1

(ii) Wash with / add (a small amount of cold) water

Ignore filtering.

1

[6]

12 (a) Sensible scales

Plotted points (including 0,0) must cover more than half the graph paper.

If axis wrong way round lose this mark but mark on consequentially.

Do not allow broken axis.

1

Plots points correctly

1

(b) Ring around the origin

1

(c) Line through points is smooth

Line must pass within ± 1 small square of each plotted point except the anomaly (allow one plot ± 2 small square – at 40 or 60s).

1

Line through points is best fit and ignores anomaly (allow one plot ± 2 small square)

Lose this mark if student's line is doubled.

Kinked line loses this mark.

Lose this mark if the line does not pass through the origin + / – 1 small square.

Lose this mark if the line deviates to anomaly.

1

(d) Draws suitable tangent

Must touch the curve at 30s and must not cross the curve.

Lose this mark if the tangent is unsuitable but mark on.

1

Chooses appropriate x and y values from their graph

Mark consequentially if axes plotted the wrong way around.

Allow information clearly shown on graph.

1

Correctly calculates y / x

Difference in x values and y values must be at least 10 small squares in either direction.

1

Gives answer with correct units (mol dm^{-3} s^{-1}) or correct variant

Lose this mark if answer not to minimum of 2 significant figures and no units or incorrect units are given.

If student has used axis the wrong way round, the unit mark can be awarded for either the correct unit based on their graph or for the correct unit for rate.

1

[9]

13 (a) M1 On the energy axis E_{mp} at the maximum of the original peak

***M1** The limits for the horizontal position of E_{mp} are defined as above the word "the" in the sentence below the graph.*

M2 The peak of their new curve is displaced to the left and higher than the original.

M3 All of the following are required

- The new curve starts at the origin and should begin to separate from the original almost immediately
- and the new curve crosses the original curve once
- and an attempt has been made to draw the new curve correctly towards the energy axis below the original curve but not to touch the original curve or the axis

3

(b) **The rate of reaction decreases as the temperature decreases because**

M1 A decrease in the number / proportion of molecules with $E \geq E_a$
OR fewer molecules have $E \geq E_a$
OR fewer molecules have sufficient / enough energy to react / decompose

In M1
Ignore "molecules have less energy".
Ignore "less energetic collisions".
Ignore "molecules do not gain activation energy".
Ignore "fewer collisions".
Credit "particles" for "molecules" but NOT "atoms".

M2 Fewer effective / productive / successful collisions in a given time / given period
OR fewer frequent effective / productive / successful collisions
OR lower rate of effective / productive / successful collisions

Ignore "chance of collision"; this alone does not gain ***M2***

2

[5]

14 (a) As concentration increases the amount of heat given out increases / temperature increases **(M1)**

Any order.
Ignore references to an exothermic reaction.

1

More successful collisions or reactions in a given time **OR** more particles have the activation energy **(M2)**

Allow could be a second / n^{th} order reaction.

1

(An increase in temperature or more heat given out) increases the rate of a reaction **(M3)**

1

(b) The magnesium is coated with an oxide / MgO **(M1)**

Allow magnesium hydroxide.

1

MgO / the coating / the corrosion product has to be removed before Mg will react
OR Mg and MgO / the coating / the corrosion product react at different rates
OR Initially MgO / the coating / the corrosion product reacts not Mg **(M2)**

Ignore inert coating.

1

(c) Any **two** from:

Any order.

Slower with hot water or faster with steam

The hot water produces $Mg(OH)_2$ / the hydroxide **OR** steam produces MgO / the oxide

(Slow) bubbling with hot water **OR** bright white light / flame / white solid with steam

2 max

(d) Magnesium sulfate is soluble <u>and</u> calcium sulfate is insoluble / slightly soluble / magnesium sulfate is more soluble / calcium sulfate is less soluble / correct trend in solubility **(M1)**

Any order.

***M1** requires a comparison of the two solubilities.*

<u>Calcium sulfate</u> coats the surface of the calcium **(M2)**

Coating prevents further contact with / reaction by the acid **(M3)**

*'Calcium sulfate forms a protective coating' scores **M2** only.*

3

[10]

15 (a) Stoppered flask or similar with side arm

Allow gas outlet through stopper.

1

Calibrated container for collection eg gas syringe

Allow collection over water, but must use calibrated vessel for collection.

Lose 1 mark if apparatus is not gas tight.

