



Cambridge International AS & A Level

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CHEMISTRY

9701/51

Paper 5 Planning, Analysis and Evaluation

May/June 2025

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.
- 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.

INFORMATION

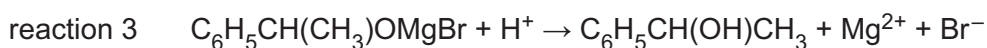
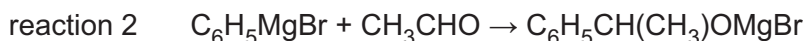
- The total mark for this paper is 30.
- The number of marks for each question or part question is shown in brackets [].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **12** pages.



- 1 Grignard reagents have the general formula RMgX , where R is a hydrocarbon group and X is a halogen. The Grignard reagent $\text{C}_6\text{H}_5\text{MgBr}$ is used as an intermediate in the reaction between bromobenzene, $\text{C}_6\text{H}_5\text{Br}$, and ethanal, CH_3CHO , to prepare 1-phenylethanol, $\text{C}_6\text{H}_5\text{CH}(\text{OH})\text{CH}_3$. An organic solvent, ethoxyethane, is used.

The equations for the three reactions that take place during the preparation are shown.



The preparation involves the following steps.

- step 1** Set up the apparatus shown in Fig. 1.1 with approximately 1.25g of Mg powder and 5cm^3 of ethoxyethane in the round-bottomed flask.
- step 2** Add 0.0500 mol of liquid $\text{C}_6\text{H}_5\text{Br}$ to the round-bottomed flask dropwise using the tap funnel. Leave until reaction 1 is complete.
- step 3** Dissolve 3.00cm^3 of CH_3CHO in 15cm^3 of ethoxyethane and add this solution to the round-bottomed flask using the tap funnel. Leave until reaction 2 is complete.
- step 4** Remove the condenser, tube Y and the tap funnel from the round-bottomed flask.
- step 5** Add 40cm^3 of dilute hydrochloric acid, $\text{HCl}(\text{aq})$, to the round-bottomed flask so that reaction 3 takes place.
- step 6** Transfer the contents of the round-bottomed flask to a separating funnel. Allow the liquids to settle so that two layers are formed.
- step 7** Open the tap of the separating funnel and run the lower layer into a beaker labelled **A**. Run the upper layer into a beaker labelled **B**.
- step 8** Allow the ethoxyethane to evaporate from the beaker containing $\text{C}_6\text{H}_5\text{CH}(\text{OH})\text{CH}_3$.

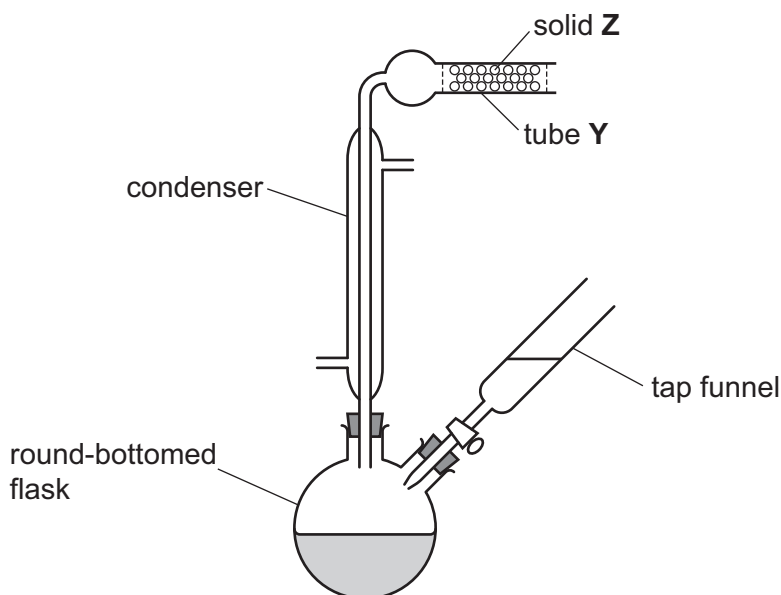


Fig. 1.1





Some relevant data are shown in Table 1.1.

Table 1.1

substance	density /g cm ⁻³	boiling point /°C	hazard
bromobenzene	1.50	156	flammable, toxic, skin irritant
distilled water	1.00	100	non-hazardous
ethoxyethane	0.714	35	flammable, toxic
ethanal	0.788	21	flammable, eye and respiratory irritant
1-phenylethanol	1.01	204	flammable, toxic, eye irritant

(a) Use the information in Table 1.1 to suggest why the following safety precautions are used.

- wearing chemically resistant gloves

.....

- using a fume hood

.....

[2]

(b) Dry apparatus and reagents are essential for steps 1–3.

- (i) Suggest how the glassware shown in Fig. 1.1 should be dried before use in step 1.

..... [1]

- (ii) The ethoxyethane contains a small amount of water.
Suggest how the water can be removed from the ethoxyethane before use in steps 1 and 3.

..... [1]

(c) Fig. 1.1 shows the apparatus for steps 1–3.

- (i) Draw a labelled arrow on Fig. 1.1 to show where the water enters the condenser. [1]

- (ii) Suggest why solid **Z** is used.

..... [1]

- (iii) Give **one** reason why the apparatus does **not** have a bung at the end of tube **Y**.

..... [1]





- (d) In step 1, approximately 1.25 g of Mg powder is needed.
Outline how the student should accurately weigh by difference using a weighing boat so that the exact mass of Mg transferred into the flask is known. Include a results table, with appropriate headings, ready for the student to fill in.

.....

.....

.....

[2]

- (e) Use the information in Table 1.1 to determine the volume, in cm^3 , of bromobenzene used in step 2.

$[M_r: \text{C}_6\text{H}_5\text{Br}, 156.9]$

volume of $\text{C}_6\text{H}_5\text{Br} = \dots\dots\dots \text{cm}^3$ [1]

- (f) The bromobenzene is added dropwise in step 2.
Suggest **one** reason why the bromobenzene is **not** added all at once.

..... [1]

- (g) Suggest why a measuring cylinder is a suitable piece of apparatus to measure 40 cm^3 of hydrochloric acid in step 5.

.....

..... [1]





- (h) The separating funnel used in steps 6 and 7 is shown in Fig. 1.2. The final product, 1-phenylethanol, is in the ethoxyethane layer.

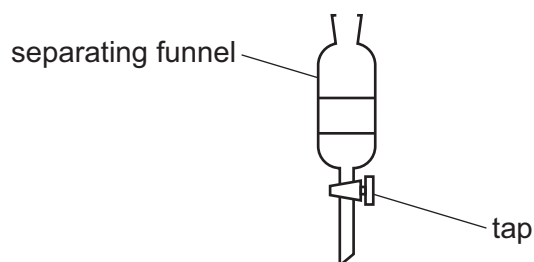


Fig. 1.2

State whether beaker **A** or beaker **B** contains the layer with 1-phenylethanol after step 7. Explain your answer using the information given in Table 1.1.

beaker

explanation

.....

[1]



- (i) The overall reaction can be represented as shown in Fig. 1.3.

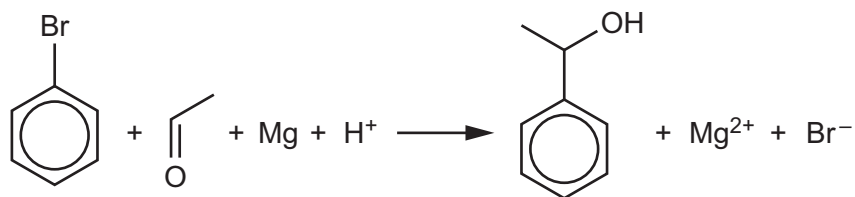


Fig. 1.3

- (i) At the end of step 8, 2.17 g of 1-phenylethanol is obtained. Determine whether bromobenzene or ethanal is the limiting reagent and hence calculate the percentage yield of 1-phenylethanol. Show your working.

$[M_r: C_6H_5CH(OH)CH_3, 122.0]$

percentage yield of $C_6H_5CH(OH)CH_3 = \dots\dots\dots\%$ [2]

- (ii) Suggest why the infrared spectrum of the product detected the presence of a C=O peak.

.....
 [1]

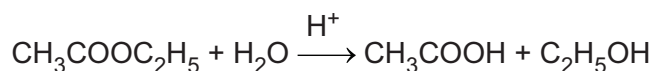
[Total: 16]





- 2 An experiment is carried out to determine the rate constant, k , for the hydrolysis of ethyl ethanoate, $\text{CH}_3\text{COOC}_2\text{H}_5$, using a hydrochloric acid, $\text{HCl}(\text{aq})$, catalyst.

