



CANDIDATE
NAME

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CENTRE
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CANDIDATE
NUMBER

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9701/51

May/June 2024

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

- The total mark for this paper is 30.
- The number of marks for each question or part question is shown in brackets [].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

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

- 1 Titration can be used to determine the concentration of dissolved oxygen in samples of river water.

The procedure for the experiment is given.

- step 1** Use five 50 cm³ graduated syringes, **A**, **B**, **C**, **D** and **E**, to collect five separate 30.0 cm³ samples of river water.
- step 2** In the laboratory, carefully add 5.0 cm³ of 0.220 mol dm⁻³ manganese(II) sulfate, MnSO₄(aq), into syringe **A** and mix well.
- step 3** Add 5.0 cm³ of alkaline aqueous potassium iodide into syringe **A** and mix well.
- step 4** Add 10.0 cm³ of dilute sulfuric acid into syringe **A** and mix well.
- step 5** Transfer the contents of syringe **A** into a 150 cm³ conical flask. Rinse syringe **A** using 10 cm³ of distilled water and add washings to the conical flask.
- step 6** Carry out **one** accurate titration of all the contents in the conical flask with 0.00200 mol dm⁻³ aqueous sodium thiosulfate, Na₂S₂O₃(aq), using starch indicator.

Repeat steps 2–6 for the samples in syringes **B–E**.

(a) Aqueous sodium thiosulfate can be prepared from Na₂S₂O₃•5H₂O(s).

- (i) Determine the mass, in g, of Na₂S₂O₃•5H₂O(s) required to prepare 500.0 cm³ of 0.00200 mol dm⁻³ Na₂S₂O₃(aq).

mass of Na₂S₂O₃•5H₂O(s) = ... g [1]

- (ii) Identify the piece of apparatus that should be used to prepare 500.0 cm³ of 0.00200 mol dm⁻³ Na₂S₂O₃(aq) after the required mass of Na₂S₂O₃•5H₂O(s) has been weighed out.

..... [1]

(b) The graduations on each syringe are every 1.0 cm³.

- (i) Calculate the percentage error in the measurement of 5.0 cm³ of alkaline aqueous potassium iodide by the syringe.

Show your working.

percentage error = ... [1]

- (ii) Place **one** tick (✓) in each row in Table 1.1 to show the effect, if any, of using a larger volume of alkaline aqueous potassium iodide.

Table 1.1

	greater effect	no effect	smaller effect
uncertainty of the measurement			
percentage error of the measurement			

[1]

- (c) The sample in the conical flask and the prepared solution of sodium thiosulfate are provided. Describe the following procedures for the experiment using syringe **A**.

- (i) Preparing the clean burette before taking any readings.

.....

.....

.....

..... [2]

- (ii) Carrying out the **one** accurate titration in step 6.

.....

.....

.....

.....

..... [2]

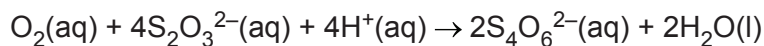
- (d) Suggest why the reaction mixture is mixed well in steps 2–4.

.....

..... [1]

- (e) Draw a table for recording the titration results for the five samples in syringes **A–E**.

- (f) The overall reaction taking place in the experiment is shown.



A student carries out the experiment and determines the mean titre to be 12.65 cm^3 .

Calculate the concentration, in mol dm^{-3} , of dissolved oxygen in the river water.

concentration of dissolved oxygen = ... mol dm^{-3} [2]

- (g) Freshly distilled water does **not** contain any dissolved oxygen.

A student decides to run the procedure on a sample of freshly distilled water and at the end obtains a value of $2.26 \times 10^{-5} \text{ mol dm}^{-3}$ dissolved oxygen.

- (i) Suggest why the student did **not** get a value of 0 mol dm^{-3} . Assume the procedure was carried out correctly.

.....
 [1]

- (ii) Suggest how the value of $2.26 \times 10^{-5} \text{ mol dm}^{-3}$ could be used to improve the answer in (f).

.....
 [1]

- (h) Suggest why this method is unsuitable for samples of tap water that have been purified by chlorination and so contain $\text{Cl}_2(\text{aq})$.

.....
 [1]

[Total: 16]

- 2 The activation energy, E_A , for the reaction between dilute hydrochloric acid, $\text{HCl}(\text{aq})$, and aqueous sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$, can be determined by an initial rates method.



The solid sulfur formed is seen as a white suspension in the reaction mixture. The reactants are mixed and the time, t , for a fixed quantity of sulfur to be formed is recorded.

A measure of the initial rate of the reaction is $\frac{1}{t}$.

Standard solutions of $0.100 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$ and $0.500 \text{ mol dm}^{-3} \text{ HCl}(\text{aq})$ are supplied.

Measurements are taken for a series of temperatures using the following procedure.

- step 1** A thermostatically controlled water bath is set up.
- step 2** A 100 cm^3 conical flask is labelled **A** and a second 100 cm^3 conical flask is labelled **B**.
- step 3** 10.00 cm^3 of $0.100 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$ is added to flask **A**. Flask **A** is placed in the water bath.
- step 4** 10 cm^3 of $0.500 \text{ mol dm}^{-3} \text{ HCl}(\text{aq})$ is added to flask **B**. Flask **B** is placed in the same water bath.
- step 5** Wait for 10 minutes.
- step 6** Flask **A** is removed from the water bath and placed on a tile marked with a black cross.
- step 7** The contents of flask **B** are added to flask **A** and a timer started.
- step 8** The timer is stopped when the black cross is no longer visible. The time is recorded.

- (a) Suggest a reason why it is necessary to wait for 10 minutes in step 5.

..... [1]

- (b) The procedure does not mention how a value for the temperature of the mixture during the reaction is obtained.

- (i) State the temperature measurements that should be taken and at which stage in the procedure they should be taken.

.....
 [1]

- (ii) State how to use the temperature measurements to determine an accurate value for the temperature of the mixture during the reaction.

.....
 [1]

- (c) A student carries out the procedure at three different temperatures and records the measurements in Table 2.1.

Complete Table 2.1. Record values for temperature to the nearest whole number and the values for $\frac{1}{t}$ to **four** decimal places.

