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9701/51

May/June 2020

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

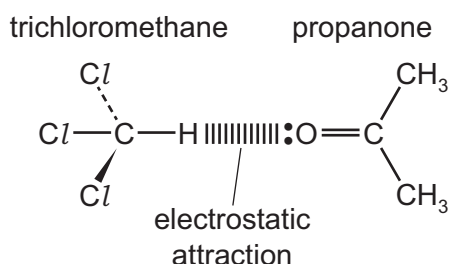
- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
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-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

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

This document has **12** pages. Blank pages are indicated.

- 1 Trichloromethane and propanone are both organic liquids. The molecules within each liquid are attracted to each other by relatively weak permanent dipole-dipole interactions.

When trichloromethane is mixed with propanone a strong electrostatic attraction forms between the two different molecules.



A student plans to perform an experiment to investigate the strength of this electrostatic attraction by finding the temperature change when equal volumes of trichloromethane and propanone are mixed together.

- (a) (i) State and explain your prediction for the temperature change for this experiment.

.....

 [1]

- (ii) The student is given **only** the following equipment and chemicals for the experiment.

1 × 25 cm³ beaker
 2 × thermometers
 2 × 25 cm³ measuring cylinders
 50 cm³ trichloromethane
 50 cm³ propanone

Outline the method the student should use in this one experiment to find the temperature change when trichloromethane is mixed with propanone. Give details of the volumes of liquids used and any readings taken.

volumes used

.....

readings taken

.....

.....

method used

.....

.....

.....

[3]

- (b) The apparatus used leads to significant heat loss.

State **one** improvement the student could make to the apparatus to reduce heat loss.

.....
 [1]

- (c) Trichloromethane and propanone are both volatile and flammable.

State **one** relevant precaution that should be taken when carrying out this experiment.

.....
 [1]

- (d) State **one** change, apart from reducing heat loss, that could be made to improve the accuracy of this experiment.

.....
 [1]

- (e) In another experiment, a student uses 37.50 g of trichloromethane and 19.75 g of propanone and determines that the energy released is 1.67 kJ.

- (i) Calculate the number of moles of each compound in this mixture.

M_r trichloromethane = 119.5

M_r propanone = 58.0

moles of trichloromethane = ... mol

moles of propanone = ... mol
 [1]

- (ii) Calculate the enthalpy change, ΔH , of the electrostatic attraction formed between trichloromethane and propanone. You must include a sign in your answer.

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

- (f) Suggest an experiment the student could carry out to test whether the number of moles of trichloromethane affects the temperature change.

.....

.....

..... [1]

[Total: 11]

- 2 Nitrogen dioxide can be prepared by strongly heating anhydrous lead nitrate, $\text{Pb}(\text{NO}_3)_2(\text{s})$. The thermal decomposition occurs according to the equation shown.



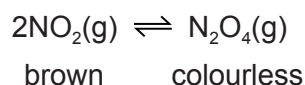
The nitrogen dioxide, NO_2 , can be separated from the oxygen by cooling the gas mixture produced until the NO_2 condenses and the oxygen does not.

	melting point/K	boiling point/K
nitrogen dioxide	262	294
oxygen	54	90

- (a) Draw a labelled diagram of the laboratory apparatus (assembled) that could be used to prepare **liquid** nitrogen dioxide from the thermal decomposition of anhydrous lead nitrate.

[2]

- (b) At room temperature, nitrogen dioxide exists in equilibrium with dinitrogen tetroxide according to the equation shown.



For this equilibrium, $K_p = p_{\text{N}_2\text{O}_4} / p_{\text{NO}_2}^2$.

$p_{\text{N}_2\text{O}_4}$ and p_{NO_2} are measured in kPa.

State the units of K_p .

..... [1]

A student plans to investigate the variation of K_p with temperature.

- (c) (i) A sample of the mixture of nitrogen oxides is introduced into a gas syringe at 295K and the gas syringe is sealed so that it is both airtight and watertight. The volume occupied by the mixture is measured at different temperatures. The K_p value is calculated at each temperature.

Name the apparatus you would use to heat the gas syringe at different temperatures between 295K and 370K so that a volume reading of the gas syringe could be easily taken.

