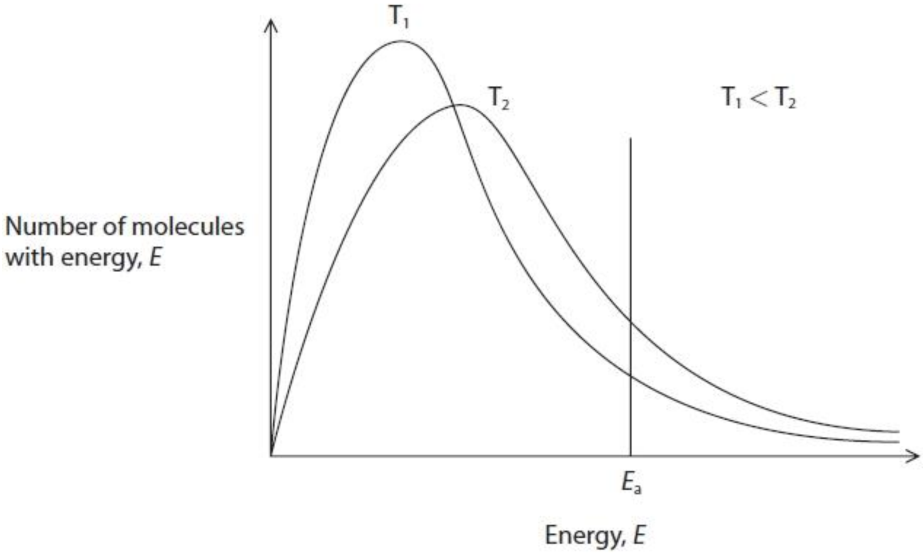
Questions

Q1.

This question is about reaction kinetics.

Maxwell-Boltzmann distributions of the molecular energies of particles in a gas are shown at two different temperatures.
The activation energy for the reaction, E_a, is labelled.



(i) The activation energy is the minimum energy required

(1)

- ☐ **A** for a reaction to take place when reactant molecules collide
- ☐ **B** for reactant molecules to collide
- ☐ **C** for all collisions to result in a reaction
- ☐ **D** for the particles to collide with the appropriate orientation

(ii) Explain, with reference to the gaseous particles, the differences in the two distributions.

(2)

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(iii) Which of the following is **not** an explanation of why increasing the temperature increases the rate of a reaction?

(1)

- ☐ **A** the area under the curve to the right of Ea is larger at a higher temperature
- ☐ **B** a greater percentage of collisions are successful at a higher temperature
- ☐ **C** molecules move faster and collide more often at a higher temperature
- ☐ **D** there are more collisions, all of which are successful, at a higher temperature

(Total for question = 4 marks)

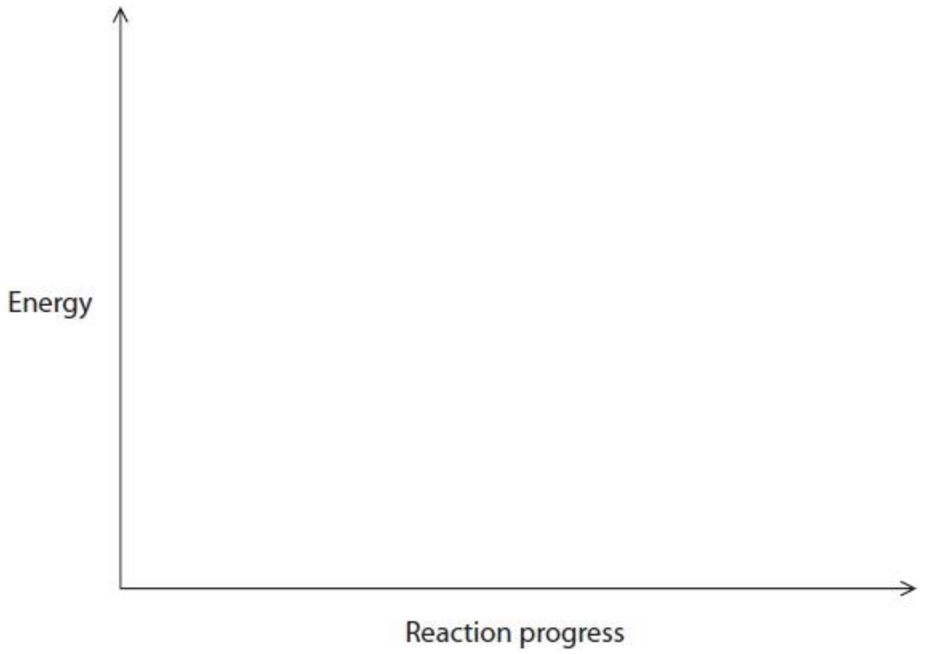
Q2.

This question is about reaction kinetics.

Reaction profiles can be used to show the effect of the addition of a catalyst on the energy changes during the course of a reaction.

(i) Draw fully labelled reaction profiles for the reaction both with and without a catalyst for an exothermic reaction.

(4)



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

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(Total for question = 5 marks)

Q3.

The progress of the reaction between iodine and propanone with an acid catalyst can be followed in an experiment using a titrimetric method.

Procedure

Step **1** Mix 25 cm^3 of 1 mol dm^{-3} aqueous propanone with 25 cm^3 of 1 mol dm^{-3} sulfuric acid in a beaker. Both these reactants are in excess.

Step **2** Start the stop clock as 50 cm^3 of 0.02 mol dm^{-3} iodine solution is added to the beaker. Mix the reactants thoroughly.

Step **3** Withdraw a 10.0 cm^3 sample of the reaction mixture, using a pipette, and transfer it to a conical flask.

Step **4** Add a spatula measure of sodium hydrogencarbonate, noting the exact time.

Step **5** Titrate the iodine present in the 10.0 cm^3 sample with 0.01 mol dm^{-3} sodium thiosulfate solution, using starch indicator.

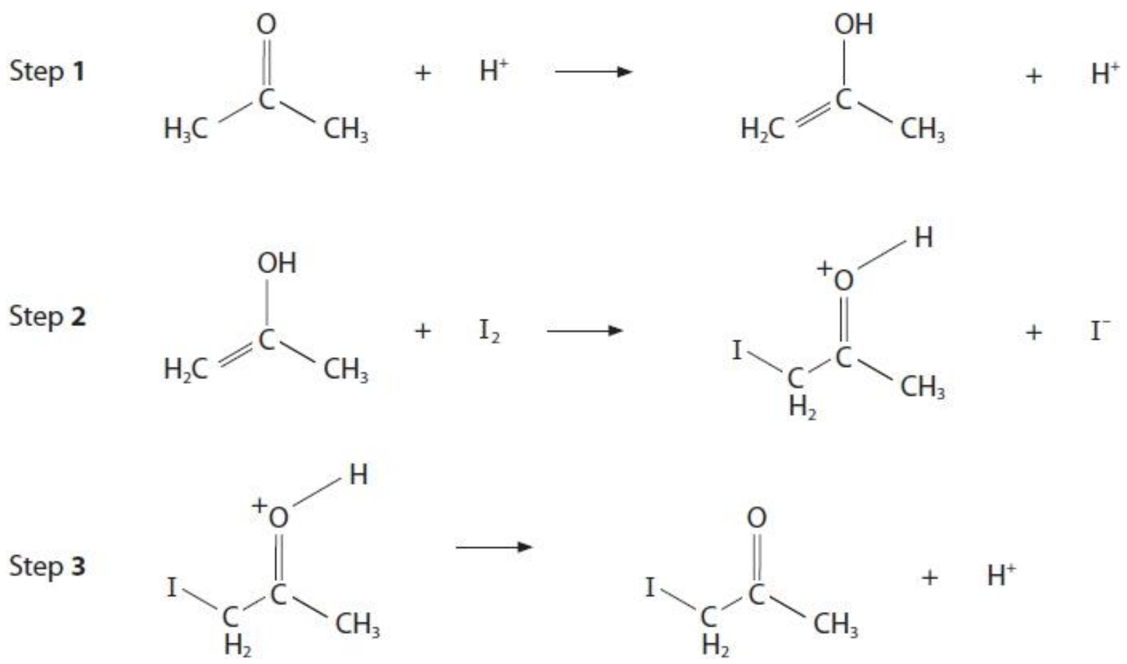
Step **6** Continue to withdraw 10.0 cm^3 samples about every two minutes, repeating Steps **4** and **5** with each sample.

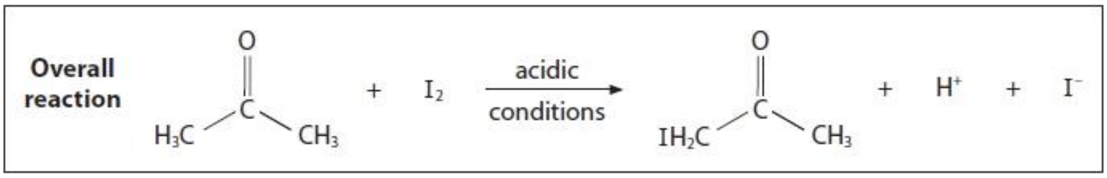
Some data from the experiment are shown.

Time sodium hydrogencarbonate is added / min	2.0	5.0	6.5	8.0	10.5	12.0
Volume of sodium thiosulfate / cm^3	19.2	15.5	14.0	12.1	9.5	7.2

The overall rate equation for the reaction is rate = $k[H^+(aq)][CH_3COCH_3(aq)]$.

A student researching the mechanism for the reaction found this example.





(i) Predict which of the three steps is the rate-determining step. Justify your answer.

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(ii) The student stated that
'The hydrogen ions cannot be acting as a catalyst.
One hydrogen ion is a reactant in Step **1** but two hydrogen ions are formed as products in Steps **1** and **3**.'
Explain whether or not this statement is valid.

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(Total for question = 4 marks)

Q4.

Methanol is manufactured from a mixture of carbon monoxide and hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -90.8\ kJ\ mol^{-1}$$

Explain why, in the industrial process involving this reaction, a catalyst is used.

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(Total for question = 2 marks)

Q5.

One of the stages in the production of sulfuric acid from sulfide ores involves the oxidation of sulfur dioxide to sulfur trioxide. The equation for the reaction is

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta rH = -197$ kJ mol^{-1}

The conditions used in one industrial process are: 420°C and a pressure of 1.7 atm together with a vanadium(V) oxide catalyst.

It is proposed to change the conditions to 600°C and 10 atm pressure, while still using the same catalyst.

* Evaluate the feasibility of each of these changes in terms of their effect on the rate, yield and economics of the reaction.

(6)

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(Total for question = 6 marks)

Q6.

This question is about transition metals.

Manganate(VII) ions, MnO_4^-, react with ethanedioate ions in acid solution.

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

The reaction starts slowly, the rate of reaction then increases, before it decreases again.

Explain this sequence.

