(i) State the time taken for all the peroxodisulfate ions to react. [1]

..... minutes

(ii) Suggest a method of measuring the rate of this reaction. [1]

.....

.....

.....

(iii) I. Sketch on the graph the line that would be obtained when the reaction is carried out at an increased temperature but keeping the other factors constant. [2]

II. Explain your answer to I. [2]

.....

.....

.....

(iv) State the concentration of the peroxodisulfate ions at the start of the reaction, explaining your answer. [2]

.....

.....

(v) Use the graph to calculate the initial rate of the reaction. [2]

..... mol dm^{-3} min^{-1}

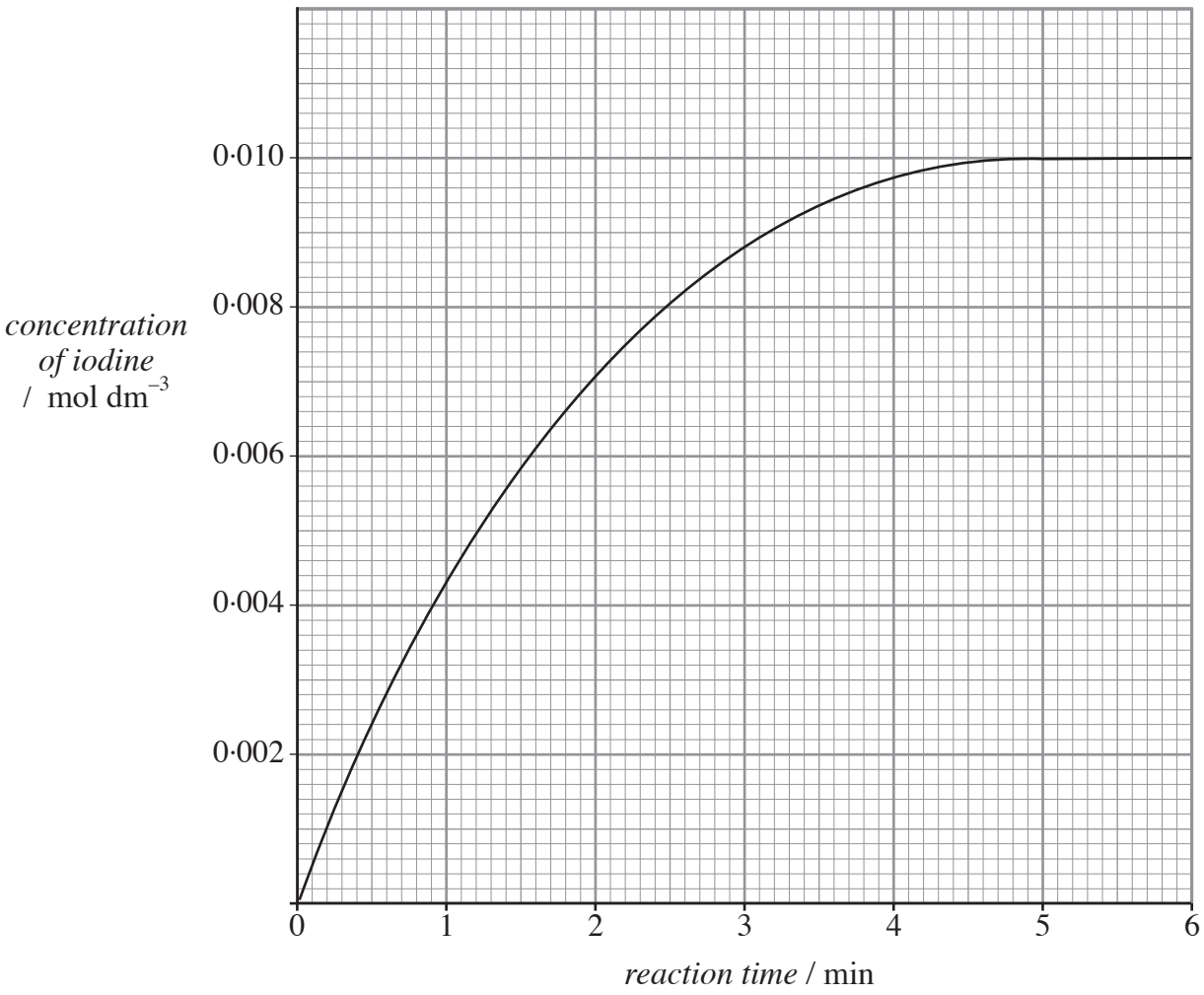
Examiner only

6. *(a)* Iodine is slowly produced, as a red-brown solution, by the reaction of aqueous peroxodisulfate ions, $S_2O_8^{2-}$, with a large excess of aqueous iodide ions, $I^-(aq)$.

$$S_2O_8^{2-}(aq) + 2I^-(aq) \longrightarrow 2SO_4^{2-}(aq) + I_2(aq)$$

colourless colourless colourless red-brown

The graph below was produced from one set of experimental results.



(b) A diluted solution of ethane-1,2-diol is used as an antifreeze.
This compound is made from epoxyethane and water in two different ways, either in neutral solution or in acidic solution using dilute sulfuric acid as a homogeneous catalyst.

Conditions	*Pressure* / atm	*Temperature* / °C	*Relative volume of water used*	*Catalyst*
neutral	14	200	smaller	none
acidic	1	60	larger	sulfuric acid (aq)

(i) Use the information in the table to suggest two reasons why the acid catalysed system is the preferred method. [2]

1. .....

2. .....

(ii) The acid catalysed system does, however, have some disadvantages.
Use the information given to suggest and explain one disadvantage of this system. [1]

.....

.....

(iii) The acid method uses a homogeneous catalyst.
Give an example of a process that uses a **heterogeneous** catalyst, stating the process and the name of the catalyst. [2]

Process .....

Catalyst .....

Total [15]

2. *(a)* Cobalt reacts with hydrochloric acid to give cobalt chloride and hydrogen.

$$Co(s) + 2HCl(aq) \longrightarrow CoCl_2(aq) + H_2(g)$$

(i) Suggest a method for measuring the rate of this reaction. [1]

.....

.....

(ii) State what could be done to the cobalt to increase the rate of this reaction. [1]

.....

.....

(b) A radioactive isotope of cobalt has a half-life of 71 days. Starting with 16 g, calculate the mass of this isotope remaining after 213 days. [1]

.....

.....

3. State the mass of carbon that contains the same number of atoms as there are molecules in 16 g sulfur dioxide, SO_2. [1]

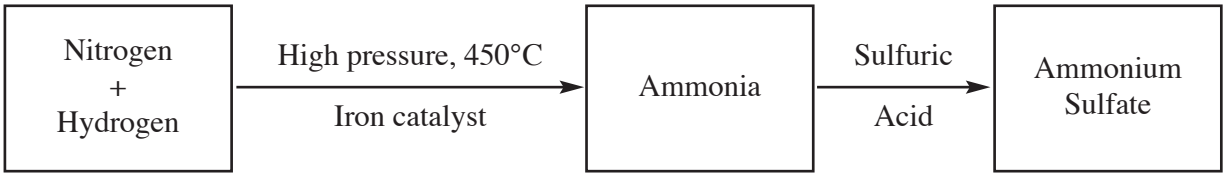
A 3 g

B 6 g

C 12 g

D 64 g .....

6. *(a)* Ammonia, a very important industrial product, is produced by the Haber process. Ammonia can be converted to ammonium sulfate, $(NH_4)_2SO_4$, a common fertiliser, by reacting it with sulfuric acid, H_2SO_4.



The Haber process can be represented by the following equation.

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

(i) Explain how a catalyst speeds up a reaction. [2]

.....

.....

.....

(ii) What **type** of catalyst is iron in the above process? [1]

.....

(iii) For the equilibrium reaction, explain why

I. there has been much research to find a better catalyst, [2]

.....

.....

.....

II. a high pressure is used, [2]

.....

.....

.....

III. ammonia is removed from the equilibrium mixture as it forms. [2]

.....

.....

.....