The equation for the reaction is shown.



The rate equation for this reaction is shown.

$$\text{rate of reaction} = k [\text{CH}_3\text{COOC}_2\text{H}_5]$$

The progress of the reaction is followed by determining how the concentration of acid changes with time.

A portion of the reaction mixture is removed every 5 minutes and titrated with sodium hydroxide, $\text{NaOH}(\text{aq})$. A final titration is carried out after 180 minutes.

A student carries out the following steps.

- step 1** Add 70 cm^3 of iced water to seven separate small conical flasks. Add a few drops of phenolphthalein indicator to each flask. Phenolphthalein is pink in alkaline conditions and colourless in acidic conditions.
- step 2** Use a measuring cylinder to transfer 100 cm^3 of 0.200 mol dm^{-3} $\text{HCl}(\text{aq})$ into a large conical flask.
- step 3** Add 5.00 cm^3 of $\text{CH}_3\text{COOC}_2\text{H}_5$ to the large conical flask and swirl the flask to mix the contents. Start a stopwatch.
- step 4** Transfer 10.00 cm^3 of reaction mixture to one of the small conical flasks containing the iced water and indicator. Record the time. Shake the small flask.
- step 5** Carry out a single titration of the mixture in the small conical flask using 0.15 mol dm^{-3} $\text{NaOH}(\text{aq})$.
- step 6** Repeat steps 4 and 5 at the times shown in Table 2.1 using a different small conical flask for each titration.

- (a) Give **two** reasons that explain why the use of iced water in step 4 decreases the rate of reaction.

reason 1

reason 2 [2]

- (b) Describe the observation that is used to determine the end-point of the titrations.

..... [1]





- (c) The results of the experiment are shown in Table 2.1.
 V_t is the titre at a given time, t .
 V_∞ is the final titre at $t = 180$ min when the reaction is assumed to be complete.

Table 2.1

1	2	3	4
time, t /min	titre, V_t/cm^3	$(V_\infty - V_t)/\text{cm}^3$	$\log[(V_\infty - V_t)/\text{cm}^3]$
0	12.00		
5	16.40		
10	22.15		
15	23.45		
20	26.30		
25	28.70		
180	45.70		

- (i) Complete Table 2.1.
 Give your answers in column 3 to **two** decimal places and your answers in column 4 to **four** significant figures. [2]
- (ii) Plot a graph on the grid in Fig. 2.1 to show the relationship between $\log[(V_\infty - V_t)/\text{cm}^3]$ and time, t . Use a cross (×) to plot each data point.
 Draw a straight line of best fit. [2]
- (iii) Circle the **one** point on the graph that you consider to be most anomalous.
 Suggest **one** reason to explain the anomalous point you have circled.
 Assume no error was made in the experimental value of the titre.

 [1]



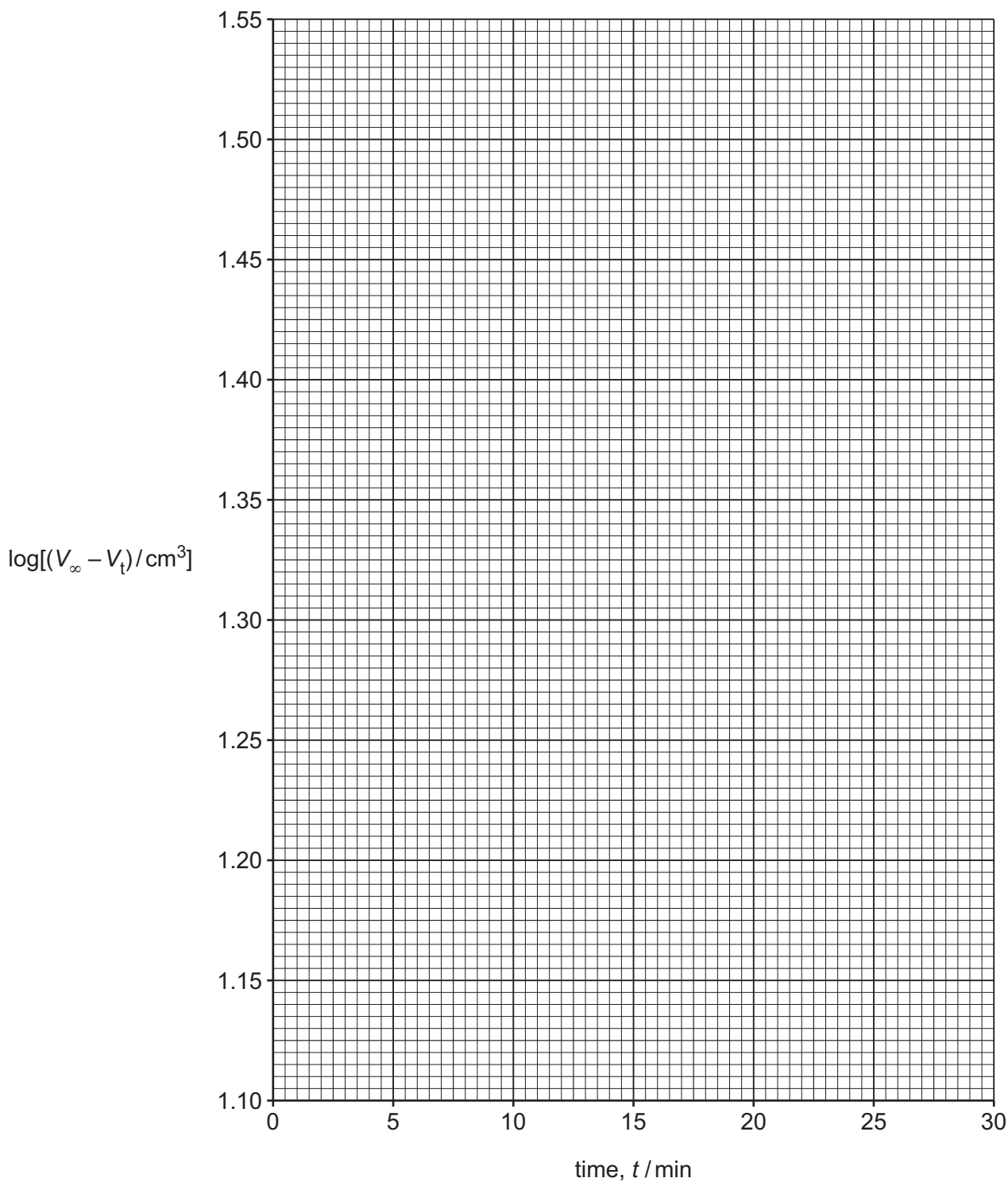


Fig. 2.1





- (iv) 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 = ... min⁻¹
[2]

- (d) The equation of the straight line plotted in Fig. 2.1 is shown.

$$\log[(V_{\infty} - V_t)/\text{cm}^3] = -\frac{kt}{2.303} + \text{constant}$$

Use the gradient determined in (c)(iv) to calculate a value for k in s⁻¹.

[If you were unable to determine an answer to (c)(iv), then use the value -0.0312 min⁻¹ for the gradient. This is **not** the correct answer.]

$k = \dots\dots\dots \text{s}^{-1}$ [2]

- (e) Use your graph in Fig. 2.1 to state whether you consider the results to be reliable. Give a reason for your answer.

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

- (f) k increases with temperature.
A second experiment is carried out at a higher temperature.

Sketch a suggested line of best fit on Fig. 2.1 for the second experiment. [1]

[Total: 14]



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	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
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													13	14	15	16	17	18



Cambridge International AS & A Level

CANDIDATE
NAME
CENTRE
NUMBER

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CANDIDATE
NUMBER

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CHEMISTRY**9701/52**

Paper 5 Planning, Analysis and Evaluation

May/June 2025**1 hour 15 minutes**

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- 1 Activated carbon is a form of carbon with the ability to adsorb solutes from solutions. The adsorption of ethanedioic acid molecules, $(\text{COOH})_2$, from dilute ethanedioic acid, $(\text{COOH})_2(\text{aq})$, onto the surface of activated carbon is studied in a series of experiments.

Before beginning the experiment, 500.0 cm^3 of $0.139 \text{ mol dm}^{-3}$ $(\text{COOH})_2(\text{aq})$, solution **X**, is made. The activated carbon is placed in an oven at 120°C for three hours.

The experimental procedure involves the following steps.

