

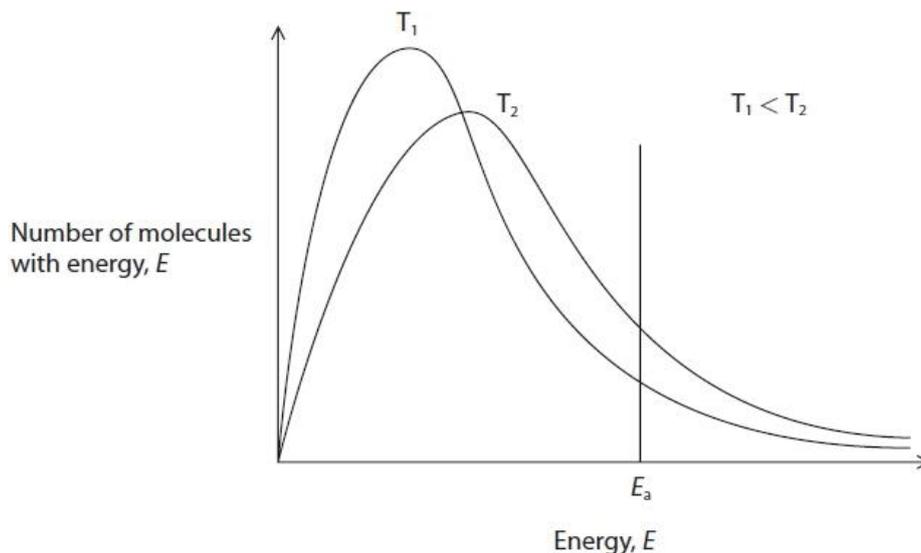
Questions

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 E_a 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)

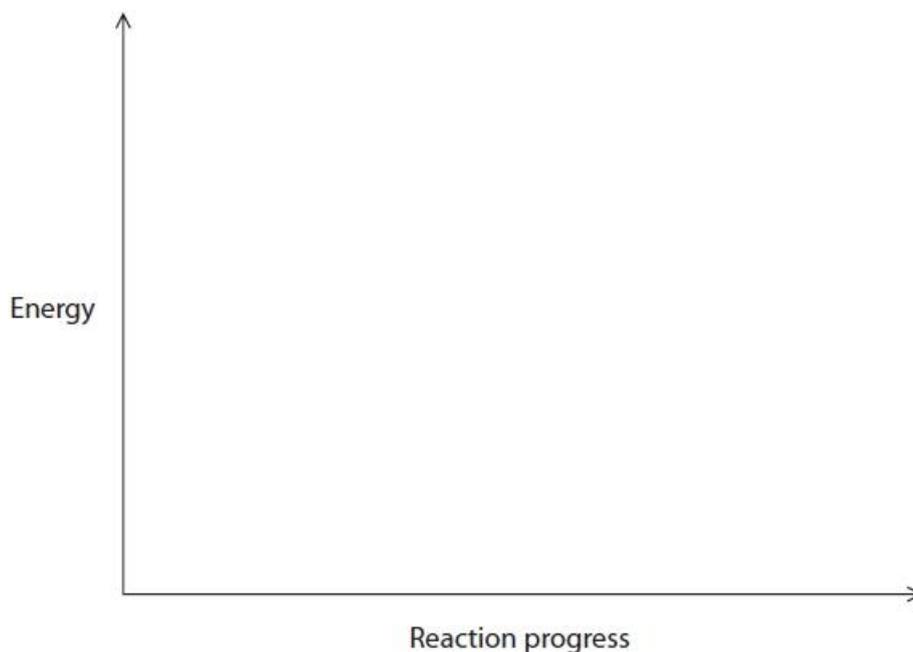
Q2.

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.

(1)

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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 cm³ of 1 mol dm⁻³ aqueous propanone with 25 cm³ of 1 mol dm⁻³ sulfuric acid in a beaker. Both these reactants are in excess.

Step 2 Start the stop clock as 50 cm³ of 0.02 mol dm⁻³ iodine solution is added to the beaker. Mix the reactants thoroughly.

Step 3 Withdraw a 10.0 cm³ 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 cm³ sample with 0.01 mol dm⁻³ sodium thiosulfate solution, using starch indicator.