1

(b) Plot a graph of 'volume (of gas)' against 'time'

1

Determine the <u>slope (gradient) at the beginning</u>

1

(c) Repeat with same volume **or** concentration of hydrogen peroxide <u>and</u> at the same temperature

Ignore references to results.

Do not allow 'keep everything the same' or words to that effect.
Must mention volume or concentration and temperature.

1

Add cobalt(II) chloride to one experiment

1

[6]

16 (a) (i) Change in concentration (of a substance / reactant / product) in unit time / given time / per (specified) unit of time

*This may be written mathematically **OR** may refer to the gradient of a graph of concentration / volume against time*

OR

Amount of substance formed / used up in unit time / given time / per (specified) unit of time

Ignore additional information including reference to collisions

1

(ii) At **W**

M1 (QoL)

The rate / it is zero

M2

The magnesium has all reacted / has been used up

Ignore reference to the acid being used up

OR

No more collisions possible between acid and Mg

OR

Reaction is complete / it has stopped

OR

No more hydrogen / product is produced

2

(iii) M1

Twice / double as many particles / hydrogen ions (in a given volume)

*Penalise reference to (hydrochloric acid) molecules in **M1***

*Penalise reference to "HCl particles" in **M1***

OR

Twice / double as much hydrochloric acid

M2

Twice / double as many effective / successful collisions (in a given time)

OR

Twice / double as many collisions with either sufficient energy to react ***OR*** with $E \geq E_a$

OR

double the successful / effective collision frequency

2

(b) (i) The activation energy is the minimum energy for a reaction to go / start

OR

Minimum energy for a successful/ effective collision

1

(ii) M1 Products lower than reactants on the profile

Mark independently

M2 Activation energy (E_a) shown and labelled correctly from reactants to peak of curve

Mark independently

2

(c) (i) $Ba + \mathbf{2}H_2O \longrightarrow Ba(OH)_2 + H_2$

$Ba + 2H_2O \longrightarrow Ba^{2+} + 2OH^- + H_2$

Allow multiples

Ignore state symbols

1

(ii) M1 $Ba^{2+} + SO_4^{2-} \longrightarrow BaSO_4$

*Ignore state symbols in **M1***

*Not multiples in **M1***

M2 White precipitate / solid

Extra ions must be cancelled

*Penalise contradictory observations in **M2***

2

(iii) M1 Barium meal / barium swallow / barium enema

*Accept a correct reference to **M1** written in the explanation in **M2**, unless contradictory*

OR used in X-rays ***OR*** to block X-rays ***OR*** X-ray contrast medium ***OR*** CT scans

M2 $BaSO_4$ / barium sulfate is insoluble (and therefore not toxic)

*For **M2** NOT barium ions*

NOT barium

NOT barium meal and NOT "It"

Ignore radio-tracing

2

[13]

17 (a) (If any factor is changed which affects an equilibrium), the (position of) equilibrium will shift / move so as to oppose / counteract the change.

Must refer to equilibrium

Ignore reference to "system" alone

A variety of wording will be seen here and the key part is the last phrase

OR

(When a system / reaction in equilibrium is disturbed), the (position of) equilibrium shifts / moves in a direction which tends to reduce the disturbance

An alternative to shift / move would be the idea of changing / altering the position of equilibrium

1

(b) (i) M1

A substance that <u>speeds up the reaction / alters the rate</u> but is <u>chemically unchanged at the end / not used up</u>

*Both ideas needed for **M1***

*Credit can score for **M1**, **M2** and **M3** from anywhere within the answer*

M2

Catalysts provide an alternative route / alternative pathway / different mechanism

M3

that has a <u>lower activation energy / E_a</u>

OR

<u>lowers the activation energy / E_a</u>

3

(ii) (Time is) less / shorter / decreases / reduces

Credit "faster", "speeds up", "quicker" or words to this effect

1

(iii) None

1

(c) (i) R

1

(ii) T

1

(iii) R

1

(iv) P

1

(v) Q

1

[11]

18 (a) **Award in either order for curve**

"Steeper" requires line to be on the left of the original line, starting from the origin

M1 curve is steeper than original and starts at the origin

M2 curve levels at the top line on the graph

2

(b) **Award in either order for curve**

"Shallower" requires line to be on the right of the original line, starting from the origin

M1 curve is shallower than original and starts at the origin

M2 curve levels at the first line on the graph

2

(c) **M1** curve would be steeper than original

"Steeper" requires line to be on the left of the original line, starting from the origin