Examiner only

(b) The corresponding reaction between hydrogen, $H_2(g)$, and iodine, $I_2(g)$,

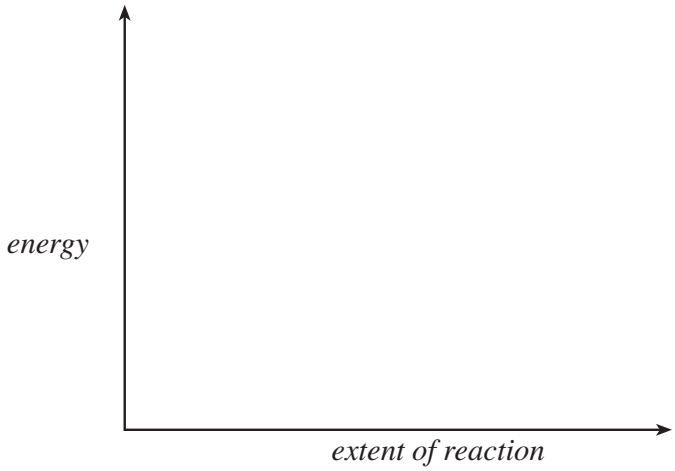
$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

for which the standard enthalpy change of reaction, $\Delta H^{\ominus}$, = –9.6 kJ mol^{-1}, is a system unaffected by light.

Sketch on the axes below the energy profile (*energy* v *extent of reaction*) for the reaction between hydrogen and iodine and use it to explain:

- the concept of *activation energy*;
- the effect of increasing temperature on the rate of reaction;
- the effect of adding a catalyst to a reaction mixture. [6]

QWC [2]



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Total [18]

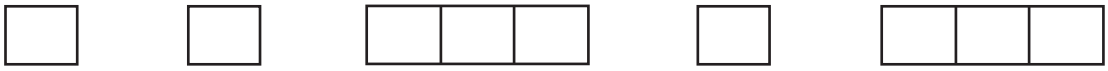
(c) (i) An atom of ^{23}Na absorbs a neutron to give ^{24}Na.
Complete the table to show any **changes** (if any) in the atomic number and mass number. [1]

	Change
Atomic number	
Mass number	

(ii) The isotope ^{24}Na decays by β-emission.
State the mass number and symbol of the species formed by the emission of one β-particle from an atom of ^{24}Na. [1]

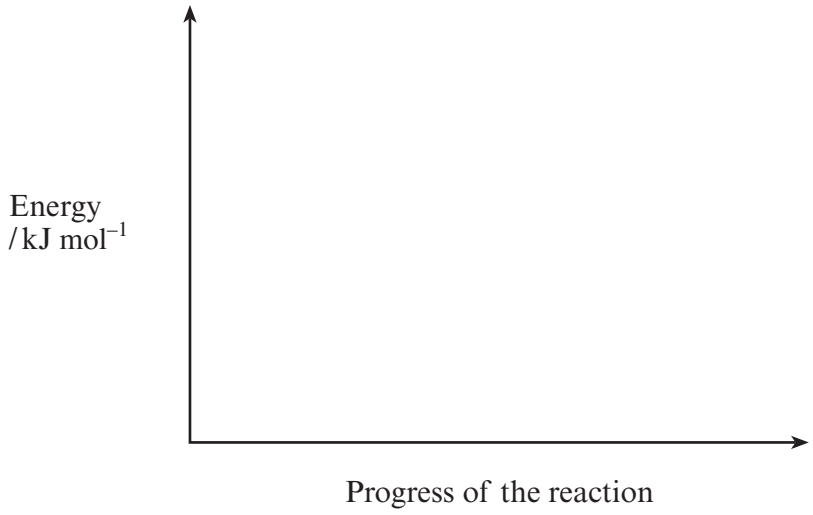
.....

(d) Using the 'arrows in boxes' notation give the electronic configuration of a magnesium atom. [1]



(e) Magnesium burns in air with a brilliant white light, forming magnesium oxide.

(i) Sketch a reaction profile for this reaction, using the axes provided. [1]

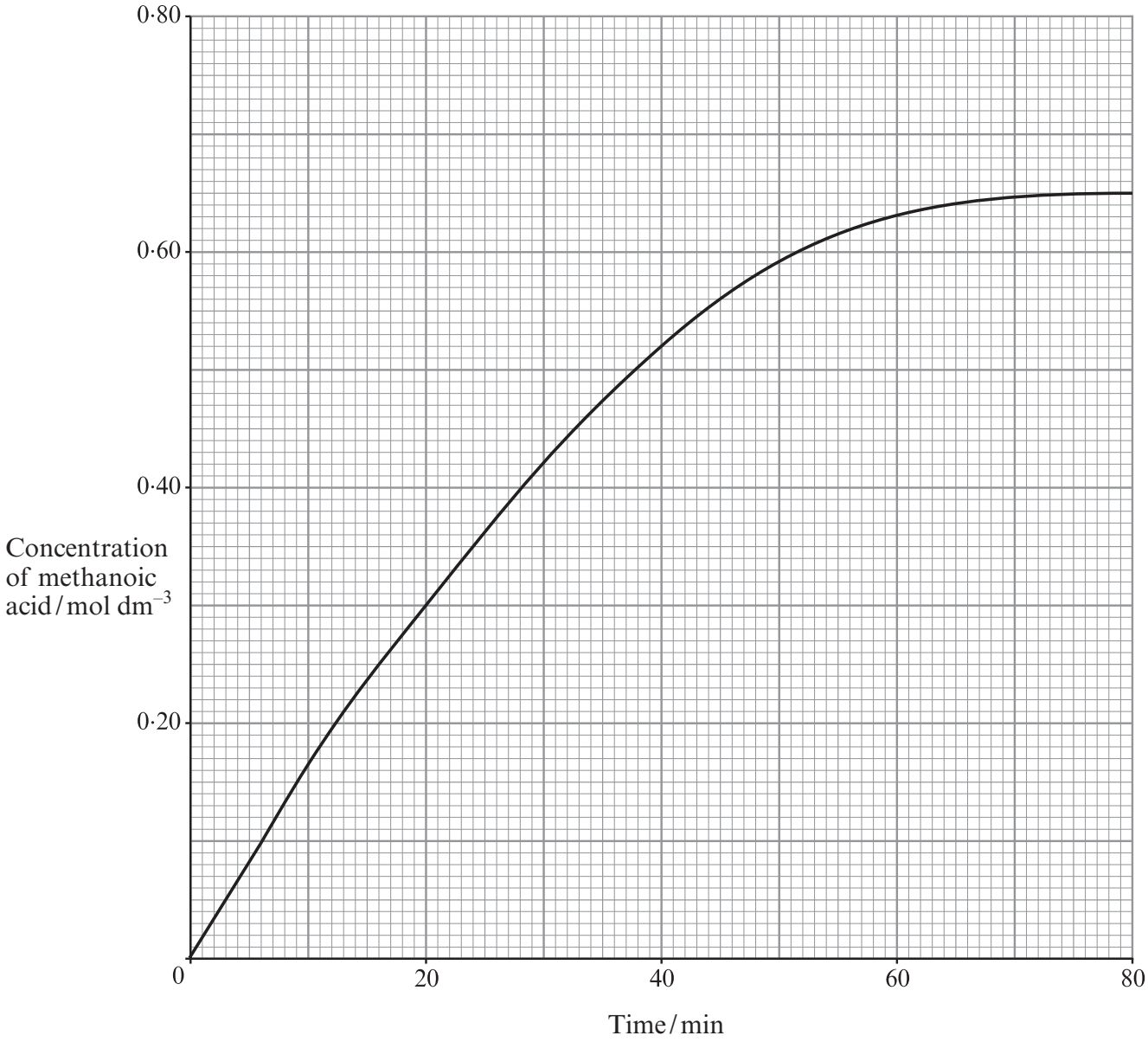


(ii) Indicate, on your profile in (i), the activation energy for the reaction. [1]

Total [12]

Examiner only

10. An organic solvent, **A**, can be slowly decomposed at room temperature, using water in the presence of catalyst **X**. Methanoic acid is one of the products and its concentration is measured at various times during the reaction. The results are shown in the following graph.



$$\underset{\text{1 mole}}{\text{A}} \longrightarrow \underset{\text{1 mole}}{\text{methanoic acid}} + \text{other products}$$

Examiner only

Use the graph to

(i) calculate the initial rate of the reaction, giving its units, [2]

.....

..... *Units* .....

