

**Catholic Junior College**  
**JC2 Preliminary Examinations**  
**Higher 2**

CANDIDATE  
NAME

CLASS

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**CHEMISTRY**

Paper 4 Practical

**9729/04**

**August 2021**

**2 hour 30 minutes**

Candidates answer on the Question Paper.

Additional Materials: As listed in the Confidential Instructions

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**READ THESE INSTRUCTIONS FIRST**

Write your name and class in the boxes above.

Give details of the practical shift and laboratory, where appropriate, in the boxes provided.

Write in dark blue or black pen.

You may use an HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions in the spaces provided on the Question Paper.

The use of an approved scientific calculator is expected, where appropriate.  
You may lose marks if you do not show your working or if you do not use appropriate units.

Qualitative Analysis Notes are printed on pages 15 and 16.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [ ] at the end of each question or part question.

<b>Shift</b>	
<b>Laboratory</b>	

<b>For Examiner's Use</b>	
1	/ 21
2	/ 18
3	/ 16
<b>Total</b>	<b>/ 55</b>

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This document consists of **16** printed pages and **0** blank page.

**[Turn over**

Answer **all** the questions in the spaces provided.

**1 To determine the stoichiometry of two redox reactions.**

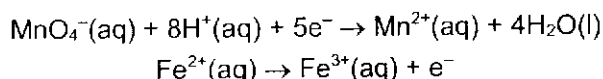
**FA 1** is  $0.0395 \text{ mol dm}^{-3}$  ammonium iron(II) sulfate,  $(\text{NH}_4)_2\text{SO}_4 \cdot \text{FeSO}_4 \cdot 6\text{H}_2\text{O}$ .

**FA 2** is  $0.0150 \text{ mol dm}^{-3}$  potassium manganate(VII),  $\text{KMnO}_4$ .

**FA 3** is  $0.0250 \text{ mol dm}^{-3}$  hydrogen peroxide,  $\text{H}_2\text{O}_2$ .

You are also provided with dilute sulfuric acid,  $\text{H}_2\text{SO}_4$ .

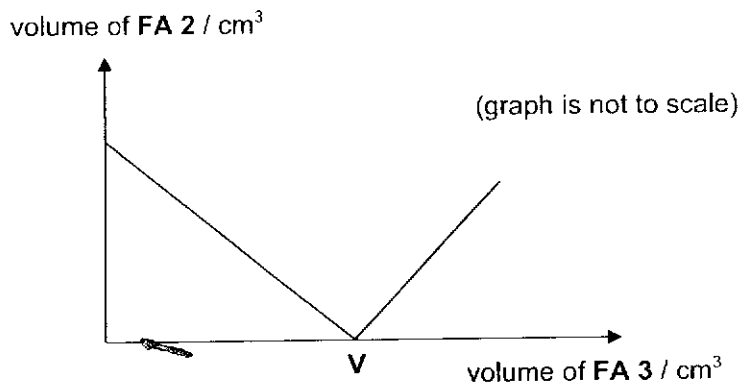
Potassium manganate(VII), **FA 2**, and hydrogen peroxide, **FA 3**, are both able to oxidise the  $\text{Fe}^{2+}(\text{aq})$  ions in acidified **FA 1**.



In the presence of acid, potassium manganate(VII), **FA 2**, can also oxidise hydrogen peroxide, **FA 3**, forming oxygen gas.

In this question, you will prepare five mixtures, each containing different volumes of **FA 3** added to  $25.0 \text{ cm}^3$  portions of **FA 1**. This mixture will then be acidified by adding sulfuric acid and titrated against **FA 2**.

A graph of the results can then be drawn.



Graphical analysis of your results will enable you to determine

- the volume, **V**, of **FA 3** which reacts with  $25.0 \text{ cm}^3$  of **FA 1**,
- the mole ratio for the reaction between  $\text{Fe}^{2+}(\text{aq})$  and  $\text{H}_2\text{O}_2(\text{aq})$ , and
- the mole ratio for the reaction between  $\text{MnO}_4^-(\text{aq})$  and  $\text{H}_2\text{O}_2(\text{aq})$ .

Each titration is to be performed **once only**, so great care should be taken that you do not overshoot the end-points.

Prepare a table in the space provided on page 4 to record, to an appropriate level of precision:

- volume of **FA 3** added in each mixture,  $V_{\text{FA3}}$ ,
- all burette readings,
- volume of **FA 2** added,  $V_{\text{FA2}}$ .

(a) **Method**

- (i) Perform **Experiment 1 and 2** as described below. Record your results ( $V_{FA3}$ , all burette readings and  $V_{FA2}$ ) to an appropriate level of precision, in your table.

**Experiment 1**

1. Fill the burette labelled **FA 3** with **FA 3**.
2. Fill the other burette with **FA 2**.
3. Pipette 25.0 cm<sup>3</sup> of **FA 1** into a 250 cm<sup>3</sup> conical flask.
4. Use a measuring cylinder to add 10 cm<sup>3</sup> of sulfuric acid into the conical flask.
5. Titrate the **FA 1** solution in the conical flask with **FA 2**.  
End-point is reached when a permanent **pale pink** colour is obtained.

**Experiment 2**

In this experiment, a very small volume of **FA 2** will be required.

6. Repeat steps 3 to 5 but, at step 5, add 12.00 cm<sup>3</sup> of **FA 3** from the burette into the conical flask and then titrate the mixture with **FA 2**.
- (ii) The volume of **FA 3** added in **Experiment 2** was insufficient to react with all the Fe<sup>2+</sup> ions in **FA 1**. Use your results from **Experiment 1 and 2** to estimate a value for the volume of **FA 3** at point **V**.

(Sketching a graph of  $V_{FA2}$  against  $V_{FA3}$  or otherwise may help in calculating the volume of **FA 3** at point **V**.)

estimated volume of **FA 3** at point **V** = ..... [1]

**(iii) Experiment 3 to 5**

Use your answer from **(a)(ii)** to select **three** further volumes of **FA 3** in order to produce a graph of the type shown in page 2.