..... [1]

- (ii) The results obtained are shown in the table.

Complete the table by calculating values for $\frac{1}{T}$ and $\log K_p$.

Record the value of $\frac{1}{T}$ to **three significant figures**.

Record the value of $\log K_p$ to **two decimal places**.

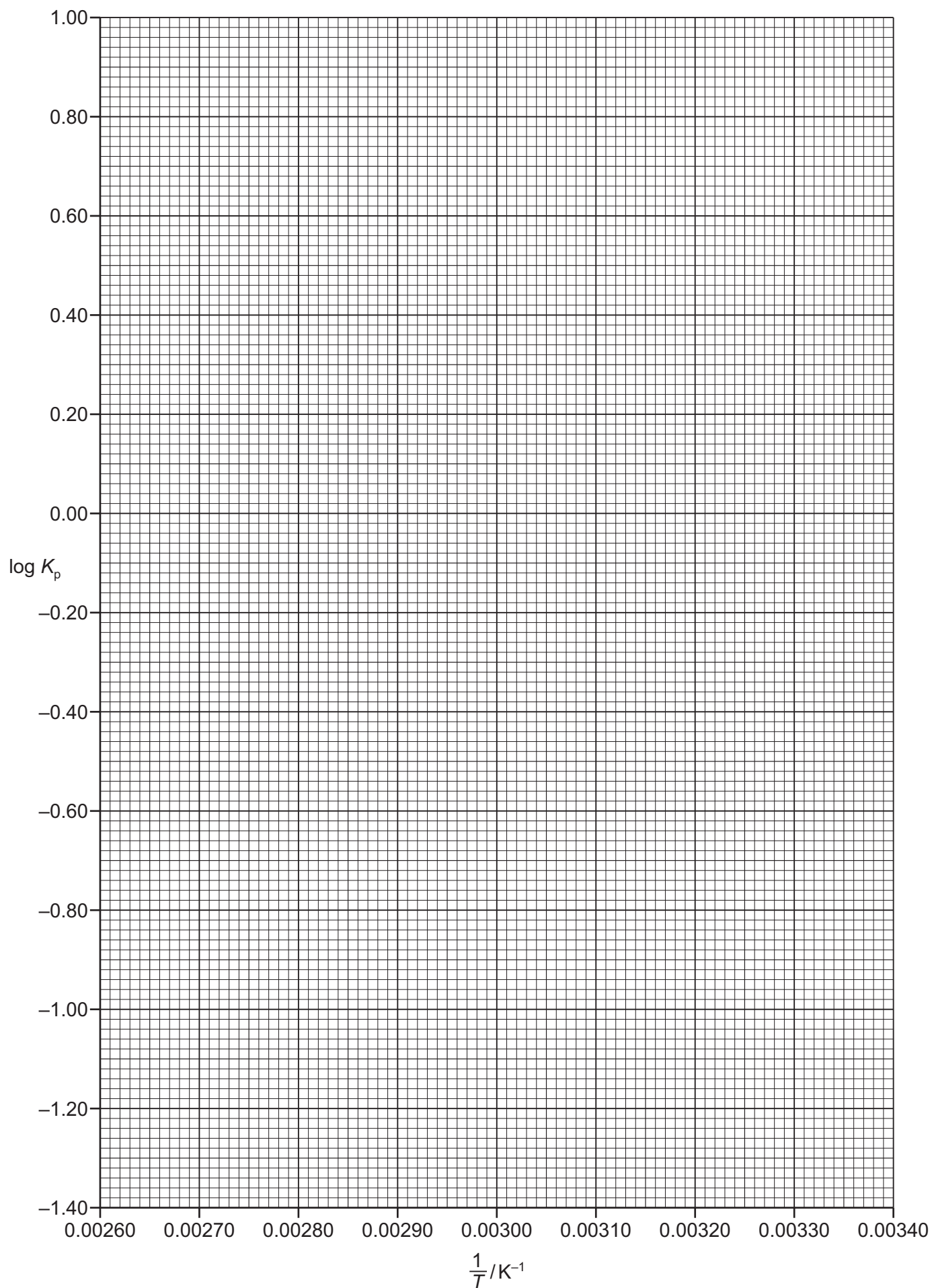
T/K	$\frac{1}{T}/\text{K}^{-1}$	K_p	$\log K_p$
377		0.076	
361		0.122	
344		0.257	
330		0.741	
315		1.506	
312		3.490	
295		9.025	

[2]

- (iii) Plot a graph on the grid of $\log K_p$ against $\frac{1}{T}$.