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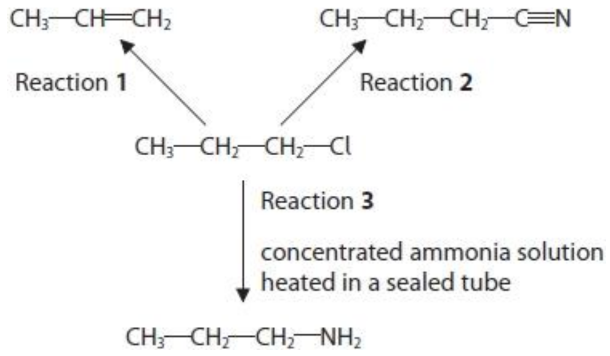
(Total for question = 3 marks)

Q7.

This question concerns halogenoalkanes.

1-chloropropane can react to form organic products as shown in the reaction scheme:



(i) State the reagent and conditions used in Reaction **1**.

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(ii) Identify a suitable reagent for Reaction **2** and include a reason why this is a particularly useful type of reaction in organic chemistry.

(2)

Reagent

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Reason

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(iii) Explain why, in Reaction **3**, the reactants are **heated** in a **sealed** container.

(2)

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(iv) Write the structural formula of the product that will be formed if 1-chloropropane is refluxed with **aqueous** potassium hydroxide solution.

(1)

(Total for question = 7 marks)

Q8.

The gas phase reaction between hydrogen and iodine is reversible.

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

(a) (i) Write the expression for the equilibrium constant, K_c, for this reaction.

(1)

(ii) If the starting concentration of both hydrogen and iodine was **a** mol dm^{-3} and it was found that 2**y** mol dm^{-3} of hydrogen iodide had formed once equilibrium had been established, write the K_c expression in terms of **a** and **y**.

(2)

(b) The expression for the equilibrium constant in (a)(ii) can be rearranged as shown.

$$\mathbf{y} = \frac{\mathbf{a}\sqrt{K_c}}{2 + \sqrt{K_c}}$$

In an experiment, air was removed from a 1 dm^3 flask and amounts of hydrogen and iodine gases were mixed together such that their initial concentrations were both **a** mol dm^{-3}. This mixture was allowed to reach equilibrium at 760 K. The equilibrium concentration of iodine was then measured.

The experiment was repeated for various initial concentrations, **a** mol dm^{-3}, and the results recorded in the table.

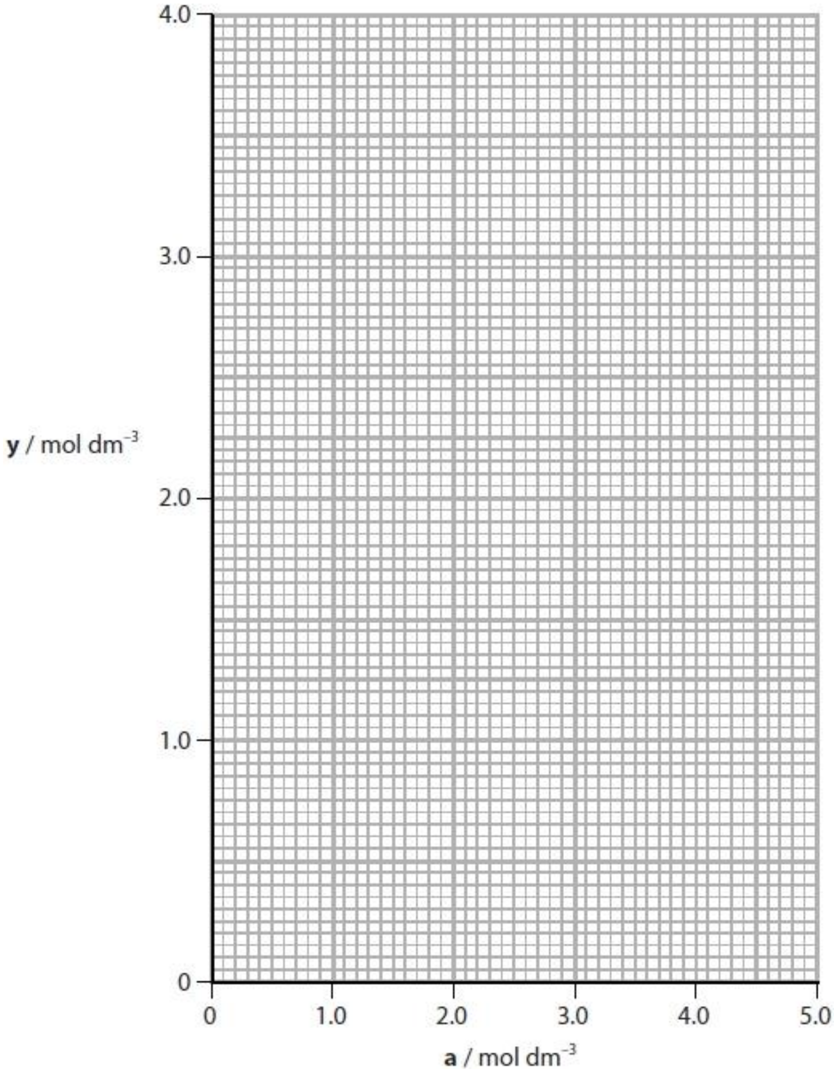
(i) Complete the table to give the two remaining values of **y** mol dm^{-3}, to **two** decimal places.

(1)

a / mol dm^{-3}	$[I_2]_{eq}$ / mol dm^{-3}	y / mol dm^{-3}
0.20	0.02	0.18
0.80	0.25	0.55
1.50	0.37	
2.10	0.57	1.53
2.80	0.65	2.15
3.80	0.87	
4.90	1.15	3.75

(ii) Plot a graph to show how **y** mol dm^{-3} varies with the initial concentrations of hydrogen and iodine, **a** mol dm^{-3}.

(2)



(iii) Determine the gradient of your graph.
Show your working on the graph.

(2)

(iv) Use your answer to (b)(iii) and the expression $y = \frac{a\sqrt{K_c}}{2 + \sqrt{K_c}}$ to calculate the value of K_c.

(2)

(c) Identify a safety issue associated with this experiment.

(1)

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(d) One of the experiments in part (b) was repeated using the same molar quantities of hydrogen and iodine but in a 500 cm^3 flask instead of the 1 dm^3 flask.

Deduce the effect, if any, that this would have on the rate of reaction and on the value of K_c calculated.

(2)

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(e) The equation for the reaction between hydrogen and iodine is

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -9.6\ kJ\ mol^{-1}$

(i) Explain the effect, if any, on the value of K_c when the temperature is increased.

(2)

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(ii) On your graph in (b)(ii), draw and label the line you would expect if the experiment was carried out at 1000 K instead of 760 K.

(1)

(Total for question = 16 marks)

Q9.

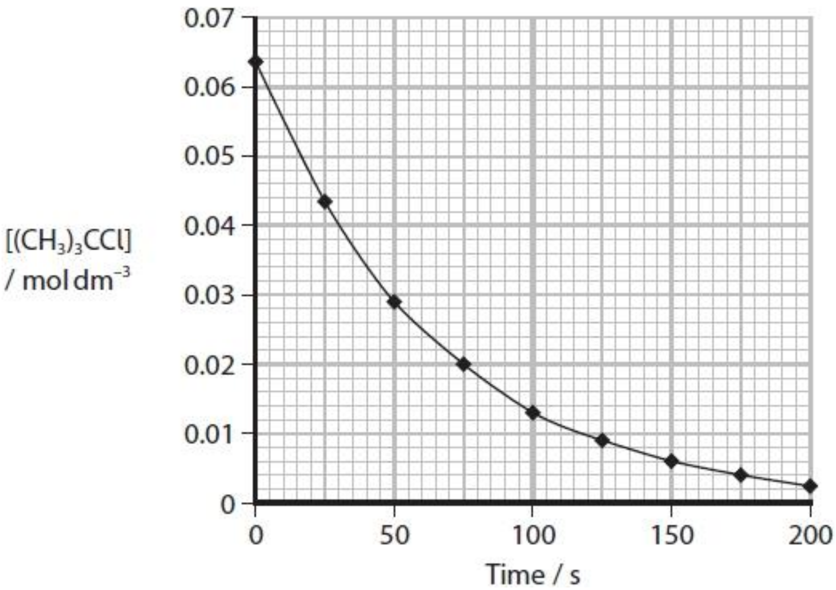
This question is about halogenoalkanes.

2-chloro-2-methylpropane can be hydrolysed by water.

The equation for this reaction is

$$(CH_3)_3CCl + H_2O \rightarrow (CH_3)_3COH + H^+ + Cl^-$$

The graph shows how the concentration of 2-chloro-2-methylpropane changes with time during an investigation of this reaction.



Calculate the rate of reaction at 50 s. Show your working on the graph.
Include units with your final answer.

(3)

Rate of reaction at 50 s = ...

(Total for question = 3 marks)

Q10.

An equation for the formation of ammonia using the Haber process is shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

Ammonia is stable in air but can be oxidised on the surface of a copper catalyst.

An equation for this reaction is

$$4NH_3(g) + 5O_2(g) \rightarrow 6H_2O(g) + 4NO(g) \qquad \Delta_r H = -905.2 \text{ kJ mol}^{-1}$$

The catalyst is usually warmed to approximately 300 °C to start the reaction, but after a short reaction time the copper catalyst often melts.

(i) Give a reason why the catalyst is warmed and a reason why the catalyst may melt.

(2)

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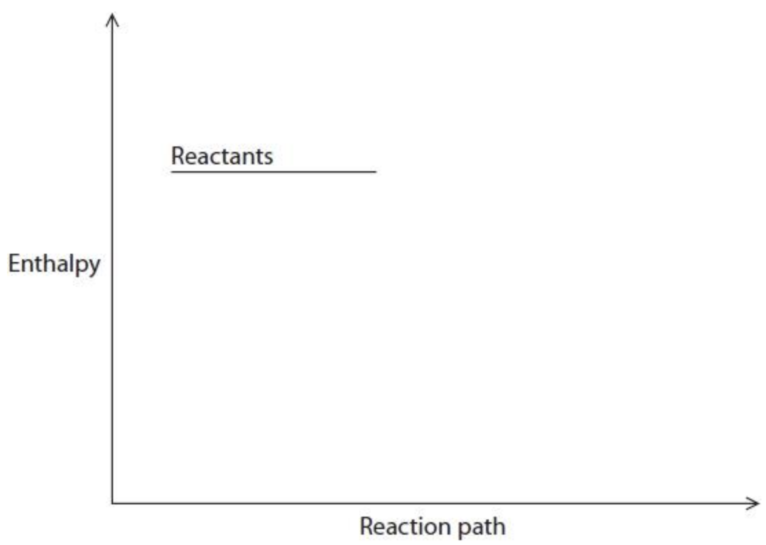
(ii) Complete the reaction profile for this catalysed oxidation of ammonia, showing the enthalpy change, $\Delta_r H$.

(2)



(iii) Describe the processes that occur on the surface of a heterogeneous catalyst during the oxidation of ammonia in air.

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(Total for question = 7 marks)

Q11.

Compound **X** reacts slowly with water according to the following equation.

$$\mathbf{X}(s) + H_2O(l) \rightarrow \mathbf{Y}(aq) + Z^-(aq) + H^+(aq)$$

The reaction is catalysed by hydrogen ions and eventually goes to completion.

Compound **X** was added to water and the concentration of compound **Y** determined at various times at a constant temperature.