Table 2.1

temperature, $T/^{\circ}\text{C}$	time, t/s	temperature, T/K	$\frac{1}{t}/\text{s}^{-1}$
15	176		
24	92		
32	62		

[2]

- (d) A second student carries out the procedure at six different temperatures and analyses their data to give the results in Table 2.2.

Table 2.2

$\frac{1}{T}/\text{K}^{-1}$	$\log\left(\frac{1}{t}\right)$
0.00353	−2.43
0.00336	−1.99
0.00325	−1.68
0.00314	−1.47
0.00302	−1.21
0.00287	−0.82

- (i) Use the results from Table 2.2 to plot a graph on the grid in Fig. 2.1 to show the relationship between $\log\left(\frac{1}{t}\right)$ and $\frac{1}{T}$. Use a cross (x) to plot each data point. Draw a line of best fit.

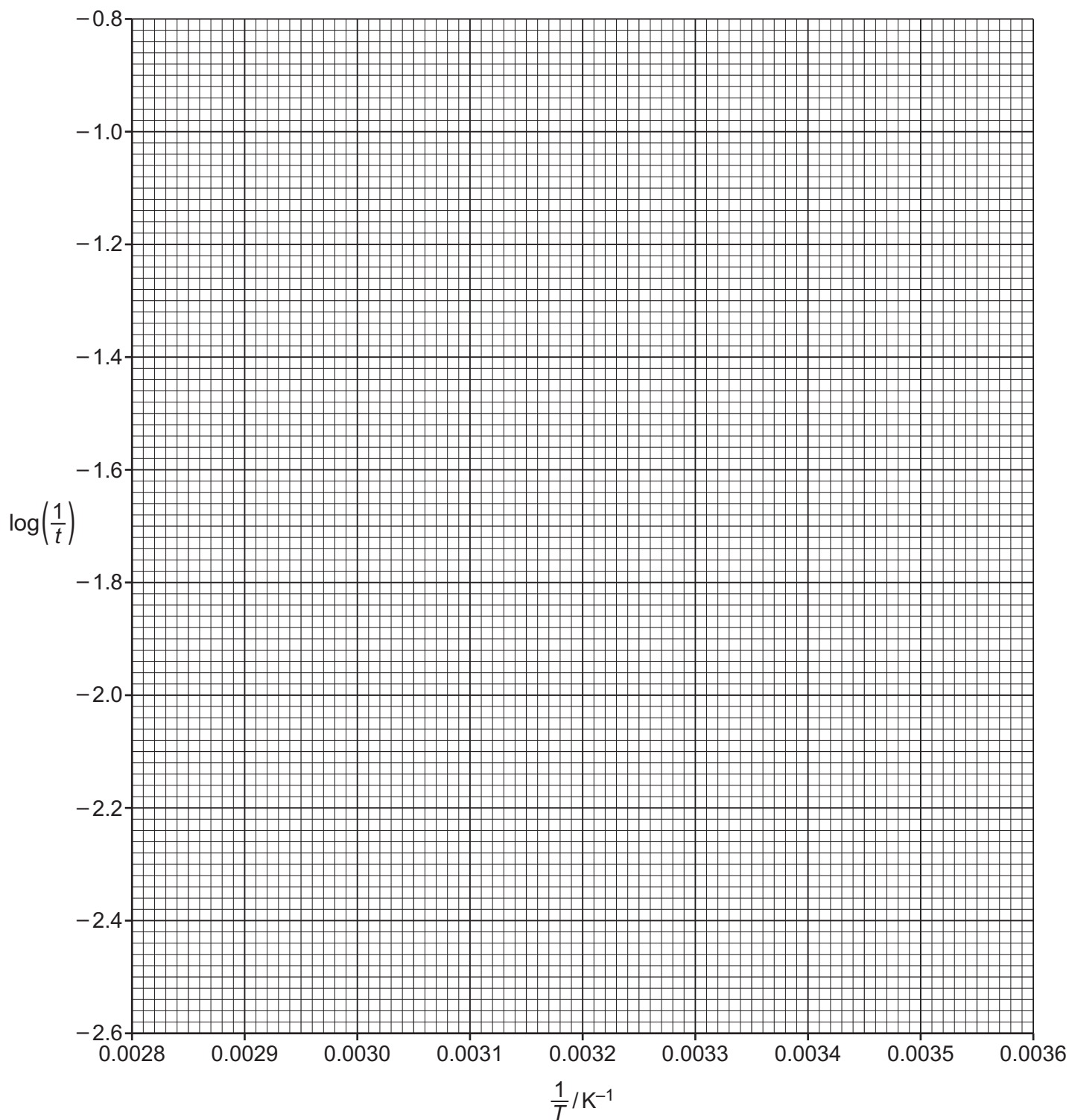


Fig. 2.1

[2]

- (ii) Determine the gradient of your line of best fit in Fig. 2.1. State the coordinates of both points you use in your calculation. These must be selected from your line of best fit. Give the gradient to **three** significant figures.

coordinates 1 coordinates 2

gradient = ... K
[2]

- (iii) An equation relating time and temperature variables is shown.

$$\log\left(\frac{1}{t}\right) = -\frac{0.434E_A}{RT} + \text{constant}$$

Determine the activation energy, E_A , of this reaction using this equation and your answer to (d)(ii).

(If you were unable to find the gradient in (d)(ii), then use the value $-3.21 \times 10^3 \text{ K}$. This is **not** the correct answer.)

Include units in your answer.

Show your working.

E_A = ...

units = ...
[3]

- (iv) Use your graph to state whether the results from the experiment are reliable. Justify your answer.

.....
..... [1]

- (e) Suggest a change to **one** controlled variable that the student could make so that the time measured for a given temperature is shorter.

