

CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/51

May/June 2021

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, 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 **8** pages. Any blank pages are indicated.



- 1 Hydrogen peroxide decomposes slowly at room temperature to give water and oxygen.



The **initial** rate of this reaction can be increased by the addition of a metal oxide catalyst.

A student is asked to investigate which metal oxide catalyst is best at increasing the **initial** rate of this reaction by using a method which involves the collection of oxygen.

The student is provided with the following metal oxides: copper(II) oxide, iron(III) oxide, manganese(IV) oxide, nickel(II) oxide and titanium(IV) oxide.

The student is also provided with an excess volume, of a known concentration, of aqueous hydrogen peroxide and any laboratory equipment needed.

- (a) (i) State the independent variable.

..... [1]

- (ii) State the dependent variable.

..... [1]

- (b) State two variables that would need to be controlled.

1

2

[2]

- (c) Draw a labelled diagram of the assembled apparatus that could be used to carry out these experiments. The apparatus should allow the accurate recording of the oxygen produced.

[3]

- (d) (i) What measurements need to be recorded during the course of each experiment to allow the **initial** rate to be determined?

..... [1]

- (ii) How is the **initial** rate determined using these measurements?

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

- (e) How can the student ensure that the results are reliable?

..... [1]

- (f) Suggest an alternative method to investigate these reactions which does not include the collection of gas.

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

- (g) Once the reaction has finished, how can the student demonstrate that the metal oxide has not been affected by the reaction?

.....
.....
.....
..... [2]

- (h) When aqueous hydrogen peroxide is stored there is a small hole in the lid of the bottle.

Suggest why this is necessary.

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

[Total: 14]

- 2 A student is given 250.0 cm³ of solution containing a mixture of Fe²⁺ and Fe³⁺ ions. The student is asked to find the total mass of iron ions and the percentage by mass of Fe³⁺ in the solution by performing titrations with aqueous potassium manganate(VII), KMnO₄.

The student is told that the Fe³⁺(aq) ions can be reduced to Fe²⁺(aq) ions by reaction with zinc.

The student is given the following instructions.

- Calculate the mass of KMnO₄ needed to make 500.0 cm³ of 0.0200 mol dm⁻³ KMnO₄(aq).
- Record the mass of an empty plastic weighing boat (a small container used to hold solid samples).
- Add the calculated mass of KMnO₄ to the weighing boat.
- Transfer the KMnO₄ from the weighing boat into a 100 cm³ beaker.
- Add 50 cm³ of distilled water to the beaker.
- Transfer the mixture from the beaker into a 500.0 cm³ volumetric flask.
- Make up to the graduation mark, dropwise, with distilled water.

- (a) (i) Calculate the mass of KMnO₄ needed to make 500.0 cm³ of 0.0200 mol dm⁻³ KMnO₄(aq).

[A_r: K, 39.1; Mn, 54.9; O, 16.0]

mass of KMnO₄ needed = ... g [1]

- (ii) The student used a balance accurate to two decimal places.

Calculate the percentage error in weighing the mass of the KMnO₄ by difference.

If you were unable to calculate a value for **2(a)(i)** use the mass 1.75 g. This is **not** the correct answer to **2(a)(i)**. Show your working.

percentage error = ... % [1]

- (iii) The student noticed that some crystals of KMnO₄ were stuck to the weighing boat after adding the KMnO₄ solid to the beaker.

State how the student should modify the instructions to ensure that the measured mass of KMnO₄ was accurate.

.....

 [1]

- (iv) Give two additional instructions that should be given to the student to ensure that the solution is prepared as accurately as possible.

1

.....

2

.....

[2]

- (b) When the $\text{KMnO}_4(\text{aq})$ is ready for use, the student is given additional instructions.

step 1 Fill a burette with $0.0200 \text{ mol dm}^{-3} \text{ KMnO}_4(\text{aq})$.

step 2 Using a measuring cylinder, transfer 25.00 cm^3 of $\text{Fe}^{2+}(\text{aq})/\text{Fe}^{3+}(\text{aq})$ solution into a conical flask.

step 3 Add 10 cm^3 of 1.0 mol dm^{-3} sulfuric acid to the conical flask.

step 4 Titrate this acidified solution of $\text{Fe}^{2+}(\text{aq})/\text{Fe}^{3+}(\text{aq})$ with $0.0200 \text{ mol dm}^{-3} \text{ KMnO}_4(\text{aq})$ until the end-point.