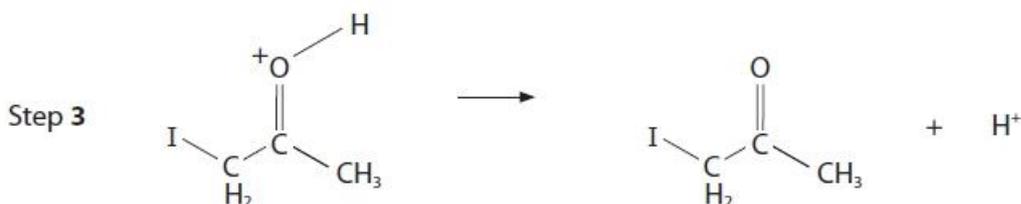
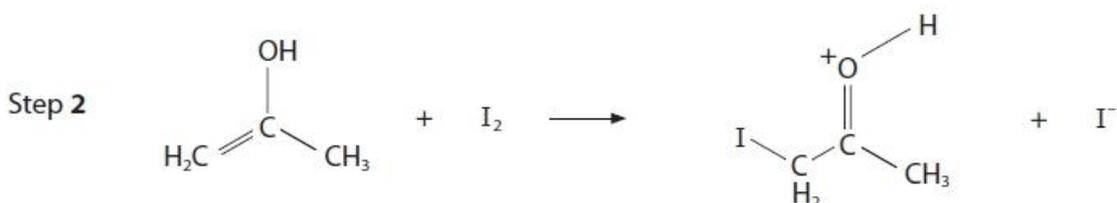
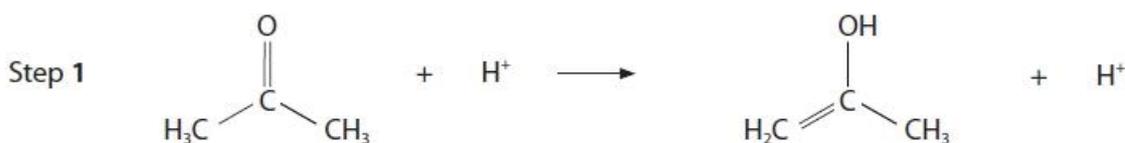
Step 6 Continue to withdraw 10.0 cm³ samples about every two minutes, repeating Steps 4 and 5 with each sample.

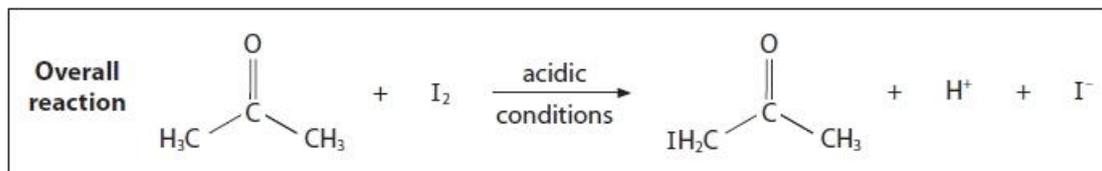
Some data from the experiment are shown.

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 = $k[\text{H}^+(\text{aq})][\text{CH}_3\text{COCH}_3(\text{aq})]$.

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.

(2)

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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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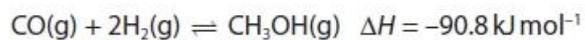
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(Total for question = 4 marks)

Q4.

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



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

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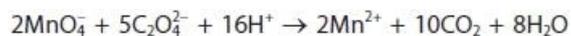
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(Total for question = 2 marks)

Q6.

This question is about transition metals.

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



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

Explain this sequence.

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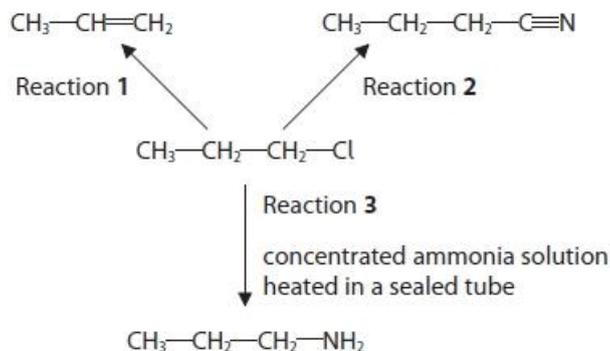
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(Total for question = 3 marks)

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.

(2)

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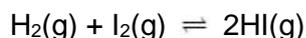
(iv) Write the structural formula of the product that will be formed if 1-chloropropane is refluxed with **aqueous** potassium hydroxide solution.

(1)

(Total for question = 7 marks)

Q8.

The gas phase reaction between hydrogen and iodine is reversible.



(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 $a \text{ mol dm}^{-3}$ and it was found that $2y \text{ mol dm}^{-3}$ 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.

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

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 $a \text{ mol dm}^{-3}$. 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, $a \text{ mol dm}^{-3}$, and the results recorded in the table.