M2 curve levels at the same original volume of O_2

2

(d) **M1** The (concentration / amount of) H_2O_2 or reactant falls / decreases / used up

Mark independently

OR

The number of H_2O_2 or reactant molecules/ particles falls / decreases

M2

The rate of reaction / rate of decomposition / rate of formation of oxygen / frequency of collisions / (effective) collisions in a given time decreases / is slower

2

(e) (i) $\mathbf{2}H_2O_2 \rightarrow \mathbf{2}H_2O + O_2$

Ignore state symbols

Accept only this equation or its multiples

Extra species must be crossed through

1

(ii) hydrogen bromide / it does not appear in the overall equation

OR

hydrogen bromide / it is not used up in the reaction / unchanged at the end of the reaction

OR

hydrogen bromide / it is regenerated / re-formed (in Step 2)

1

[10]

19 (a) $q = 500 \times 4.18 \times 40$

Do not penalise precision.

1

$= 83600$ J

Accept this answer only.

Ignore conversion to 83.6 kJ if 83600 J shown.

Unit not required but penalise if wrong unit given.

Ignore the sign of the heat change.

An answer of 83.6 with no working scores one mark only.

An answer of 83600 with no working scores both marks.

1

(b) Moles (= 83.6 / 51.2) = 1.63

Using 77400 alternative gives 1.51 mol

Allow (a) in kJ / 51.2

Do not penalise precision.

1

Mass = 1.63 × 40(.0) = 65.2 (g)

Allow 65.3 (g)

Using 77400 alternative gives 60.4 to 60.5

Allow consequential answer on M1.

1 mark for M_r (shown, not implied) and 1 for calculation.

Do not penalise precision.

2

(c) Molarity = 1.63 / 0.500 = 3.26 mol dm–3

Allow (b) M1 × 2

Using 1.51 gives 3.02

1

(d) Container splitting <u>and</u> releasing irritant / corrosive chemicals

Must have reference to both aspects; splitting or leaking (can be implied such as contact with body / hands) ***and*** *hazardous chemicals.*

Allow 'burns skin / hands' as covering both points

Ignore any reference to 'harmful'.

Do not allow 'toxic'.

1

(e) (i) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$

Allow fractions / multiples in equation.

Ignore state symbols.

1

(ii) Iron powder particle size could be increased / surface area lessened

Decrease in particle size, chemical error = 0 / 3

Change in oxygen, chemical error = 0 / 3

1

Not all the iron reacts / less reaction / not all energy released / slower release of energy / lower rate of reaction

Mark points M2 and M3 independently.

1

Correct consequence of M2

An appropriate consequence, for example

- *too slow to warm the pouch effectively*
- *lower temperature reached*
- *waste of materials*

1

(f) (i) Conserves resources / fewer disposal problems / less use of landfill / fewer waste products

Must give a specific point.

Do not allow 'does not need to be thrown away' without qualification.

Do not accept 'no waste'.

1

(ii) Heat to / or above 80 °C (to allow thiosulfate to redissolve)

Accept 'heat in boiling water'.

If steps are transposed, max 1 mark.

1

Allow to cool before using again

Reference to crystallisation here loses this mark.

1

[14]

20 (a) Number / proportion / percentage / fraction of molecules

Ignore "particles"

1

(b) None ***OR*** no effect ***OR*** no change

1

(c) **X**

1

(d) **Answers in either order**

M1 collision ***OR*** collide

Mark independently

M2 collision / molecules / particles

Ignore "correct" amount of energy

with the activation energy

OR with $E \geq E_{act}$

OR with sufficient /enough energy

OR with the minimum energy

OR with the correct orientation

2

(e) A small increase in temperature results in many more / much higher proportion of / a lot more / significantly more molecules / particles / collisions with $E \geq E_{act}$ / energy greater than the activation energy / sufficient energy / enough energy / minimum energy to react
(compared with a small increase in concentration)

Not just "more molecules with $E \geq E_{act}$"

The answer must convey that the increase is ***significant***

Accept reference to "atoms", "molecules", "particles"

Ignore "species"

1

[6]

21

(a) **M1** The activation energy is the minimum / least / lowest energy

Mark independently

Ignore "heat" and ignore "enthalpy"

M2 (energy) for a reaction to occur / to go / to start

OR (energy) for a successful / effective collision

Ignore "breaking the bonds"

2

(b) **M1** Catalysts provide an alternative route OR an alternative mechanism OR alternative / different path(way)