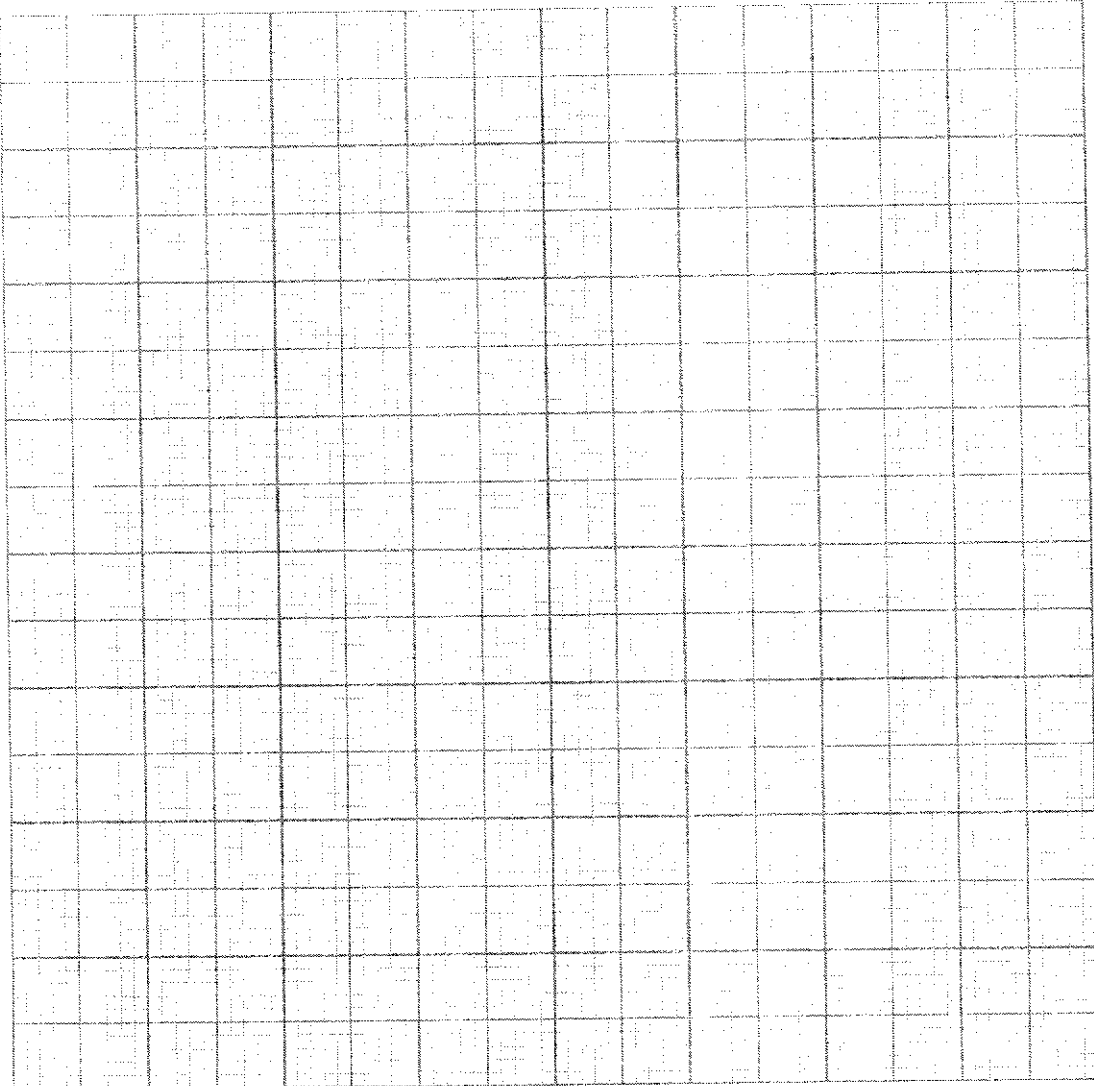
Repeat **Experiment 2** but use your selected volumes of **FA 3** at step 5 and then titrate each mixture with **FA 2**.

**Results:**

[5]



- (b) Plot on the grid below, a graph of  $V_{FA2}$  on the y-axis against  $V_{FA3}$  on the x-axis. Draw **two** best-fit straight line for the point before and after **V**. Hence, obtain a value for the volume at **V**.



volume of FA 3 at point **V** = ..... [5]

- (c) (i) Calculate the amount of  $\text{H}_2\text{O}_2$  present in  $V \text{ cm}^3$  of **FA 3** and hence deduce the amount of  $\text{H}_2\text{O}_2$  that will react exactly with 1.00 mol of  $\text{Fe}^{2+}$  ions. Give your answers to three significant figures.

amount of  $\text{H}_2\text{O}_2$  present in  $V \text{ cm}^3$  of **FA 3** = ..... [1]

amount of  $\text{H}_2\text{O}_2$  that reacts exactly with 1.00 mol of  $\text{Fe}^{2+}$  ions = ..... [1]

- (ii) Calculate the gradient of the **line to the right of V** to three significant figures, showing clearly how you did this.

gradient = ..... [2]

- (iii) Use the following relationship to calculate the mole ratio for the reaction between  $\text{H}_2\text{O}_2$  and  $\text{MnO}_4^-$  ions.

$$\text{gradient} = \frac{\text{mol of MnO}_4^- \times [\text{FA 3}]}{\text{mol of H}_2\text{O}_2 \times [\text{FA 2}]}$$

mole ratio  $\text{H}_2\text{O}_2 : \text{MnO}_4^- = \dots\dots\dots$  [1]

(d) Explain, in terms of the chemistry involved, the direction of the slope of your graph

(i) to the left of V

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

(ii) to the right of V

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

(e) A student repeated the experiment described in (a) but used  $0.0395 \text{ mol dm}^{-3}$  hydrogen peroxide instead of FA 3.

Suggest what effect this would have on the value of V, explain your answer clearly.

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

(f) (i) One source of potential error in this experiment involves taking readings from a burette. A student carried out **Experiment 2** and recorded the initial and final burette readings as  $16.50 \text{ cm}^3$  and  $21.85 \text{ cm}^3$  respectively. Calculate, to three significant figures, the maximum percentage error in his titre value.

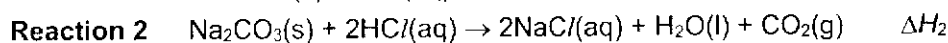
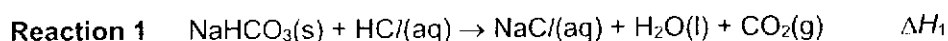
maximum percentage error = .....% [1]

(ii) Suggest one improvement to the method described in (a) which could significantly improve the accuracy of the experiment.

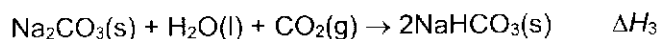
.....  
..... [1]

[Total: 21]

- 2 The enthalpy change for the reaction of sodium carbonate,  $\text{Na}_2\text{CO}_3$ , with water and carbon dioxide to form sodium hydrogencarbonate,  $\text{NaHCO}_3$ , cannot be determined directly. However both  $\text{Na}_2\text{CO}_3(\text{s})$  and  $\text{NaHCO}_3(\text{s})$  react with dilute hydrochloric acid.



In this experiment you will determine the enthalpy change  $\Delta H_1$  for **reaction 1** and  $\Delta H_2$  for **reaction 2**, and then use your results to calculate  $\Delta H_3$  for the reaction:

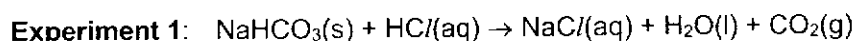


**FA 4** is sodium hydrogen carbonate,  $\text{NaHCO}_3$ .

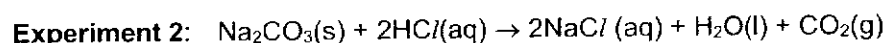
**FA 5** is sodium carbonate,  $\text{Na}_2\text{CO}_3$ .

**FA 6** is  $2.0 \text{ mol dm}^{-3}$  hydrochloric acid,  $\text{HCl}$ .

**(a) Method**



- Use a measuring cylinder to transfer  $25 \text{ cm}^3$  of the acid, **FA 6**, into a polystyrene cup supported in a  $250 \text{ cm}^3$  beaker. The acid is in excess.
- Weigh the container with **FA 4** and record the balance reading.
- Place the thermometer in the acid and record its initial temperature.
- Carefully tip all the **FA 4**, in small portions, into the acid and stir to dissolve.
- Record the lowest temperature reached.
- Reweigh the container with any residual **FA 4** and record the balance reading and the mass of **FA 4** used.