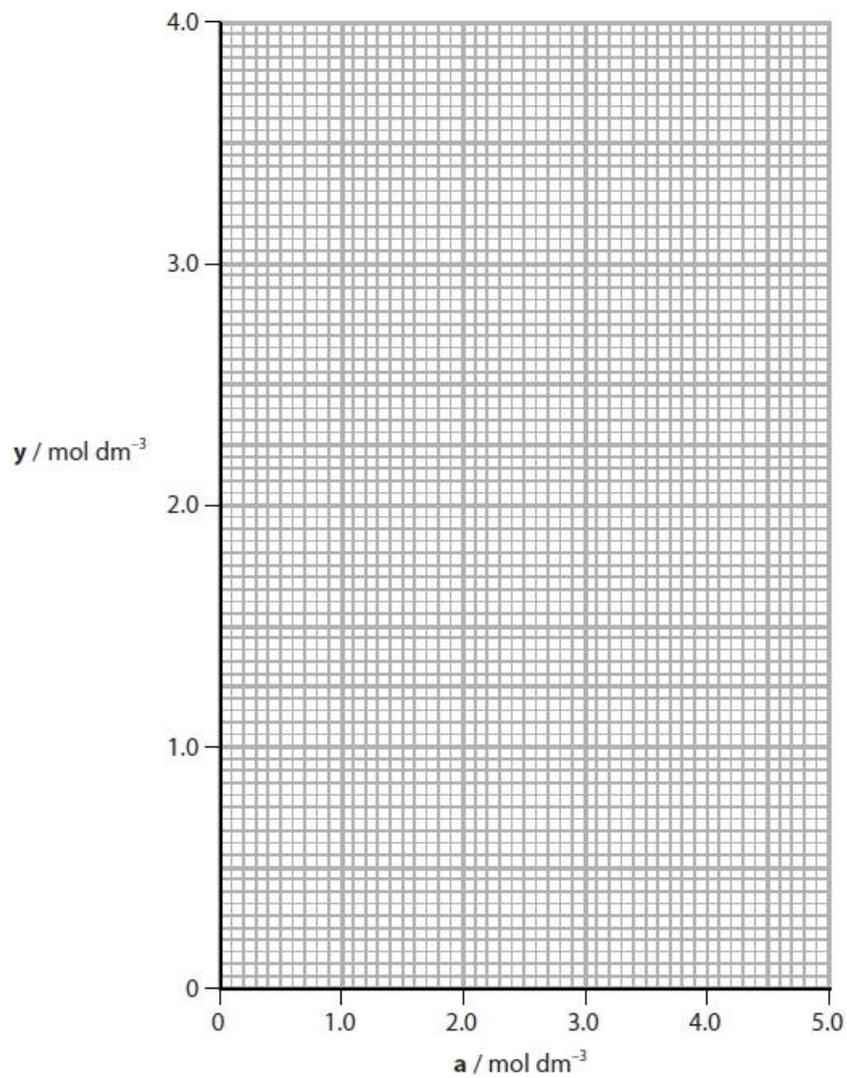
(i) Complete the table to give the two remaining values of $y \text{ mol dm}^{-3}$, to **two** decimal places.

(1)

$a / \text{mol dm}^{-3}$	$[\text{I}_2]_{\text{eq}} / \text{mol dm}^{-3}$	$y / \text{mol dm}^{-3}$
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 $y \text{ mol dm}^{-3}$ varies with the initial concentrations of hydrogen and iodine, $a \text{ mol dm}^{-3}$.

(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 cm³ flask instead of the 1 dm³ 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



- (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)

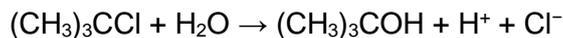
(Total for question = 16 marks)

Q9.

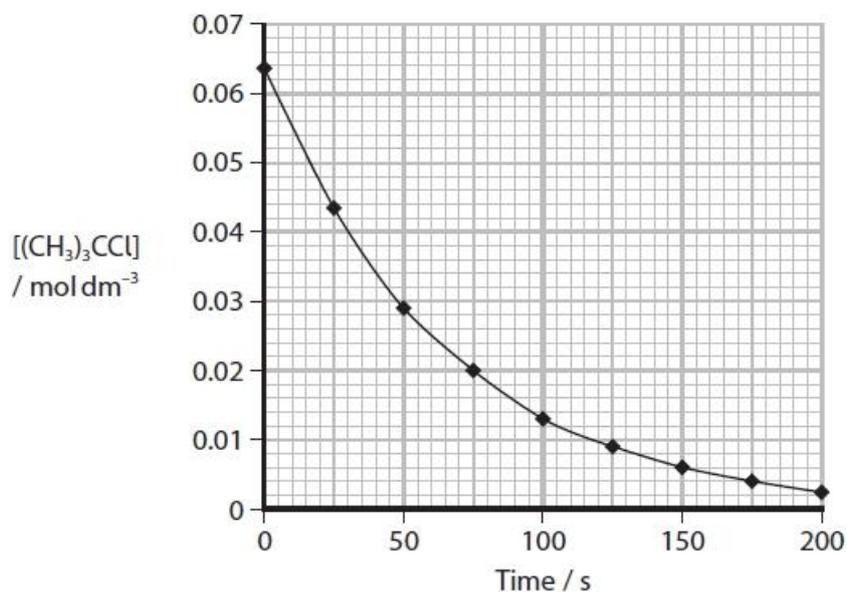
This question is about halogenoalkanes.