M2 Lowers the activation energy

Mark independently

Ignore reference to "surface"

2

(c) (i) Stay(s) the same

1

(ii) Increases

Credit "increase" or "increased"

1

(iii) Increases

Credit "increase" or "increased"

1

(iv) Stay(s) the same

1

(d) (i) **M1** yeast or zymase

M2 <u>ethanol</u>

Ignore "enzyme"

In M2, ignore "alcohol" and ignore any formula

2

(ii) **M1** (Concentrated) H_3PO_4 OR (Concentrated) H_2SO_4

M2 <u>butan-2-ol</u>

Credit correct names

Ignore "hydrogenphosphate or hydrogensulfate"

Ignore "dilute" or "aq"

Do not penalise absence of hyphens in name.

In M2, ignore any formula

2

[12]

22 (a) (i) **M1** The peak of the new curve is displaced to the right.

M2 All of the following are required

- The new curve starts at the origin
- The peak of the new curve is lower than the original
- and the new curve only crosses the original curve once
- and an attempt has been made to draw the new curve correctly towards the energy axis but not to touch the original curve
- the new curve must not start to diverge from the original curve

M1 is low demand

M2 is higher demand.

2

(ii) **M1** Increase in the number/proportion of molecules with $E \geq E_a$

OR more molecules have $E \geq E_a$

OR more molecules have sufficient energy to react

M2 More effective/productive/successful collisions

Ignore "molecules have more energy"

Ignore "more energetic collisions"

Ignore "molecules gain activation energy"

Ignore "more collisions"

Accept "particles" for "molecules" but NOT "atoms"

Ignore "chance of collision"; this alone does not gain M2

2

(b) (i) Iron ***OR*** Fe

1

(ii) **M1** Catalysts provide an alternative route/pathway/mechanism

OR

(in this case) surface adsorption/surface reaction occurs.

For M1, not simply "provides a surface" alone

M2 that has a lower activation energy

OR

lowers the activation energy

For M2, the candidate may use a definition of activation energy without referring to the term

2

[7]

23 (a) (i) **M1** drawn curve starts at reactants and ends at products

Tapered lines into the original curve gain credit for M1

M2 curve peak is below the one drawn in the question
(and may show one/two humps)

Mark M1 and M2 independently

2

(ii) Exothermic (reaction)

Ignore "ΔH is negative"

1

(iii) Σ bond (enthalpy) reactants < Σ bond (enthalpy) products

The sum for H_2 and I_2/reactants is less than/lower than/smaller than the sum for 2HI/products
OR
The sum for 2HI/products is more than/larger than/bigger than the sum for H_2 and I_2/reactants

Accept "It OR the sum will be smaller or less"

1

(iv) **M1** *p*

2

M2 – (*q* – *p*)

OR

p – *q*

OR

– *q* + *p*

M2 demands that the sign for an exothermic reaction is part of the outcome mathematically.
Ignore case

(b) (i) Increase/speed up/faster (rate of attainment of equilibrium)

OR

Increase/speed up/faster rate of <u>both</u> forward <u>and</u> reverse reaction

OR

Increase/speed up/faster rate of reaction

Credit "It took less time"

1

(ii) **M1** Increase/speed up/faster (rate of attainment of equilibrium)

M2 More particles/molecules in a given volume/space
OR the particles/molecules are closer together
OR an increase in concentration.

M3 More/higher chance of successful/effective/productive collisions (between particles)
OR more collisions/higher chance of collisions (of particles) with $E>E_{Act}$

If M1 is blank, mark on and credit M1 in the text

If M1 is given as "decrease"/"no effect"/"no change" then CE = 0 for clip

In M1, if increase both the forward and reverse reaction, but no mention of rate, penalise M1 but mark on.

In M1, if increase either forward rate or reverse rate only, then penalise M1 but mark on.

Penalise M3 if an increase in the value of E_{Act}/energy of particles is stated.

