



CANDIDATE
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9701/51

October/November 2021

1 hour 15 minutes

You must answer on the question paper.

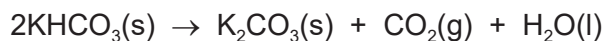
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- Answer **all** questions.
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- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working, use appropriate units and use an appropriate number of significant figures.

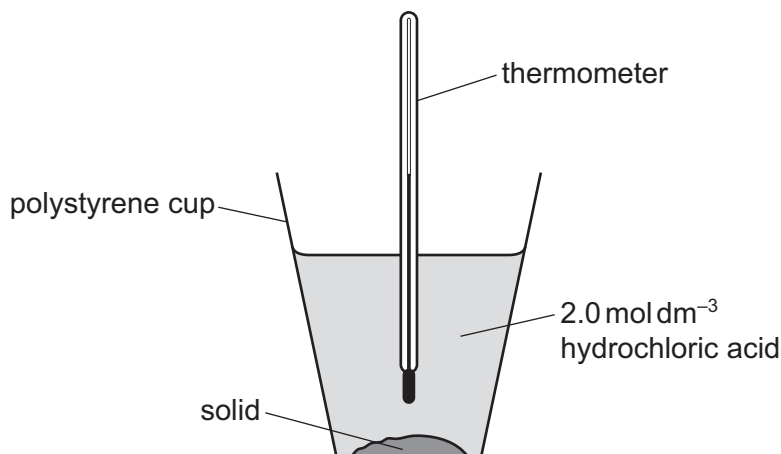
- The total mark for this paper is 30.
- The number of marks for each question or part question is shown in brackets [].

This document has **12** pages. Any blank pages are indicated.

- 1 Potassium hydrogencarbonate, KHCO_3 , decomposes when strongly heated to form potassium carbonate, K_2CO_3 .



A student plans to determine the value for the enthalpy change for this reaction, ΔH_r , which cannot be determined directly. The student carries out two separate experiments using the following apparatus.



Experiment 1 uses solid KHCO_3 .

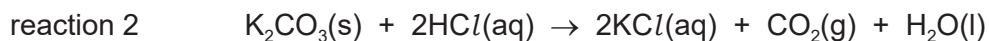
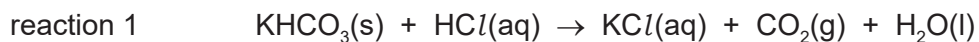
Experiment 2 uses solid K_2CO_3 .

The following method is used for both experiments:

- Transfer 50.00 cm^3 , an excess, of 2 mol dm^{-3} hydrochloric acid into a cup.
- After 2 minutes, record the temperature of the acid.
- Weigh approximately 0.0250 moles of solid.
- Add the solid to the acid, stir the mixture using a thermometer and record the temperature throughout the reaction.

Hazard information: 2 mol dm^{-3} hydrochloric acid is irritant, solid potassium hydrogencarbonate and solid potassium carbonate may cause irritation to the skin and eyes.

The equations for the two reactions are:



- (a) Suggest why it is not possible to measure ΔH_r for the decomposition reaction directly.

.....
 [1]

- (b) (i) Calculate the mass of 0.0250 moles of each solid. Give your answers to **three** decimal places.

[A_r: K, 39.1; H, 1.0; C, 12.0; O, 16.0]

mass of KHCO₃ = ... g

mass of K₂CO₃ = ... g
[1]

- (ii) The masses of solid are measured using a three decimal place balance.

Calculate the percentage error in the measurement of the mass of KHCO₃.

Show your working.

percentage error = ... [1]

- (c) The student obtained the following results.

solid	initial temperature / °C	maximum / minimum temperature / °C	temperature change, ΔT / °C
KHCO ₃	17.5	14.0	
K ₂ CO ₃	19.0	20.5	

- (i) Complete the table by calculating temperature change.

Use the formula $q = mc\Delta T$ to determine the energy change, q , that took place during **experiment 1**. Use q to calculate the enthalpy change of reaction 1, ΔH_1 , in kJ mol⁻¹.

Include a sign in your answer.

Assume 1.00 cm³ of solution has a mass of 1.00 g.
 $c = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$

$\Delta H_1 = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

- (ii) Use the formula $q = mc\Delta T$ to determine the energy change, q , that took place during **experiment 2**. Use q to calculate the enthalpy change of reaction 2, ΔH_2 , in kJ mol^{-1} .

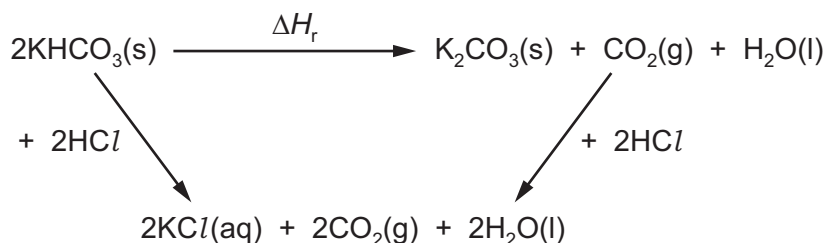
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Assume 1.00 cm^3 of solution has a mass of 1.00 g .