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

The equation for this reaction is



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.

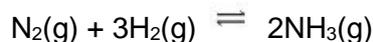
(3)

Rate of reaction at 50 s =

(Total for question = 3 marks)

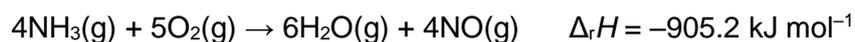
Q10.

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



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

An equation for this reaction is



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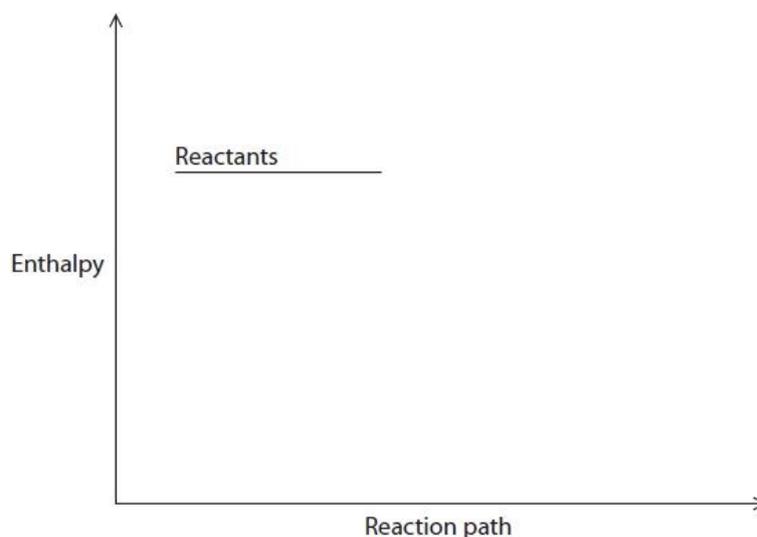
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(ii) Complete the reaction profile for this catalysed oxidation of ammonia, showing the enthalpy change, $\Delta_r H$.

(2)



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

(3)

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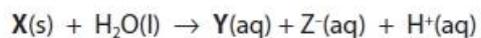
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(Total for question = 7 marks)

Q11.

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



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

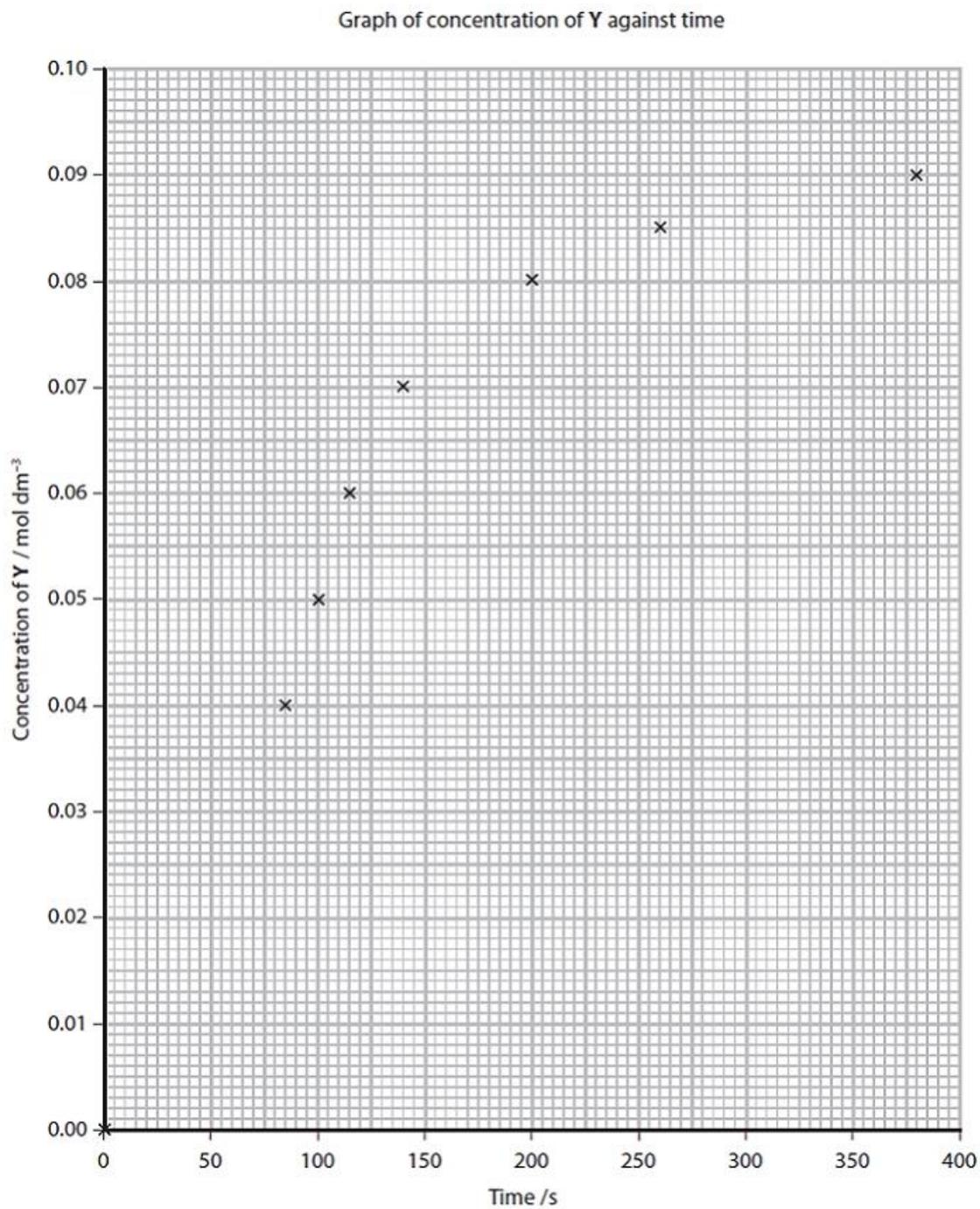
Compound **X** was added to water and the concentration of compound **Y** determined at various times at a constant temperature.

