EUNOIA JUNIOR COLLEGE
JC2 Preliminary Examination 2021
General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME								
CIVICS GROUP	2	0	–			INDEX NUMBER		

CHEMISTRY

9729/04

Paper 4 Practical

31 August 2021

2 hours 30 minutes

Candidates answer on the Question Paper.

Additional Materials: As listed in the Confidental Instructions

READ THESE INSTRUCTIONS FIRST

Write your name, civics group and registration number on the work you hand in.
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 paper clips, highlighters, 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 23 and 24.

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.

Shift
Laboratory

For Examiner's Use	
1	/ 22
2	/ 22
3	/ 11
Total	/ 55

This document consists of **22** printed pages and **2** blank pages.

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

For Examiner's Use

1 Investigation on the behaviour of acids and bases in aqueous solution

FA 1 is 1.00 mol dm^{-3} sodium hydrogencarbonate, $NaHCO_3$
FA 2 is sodium hydroxide, NaOH, of concentration between 1.5 mol dm^{-3} and 2.0 mol dm^{-3}
FA 3 is 2.00 mol dm^{-3} sulfuric acid, H_2SO_4

According to the Arrhenius theory, an acid-base neutralisation reaction involves reacting together $H^+(aq)$ and $OH^-(aq)$ to produce water molecules.

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l) \qquad \Delta H_{neutralisation} = -57.1 \text{ kJ mol}^{-1}$$

This task involves two different acid-base reactions.

The first reaction is between sodium hydrogencarbonate, **FA 1**, and sodium hydroxide, **FA 2**.

reaction 1 $NaHCO_3(aq) + NaOH(aq) \rightarrow Na_2CO_3(aq) + H_2O(l)$ $\Delta H_{reaction\ 1}$

The molar enthalpy change for **reaction 1**, $\Delta H_{reaction\ 1}$, is the enthalpy change when 1.00 mol of $NaHCO_3$ reacts completely with NaOH.

Instead of using an indicator to determine the endpoint, you will perform a thermometric titration to determine the equivalence point of the reaction. The equivalence point is that point where $H^+(aq)$ from the acid and $OH^-(aq)$ from the base are present in equal molar amounts.

The second reaction is between sodium hydrogencarbonate, **FA 1**, and sulfuric acid, **FA 3**.

reaction 2 $NaHCO_3(aq) + \frac{1}{2}H_2SO_4(aq) \rightarrow \frac{1}{2}Na_2SO_4(aq) + H_2O(l) + CO_2(g)$ $\Delta H_{reaction\ 2}$

The molar enthalpy change for **reaction 2**, $\Delta H_{reaction\ 2}$, is the enthalpy change when 1.00 mol of $NaHCO_3$ reacts completely with H_2SO_4.

In your first experiment, you will perform a thermometric titration by adding portions of **FA 2** progressively to a known volume of **FA 1**. You will continue adding **FA 2** until the equivalence point is reacted and passed. Throughout the experiment you will note and record the temperature of the mixture after each addition.

You will then analyse your results graphically in order to determine the

- titration volume at the equivalence point, $V_{equivalence}$,
- maximum temperature change, $\Delta T_{maximum\ 1}$,
- molar enthalpy change, $\Delta H_{reaction\ 1}$, for **reaction 1**.

In your second experiment, you will mix together a given volume of **FA 1** with a suitable volume of **FA 3**.

You will then determine the

- maximum temperature change, $\Delta T_{maximum\ 2}$,
- molar enthalpy change, $\Delta H_{reaction\ 2}$, for **reaction 2**.

For Examiner's Use

(a) The reaction between FA 1 and FA 2

In this task you will need to record the maximum temperature of the reaction mixture when specified volumes of **FA 2** have been added. It is important that the volume of **FA 2** recorded is the total volume you have added up to that point when the temperature reading was made.

Note: If you overshoot on an addition, record the **actual** total volume of **FA 2** added up to that point.

In an appropriate format in the space provided on page 4, record all values of temperature, *T*, and each total volume of **FA 2** added.

(i) 1. Fill a burette with **FA 2**.

2. Place a Styrofoam cup inside a second Styrofoam cup which is held in a glass beaker to prevent it tipping over.

3. Using a pipette, transfer 25.0 cm^3 of **FA 1** to the first Styrofoam cup.

4. Stir the **FA 1** solution in the cup with the thermometer. Read and record its temperature.

5. From the burette, add 2.00 cm^3 of **FA 2** to the cup and stir the mixture thoroughly.

6. Read and record the maximum temperature of the mixture, *T*, and the volume of **FA 2** added.

7. Repeat points 5 and 6 until a total of 30.00 cm^3 of **FA 2** has been added. After each addition of **FA 2**, record the maximum temperature of the mixture and the total volume of **FA 2** added up to that point.