$c = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$

$\Delta H_2 = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

- (d) Use the following cycle to calculate ΔH_r .



$\Delta H_r = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

- (e) A textbook states the value of the enthalpy change for the decomposition of potassium hydrogencarbonate as $+76.0 \text{ kJ mol}^{-1}$.

Suggest **two** reasons why the experimental value is different to the actual value.

1

2

[2]

- (f) Suggest **one** improvement to the apparatus which would reduce the difference between the experimental value and the actual value.

..... [1]

- (g) Name a suitable piece of apparatus which should be used to measure the volume of acid used in **experiment 1**.

..... [1]

- (h) Apart from wearing safety glasses and a lab coat, state **one** safety precaution which must be taken during **experiment 1**. Explain your answer.

.....

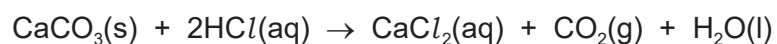
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..... [1]

[Total: 14]

- 2 The rate of reaction between calcium carbonate, CaCO_3 , and hydrochloric acid, HCl , can be followed by collecting and measuring the volume of carbon dioxide produced at 30-second intervals.

The equation for the reaction is:



- (a) A student plans to collect the carbon dioxide by displacement of water.

Draw a labelled diagram of the apparatus that could be used to carry out this experiment.

The apparatus should allow the accurate recording of the volume of carbon dioxide produced.

[3]

Question 2 continues on the next page.

- (b) The student carried out the investigation using an excess of calcium carbonate with dilute hydrochloric acid. The student stopped timing after 330 seconds had passed. The volume of carbon dioxide produced was 93 cm^3 .

V_{final} is the final volume of carbon dioxide collected at 330 seconds.

V_t is the volume of carbon dioxide collected at each interval of time, t .

$V_{\text{final}} - V_t$ is proportional to the concentration of hydrochloric acid at a given time.

time, t/s	volume of carbon dioxide collected/ cm^3	$V_{\text{final}} - V_t/\text{cm}^3$
0	0	
30	22	
60	37	
90	50	
120	61	
150	68	
180	75	
210	78	
240	79	
270	87	
300	90	
330	93	

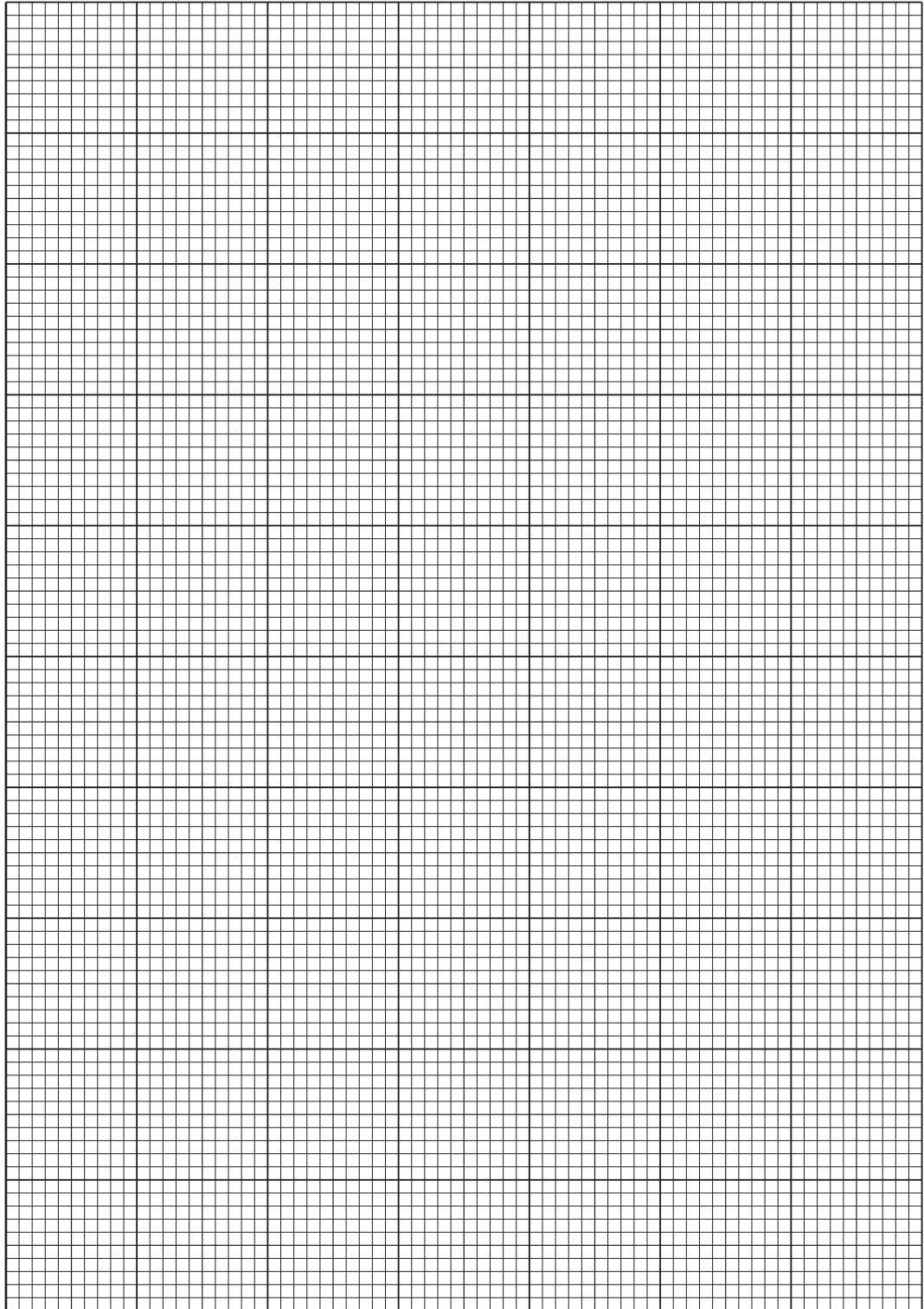
- (i) Complete the table.