Max 1 for M2 and M3 if reference to "atoms"

3

[10]

24 Measure volume of gas / mass loss

If 'measure concentration' must explain how to score mark

1

At (regular) time intervals

Ignore references to temperature
Accept 'against time'
Do not accept 'with time' or 'over time' on its own

1

[2]

25 (a) Antacid

OR

to neutralise acidity

OR

eases indigestion

Credit suitable reference to indigestion or to laxative or to relief of constipation

1

(b) **M1** Decrease in T decreases the energy of the particles/ions/H^+/molecules

M2 (also scores M1) Decrease in the number of/less particles/ions/ H^+/molecules with $E \geq E_{Act}$ or $E \geq$ minimum energy to react

*In **M1** and **M2,** credit "atoms" but ignore "calcium carbonate", ignore "calcium", ignore any ion formula except H^+*

M3 Few(er)/Less effective/productive/successful collisions

QoL

3

(c) (i) Strontium has a higher melting point than barium, because

Correct reference to size of cations/proximity of electrons
M1 (For Sr) delocalised electrons closer to cations/positive ions/atoms/nucleus

OR

cations/positive ions/atoms are smaller

OR

cation/positive ion/atom or it has fewer (electron) shells/levels

Ignore general Group 2 statements

Penalise M1 if Sr or Ba is said to have more or less delocalised electrons

Ignore reference to shielding

***CE = 0** for reference to molecules or intermolecular forces or covalent bonds*

Relative strength of metallic bonding
M2 (Sr) has stronger attraction between the cations/positive ions/ atoms/nucleus and the delocalised electrons

OR

stronger metallic bonding
(assume argument refers to Sr but accept converse argument for Ba) 2

Ignore "Van der Waals forces (between atoms)" but penalise if "between molecules"

(ii) $Sr + \mathbf{2}H_2O \rightarrow Sr(OH)_2 + H_2$

Or multiples

1

(d) **2**Mg + $TiCl_4$ → **2**$MgCl_2$ + Ti

Or multiples

1

[9]

26 (a) (i) Oxidation

OR

Oxidised ONLY

1

(ii) Any one from

- to provide/overcome activation energy
- to provide the minimum energy to make the reaction go/start

NOT simply to increase the (initial) reaction rate.

1

(iii) The reaction is exothermic OR releases heat (energy)

1

(iv) M1
Catalysts provide an alternative route/pathway OR an alternative mechanism

OR

(in this case) surface adsorption occurs (or a description of adsorption)

Ignore reference to "surface" alone

M2
Lowers the activation energy

OR

of lower activation energy

2

(b) M1
The (forward) reaction is exothermic OR the (forward) reaction releases heat

OR

The reverse reaction is endothermic or absorbs heat

M2 – Direction of change N.B. M2 depends on correct M1
At lower temperatures,

- the equilibrium yield of NO_2 is greater
- more NO_2 is formed
- equilibrium shifts (left) to right
- (equilibrium) favours the forward reaction

(***OR*** converse for higher temperatures)

2

(c) NO_2 (+) 4

NO_3^- (+) 5

HNO_2 (+) 3

3

[10]

27 (a) Sulfur OR S OR S_8

Sulphur

1

(b) **M1** The activation energy is the <u>minimum</u> / <u>least</u> / <u>lowest</u>

Mark these independently

1

M2 Energy for a reaction to occur / to go / to start
OR
Energy for a <u>successful / effective</u> collision

1

(c) Explanation:

M1 Twice as many / double number of particles

M1 NOT molecules

1

M2 More / twice / double (effective) collisions (in a given time)

OR

Double / greater / increased collision frequency

1

(d) (i) (Measured) change in concentration (of a substance) in unit time / given time

May be written mathematically

OR the gradient of the concentration (against) time

1

(ii) The measured change / amount (of precipitate) / cloudiness is fixed or constant or unchanged

1

[7]

28

(a) Temperature / pressure;

Do not allow 'amount' or concentration of reactants.

1

(b) Determine gradient;

Do not allow volume / time.

Accept 'steepness' or 'slope'

1

[2]

29

(a) Peak lower

1

and moved to right

1

start at the origin and curve crosses once only

1

(b) (i) (Rate of reaction) increases

1

(At a higher temperature) more molecules/particles

1

have the minimum energy needed to react/have activation energy/have successful collisions

Mark CE if incorrect effect given

1

(ii) (Rate of reaction) <u>increases</u> 1

lowers activation energy 1

so that more molecules are able to react 1

Mark CE if incorrect effect given

[9]