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.

(4)

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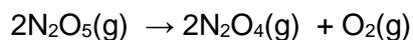
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(Total for question = 6 marks)

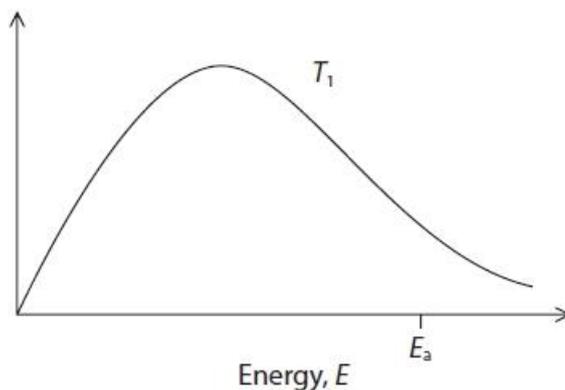
Q12.

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



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.



(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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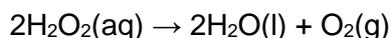
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(Total for question = 2 marks)

Q15.

Aqueous hydrogen peroxide decomposes according to the following equation.



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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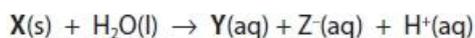
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(Total for question = 4 marks)

Q16.

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



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.

(2)

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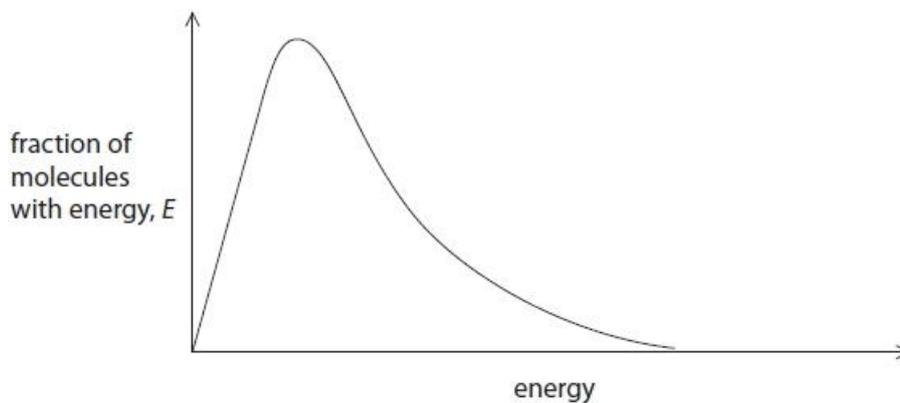
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(Total for question = 2 marks)

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.

(3)

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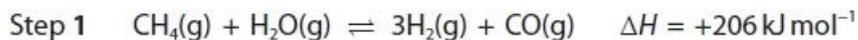
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(Total for question = 4 marks)

Q18.

Methanol, CH₃OH, is a liquid fuel.

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



(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.

(3)

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(Total for question = 7 marks)

Q19.