[1]

- (ii) Plot a graph of $V_{\text{final}} - V_t$ (y-axis) against time, t (x-axis).

Use a cross (x) to plot each data point. Draw a curved line of best fit.

$V_{\text{final}} - V_t$
/ cm³



time, t/s

[2]

- (iii) Circle the point which you consider to be most anomalous.

[1]

- (iv) Suggest **one** reason for this anomalous point.

.....
 [1]

- (v) Draw construction lines on the graph to calculate two consecutive half-lives for this reaction. Use these half-lives to determine the mean half-life, $t_{\frac{1}{2}}$.

first half-life = ... s

second half-life = ... s

mean half-life, $t_{\frac{1}{2}}$ = ... s
 [2]

- (vi) The rate constant, k , for this reaction can be calculated using the following expression.

$$t_{\frac{1}{2}} = \frac{0.693}{k}$$

Calculate k .

If you did not obtain a value for $t_{\frac{1}{2}}$ in (v) you may use 95 seconds. This is **not** the correct answer.

k = ... s⁻¹ [1]

- (c) State how an increase in temperature would affect the value of k for this reaction. Explain your answer.

.....
 [1]

(d) Calcium carbonate is a component of antacid tablets.

An alternative method of studying the rate of reaction between calcium carbonate and hydrochloric acid is:

- Place one antacid tablet into a beaker.
- Add 50 cm³, **an excess**, of 2.0 mol dm⁻³ hydrochloric acid and start the stop-clock immediately.
- Record the time taken for the fizzing to stop.

(i) An antacid tablet typically contains 1.0 g of CaCO₃.

Complete columns A, B and C in the table to show four more concentrations of **excess** HCl(aq) which would allow this method to be carried out.

Each sample of HCl(aq) must be made by dilution of 2.0 mol dm⁻³ HCl.

[A_r: Ca, 40.1; C, 12.0; O, 16.0]

A	B	C	D
volume of 2.0 mol dm ⁻³ HCl /cm ³	volume of distilled water /cm ³	concentration of HCl /mol dm ⁻³	time taken for fizzing to stop /s
50.0	0.0	2.0	

[2]

(ii) Identify the dependent variable in this investigation.

..... [1]

(iii) Suggest how the reliability of the results could be improved.

.....
 [1]

[Total: 16]

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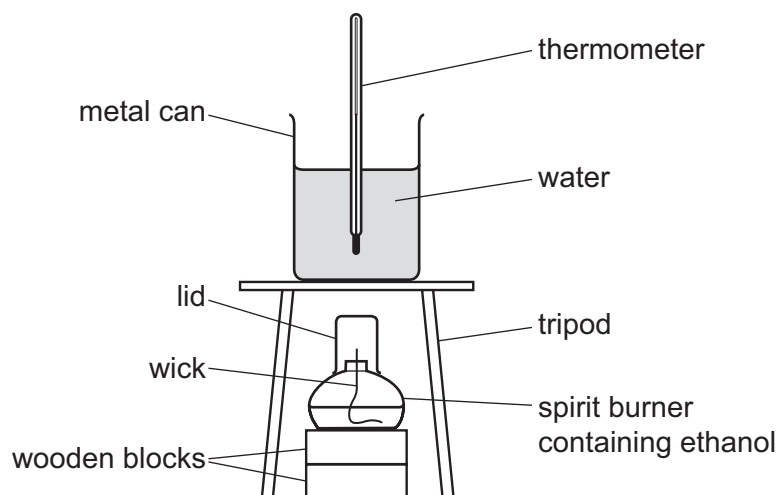
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- 1 It is possible to measure the enthalpy change of combustion, ΔH_c , of ethanol, C_2H_5OH , using the following apparatus.