step 5 Repeat titrations until the titres are concordant.
This set of results is **set A**.

step 6 Using a measuring cylinder, add 100 cm^3 of the $\text{Fe}^{2+}(\text{aq})/\text{Fe}^{3+}(\text{aq})$ solution into a beaker then add excess zinc. Allow time for reduction to $\text{Fe}^{2+}(\text{aq})$ to take place.

step 7 Filter the mixture into a beaker.

step 8 Transfer 25.00 cm^3 of the filtrate into a conical flask and add 10 cm^3 of 1.0 mol dm^{-3} sulfuric acid.

step 9 Titrate this acidified solution of the filtrate with $0.0200 \text{ mol dm}^{-3} \text{ KMnO}_4(\text{aq})$ until the end-point.

step 10 Repeat **steps 8** and **9** twice.
This set of results is **set B**.

- (i) How should the burette be prepared for use before it is filled in **step 1**?

.....

..... [1]

- (ii) What must be done to ensure as accurate an end-point as possible?

.....

..... [1]

- (c) (i) Identify an experimental weakness in **step 2**. Explain how this would affect the results.

.....

.....

..... [1]

- (ii) How could this weakness be overcome?

..... [1]

- (d) The results for each set of titrations are shown.

set A

	rough	titration 1	titration 2	titration 3
final volume / cm ³	18.40	17.25	34.55	18.00
initial volume / cm ³	0.65	0.15	17.25	0.95
titre / cm ³				

set B

	rough	titration 1	titration 2	titration 3
final volume / cm ³	45.05	43.60	43.70	
initial volume / cm ³	0.20	0.15	0.10	
titre / cm ³				

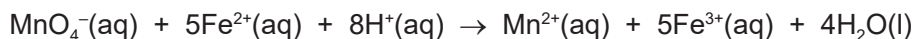
- (i) Complete both tables and calculate an appropriate average titre for each set of results. The student could **not** carry out titration 3 in **set B**.

Record the average titre to **one decimal place**.

set A average titre = ... cm³

set B average titre = ... cm³
[2]

- (ii) The reaction taking place during the titrations is shown by the equation.



Calculate the mass of Fe^{2+} ions in 100 cm^3 of the reduced solution, produced in **step 6**, by using the appropriate average titre from **(d)(i)**.

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

[A_r: Fe, 55.8]

mass of Fe^{2+} ions = ... g [2]

- (iii) Calculate the mass of Fe^{2+} ions in the original 250.0 cm^3 $\text{Fe}^{2+}(\text{aq})/\text{Fe}^{3+}(\text{aq})$ solution, using the appropriate average titre from **2(d)(i)**.

mass of Fe^{2+} ions = ... g [1]

- (iv) Calculate the percentage by mass of Fe^{3+} ions in the original 250.0 cm^3 $\text{Fe}^{2+}(\text{aq})/\text{Fe}^{3+}(\text{aq})$ solution.

percentage by mass of Fe^{3+} ions = ... % [1]

- (v) State what change could be made to the procedure to enable titration 3 to be carried out in **set B**.

.....
 [1]

[Total: 16]

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Cambridge International AS & A Level

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CHEMISTRY

9701/52

Paper 5 Planning, Analysis and Evaluation

May/June 2021

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

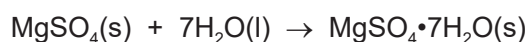
- Answer **all** questions.
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- You may use a calculator.
- You should show all your working, use appropriate units and use an appropriate number of significant figures.

INFORMATION

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

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

- 1 A student is asked to find the enthalpy change for the reaction between anhydrous magnesium sulfate and water.



This enthalpy change cannot be measured directly.

- (a) Predict whether the enthalpy change for this reaction is positive or negative. Explain the reason for your prediction.

prediction

explanation

..... [1]

- (b) The student decided to do two separate experiments.

Experiment 1

To find the enthalpy change of solution of anhydrous magnesium sulfate, $\text{MgSO}_4(\text{s})$, 0.0250 moles of $\text{MgSO}_4(\text{s})$ are dissolved in 50.0 cm^3 distilled water.

Experiment 2

To find the enthalpy change of solution of hydrated magnesium sulfate, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}(\text{s})$, 0.0250 moles of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}(\text{s})$ are dissolved in 50.0 cm^3 distilled water.