Draw a line of best fit through the plotted points.

[2]



- (d) (i) State and explain what your graph shows about the accuracy of the experimental results.

.....

 [1]

- (ii) Suggest a reason for your answer in (d)(i).

.....
 [1]

- (iii) Suggest what the student could do to improve the accuracy of the experiment.

.....
 [1]

- (e) (i) Use the graph to determine the gradient of the line of best fit.

State the coordinates of both points you used in your calculation. These must be on your line of best fit.

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

coordinates 1 coordinates 2

gradient = ... K
 [2]

- (ii) The relationship between $\log K_p$ and $\frac{1}{T}$ is given by the equation shown.

$$\log K_p = (-\Delta H / 2.303 RT) + \text{constant}$$

$$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$$

Use the gradient determined to calculate a value for ΔH .

If you were unable to determine a value for the gradient, use the value 2800 K. This is **not** the correct value.

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

[2]

- (f) (i) With reference to the results obtained in this experiment, state and explain how K_p varies with temperature.

.....
 [2]

- (ii) With reference to (b) and the data for K_p in the table in (c)(ii) suggest how the colour of the equilibrium mixture at 370 K will differ, if at all, from the colour at room temperature. Explain your answer.

difference in colour of mixture

explanation

.....

..... [2]

[Total: 19]

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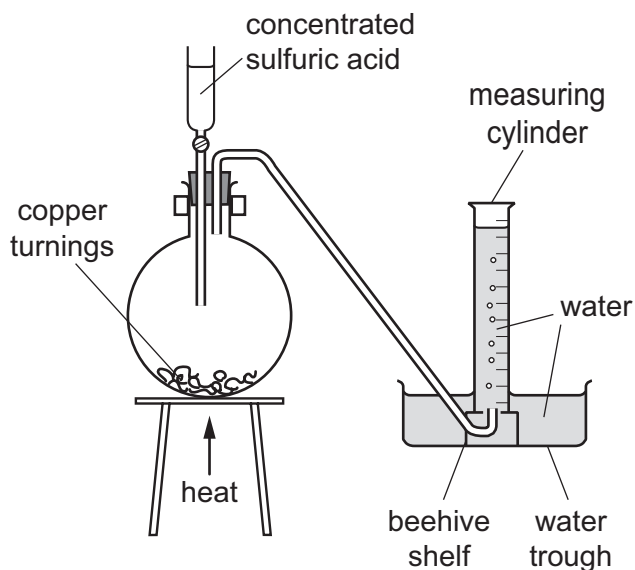
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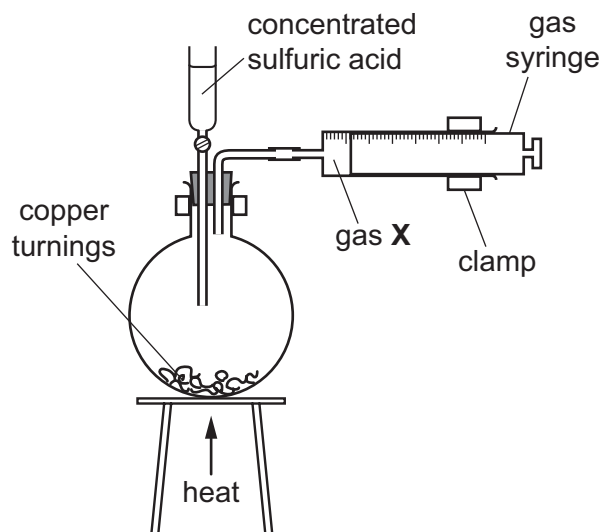
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- 1 A student plans to carry out an experiment to find the relative molecular mass, M_r , of a soluble acidic gas, **X**, by finding the mass of a measured volume of gas **X**. Gas **X** can be prepared by the reaction between concentrated sulfuric acid and copper.