A student carries out an experiment to determine the value for ΔH_c of ethanol using the following instructions:

- Weigh the spirit burner with ethanol and lid, record the starting mass to two decimal places.
- Measure 100.00 cm^3 of water and place it into the metal can.
- Place a thermometer, with 0.1°C graduations, into the water and stir it, wait for 2 minutes.
- Record the temperature of the water.
- Light the wick and allow the flame to heat the water.
- Continue to stir the water using the thermometer.
- After the temperature has risen by approximately 20°C place the lid on the flame to extinguish it.
- Record the maximum temperature of the water.
- Weigh the spirit burner and record the final mass.

The student obtained the following results.

initial temperature of water/ $^\circ\text{C}$	maximum temperature of water/ $^\circ\text{C}$	change in temperature of water, $\Delta T/^\circ\text{C}$	initial mass of spirit burner/g	final mass of spirit burner/g	mass of ethanol burned/g
18.1	38.2		153.29	152.76	

(a) Complete the table. Record your answers to the correct number of decimal places. [1]

(b) Calculate the number of moles of ethanol burned. Give your answer to **three** significant figures.

[A_r : C, 12.0; H, 1.0; O, 16.0]

moles of ethanol = ... [1]

- (c) Use the formula $q = mc\Delta T$ to determine the energy change, q , that took place during the experiment. Use q and your answer to (b) to calculate the enthalpy change of combustion of ethanol, ΔH_c , in kJ mol^{-1} .

Include a sign in your answer.

1.00 cm^3 of water has a mass of 1.00 g
 $c = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$

$\Delta H_c = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

- (d) Calculate the percentage error of the temperature change recorded in the table in (a).

Show your working.

percentage error = $\dots\dots\dots$ [1]

- (e) State the effect, if any at all, on the accuracy of the experiment if the spirit burner was allowed to burn for longer. Explain your answer.

$\dots\dots\dots$
 $\dots\dots\dots$
 $\dots\dots\dots$
 $\dots\dots\dots$ [1]

- (f) The flame was extinguished, but the lid of the spirit burner was not replaced immediately.

Predict how this would affect the value of ΔH_c . Explain your answer.

$\dots\dots\dots$
 $\dots\dots\dots$
 $\dots\dots\dots$
 $\dots\dots\dots$ [2]

(g) The value for ΔH_c of ethanol under standard conditions is $-1367 \text{ kJ mol}^{-1}$.

- (i) Other than the reaction not being carried out under standard conditions, suggest **two** reasons why the value the student obtained in (c) is different from the actual value.

1

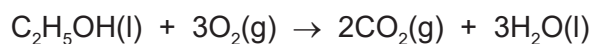
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2

.....

[2]

- (ii) It is possible to calculate ΔH_c of ethanol using average bond enthalpies and the chemical equation for the reaction.



Using average bond enthalpies, ΔH_c of ethanol is $-1297 \text{ kJ mol}^{-1}$.

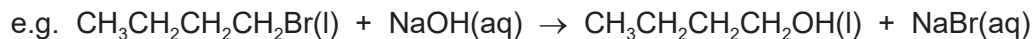
Explain why this value is different from the actual value for ΔH_c of ethanol under standard conditions.

.....

..... [1]

[Total: 11]

2 Halogenoalkanes undergo hydrolysis with aqueous sodium hydroxide to form alcohols.



A student carried out an experiment to compare the rate at which three halogenoalkanes, 1-chlorobutane, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl}$, 1-bromobutane, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$, and 1-iodobutane, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{I}$, undergo hydrolysis. The method used was as follows:

- Place a 5 cm^3 sample of each halogenoalkane into separate test-tubes.
- Add 1 cm^3 of organic solvent to each test-tube.
- Add 2 cm^3 aqueous sodium hydroxide to each test-tube.
- Add 3 drops of acid–base indicator to the mixture.
- Heat the test-tubes in a thermostatically controlled, electrically heated water bath.
- Record the time taken for the indicator to change colour.

(a) Give **two** reasons why the experiment was carried out using an electrically heated water bath.

1

.....

2

.....

[2]

(b) Sodium hydroxide is corrosive.

Apart from wearing safety glasses and a lab coat, state **one** safety precaution which must be taken when handling sodium hydroxide.

..... [1]

(c) Suggest why an organic solvent must be used in this experiment.

.....

..... [1]

(d) Why is acid–base indicator added to the reaction mixture?

.....