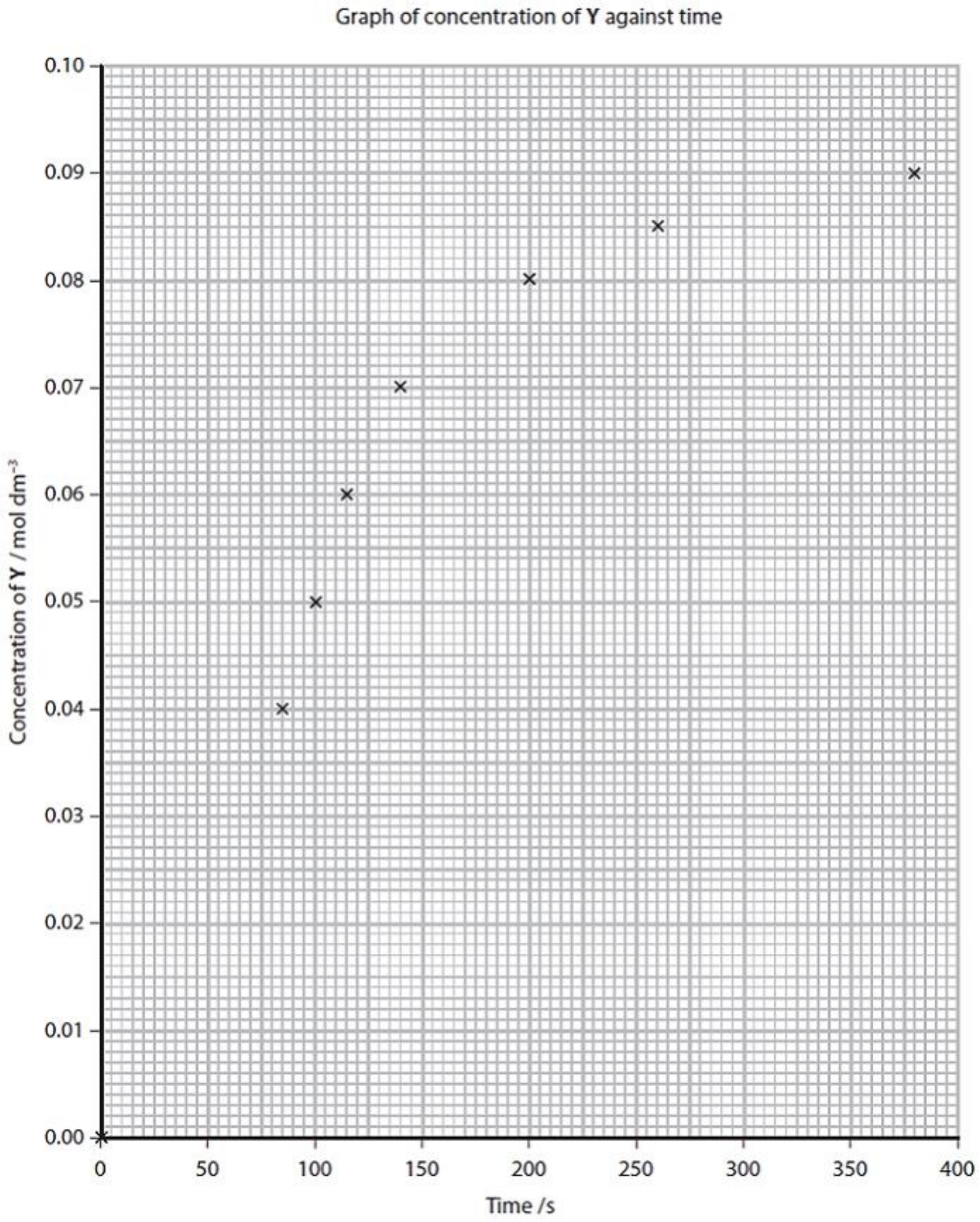
The results of the experiment are shown.

Time / s	Concentration of **Y** / mol dm^{-3}
0	0.000
25	0.002
40	0.005
50	0.010
65	0.020
75	0.030
85	0.040
100	0.050
115	0.060
140	0.070
200	0.080
260	0.085
380	0.090

(i) Complete the graph of concentration against time by adding the six missing points.

Draw a line to pass through **all** the points.

(2)



Describe how you would find a numerical value for the initial rate of reaction
and for the maximum rate of reaction in this experiment from the graph.
No actual calculations are required.

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(Total for question = 6 marks)

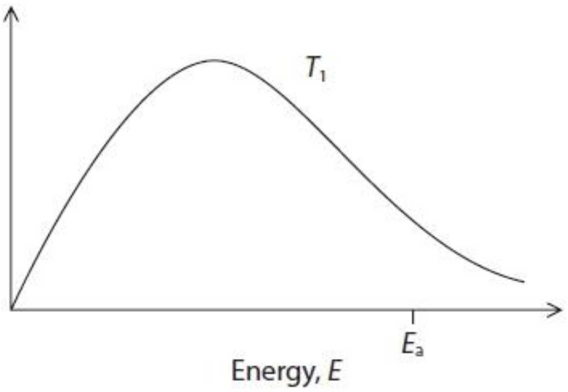
Q12.

This question is about the effect of temperature on the rate of decomposition of nitrogen(V) oxide.

$$2N_2O_5(g) \rightarrow 2N_2O_4(g) + O_2(g)$$

The diagram shows the Maxwell-Boltzmann distribution of molecular energies for nitrogen(V) oxide at a temperature T_1.

E_a is the activation energy of this reaction.



(i) Give the label for the vertical axis.

(1)

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(ii) Draw a second curve on the same set of axes for the same gas at a **lower** temperature, T_2.

(2)

(iii) Explain, in terms of collisions and energy, why lowering the temperature decreases the rate of reaction.

(2)

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(iv) A catalyst is added to the gas.

Label the diagram above with the symbol E_{cat} to show a possible activation energy for the reaction in the presence of a catalyst.

(1)

(Total for question = 6 marks)

Q13.

This question is about the oxidation of ammonia.

In fact, this oxidation to form nitrogen(II) oxide is an equilibrium reaction.

(i) Explain the effect, if any, of increasing pressure on the equilibrium **yield** of NO in this reaction.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$$

(2)

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(ii) Explain the effect, if any, of an increase in pressure on the **rate** of this reaction.

(2)

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(iii) The platinum-rhodium catalyst used in this reaction is a **heterogeneous** catalyst. State what is meant by the term 'heterogeneous' and why a catalyst has no effect on the yield of the products in the reaction.

(2)

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(Total for question = 6 marks)

Q14.

This question is about how catalysts work.

Catalytic converters of car exhaust systems have internal honeycomb structures as shown.

Explain why the honeycomb structure is used in a car exhaust system.

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(Total for question = 2 marks)

Q15.

Aqueous hydrogen peroxide decomposes according to the following equation.

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

The decomposition is catalysed by manganese(IV) oxide.

This can be investigated by measuring the volume of oxygen produced at various times as the reaction proceeds.

Catalysts are not used up during a reaction. Manganese(IV) oxide acts as a heterogeneous catalyst.

Describe in outline a method to show that the manganese(IV) oxide is not used up in the decomposition of hydrogen peroxide **and** that it still functions as a catalyst.

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(Total for question = 4 marks)

Q16.

Compound **X** reacts slowly with water according to the following equation.

$$X(s) + H_2O(l) \rightarrow Y(aq) + Z^-(aq) + H^+(aq)$$

The reaction is catalysed by hydrogen ions and eventually goes to completion.

Compound **X** was added to water and the concentration of compound **Y** determined at various times at a constant temperature.

The results of the experiment are shown.

Time / s	Concentration of **Y** / mol dm^{-3}
0	0.000
25	0.002
40	0.005
50	0.010
65	0.020
75	0.030
85	0.040
100	0.050
115	0.060
140	0.070
200	0.080
260	0.085
380	0.090

For many reactions, the values of the initial rate and the maximum rate are the same.

Explain why the values of the two reaction rates obtained in this experiment are different from each other.

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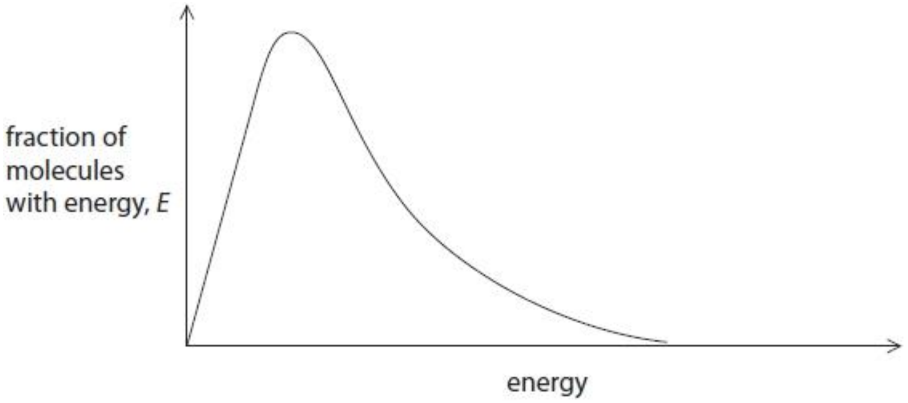
(Total for question = 2 marks)

Q17.

The graph shows the Maxwell-Boltzmann distribution of molecular energies of a gaseous system.



(i) On the graph, draw the Maxwell-Boltzmann distribution for the same system at a higher temperature.

(1)

(ii) Use the graph to explain why a small increase in temperature results in a large increase in the rate of a gaseous reaction.

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(Total for question = 4 marks)

Q18.

Methanol, CH_3OH, is a liquid fuel.

Methanol can be synthesised from methane and steam by a process that occurs in two steps.

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

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

(i) Explain the effects of increasing the pressure on the yield of the products and on the rate of the reaction in Step **1**.

(4)

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(ii) Step **2** is carried out at a compromise temperature of 500 K.

Explain why 500 K is considered to be a compromise for Step **2** by considering what would happen at higher and lower temperatures.

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(Total for question = 7 marks)

Q19.

This question is about the identification of a Group 2 carbonate.

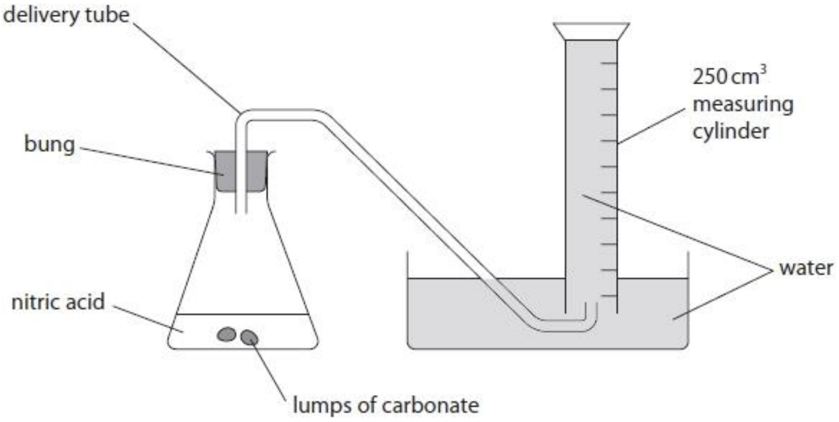
A chemistry teacher found a bottle containing lumps of a white solid. The original label was missing from the bottle. However, someone had written 'Group 2 carbonate' on the bottle. The lumps of the anhydrous white solid were pure and dry.