Two methods of gas collection are available to the student, as shown.



method **A**



method **B**

- (a) (i) Explain why the first sample of gas collected from either apparatus should not be used for the M_r determination of gas **X**.

..... [1]

- (ii) Give **two** reasons, other than your answer to (a)(i), why, for this experiment, the apparatus in method **A** is less suitable than the apparatus in method **B** for collecting a sample of gas **X**.

reason 1

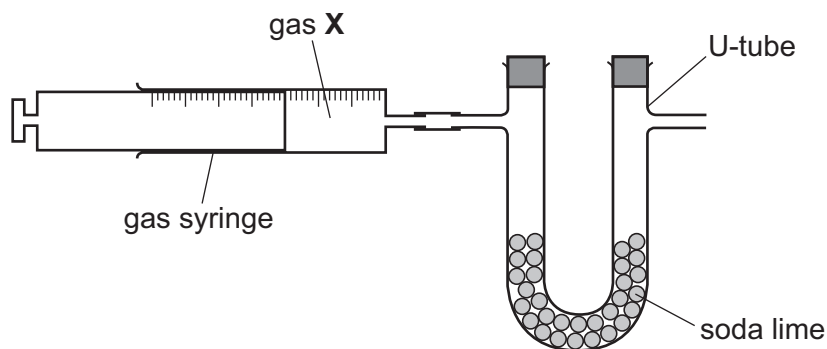
.....

reason 2

.....

[2]

- (b) The student is told to use the U-tube shown to find the mass of a sample of gas X.



A 100.0 cm^3 sample of pure gas X is placed in a gas syringe. The gas syringe is attached to a U-tube containing small lumps of solid soda lime, a mixture of sodium hydroxide and calcium hydroxide. All of gas X is slowly passed into the U-tube and the mass of gas X absorbed determined.

The temperature and the pressure of the room are recorded.

- (i) State the measurements that are needed to determine the mass of gas X absorbed.

.....
 [1]

- (ii) Suggest why soda lime is used to absorb gas X.

.....
 [1]

- (c) Gas X can cause respiratory distress.

State an appropriate precaution that should be taken when doing this experiment.

.....
 [1]

- (d) Experiment 1 is carried out at a temperature of 21°C , a pressure of $9.8 \times 10^4 \text{ Pa}$, and uses 100 cm^3 of pure gas **X**.

- (i) Calculate the number of moles of gas **X** present in Experiment 1.

You should assume that gas **X** behaves like an ideal gas and so use $PV = nRT$.

$$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$$

moles of gas **X** = ... mol [2]

- (ii) The sample of gas **X** is found to have a mass of 0.251 g .

Explain how the student should use this information and their results to determine the M_r of **X**.

.....

 [1]

- (iii) Not all of gas **X** is absorbed by the soda lime.

State what effect, if any, this has on the student's calculated value of the M_r of gas **X**.

.....
 [1]

- (iv) In Experiment 2, the same mass of gas **X** is used, but the student did not record the temperature and pressure.

The calculated M_r of **X** for Experiment 2 is higher than the value calculated by the student for Experiment 1.

State and explain how the value of $\frac{P}{T}$ changes from Experiment 1 to Experiment 2.

.....

 [1]

- (e) State how the reliability of the results in Experiment 1 could be improved.

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

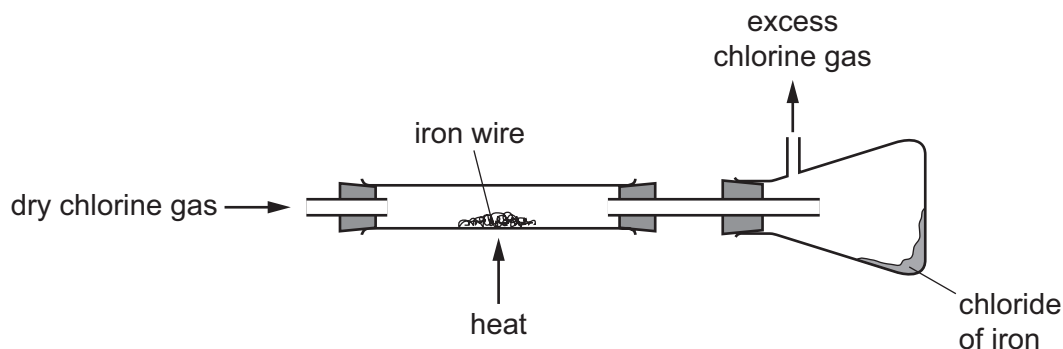
- (f) A different gas, methylamine, is alkaline.