30 (a) Equation $1/2N_2 + 3/2H_2 \rightarrow NH_3$

1

$\Delta Hf = [(945 \times 0.5) + (426 \times 1.5)] - (391 \times 3)$

1

$= -46.5 \text{ kJ mol}^{-1}$

1

Mark Range	The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of QWC but the candidates' QWC in this answer will be one of the criteria used to assign a level and award the marks for this part of the question **Descriptor** an answer will be expected to meet most of the criteria in the level descriptor
4-5	– claims supported by an appropriate range of evidence – good use of information or ideas about chemistry, going beyond those given in the question – argument well structured with minimal repetition or irrelevant points – accurate and clear expression of ideas with only minor errors of grammar, punctuation and spelling
2-3	– claims partially supported by evidence – good use of information or ideas about chemistry given in the question but limited beyond this – the argument shows some attempt at structure – the ideas are expressed with reasonable clarity but with a few errors of grammar, punctuation and spelling
0-1	– valid points but not clearly linked to an argument structure – limited use of information or ideas about chemistry – unstructured – errors in spelling, punctuation and grammar or lack of fluency

(b) The higher the temperature the faster the reaction QWC

1

but, since the reaction is exothermic

1

the equilibrium yield is lower QWC

1

The higher the pressure the greater the equilibrium yield QWC

1

because there is a reduction in the number of moles of gas in the reaction

1

but higher pressure is expensive to produce or plant is more expensive to build QWC

1

A better catalyst would lessen the time to reach equilibrium

1

and allow more ammonia to be produced in a given time QWC

1

[11]

31 (a) (i) Z (1)

1

(ii) Collisions (1)

Cause some molecules to slow down or lose energy (1)

2

(b) Curve starts at origin and is displaced to the right (1)

Curve lower and does not touch energy axis (1)

2

(c) (i) Only a small percentage/very few collisions have $E > E_a$ (1)

1

(ii) Add a catalyst (1)

Lowers E_a (1)

More collisions/molecules have energy > E_a (1)

3

[9]

32

(a) minimum energy

1

to start a reaction/ for a reaction to occur/ for a successful collision

1

(b) activation energy is high / few molecules/particles have sufficient energy to react/few molecules/particles have the required activation energy

(or breaking bonds needs much energy)

1

(c) molecules are closer together/ more particles in a given volume

1

therefore collide more often

1

(d) many

1

more molecules have energy greater than activation energy (QoL)

1

(e) speeds up a reaction but is chemically unchanged at the end

1

(f) increases the surface area

1

[9]

33

(a) the minimum energy;

1

Energy required for a reaction to occur;

(or to start a reaction or for successful collisions)

1

(b) axes labelled:- y: number *(or fraction or %)* of molecules *(or particles)*
x: energy *(or KE);*

1

curve starts at origin;

1

skewed to right;

1

approaches x axis as an asymptote;

(penalise a curve that levels off > 10% of max peak height or a curve that crosses the energy axis)

1

second curve displaced to the left (and does not cross T_1 curve for a second time)

1

and peak higher;

1

many fewer molecules;

1

fewer molecules have $E > E_a$;

(can score this mark from suitably marked curves)

1

(c) molecules *(or particles or collisions)* do not have enough energy;

(or orientation may be wrong)

1

increase the pressure;

1

(or increase the concentration or reduce the volume)
increases the collision frequency;

(or more collisions)
(do not allow if stated to be due to increase in energy implied by temperature increase)

1

add a catalyst;

1

lowers activation energy (or E_a) *(Q of L mark);*

1

[15]

34 (a) Gradient (or slope) (or draw a tangent)

1

(b) (i) Curve **X** is lower and starts at origin

1

And levels out at same volume as original curve

1

(ii) Curve **Y** is steeper than original and starts at origin

1

Then levels out at half the volume of the original

1

(c) (i) $2H_2O_2 \rightarrow 2H_2O + O_2$

1

(ii) Speeds up (alters the rate of) a chemical reaction

1

Remains unchanged (or not used up)

1

(iii) Remains unchanged (or not used up or not in the overall reaction equation)

1

Offers alternative reaction route (or acts as an intermediate)

1

[10]

35 R

[1]

36 (a) Graph starts at origin

1

Graph skewed to left and has decreasing gradient to maximum

1

Graph after maximum decreases in steepness, never touches *x* axis, levels out less than 5 mm from *x* axis.