(ii) describe how the rate changes during the reaction. Explain the reason for this change in terms of simple collision theory. [4]

QWC [2]

.....

.....

.....

.....

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.....

.....

(iii) A more effective catalyst, **Y**, has been found for this reaction. The decomposition of solvent **A** is repeated under the same conditions using catalyst **Y**.

I Use the graph to suggest a possible concentration of methanoic acid after 20 minutes when catalyst **Y** is used in place of catalyst **X**. [1]

..... mol dm^{-3}

II Using catalyst **X** the concentration of methanoic acid at the end of the reaction is 0.65 mol dm^{-3}.
State and explain if this final concentration would change when catalyst **Y** replaces catalyst **X**. [2]

.....

.....

(iv) At the start of the reaction using catalyst **X** the concentration of solvent **A** was 48.1 g dm^{-3}.
If the concentration of methanoic acid at the end of the reaction was 0.65 mol dm^{-3}, use the word equation under the graph to calculate the relative molecular mass of solvent **A**. [2]

.....

.....

.....

Total [13]

Examiner only

7. Eurig is asked to measure the rate of reaction of calcium carbonate with dilute hydrochloric acid. He is given 1.50 g of the carbonate and 10.0 cm^3 of acid of concentration 2.00 mol dm^{-3}.

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

(a) Give an observation that Eurig makes during this reaction. [1]

.....

.....

(b) Name a piece of apparatus that he could use to collect and measure the volume of carbon dioxide produced. [1]

.....

(c) Suggest a method, other than measuring the amount of carbon dioxide produced at set time intervals, that Eurig could have used to follow the rate of this reaction. [1]

.....

.....

(d) (i) Calculate the number of moles of hydrochloric acid used in this reaction. [1]

.....

.....

(ii) Calculate the **minimum** mass of calcium carbonate needed to react **completely** with this amount of acid. [2]

.....

.....

.....

(iii) Calculate the volume of carbon dioxide gas that would be produced at 25 °C. [2]
(1 mole of carbon dioxide occupies 24 dm^3 at 25 °C.)

.....

.....

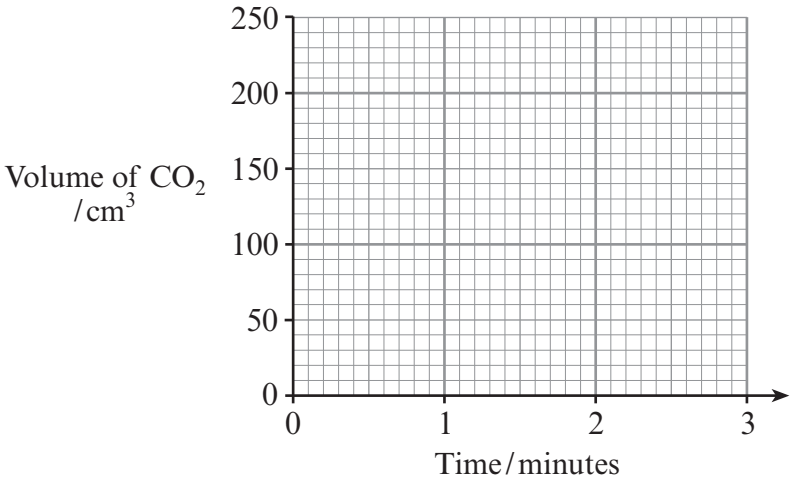
.....

Examiner only

(e) Eurig repeats the experiment starting with a greater mass of calcium carbonate. He follows the rate of the reaction for 3 minutes.

He takes a number of measurements which include 150 cm^3 of carbon dioxide at 1 minute and 200 cm^3 at 2 minutes, when the reaction finishes.

(i) Sketch a curve on the grid below to show these results. Label this graph **A**. [1]



(ii) On the same grid sketch the graph that would be obtained if the experiment were repeated using hydrochloric acid of half the original concentration, keeping all other factors the same. Label this graph **B**. [2]

(iii) Explain, using simple collision theory, why the rates of these two reactions are different. [2]

.....

.....

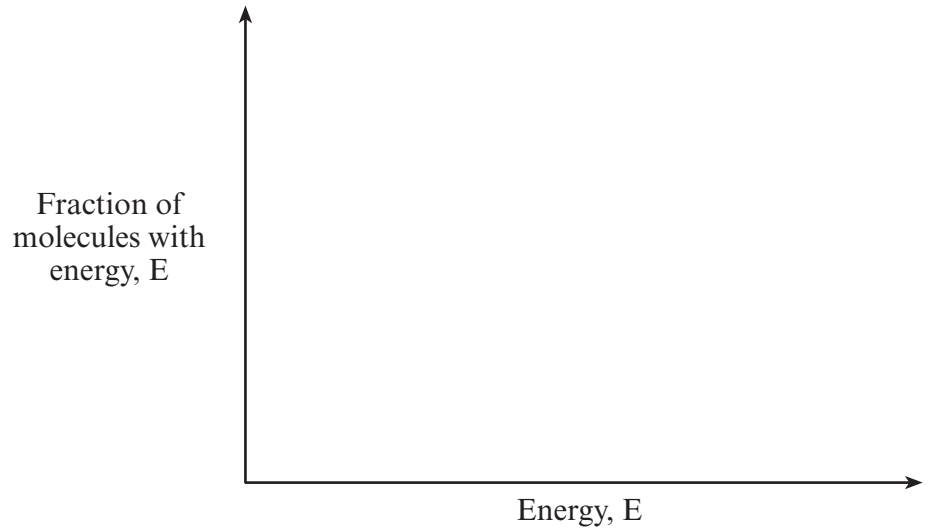
.....

1091 010007

Examiner only

(f) With the aid of an energy distribution curve diagram, explain why raising the temperature by a small amount causes the rate of a chemical reaction to increase by a large amount. [3]

QWC [1]



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Total [17]

Examiner only

10. Measuring the rates of chemical reactions is very important in industrial processes, environmental studies and medical work.

(a) Name **three** factors that can affect the rate of a chemical reaction. [3]

.....

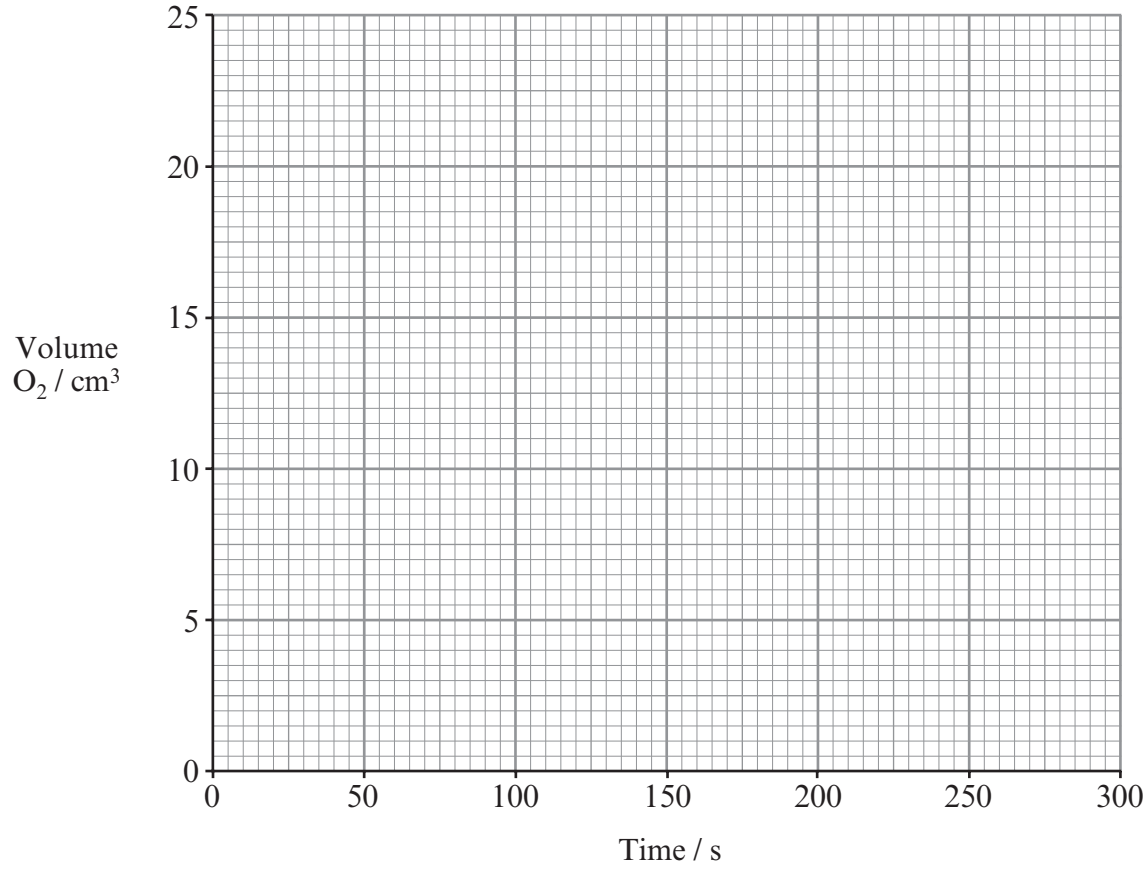
.....