The results for **Experiment 1** are shown in the graph of temperature against time on page 3.

- (i) Draw and extrapolate the cooling curve back to 180 seconds. Determine the temperature change during the reaction.

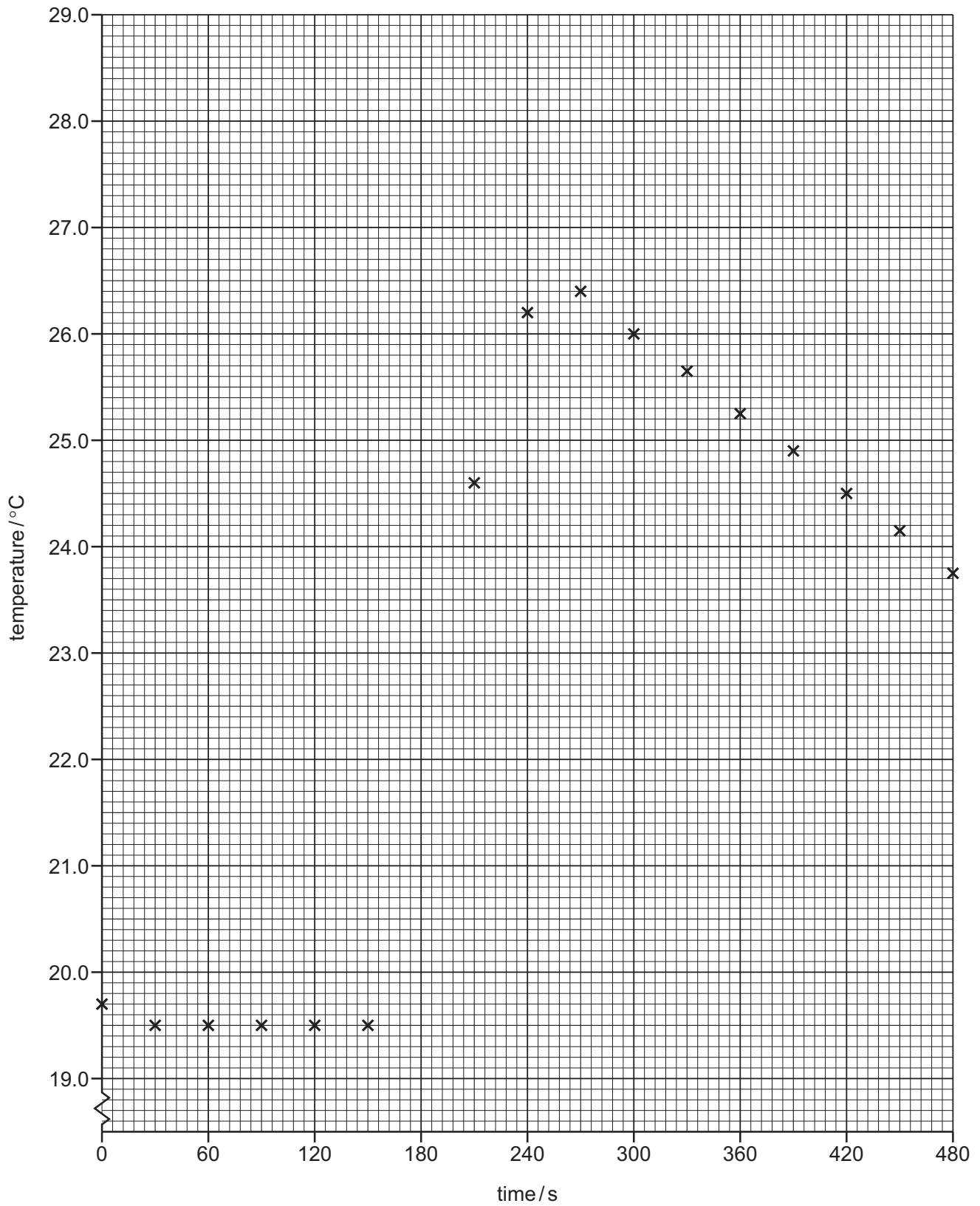
temperature change = ... °C [1]

- (ii) The anhydrous magnesium sulfate was not added when the timing started.

Explain why.

.....