State a change that would have to be made to the apparatus so that the M_r of methylamine could be determined.

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

[Total: 13]

- 2 Each student in a class of nine students performs an experiment to find the formula of a chloride of iron. Each student prepares the chloride of iron by passing a stream of chlorine gas over a sample of iron wire as shown in the diagram.



- (a) Each student carries out the following steps in the order shown in the list. Some of the measurement steps are missing from the list.

- Weigh the reaction tube containing a quantity of iron wire.
- Set up the apparatus as shown in the diagram.
- Start the flow of dry chlorine gas.
- Heat the iron wire until it has completely reacted.
- Allow the apparatus to cool, with chlorine gas still flowing.
- Weigh the side-arm conical flask containing the chloride of iron.

- (i) State the **two** additional measurement steps that each student must perform in order to find the formula of the chloride of iron.

1

2 [1]

- (ii) The flow of dry chlorine gas must start before the iron wire is heated.

Explain why.

.....

..... [1]

- (iii) State an assumption that has to be made for the measurements made in this experiment to be valid.

.....

..... [1]

(b) (i) The class results are shown in the table.

student	mass of iron wire /g	mass of iron chloride /g	mass of chlorine /g	amount of iron /mol	amount of chlorine atoms /mol
1	0.57	1.64			
2	1.10	3.16			
3	1.40	4.03			
4	1.95	5.61			
5	2.18	5.89			
6	2.75	7.90			
7	3.05	8.77			
8	3.45	9.80			
9	3.90	11.18			

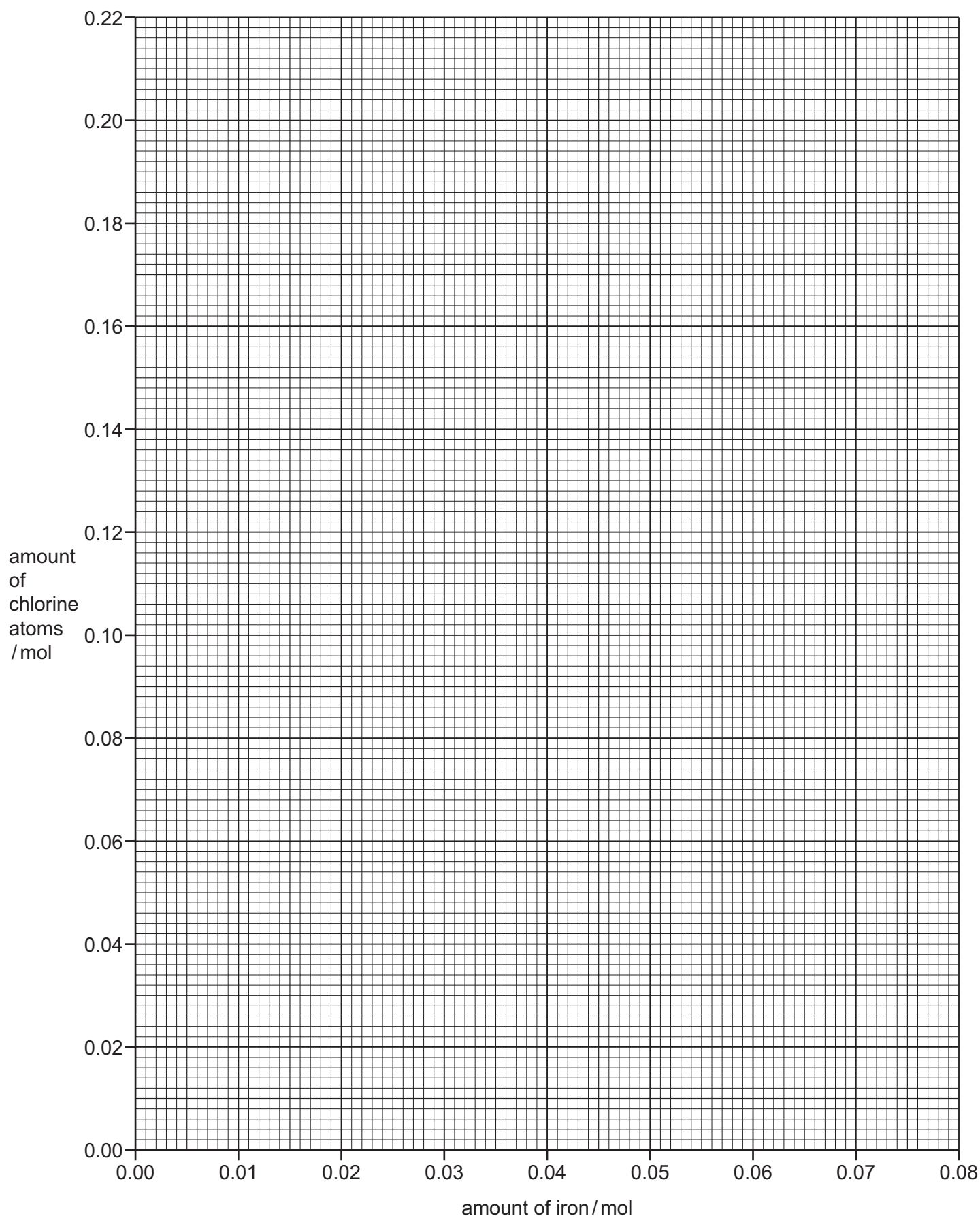
Calculate the mass of chlorine that reacts with the iron wire in each experiment. Record each mass to **two decimal places**.