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

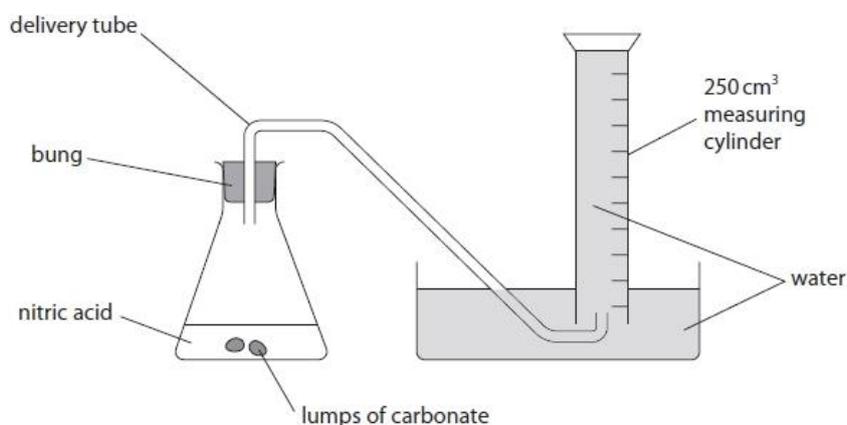
A chemistry teacher found a bottle containing lumps of a white solid. The original label was missing from the bottle. However, someone had written 'Group 2 carbonate' on the bottle. The lumps of the anhydrous white solid were pure and dry.

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 cm³ conical flask.
- Student 1 then added 100 cm³ 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 $0.200 \text{ mol dm}^{-3}$ dilute nitric acid, instead of 100 cm^3 of $0.200 \text{ mol dm}^{-3}$ 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 $300 \text{ }^\circ\text{C}$ and the pressure is $140\,000 \text{ Pa}$.

(4)

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



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.

(3)

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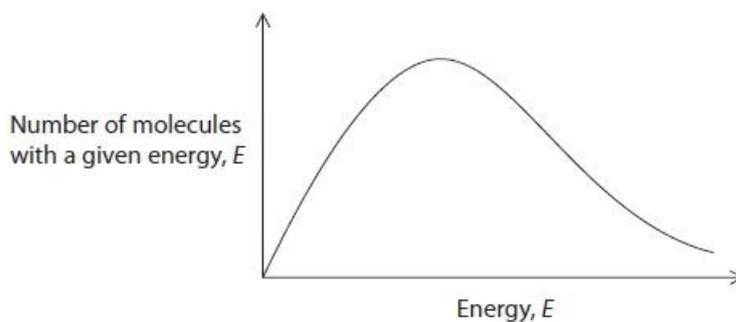
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- (d) The Maxwell-Boltzmann distribution diagram shows the molecular energies for the gaseous system immediately after the airbag has been deployed.



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.

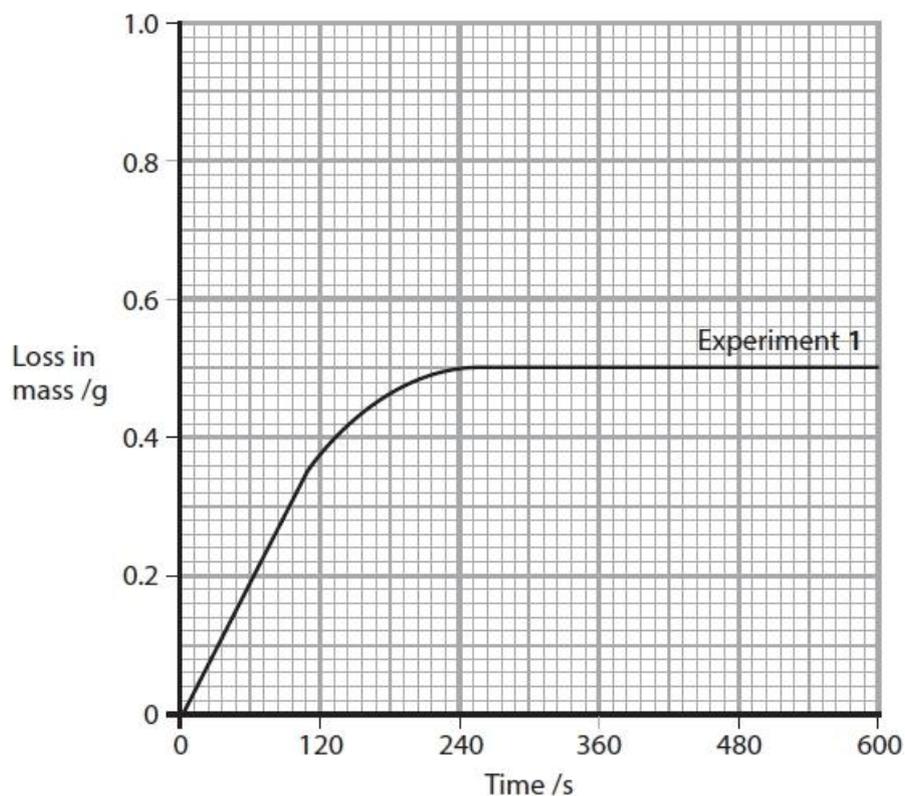
A series of experiments was carried out to investigate the factors which affect the rate of reaction between calcium carbonate and dilute hydrochloric acid.



- 50.0 cm³ 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.