..... [1]



- (iii) 3.01 g (0.0250 mol) of anhydrous magnesium sulfate is weighed.

Outline the next steps that should be taken in order to obtain the results in **Experiment 1**.

Write your answer using a series of numbered steps.

.....

.....

.....

.....

.....

.....

..... [4]

- (c) (i) The student realised that when dissolving 0.0250 moles $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}(\text{s})$, the amount of water present in the compound alters the total volume of water used in **Experiment 2**.

Calculate the volume of distilled water needed to make the total volume of water 50.00 cm^3 in **Experiment 2**.

Give your answer to the nearest 0.05 cm^3 .

Assume that 1.00 cm^3 of distilled water has a mass of 1.00 g.

[A_r : O, 16.0; H, 1.0]

volume of distilled water = ... cm^3 [1]

- (ii) State which piece of apparatus should be used to measure the volume of distilled water in (c)(i).

Explain your answer.

apparatus

explanation

[2]

- (d) The temperature change when 0.0250 moles of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}(\text{s})$ is added to the water is very small.

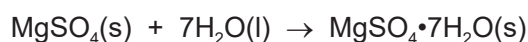
Suggest how the student should modify the experimental procedure to make the temperature change larger.

..... [1]

- (e) (i) The energy released by 0.0250 moles of $\text{MgSO}_4(\text{s})$, in **Experiment 1**, is 2125 J. The energy absorbed by 0.0250 moles of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}(\text{s})$, in **Experiment 2**, is 477.5 J.

Calculate the enthalpy change, ΔH , for the reaction.

Include a sign in your answer. Give your answer to **one** decimal place.



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

- (ii) The student noticed that some $\text{MgSO}_4(\text{s})$ in **Experiment 1** was left undissolved.

State and explain the effect this would have on the value of the enthalpy change for the reaction in **Experiment 1**.

effect

explanation

[1]

[Total: 14]

- 2 A student is asked to determine the acid dissociation constant, K_a , for butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$.

$$K_a = \frac{[\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-][\text{H}^+]}{[\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}]}$$

The student is told to measure the pH of eight buffer solutions containing $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ and the salt sodium butanoate, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-\text{Na}^+$. The salt provides butanoate ions, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-$, as the base.

Each buffer solution contains a different ratio of $[\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}]$ to $[\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-]$.

Each buffer solution is prepared by mixing different volumes of distilled water, 2.00 mol dm^{-3} $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ and 2.00 mol dm^{-3} $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-\text{Na}^+$.

- (a) Pure butanoic acid must be kept away from naked flames.

Explain why.

..... [1]

- (b) (i) What is the maximum volume of a 2.00 mol dm^{-3} solution that can be prepared using 55.0 g of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-\text{Na}^+(\text{s})$?

[A_r : Na, 23.0; O, 16.0; C, 12.0; H, 1.0]

volume = ... cm^3 [1]

- (ii) A student is given 55.0 g of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-\text{Na}^+(\text{s})$ in a beaker.

Describe the next steps the student should take to make a 2.00 mol dm^{-3} solution of the volume calculated in (b)(i).

Give the name and capacity of any key apparatus which should be used.

Write your answer as a series of numbered steps.

.....

.....

.....

.....

.....

.....

.....

..... [3]

- (iii) Complete the table to show the volumes of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-\text{Na}^+(\text{aq})$ and distilled water that would be needed to provide the stated number of moles of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ and $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-$ for a 50.0 cm^3 buffer solution.

moles of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$	volume of 2.00 mol dm^{-3} $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ $/\text{cm}^3$	moles of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-$	volume of 2.00 mol dm^{-3} $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-\text{Na}^+$ $/\text{cm}^3$	volume of distilled water $/\text{cm}^3$
0.050	25.0	0.005		
0.050	25.0	0.008		
0.050	25.0	0.010		
0.050	25.0	0.025		
0.030	15.0	0.050		
0.010	5.0	0.050		
0.006	3.0	0.050		
0.004	2.0	0.050		

[2]

(c) The pH of each buffer solution is measured.

The value of the pH is recorded in the table along with the number of moles of the $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ and $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-$ in each 50 cm^3 solution of buffer.