.....
..... [1]

[Total: 14]

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Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

The Periodic Table of Elements

Group																									
1	2	Key										13	14	15	16	17	18								
		atomic number atomic symbol name relative atomic mass										1 H hydrogen 1.0							2 He helium 4.0						
3	4											5	6	7	8	9									
Li lithium 6.9	Be beryllium 9.0											B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0	F fluorine 19.0	Ne neon 20.2								
11	12											13	14	15	16	17	18								
Na sodium 23.0	Mg magnesium 24.3											Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5	Ar argon 39.9								
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36								
K potassium 39.1	Ca calcium 40.1	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8								
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54								
Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3								
55	56	57–71 lanthanoids	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86								
Cs caesium 132.9	Ba barium 137.3											Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —								
87	88	89–103 actinoids	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118								
Fr francium —	Ra radium —											Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganesson —								

lanthanoids

actinoids

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
lanthanum	cerium	praseodymium	neodymium	promethium	samarium	europlum	gadolinium	terbium	dysprosium	holmium	erbium	thulium	ytterbium	lutetium
138.9	140.1	140.9	144.2	—	150.4	152.0	157.3	158.9	162.5	164.9	167.3	168.9	173.1	175.0
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
actinium	thorium	protactinium	uranium	neptunium	plutonium	americium	curium	berkelium	californium	einsteinium	fermium	mendelevium	nobelium	lawrencium
—	232.0	231.0	238.0	—	—	—	—	—	—	—	—	—	—	—



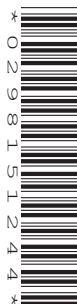
Cambridge International AS & A Level

CANDIDATE
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NUMBER

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CHEMISTRY

9701/52

Paper 5 Planning, Analysis and Evaluation

May/June 2024

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
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INFORMATION

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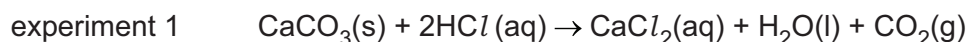


- 1 Calcium carbonate, $\text{CaCO}_3(\text{s})$, decomposes when heated, as shown.

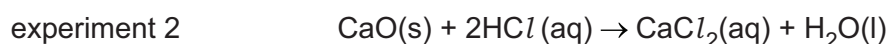


The enthalpy change of reaction, ΔH_r , for the thermal decomposition of $\text{CaCO}_3(\text{s})$ **cannot** be measured directly. Instead, a procedure involving two experiments is used. In each experiment, the enthalpy change of a different reaction is determined.

The equation for the reaction in experiment 1 is shown. The enthalpy change for this reaction is ΔH_1 .



The equation for the reaction in experiment 2 is shown. The enthalpy change for this reaction is ΔH_2 .



Experiment 1

- step 1** Weigh a 0.0500 mol sample of powdered $\text{CaCO}_3(\text{s})$.
- step 2** Transfer 50.00 cm³, an excess, of 2.00 mol dm⁻³ hydrochloric acid, $\text{HCl}(\text{aq})$, into a small glass beaker.
- step 3** Start a timer and measure the temperature of the $\text{HCl}(\text{aq})$ in the beaker every 30 seconds for 2 $\frac{1}{2}$ minutes.
- step 4** After 3 minutes add the sample of $\text{CaCO}_3(\text{s})$ to the $\text{HCl}(\text{aq})$ in the beaker. Continue measuring the temperature of the reaction mixture every 30 seconds for a further 5 minutes.

Experiment 2

Repeat experiment 1 using calcium oxide, $\text{CaO}(\text{s})$, instead of $\text{CaCO}_3(\text{s})$.

- (a) Suggest why the enthalpy change of reaction for the thermal decomposition of calcium carbonate **cannot** be measured directly.

..... [1]

- (b) (i) Calculate the mass, in g, of $\text{CaCO}_3(\text{s})$ to be weighed using a two-decimal-place balance in step 1.

mass of $\text{CaCO}_3(\text{s})$ = ... g [1]





- (ii) Outline how a student should weigh by difference using a weighing boat in order to determine the exact mass of $\text{CaCO}_3(\text{s})$ added to $\text{HCl}(\text{aq})$ in the beaker. Draw a results table, with appropriate headings, ready for the student to complete.

.....

.....

[2]

- (c) Identify which piece of apparatus should be used to measure the volume of $\text{HCl}(\text{aq})$ in step 2 and give a reason for your choice.

.....

..... [1]

- (d) Without making any changes to the apparatus, suggest an instruction to be added to step 3 and step 4 to make the experiment more accurate.

..... [1]





(e) A student carries out experiment 1 and obtains the results given in Table 1.1.

Table 1.1

time / minutes	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
temperature / °C	19.0	19.0	19.0	19.0	19.0		27.5	36.0	34.5	32.5	32.0	31.0

time / minutes	6.5	7.0	7.5	8.0
temperature / °C	29.0	28.0	26.0	25.5

- (i) Plot a graph on the grid in Fig. 1.1 to show the relationship between temperature and time. Use a cross (×) to plot each data point.

The points and line of best fit for the data before 3 minutes have been drawn for you. Draw a line of best fit for the data after 3 minutes that will enable you to determine the theoretical temperature increase at 3.0 minutes.