(b) The following results were obtained in an experiment to find the rate of decomposition of hydrogen peroxide.

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

Time / s	0	50	100	150	200	250	300
Volume O_2 / cm^3	0	5.0	10.0	14.8	19.0	22.5	25.0

(i) Plot these results on the grid below and calculate the initial rate of reaction from your plot. **Show your working and state the units for the rate**. [5]



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Examiner only

(ii) State how the rate of reaction changes over time and give a reason for any difference. [2]

.....

.....

(iii) Describe briefly how this experiment could be carried out. [2]

.....

.....

.....

(c) Using collision theory for a reaction such as

$$A(g) + B(g) \longrightarrow C(g)$$

explain why the rate of reaction depends on both the pressure of the reactants and the temperature. [4]

QWC [1]

.....

.....

.....

.....

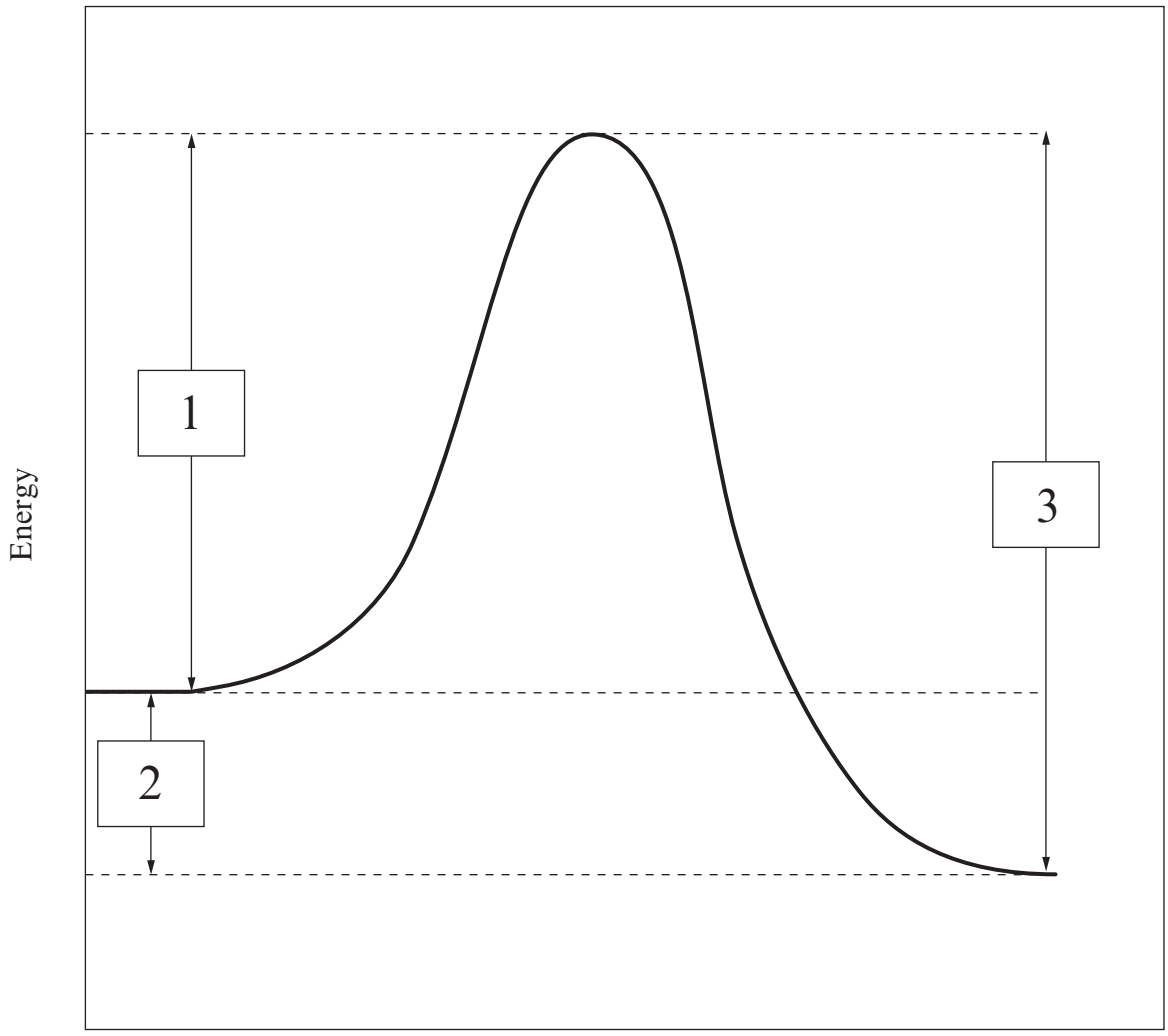
.....

.....

Total [17]

Examiner only

5. The diagram below shows the reaction profile for a chemical reaction. Three energy differences are marked on it with arrows labelled 1, 2 and 3.



Select which of the following correctly assigns the three energy differences.

	Activation energy of forward reaction	Activation energy of reverse reaction	Enthalpy change of reaction
A	1	3	2
B	2	1	3
C	2	3	1
D	3	2	1

..... [1]

Examiner only

(b) The Fischer-Tropsch process uses a heterogeneous catalyst containing iron.

(i) State what is meant by the term *heterogeneous* in this context. [1]

.....

.....

(ii) Explain how a catalyst increases the rate of a chemical reaction. [2]

.....

.....

(iii) Chemical manufacturers consider catalysts to be a key part of production methods that have the minimum possible effect on the environment ('Green Chemistry'). Give **one** reason why the use of catalysts reduces the effect on the environment.[1]

.....

.....

.....

(iv) An alternative method of increasing the rate of a chemical reaction is to increase the temperature. Explain why temperature affects the rate of a chemical reaction. [3]
QWC [1]

.....

.....

.....

.....

Examiner only

7. Judith carried out three experiments to study the reaction between powdered magnesium and hydrochloric acid.
She used a gas syringe to measure the volume of hydrogen evolved, at room temperature and pressure, at set intervals. In each case, the amount of acid used was sufficient to react with all the magnesium.

$$Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$$

The details of each experiment are shown in Table 1 below.

Experiment	Mass of magnesium / g	Volume of HCl / cm^3	Concentration of HCl / mol dm^{-3}
A	0.061	40.0	0.50
B	0.101	40.0	1.00
C	0.101	20.0	2.00

Table 1

The results obtained in experiment **C** are shown in Table 2 below.