The chemistry teacher tried to identify the carbonate with the help of three students. The three students worked under identical conditions and shared the same weighing balance.

Student **1** recognised that if an acid is added to a carbonate, carbon dioxide is evolved. The student decided to measure the volume of carbon dioxide evolved when the Group 2 carbonate reacts with excess nitric acid.

The student knew that 1 mol of a Group 2 carbonate produces 1 mol of carbon dioxide.

Student **1** set up the apparatus shown below.



- Student **1** weighed out some of the Group 2 carbonate and added it to a 250 cm^3 conical flask.
- Student **1** then added 100 cm^3 of 0.200 mol dm^{-3} nitric acid to the conical flask and replaced the bung.
- Student **1** measured the volume of gas collected in the inverted measuring cylinder at room temperature and pressure (r.t.p.) when all the Group 2 carbonate had reacted.
- Student **1** obtained the results shown in Table 1.

Measurement		Value
Mass of weighing bottle and carbonate	/ g	13.247
Mass of empty weighing bottle	/ g	12.431
Mass of carbonate used	/ g	....
Volume of acid used	/ cm^3	100
Volume of gas collected	/ cm^3	225

Table 1

(a) Complete Table 1 to show the mass of the carbonate used.

(1)

(b) Calculate the amount, in moles, of carbon dioxide collected in the measuring cylinder at r.t.p.

(1)

(c) Calculate the molar mass of the Group 2 carbonate to an appropriate number of significant figures and hence deduce the identity of the Group 2 metal.

(4)

(d) Student **2** carried out the same experiment as Student **1**, using the same mass of the Group 2 carbonate.

Student **2** made no errors in their measurements or calculations but obtained a value for the molar mass which was 10 g mol^{-1} greater than the value obtained by Student **1**.
(i) Explain **one** procedural error which could have resulted in Student **2** obtaining a molar mass greater than that of Student **1**.

(2)

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(ii) It was later discovered that Student **2** had used 110 cm^3 of 0.200 mol dm^{-3} dilute nitric acid, instead of 100 cm^3 of 0.200 mol dm^{-3} dilute nitric acid.
Give a reason why this mistake would **not** have affected Student **2**'s result.
No calculation is required.

(1)

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(iii) The teacher noticed that Student **2** had used the Group 2 carbonate in powdered form rather than in lumps.
Explain how, if at all, this would affect the rate of reaction and the final volume of gas produced in the reaction.

(2)

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(e) Student **3** suggested a different experiment.

Student **3** realised that, by heating the carbonate, carbon dioxide would be lost and an oxide would remain.
Student **3** decided to measure the change in mass of the carbonate and to use this information to calculate its molar mass.

- Student **3** weighed an empty test tube.
- Using a spatula, Student **3** added some of the carbonate to the test tube.
- The test tube containing the carbonate was then weighed.
- The test tube and its contents were heated to constant mass.
- The results obtained by Student **3** are shown in Table 2.

Measurement		Value
Mass of carbonate + test tube	/ g	20.447
Mass of oxide + test tube	/ g	20.205
Mass of empty test tube	/ g	19.996

Table 2

(i) Write an equation, including state symbols, for the thermal decomposition of a Group 2 carbonate, MCO_3, where M represents the metal.

(1)

(ii) Using Student **3**'s results, calculate the molar mass of the Group 2 carbonate.

(3)

(f) Student **3** used the same balance as Student **1**.

Give a reason why the mass of the carbonate measured by Student **3** has a greater percentage uncertainty than that measured by Student **1**.

(1)

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(g) Student **3** noticed that on heating the test tube some solid was lost.

Explain how this would affect the calculated value for the molar mass of the Group 2 carbonate.

(2)

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(Total for question = 18 marks)

Q20.

Many vehicles are fitted with airbags which provide a gas-filled safety cushion to protect the occupant of the vehicle if there is a crash.

(a) The first reaction in airbags is the thermal decomposition of sodium azide, NaN_3, to form sodium and nitrogen gas.

(i) Write the equation for this decomposition of sodium azide.
State symbols are not required.

(1)

(ii) In the reaction in (i), a typical airbag is inflated by about 67 dm^3 of gas.
Calculate the **minimum mass** of sodium azide, in grams, needed to produce this volume of gas. Use the Ideal Gas Equation and give your answer to an appropriate number of significant figures.
For the purpose of this calculation, assume that the temperature is 300 °C and the pressure is 140 000 Pa.

(4)

(b) The second reaction in the airbag is between the sodium produced in the reaction (a)(i) and potassium nitrate.

$$\ldots Na + \ldots KNO_3 \rightarrow \ldots K_2O + \ldots Na_2O + \ldots N_2$$

Balance the above equation, justifying your answer in terms of the changes in oxidation numbers.

(3)

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(c) The third reaction in the airbag is between the metal oxides and silicon dioxide.

State the type of reaction taking place and justify why this reaction is necessary.

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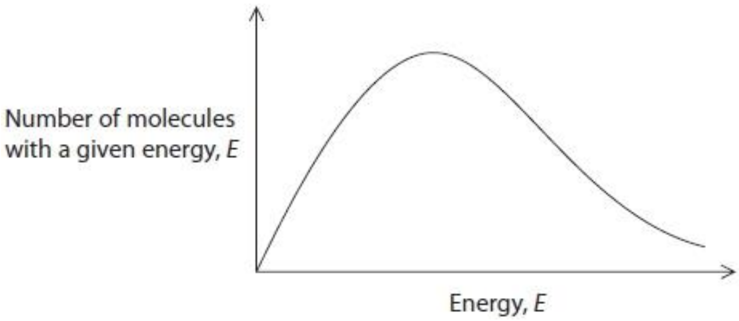
(d) The Maxwell-Boltzmann distribution diagram shows the molecular energies for the gaseous system immediately after the airbag has been deployed.



What is the change in shape of the curve when the airbag **cools**?

(1)

- ☐ **A** the peak would shift to the left and be higher
- ☐ **B** the peak would shift to the left and be lower
- ☐ **C** the peak would shift to the right and be higher
- ☐ **D** the peak would shift to the right and be lower

(Total for question = 12 marks)

Q21.

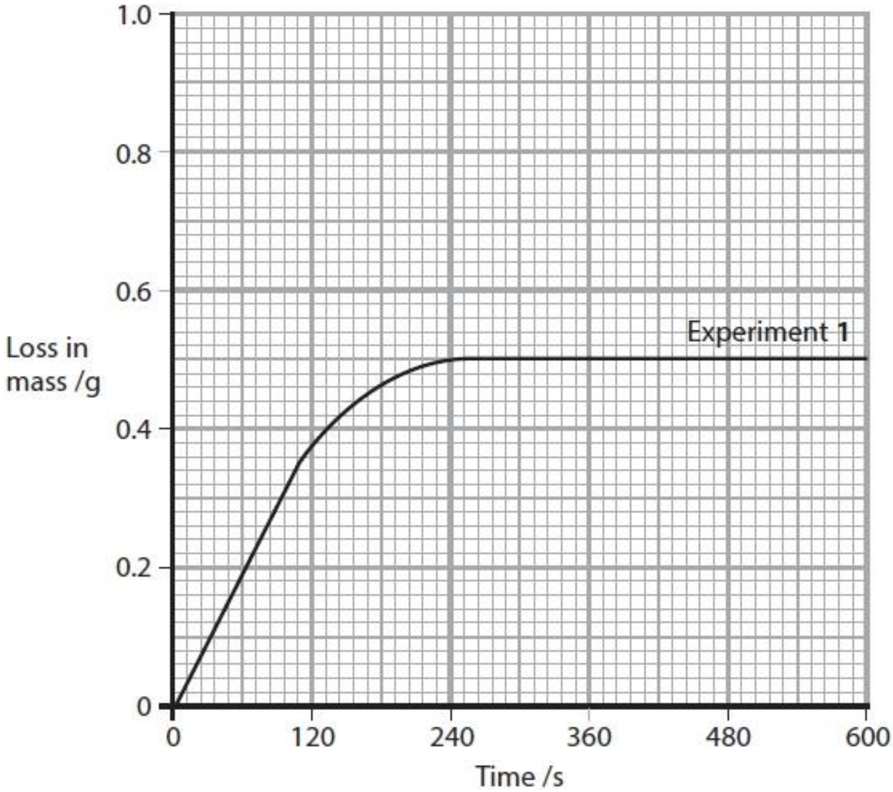
A series of experiments was carried out to investigate the factors which affect the rate of reaction between calcium carbonate and dilute hydrochloric acid.

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

- 50.0 cm^3 of hydrochloric acid was added to 10 g of calcium carbonate (an excess) in a conical flask placed on an electronic balance.
- The loss in mass of the flask and its contents was recorded every 30 seconds for 10 minutes.
- The experiment was repeated using different sized pieces of calcium carbonate, a different concentration of hydrochloric acid or a different temperature.

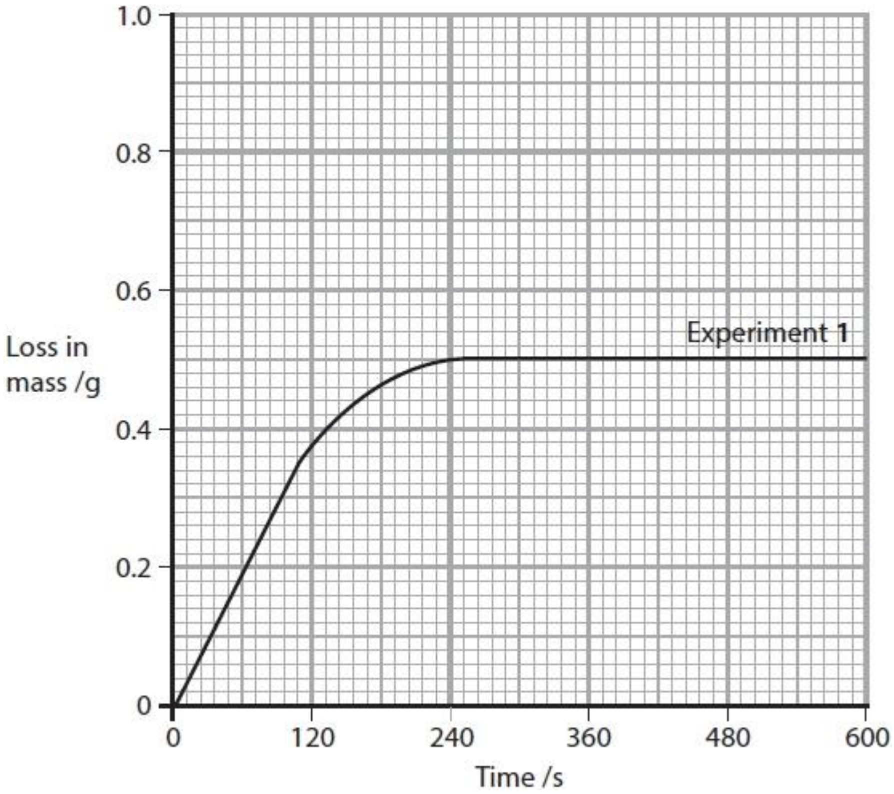
Experiment	Size of calcium carbonate	Concentration of hydrochloric acid / mol dm^{-3}	Temperature /°C
1	small pieces	0.50	20
2	small pieces	0.50	60
3	one large piece	0.50	20
4	small pieces	1.00	20

The results of Experiment **1** are shown on the graph.