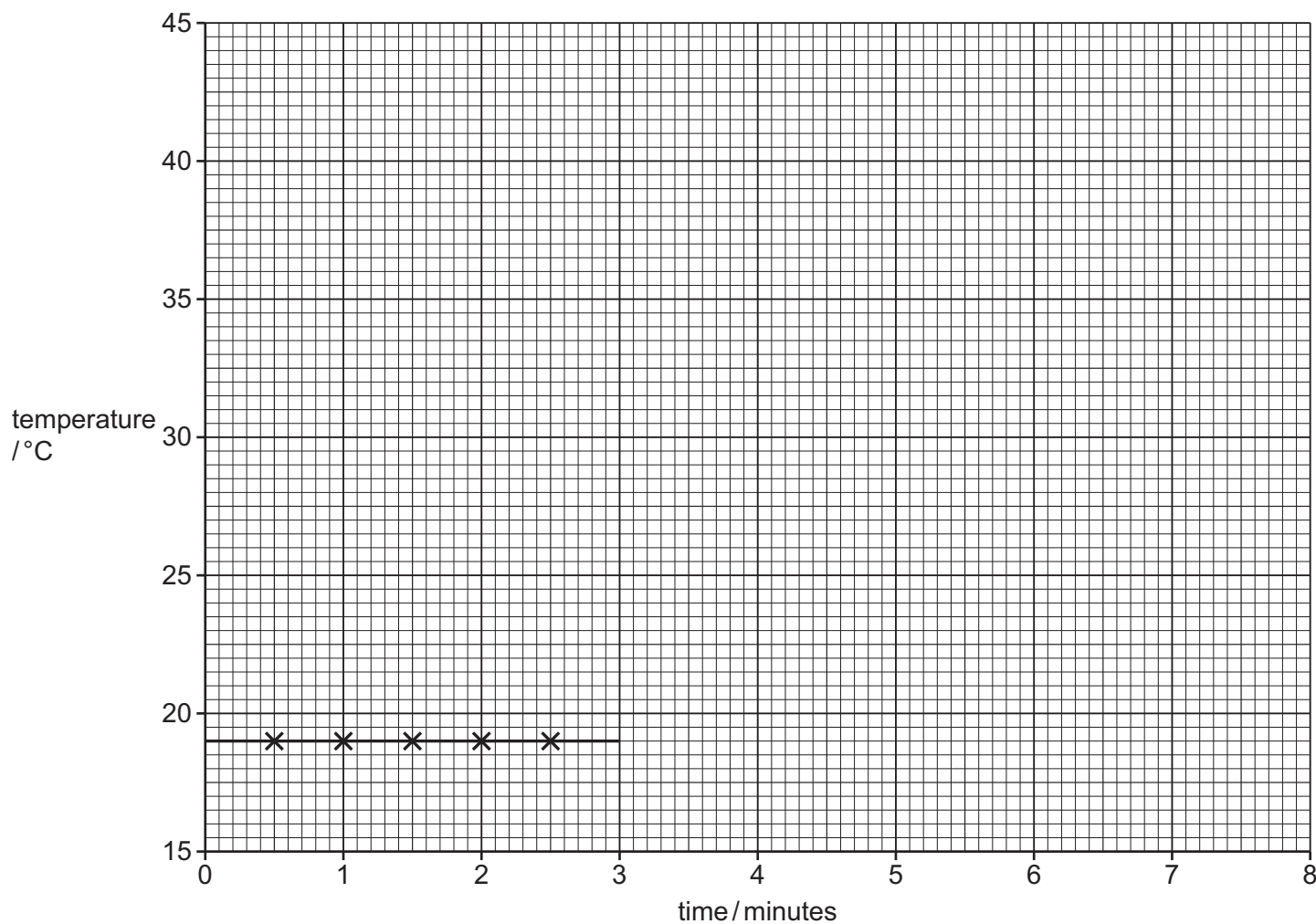


Fig. 1.1

[2]

- (ii) Use your graph to determine the theoretical temperature increase at 3.0 minutes.

theoretical temperature increase at 3.0 minutes = ... °C [1]



- (f) Suggest why the temperature measured at 3.5 minutes is lower than the temperature measured at 4.0 minutes.

..... [1]

- (g) A student carries out experiment 2 and determines a temperature increase of 62.0°C . The heat released by the reaction, q , is given by:

$$q = mc\Delta T$$

where m is the mass of $\text{HCl}(\text{aq})$. Assume that 1.00 cm^3 of $\text{HCl}(\text{aq})$ has a mass of 1.00 g and that the specific heat capacity of the solution, c , is $4.18\text{ J g}^{-1}\text{ K}^{-1}$.

Calculate q , in J, for experiment 2 and hence determine ΔH_2 in kJ mol^{-1} .

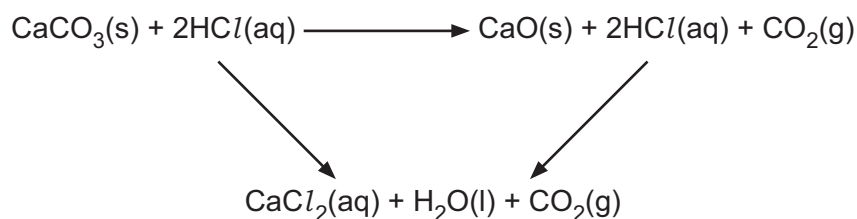
$$q = \dots\dots\dots \text{ J}$$

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

- (h) Use the energy cycle below, your answer to (g) and the information given to determine ΔH_r for the thermal decomposition of CaCO_3 .

Enthalpy change for experiment 1, $\Delta H_1 = -84\text{ kJ mol}^{-1}$.

(If you were unable to calculate a final answer in (g), assume a value of 179 kJ mol^{-1} . This is **not** the correct answer and the sign has been omitted.)



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

- (i) Identify the main weakness of the experimental procedure and suggest **one** improvement to overcome this weakness. The main weakness is **not** the type of thermometer used.

main weakness

improvement

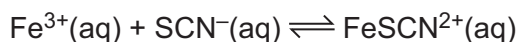
..... [2]

[Total: 15]





- 2 This question is about an experiment to investigate the effect of temperature on the equilibrium constant, K_1 , of the reaction shown.



The data collected is used to determine the value of the enthalpy change of the reaction.

To set up the equilibrium, aqueous iron(III) nitrate, $\text{Fe}(\text{NO}_3)_3(\text{aq})$, is mixed with aqueous potassium thiocyanate, $\text{KSCN}(\text{aq})$. Aqueous iron thiocyanate ions, $\text{FeSCN}^{2+}(\text{aq})$, have a red colour.

A colorimeter is used to measure the absorbance of the reaction mixture. A calibration graph can then be used to determine the concentration of $\text{FeSCN}^{2+}(\text{aq})$ in the reaction mixture.

Table 2.1 shows the solutions for the experiments.

Table 2.1

solution	ion	concentration / mol dm^{-3}
A	$\text{SCN}^{-}(\text{aq})$	0.00920
B	$\text{SCN}^{-}(\text{aq})$	0.00200
C	$\text{Fe}^{3+}(\text{aq})$	0.00200
D	$\text{Fe}^{3+}(\text{aq})$	0.500

- (a) Describe how you would prepare 100.0 cm^3 of solution **B** from solution **A**.

Include a calculation of the volume of solution **A** required for the preparation of solution **B**. Give the name and capacity of any key apparatus that should be used.

Write your answer as a series of numbered steps.

.....

.....

.....