..... [1]

(e) The student obtained the following results.

halogenoalkane	time taken for indicator to change colour/s	$\frac{1}{\text{time}}/\text{s}^{-1}$
1-chlorobutane	417	
1-bromobutane	238	
1-iodobutane	135	

(i) Complete the table to show $\frac{1}{\text{time}}$. [1]

(ii) $\frac{1}{\text{time}}$ can be used to represent rate of reaction.

Suggest what the $\frac{1}{\text{time}}$ values tell you about the trend in carbon-halogen bond enthalpies.

.....
 [1]

(f) Identify **one** additional variable that must be controlled in this experiment.

..... [1]

Question 2 continues on the next page.

- (g) The student decided to investigate the order of reaction with respect to aqueous sodium hydroxide.



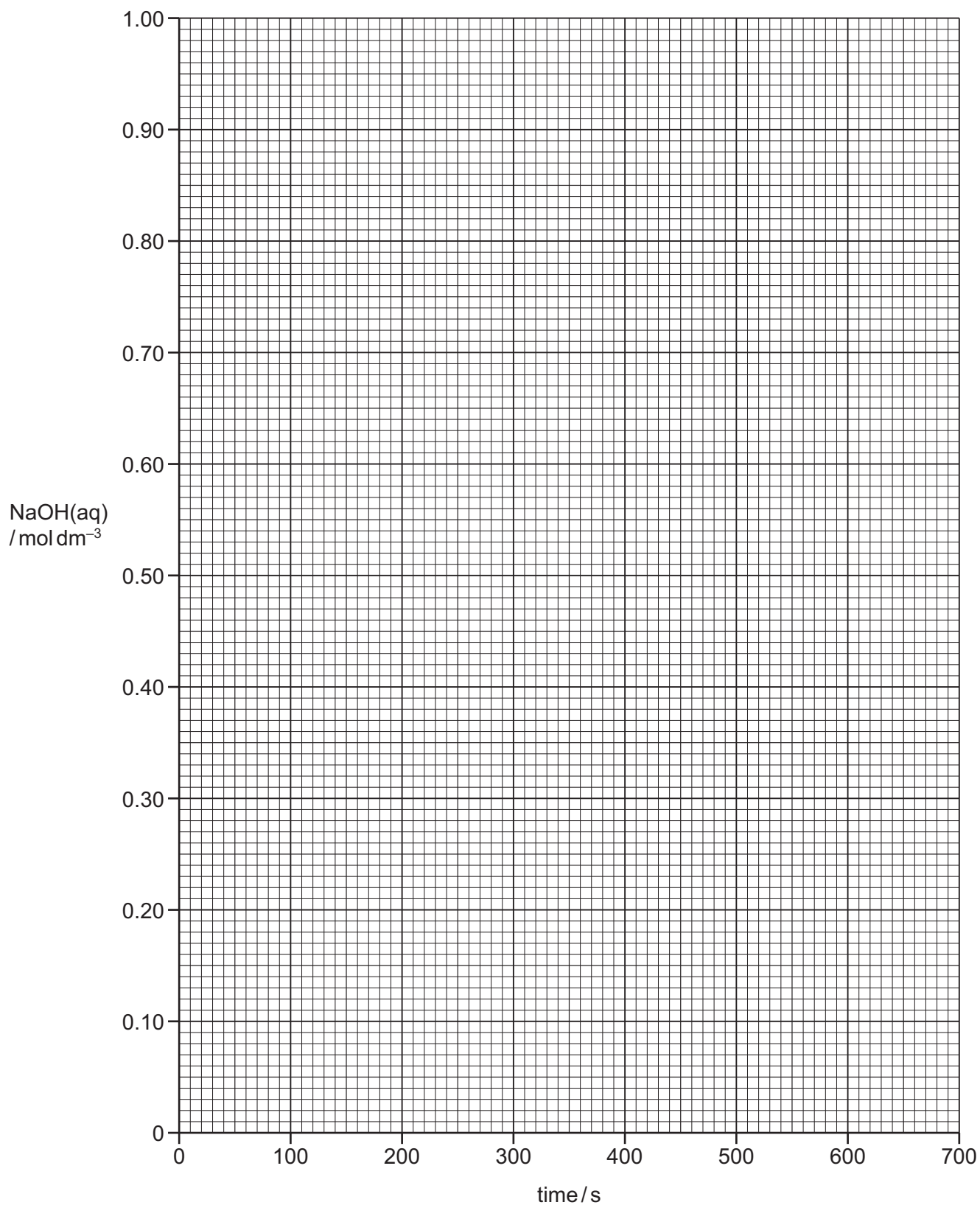
- step 1 An excess of 1-chlorobutane was mixed with 1.00 mol dm^{-3} NaOH(aq), at room temperature.
- step 2 A stop-clock was immediately started.
- step 3 At intervals of 60 seconds the student took 10.00 cm^3 samples from the reaction mixture, for 11 minutes.
- step 4 Each 10.00 cm^3 sample was immediately added to ice in a conical flask.
- step 5 The concentration of NaOH(aq) in each sample was determined by titration.

