



CANDIDATE
NAME

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CENTRE
NUMBER

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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.

.....

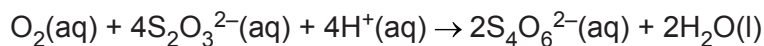
 [2]

- (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.

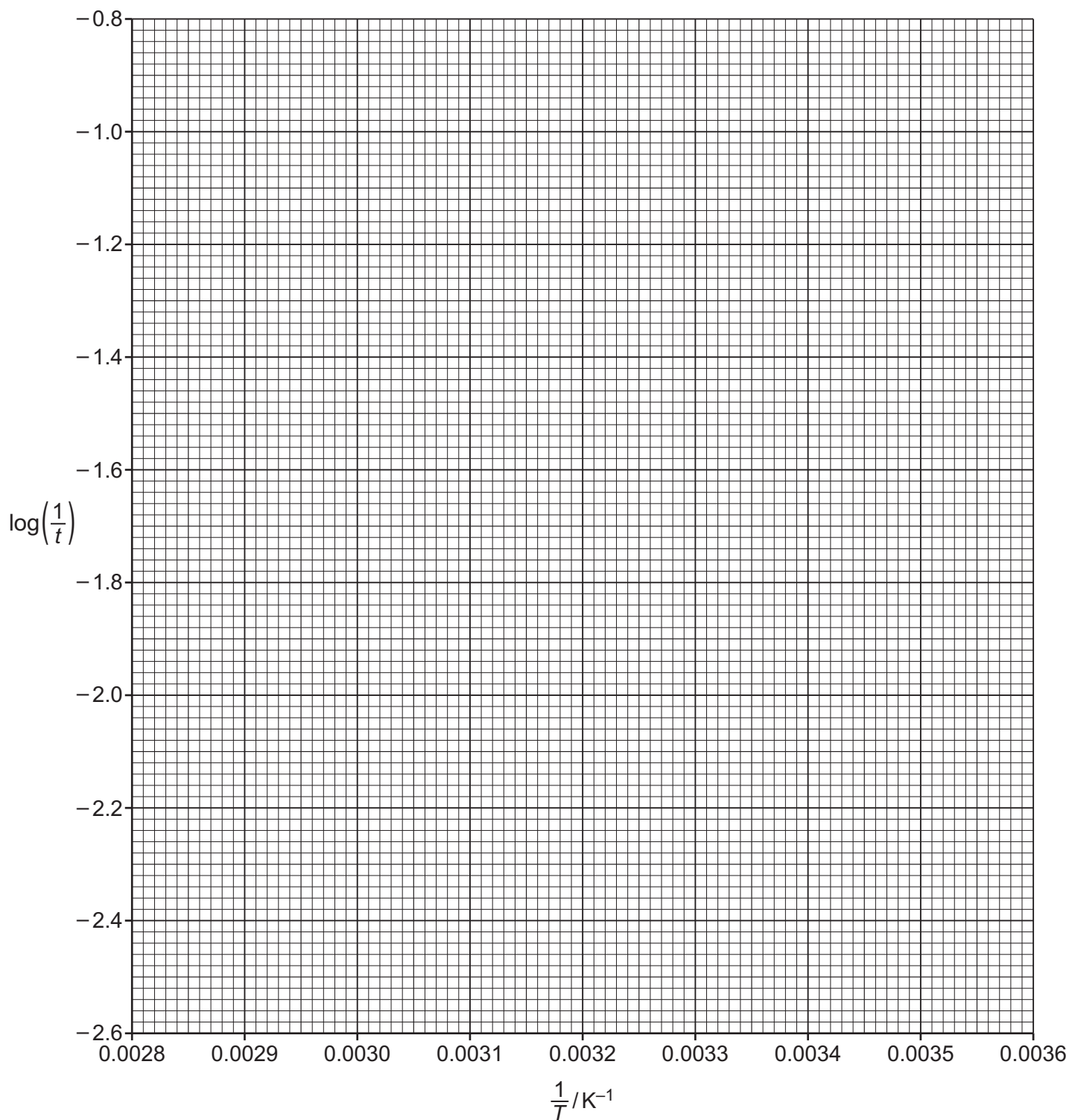


Fig. 2.1

[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 1Hhydrogen1.0												13	14	15	16	17	18								
3	4	atomic number atomic symbol name relative atomic mass												5	6	7	8	9	10	11	12	13	14	15	16	17	18
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								
11Na sodium 23.0	12Mg magnesium 24.3													13Al aluminium 27.0	14Si silicon 28.1	15P phosphorus 31.0	16S sulfur 32.1	17Cl chlorine 35.5	18Ar argon 39.9								
19K potassium 39.1	20Ca calcium 40.1	21Sc scandium 45.0	22Ti titanium 47.9	23V vanadium 50.9	24Cr chromium 52.0	25Mn manganese 54.9	26Fe iron 55.8	27Co cobalt 58.9	28Ni nickel 58.7	29Cu copper 63.5	30Zn zinc 65.4	31Ga gallium 69.7	32Ge germanium 72.6	33As arsenic 74.9	34Se selenium 79.0	35Br bromine 79.9	36Kr krypton 83.8										
37Rb rubidium 85.5	38Sr strontium 87.6	39Y yttrium 88.9	40Zr zirconium 91.2	41Nb niobium 92.9	42Mo molybdenum 95.9	43Tc technetium	44Ru ruthenium 101.1	45Rh rhodium 102.9	46Pd palladium 106.4	47Ag silver 107.9	48Cd cadmium 112.4	49In indium 114.8	50Sn tin 118.7	51Sb antimony 121.8	52Te tellurium 127.6	53I iodine 126.9	54Xe xenon 131.3										
55Cs caesium 132.9	56Ba barium 137.3	57–71 lanthanoids		72Hf hafnium 178.5	73Ta tantalum 180.9	74W tungsten 183.8	75Re rhenium 186.2	76Os osmium 190.2	77Ir iridium 192.2	78Pt platinum 195.1	79Au gold 197.0	80Hg mercury 200.6	81Tl thallium 204.4	82Pb lead 207.2	83Bi bismuth 209.0	84Po polonium	85At astatine	86Rn radon									
87Fr francium	88Ra radium	89–103 actinoids		104Rf rutherfordium	105Db dubnium	106Sg seaborgium	107Bh bohrium	108Hs hassium	109Mt meitnerium	110Ds darmstadtium	111Rg roentgenium	112Cn copernicium	113Nh nihonium	114Fl flerovium	115Mc moscovium	116Lv livermorium	117Ts tennessine	118Og oganesson									
lanthanoids		57La lanthanum 138.9	58Ce cerium 140.1	59Pr praseodymium 140.9	60Nd neodymium 144.2	61Pm promethium	62Sm samarium 150.4	63Eu europium 152.0	64Gd gadolinium 157.3	65Tb terbium 158.9	66Dy dysprosium 162.5	67Ho holmium 164.9	68Er erbium 167.3	69Tm thulium 168.9	70Yb ytterbium 173.1	71Lu lutetium 175.0											
actinoids		89Ac actinium	90Th thorium 232.0	91Pa protactinium 231.0	92U uranium 238.0	93Np neptunium	94Pu plutonium	95Am americium	96Cm curium	97Bk berkelium	98Cf californium	99Es einsteinium	100Fm fermium	101Md mendelevium	102No nobelium	103Lr lawrencium											

lanthanoids

actinoids

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