.....

.....

.....

.....

..... [3]



- (b) Before starting the experiment, solutions **B** and **D** are used to produce a calibration graph. Known volumes of each solution are added together and the absorbance for each mixture is recorded. The calibration graph is shown in Fig. 2.1.

The concentration of solution **D** is much greater than the concentration of solution **B** in order that solution **D** is in excess. Suggest a reason why solution **D** is in excess.

..... [1]

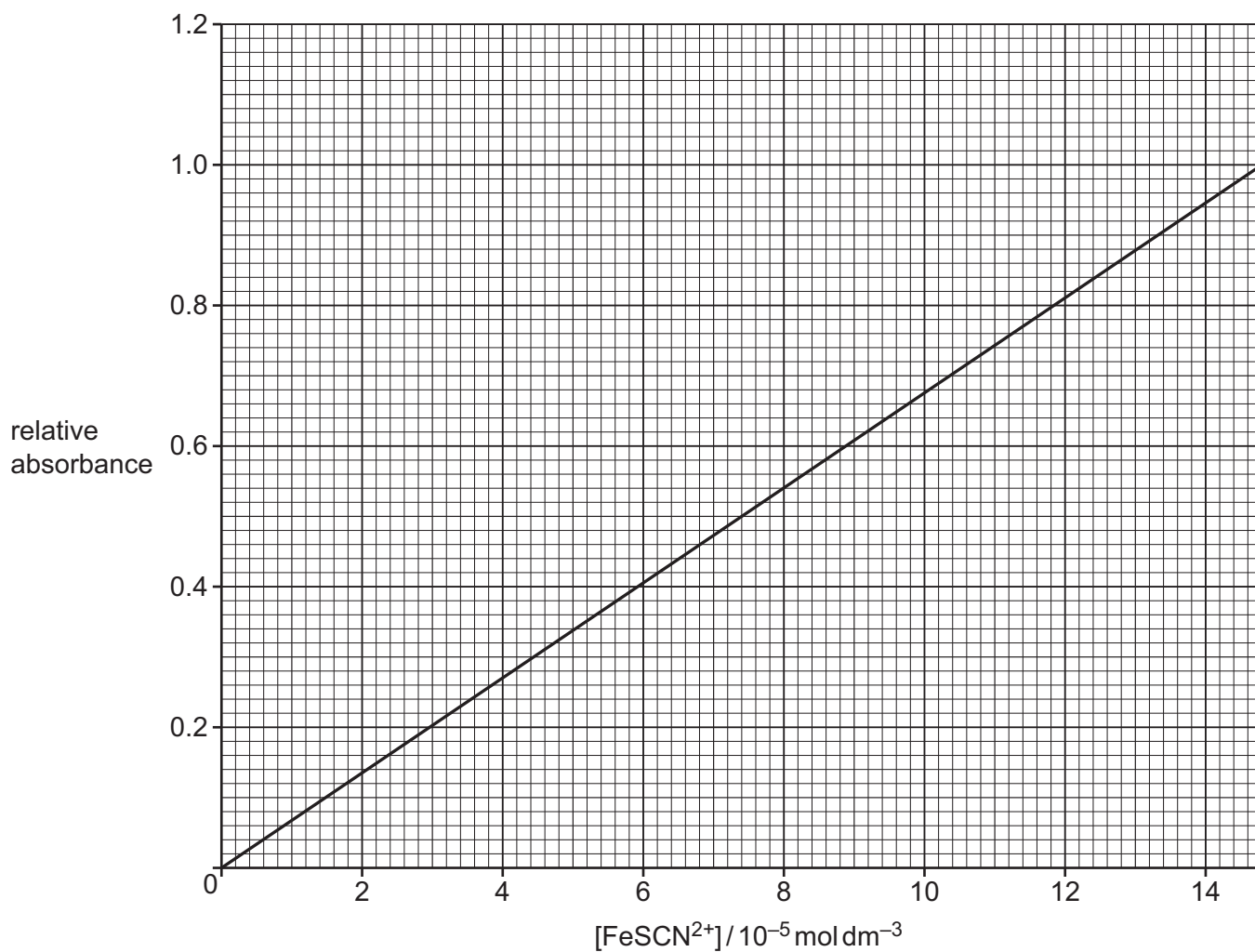


Fig. 2.1





(c) The following experimental procedure is used.

- step 1** Half-fill a large beaker with water at room temperature (25 °C).
- step 2** Transfer about 40 cm³ of solution **B** into a boiling tube and place the boiling tube in the beaker of water.
- step 3** Transfer 5.00 cm³ of solution **C** into a test-tube and place the test-tube in the beaker of water.
- step 4** Wait for 10 minutes.
- step 5** Transfer 5.00 cm³ of solution **B** from the boiling tube to the test-tube containing solution **C**. Stir the mixture in the test-tube and record the temperature of the mixture.
- step 6** Measure the absorbance of the mixture in the test-tube using the colorimeter.

Change the temperature of the water in the beaker and repeat **steps 3 to 6** for different temperatures.

(i) Identify the dependent variable.

..... [1]

(ii) Describe how you would adjust the temperature of the water in the large beaker to obtain a temperature of 10 °C.

..... [1]

(d) A student obtains the results given in Table 2.2.

Table 2.2

1	2	3	4
temperature / °C	relative absorbance	[FeSCN ²⁺] / 10 ⁻⁵ mol dm ⁻³	K_1
25	0.60		
55	0.42		

The value of the equilibrium constant, K_1 , can be determined using equation 1.

$$\text{equation 1} \quad K_1 = \frac{x}{(0.0010 - x)^2}$$

x is the value of [FeSCN²⁺] in mol dm⁻³.

(i) Use the calibration graph in Fig. 2.1 to complete column 3 in Table 2.2.
Record values to **one** decimal place.

[1]

(ii) Use equation 1 to complete column 4 in Table 2.2.
Record values to the nearest whole number.

[1]



- (e) Another student does the same experiment for seven different temperatures, plots a graph and draws the line of best fit, as shown in Fig. 2.2.