- step 1** Prepare 100.0 cm^3 of $0.00556 \text{ mol dm}^{-3}$ $(\text{COOH})_2(\text{aq})$ from solution **X**.
- step 2** Transfer 50.0 cm^3 of the $0.00556 \text{ mol dm}^{-3}$ $(\text{COOH})_2(\text{aq})$ into a conical flask.
- step 3** Add 0.500 g of activated carbon to the conical flask and start a stopwatch.
- step 4** Shake the flask and immediately remove a 5.0 cm^3 sample from the flask. Determine the mass of non-adsorbed $(\text{COOH})_2$ in the sample using chromatography.
- step 5** Repeat step 4 at suitable time intervals until there is no further change in the mass of non-adsorbed $(\text{COOH})_2$ in the sample.

(a) Solid ethanedioic acid has the formula $(\text{COOH})_2 \cdot 2\text{H}_2\text{O}$.

- (i) Calculate the mass of $(\text{COOH})_2 \cdot 2\text{H}_2\text{O}(\text{s})$ required to prepare 500.0 cm^3 of $0.139 \text{ mol dm}^{-3}$ $(\text{COOH})_2(\text{aq})$, solution **X**.

mass = ... g [1]

- (ii) The mass of $(\text{COOH})_2 \cdot 2\text{H}_2\text{O}(\text{s})$ calculated in (a)(i) is placed into a 100 cm^3 beaker. Describe the steps taken to prepare 500.0 cm^3 of $0.139 \text{ mol dm}^{-3}$ $(\text{COOH})_2(\text{aq})$.

Give the name and capacity of any apparatus used.

Write your answer using a series of numbered steps.

.....

.....

.....

.....

.....

.....

.....

..... [3]



- (b) $(\text{COOH})_2 \cdot 2\text{H}_2\text{O}(\text{s})$ is corrosive. Other than wearing eye protection and a lab coat, state **one** safety precaution that should be taken when using $(\text{COOH})_2 \cdot 2\text{H}_2\text{O}(\text{s})$.

..... [1]

- (c) Suggest why the activated carbon is placed in the oven before use.

..... [1]

- (d) In step 1, solution **X** is diluted to a concentration of $0.00556 \text{ mol dm}^{-3}$.

Calculate the volume of solution **X** needed to make 100.0 cm^3 of $0.00556 \text{ mol dm}^{-3}$ $(\text{COOH})_2(\text{aq})$.

volume of solution **X** = ... cm^3 [1]

- (e) Identify the most appropriate piece of equipment to transfer 50.0 cm^3 of diluted $(\text{COOH})_2(\text{aq})$ in step 2.

..... [1]

- (f) Suggest a reason why the conical flask is shaken in step 4.

..... [1]





(g) The results of the experiment are shown in Table 1.1.

Table 1.1

time, t /min	mass of non-adsorbed $(\text{COOH})_2$ in 5.0 cm^3 sample /mg	mass of $(\text{COOH})_2$ adsorbed by activated carbon in 5.0 cm^3 sample /mg
0	2.50	0.00
5	1.90	
15	1.52	
30	1.43	
45	0.99	
60	0.88	
90	0.81	
120	0.80	
150	0.80	

(i) Complete Table 1.1. [1]

(ii) Plot a graph on the grid in Fig. 1.1 to show the relationship between mass of $(\text{COOH})_2$ adsorbed by activated carbon in 5.0 cm^3 sample and time, t . Use a cross ($\times$) to plot each data point.

Draw a curved line of best fit.

[2]

(iii) Identify the independent variable.

..... [1]

(iv) Suggest **one** variable that needs to be controlled that is **not** stated in the experimental procedure.

..... [1]

(v) Circle the **one** point on the graph that you consider to be most anomalous.

Explain the error in timing that may have led to this anomalous point.

..... [1]





mass of $(\text{COOH})_2$
adsorbed by
activated carbon
in 5.0 cm^3
sample / mg

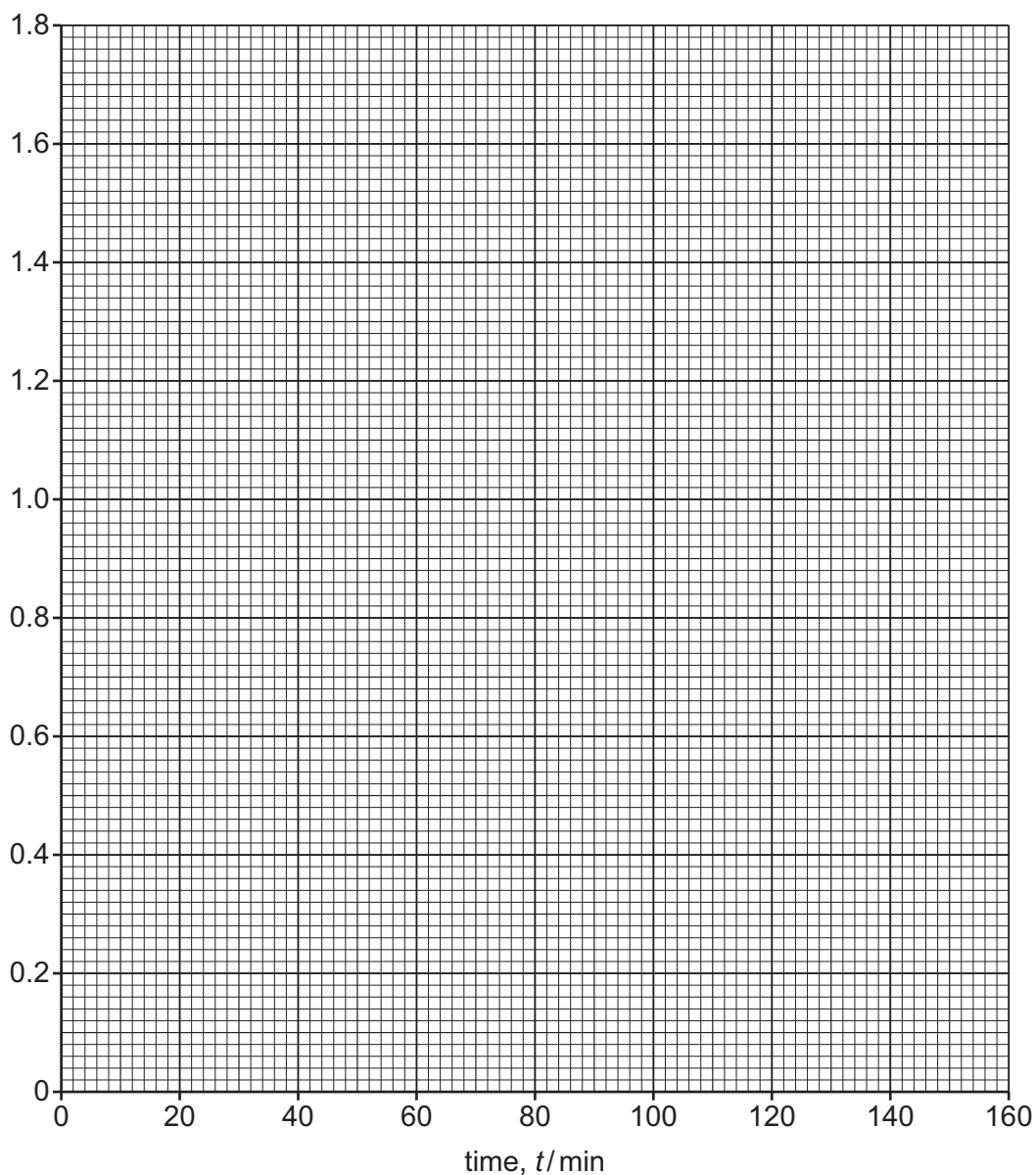


Fig. 1.1





- (h) The experiment is repeated using different concentrations of $(\text{COOH})_2(\text{aq})$ prepared in step 1. The results are shown in Table 1.2.

Table 1.2

1	2	3	4	5
m_i/mg	m_e/mg	$(m_i - m_e)/\text{mg}$	$q_e/\text{mg g}^{-1}$	$\frac{m_e}{q_e}/\text{g}$
2.5	0.80	1.70	34.0	0.0235
5.0	2.10	2.90	58.0	0.0362
7.5	4.03	3.47	69.4	0.0581
10.0	6.41	3.59	71.8	0.0893
12.5	8.87	3.63	72.6	0.1222

m_i is the initial mass of $(\text{COOH})_2$ in 5.0 cm^3 sample.

m_e is the mass of non-adsorbed $(\text{COOH})_2$ in the final 5.0 cm^3 sample at the end of step 5.

q_e is the mass of $(\text{COOH})_2$ adsorbed per gram of activated carbon.