1

(b) Minimum energy

1

To start a reaction (*or for a reaction to occur*)

1

(c) Molecules gain energy (*or always some molecules have* $E > E_a$)

1

Due to collisions

1

(d) Decreases

1

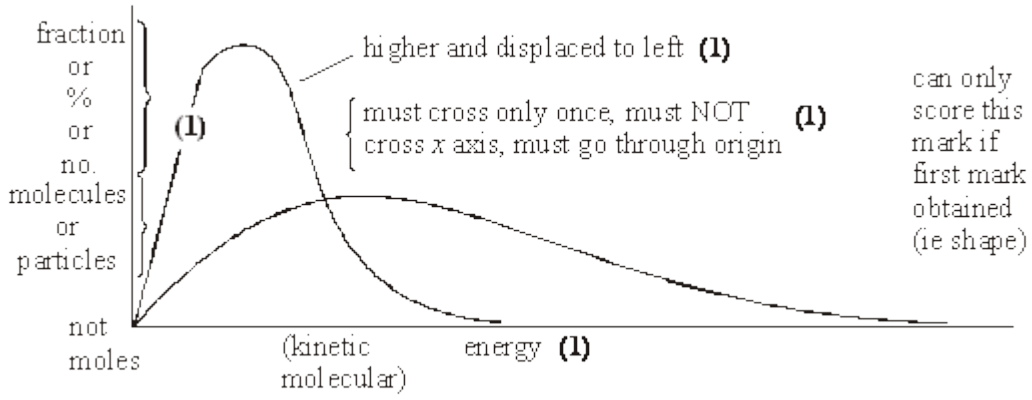
E_a lowered **(1)**
By alternative route **(1)**
So more molecules have energy > E_a **(1)**

max 2

[10]

37

(a)



2

(b) See above

2

(c) Energy < E_a or must have enough energy (to react) **(1)**

1

(d) Increase concentration (or pressure) **(1)**

1

(e) Many **(1)** more molecules have E > E_a / enough energy **(1)**

NOT KE increases with T

2

(f) Lowers E_a **(1)**
alternative route **(1)**

2

[10]

38

(a) <u>minimum</u> energy **(1)**
required before a reaction can occur or go or start **(1)**

2

(b) speeds up (changes) reaction rate **(1)**
without being (chemically) changed **(used up) (1)**

2

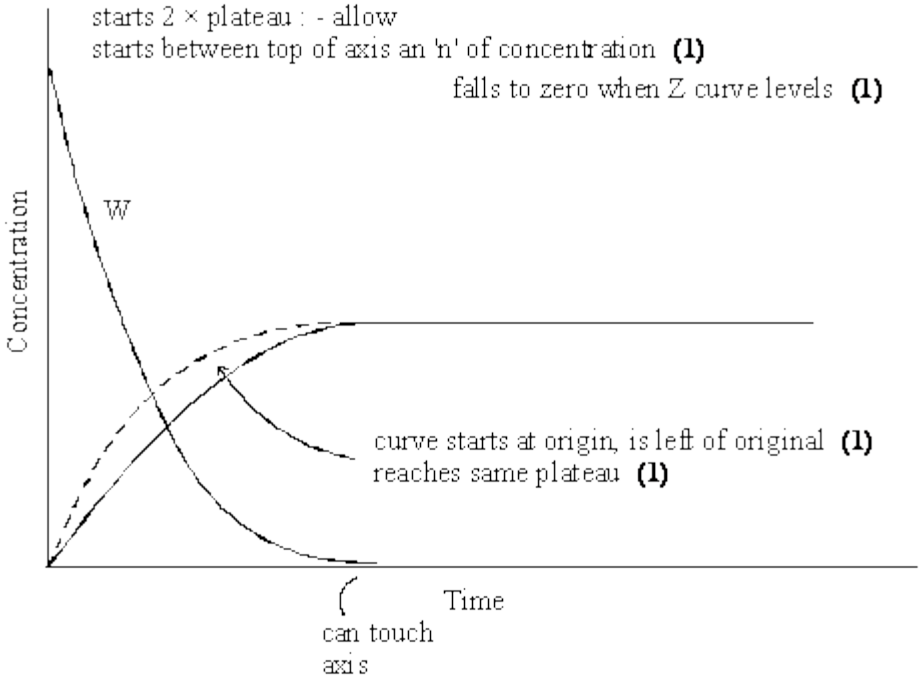
(c) provides alternative reaction route **(1)**
with a lower activation energy **(1)**

in (b) and (c) reward 4 marks for 4 points wherever found

2

(d) (i)

(ii)