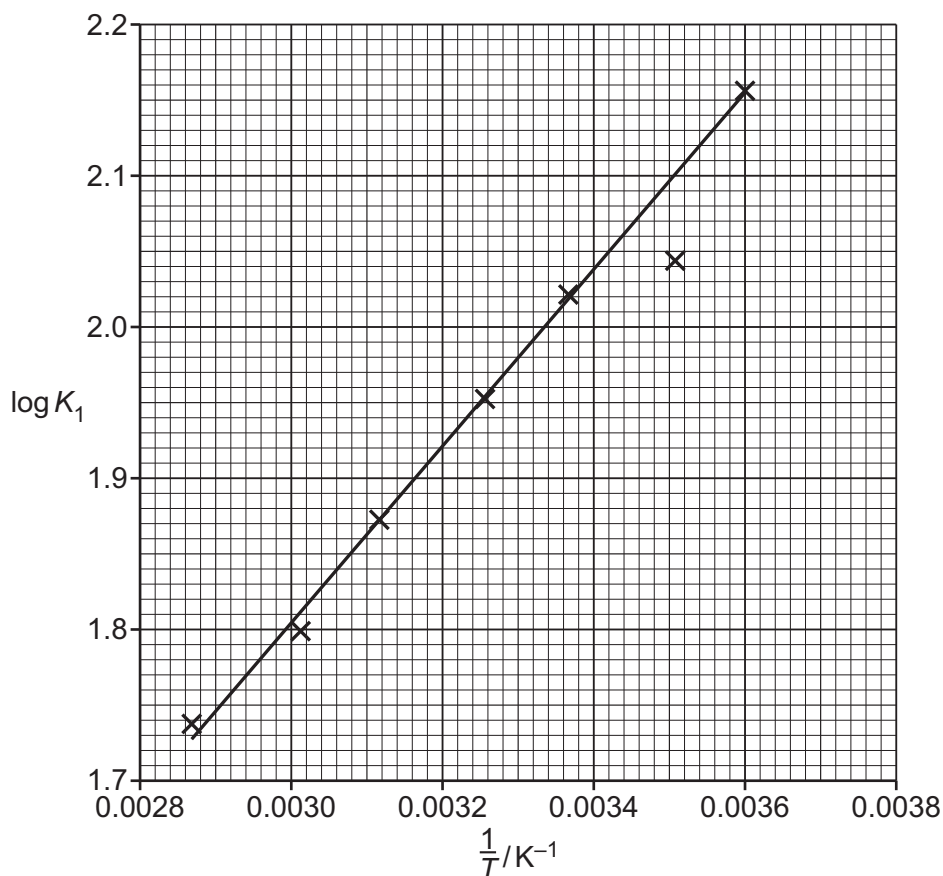


Fig. 2.2

Theory predicts that the relationship between K_1 and T is given by equation 2.

$$\text{equation 2} \quad \log K_1 = \frac{-\Delta H}{2.303RT} + \text{constant}$$

ΔH is the enthalpy change of reaction and T is the temperature in Kelvin.

- (i) Explain why the graph supports the relationship between K_1 and T given in equation 2.

..... [1]

- (ii) Circle the point on the graph in Fig. 2.2 that you consider to be most anomalous.

There were no errors in the measurements in the experiment.

A student correctly suggests that the anomaly was caused because the absorbance was lower than expected by the line of best fit. Suggest why the absorbance was lower than expected.

..... [2]





- (iii) Determine the gradient of the line of best fit in Fig. 2.2. State the coordinates of both points you use in your calculation. These must be selected from the line of best fit. Give the gradient to **three** significant figures.

coordinates 1 coordinates 2

gradient = ... K
[2]

- (iv) Use the gradient calculated in (e)(iii) and equation 2 to calculate a value for the enthalpy change of reaction, ΔH .

$$\text{equation 2} \quad \log K_1 = \frac{-\Delta H}{2.303RT} + \text{constant}$$

(If you were unable to obtain an answer to (e)(iii), then use the value 635 K. This is **not** the correct answer.)

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

[Total: 15]



Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)





The Periodic Table of Elements

Group																			
1	2	Key										13	14	15	16	17	18		
		atomic number atomic symbol name relative atomic mass										1 H hydrogen 1.0							
3	4											5	6	7	8	9	10	11	12
Li lithium 6.9	Be beryllium 9.0											B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0	F fluorine 19.0	Ne neon 20.2		
11	12											13	14	15	16	17	18		
Na sodium 23.0	Mg magnesium 24.3											Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5	Ar argon 39.9		
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
K potassium 39.1	Ca calcium 40.1	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8		
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54		
Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3		
55	56	lanthanoids		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	
Cs caesium 132.9	Ba barium 137.3			Hf hafnium 178.5	Ta tantalum 180.9	W tungsten 183.8	Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —	
87	88	actinoids		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	
Fr francium —	Ra radium —			Rf rutherfordium —	Db dubnium —	Sg seaborgium —	Bh bohrium —	Hs hassium —	Mt meitnerium —	Ds darmstadtium —	Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganeson —	

lanthanoids														
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La lanthanum 138.9	Ce cerium 140.1	Pr praseodymium 140.9	Nd neodymium 144.2	Pm promethium —	Sm samarium 150.4	Eu europium 152.0	Gd gadolinium 157.3	Tb terbium 158.9	Dy dysprosium 162.5	Ho holmium 164.9	Er erbium 167.3	Tm thulium 168.9	Yb ytterbium 173.1	Lu lutetium 175.0
actinoids														
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac actinium —	Th thorium 232.0	Pa protactinium 231.0	U uranium 238.0	Np neptunium —	Pu plutonium —	Am americium —	Cm curium —	Bk berkelium —	Cf californium —	Es einsteinium —	Fm fermium —	Md mendelevium —	No nobelium —	Lr lawrencium —





* 0 1 3 0 5 7 2 5 5 7 *

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9701/53

May/June 2024

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

- The total mark for this paper is 30.
- The number of marks for each question or part question is shown in brackets [].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

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

- 1 Titration can be used to determine the concentration of dissolved oxygen in samples of river water.

The procedure for the experiment is given.