- (i) A plot of $\frac{m_e}{q_e}$ against m_e gives the line of best fit shown in Fig. 1.2.

Use Fig. 1.2 to determine the gradient of the line of best fit.

State the coordinates of both points you used in your calculation.

coordinates 1 coordinates 2

Include units in your answer.

gradient = ...

units = ...

[3]

- (ii) The adsorption parameter, q_0 , is the maximum mass of $(\text{COOH})_2$ adsorbed per gram of activated carbon.

The equation of the line of best fit plotted in Fig. 1.2 is shown.

$$\frac{m_e}{q_e} = \frac{m_e}{q_0} + \text{constant}$$

Use the gradient determined in (h)(i) to calculate the adsorption parameter, q_0 .

[If you were unable to determine an answer to (h)(i), then use the value 0.0136 for the gradient. This is **not** the correct answer.]

$q_0 = \dots\dots\dots \text{mg g}^{-1}$ [1]



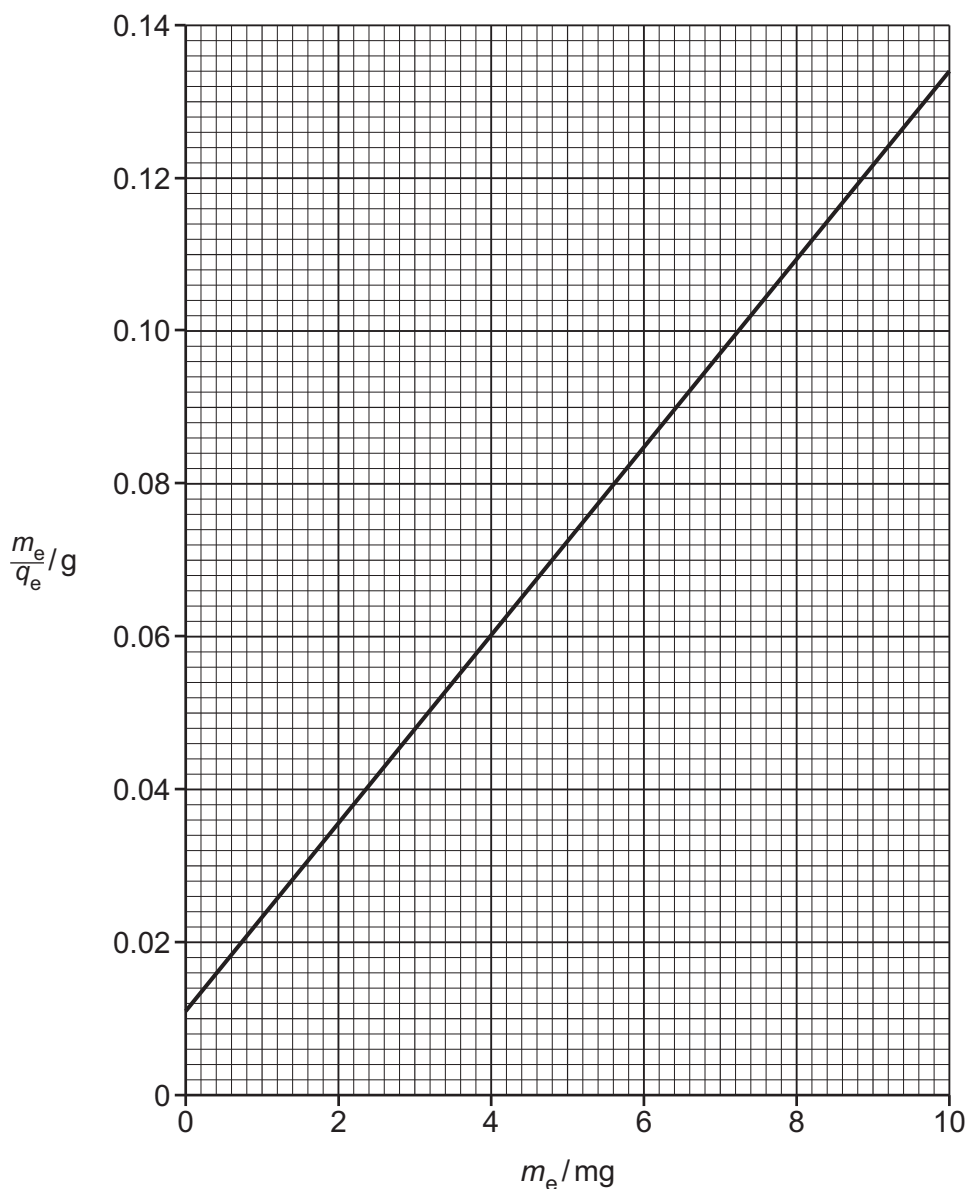


Fig. 1.2

- (i) The experiment is repeated and the value of q_0 is calculated to be 78.1 mg g^{-1} . The total percentage error from the experimental procedure is 6.5%.

The data book value of q_0 is 86.0 mg g^{-1} .

Use this information to determine whether the error in the repeated experiment could be accounted for by experimental errors or is caused by other factors.

Show your working.

..... [1]

[Total: 20]





- 2 The enthalpy change of combustion, ΔH_c , of butane, C_4H_{10} , can be determined using the apparatus shown in Fig. 2.1.

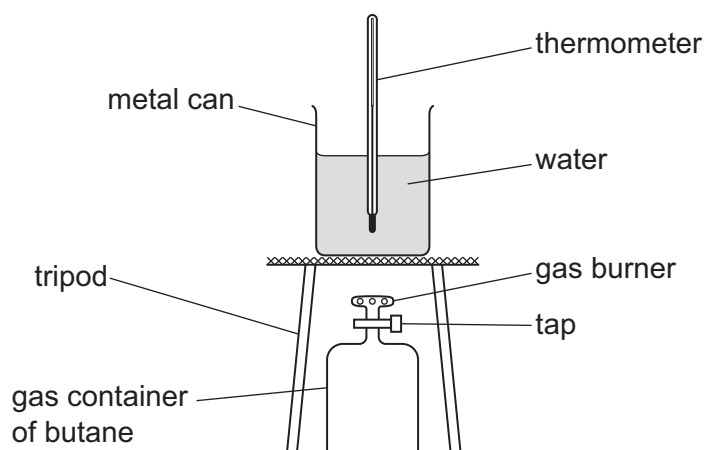


Fig. 2.1

The following steps are carried out.

- step 1** Use a 500 cm^3 measuring cylinder to transfer 320 cm^3 of water into a metal can.
- step 2** Place a thermometer into the water. Record the initial temperature of the water in the metal can.
- step 3** Weigh the gas container with burner and record the initial mass.
- step 4** Set up the apparatus as shown in Fig. 2.1.
- step 5** Light the burner and allow the flame to heat the water in the metal can for three minutes.
- step 6** Switch off the burner and record the maximum temperature reached.
- step 7** When cool, reweigh the gas container with burner and record the final mass.

The results are shown in Table 2.1.

Table 2.1

initial temperature of water / $^{\circ}\text{C}$	maximum temperature of water / $^{\circ}\text{C}$	change in temperature of water, ΔT / $^{\circ}\text{C}$	initial mass of gas container with burner / g	final mass of gas container with burner / g	mass of butane burned / g
19.3	76.6		183.56	181.46	

- (a) Complete Table 2.1. Record your answers to the appropriate number of decimal places. [2]





- (b) Use the relationship $q = mc\Delta T$ to calculate the energy, q , in J, gained by the water. 1.00 cm^3 of water has a mass of 1.00 g .

$q = \dots\dots\dots \text{ J [1]}$

- (c) Calculate the enthalpy change of combustion, ΔH_c , of butane, in kJ mol^{-1} .

Give your answer to **three** significant figures.

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

- (d) Without changing the apparatus, suggest what should be done in step 6 before recording the maximum temperature reached to improve the experimental procedure.

$\dots\dots\dots [1]$

- (e) The 500 cm^3 measuring cylinder has graduations every 5 cm^3 .
Calculate the percentage error in the measurement of the volume of water.
Show your working.

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

- (f) A student suggests that the value calculated in (c) is different from the actual value of ΔH_c of butane because of heat lost during the experiment. Suggest **one** change to the apparatus that would reduce the heat lost.

$\dots\dots\dots [1]$

- (g) The experiment was repeated but the burner was switched off after only two minutes.

- (i) Suggest why this might contribute to a reduction in the accuracy of ΔH_c of butane.

$\dots\dots\dots [1]$

- (ii) Suggest why this might contribute to an increase in the accuracy of ΔH_c of butane.