- Replace the wet polystyrene cup with a clean, dry polystyrene cup.
- Repeat **Experiment 1** but use **FA 5** in place of **FA 4** and record the highest temperature reached.
- Reweigh the container with any residual **FA 5** and record the balance reading and the mass of **FA 5** used.

**Results**

Record **all** weighings and temperature readings in the table below.

	Experiment 1	Experiment 2
mass of container + solid sample / g		
mass of container + residual <b>solid</b> / g		
mass of <b>solid</b> added / g		
initial temperature, $T_i$ , of <b>FA 6</b> / °C		
final temperature, $T_f$ / °C		
temperature change, $\Delta T$ / °C		

[5]



- (b) (i) Calculate the heat energy absorbed when **FA 4** was added to the acid in **Experiment 1** and hence, the enthalpy change, in  $\text{kJ mol}^{-1}$ , when 1 mol of **FA 4**,  $\text{NaHCO}_3$ , reacts with the acid. [Ar: H, 1.0; C, 12.0; O, 16.0; Na, 23.0]  
[Assume that 4.18 J of heat energy changes the temperature of  $1.0 \text{ cm}^3$  of solution by  $1.0 \text{ }^\circ\text{C}$ .]

heat energy absorbed = ..... J

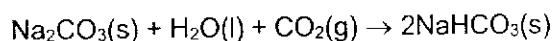
enthalpy change,  $\Delta H_1 = \dots\dots\dots \text{kJ mol}^{-1}$   
[3]

- (ii) Calculate the heat energy produced when **FA 5** was added to the acid in **Experiment 2** and hence, the enthalpy change, in  $\text{kJ mol}^{-1}$ , when 1 mol of **FA 5**,  $\text{Na}_2\text{CO}_3$ , reacts with the acid. [Ar: C, 12.0; O, 16.0; Na, 23.0].  
[Assume that 4.18 J of heat energy changes the temperature of  $1.0 \text{ cm}^3$  of solution by  $1.0 \text{ }^\circ\text{C}$ .]

heat energy produced = ..... J

enthalpy change,  $\Delta H_2 = \dots\dots\dots \text{kJ mol}^{-1}$   
[3]

- (iii) Using your answers to (b)(i) and (b)(ii) and the equations for **Experiment 1** and **Experiment 2**, determine the enthalpy change for the reaction:

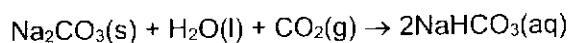


enthalpy change,  $\Delta H_3 = \dots\dots\dots$   $\text{kJ mol}^{-1}$  [2]

**(c) Planning**

You are provided with **FA 4**, solid sodium hydrogencarbonate,  $\text{NaHCO}_3$ , and distilled water.

Using only these materials, you are to **plan** and carry out an additional experiment to determine a further enthalpy change,  $\Delta H_4$ , which can be put together with those from **Experiment 1** and **Experiment 2** to determine the enthalpy change for the reaction:



- Outline your plan as a series of numbered steps.

.....

.....

.....

.....

.....

.....

.....

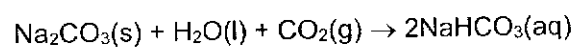
.....

.....

.....

- Carry out your plan and record your results, in a suitable form, in the space below.

- Show how you would use your results to determine the enthalpy change for the reaction:



[5]

**[Total: 18]**

### 3 Qualitative Analysis

You are provided with **FA 7**, an aqueous solution containing two cations and one anion.

In this question, you will carry out tests on **FA 7** to identify the ions present in the sample.

- (a) Carry out the following tests and record your observations in the table. You should test and identify any gases evolved. If there is no observable reaction, write 'No observable change' in the observations column.

test	observations
<b>Test 1</b> Place a drop of <b>FA 7</b> on the Universal Indicator (UI) paper and compare the colour against the UI colour chart provided.	
<b>Test 2</b> Place 1 cm depth of <b>FA 7</b> in a clean test-tube. Add an equal volume of dilute nitric acid slowly with shaking.	
<b>Test 3</b> Place 1 cm depth of <b>FA 7</b> in a clean boiling tube. Add aqueous sodium hydroxide slowly with shaking until no further change is seen. Warm the mixture gently.	
<b>Test 4</b> Place 1 cm depth of potassium iodide in a clean test-tube. Add 8 drops of <b>FA 7</b> . Then add 3 drops of starch solution.	
<b>Test 5</b> Place 1 cm depth of hydrogen peroxide in a clean test-tube. Add an equal volume of <b>FA 7</b> . Make observations for about 2 minutes before recording your results.	

[7]

(b) (i) Identify the two cations present in **FA 7** and provide evidence to support your answer.

cation 1 .....

evidence .....

.....

cation 2 .....

evidence .....

.....

[2]

(ii) Explain, in terms of ions present, the pH of the **FA 7** solution observed in **3(a)**.

.....

.....

..... [1]

(iii) Suggest, with explanation, the nature of **FA 7** as observed in **Test 4**.

**FA 7** is .....

explanation .....

..... [1]

(iv) State the role of hydrogen peroxide in **Test 5**.

..... [1]

(c) The anions that may be present in **FA 7** are bromide, carbonate and sulfate.

(i) From the observations in **3(a)**, one of the above anion can be ruled out. Identify this anion and provide evidence to support your answer.

anion **not** present in **FA 7** .....

evidence .....

..... [1]

- (ii) Plan and carry out other tests to confirm the identity of the anion present in **FA 7**. Record your results in the table below. Draw a line after each test. You are **not** to identify the anion by elimination.

test	observations

anion present in **FA 7** is .....

[3]

[Total: 16]

### Qualitative Analysis Notes

[ppt. = precipitate]

#### (a) Reactions of aqueous cations

cation	reaction with	
	NaOH(aq)	NH <sub>3</sub> (aq)
aluminium, Al <sup>3+</sup> (aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH <sub>4</sub> <sup>+</sup> (aq)	ammonia produced on heating	–
barium, Ba <sup>2+</sup> (aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca <sup>2+</sup> (aq)	white ppt. with high [Ca <sup>2+</sup> (aq)]	no ppt.
chromium(III), Cr <sup>3+</sup> (aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu <sup>2+</sup> (aq)	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II), Fe <sup>2+</sup> (aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe <sup>3+</sup> (aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg <sup>2+</sup> (aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn <sup>2+</sup> (aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn <sup>2+</sup> (aq)	white ppt. soluble in excess	white ppt. soluble in excess

**(b) Reactions of anions**

<i>ion</i>	<i>reaction</i>
carbonate, $\text{CO}_3^{2-}$	$\text{CO}_2$ liberated by dilute acids
chloride, $\text{Cl}^-(\text{aq})$	gives white ppt. with $\text{Ag}^+(\text{aq})$ (soluble in $\text{NH}_3(\text{aq})$ )
bromide, $\text{Br}^-(\text{aq})$	gives pale cream ppt. with $\text{Ag}^+(\text{aq})$ (partially soluble in $\text{NH}_3(\text{aq})$ )
iodide, $\text{I}^-(\text{aq})$	gives yellow ppt. with $\text{Ag}^+(\text{aq})$ (insoluble in $\text{NH}_3(\text{aq})$ )
nitrate, $\text{NO}_3^-(\text{aq})$	$\text{NH}_3$ liberated on heating with $\text{OH}^-(\text{aq})$ and Al foil
nitrite, $\text{NO}_2^-(\text{aq})$	$\text{NH}_3$ liberated on heating with $\text{OH}^-(\text{aq})$ and Al foil; NO liberated by dilute acids (colourless NO $\rightarrow$ (pale) brown $\text{NO}_2$ in air)
sulfate, $\text{SO}_4^{2-}(\text{aq})$	gives white ppt. with $\text{Ba}^{2+}(\text{aq})$ (insoluble in excess dilute strong acids)
sulfite, $\text{SO}_3^{2-}(\text{aq})$	$\text{SO}_2$ liberated with dilute acids; gives white ppt. with $\text{Ba}^{2+}(\text{aq})$ (soluble in dilute strong acids)