For Examiner's Use

Results

[2]

(ii) On the grid below, plot a graph of temperature, *T* (*y-axis*) against volume of **FA 2** added (*x-axis*).

For Examiner's Use

[4]

(iii) Draw **two** smooth lines of best fit.

- The first best-fit line should be drawn using the plotted points where the temperature is **rising**.
- The second best-fit line should be drawn using the plotted points where the temperature is **falling**.
- Extrapolate these lines until they cross.

Note: Each line should have a shape best suited to its plotted points.

For Examiner's Use

(iv) Determine from your graph
- the maximum temperature reached, $T_{maximum}$,
- the maximum temperature change, $\Delta T_{maximum\ 1}$,
- the volume, $V_{equivalence}$, of **FA 2** needed to completely react with 25.0 cm^3 of **FA 1**.

Show on your graph how you obtained these values.

Record these values in the spaces provided below.

maximum temperature reached, $T_{maximum}$ = ...

maximum temperature change, $\Delta T_{maximum\ 1}$ = ...

volume of **FA 2** used, $V_{equivalence}$ = ...

[3]

(b) Ideally, the graph line **before** the equivalence point should be an *increasing* curve that *concaves downward* (that is, gradient of the curve decreases).

(i) Explain why the graph line is increasing.

....

....

....

....[1]

(ii) Explain why the graph line concaves downward.

....

....

....

....[1]

For Examiner's Use

(c) The reaction between FA 1 and FA 3

The molar enthalpy change for **reaction 2**, $\Delta H_{reaction2}$, is the enthalpy change when 1.00 mol of $NaHCO_3$ reacts completely with H_2SO_4.

In this task you will calculate a value for the molar enthalpy change, $\Delta H_{reaction\ 2}$. To do this, you will need to determine the maximum temperature change produced when measured volumes of **FA 1** and **FA 3** are mixed.

Upon considering the concentrations of **FA 1** and **FA 3**, 15 cm^3 of **FA 3** was chosen to add to 40 cm^3 of **FA 1**.

Note: You should be aware that the reaction mixture will produce considerable frothing.

(i) Explain why 15 cm^3 of **FA 3** was chosen to add to 40 cm^3 of **FA 1**.

....

....

....

....[1]

(ii) Identify the apparatus you intend to use to measure the volume of **FA 1**.

Explain your choice.

apparatus ....

explanation ....

....

....

[1]

For Examiner's Use

(iii) In an appropriate format in the space provided below, record all values of measured temperature for this experiment.

1. Place a Styrofoam cup inside a second Styrofoam cup which is held in a glass beaker to prevent it tipping over.

2. Transfer 40 cm^3 of **FA 1** into the first Styrofoam cup using the apparatus identified in **1(c)(ii)**.

3. Stir the **FA 1** solution in the cup with the thermometer. Read and record its temperature, $T_{FA\,1}$. This is the initial temperature of **FA 1**.

4. Wash and dry the thermometer.

5. Measure 15.0 cm^3 of **FA 3** using an appropriate measuring cylinder. Stir the **FA 3** solution in the measuring cylinder with the thermometer. Read and record its temperature, $T_{FA\,3}$. This is the initial temperature of **FA 3**.

6. Carefully add the contents of the measuring cylinder to the Styrofoam cup in **small** portions to avoid too much frothing.

7. Place the lid on the cup and insert the thermometer through the lid. Stir the mixture.

8. Continue to stir the mixture. Measure and record the temperature, $T_{mixture}$ that shows the maximum change from the initial temperature.

Results

[1]

For Examiner's Use

Calculations

(d) For the purpose of these calculations, you should assume that the reaction mixture has a density of 1.00 g cm^{-3} and a specific heat capacity, *c*, of 4.18 J g^{-1} K^{-1}.

Use your results from **(a)(iv)** to calculate

(i) the concentration of sodium hydroxide, [NaOH], in **FA 2**,

[NaOH] in **FA 2** = ... [1]

(ii) the heat change, *q*, for the reaction occurring in **(a)(i)**, and hence determine a value for the molar enthalpy change for **reaction 1**, $\Delta H_{reaction\ 1}$.

q = ...

$\Delta H_{reaction\ 1}$ = ...