Determine the initial rate of reaction for Experiment **1**.
You must show your working on the graph.
Include units in your answer.

(3)



Initial rate of reaction ....

(Total for question = 3 marks)

Q22.

This question is about reaction kinetics.

State why a **solid** (heterogeneous) catalyst is suitable for a reaction in the **gas** phase.

(1)

....

....

....

(Total for question = 1 mark)

Q23.

Compound **X** reacts slowly with water according to the following equation.

$$X(s) + H_2O(l) \rightarrow Y(aq) + Z^-(aq) + H^+(aq)$$

The reaction is catalysed by hydrogen ions and eventually goes to completion.

Compound **X** was added to water and the concentration of compound **Y** determined at various times at a constant temperature.

The results of the experiment are shown.

Time / s	Concentration of **Y** / mol dm^{-3}
0	0.000
25	0.002
40	0.005
50	0.010
65	0.020
75	0.030
85	0.040
100	0.050
115	0.060
140	0.070
200	0.080
260	0.085
380	0.090

Give a reason why the measurement of the initial rate of reaction is likely to be less accurate than the measurement of the maximum rate.

(1)

....

....

....

(Total for question = 1 mark)

Q24.

Aqueous hydrogen peroxide decomposes according to the following equation.

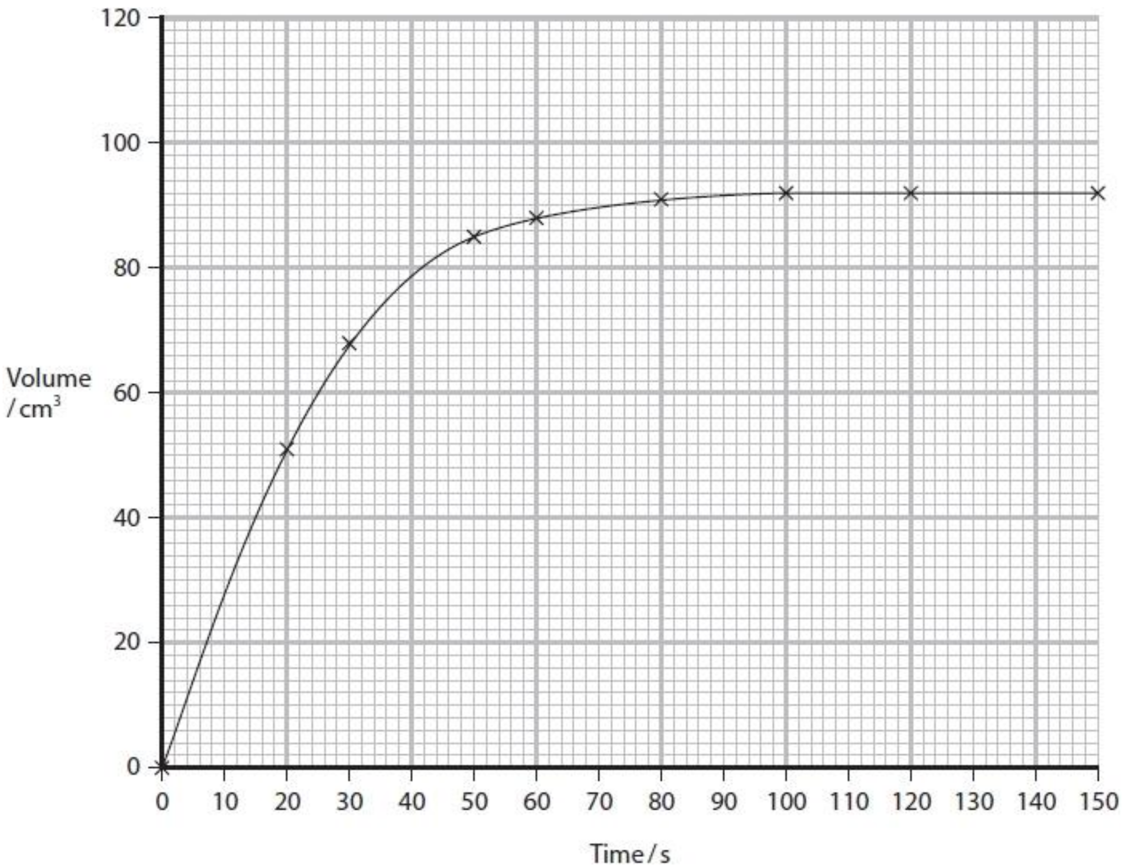
$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

The decomposition is catalysed by manganese(IV) oxide.

This can be investigated by measuring the volume of oxygen produced at various times as the reaction proceeds.

An experiment was carried out using 0.25 g of manganese(IV) oxide granules and 50 cm^3 of aqueous hydrogen peroxide of concentration 0.16 mol dm^{-3}. The results are shown in the table and plotted on a graph.

Time / s	0.0	20.0	30.0	50.0	60.0	80.0	100	120	150
Volume of O_2 / cm^3	0	51	68	85	88	91	92	92	92



(i) The rate of reaction may be assumed to be approximately constant up to the first volume measurement (20.0 s in this experiment).

Use this approximation to calculate the initial rate of this reaction, giving the **units** with your answer.

(1)

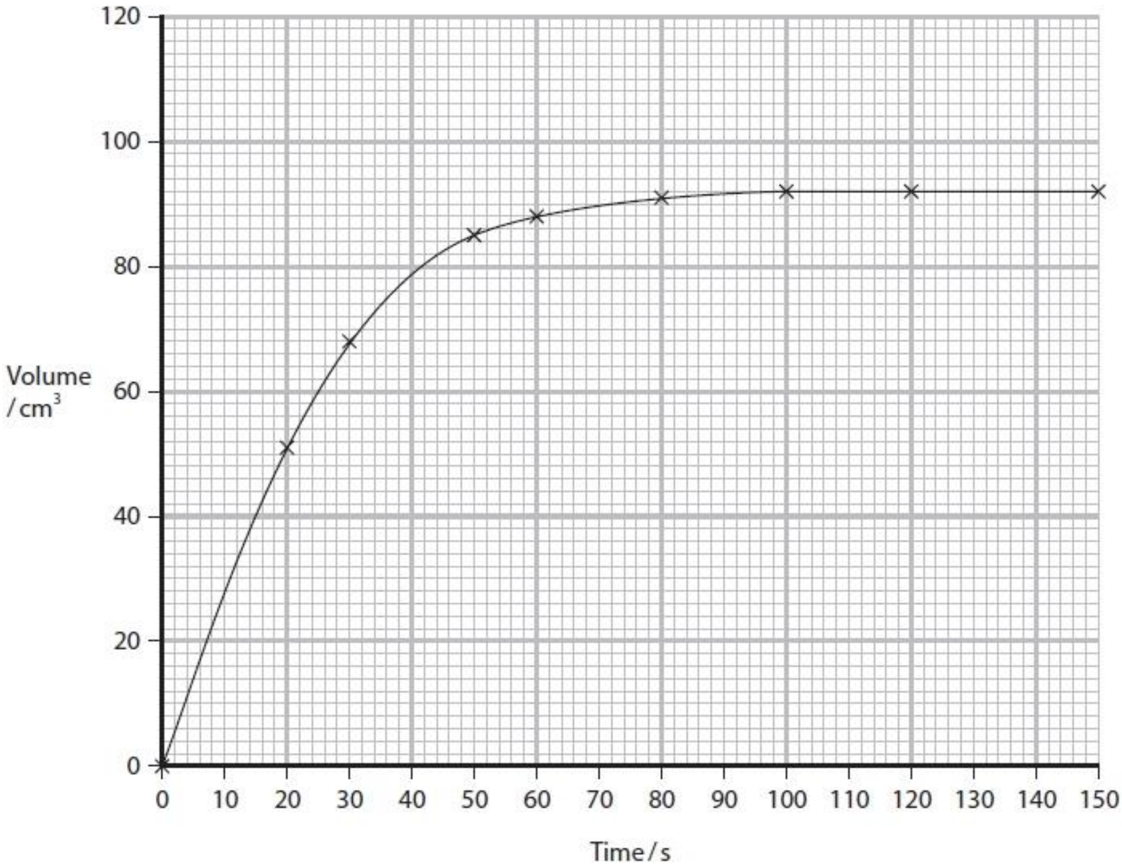
(ii) Draw a tangent at 40 s on the graph on Page 20 and use it to calculate the rate of reaction at this time.

(2)

(iii) The experiment was repeated on a different day when the laboratory was 20 °C warmer. The volume of oxygen was recorded for the same total time of 150 s.

Draw the line that you would expect to obtain in this experiment. Assume the pressure in the laboratory is the same. No calculation is required.

(2)



(iv) Explain, using collision theory, any differences between the line you have drawn and the original line of best fit.

(2)

....

....

....

(Total for question = 7 marks)

Mark Scheme

Q1.

Question Number	Answer	Mark
(i)	The only correct answer is **A** (The minimum energy required for a reaction to take place when reactant molecules collide) ***B*** *is not correct because very little energy is required for molecules to collide, but they just bounce off one another* ***C*** *is not correct because not all collisions result in a reaction under most conditions, the particles bounce off one another* ***D*** *is not correct because particles can collide with the appropriate orientation with very little energy so will bounce off one another unless there is enough energy in the collision*	**(1)**

Question Number	Answer	Additional Guidance	Mark
(ii)	An answer that makes reference to the following points: • (at higher temperature) the peak shifts to the right and is lower **(1)** • because at higher temperatures there are more particles with higher energy **(1)**	Allow reverse arguments for lower temperatures Allow at higher temperatures the particles are distributed over a wider range (of energies) Allow fewer particles are present at the modal / average temperature If no other mark is scored allow at higher temperature / T_2 (on average) the particles have greater (kinetic) energy Ignore comments about the area under the curves Ignore comments about the area under the curves Ignore comparisons of activation energy or particles which have the activation energy Ignore discussion of collisions and/or rate of reaction	**(2)**

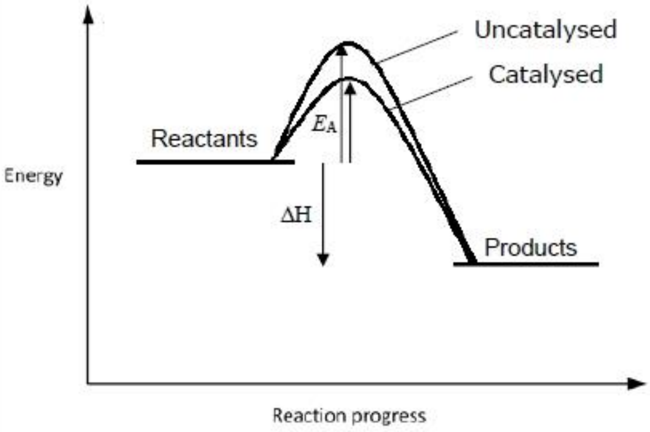
Question Number	Answer	Mark
(iii)	The only correct answer is **D** (there are more collisions, all of which are successful, at a higher temperature) ***A*** *is not correct because the number of particles under the curve are those which can react in a collision and there are more at a higher temperature* ***B*** *is not correct because on average particles have more energy so a larger percentage of collisions are successful at a higher temperature* ***C*** *is not correct because more collisions result in more successful collisions giving a faster rate of reaction*	**(1)**

Q2.