The results are shown.

time/s	concentration of NaOH(aq)/ mol dm^{-3}
0	1.00
60	0.75
120	0.62
180	0.51
240	0.39
300	0.31
360	0.24
420	0.19
480	0.12
540	0.13
600	0.11
660	0.09

- (i) Plot a graph of concentration of NaOH(aq) (y-axis) against time (x-axis).

Use a cross (×) to plot each data point. Draw a curved line of best fit.



[2]

- (ii) Circle the point which you consider to be most anomalous.

[1]

- (iii) Suggest **one** reason for this anomalous point.

.....
 [1]

- (iv) Draw construction lines on the graph to calculate two consecutive half-lives for this reaction.

first half-life = ... s

second half-life = ... s
 [2]

- (v) State whether you consider this to be a first-order reaction with respect to NaOH.
 Explain your answer.

.....
 [1]

- (h) The total volume of the reaction mixture at the start of the experiment was 250 cm³.

- (i) Name a piece of apparatus that could be used to remove 10.00 cm³ samples from the reaction mixture.

..... [1]

- (ii) Suggest why the student did not remove 25.00 cm³ samples for titration from the reaction mixture.

.....
 [1]

- (iii) Explain why each sample is added to ice in step 4.

.....
 [1]

- (i) Another method for following the rate of a reaction is to measure changes in electrical conductivity.

Explain why this would not be a suitable method for following this reaction.

.....
 [1]

[Total: 19]

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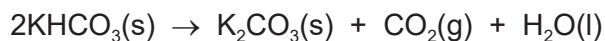
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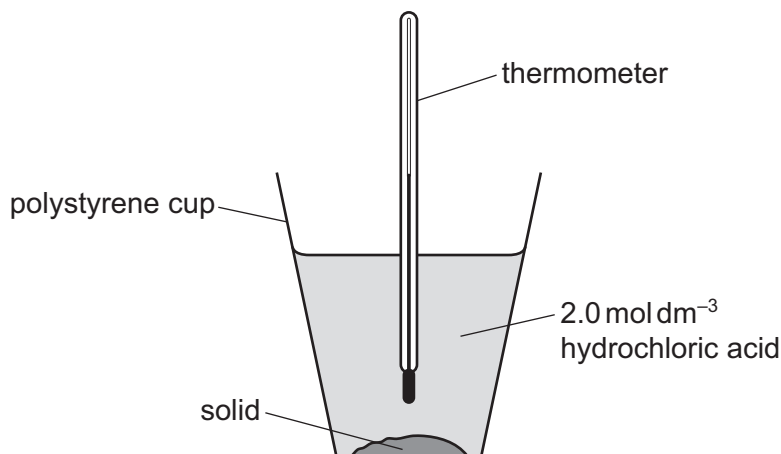
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A student plans to determine the value for the enthalpy change for this reaction, ΔH_r , which cannot be determined directly. The student carries out two separate experiments using the following apparatus.



Experiment 1 uses solid KHCO_3 .

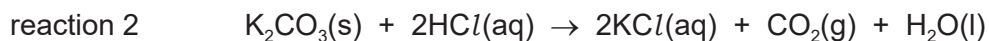
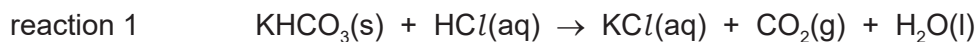
Experiment 2 uses solid K_2CO_3 .

The following method is used for both experiments:

- Transfer 50.00 cm^3 , an excess, of 2 mol dm^{-3} hydrochloric acid into a cup.
- After 2 minutes, record the temperature of the acid.
- Weigh approximately 0.0250 moles of solid.
- Add the solid to the acid, stir the mixture using a thermometer and record the temperature throughout the reaction.

Hazard information: 2 mol dm^{-3} hydrochloric acid is irritant, solid potassium hydrogencarbonate and solid potassium carbonate may cause irritation to the skin and eyes.

The equations for the two reactions are:



- (a) Suggest why it is not possible to measure ΔH_r for the decomposition reaction directly.

.....
 [1]

- (b) (i) Calculate the mass of 0.0250 moles of each solid. Give your answers to **three** decimal places.

[A_r : K, 39.1; H, 1.0; C, 12.0; O, 16.0]

mass of KHCO_3 = ... g

mass of K_2CO_3 = ... g
[1]

- (ii) The masses of solid are measured using a three decimal place balance.

Calculate the percentage error in the measurement of the mass of KHCO_3 .

Show your working.

percentage error = ... [1]

- (c) The student obtained the following results.

solid	initial temperature / °C	maximum / minimum temperature / °C	temperature change, ΔT / °C
KHCO_3	17.5	14.0	
K_2CO_3	19.0	20.5	

- (i) Complete the table by calculating temperature change.