- step 1** Use five 50 cm³ graduated syringes, **A**, **B**, **C**, **D** and **E**, to collect five separate 30.0 cm³ samples of river water.
- step 2** In the laboratory, carefully add 5.0 cm³ of 0.220 mol dm⁻³ manganese(II) sulfate, MnSO₄(aq), into syringe **A** and mix well.
- step 3** Add 5.0 cm³ of alkaline aqueous potassium iodide into syringe **A** and mix well.
- step 4** Add 10.0 cm³ of dilute sulfuric acid into syringe **A** and mix well.
- step 5** Transfer the contents of syringe **A** into a 150 cm³ conical flask. Rinse syringe **A** using 10 cm³ of distilled water and add washings to the conical flask.
- step 6** Carry out **one** accurate titration of all the contents in the conical flask with 0.00200 mol dm⁻³ aqueous sodium thiosulfate, Na₂S₂O₃(aq), using starch indicator.

Repeat steps 2–6 for the samples in syringes **B–E**.

(a) Aqueous sodium thiosulfate can be prepared from Na₂S₂O₃•5H₂O(s).

- (i) Determine the mass, in g, of Na₂S₂O₃•5H₂O(s) required to prepare 500.0 cm³ of 0.00200 mol dm⁻³ Na₂S₂O₃(aq).

mass of Na₂S₂O₃•5H₂O(s) = ... g [1]

- (ii) Identify the piece of apparatus that should be used to prepare 500.0 cm³ of 0.00200 mol dm⁻³ Na₂S₂O₃(aq) after the required mass of Na₂S₂O₃•5H₂O(s) has been weighed out.

..... [1]

(b) The graduations on each syringe are every 1.0 cm³.

- (i) Calculate the percentage error in the measurement of 5.0 cm³ of alkaline aqueous potassium iodide by the syringe.

Show your working.

percentage error = ... [1]

- (ii) Place **one** tick (✓) in each row in Table 1.1 to show the effect, if any, of using a larger volume of alkaline aqueous potassium iodide.

Table 1.1

	greater effect	no effect	smaller effect
uncertainty of the measurement			
percentage error of the measurement			

[1]

- (c) The sample in the conical flask and the prepared solution of sodium thiosulfate are provided. Describe the following procedures for the experiment using syringe **A**.

- (i) Preparing the clean burette before taking any readings.

.....

 [2]

- (ii) Carrying out the **one** accurate titration in step 6.

.....

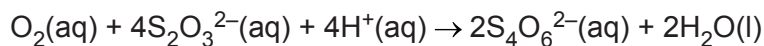
 [2]

- (d) Suggest why the reaction mixture is mixed well in steps 2–4.

.....
 [1]

- (e) Draw a table for recording the titration results for the five samples in syringes **A–E**.

- (f) The overall reaction taking place in the experiment is shown.



A student carries out the experiment and determines the mean titre to be 12.65 cm^3 .

Calculate the concentration, in mol dm^{-3} , of dissolved oxygen in the river water.

concentration of dissolved oxygen = ... mol dm^{-3} [2]

- (g) Freshly distilled water does **not** contain any dissolved oxygen.

A student decides to run the procedure on a sample of freshly distilled water and at the end obtains a value of $2.26 \times 10^{-5} \text{ mol dm}^{-3}$ dissolved oxygen.

- (i) Suggest why the student did **not** get a value of 0 mol dm^{-3} . Assume the procedure was carried out correctly.

.....
 [1]

- (ii) Suggest how the value of $2.26 \times 10^{-5} \text{ mol dm}^{-3}$ could be used to improve the answer in (f).

.....
 [1]

- (h) Suggest why this method is unsuitable for samples of tap water that have been purified by chlorination and so contain $\text{Cl}_2(\text{aq})$.

.....
 [1]

[Total: 16]

- 2 The activation energy, E_A , for the reaction between dilute hydrochloric acid, $\text{HCl}(\text{aq})$, and aqueous sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$, can be determined by an initial rates method.



The solid sulfur formed is seen as a white suspension in the reaction mixture. The reactants are mixed and the time, t , for a fixed quantity of sulfur to be formed is recorded.

A measure of the initial rate of the reaction is $\frac{1}{t}$.

Standard solutions of $0.100 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$ and $0.500 \text{ mol dm}^{-3} \text{ HCl}(\text{aq})$ are supplied.

Measurements are taken for a series of temperatures using the following procedure.

- step 1** A thermostatically controlled water bath is set up.
- step 2** A 100 cm^3 conical flask is labelled **A** and a second 100 cm^3 conical flask is labelled **B**.
- step 3** 10.00 cm^3 of $0.100 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$ is added to flask **A**. Flask **A** is placed in the water bath.
- step 4** 10 cm^3 of $0.500 \text{ mol dm}^{-3} \text{ HCl}(\text{aq})$ is added to flask **B**. Flask **B** is placed in the same water bath.
- step 5** Wait for 10 minutes.
- step 6** Flask **A** is removed from the water bath and placed on a tile marked with a black cross.
- step 7** The contents of flask **B** are added to flask **A** and a timer started.
- step 8** The timer is stopped when the black cross is no longer visible. The time is recorded.

- (a) Suggest a reason why it is necessary to wait for 10 minutes in step 5.

..... [1]

- (b) The procedure does not mention how a value for the temperature of the mixture during the reaction is obtained.

- (i) State the temperature measurements that should be taken and at which stage in the procedure they should be taken.

.....
 [1]

- (ii) State how to use the temperature measurements to determine an accurate value for the temperature of the mixture during the reaction.

.....
 [1]

- (c) A student carries out the procedure at three different temperatures and records the measurements in Table 2.1.

Complete Table 2.1. Record values for temperature to the nearest whole number and the values for $\frac{1}{t}$ to **four** decimal places.

Table 2.1

temperature, $T/^{\circ}\text{C}$	time, t/s	temperature, T/K	$\frac{1}{t}/\text{s}^{-1}$
15	176		
24	92		
32	62		

[2]

- (d) A second student carries out the procedure at six different temperatures and analyses their data to give the results in Table 2.2.