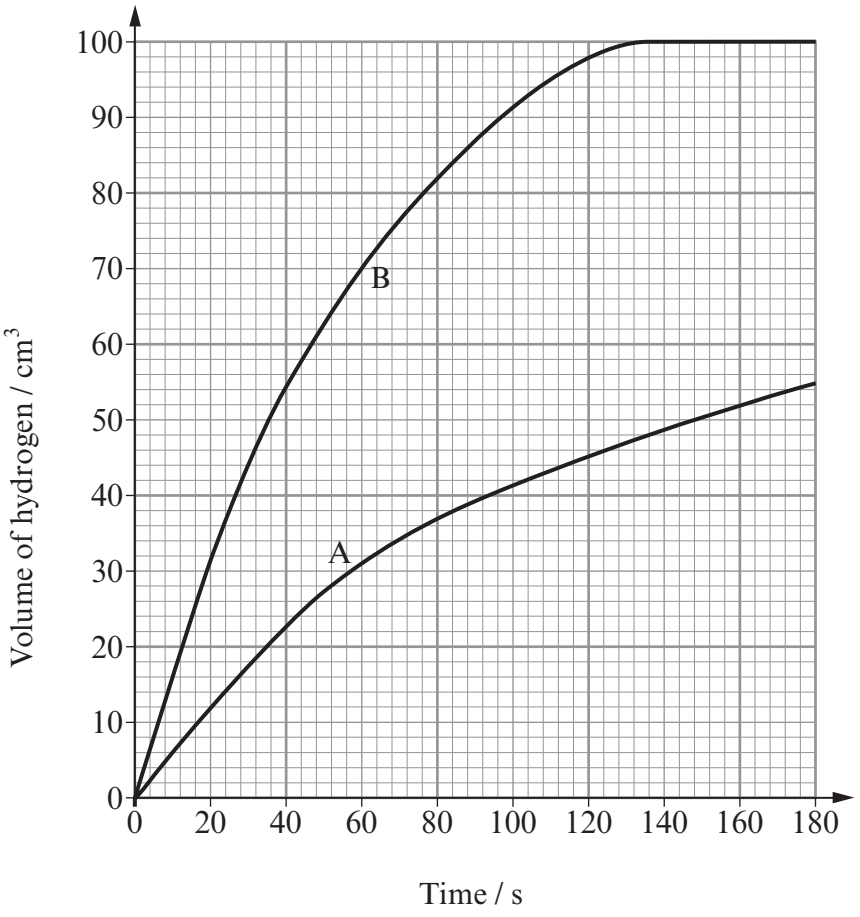
Time / s	Volume of hydrogen / cm^3
0	0
20	50
40	75
60	88
80	92
100	100
120	100

Table 2

Examiner only

(a) The results for experiments **A** and **B** have already been plotted on the grid below.

On the same grid, plot the results for experiment **C** and draw a line of best fit. [3]



(b) (i) State in which experiment the reaction begins most rapidly and **use the graph** to explain your choice. [2]

.....

.....

(ii) By referring to Table 1 give an explanation of your answer in part (i). [1]

.....

.....

(c) State the volume of hydrogen evolved after 30 seconds in experiment **B**. [1]

.....

Examiner only

(d) Using **only** the values in Table 1, show that the acid is in excess in experiment **C**. [2]

.....

.....

.....

(e) (i) In experiment **A**, 0.061 g of magnesium produces 60 cm^3 of hydrogen. If 0.122 g of magnesium were used, under the same conditions, then 120 cm^3 would be produced. Explain why using 0.610 g would not produce 600 cm^3 of hydrogen. [1]

.....

.....

(ii) Calculate the volume of hydrogen produced using 0.610 g of magnesium. [2]

(1 mole of gas molecules occupies 24 dm^3 at 25 °C)

.....

.....

.....

(f) State one method of slowing down the reaction in experiment **C** and use collision theory to explain your choice. Assume that the quantities of magnesium and hydrochloric acid are the same as those in Table 1. [3]
QWC [1]

.....

.....

.....

.....

Total [16]

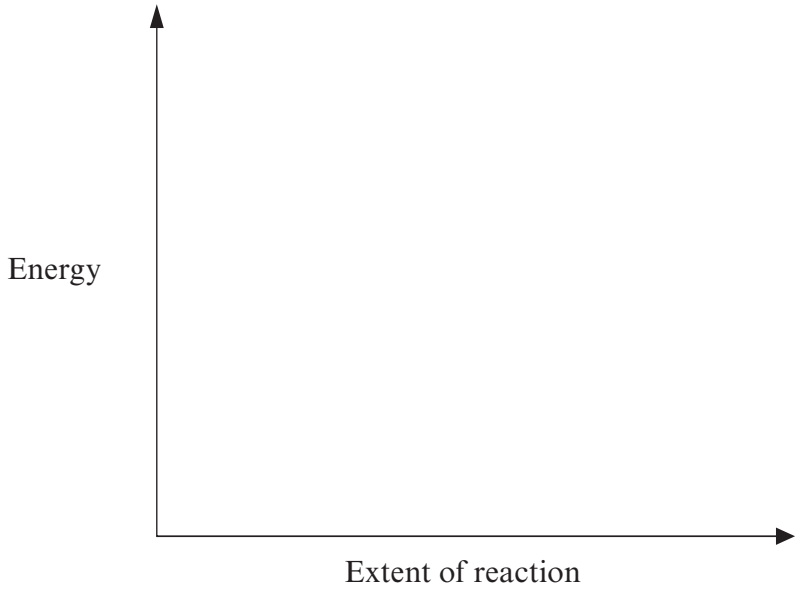
Examiner only

(e) Phosphoric acid is an example of a heterogeneous catalyst.
Explain the term *heterogeneous* in this context. [1]

.....

.....

(f) (i) Sketch on the axes below the energy profile for an exothermic reaction. [1]



(ii) On the same axes, sketch and label the energy profile if the same reaction is carried out using a catalyst. [1]

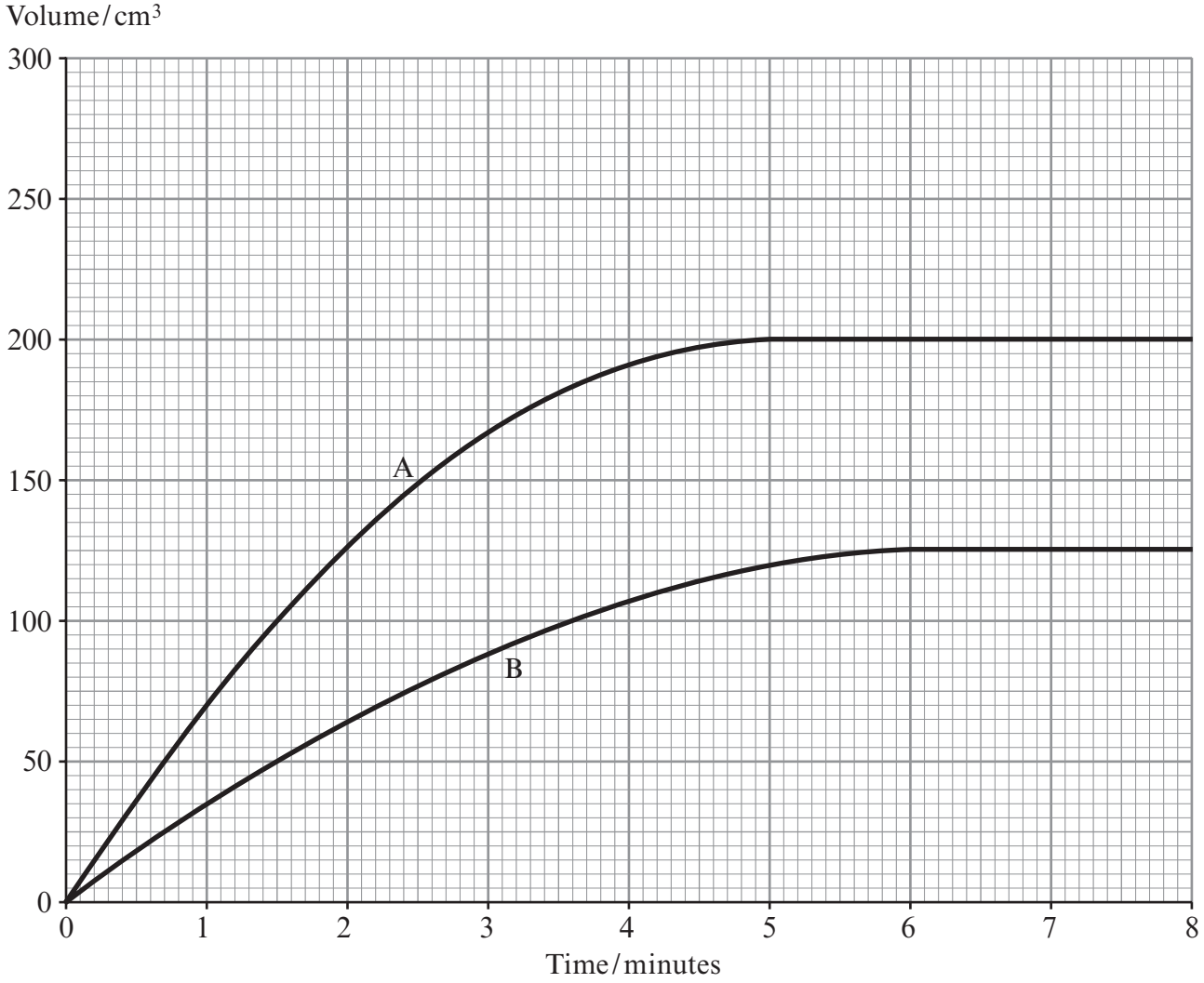
Total [16]

Examiner only

8. Dolomite, $MgCO_3.CaCO_3$, is a mineral containing magnesium carbonate and calcium carbonate.

(a) Some students were asked to react samples of dolomite, each of mass 0.50 g, with an excess of dilute hydrochloric acid and to follow the rate of the reaction by measuring the volume of carbon dioxide evolved at suitable time intervals.