Calculate the amount of iron, in mol, and amount of chlorine atoms, in mol, that reacts in each experiment. Record the number of moles to **three significant figures**.

[A_r : Fe, 55.8; Cl, 35.5]

[3]

- (ii) Plot a graph on the grid of the amount of chlorine atoms against the amount of iron. Use a cross (x) to plot each data point. Draw a line of best fit through the plotted points. You should consider whether (0,0) should be on the line of best fit. [2]



- (iii) Circle the point on the graph you consider to be most anomalous.
Suggest **one** reason why this anomaly may have occurred during this experimental procedure.

.....
 [2]

- (c) Use the graph to determine the gradient of the line of best fit.

State the coordinates of both points you used in your calculation. These must be on your line of best fit.

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

coordinates 1 coordinates 2

gradient = ... [2]

- (d) The formula of the chloride of iron produced in this experiment is FeCl_3 .

State how the results student 4 obtains could be used to determine this formula.

.....

 [1]

- (e) (i) Student 3 weighs the conical flask using a balance accurate to two decimal places and records its mass. After the chloride of iron is produced the mass increases by 4.03 g.

Calculate the percentage error in measuring the mass of this chloride of iron.

percentage error = ... % [1]

- (ii) Student 8 follows the same procedure as student 3.

State whether the results from student 8 will have more or less percentage error than those from student 3.

Explain your answer.

.....
 [1]

- (f) Another student suggested that the chloride of iron could also be prepared by the reaction between iron wire and hydrochloric acid.

- (i) A sample of a chloride of iron prepared in this way contains 44% iron by mass.

Show that the formula of this chloride of iron is FeCl_2 .

[A_r : Fe, 55.8; Cl, 35.5]

[1]

- (ii) Explain, using the electrode potential values in the table, why the methods in (a) and (f) do not produce the same chlorides of iron.

reaction	electrode potential, E°/V
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	-0.44
$2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g})$	0.00
$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77

.....

 [1]

[Total: 17]

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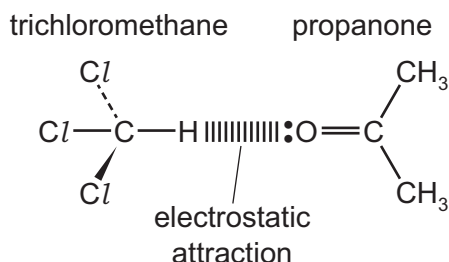
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 [1]

- (ii) The student is given **only** the following equipment and chemicals for the experiment.