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>(i)</td>
<td>

- position of reactants and products with labels **(1)**
- two curves with at least one correctly labelled as catalysed or uncatalysed **(1)**
- approximately vertical arrow from approximately the reactant line to nearly the height of the top of one or both of the curves labelled E_a / activation energy **(1)**
- approximately vertical arrow from reactant line to products line labelled energy change / enthalpy change / ΔH **(1)**

</td>
<td>



Allow any suitable equivalent labels
Ignore any transition states, labelled or not
Do not award straight lines for curves
Penalise double headed arrow once only
Do not award the arrow in the wrong direction
Do not award –ΔH instead of ΔH
For an endothermic reaction do not award M1

</td>
<td>(4)</td>
</tr>
</table>

Question Number	Answer	Additional Guidance	Mark
(ii)	An answer that makes reference to the following points: • a catalyst lowers the activation energy (for the reaction without being used up by it)	Ignore just 'provides an alternative pathway' Do not award lowers the activation energy without taking part in the reaction	(1)

Q3.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • Step **1** is the rate determining step **(1)** • as it involves (1 mol of) both propanone and hydrogen ions (which matches the rate equation) **(1)**	Stand alone Allow RDS / slow step Conditional on M1 Allow it does not involve I_2 (which is zero order) Allow it involves both species in the rate equation Allow I_2 is not involved in the RDS so RDS must be before Step 2	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: (The statement is not valid because) • one hydrogen ion is regenerated / reformed (so is acting as a catalyst) **(1)** • the other hydrogen ion is lost from the propanone (when replaced by iodine) / is a (by-)product of the reaction / is used to form HI **(1)**	Ignore reference to specific steps. Do not award M1 if candidate states that it is valid Ignore it is an autocatalyst	(2)

Q4.

Question Number	Acceptable Answer	Additional Guidance	Mark
	An explanation which makes reference to the following points: • a catalyst increases the rate at which the reaction moves towards equilibrium / decreases the time a reaction takes to arrive at a particular yield of product / (provides a reaction pathway with) a lower activation energy **(1)** • allows milder conditions to be used (lowering cost) **(1)**	Allow a catalyst increases the rate of attainment of equilibrium / decreases the time a reaction takes to arrive at equilibrium Do not award just 'a catalyst increases the rate of reaction' Allow lower temperature and/or lower pressure and/or lower energy conditions Allow more product for the same energy Do not award just 'decreases the cost'	**(2)**

Q5.

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*</td>
<td>
This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
The following table shows how the marks should be awarded for structure and lines of reasoning.
<table>
<tr><th></th><th>Number of marks awarded for structure and sustained lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning.</td><td>1</td></tr>
<tr><td>Answer has no linkages between points and is unstructured.</td><td>0</td></tr>
</table>
</td>
<td>
Guidance on how the mark scheme should be applied:

The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning, scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).

If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

In general it would be expected that 5 or 6 indicative points would get 2 reasoning marks, and 3 or 4 indicative points would get 1 mark for reasoning, and 0, 1 or 2 indicative points would score zero marks for reasoning.

If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).
Comment: Look for the indicative marking points first, then consider the mark for the structure of the answer and sustained line of reasoning.
</td>
<td>(6)</td>
</tr>
</table>

	Indicative content: • IP1 increase in temperature will increase rate • IP2 (but) increase in temperature will decrease yield/move the equilibrium to the LHS/ produce less SO_3 **because** it is an exothermic reaction (in the forward direction) • IP3 increase in temperature increases **energy** costs • IP4 increase in pressure has no effect on rate (because all the active sites are already occupied on a heterogeneous catalyst). **OR** increase in pressure will increase rate (of reaction) • IP5 increase in pressure will move position of eqm to RHS/increase yield **because** there are less moles/molecules (of gas) on the RHS • IP6 but increased pressure increases (construction and running) costs/reduces economic viability	Decreased yield with no reference to exothermic reaction does not get IP2. Allow increases yield of reactants/SO_2 **and** O_2 (with reference to exothermic reaction) Increased yield with no reference to number of moles does not get IP5. Award one mark for IP2 and IP5 if correct references to yield in both but reasons not given Allow IP3 and IP6 if increased costs of higher temperature and pressure are mentioned together **provided** that the temperature costs are linked to energy costs. Otherwise only IP6 can be awarded. Ignore any reference to catalyst	

Q6.

Question Number	Acceptable Answer	Additional Guidance	Mark
	An explanation that makes reference to the following points: • (the initial rate of reaction is slow) because both reacting species are negatively charged / repel each other **or** the reaction has a high activation energy / few particles have energy greater than (or equal to) the activation energy **(1)** • (the rate of reaction increases) because **Mn^{2+} ions** (are formed) **and** they act as a catalyst / are autocatalytic / provide an alternative route with a lower activation energy **(1)** • (the rate decreases) because the concentrations /amounts of the reactants decrease / the reactants are used up **(1)**	Allow because there is no catalyst / no Mn^{2+} ions present at the start Allow a description of how the Mn^{2+} ions are acting as a catalyst e.g. the idea of Mn^{2+} ions reacting **and** being regenerated Do not award 'enzyme' Allow example of one of the reagents used up / becoming a limiting factor Do not award 'the Mn^{2+} ions are used up'	**(3)**

Q7.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	Reagent • (concentrated) NaOH/KOH **(1)** Conditions • ethanol (solvent) <u>and</u> heat/warm **(1)**	do not award OH^- or just 'hydroxide' do not award M1 if 'acidified' allow reflux M2 is dependent on M1 except for a near miss e.g. OH^-	**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• Reagent: KCN/NaCN /potassium cyanide / sodium cyanide **(1)** • Reason: increases the number of carbon atoms in the carbon chain/ length of carbon chain **(1)**	ignore any mention of the solvent (aq ethanol) and conditions (reflux) do not award just CN^- /cyanide/HCN	**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	An explanation that makes reference to the following: • heating increases rate (of reaction) **(1)** • no sealed tube would result in loss of ammonia (gas)/ reactants / gas **(1)**	ignore reference to activation energy/ starting the reaction/ reaction is endothermic ignore toxicity of reactants	**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(iv)	$CH_3—CH_2—CH_2—OH$	allow displayed/structural/skeletal formula ignore name do not award just C_3H_7OH	**(1)**

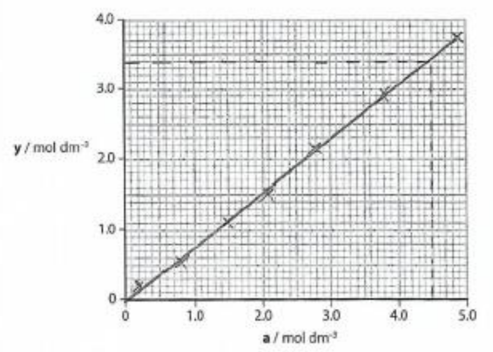
Q8.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)(i)	$(K_c =) \dfrac{[HI(g)]^2}{[H_2(g)][I_2(g)]}$	Ignore missing state symbols or units Do not award round brackets	**(1)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)(ii)	$(K_c =) \dfrac{4y^2}{(a-y)^2}$ • Numerator term correct **(1)** • Denominator term correct **(1)**	Allow square brackets Allow $(2y)^2$ Allow $(a^2 - 2ay+y^2)$ or $(a-y)(a-y)$	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(i)	• both values correct to 2 DP	1.13 2.93	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(ii)	• All 7 points plotted correctly (1) • Appropriate straight line of best fit, drawn through the origin (1)	Allow TE for incorrect values from 9(b)(i) Do not allow all points above or below the line of best fit Allow line of best fit to intersect one square either side of the origin	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(iii)	• co-ordinates correctly read off the line on graph (1)  • gradient correctly calculated (1)	At least 1 line must be shown on the graph to indicate selection of co-ordinates Example of calculation $\frac{3.40 - 0.00}{4.50 - 0.00}$ = gradient of graph Gradient = 0.76 Ignore SF except 1SF Do not allow units for the gradient Allow a value from 0.71 to 0.81 inclusive	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(iv)	• $\frac{\sqrt{K_c}}{2 + \sqrt{K_c}}$ = gradient / $\frac{\mathbf{y}}{\mathbf{a}}$ (1) • re-arrangement of expression and calculation of K_c (1)	Example of calculation $\frac{\sqrt{K_c}}{2 + \sqrt{K_c}} = 0.76$ K_c = 40.1 /40 (no units) Allow TE on gradient from part (iii) $K_c = [(2 \text{ x grad})/(1\text{-grad})]^2$ Correct answer with no working scores (2)	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)	• hydrogen is flammable / explosive	Allow iodine vapour damages eyes /toxic Allow hydrogen iodide is corrosive / acidic / irritant (if qualified) / lachrymator Ignore references to high pressure Ignore references to safety precautions	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)	• Faster rate of reaction / increased rate **(1)** • K_c unchanged **(1)**	Ignore references to shifting position of equilibrium	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(e)(i)	An explanation that makes reference to the following points: • (K_c is) smaller / decreases / gets less **(1)** • (forward) reaction is exothermic **(1)**	Allow reverse/backwards reaction is endothermic MP2 dependent on MP1	(2)

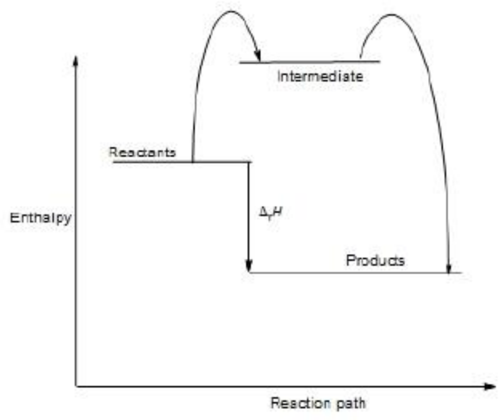
Question Number	Acceptable Answers	Additional Guidance	Mark
(e)(ii)	• straight line drawn on the graph with a less steep gradient (and goes through the origin)	Do not allow if lines cross	(1)

Q9.