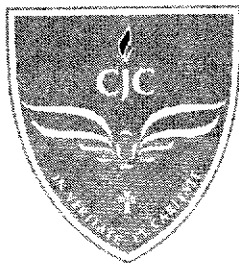
**(c) Tests for gases**

<i>gas</i>	<i>test and test result</i>
ammonia, $\text{NH}_3$	turns damp red litmus paper blue
carbon dioxide, $\text{CO}_2$	gives a white ppt. with limewater (ppt. dissolves with excess $\text{CO}_2$ )
chlorine, $\text{Cl}_2$	bleaches damp litmus paper
hydrogen, $\text{H}_2$	"pops" with a lighted splint
oxygen, $\text{O}_2$	relights a glowing splint
sulfur dioxide, $\text{SO}_2$	turns aqueous acidified potassium manganate(VII) from purple to colourless

**(d) Colour of halogens**

<i>halogen</i>	<i>colour of element</i>	<i>colour in aqueous solution</i>	<i>colour in hexane</i>
chlorine, $\text{Cl}_2$	greenish yellow gas	pale yellow	pale yellow
bromine, $\text{Br}_2$	reddish brown gas / liquid	orange	orange-red
iodine, $\text{I}_2$	black solid / purple gas	brown	purple





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**2 hour 30 minutes**

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<b>Total</b>	<b>/ 55</b>

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**1 To determine the stoichiometry of two redox reactions.**

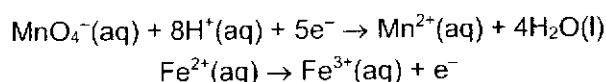
**FA 1** is  $0.0395 \text{ mol dm}^{-3}$  ammonium iron(II) sulfate,  $(\text{NH}_4)_2\text{SO}_4 \cdot \text{FeSO}_4 \cdot 6\text{H}_2\text{O}$ .

**FA 2** is  $0.0150 \text{ mol dm}^{-3}$  potassium manganate(VII),  $\text{KMnO}_4$ .

**FA 3** is  $0.0250 \text{ mol dm}^{-3}$  hydrogen peroxide,  $\text{H}_2\text{O}_2$ .

You are also provided with dilute sulfuric acid,  $\text{H}_2\text{SO}_4$ .

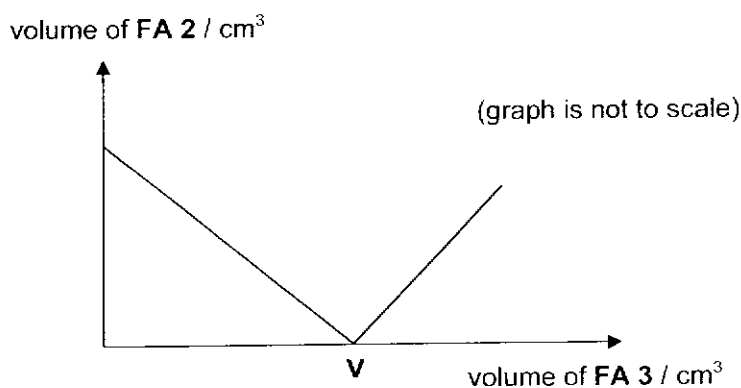
Potassium manganate(VII), **FA 2**, and hydrogen peroxide, **FA 3**, are both able to oxidise the  $\text{Fe}^{2+}(\text{aq})$  ions in acidified **FA 1**.



In the presence of acid, potassium manganate(VII), **FA 2**, can also oxidise hydrogen peroxide, **FA 3**, forming oxygen gas.

In this question, you will prepare five mixtures, each containing different volumes of **FA 3** added to  $25.0 \text{ cm}^3$  portions of **FA 1**. This mixture will then be acidified by adding sulfuric acid and titrated against **FA 2**.

A graph of the results can then be drawn.



Graphical analysis of your results will enable you to determine

- the volume, **V**, of **FA 3** which reacts with  $25.0 \text{ cm}^3$  of **FA 1**,
- the mole ratio for the reaction between  $\text{Fe}^{2+}(\text{aq})$  and  $\text{H}_2\text{O}_2(\text{aq})$ , and
- the mole ratio for the reaction between  $\text{MnO}_4^-(\text{aq})$  and  $\text{H}_2\text{O}_2(\text{aq})$ .

Each titration is to be performed **once only**, so great care should be taken that you do not overshoot the end-points.

Prepare a table in the space provided on page 4 to record, to an appropriate level of precision:

- volume of **FA 3** added in each mixture,  $V_{\text{FA3}}$ ,
- all burette readings,
- volume of **FA 2** added,  $V_{\text{FA2}}$ .

(a) **Method**

- (i) Perform **Experiment 1 and 2** as described below. Record your results ( $V_{FA3}$ , all burette readings and  $V_{FA2}$ ) to an appropriate level of precision, in your table.

**Experiment 1**

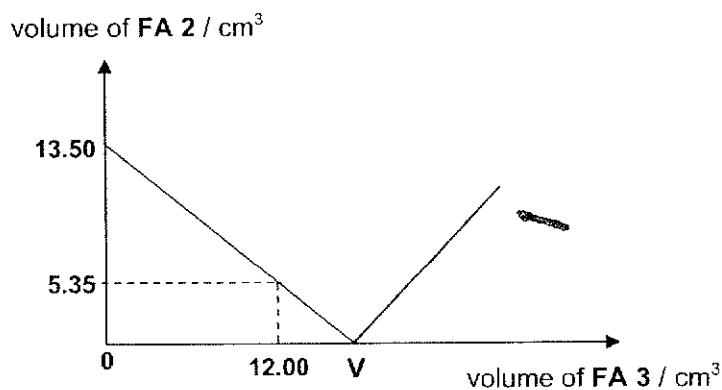
1. Fill the burette labelled **FA 3** with **FA 3**.
2. Fill the other burette with **FA 2**.
3. Pipette  $25.0 \text{ cm}^3$  of **FA 1** into a  $250 \text{ cm}^3$  conical flask.
4. Use a measuring cylinder to add  $10 \text{ cm}^3$  of sulfuric acid into the conical flask.
5. Titrate the **FA 1** solution in the conical flask with **FA 2**.  
End-point is reached when a permanent **pale pink** colour is obtained.

**Experiment 2**

In this experiment, a very small volume of **FA 2** will be required.

6. Repeat steps 3 to 5 but, at step 5, add  $12.00 \text{ cm}^3$  of **FA 3** from the burette into the conical flask and then titrate the mixture with **FA 2**.
- (ii) The volume of **FA 3** added in **Experiment 2** was insufficient to react with all the  $\text{Fe}^{2+}$  ions in **FA 1**. Use your results from **Experiment 1 and 2** to estimate a value for the volume of **FA 3** at point **V**.