Use the formula $q = mc\Delta T$ to determine the energy change, q , that took place during **experiment 1**. Use q to calculate the enthalpy change of reaction 1, ΔH_1 , in kJ mol^{-1} .

Include a sign in your answer.

Assume 1.00 cm^3 of solution has a mass of 1.00 g.
 $c = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$

ΔH_1 = ... kJ mol^{-1} [2]

- (ii) Use the formula $q = mc\Delta T$ to determine the energy change, q , that took place during **experiment 2**. Use q to calculate the enthalpy change of reaction 2, ΔH_2 , in kJ mol^{-1} .

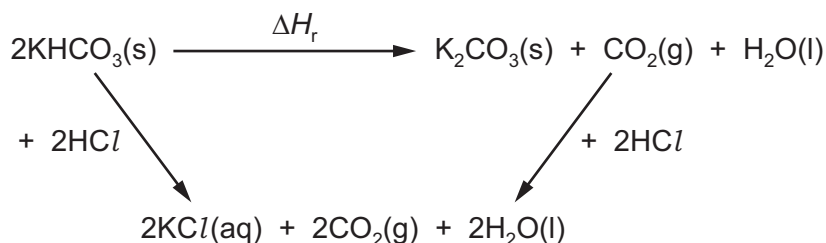
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Assume 1.00 cm^3 of solution has a mass of 1.00 g .

$c = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$

$\Delta H_2 = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

- (d) Use the following cycle to calculate ΔH_r .



$\Delta H_r = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

- (e) A textbook states the value of the enthalpy change for the decomposition of potassium hydrogencarbonate as $+76.0 \text{ kJ mol}^{-1}$.

Suggest **two** reasons why the experimental value is different to the actual value.

1

2

[2]

- (f) Suggest **one** improvement to the apparatus which would reduce the difference between the experimental value and the actual value.

..... [1]

- (g) Name a suitable piece of apparatus which should be used to measure the volume of acid used in **experiment 1**.

..... [1]

- (h) Apart from wearing safety glasses and a lab coat, state **one** safety precaution which must be taken during **experiment 1**. Explain your answer.

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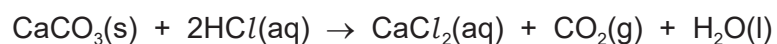
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[Total: 14]

- 2 The rate of reaction between calcium carbonate, CaCO_3 , and hydrochloric acid, HCl , can be followed by collecting and measuring the volume of carbon dioxide produced at 30-second intervals.

The equation for the reaction is:



- (a) A student plans to collect the carbon dioxide by displacement of water.

Draw a labelled diagram of the apparatus that could be used to carry out this experiment.

The apparatus should allow the accurate recording of the volume of carbon dioxide produced.

[3]

Question 2 continues on the next page.

- (b) The student carried out the investigation using an excess of calcium carbonate with dilute hydrochloric acid. The student stopped timing after 330 seconds had passed. The volume of carbon dioxide produced was 93 cm^3 .

V_{final} is the final volume of carbon dioxide collected at 330 seconds.

V_t is the volume of carbon dioxide collected at each interval of time, t .

$V_{\text{final}} - V_t$ is proportional to the concentration of hydrochloric acid at a given time.

time, t/s	volume of carbon dioxide collected/ cm^3	$V_{\text{final}} - V_t/\text{cm}^3$
0	0	
30	22	
60	37	
90	50	
120	61	
150	68	
180	75	
210	78	
240	79	
270	87	
300	90	
330	93	