(i) Complete the table. Give your values of $-\log\left(\frac{[\text{acid}]}{[\text{base}]}\right)$ to **two** decimal places.

moles of acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$	moles of base, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-$	ratio of [acid]/[base]	$-\log\left(\frac{[\text{acid}]}{[\text{base}]}\right)$	pH
0.050	0.005	10.00		3.82
0.050	0.008	6.25		4.01
0.050	0.010	5.00		4.12
0.050	0.025	2.00		4.70
0.030	0.050	0.60		5.04
0.010	0.050	0.20		5.52
0.006	0.050	0.12		5.74
0.004	0.050	0.08		5.91

[1]

(ii) Plot a graph of pH (y-axis) against $-\log\left(\frac{[\text{acid}]}{[\text{base}]}\right)$ (x-axis) on the grid on page 9.

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

[2]

(iii) Circle the point on the graph you consider to be most anomalous.

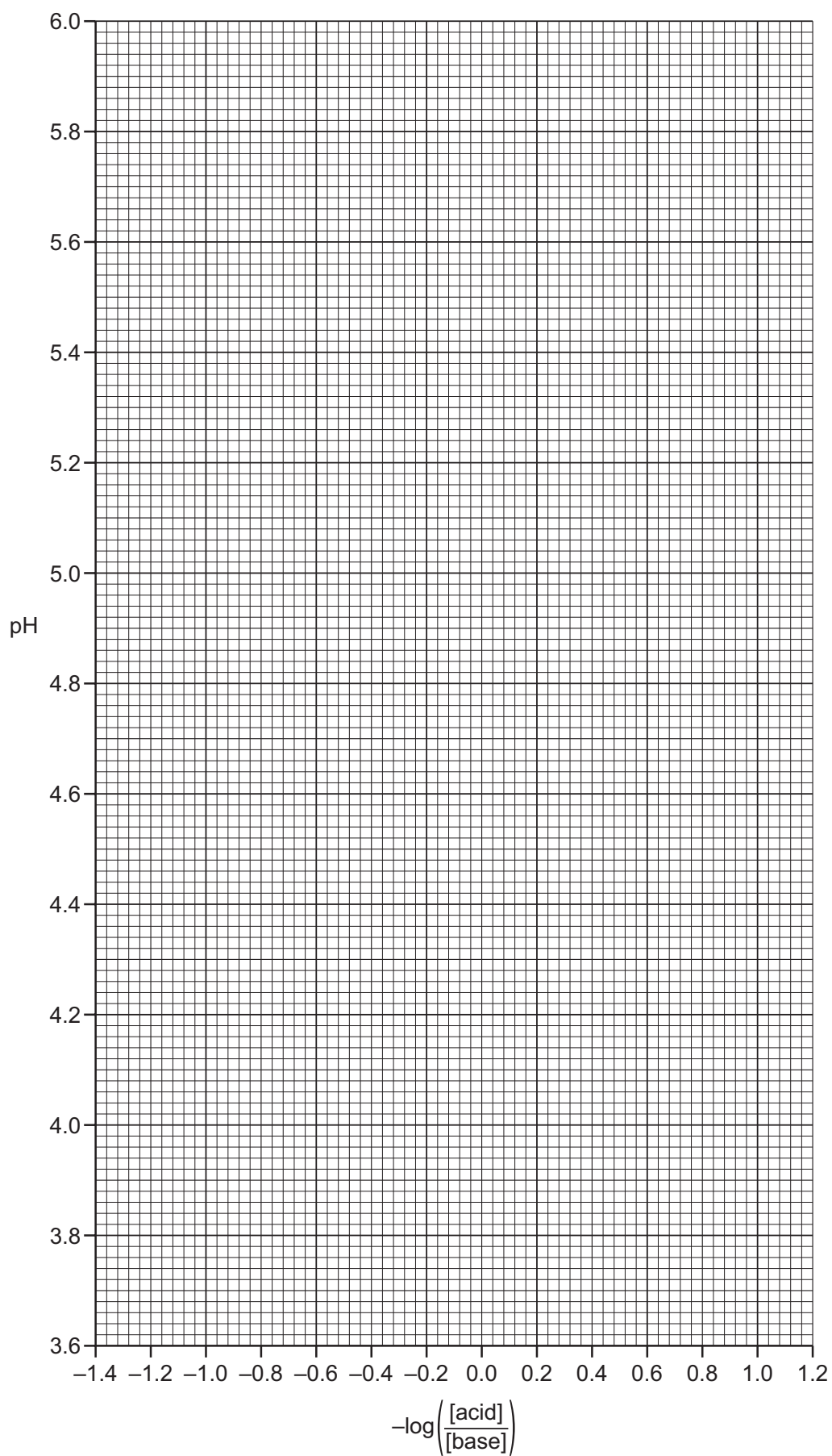
Suggest **one** reason why this anomaly may have occurred during this experimental procedure. Assume no error was made in recording the pH.