(Sketching a graph of  $V_{FA2}$  against  $V_{FA3}$  or otherwise may help in calculating the volume of **FA 3** at point **V**.)



$$\begin{aligned} \text{estimated vol of FA 3} &= \frac{13.500}{13.50 - 5.35} \times 12.00 \\ &= 19.88 \text{ cm}^3 \end{aligned}$$

estimated volume of **FA 3** at point **V** = ..... **19.88 cm<sup>3</sup>** ..... [1]

**(iii) Experiment 3 to 5**

Use your answer from **(a)(ii)** to select **three** further volumes of **FA 3** in order to produce a graph of the type shown in page 1.

Repeat **Experiment 2** but use your selected volumes of **FA 3** at step 5 and then titrate each mixture with **FA 2**.

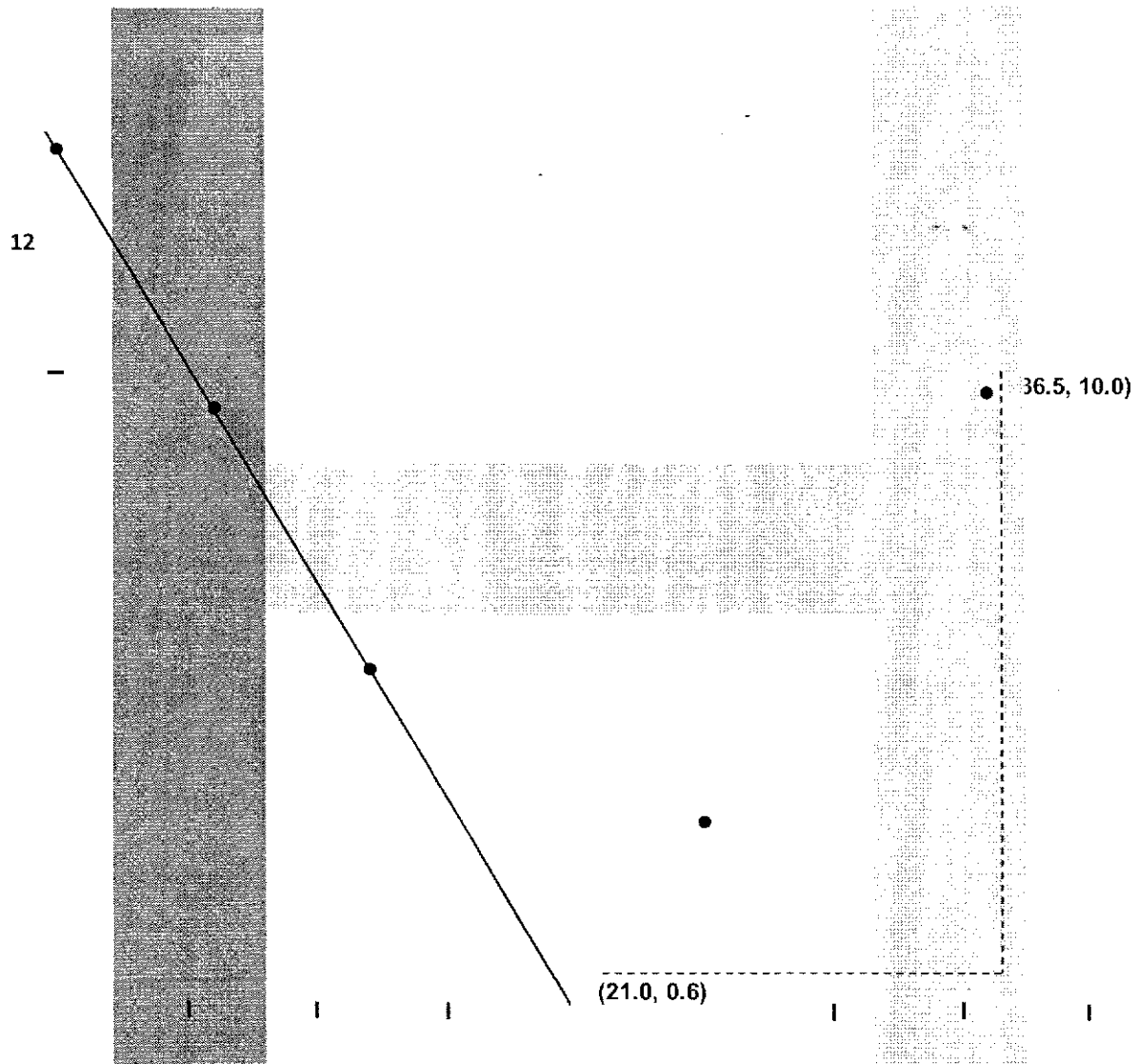
**Results:**

	Expt 1	Expt 2	Expt 3	Expt 4	Expt 5
vol. of <b>FA 3</b> added, $V_{FA3}$ / $\text{cm}^3$	<b>0.00</b>	<b>12.00</b>	6.00	25.00	36.00
final burette reading / $\text{cm}^3$	13.50	21.85	31.45	6.95	16.30
initial burette reading / $\text{cm}^3$	0.00	16.50	22.00	4.00	6.60
vol. of <b>FA 2</b> added, $V_{FA2}$ / $\text{cm}^3$	13.50	5.35	9.45	2.95	9.70

single table with appropriate headings and units  
all burette readings to 2 d.p. (read to 0.05  $\text{cm}^3$ )  
choice of one  $V_{FA3} < \text{predicted vol at } V$  and two  $V_{FA3} > \text{predicted vol at } V$   
accuracy – max 2 marks

[5]

- (b) Plot on the grid below, a graph of  $V_{FA2}$  on the  $y$ -axis against  $V_{FA3}$  on the  $x$ -axis. Draw **two** best-fit straight line for the point before and after **V**. Hence, obtain a value for the volume at **V**.



volume of FA 3 at point **V** = .....00 cm<sup>3</sup> [5]

- axes correctly labelled, with units, plus sensible linear scale with plotted points cover about half of graph grid for both axes
- all points accurately plotted to within  $\frac{1}{2}$  small square and in correct small square
- both straight lines meet at x-axis and **V** correctly read from graph within  $\frac{1}{2}$  small square
- **V** correctly read from graph within  $\frac{1}{2}$  small square
- all but one of the plotted points within 1 small square of best-fit line

5

- (c) (i) Calculate the amount of  $\text{H}_2\text{O}_2$  present in  $V \text{ cm}^3$  of FA 3 and hence deduce the amount of  $\text{H}_2\text{O}_2$  that will react exactly with 1.00 mol of  $\text{Fe}^{2+}$  ions. Give your answers to three significant figures.

$$\begin{aligned} \text{amount of H}_2\text{O}_2 &= 0.0250 \times \frac{20.00}{1000} && 0.0250 \times \frac{V}{1000} \\ &= 5.00 \times 10^{-4} \text{ mol} && \text{(must be 3 s.f.)} \end{aligned}$$

$$\text{amount of H}_2\text{O}_2 \text{ present in } V \text{ cm}^3 \text{ of FA 3} = \dots\dots\dots 5.00 \times 10^{-4} \text{ mol} \dots\dots [1]$$

$$\begin{aligned} \text{amount of Fe}^{2+} \text{ in } 25.0 \text{ cm}^3 \text{ of FA 1} &= 0.0395 \times \frac{25.0}{1000} \\ &= 9.88 \times 10^{-4} \text{ mol} \end{aligned}$$

$$\begin{aligned} \text{amount of H}_2\text{O}_2 \text{ that react exactly with 1.00 mol of Fe}^{2+} \\ &= \frac{5.00 \times 10^{-4}}{9.88 \times 10^{-4}} = 0.506 \text{ mol} \quad \frac{\text{above answer}}{9.88 \times 10^{-4}} \\ &\hspace{15em} \text{(must be 3 s.f.)} \end{aligned}$$

$$\text{amount of H}_2\text{O}_2 \text{ that reacts exactly with 1.00 mol of Fe}^{2+} \text{ ions} = \dots\dots\dots 0.506 \text{ mol} \dots\dots [1]$$