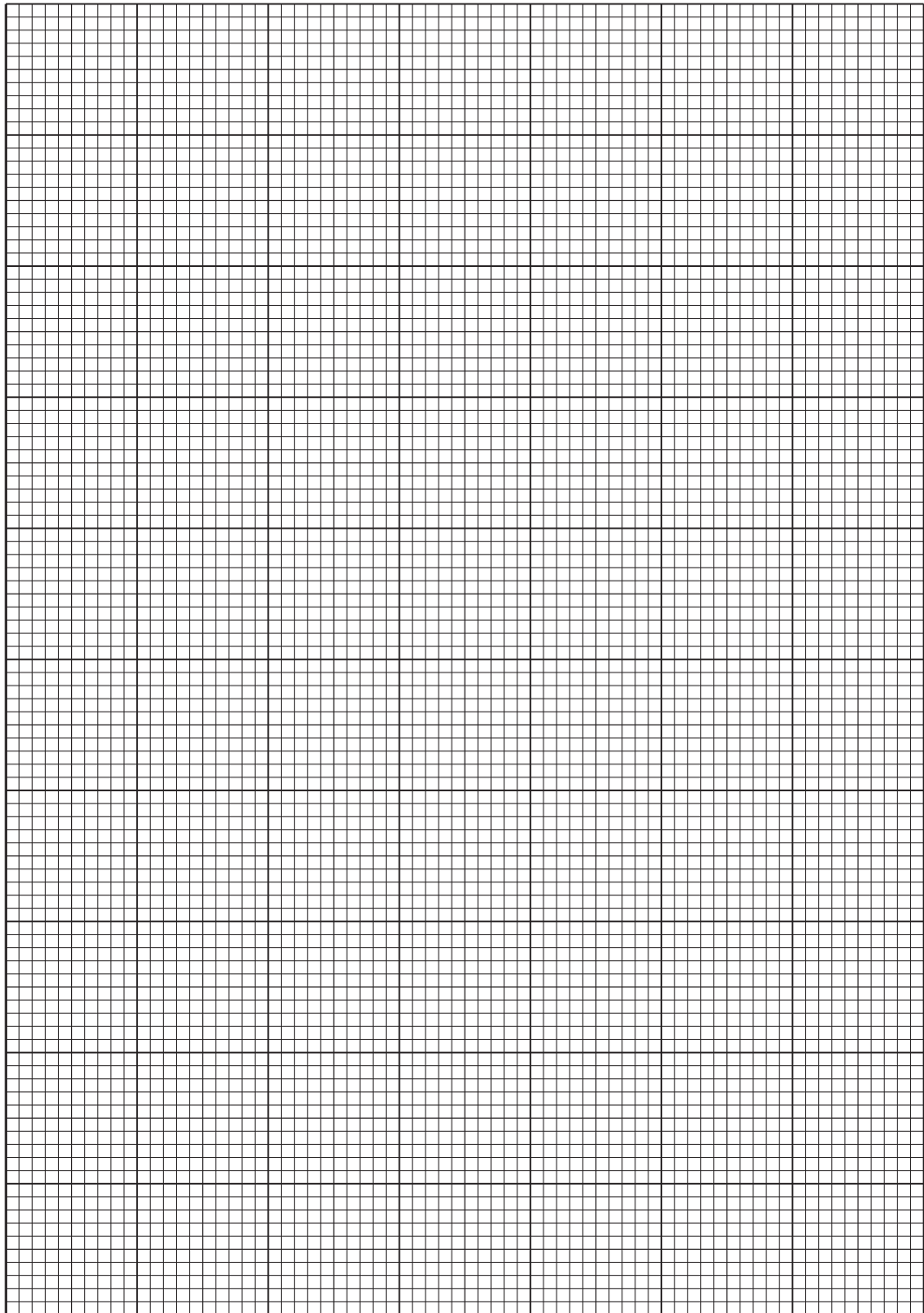
- (i) Complete the table.

[1]

- (ii) Plot a graph of $V_{\text{final}} - V_t$ (y-axis) against time, t (x-axis).

Use a cross (x) to plot each data point. Draw a curved line of best fit.

$V_{\text{final}} - V_t$
/ cm³



time, t/s

[2]

- (iii) Circle the point which you consider to be most anomalous.

[1]

- (iv) Suggest **one** reason for this anomalous point.

.....
 [1]

- (v) Draw construction lines on the graph to calculate two consecutive half-lives for this reaction. Use these half-lives to determine the mean half-life, $t_{\frac{1}{2}}$.

first half-life = ... s

second half-life = ... s

mean half-life, $t_{\frac{1}{2}}$ = ... s
 [2]

- (vi) The rate constant, k , for this reaction can be calculated using the following expression.

$$t_{\frac{1}{2}} = \frac{0.693}{k}$$

Calculate k .

If you did not obtain a value for $t_{\frac{1}{2}}$ in (v) you may use 95 seconds. This is **not** the correct answer.

k = ... s⁻¹ [1]

- (c) State how an increase in temperature would affect the value of k for this reaction. Explain your answer.

.....
 [1]

(d) Calcium carbonate is a component of antacid tablets.

An alternative method of studying the rate of reaction between calcium carbonate and hydrochloric acid is:

- Place one antacid tablet into a beaker.
- Add 50 cm³, **an excess**, of 2.0 mol dm⁻³ hydrochloric acid and start the stop-clock immediately.
- Record the time taken for the fizzing to stop.

(i) An antacid tablet typically contains 1.0 g of CaCO₃.

Complete columns A, B and C in the table to show four more concentrations of **excess** HCl(aq) which would allow this method to be carried out.

Each sample of HCl(aq) must be made by dilution of 2.0 mol dm⁻³ HCl.

[A_r: Ca, 40.1; C, 12.0; O, 16.0]

A	B	C	D
volume of 2.0 mol dm ⁻³ HCl /cm ³	volume of distilled water /cm ³	concentration of HCl /mol dm ⁻³	time taken for fizzing to stop /s
50.0	0.0	2.0	

[2]

(ii) Identify the dependent variable in this investigation.

..... [1]

(iii) Suggest how the reliability of the results could be improved.

.....
 [1]

[Total: 16]

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