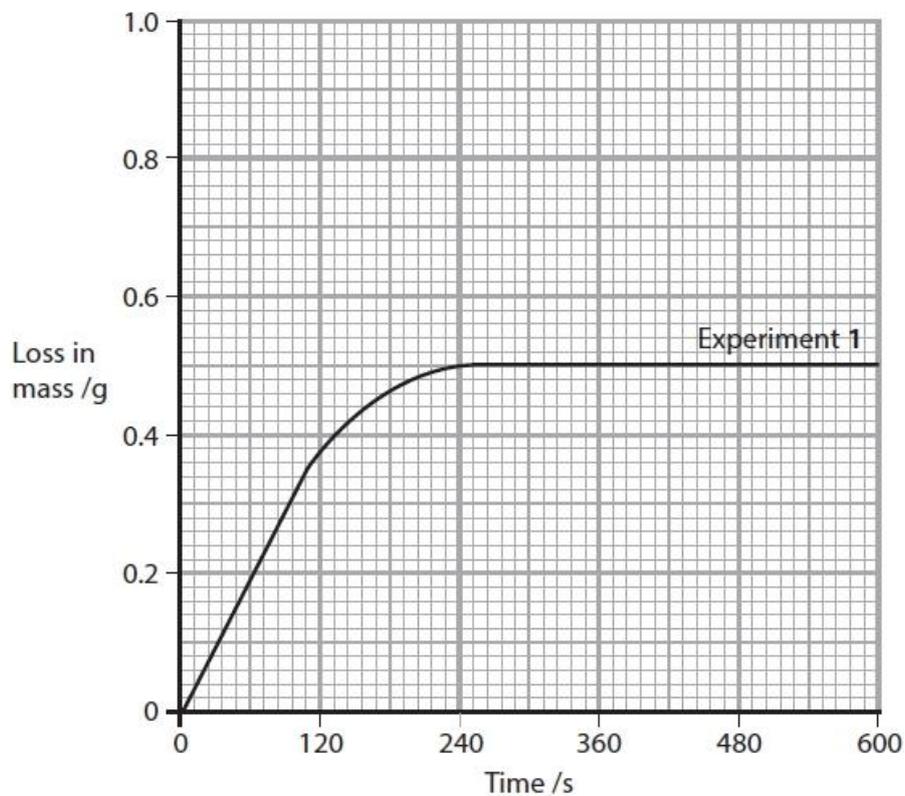
Experiment	Size of calcium carbonate	Concentration of hydrochloric acid / mol dm ⁻³	Temperature /°C
1	small pieces	0.50	20
2	small pieces	0.50	60
3	one large piece	0.50	20
4	small pieces	1.00	20

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)

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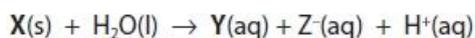
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(Total for question = 1 mark)

Q23.

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



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)

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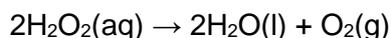
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(Total for question = 1 mark)

Q24.

Aqueous hydrogen peroxide decomposes according to the following equation.