$\dots\dots\dots [1]$

[Total: 10]





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	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
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	1 Hhydrogen1.0										13	14	15	16	17	18								
		Key atomic number atomic symbol name relative atomic mass																							
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	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			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	89–103 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 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	mendeleevium	nobelium	lawrencium
—	232.0	231.0	238.0	—	—	—	—	—	—	—	—	—	—	—





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CHEMISTRY

9701/53

Paper 5 Planning, Analysis and Evaluation

May/June 2025

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.
- 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.

INFORMATION

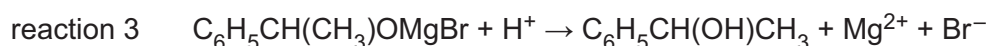
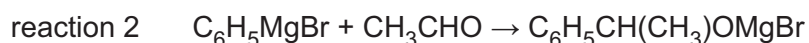
- The total mark for this paper is 30.
- The number of marks for each question or part question is shown in brackets [].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **12** pages.



- 1 Grignard reagents have the general formula RMgX , where R is a hydrocarbon group and X is a halogen. The Grignard reagent $\text{C}_6\text{H}_5\text{MgBr}$ is used as an intermediate in the reaction between bromobenzene, $\text{C}_6\text{H}_5\text{Br}$, and ethanal, CH_3CHO , to prepare 1-phenylethanol, $\text{C}_6\text{H}_5\text{CH}(\text{OH})\text{CH}_3$. An organic solvent, ethoxyethane, is used.

The equations for the three reactions that take place during the preparation are shown.



The preparation involves the following steps.

- step 1** Set up the apparatus shown in Fig. 1.1 with approximately 1.25g of Mg powder and 5cm^3 of ethoxyethane in the round-bottomed flask.
- step 2** Add 0.0500 mol of liquid $\text{C}_6\text{H}_5\text{Br}$ to the round-bottomed flask dropwise using the tap funnel. Leave until reaction 1 is complete.
- step 3** Dissolve 3.00cm^3 of CH_3CHO in 15cm^3 of ethoxyethane and add this solution to the round-bottomed flask using the tap funnel. Leave until reaction 2 is complete.
- step 4** Remove the condenser, tube Y and the tap funnel from the round-bottomed flask.
- step 5** Add 40cm^3 of dilute hydrochloric acid, $\text{HCl}(\text{aq})$, to the round-bottomed flask so that reaction 3 takes place.
- step 6** Transfer the contents of the round-bottomed flask to a separating funnel. Allow the liquids to settle so that two layers are formed.
- step 7** Open the tap of the separating funnel and run the lower layer into a beaker labelled **A**. Run the upper layer into a beaker labelled **B**.
- step 8** Allow the ethoxyethane to evaporate from the beaker containing $\text{C}_6\text{H}_5\text{CH}(\text{OH})\text{CH}_3$.

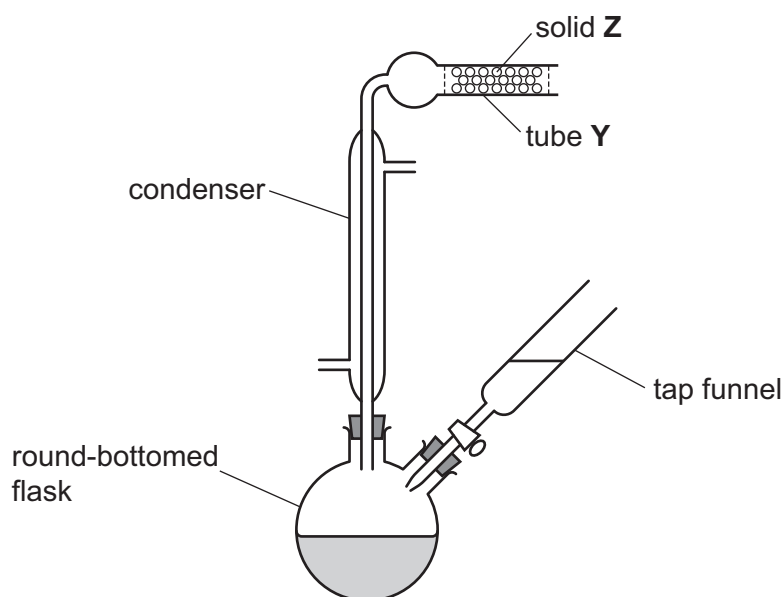


Fig. 1.1





Some relevant data are shown in Table 1.1.

Table 1.1

substance	density /g cm ⁻³	boiling point /°C	hazard
bromobenzene	1.50	156	flammable, toxic, skin irritant
distilled water	1.00	100	non-hazardous
ethoxyethane	0.714	35	flammable, toxic
ethanal	0.788	21	flammable, eye and respiratory irritant
1-phenylethanol	1.01	204	flammable, toxic, eye irritant

(a) Use the information in Table 1.1 to suggest why the following safety precautions are used.

- wearing chemically resistant gloves

.....

- using a fume hood

.....

[2]

(b) Dry apparatus and reagents are essential for steps 1–3.

- (i) Suggest how the glassware shown in Fig. 1.1 should be dried before use in step 1.

..... [1]

- (ii) The ethoxyethane contains a small amount of water.
Suggest how the water can be removed from the ethoxyethane before use in steps 1 and 3.

..... [1]

(c) Fig. 1.1 shows the apparatus for steps 1–3.

- (i) Draw a labelled arrow on Fig. 1.1 to show where the water enters the condenser. [1]

- (ii) Suggest why solid **Z** is used.

..... [1]

- (iii) Give **one** reason why the apparatus does **not** have a bung at the end of tube **Y**.

..... [1]





- (d) In step 1, approximately 1.25 g of Mg powder is needed.
Outline how the student should accurately weigh by difference using a weighing boat so that the exact mass of Mg transferred into the flask is known. Include a results table, with appropriate headings, ready for the student to fill in.

.....

.....

.....

[2]

- (e) Use the information in Table 1.1 to determine the volume, in cm^3 , of bromobenzene used in step 2.

$[M_r: \text{C}_6\text{H}_5\text{Br}, 156.9]$

volume of $\text{C}_6\text{H}_5\text{Br} = \dots\dots\dots \text{cm}^3$ [1]

- (f) The bromobenzene is added dropwise in step 2.
Suggest **one** reason why the bromobenzene is **not** added all at once.

..... [1]

- (g) Suggest why a measuring cylinder is a suitable piece of apparatus to measure 40 cm^3 of hydrochloric acid in step 5.

.....

..... [1]





- (h) The separating funnel used in steps 6 and 7 is shown in Fig. 1.2. The final product, 1-phenylethanol, is in the ethoxyethane layer.

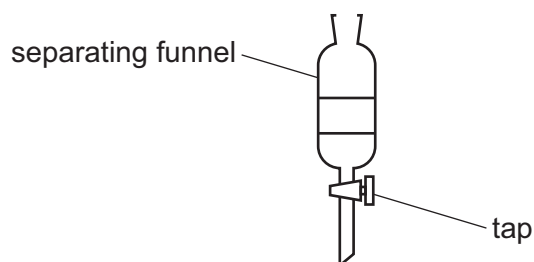


Fig. 1.2

State whether beaker **A** or beaker **B** contains the layer with 1-phenylethanol after step 7. Explain your answer using the information given in Table 1.1.

beaker

explanation

.....

[1]



- (i) The overall reaction can be represented as shown in Fig. 1.3.

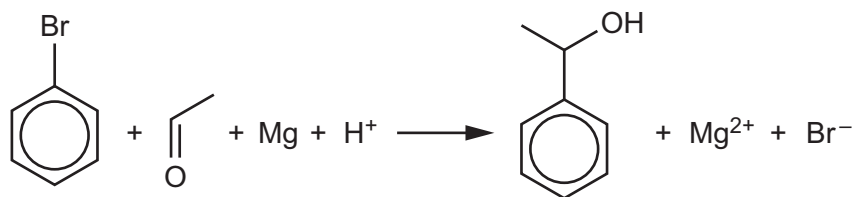


Fig. 1.3

- (i) At the end of step 8, 2.17 g of 1-phenylethanol is obtained. Determine whether bromobenzene or ethanal is the limiting reagent and hence calculate the percentage yield of 1-phenylethanol. Show your working.

[M_r : C₆H₅CH(OH)CH₃, 122.0]

percentage yield of C₆H₅CH(OH)CH₃ = ... % [2]

- (ii) Suggest why the infrared spectrum of the product detected the presence of a C=O peak.