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 50 cm³ trichloromethane
 50 cm³ propanone

Outline the method the student should use in this one experiment to find the temperature change when trichloromethane is mixed with propanone. Give details of the volumes of liquids used and any readings taken.

volumes used

.....

readings taken

.....

.....

method used

.....

.....

.....

[3]

- (b) The apparatus used leads to significant heat loss.

State **one** improvement the student could make to the apparatus to reduce heat loss.

.....
 [1]

- (c) Trichloromethane and propanone are both volatile and flammable.

State **one** relevant precaution that should be taken when carrying out this experiment.

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 [1]

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- (e) In another experiment, a student uses 37.50 g of trichloromethane and 19.75 g of propanone and determines that the energy released is 1.67 kJ.

- (i) Calculate the number of moles of each compound in this mixture.

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M_r propanone = 58.0

moles of trichloromethane = ... mol

moles of propanone = ... mol
 [1]

- (ii) Calculate the enthalpy change, ΔH , of the electrostatic attraction formed between trichloromethane and propanone. You must include a sign in your answer.

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

- (f) Suggest an experiment the student could carry out to test whether the number of moles of trichloromethane affects the temperature change.

.....

.....

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- 2 Nitrogen dioxide can be prepared by strongly heating anhydrous lead nitrate, $\text{Pb}(\text{NO}_3)_2(\text{s})$. The thermal decomposition occurs according to the equation shown.



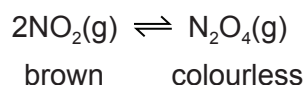
The nitrogen dioxide, NO_2 , can be separated from the oxygen by cooling the gas mixture produced until the NO_2 condenses and the oxygen does not.

	melting point/K	boiling point/K
nitrogen dioxide	262	294
oxygen	54	90

- (a) Draw a labelled diagram of the laboratory apparatus (assembled) that could be used to prepare **liquid** nitrogen dioxide from the thermal decomposition of anhydrous lead nitrate.

[2]

- (b) At room temperature, nitrogen dioxide exists in equilibrium with dinitrogen tetroxide according to the equation shown.



For this equilibrium, $K_p = p_{\text{N}_2\text{O}_4} / p_{\text{NO}_2}^2$.

$p_{\text{N}_2\text{O}_4}$ and p_{NO_2} are measured in kPa.

State the units of K_p .

..... [1]

A student plans to investigate the variation of K_p with temperature.

- (c) (i) A sample of the mixture of nitrogen oxides is introduced into a gas syringe at 295K and the gas syringe is sealed so that it is both airtight and watertight. The volume occupied by the mixture is measured at different temperatures. The K_p value is calculated at each temperature.

Name the apparatus you would use to heat the gas syringe at different temperatures between 295K and 370K so that a volume reading of the gas syringe could be easily taken.

..... [1]

- (ii) The results obtained are shown in the table.

Complete the table by calculating values for $\frac{1}{T}$ and $\log K_p$.

Record the value of $\frac{1}{T}$ to **three significant figures**.

Record the value of $\log K_p$ to **two decimal places**.