.....
 [2]

(iv) When the concentration of acid is equal to the concentration of base, $\text{pH} = \text{p}K_a$.

Use this information and your graph to find the value for the $\text{p}K_a$.

$\text{p}K_a = \dots\dots\dots$ [1]



- (v) Use your answer to (c)(iv) to calculate the value of K_a . State the units of K_a . Give your answer to **three significant figures**.

$$pK_a = -\log K_a$$

$$K_a = \dots\dots\dots$$

$$\text{units} = \dots\dots\dots$$

[2]

- (d) The value of pK_a is lower when the experiment is repeated at a higher temperature.

What does this tell you about the enthalpy of dissociation of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$?

Explain your answer.

.....

..... [1]

[Total: 16]

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- 1 Hydrogen peroxide decomposes slowly at room temperature to give water and oxygen.



The **initial** rate of this reaction can be increased by the addition of a metal oxide catalyst.

A student is asked to investigate which metal oxide catalyst is best at increasing the **initial** rate of this reaction by using a method which involves the collection of oxygen.

The student is provided with the following metal oxides: copper(II) oxide, iron(III) oxide, manganese(IV) oxide, nickel(II) oxide and titanium(IV) oxide.

The student is also provided with an excess volume, of a known concentration, of aqueous hydrogen peroxide and any laboratory equipment needed.

- (a) (i) State the independent variable.

..... [1]

- (ii) State the dependent variable.

..... [1]

- (b) State two variables that would need to be controlled.

1

2

[2]

- (c) Draw a labelled diagram of the assembled apparatus that could be used to carry out these experiments. The apparatus should allow the accurate recording of the oxygen produced.

[3]

- (d) (i) What measurements need to be recorded during the course of each experiment to allow the **initial** rate to be determined?

..... [1]

- (ii) How is the **initial** rate determined using these measurements?

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

- (e) How can the student ensure that the results are reliable?

..... [1]

- (f) Suggest an alternative method to investigate these reactions which does not include the collection of gas.

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

- (g) Once the reaction has finished, how can the student demonstrate that the metal oxide has not been affected by the reaction?

.....
.....
.....
..... [2]

- (h) When aqueous hydrogen peroxide is stored there is a small hole in the lid of the bottle.

Suggest why this is necessary.

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

[Total: 14]

- 2 A student is given 250.0 cm³ of solution containing a mixture of Fe²⁺ and Fe³⁺ ions. The student is asked to find the total mass of iron ions and the percentage by mass of Fe³⁺ in the solution by performing titrations with aqueous potassium manganate(VII), KMnO₄.

The student is told that the Fe³⁺(aq) ions can be reduced to Fe²⁺(aq) ions by reaction with zinc.

The student is given the following instructions.

- Calculate the mass of KMnO₄ needed to make 500.0 cm³ of 0.0200 mol dm⁻³ KMnO₄(aq).
- Record the mass of an empty plastic weighing boat (a small container used to hold solid samples).
- Add the calculated mass of KMnO₄ to the weighing boat.
- Transfer the KMnO₄ from the weighing boat into a 100 cm³ beaker.
- Add 50 cm³ of distilled water to the beaker.
- Transfer the mixture from the beaker into a 500.0 cm³ volumetric flask.
- Make up to the graduation mark, dropwise, with distilled water.

- (a) (i) Calculate the mass of KMnO₄ needed to make 500.0 cm³ of 0.0200 mol dm⁻³ KMnO₄(aq).

[A_r: K, 39.1; Mn, 54.9; O, 16.0]

mass of KMnO₄ needed = ... g [1]

- (ii) The student used a balance accurate to two decimal places.

Calculate the percentage error in weighing the mass of the KMnO₄ by difference.