.....
 [1]

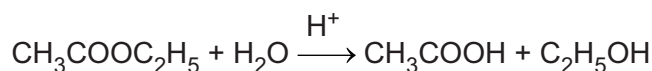
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- 2 An experiment is carried out to determine the rate constant, k , for the hydrolysis of ethyl ethanoate, $\text{CH}_3\text{COOC}_2\text{H}_5$, using a hydrochloric acid, $\text{HCl}(\text{aq})$, catalyst.

The equation for the reaction is shown.



The rate equation for this reaction is shown.

$$\text{rate of reaction} = k [\text{CH}_3\text{COOC}_2\text{H}_5]$$

The progress of the reaction is followed by determining how the concentration of acid changes with time.

A portion of the reaction mixture is removed every 5 minutes and titrated with sodium hydroxide, $\text{NaOH}(\text{aq})$. A final titration is carried out after 180 minutes.

A student carries out the following steps.

- step 1** Add 70 cm^3 of iced water to seven separate small conical flasks. Add a few drops of phenolphthalein indicator to each flask. Phenolphthalein is pink in alkaline conditions and colourless in acidic conditions.
- step 2** Use a measuring cylinder to transfer 100 cm^3 of 0.200 mol dm^{-3} $\text{HCl}(\text{aq})$ into a large conical flask.
- step 3** Add 5.00 cm^3 of $\text{CH}_3\text{COOC}_2\text{H}_5$ to the large conical flask and swirl the flask to mix the contents. Start a stopwatch.
- step 4** Transfer 10.00 cm^3 of reaction mixture to one of the small conical flasks containing the iced water and indicator. Record the time. Shake the small flask.
- step 5** Carry out a single titration of the mixture in the small conical flask using 0.15 mol dm^{-3} $\text{NaOH}(\text{aq})$.
- step 6** Repeat steps 4 and 5 at the times shown in Table 2.1 using a different small conical flask for each titration.

- (a) Give **two** reasons that explain why the use of iced water in step 4 decreases the rate of reaction.

reason 1

reason 2 [2]

- (b) Describe the observation that is used to determine the end-point of the titrations.

..... [1]





- (c) The results of the experiment are shown in Table 2.1.
 V_t is the titre at a given time, t .
 V_∞ is the final titre at $t = 180$ min when the reaction is assumed to be complete.

Table 2.1

1	2	3	4
time, t/min	titre, V_t/cm^3	$(V_\infty - V_t)/\text{cm}^3$	$\log[(V_\infty - V_t)/\text{cm}^3]$
0	12.00		
5	16.40		
10	22.15		
15	23.45		
20	26.30		
25	28.70		
180	45.70		

- (i) Complete Table 2.1.
 Give your answers in column 3 to **two** decimal places and your answers in column 4 to **four** significant figures. [2]
- (ii) Plot a graph on the grid in Fig. 2.1 to show the relationship between $\log[(V_\infty - V_t)/\text{cm}^3]$ and time, t . Use a cross (x) to plot each data point.
 Draw a straight line of best fit. [2]
- (iii) Circle the **one** point on the graph that you consider to be most anomalous.
 Suggest **one** reason to explain the anomalous point you have circled.
 Assume no error was made in the experimental value of the titre.

 [1]



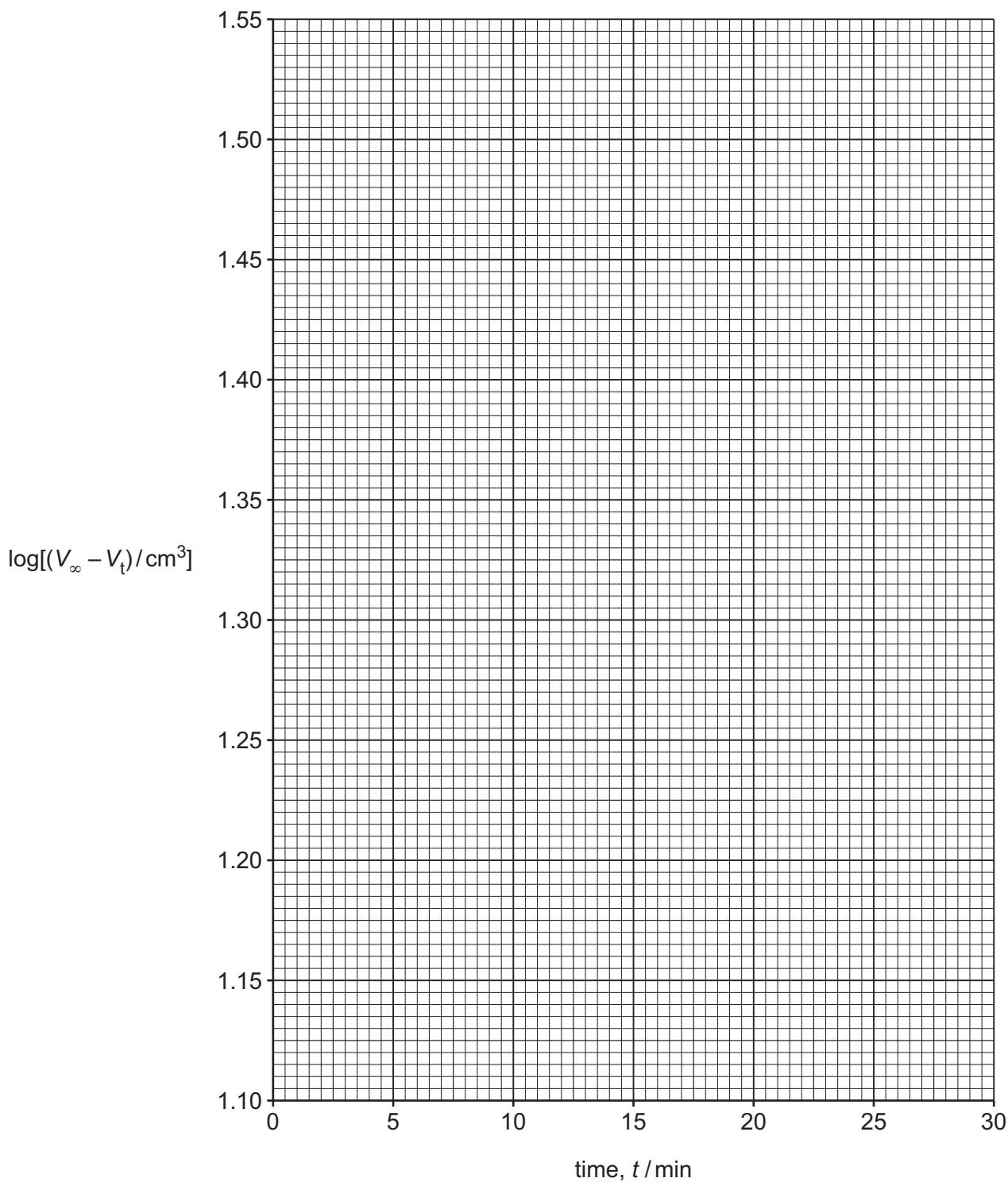


Fig. 2.1





- (iv) 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 = ... min⁻¹
[2]

- (d) The equation of the straight line plotted in Fig. 2.1 is shown.

$$\log[(V_{\infty} - V_t)/\text{cm}^3] = -\frac{kt}{2.303} + \text{constant}$$

Use the gradient determined in (c)(iv) to calculate a value for k in s⁻¹.

[If you were unable to determine an answer to (c)(iv), then use the value -0.0312 min⁻¹ for the gradient. This is **not** the correct answer.]

$k = \dots\dots\dots \text{s}^{-1}$ [2]

- (e) Use your graph in Fig. 2.1 to state whether you consider the results to be reliable. Give a reason for your answer.

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

- (f) k increases with temperature.
A second experiment is carried out at a higher temperature.

Sketch a suggested line of best fit on Fig. 2.1 for the second experiment. [1]

[Total: 14]



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	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
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 Li lithium 6.9	4 Be beryllium 9.0																					
11 Na sodium 23.0	12 Mg magnesium 24.3	3 Sc scandium 45.0	4 Ti titanium 47.9	5 V vanadium 50.9	6 Cr chromium 52.0	7 Mn manganese 54.9	8 Fe iron 55.8	9 Co cobalt 58.9	10 Ni nickel 58.7	11 Cu copper 63.5	12 Zn zinc 65.4	13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9					
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8					
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium —	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3					
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium —	85 At astatine —	86 Rn radon —					
87 Fr francium —	88 Ra radium —	89–103 actinoids	104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —	113 Nh nihonium —	114 Fl flerovium —	115 Mc moscovium —	116 Lv livermorium —	117 Ts tennessine —	118 Og oganeson —					

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	eucadium	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	—

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CHEMISTRY

9701/54

Paper 5 Planning, Analysis and Evaluation

May/June 2025

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
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- Important values, constants and standards are printed in the question paper.