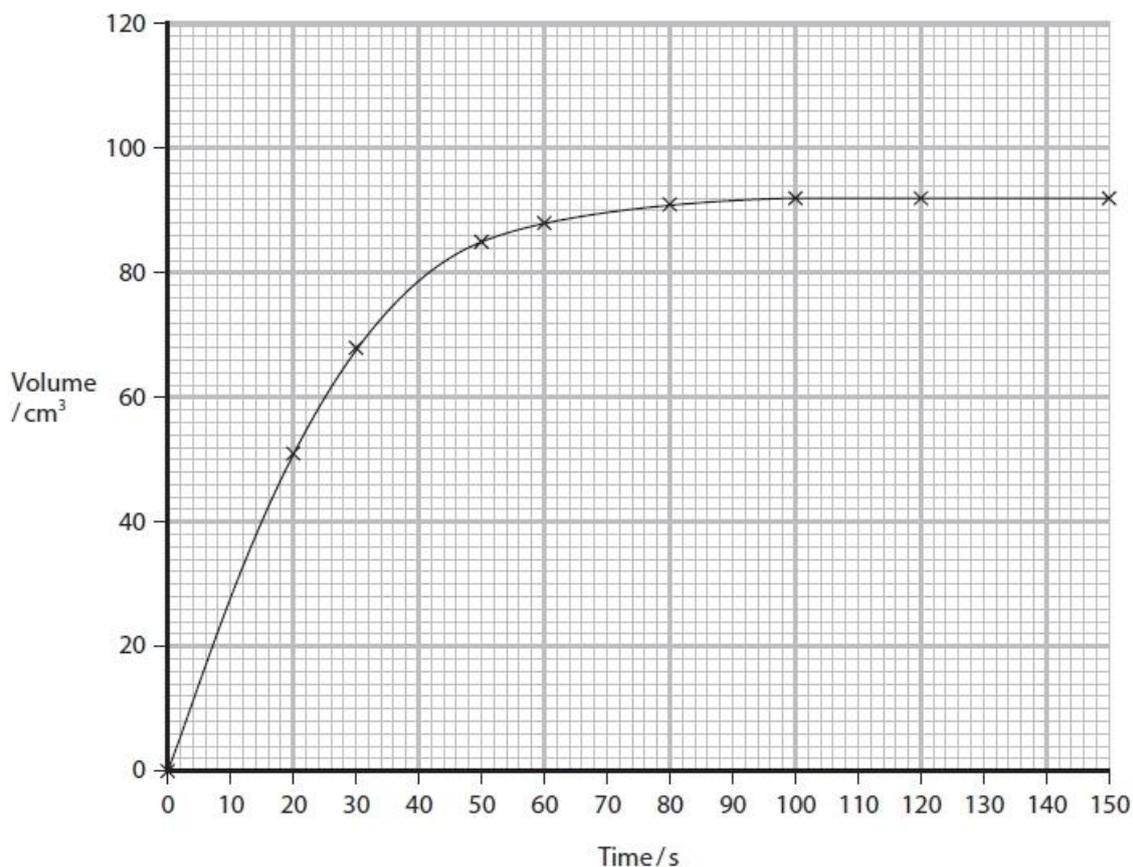


The decomposition is catalysed by manganese(IV) oxide.

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 cm³ 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)

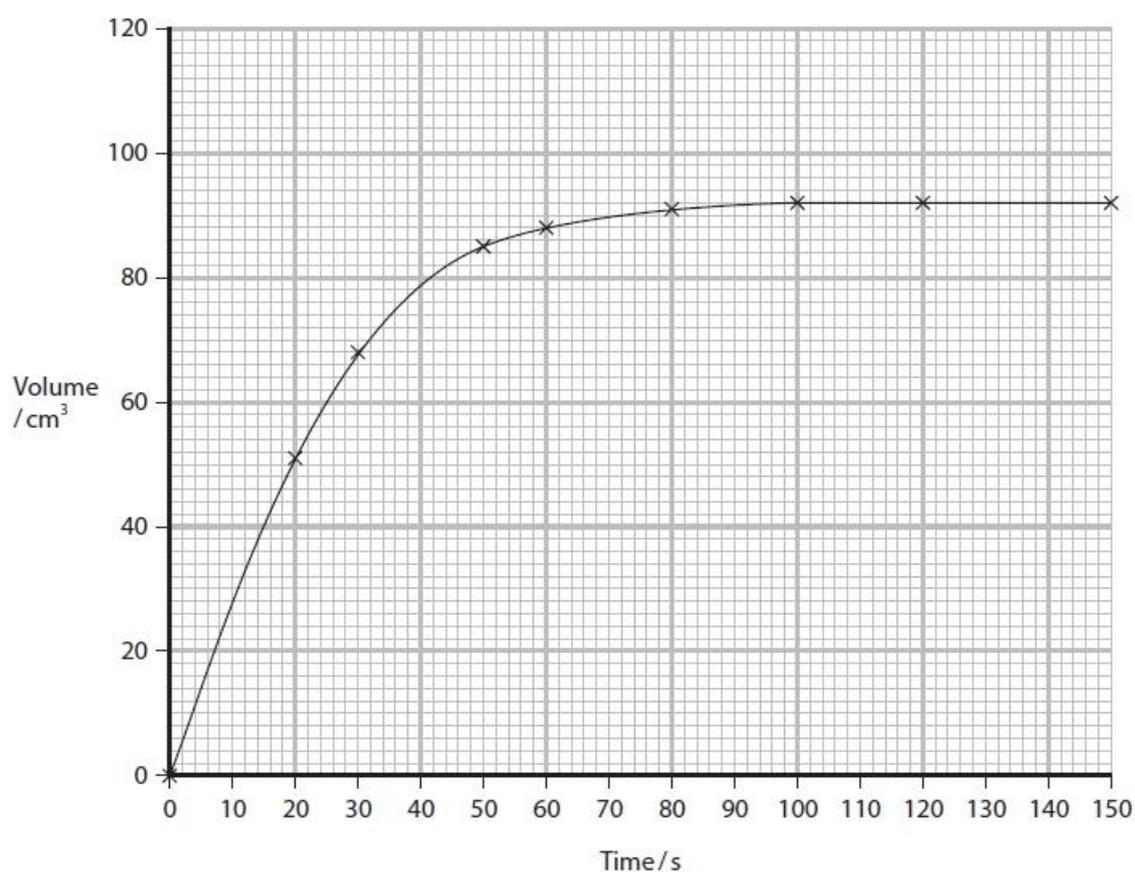
- (ii) Draw a tangent at 40 s on the graph on Page 20 and use it to calculate the rate of reaction at this time.

(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)

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(Total for question = 7 marks)