Table 2.2

$\frac{1}{T}/\text{K}^{-1}$	$\log\left(\frac{1}{t}\right)$
0.00353	−2.43
0.00336	−1.99
0.00325	−1.68
0.00314	−1.47
0.00302	−1.21
0.00287	−0.82

- (i) Use the results from Table 2.2 to plot a graph on the grid in Fig. 2.1 to show the relationship between $\log\left(\frac{1}{t}\right)$ and $\frac{1}{T}$. Use a cross (x) to plot each data point. Draw a line of best fit.

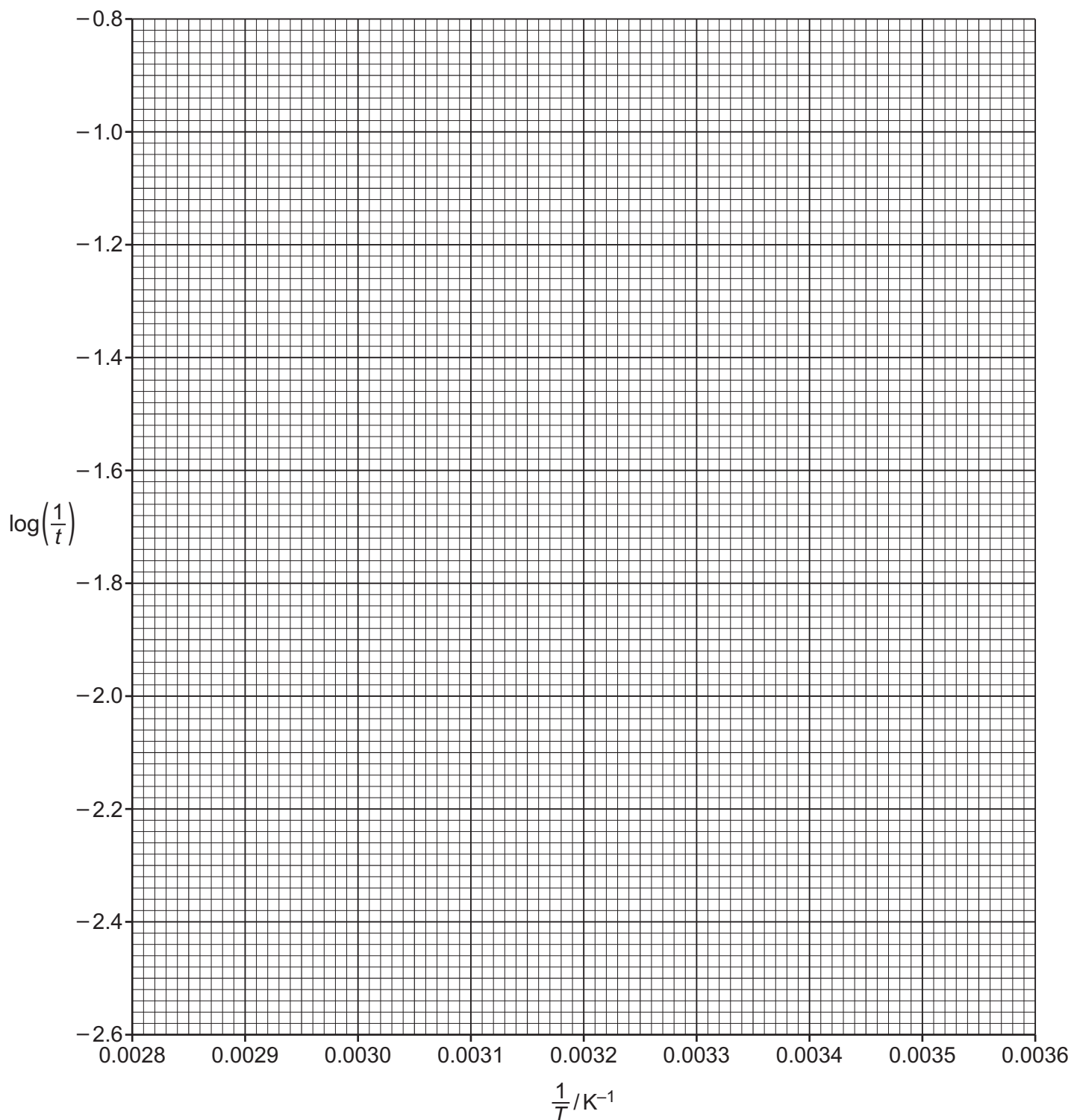


Fig. 2.1

[2]

- (ii) Determine the gradient of your line of best fit in Fig. 2.1. State the coordinates of both points you use in your calculation. These must be selected from your line of best fit. Give the gradient to **three** significant figures.

coordinates 1 coordinates 2

gradient = ... K
[2]

- (iii) An equation relating time and temperature variables is shown.

$$\log\left(\frac{1}{t}\right) = -\frac{0.434E_A}{RT} + \text{constant}$$

Determine the activation energy, E_A , of this reaction using this equation and your answer to (d)(ii).

(If you were unable to find the gradient in (d)(ii), then use the value $-3.21 \times 10^3 \text{ K}$. This is **not** the correct answer.)

Include units in your answer.

Show your working.

E_A = ...

units = ...
[3]

- (iv) Use your graph to state whether the results from the experiment are reliable. Justify your answer.

.....
..... [1]

- (e) Suggest a change to **one** controlled variable that the student could make so that the time measured for a given temperature is shorter.

.....
..... [1]

[Total: 14]

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Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
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specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

The Periodic Table of Elements

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11	12											13	14	15	16	17	18								
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19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36								
K potassium 39.1	Ca calcium 40.1	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8								
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87	88	89–103 actinoids	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118								
Fr francium —	Ra radium —											Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganesson —								

lanthanoids

actinoids

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
lanthanum	cerium	praseodymium	neodymium	promethium	samarium	europlum	gadolinium	terbium	dysprosium	holmium	erbium	thulium	ytterbium	lutetium
138.9	140.1	140.9	144.2	—	150.4	152.0	157.3	158.9	162.5	164.9	167.3	168.9	173.1	175.0
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
actinium	thorium	protactinium	uranium	neptunium	plutonium	americium	curium	berkelium	californium	einsteinium	fermium	mendelevium	nobelium	lawrencium
—	232.0	231.0	238.0	—	—	—	—	—	—	—	—	—	—	—