(i) Line **A** on the graph shows Natalie's results. Her teacher said that this was correct. David's line is labelled **B**. Although his line represents his results, the teacher said that he must have done something wrong during the experiment to obtain these results.



Suggest and explain **two** things that he might have done wrongly to obtain these results. [2]

1. .....

.....

2. .....

.....

Examiner only

(ii) Explain why, in Natalie's experiment, 0.25 g of the dolomite has reacted in 1.5 minutes but the remaining 0.25 g has taken a further 3.5 minutes to react. [2]

.....

.....

.....

(iii) Emma asked what the volume of carbon dioxide collected from the samples would be if the temperature rose from 298 K to 323 K.
The teacher explained that, if the pressure remained the same, volume V (in cm^3) and temperature T (in Kelvin) were linked by the equation

$$V = k \times T \qquad \text{where k is constant.}$$

The volume of carbon dioxide evolved at 298 K is 130 cm^3. By finding the value of k, or by other means, calculate the volume of this carbon dioxide when its temperature is raised to 323 K. [2]

Volume of carbon dioxide = ... cm^3

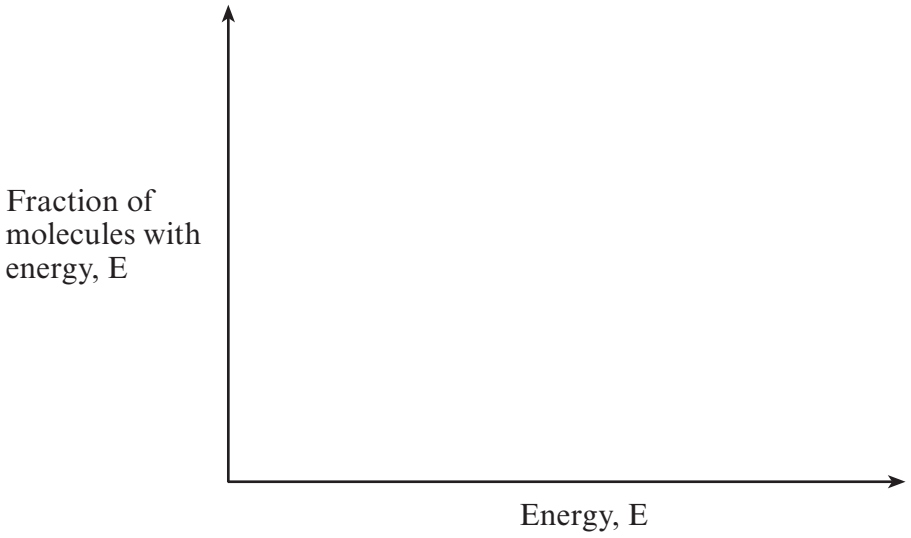
600010
1601

Examiner only

(c) The rate of the reaction between dolomite and hydrochloric acid increases by a large amount if the temperature is increased.

Complete the following energy distribution curve diagram by drawing two lines that show the distribution of energies at two different temperatures.
Label the line at lower temperature T_1 and the line at higher temperature T_2.
Use the diagram to help you explain why the rate increases as the temperature increases. [3]

QWC [1]



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(d) Briefly outline a different method of following the rate of the reaction between dolomite and hydrochloric acid. [2]

.....

.....

.....

.....

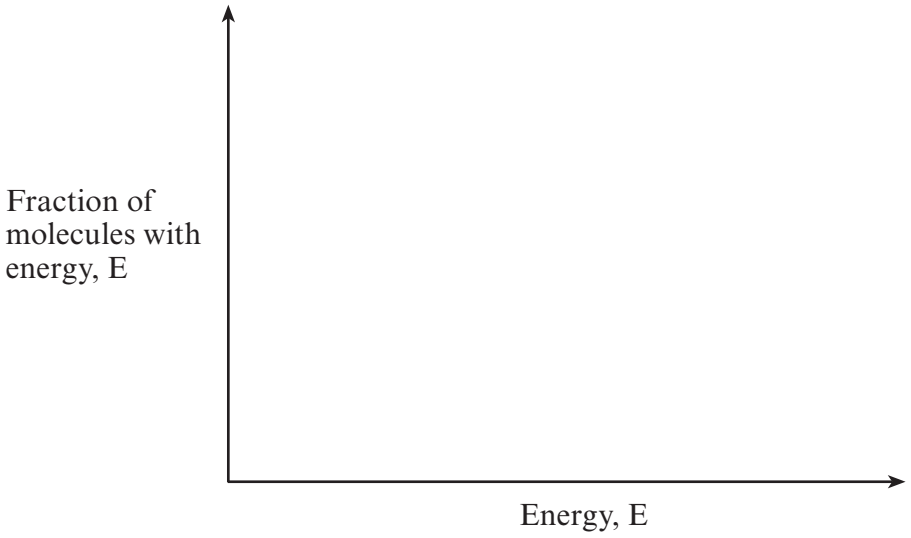
Total [14]

Examiner only

(c) The rate of the reaction between dolomite and hydrochloric acid increases by a large amount if the temperature is increased.

Complete the following energy distribution curve diagram by drawing two lines that show the distribution of energies at two different temperatures.
Label the line at lower temperature T_1 and the line at higher temperature T_2.
Use the diagram to help you explain why the rate increases as the temperature increases. [3]

QWC [1]



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(d) Briefly outline a different method of following the rate of the reaction between dolomite and hydrochloric acid. [2]

.....

.....

.....

.....

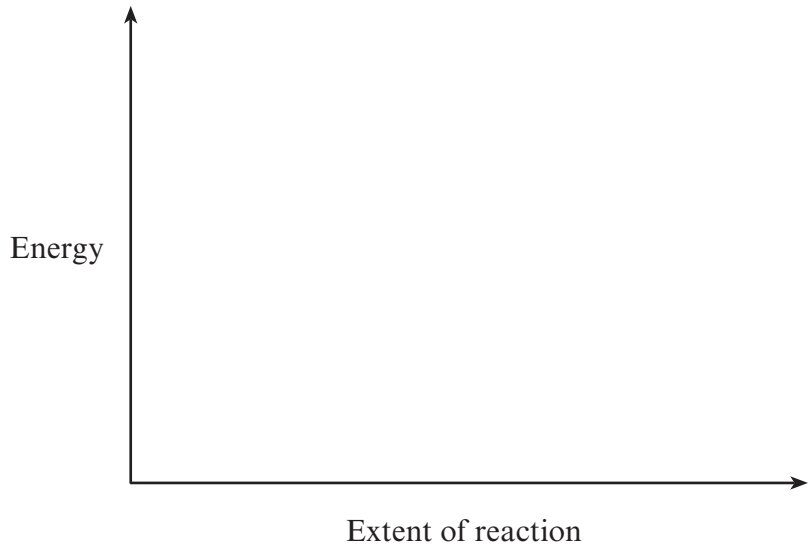
Total [14]

Examiner only

(b) A new method for producing phenol, C_6H_5OH, is by reacting benzene, C_6H_6, with nitrogen(I) oxide at 400 °C in the presence of a suitable catalyst.

$$C_6H_6 + N_2O \longrightarrow C_6H_5OH + N_2 \qquad \Delta H = -286\,kJ\,mol^{-1}$$

(i) Sketch the energy profiles for the catalysed and uncatalysed reactions using the axes shown below.
Label your profiles as *catalysed* and *uncatalysed*. [2]



(ii) A pilot-scale plant used 156 kg of benzene ($M_r = 78$) to produce phenol ($M_r = 94$).