- (ii) Calculate the gradient of the line to the right of V to three significant figures, showing clearly how you did this.

$$\text{gradient} = \frac{10.0 - 0.6}{36.5 - 21.0} = \frac{9.4}{15.5} = 0.606$$

$$\text{gradient} = \dots\dots\dots 0.606 \dots\dots [2]$$

- (iii) Use the following relationship to calculate the mole ratio for the reaction between  $\text{H}_2\text{O}_2$  and  $\text{MnO}_4^-$  ions.

$$\text{gradient} = \frac{\text{mol of MnO}_4^- \times [\text{FA 3}]}{\text{mol of H}_2\text{O}_2 \times [\text{FA 2}]}$$

$$\text{gradient} = \frac{\text{mol of MnO}_4^- \times [\text{FA 3}]}{\text{mol of H}_2\text{O}_2 \times [\text{FA 2}]}$$

$$\frac{\text{mol of H}_2\text{O}_2}{\text{mol of MnO}_4^-} = \frac{[\text{FA 3}]}{[\text{FA 2}]} \times \frac{1}{\text{gradient}}$$

$$= \frac{0.0250}{0.0150} \times \frac{1}{0.606}$$

$$= 2.75$$

$$\text{mole ratio H}_2\text{O}_2 : \text{MnO}_4^- = \dots\dots\dots 2.75 : 1 \dots\dots [1]$$

(d) Explain, in terms of the chemistry involved, the direction of the slope of your graph

(i) to the left of V

A negative slope is obtained because as more of H<sub>2</sub>O<sub>2</sub>, FA 3, is added,

less of Fe<sup>2+</sup>(aq) is left and so, less KMnO<sub>4</sub>, FA 2, is needed for

oxidation.

[1]

(ii) to the right of V

A positive slope is obtained because to the right of V, all the Fe<sup>2+</sup>(aq)

has reacted with H<sub>2</sub>O<sub>2</sub> and so, as more of H<sub>2</sub>O<sub>2</sub>, FA 3, is added, more

KMnO<sub>4</sub>, FA 2, is needed to oxidise the H<sub>2</sub>O<sub>2</sub>.

[1]

(e) A student repeated the experiment described in (a) but used 0.0395 mol dm<sup>-3</sup> hydrogen peroxide instead of FA 3.

Suggest what effect this would have on the value of V, explain your answer clearly.

Value of V will be smaller.

Since [H<sub>2</sub>O<sub>2</sub>] used is higher than concentration of FA3, smaller volume of H<sub>2</sub>O<sub>2</sub> is needed to provide same amount of H<sub>2</sub>O<sub>2</sub> to react with Fe<sup>2+</sup> in 25.0 cm<sup>3</sup> of FA 1. [1]

(f) (i) One source of potential error in this experiment involves taking readings from a burette. A student carried out **Experiment 2** and recorded the initial and final burette readings as 16.50 cm<sup>3</sup> and 21.85 cm<sup>3</sup> respectively. Calculate, to three significant figures, the maximum percentage error in his titre value.

$$\text{titre value} = 21.85 - 16.50 = 5.35 \text{ cm}^3$$

$$\% \text{ error} = \frac{2 \times 0.05}{5.35} \times 100 = 1.87 \%$$

maximum percentage error = .....1.87....% [1]

(ii) Suggest one improvement to the method described in (a) which could significantly improve the accuracy of the experiment.

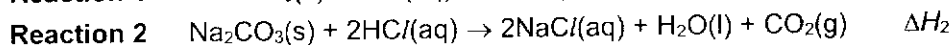
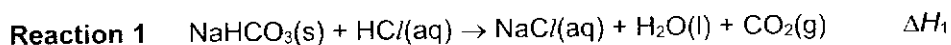
Repeat each titration for consistent titres (within ±0.10 cm<sup>3</sup> of each other).

OR carry out more titrations with different volumes of FA 3 to get more [1]

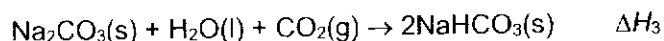
data points for graph plotting.

[Total: 21]

- 2 The enthalpy change for the reaction of sodium carbonate,  $\text{Na}_2\text{CO}_3$ , with water and carbon dioxide to form sodium hydrogencarbonate,  $\text{NaHCO}_3$ , cannot be determined directly. However both  $\text{Na}_2\text{CO}_3(\text{s})$  and  $\text{NaHCO}_3(\text{s})$  react with dilute hydrochloric acid.



In this experiment you will determine the enthalpy change  $\Delta H_1$  for **reaction 1** and  $\Delta H_2$  for **reaction 2**, and then use your results to calculate  $\Delta H_3$  for the reaction:

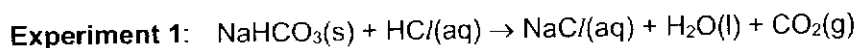


**FA 4** is sodium hydrogen carbonate,  $\text{NaHCO}_3$ .

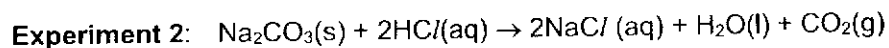
**FA 5** is sodium carbonate,  $\text{Na}_2\text{CO}_3$ .

**FA 6** is  $2.0 \text{ mol dm}^{-3}$  hydrochloric acid,  $\text{HCl}$ .

(a) **Method**



- Use a measuring cylinder to transfer  $25 \text{ cm}^3$  of the acid, **FA 6**, into a polystyrene cup supported in a  $250 \text{ cm}^3$  beaker. The acid is in excess.
- Weigh the container with **FA 4** and record the balance reading.
- Place the thermometer in the acid and record its initial temperature.
- Carefully tip all the **FA 4**, in small portions, into the acid and stir to dissolve.
- Record the lowest temperature reached.
- Reweigh the container with any residual **FA 4** and record the balance reading and the mass of **FA 4** used.



- Replace the wet polystyrene cup with a clean, dry polystyrene cup.
- Repeat **Experiment 1** but use **FA 5** in place of **FA 4** and record the highest temperature reached.
- Reweigh the container with any residual **FA 5** and record the balance reading and the mass of **FA 5** used.



## Results

Record **all** weighings and temperature readings in the table below.

	Experiment 1	Experiment 2
mass of container + solid sample / g	10.625	7.599
mass of container + residual <b>solid</b> / g	8.129	5.607
mass of <b>solid</b> added / g	2.496	1.992
initial temperature, $T_i$ , of <b>FA 6</b> / °C	28.0	28.0
final temperature, $T_f$ / °C	20.3	34.0
temperature change, $\Delta T$ / °C	-7.7	6.0

[5]

all mass recorded consistently to 2 or 3 d.p. & all temperature readings recorded to 1 d.p.