If you were unable to calculate a value for **2(a)(i)** use the mass 1.75 g. This is **not** the correct answer to **2(a)(i)**. Show your working.

percentage error = ... % [1]

- (iii) The student noticed that some crystals of KMnO₄ were stuck to the weighing boat after adding the KMnO₄ solid to the beaker.

State how the student should modify the instructions to ensure that the measured mass of KMnO₄ was accurate.

.....

 [1]

- (iv) Give two additional instructions that should be given to the student to ensure that the solution is prepared as accurately as possible.

1

.....

2

.....

[2]

- (b) When the $\text{KMnO}_4(\text{aq})$ is ready for use, the student is given additional instructions.

step 1 Fill a burette with $0.0200 \text{ mol dm}^{-3} \text{ KMnO}_4(\text{aq})$.

step 2 Using a measuring cylinder, transfer 25.00 cm^3 of $\text{Fe}^{2+}(\text{aq})/\text{Fe}^{3+}(\text{aq})$ solution into a conical flask.

step 3 Add 10 cm^3 of 1.0 mol dm^{-3} sulfuric acid to the conical flask.

step 4 Titrate this acidified solution of $\text{Fe}^{2+}(\text{aq})/\text{Fe}^{3+}(\text{aq})$ with $0.0200 \text{ mol dm}^{-3} \text{ KMnO}_4(\text{aq})$ until the end-point.

step 5 Repeat titrations until the titres are concordant.
This set of results is **set A**.

step 6 Using a measuring cylinder, add 100 cm^3 of the $\text{Fe}^{2+}(\text{aq})/\text{Fe}^{3+}(\text{aq})$ solution into a beaker then add excess zinc. Allow time for reduction to $\text{Fe}^{2+}(\text{aq})$ to take place.

step 7 Filter the mixture into a beaker.

step 8 Transfer 25.00 cm^3 of the filtrate into a conical flask and add 10 cm^3 of 1.0 mol dm^{-3} sulfuric acid.

step 9 Titrate this acidified solution of the filtrate with $0.0200 \text{ mol dm}^{-3} \text{ KMnO}_4(\text{aq})$ until the end-point.

step 10 Repeat **steps 8** and **9** twice.
This set of results is **set B**.

- (i) How should the burette be prepared for use before it is filled in **step 1**?

.....

..... [1]

- (ii) What must be done to ensure as accurate an end-point as possible?

.....

..... [1]

- (c) (i) Identify an experimental weakness in **step 2**. Explain how this would affect the results.

.....

.....

..... [1]

- (ii) How could this weakness be overcome?

..... [1]

- (d) The results for each set of titrations are shown.

set A

	rough	titration 1	titration 2	titration 3
final volume / cm ³	18.40	17.25	34.55	18.00
initial volume / cm ³	0.65	0.15	17.25	0.95
titre / cm ³				

set B

	rough	titration 1	titration 2	titration 3
final volume / cm ³	45.05	43.60	43.70	
initial volume / cm ³	0.20	0.15	0.10	
titre / cm ³				

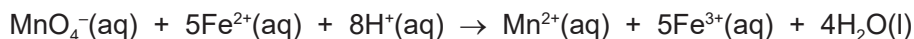
- (i) Complete both tables and calculate an appropriate average titre for each set of results. The student could **not** carry out titration 3 in **set B**.

Record the average titre to **one decimal place**.

set A average titre = ... cm³

set B average titre = ... cm³
[2]

- (ii) The reaction taking place during the titrations is shown by the equation.



Calculate the mass of Fe^{2+} ions in 100 cm^3 of the reduced solution, produced in **step 6**, by using the appropriate average titre from **(d)(i)**.

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

[A_r: Fe, 55.8]

mass of Fe^{2+} ions = ... g [2]

- (iii) Calculate the mass of Fe^{2+} ions in the original 250.0 cm^3 $\text{Fe}^{2+}(\text{aq})/\text{Fe}^{3+}(\text{aq})$ solution, using the appropriate average titre from **2(d)(i)**.

mass of Fe^{2+} ions = ... g [1]

- (iv) Calculate the percentage by mass of Fe^{3+} ions in the original 250.0 cm^3 $\text{Fe}^{2+}(\text{aq})/\text{Fe}^{3+}(\text{aq})$ solution.

percentage by mass of Fe^{3+} ions = ... % [1]

- (v) State what change could be made to the procedure to enable titration 3 to be carried out in **set B**.

.....
 [1]

[Total: 16]

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