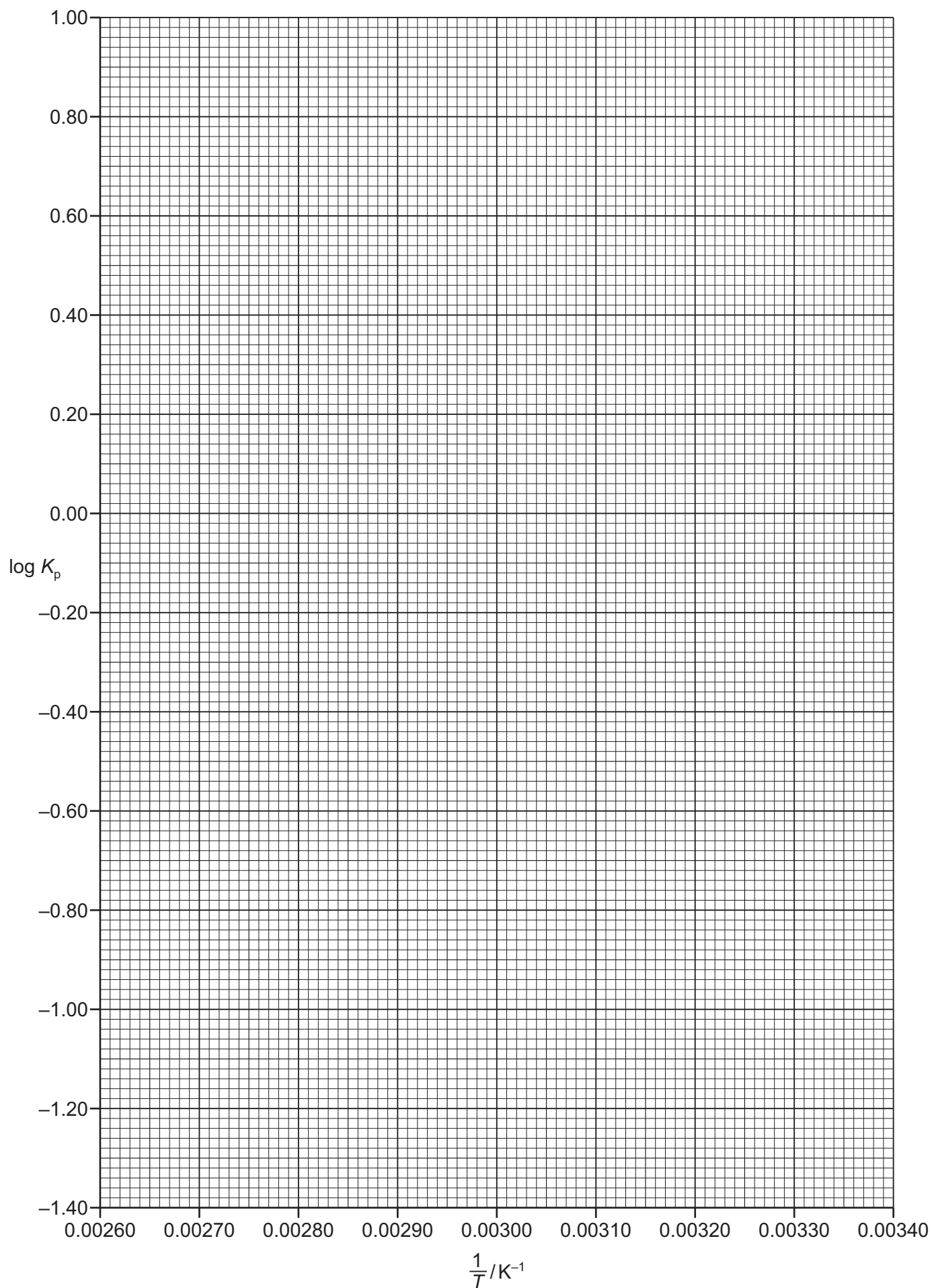
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- (iii) Plot a graph on the grid of $\log K_p$ against $\frac{1}{T}$.

Draw a line of best fit through the plotted points.

[2]



- (d) (i) State and explain what your graph shows about the accuracy of the experimental results.

.....

 [1]

- (ii) Suggest a reason for your answer in (d)(i).

.....
 [1]

- (iii) Suggest what the student could do to improve the accuracy of the experiment.

.....
 [1]

- (e) (i) Use the graph to determine the gradient of the line of best fit.

State the coordinates of both points you used in your calculation. These must be on your line of best fit.

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

coordinates 1 coordinates 2

gradient = ... K
 [2]

- (ii) The relationship between $\log K_p$ and $\frac{1}{T}$ is given by the equation shown.

$$\log K_p = (-\Delta H / 2.303 RT) + \text{constant}$$

$$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$$

Use the gradient determined to calculate a value for ΔH .

If you were unable to determine a value for the gradient, use the value 2800 K. This is **not** the correct value.

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

[2]

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- (ii) With reference to (b) and the data for K_p in the table in (c)(ii) suggest how the colour of the equilibrium mixture at 370 K will differ, if at all, from the colour at room temperature. Explain your answer.

difference in colour of mixture

explanation

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