This document has **12** pages.



- 1 The relative molecular mass, M_r , of an unknown volatile liquid, **Y**, can be determined experimentally.

A student uses the following method to determine the volume of a conical flask.

step 1 Weigh a dry conical flask.

step 2 Fill the conical flask completely with distilled water.

step 3 Weigh the conical flask when filled with distilled water.

step 4 Use a thermometer to measure the temperature of the distilled water in the conical flask.

The student collects the results shown in Table 1.1.

Table 1.1

mass of dry flask/g	31.022
mass of flask filled with water/g	161.175
temperature of water in flask/°C	23.0
laboratory atmospheric pressure/kPa	99.0

- (a) Fig. 1.1 shows the variation of the density of water with temperature.

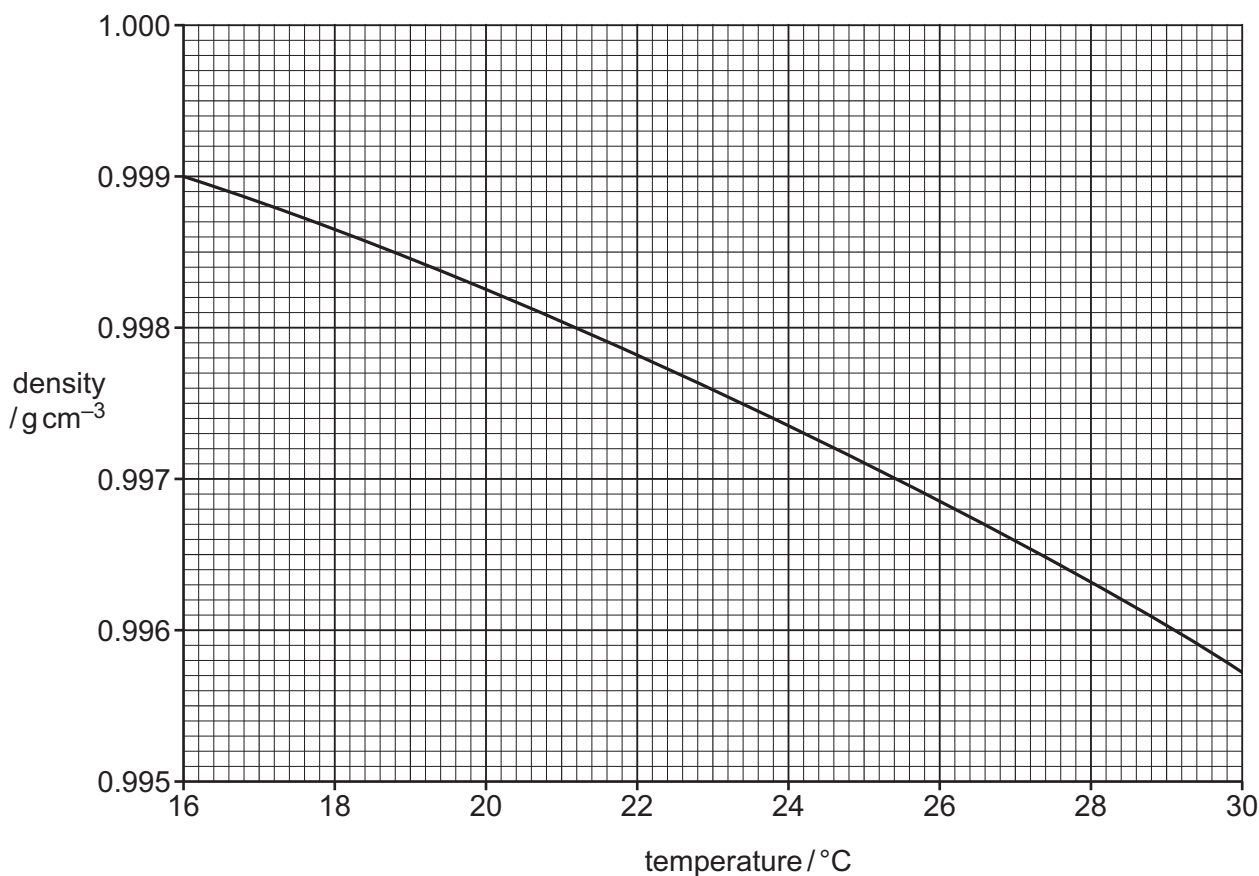


Fig. 1.1



- (i) Use Fig. 1.1 to determine the density of water at 23.0 °C.
Give your answer to **four** decimal places.

density of water = ... g cm⁻³ [1]

- (ii) Calculate the volume of the flask, using the density of water determined in (a)(i).

volume of flask = ... cm³ [2]

- (b) Another student determines the volume of a different conical flask to be 129.56 cm³. This conical flask is used to determine the M_r of unknown volatile liquid **Y**.

The following method is used.

step 1 Cover the opening of the dry conical flask with aluminium foil and secure using a rubber band.

step 2 Weigh the conical flask, aluminium foil and rubber band. Record the mass.

step 3 Use a syringe with a needle to make a small hole in the aluminium foil and inject approximately 5 cm³ of **Y** into the conical flask. Remove the syringe.

step 4 Place the conical flask in a water-bath containing boiling water.

step 5 Allow all of **Y** to evaporate. Keep the conical flask containing vaporised **Y** in the boiling water for a further 3 minutes.

step 6 Carefully remove the conical flask from the boiling water and dry the outside surface thoroughly.

step 7 Weigh the conical flask, aluminium foil, rubber band and contents. Record this mass.

- (i) Suggest why the conical flask containing vaporised **Y** is kept in boiling water for 3 minutes in step 5.

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

- (ii) Suggest why it is **not** necessary to determine the mass of liquid **Y** injected into the conical flask by the syringe in step 3.

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

- (iii) The student thinks that **Y** is toxic. Other than wearing safety glasses and a lab coat, state **one** safety precaution that must be taken when carrying out this experiment.

..... [1]





(c) Table 1.2 shows the student's results.

Table 1.2

temperature of water-bath / °C	100.0
laboratory atmospheric pressure / kPa	99.0
mass of conical flask, aluminium foil and rubber band measured in step 2 / g	31.123
mass of conical flask, aluminium foil, rubber band and Y measured in step 7 / g	31.429
mass of Y in flask in step 7 / g	0.306
volume of conical flask used / cm ³	129.56

- (i) Calculate the percentage error in the mass measured in step 2.

Show your working.

percentage error = ... [1]

- (ii) The student assumes that the vapour formed from liquid **Y** is an ideal gas. The ideal gas equation is shown.

$$pV = nRT$$

p = pressure of gas measured in Pa

V = volume of gas in m³

n = number of moles of gas

R = molar gas constant

T = temperature in K

Use the ideal gas equation and the results in Table 1.2 to calculate the amount, in mol, of **Y** in the conical flask in step 7.

Assume that the temperature of the vapour formed from liquid **Y** is 100 °C.

amount of **Y** = ... mol [2]





(iii) Calculate the M_r of **Y**.

M_r of **Y** = ... [1]

- (d) The actual temperature of the vapour formed from liquid **Y** is less than 100 °C. Describe and explain the effect this has on the calculated value of the M_r .

effect on calculated M_r

explanation

..... [1]

- (e) The boiling point of methylbenzene is 111 °C.
Suggest why the M_r of methylbenzene **cannot** be determined using this method.

.....

..... [1]

[Total: 12]





- 2 A student carries out an experiment to determine the charge of an aqueous ion, $M^{n+}(aq)$, of metal **M**.

The student prepares 100.0 cm^3 of 1.00 mol dm^{-3} aqueous copper(II) nitrate, $\text{Cu}(\text{NO}_3)_2(aq)$, to use in the experiment.

- (a) Calculate the mass of $\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}(s)$ required to prepare 100.0 cm^3 of 1.00 mol dm^{-3} $\text{Cu}(\text{NO}_3)_2(aq)$.

mass = ... g [1]

- (b) Describe the steps the student should take to prepare 100.0 cm^3 of 1.00 mol dm^{-3} $\text{Cu}(\text{NO}_3)_2(aq)$ starting from the mass calculated in (a) supplied in a small beaker.

Give the name and capacity of any apparatus used.

Write your answer using a series of numbered steps.

.....

.....

.....

.....

.....

.....