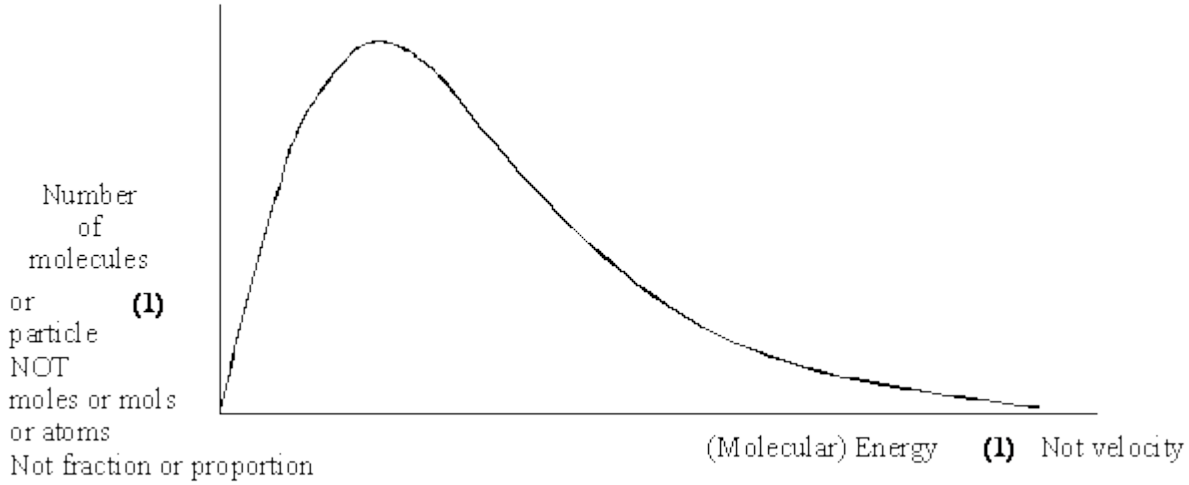
(iii) fewer collisions **(1)**
W used up **(1)**

or reactants
or reagents
or fewer particles

6

[12]

39 (a) (i)



(ii) The total number of particles (or molecules) in the sample

OR the number of molecules present

(iii) No molecules have no energy

OR all molecules have some energy

Do not allow "if there are no molecules there is no energy"

4

(b) (i) The minimum energy required **(1)**

for a reaction to occur **(1)**

OR to start reaction or for a successful collision

(ii) Changes: Catalyst **(1)**

Explanation: Alternative route **(1),** with a lower activation energy **(1)**

OR a lower activation energy (1)
so more molecules can react (1)/more molecules have this energy

If change incorrect CE = 0

Allow answers anywhere in b (ii)

5

[9]

40 (a) **Increase in temperature:**

Yield is increased **(Allow if for H_2 (g) or products) (1)**
Reaction endothermic **(1)**
Equilibrium moves to the right **OR** forward, **OR** Equilibrium moves to oppose change **OR** to absorb heat **(1)**

If "Yield statement" incorrect allow max one if reaction stated to be endothermic

Increase in pressure:

Yield is decreased **(Allow if for H_2 (g) or products) (1)**
Increase in moles of gas **or** 2 moles increased to 4 moles **or** more moles on right **(1)**
Equilibrium moves to the left **OR** backwards, **OR** Equilibrium moves to oppose change **OR** to reduce pressure **(1)**

If "Yield statement" incorrect allow max one if number of moles change is correct.

6

(b) **Equilibrium yield:**
Unaffected **or** equilibrium unchanged **(1)**
Rate or speed increased **(1)**
Forward and backwards reactions equally or by the same amount **(1)**

Amount of hydrogen produced:
More hydrogen produced (1)

4

[10]

41 B

[1]

42 (a) Activation energy;-
The minimum energy needed for a reaction to occur / start **(1)**

1

(b) Catalyst effect:-
Alternative route (or more molecules have Ea) **(1)**
Lower activation energy **(1)**

2

(c) Increase in moles of gas:-

Position of E_{mp} unchanged **(1)**

More molecules with E_{mp} **(1)**

Area under curve increases **(1)**

Molecules with $E \geq E_a$ increased **(1)**

Temperature decreased:-

Position of E_{mp} moves to the left **(1)**

More molecules with E_{mp} **(1)**

Area under curve unchanged **(1)**

Molecules with $E \geq E_a$ decreased **(1)**

Catalyst introduced:-

Position of E_{mp} unchanged **(1)**

Molecules with E_{mp} unchanged **(1)**

Area under curve unchanged **(1)**

Molecules with $E \geq E_a$ increased **(1)**

12

[15]

43 D

[1]

44 D

[1]