Question Number	Answer	Additional Guidance	Mark
	• tangent drawn on graph at 50 s (1) • calculation of rate (1) • units (1)	<u>Example of calculation</u> vertical axis 0.055 mol dm^{-3} horizontal axis 110 s rate = 0.055 ÷ 110 = (-)5.0 x 10^{-4} Allow answers in the range (-)4.0 – (-)6.0 x 10^{-4} Ignore missing negative sign mol dm^{-3} s^{-1} mol dm^{-3} /s mol dm^{-3} per s	(3)

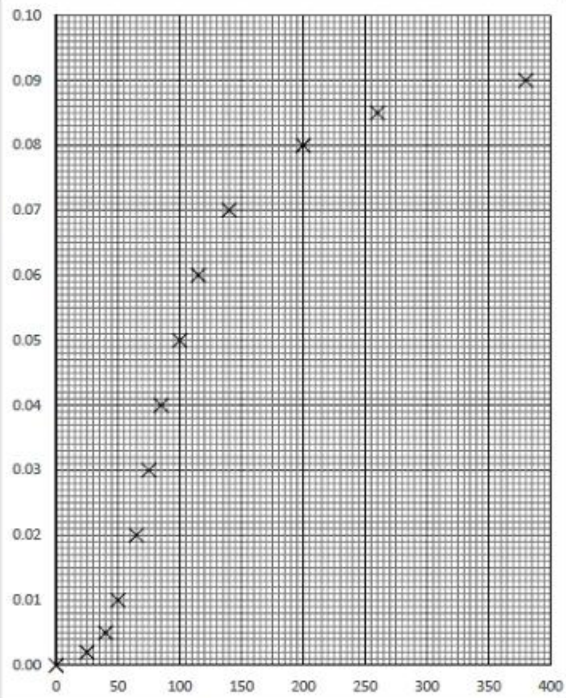
Q10.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • provide / overcome the activation energy or (is slow at room temperature but) accelerates as temperature rises (1) • (sufficiently / very) exothermic enough to melt the copper / break bonds in copper (1)	Do not allow 'to lower the activation energy' Allow answers that link rise in temperature to rising rate	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	 • intermediate energy level/transition state (1) • product line below level of reactant line **and** $\Delta_r H$ / ΔH shown on down/ vertical arrow (1)	Allow transition state for intermediate Ignore type of arrows to and from intermediate Allow any diagram with a hump shown, with / without intermediate / transition state label Do not penalise missing 'Products' label Allow use of $\Delta_r H$ / -905.2 (kJ mol^{-1})	(2)

Question Number	Answer	Additional Guidance	Mark
(iii)	An answer that makes reference to any **three** of the following points: • reactants **adsorb** onto catalyst / surface (1) • (there are) active sites on catalyst (surface) (1) • bonds in reactants weakened / broken **or** reaction takes place (1) • products **desorb** from the catalyst/active site (1)	Do not allow absorb	(3)

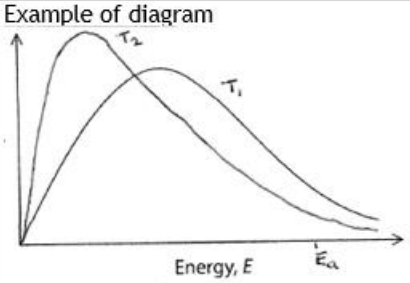
Q11.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• five points plotted correctly Comment Ignore a sixth additional point **(1)** • smooth curve passing through all the points (to within 1 square) excluding any anomalous incorrectly plotted points **(1)**		**(2)**

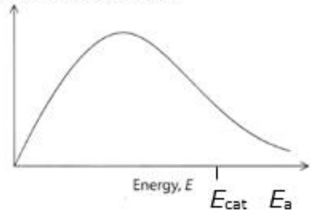
Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	A description which refers to the following points: • take a tangent to the curve **(1)** • (tangent taken at) time = 0 (for the initial rate) / at the start **(1)** • (tangent taken at) at the steepest part of the curve (for the maximum rate) **(1)** • find the gradient (of the tangent by change in concentration over change in time) **(1)**	Marks may be scored by tangents on the graph Allow assume that the very first part of the graph is a straight line and extrapolate / extend (up to 25 s) Allow where the slope is closest to vertical / at about 100 s / 0.050 mol dm^{-3} Ignore just 'highest' Allow description of finding the gradient e.g. finding dy/dx / dy/dt Ignore just mol dm^{-3} / s	**(4)**

Q12.

Question Number	Answer	Additional Guidance	Mark
(i)	• fraction / proportion / number of molecules / particles with energy, *E*	Allow fraction / proportion / number of molecules / particles Allow label written on y axis on diagram	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	• peak for T_2 to the left of T_1 **(1)** • peak for T_2 higher than T_1 **and** asymptote lower than T_1 line and not touching the x axis **(1)**	Example of diagram  Ignore missing label from added line Do not award M2 if added line curves upwards at the end	(2)

Question Number	Answer	Additional Guidance	Mark
(iii)	An explanation that makes reference to the following points: • (at a lower temperature the) molecules / particles / collisions have lower (kinetic) energy **(1)** • so fewer molecules / particles / collisions have energy greater than (or equal to) the activation energy / E_a **(1)**	Ignore molecules / particles move more slowly Allow fewer molecules / particles have (enough energy to overcome) the activation energy Allow this shown as labelled shading on the diagram Ignore just 'fewer successful collisions'	(2)

Question Number	Answer	Additional Guidance	Mark
(iv)	• E_{cat} labelled anywhere between the energy corresponding to the highest point of the peak and to the left of E_a	Example of label  Allow other clear labels for E_{cat}	(1)

Q13.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • yield (of NO) decreases **(1)** • increase in pressure shifts equilibrium (position) to the side of fewer moles (of gas molecules) **(1)**	if M1 and M2 are contradictory then do not award any marks allow 9 mol on LHS and 10 mol on RHS, may be shown above the equation allow more moles of product allow fewer moles of reactant allow marking points in either order	**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	An answer that makes reference to the following points: (on increasing the pressure) • Rate increases because there are more molecules per unit volume **(1)** so increase in frequency of collisions (between reacting molecules) **(1)**	allow increase in concentration of (gas) molecules allow any implication of more particles in a given volume, e.g. particles are closer together allow more collisions per unit time ignore just 'more collisions'/'more successful collisions' with no reference to time allow answers based on a solid catalyst	**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	An answer that makes reference to: • heterogeneous: (the catalyst is in) a different phase/state to the reactants **(1)** • increases the rate of the forward and backward / reverse reactions **(1)**	ignore reference to products	**(2)**

Q14.

Question Number	Acceptable Answer	Additional guidance	Mark
	An explanation that makes reference to the following: • increase surface (area) / more active sites **(1)** • (honeycomb structure) allows gases to flow through (the exhaust) **(1)**	Do not award a**b**sorption Ignore reference to rate of reaction / remove pollutants Do not award if comments are made that refer to the structure acting like a filter for the particulates or other substances	**(2)**

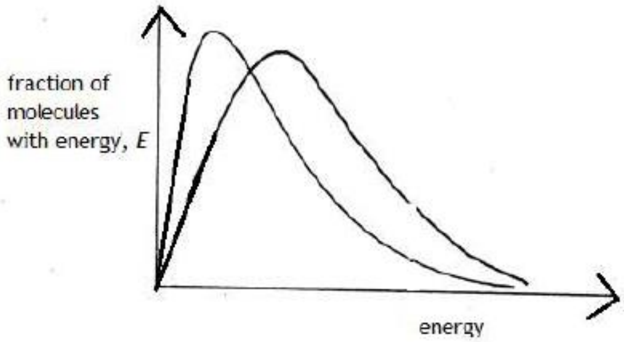
Q15.

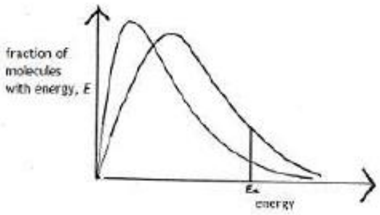
Question Number	Answer	Additional Guidance	Mark
	A description that makes reference to the following points: • filter the solid from the solution after the experiment **(1)** • (rinse with solvent / water and) dry **(1)** • reweigh the solid (it should weigh 0.25 g) **(1)** • repeat the experiment to see if identical results occur / to check catalyst still works **(1)**	Do not award measure the volume of catalyst	**(4)**

Q16.

Question Number	Acceptable Answer	Additional Guidance	Mark
	An explanation which makes reference to the following points: • (the reaction is catalysed by hydrogen ions and the) concentration of hydrogen ions is initially very low **(1)** • hydrogen ions are formed by the reaction so the concentration of catalyst increases / rate of reaction increases **(1)**	Allow concentration of hydrogen ions is zero Allow initially the reaction is not catalysed (due to lack of hydrogen ions) Allow the reaction is autocatalytic Allow the reaction is exothermic so it heats up after the start (and so gets faster) for 1 mark If M1 and M2 are not scored allow a comment that hydrogen ions catalyse the reaction for 1 mark	**(2)**

Q17.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	• additional curve added with peak to the right <u>and</u> lower	 Allow curve at start of line Do not allow the additional line to touch or cross the original curve more than once	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: • (higher temperature gives) molecules / particles more (kinetic) energy (and there is a higher collision frequency) **(1)** • a single activation energy marked on graph **or** more molecules / particles /collisions have energy greater than / equal to the activation energy **or** more molecules / particles / collisions have the activation energy **(1)**	Allow reverse argument for a decrease in temperature Allow collisions have more energy Ignore molecules/particles move faster Do not allow just 'gases/reactants/atoms' once only  Allow more molecules have enough energy to overcome the activation energy Do not allow any indication that the activation energy changes Do not allow any mention that the total area under the curve increases	(3)

	• so a greater proportion of the collisions result in a reaction **(1)**	Allow so more collisions are successful Ignore just 'more frequent collisions'	

Q18.

Question Number	Answer	Additional Guidance	Mark
(i)	An explanation that makes reference to the following points: • (increasing the pressure) decreases the yield **(1)** • as the right hand side / products contain more moles of gas **(1)** • (increasing the pressure) increases the rate of reaction **(1)** • as collisions occur at an increased frequency **(1)**	Award 4 moles of product formed from 2 moles of reactant Allow more particles in a given volume / particles are more likely to collide Ignore more collisions are of the correct orientation	**(4)**

Question Number	Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: • at higher temperatures the yield of product would be less (as forward reaction is exothermic) **(1)** • at lower temperatures the reaction would be slower **(1)** • (500 K is a compromise) giving a reasonable yield at a reasonable rate / between yield and rate **(1)**		**(3)**

Q19.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)	0.816 / 8.16 x 10^{-1} (g)		(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)	• calculation of moles of CO_2	Example of calculation: (moles CO_2 = $\frac{225}{24000}$ =) 0.009375 Allow 9.375 x 10^{-3} / 9.38 x 10^{-3} / 9.4 x 10^{-3} Ignore SF except 1SF	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)	• moles of MCO_3 **(1)** • method for calculation of molar mass of MCO_3 **(1)** • molar mass final answer to 1, 2 or 3 SF **(1)** • consequential identification of Group 2 metal by name or formula **(1)** NOTE Alternative method can score 3 MAX Calculation of moles of CO_3^{2-} **(1)** (Calculation of mass of CO_3^{2-}) Deduction of mass of M by subtraction **(1)** Calculation of Ar of M to 1, 2 or 3 SF **AND** Identification of group 2 metal **(1)**	Example of calculation: Moles of MCO_3 = moles CO_2 = 0.009375 (mol) Molar mass of MCO_3 = $\frac{0.816}{0.009375}$ (= 87.04 (g mol^{-1})) M2 subsumes mark for M1 = 87.0 / 87 / 90 (g mol^{-1}) NOTE M3 mark subsumes mark for M2 and M1 (87.0 − 60) = 27 **AND** Mg / Magnesium / $MgCO_3$ Allow TE on answers to parts (a) and (b), with Metal consequential on calculated molar mass but M must be a Group 2 element Moles CO_3^{2-} = 0.009375 (Mass of CO_3^{2-} = 0.009375 x 60 = 0.5625 g) Mass of M = 0.2535 g Ar = 0.2535/0.009375 = 27.0 / 27 / 30 (g mol^{-1}) **AND** Mg / Magnesium / $MgCO_3$	(4)