..... [3]



- (c) The student sets up the electrochemical cell shown in Fig. 2.1 to investigate the effect of changing the concentration of $M^{n+}(aq)$ on the measured cell potential, E_{cell} .

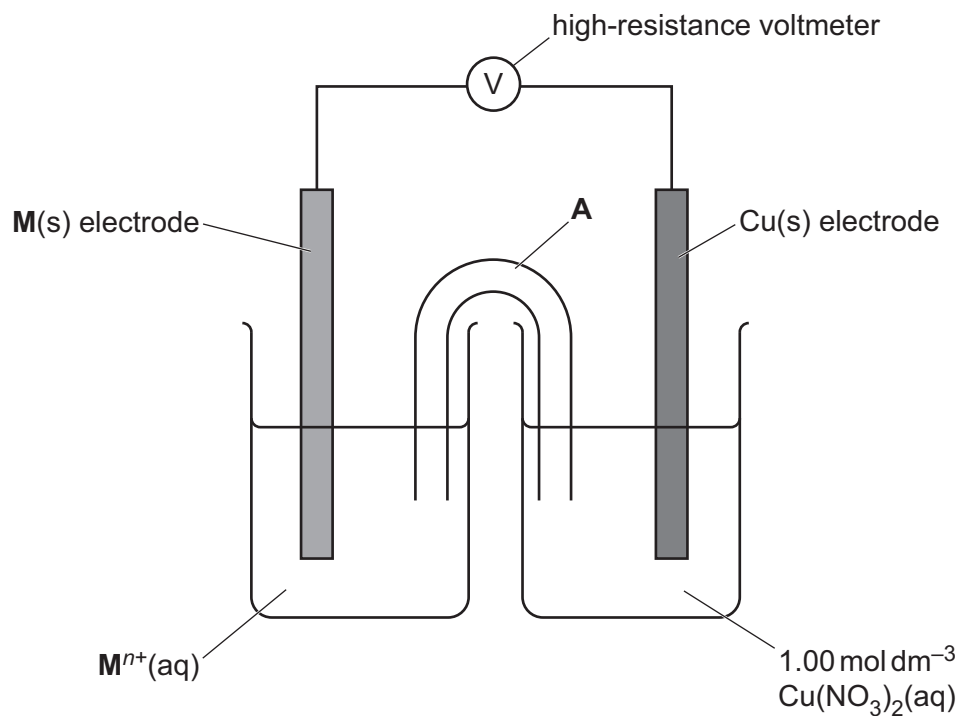


Fig. 2.1

Suggest the function of the item labelled **A** in Fig. 2.1.

.....

..... [1]





- (d) The student uses the apparatus in Fig. 2.1 to measure the cell potentials, using six solutions each with a different concentration of $M^{n+}(aq)$.

Table 2.1 shows the results obtained by the student.

Table 2.1

concentration of $M^{n+}(aq)$ / mol dm^{-3}	cell potential, E_{cell}/V	$\log [M^{n+}]$	electrode potential of $M^{n+}(aq)/M(s)$ /V
1.00×10^{-2}	3.295	-2.00	
5.00×10^{-3}	3.304	-2.30	
1.00×10^{-3}	3.325	-3.00	
5.00×10^{-4}	3.343	-3.30	
1.00×10^{-4}	3.354	-4.00	
1.00×10^{-5}	3.384	-5.00	

electrode potential of $M^{n+}(aq)/M(s) = E_{\text{Cu}} - E_{\text{cell}}$

electrode potential of $\text{Cu}^{2+}(aq)/\text{Cu}(s)$, $E_{\text{Cu}} = 0.337 \text{ V}$

Complete Table 2.1. Record your values to **three** decimal places.

[1]

- (e) Identify the independent variable in this experiment.

..... [1]





- (f) (i) Plot a graph on the grid in Fig. 2.2 to show the relationship between the electrode potential of $M^{n+}(aq)/M(s)$ and $\log [M^{n+}]$. Use a cross (x) to plot each data point. Draw a straight line of best fit.

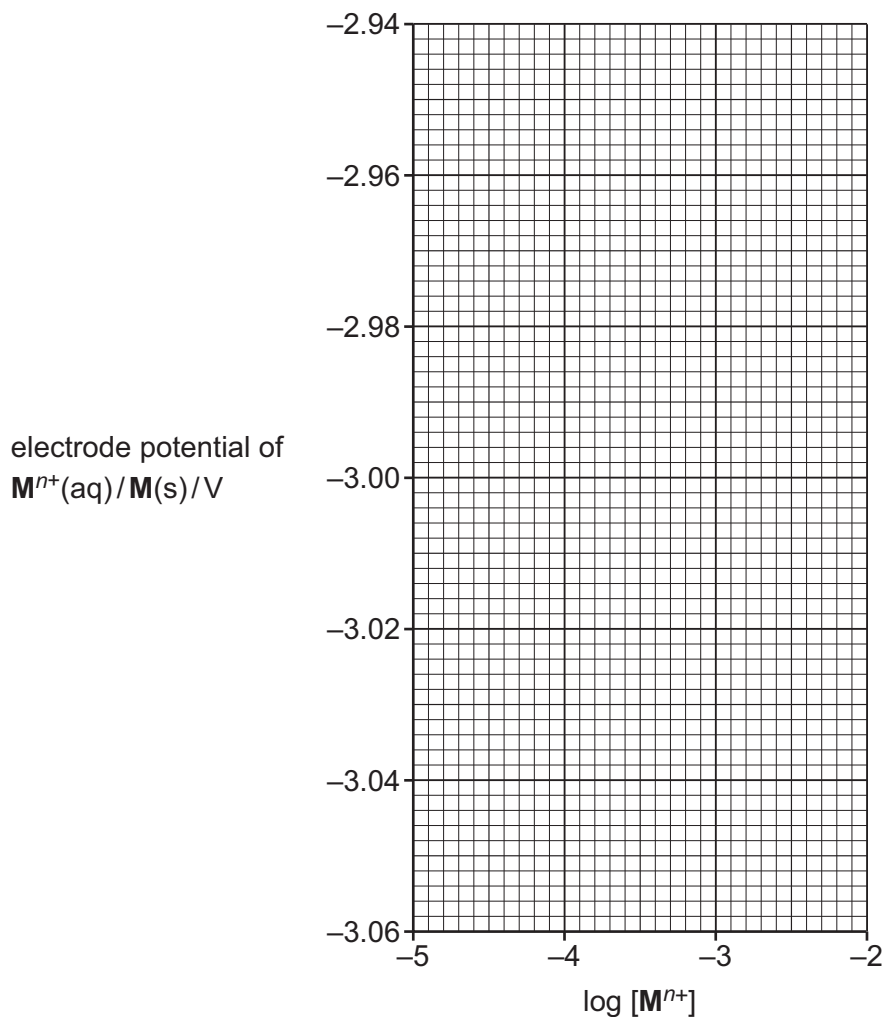


Fig. 2.2

[2]

- (ii) Circle the **one** point on the graph that you consider to be most anomalous.

Suggest **one** reason why this anomaly may have occurred during the experimental procedure. Assume no error was made in the measurement of the cell potential.

.....
 [1]

- (iii) Suggest how the reliability of the data shown in Table 2.1 could be improved.

.....
 [1]





- (g) (i) Use Fig. 2.2 to determine the gradient of the line of best fit. State the coordinates of both points you used 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 = ... [2]

- (ii) For the electrode equilibrium,



the Nernst equation can be written as shown.

$$E = E^{\ominus} + \frac{2.303 RT}{nF} \log [\text{M}^{n+}]$$

E = electrode potential

$E^{\ominus}$ = standard electrode potential

R = molar gas constant

T = temperature in K

F = Faraday constant

The equation for a straight line is $y = mx + c$.

State which parts in the Nernst equation correspond to y , m and c .

y = ...

m = ...

c = ... [3]

- (iii) Use the value that you calculated for the gradient of your line of best fit in (g)(i) and the Nernst equation to calculate the value of n in $\text{M}^{n+}(\text{aq})$.

The experiment is carried out at 25.0 °C.

(If you were unable to determine an answer to (g)(i), then use the value 0.0285 for the gradient. This is **not** the correct value.)

n = ... [2]

[Total: 18]





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	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
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	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ ($4.18 \text{ J g}^{-1} \text{ K}^{-1}$)





The Periodic Table of Elements

Group																			
1	2													13	14	15	16	17	18
		Key																	
		1 Hhydrogen1.0																	

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	mendeleevium	nobelium	lawrencium
—	232.0	231.0	238.0	—	—	—	—	—	—	—	—	—	—	—