I Calculate the number of moles of benzene used. [1]

Moles of benzene = ... mol

II The yield of phenol was 95%. Using your answer to I and the equation below (or another suitable method), calculate the mass of phenol obtained. Show your working. [3]

$$C_6H_6 + N_2O \longrightarrow C_6H_5OH + N_2$$

Mass of phenol = ... kg

Examiner only

12. *(a)* The combustion of fossil fuels containing sulfur impurities is known to cause acid rain. This acid rain can cause the erosion of marble statues as the calcium carbonate in them reacts with the acid in the rain.

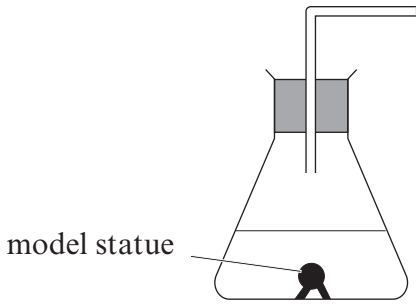
Give **one** other problem caused by acid rain. [1]

.....

.....

(b) A chemist is developing coatings for marble that will slow down the rate of their erosion by acid rain. To compare different coatings he uses small model statues, all of which are the same size and shape as each other. He proposes to measure the rate of reaction by adding acid and measuring the volume of gas given off at set time intervals.

(i) Complete the diagram to show the apparatus that could be used to perform this experiment. [1]



(ii) Explain why it is important that the model statues are the same size and shape as each other. [1]

.....

.....

(iii) State **two** other factors he will need to keep constant if he is to collect valid data. [2]

.....

.....

Examiner only

(c) One gas that causes acid rain is sulfur dioxide. This gas is used to produce sulfur trioxide in the Contact Process. The reaction occurring is shown in the following equation.

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

(i) State and explain the effect of increasing pressure on the equilibrium yield of sulfur trioxide. [2]

.....

.....

.....

.....

(ii) When the temperature is increased the rate at which equilibrium is reached is increased and the yield of sulfur trioxide is decreased.

I State whether this reaction is endothermic, exothermic or neither, giving a reason for your answer. [2]

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Examiner only

II Explain why increasing the temperature leads to an increase in the rate of reaction. [3]

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.....

.....

III To increase the rate of a reaction, a catalyst can be used. Give a **different** catalysed reaction and name the catalyst for this reaction. [1]

.....

.....

Examiner only

(d) Ethanoic acid, CH_3COOH, is one of the most familiar compounds used as a flavouring and preservative for food. Originally ethanoic acid was produced by oxidation of ethanol by bacteria in the presence of air (route **A** below). Today there are many other possible routes and three of these are shown as routes **B**, **C** and **D** below.

Route	Carbon-containing starting materials	Conditions	Overall equation	Atom economy
A	ethanol		$C_2H_5OH + O_2 \rightarrow CH_3COOH + H_2O$	76.9%
B	methanol, carbon monoxide	150 °C, 30 atm	$CH_3OH + CO \rightleftharpoons CH_3COOH$	100.0%
C	butane	150 °C, 55 atm	$2C_4H_{10} + 5O_2 \rightarrow 4CH_3COOH + 2H_2O$	87.0%
D	sugars		$C_6H_{12}O_6 \rightarrow 3CH_3COOH$	

(i) State the atom economy of route **D** for production of ethanoic acid. [1]

.....

(ii) Route **B** is the route most commonly used for producing ethanoic acid today for both financial and *Green Chemistry* reasons. Apply the principles of *Green Chemistry* to the information above to give **two** reasons why route **B** is favoured over route **C**. [2]

1. .....

.....

2. .....

.....

(iii) Route **B** uses a homogeneous catalyst. State what effect the catalyst will have on the position of this equilibrium. [1]

.....

.....

Total [17]

Section B Total [70]

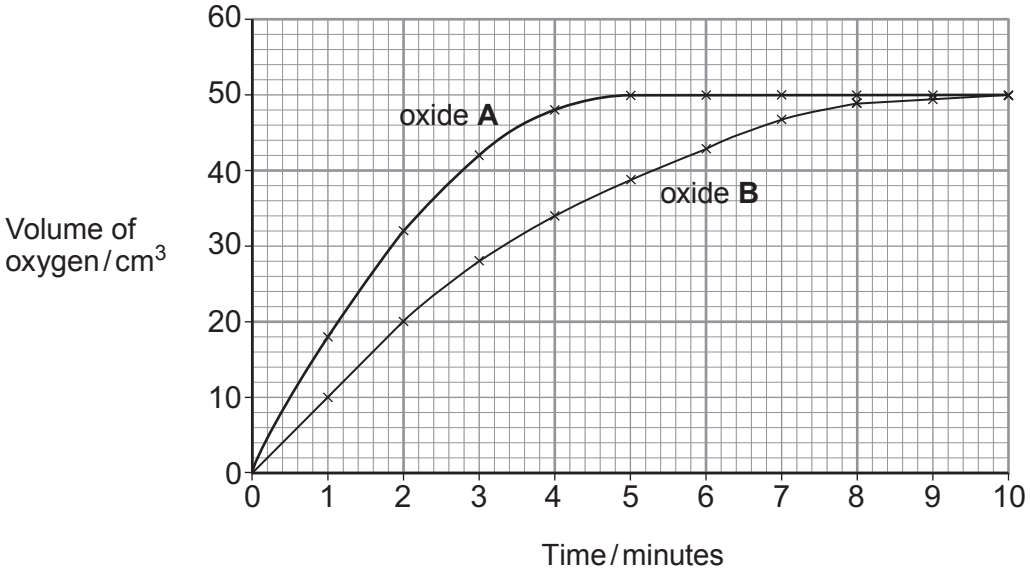
Examiner only

7. Oxygen can be produced in the laboratory by the decomposition of hydrogen peroxide.

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

Trystan carried out experiments to study the effect of using two metal oxides, **A** and **B**, to catalyse the reaction. He used 0.5 g of each metal oxide and diluted 10 cm^3 of a hydrogen peroxide solution with 90 cm^3 of water in each case. Following dilution the solutions were kept at a constant temperature of 35 °C throughout the experiment.

He plotted his results on the graph shown below.



(a) Outline a suitable method, including essential apparatus, for carrying out an experiment to obtain these results. You may include a diagram if you consider it helpful. [4]

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Examiner only

(b) State, giving a reason, which oxide is the more efficient catalyst. [1]

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(c) In the experiment with oxide **A**, calculate the volume of oxygen evolved

(i) during the first minute, [1]

.....

(ii) during the third minute. [1]

.....

(d) Explain the difference between the answers in *(c)*(i) and *(c)*(ii). [2]

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(e) Give a reason why the total volume of oxygen obtained in the two experiments is the same. [1]

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(f) If Trystan repeated the experiment using 5 cm^3 of the original hydrogen peroxide solution diluted with 95 cm^3 of water, state the final volume of oxygen that would be evolved. [1]

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Examiner only

(g) If he carried out the experiments at 45 °C instead of 35 °C, state what effect this would have on the time required to obtain the final volume of oxygen. Use collision theory to explain your answer. [3]

QWC [1]