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(i)	An explanation that makes reference to the following points: • the bung was not replaced quickly enough **(1)** • (So) CO_2 / gas lost (to the surroundings) **(1)**	Allow bung not fitting tightly resulting in leaks Ignore references to CO_2 dissolving Ignore references to other types of gas leak Allow 'smaller volume of gas collected' / lower reading of gas volume Mark points M1 and M2 independently	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(ii)	An answer that makes reference to the following point: The acid was (already) in excess (and more acid won't affect this)	Allow The carbonate is the limiting reactant / the acid is not the limiting reactant	**(1)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(iii)	An explanation that makes reference to the following points: • rate of reaction is faster **and** powder has greater surface area **(1)** • no effect on (final) volume of gas **and** moles of (metal) carbonate are unchanged **or** because the rate is faster more gas will be lost before the bung is replaced so the (final) volume will be less **(1)**	Mark points M1 and M2 independently Both parts of statement needed Both parts of statement needed Allow mass / amount for moles Allow reactant for metal carbonate	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(e)(i)	• balanced equation with state symbols	<u>Example of equation:</u> $MCO_3(s) \rightarrow MO(s) + CO_2(g)$ Allow a correct equation for the decomposition of any Group 2 carbonate	**(1)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(e)(ii)	• subtractions to obtain masses **(1)** • calculation of moles of CO_2 **(1)** • calculation of molar mass of MCO_3 **(1)**	Example of calculation: (mass of CO_2 = 20.447 − 20.205) = 0.242 **AND** (mass of MCO_3 = 20.447 − 19.996) = 0.451 moles of $CO_2 = \frac{0.242}{44}$ = 0.0055(0) (mol) / 5.5(0) x 10^{-3} (mol) ALLOW TE from M2 to M3 Mr of $MCO_3 = \frac{0.451}{0.0055(0)}$ = 82 (g mol^{-1}) Correct answer with or without working scores 3 Ignore SF except 1 Ignore attempts to identify the metal	**(3)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(f)	An answer that makes reference to the following point: Student 3 used a smaller mass / less (and the uncertainty of the balance was the same) **or** Student 1 used a larger mass / more (and the uncertainty of the balance was the same)	Allow calculations comparing the two percentage errors: e.g. Student 1:- (0.001/0.816) x 100% = 0.12% **and** Student 3:- 0.001/0.451 x 100% = 0.22%	**(1)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(g)	An explanation that makes reference to the following points: • more CO_2 (would appear to be) given off **(1)** • (So) calculated molar mass is smaller **(1)** **OR** • Less MO would appear to have been formed **(1)** • Calculated molar mass would be greater **(1)**	 M2 dependent on M1 M2 dependent on M1	**(2)**

Q20.

Question Number	Acceptable Answer	Additional guidance	Mark
(a)(i)	correct equation	Example of equation: $2NaN_3 \rightarrow 2Na + 3N_2$ Allow multiples Ignore state symbols even if incorrect	**(1)**

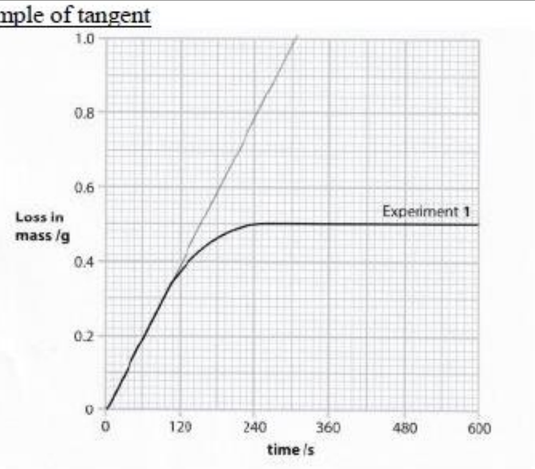
Question Number	Acceptable Answer	Additional guidance	Mark
(a)(ii)	• conversion of volume and temperature to correct units **(1)** • rearrangement of ideal gas equation so n=*pV* ÷ *RT* and calculation of $n(N_2)$ in moles **(1)** • evaluation of $n(NaN_3)$ **(1)** • answer converted into mass to 2/3 SF **(1)** Allow TE at each stage	Example of calculation: 67 dm^3 = 0.067 m^3, 300°C = 573 K $n(N_2) = \frac{140\ 000 \times 0.067}{8.31 \times 573}$ = = 1.9699.....(mol) $n(NaN_3)$ = (2/3 x 1.9699.....=) 1.313....(mol) m= (1.313 .... x 65 = 85.3629..=) = 85.4 / 85 (g) Correct answer without working scores (4)	**(4)**

Question Number	Acceptable Answer	Additional guidance	Mark
(b)	An answer that makes reference to the following points: • Nitrogen (is reduced) from +5 to 0 **(1)** • Sodium (is oxidised) from 0 to +1 **(1)** • Balanced equation **(1)**	Look for oxidation numbers annotated on the equation Do not award potassium oxidised Penalise omission of "+" sign, once only Example of balanced equation: $\mathbf{10}Na + \mathbf{2}KNO_3 \rightarrow K_2O + \mathbf{5}Na_2O + N_2$ Allow multiples	**(3)**

Question Number	Acceptable Answer	Additional guidance	Mark
(c)	An answer that makes reference to the following points: • Neutralisation reaction / acid base reaction **(1)** • Sodium and/or potassium oxides are caustic / corrosive **(1)** • Salts (silicates) formed are inert / unreactive **(1)**	Allow salt formation Allow "metal oxides" Ignore "harmful" / "alkaline" Allow "not harmful"/ "not caustic" Ignore "neutral"	**(3)**

Question Number	Acceptable Answer	Mark
(d)	The only correct answer is **A** ***B*** *is incorrect because the peak would shift to the left and be higher* ***C*** *is incorrect because the peak would shift to the left not to the right* ***D*** *is incorrect because the peak would be shift to the left not to the right*	**(1)**

Q21.

Question Number	Answer	Additional Guidance	Mark
	• tangent drawn to curve when time = 0 tangent must touch curve for at least first 3 small squares on x axis and extend to at least 120 s (1) • calculation of gradient (1) • units (1)	Example of tangent  gradient = $\frac{1.0}{300}$ = 3.33×10^{-3} Allow 3.13×10^{-3} to 3.53×10^{-3} TE on tangent drawn or measurements from line on graph with no tangent Ignore SF including 1SF g s^{-1} or g/s stand alone mark	(3)

Q22.

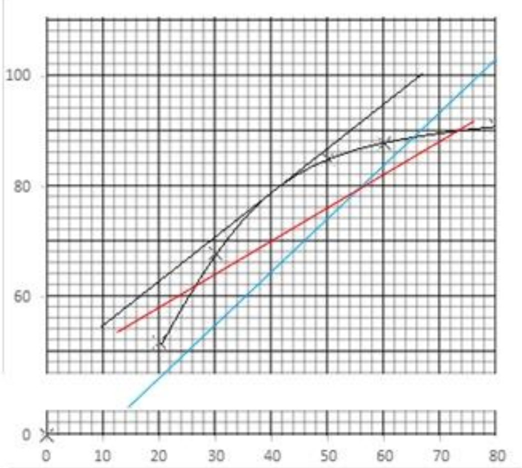
Question Number	Answer	Additional Guidance	Mark
	An answer that makes reference to the following points: • provides a surface for the reaction	Ignore References to lowering the activation energy Providing alternative route Details of adsorption, weakening of the bonds and desorption Easy to separate after the reaction	(1)

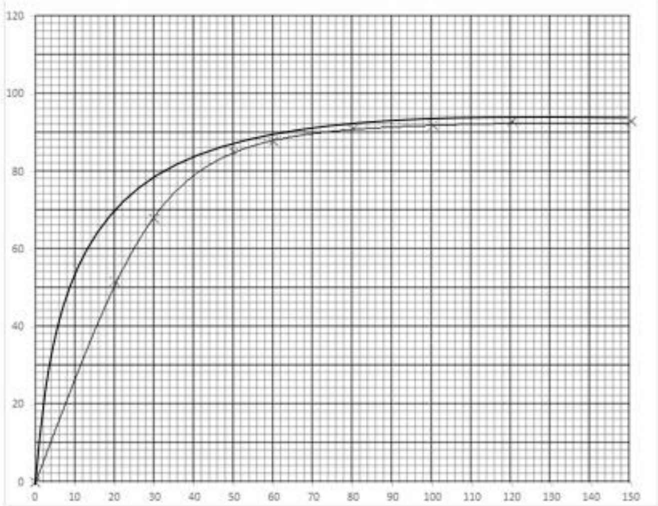
Q23.

Question Number	Acceptable Answer	Additional Guidance	Mark
	An answer which makes reference to the following point: • it is very difficult to judge where the tangent should be drawn for the initial rate compared to other points on the line	Allow comments about the tangent being difficult to measure initially or easier at the maximum rate	**(1)**

Q24.

Question Number	Answer	Additional Guidance	Mark
(i)	• calculation of the rate of reaction **and** units	Example of calculation $= \frac{51}{20}$ $=$ 2.55 $cm^3\ s^{-1}$ / 2.55 cm^3/s Do not award cm^3/s^{-1} Allow $= \frac{50}{20} = 2.5\ cm^3\ s^{-1}$ Ignore SF except 1SF	**(1)**

Question Number	Answer	Additional Guidance	Mark
(ii)	• draw suitable tangent **(1)** • calculation of gradient **(1)**	 Example of calculation $= \frac{100 - 54}{66 - 10} = 0.82143$ ($cm^3\ s^{-1}$) Ignore units even if incorrect Ignore SF Correctly calculated values in a range 0.950 – 0.600 score (2) (approx. blue line – red line) Values outside this range max (1).	(2)

Question Number	Answer	Additional Guidance	Mark
(iii)	• line rising more steeply than original line of best fit, always above / to the left **(1)** • finishing at a volume slightly above the original but less than 100. **(1)**	 Do not award if the volume exceeds 100 cm^3	**(2)**

Question Number	Answer	Additional Guidance	Mark
(iv)	An explanation that makes reference to the following points: EITHER • the rate of reaction is faster (at a higher temperature) / more gas is produced at a given time **(1)** • because there is a greater proportion of collisions with energy greater than the activation energy (for the reaction) **(1)** OR • the volume is higher than before because of the increased temperature **(1)** • the volume of gases increases with temperature **(1)**	Allow the gradient / line is steeper Allow just particles have more energy Award converse arguments for lower temperature Ignore just more collisions Do not award just 'more gas is produced'	**(2)**