Accuracy:

Experiment 1: max 2 marks

Experiment 2: max 2 marks

- (b) (i) Calculate the heat energy absorbed when **FA 4** was added to the acid in **Experiment 1** and hence, the enthalpy change, in  $\text{kJ mol}^{-1}$ , when 1 mol of **FA 4**,  $\text{NaHCO}_3$ , reacts with the acid. [Ar: H, 1.0; C, 12.0; O, 16.0; Na, 23.0]  
[Assume that 4.18 J of heat energy changes the temperature of  $1.0 \text{ cm}^3$  of solution by  $1.0 \text{ }^\circ\text{C}$ .]

$$\begin{aligned} \text{heat absorbed} &= mc \Delta T \\ &= 25 \times 4.18 \times 7.7 && 25 \times 4.18 \times \Delta T_{\text{expt1}} \\ &= 804.6 \text{ J} \end{aligned}$$

heat energy absorbed = .....804.6..... J

$$M_r \text{ of NaHCO}_3 = 23.0 + 1.0 + 12.0 + 3(16.0) = 84.0$$

$$\text{mol of NaHCO}_3 = \frac{2.496}{84.0} = 0.0297 \text{ mol}$$

$$\begin{aligned} \therefore \Delta H_1 &= +\frac{804.6}{0.0297} \text{ J mol}^{-1} \\ &= +27090 \text{ J mol}^{-1} \\ &= +27.1 \text{ kJ mol}^{-1} \end{aligned}$$

enthalpy change,  $\Delta H_1 = \dots\dots+27.1\dots\dots \text{ kJ mol}^{-1}$

[3]

- (ii) Calculate the heat energy produced when **FA 5** was added to the acid in **Experiment 2** and hence, the enthalpy change, in  $\text{kJ mol}^{-1}$ , when 1 mol of **FA 5**,  $\text{Na}_2\text{CO}_3$ , reacts with the acid. [ $A_r$ : C, 12.0; O, 16.0; Na, 23.0].  
[Assume that 4.18 J of heat energy changes the temperature of  $1.0 \text{ cm}^3$  of solution by  $1.0 \text{ }^\circ\text{C}$ .]

$$\begin{aligned} \text{heat evolved} &= mc \Delta T \\ &= 25 \times 4.18 \times 6.0 \quad 25 \times 4.3 \times \Delta T_{\text{expt2}} \\ &= 627 \text{ J} \end{aligned}$$

$$\text{heat energy produced} = \dots 627 \dots \text{ J}$$

$$M_r \text{ of } \text{Na}_2\text{CO}_3 = 2(23.0) + 12.0 + 3(16.0) = 106.0$$

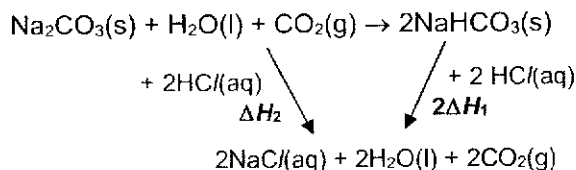
$$\text{mol of } \text{Na}_2\text{CO}_3 = \frac{1.992}{106.0} = 0.0188 \text{ mol}$$

$$\begin{aligned} \therefore \Delta H_2 &= - \frac{627}{0.0188} \text{ J mol}^{-1} \\ &= - 33350 \text{ J mol}^{-1} \\ &= - 33.4 \text{ kJ mol}^{-1} \end{aligned}$$

$$\text{enthalpy change, } \Delta H_2 = \dots -33.4 \dots \text{ kJ mol}^{-1}$$

[3]

(iii) Using your answers to (b)(i) and (b)(ii) and the equations for **Experiment 1** and **Experiment 2**, determine the enthalpy change for the reaction:



By Hess' Law,

$$\begin{aligned} \Delta H &= \Delta H_2 - 2\Delta H_1 \\ &= (-33.4) - 2(+27.1) \\ &= -87.6 \text{ kJ mol}^{-1} \end{aligned}$$

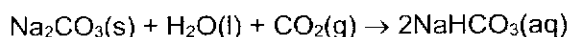
3 or 4 sf in all final answers

enthalpy change,  $\Delta H_3 = \dots\dots\dots -87.6 \dots\dots\dots \text{ kJ mol}^{-1}$  [2]

**(c) Planning**

You are provided with **FA 4**, solid sodium hydrogencarbonate,  $\text{NaHCO}_3$ , and distilled water.

Using only these materials, you are to plan and carry out an additional experiment to determine a further enthalpy change,  $\Delta H_4$ , which can be put together with those from **Experiment 1** and **Experiment 2** to determine the enthalpy change for the reaction:

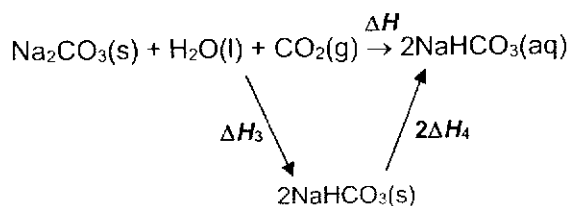


- Outline your plan as a series of numbered steps.
1. Use a measuring cylinder to transfer 25 cm<sup>3</sup> of distilled water into a plastic cup, supported in a 250 cm<sup>3</sup> beaker. Record its initial temperature.
  2. Weigh 3.00 g of **FA 4** and carefully tip all the **FA 4**, in small portions, into the water and stir to dissolve.
  3. Record the lowest temperature reached.
  4. Reweigh the container with any residual **FA 4** and record the balance reading and the mass of **FA 4** used.
- .....
- .....
- .....

- Carry out your plan and record your results, in a suitable form, in the space below.

mass of container + FA 4 / g	8.599
mass of container + residual FA 4 / g	5.504
mass of FA 4 added / g	3.095
initial temperature of water / °C	24.8
lowest temperature reached / °C	20.5
temperature fall, $\Delta T$ / °C	4.3

- Show how you would use your results to determine the enthalpy change for the reaction:



$$\begin{aligned}
 \text{heat absorbed} &= mc \Delta T \\
 &= 25 \times 4.18 \times 4.3 \\
 &= 449 \text{ J} \quad \text{calculates energy change for vol of solution used}
 \end{aligned}$$

$$M_r \text{ of NaHCO}_3 = 23.0 + 1.0 + 12.0 + 3(16.0) = 84.0$$

$$\text{mol of NaHCO}_3 = \frac{3.095}{84.0} = 0.0368 \text{ mol}$$

$$\begin{aligned}
 \therefore \Delta H_4 &= +\frac{449}{0.0368} \text{ J mol}^{-1} \\
 &= +12200 \text{ J mol}^{-1} \\
 &= +12.2 \text{ kJ mol}^{-1} \quad \text{calculates } \Delta H_4 \text{ including sign}
 \end{aligned}$$

By Hess' Law,

$$\begin{aligned}
 \Delta H &= \Delta H_3 + 2\Delta H_4 \\
 &= (-87.6) + 2(+12.2) \quad \text{adds } 2 \Delta H_4 \text{ to ans to (b)(iii)} \\
 &= -63.2 \text{ kJ mol}^{-1}
 \end{aligned}$$

[5]

[Total: 18]

### 3 Qualitative Analysis

You are provided with **FA 7**, an aqueous solution containing two cations and one anion.

In this question, you will carry out tests on **FA 7** to identify the ions present in the sample.