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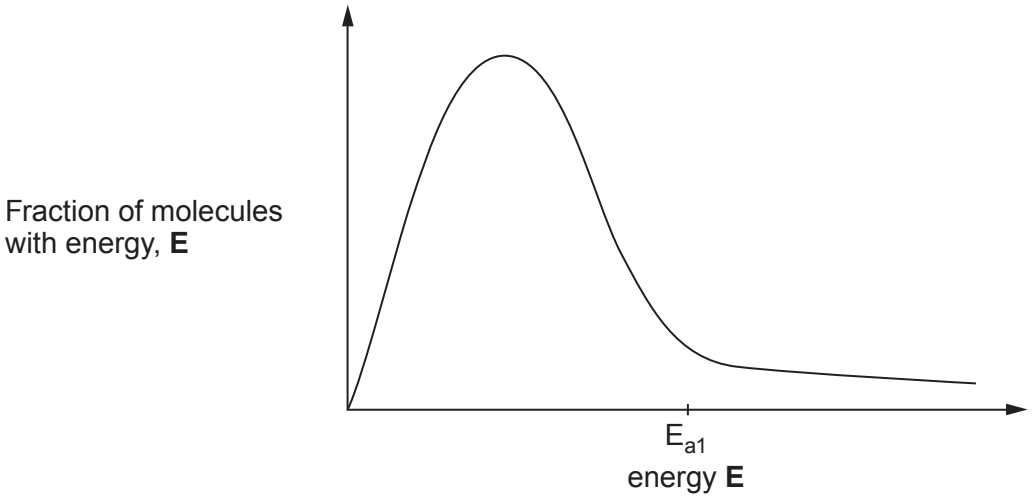
Total [15]

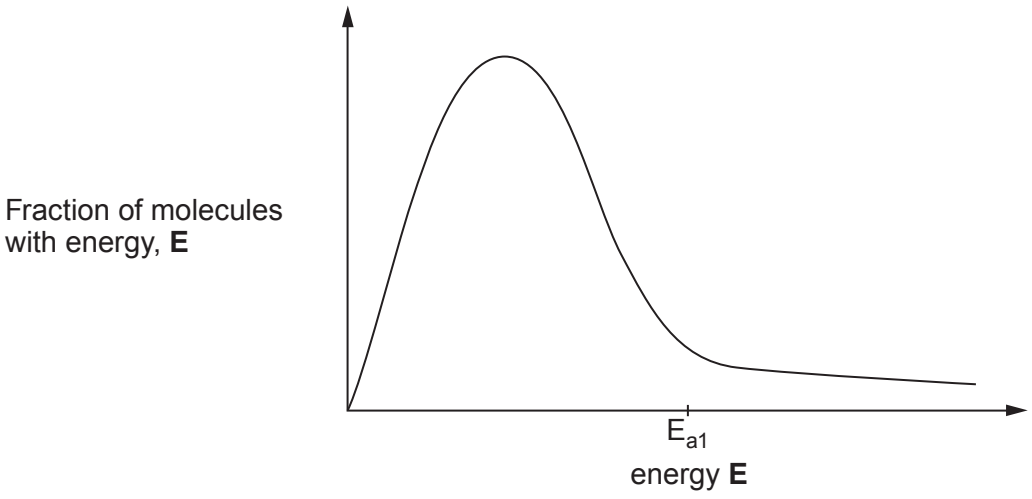
Examiner only

7. The diagrams show the energy distribution curve for gaseous molecules at a fixed temperature.

(a) On the diagram below, E_{a1} shows the activation energy of a particular reaction without a catalyst. Indicate on the diagram the fraction of molecules that react. [1]



(b) Indicate on the diagram below the activation energy, E_{a2}, and the fraction of molecules that react when the reaction proceeds with a catalyst. [1]



Section A Total [10]

Examiner only

12. Hydromagnesite is a mixture of magnesium carbonate and soluble impurities. A student crushed some hydromagnesite and added a sample of mass 0.889 g to excess dilute hydrochloric acid so that the magnesium carbonate component reacted fully.

(a) Explain why the rock was crushed before being added to the acid. [1]

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(b) Write the equation for the reaction between magnesium carbonate and dilute hydrochloric acid. [1]

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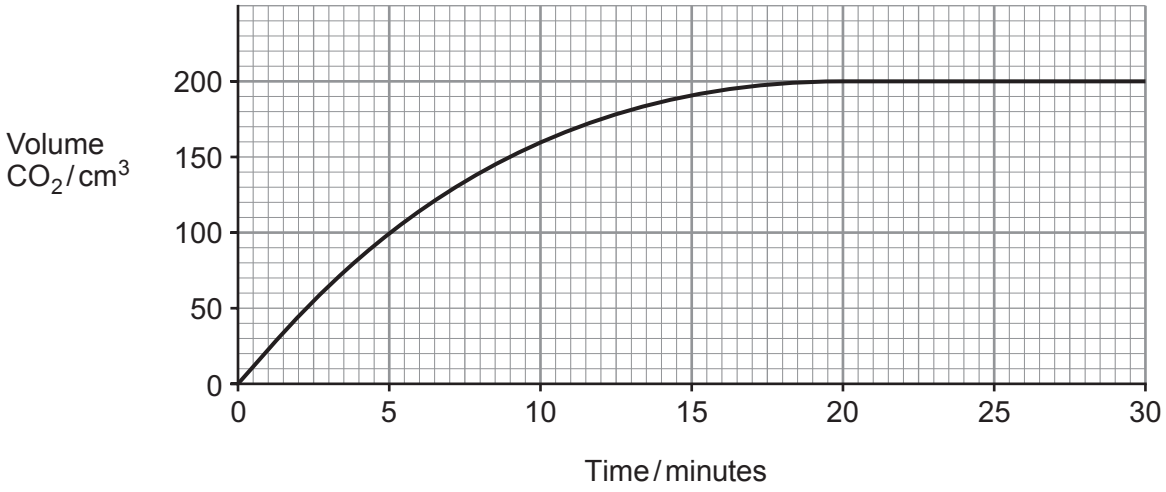
(c) The gas formed was collected in a gas syringe and its volume was measured over a period of time. The volumes and times were plotted. The volume of 1 mol of gas under these conditions is 24.0 dm^3.



Describe what happened to the rate of the reaction over the 30 minute period. Explain why any changes in the rate occurred. [3]

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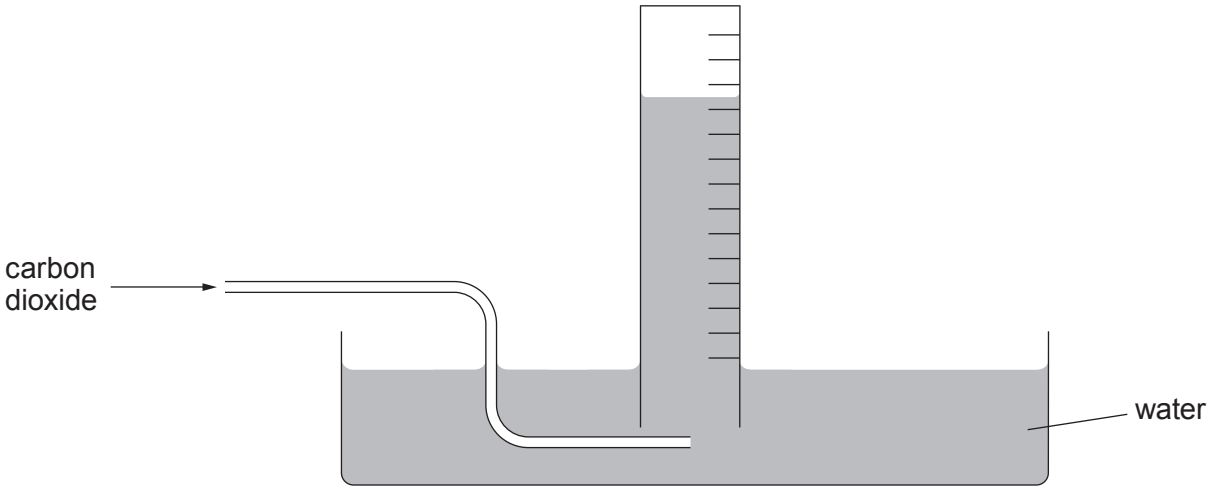
Examiner only

(f) A student wanted to carry out this experiment on another sample of hydromagnesite. He did not have a gas syringe and therefore he decided to collect the carbon dioxide over water in a measuring cylinder.



Explain what effect this would have on the results of the experiment. You should assume that the gas syringe and the measuring cylinder can both be read to the same precision. [2]

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(g) When magnesium carbonate is heated it decomposes to make magnesium oxide and carbon dioxide.

$$MgCO_3(s) \longrightarrow MgO(s) + CO_2(g)$$

Magnesium oxide has a very high melting temperature and so can be used to line furnaces.

What is the atom economy for the production of magnesium oxide from magnesium carbonate? [2]

Atom economy = ... %

Total [14]

Section B Total [70]

END OF PAPER