- (a) Carry out the following tests and record your observations in the table. You should test and identify any gases evolved. If there is no observable reaction, write 'No observable change' in the observations column.

test	observations
<p><b>Test 1</b> Place a drop of <b>FA 7</b> on the Universal Indicator (UI) paper and compare the colour against the UI colour chart provided.</p>	<p>colour on UI paper corresponds to <u>pH 2</u>.</p>
<p><b>Test 2</b> Place 1 cm depth of <b>FA 7</b> in a clean test-tube. Add an equal volume of dilute nitric acid slowly with shaking.</p>	<p>yellow solution turns <u>colourless</u> No effervescence observed.</p>
<p><b>Test 3</b> Place 1 cm depth of <b>FA 7</b> in a clean boiling tube. Add aqueous sodium hydroxide slowly with shaking until no further change is seen. Warm the mixture gently.</p>	<p><u>red-brown ppt insoluble in excess</u>  <u>pungent gas liberated turns damp red litmus paper blue. NH<sub>3</sub>(g) liberated.</u></p>
<p><b>Test 4</b> Place 1 cm depth of potassium iodide in a clean test-tube. Add 8 drops of <b>FA 7</b>. Then add 3 drops of starch solution.</p>	<p>solution turns <u>orange / orange-brown / brown</u> solution turns <u>blue-black</u></p>
<p><b>Test 5</b> Place 1 cm depth of hydrogen peroxide in a clean test-tube. Add an equal volume of <b>FA 7</b>. Make observations for about 2 minutes before recording your results.</p>	<p><u>effervescence</u> <u>gas relights a glowing splint</u> <u>O<sub>2</sub>(g) liberated.</u></p>

[7]

- (b) (i) Identify the two cations present in FA 7 and provide evidence to support your answer.

cation 1  $\text{Fe}^{3+}$  .....

evidence **Test 3 - red-brown ppt insoluble in excess NaOH** .....

.....

cation 2  $\text{NH}_4^+$  .....

evidence **Test 3 -  $\text{NH}_3(\text{g})$  liberated when warmed with NaOH** .....

.....

[2]

- (ii) Explain, in terms of ions present, the pH of the FA 7 solution observed in 3(a).  
**pH of FA 7 solution is about 2, showing that the solution is acidic and contains  $\text{H}^+$  ions, due to hydrolysis of  $\text{Fe}^{3+}(\text{aq})$  and  $\text{NH}_4^+(\text{aq})$ .** .....

[1]

- (iii) Suggest, with explanation, the nature of FA 7 as observed in Test 4.

FA 7 is **oxidising / an oxidising agent / oxidant** .....

explanation **FA 7 oxidised  $\text{I}^-$  ions to  $\text{I}_2$  (brown solution).** .....

[1]

- (iv) State the role of hydrogen peroxide in Test 5.

**$\text{H}_2\text{O}_2$  acts as a reducing agent.** .....

[1]

- (c) The anions that may be present in FA 7 are bromide, carbonate and sulfate.

- (i) From the observations in 3(a), one of the above anion can be ruled out. Identify this anion and provide evidence to support your answer.

anion **not present in FA 7** **carbonate,  $\text{CO}_3^{2-}$**  .....

evidence **In Test 2, no effervescence of  $\text{CO}_2(\text{g})$  observed when dilute** .....

**nitric acid is added to FA 7.** .....

[1]

- (ii) Plan and carry out other tests to confirm the identity of the anion present in **FA 7**. Record your results in the table below. Draw a line after each test. You are **not** to identify the anion by elimination.

test	observations
Place 1 cm depth of <b>FA 7</b> in a clean test-tube. Add a few drops of aqueous silver nitrate.	<b>no ppt / no observable change.</b>
Place 1 cm depth of <b>FA 7</b> in a clean test-tube. Add a few drops of aqueous barium chloride.	<b>white ppt.</b>

anion present in **FA 7** is sulfate,  $\text{SO}_4^{2-}$

[3]

[Total: 16]

### Qualitative Analysis Notes

[ppt. = precipitate]

#### (a) Reactions of aqueous cations

cation	reaction with	
	NaOH(aq)	NH <sub>3</sub> (aq)
aluminium, Al <sup>3+</sup> (aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH <sub>4</sub> <sup>+</sup> (aq)	ammonia produced on heating	–
barium, Ba <sup>2+</sup> (aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca <sup>2+</sup> (aq)	white ppt. with high [Ca <sup>2+</sup> (aq)]	no ppt.
chromium(III), Cr <sup>3+</sup> (aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu <sup>2+</sup> (aq)	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II), Fe <sup>2+</sup> (aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe <sup>3+</sup> (aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg <sup>2+</sup> (aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn <sup>2+</sup> (aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn <sup>2+</sup> (aq)	white ppt. soluble in excess	white ppt. soluble in excess



**(b) Reactions of anions**

<i>ion</i>	<i>reaction</i>
carbonate, $\text{CO}_3^{2-}$	$\text{CO}_2$ liberated by dilute acids
chloride, $\text{Cl}^-(\text{aq})$	gives white ppt. with $\text{Ag}^+(\text{aq})$ (soluble in $\text{NH}_3(\text{aq})$ )
bromide, $\text{Br}^-(\text{aq})$	gives pale cream ppt. with $\text{Ag}^+(\text{aq})$ (partially soluble in $\text{NH}_3(\text{aq})$ )
iodide, $\text{I}^-(\text{aq})$	gives yellow ppt. with $\text{Ag}^+(\text{aq})$ (insoluble in $\text{NH}_3(\text{aq})$ )
nitrate, $\text{NO}_3^-(\text{aq})$	$\text{NH}_3$ liberated on heating with $\text{OH}^-(\text{aq})$ and Al foil
nitrite, $\text{NO}_2^-(\text{aq})$	$\text{NH}_3$ liberated on heating with $\text{OH}^-(\text{aq})$ and Al foil; $\text{NO}$ liberated by dilute acids (colourless $\text{NO} \rightarrow$ (pale) brown $\text{NO}_2$ in air)
sulfate, $\text{SO}_4^{2-}(\text{aq})$	gives white ppt. with $\text{Ba}^{2+}(\text{aq})$ (insoluble in excess dilute strong acids)
sulfite, $\text{SO}_3^{2-}(\text{aq})$	$\text{SO}_2$ liberated with dilute acids; gives white ppt. with $\text{Ba}^{2+}(\text{aq})$ (soluble in dilute strong acids)

**(c) Tests for gases**

<i>gas</i>	<i>test and test result</i>
ammonia, $\text{NH}_3$	turns damp red litmus paper blue
carbon dioxide, $\text{CO}_2$	gives a white ppt. with limewater (ppt. dissolves with excess $\text{CO}_2$ )
chlorine, $\text{Cl}_2$	bleaches damp litmus paper
hydrogen, $\text{H}_2$	"pops" with a lighted splint
oxygen, $\text{O}_2$	relights a glowing splint
sulfur dioxide, $\text{SO}_2$	turns aqueous acidified potassium manganate(VII) from purple to colourless

**(d) Colour of halogens**

<i>halogen</i>	<i>colour of element</i>	<i>colour in aqueous solution</i>	<i>colour in hexane</i>
chlorine, $\text{Cl}_2$	greenish yellow gas	pale yellow	pale yellow
bromine, $\text{Br}_2$	reddish brown gas / liquid	orange	orange-red
iodine, $\text{I}_2$	black solid / purple gas	brown	purple