[2]

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(e) Use your results from **(c)(iii)** to calculate a value for the molar enthalpy change for **reaction 2**, $\Delta H_{reaction\ 2}$. For the experiment in **(c)(iii)**, the weighted average initial temperature, $T_{average}$, of **FA 1** and **FA 3** may be calculated using the formula given below.

$$T_{average} = \frac{(V_{FA1} \times T_{FA1}) + (V_{FA3} \times T_{FA3})}{(V_{FA1} + V_{FA3})}$$

q = ...

$\Delta H_{reaction\ 2}$ = ...[1]

(f) Ionic equations for neutralisation, **reaction 1**, and **reaction 2** are shown below.

$H^+ + OH^- \rightarrow H_2O$	$\Delta H_{neutralisation} = -57.1\ kJ\ mol^{-1}$
$HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$	$\Delta H_{reaction\ 1}$
$HCO_3^- + H^+ \rightarrow H_2O + CO_2$	$\Delta H_{reaction\ 2}$

Carbon dioxide may be removed from stale air by bubbling the air through aqueous alkali. An equation for this reaction is given below.

reaction 3 $2OH^-(aq) + CO_2(g) \rightarrow CO_3^{2-}(aq) + H_2O(l)$ $\Delta H_{reaction\ 3}$

Use your answers to **(d)(ii)** and **(e)**, together with the molar enthalpy change of neutralisation, $\Delta H_{neutralisation}$, to determine a value for the molar enthalpy change for this reaction, $\Delta H_{reaction\ 3}$.

$\Delta H_{reaction\ 3}$ = ...[1]

For Examiner's Use

(g) Another student planned a different thermometric titration experiment to determine the value of the titration volume at the equivalence point, $V_{equivalence}$, and the maximum temperature change, $\Delta T_{maximum\ 1}$, for **reaction 1**.

In this other experiment, different volumes of **FA 1** and **FA 2** as shown in Table 1.1 are mixed, and the maximum temperature change, ΔT_{max}, is determined for each mixture.

Table 1.1

experiment	1	2	3	4	5	6	7	8
$V_{FA\ 2}$ / cm^3	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00
$V_{FA\ 1}$ / cm^3	45.00	40.00	35.00	30.00	25.00	20.00	15.00	10.00

ΔT_{max} is plotted against the volume of **FA 2** used, $V_{FA\ 2}$. $V_{equivalence}$ and $\Delta T_{maximum\ 1}$ are determined from the intersection of the two straight lines drawn as shown in Fig. 1.1.

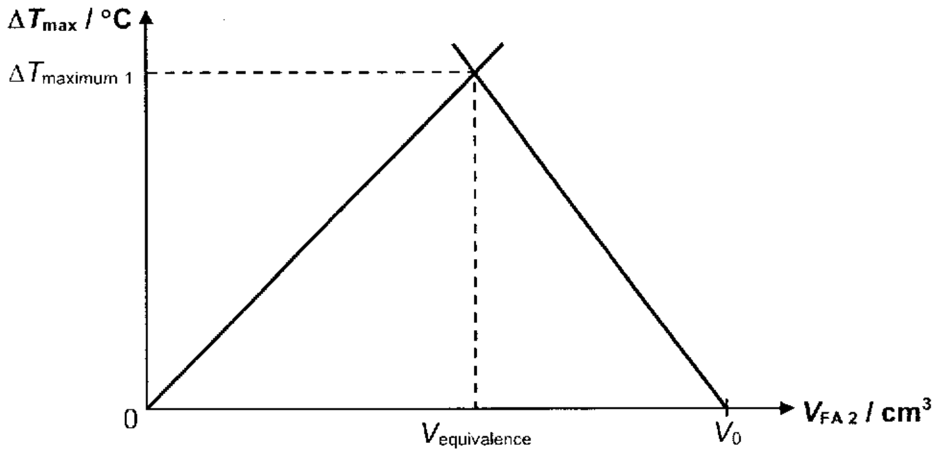

Fig. 1.1

(i) Suggest a value for V_0 in Fig. 1.1.

V_0 = ... cm^3 [1]

(ii) The student claimed that this method gives a more accurate value of $V_{equivalence}$ and $\Delta T_{maximum\ 1}$ compared to the method in **1(a)**.

Do you agree with the student? Explain.

$V_{equivalence}$ ....

....

....

....

....

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$\Delta T_{maximum\ 1}$ ....

....

....

....

.... [2]

[Total: 22]

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For Examiner's Use

For Examiner's Use

2 Determination of identity of the impurity in FA 4, the decomposition route of $NaHCO_3$, the percentage purity of FA 4

Solid FA 4 is anhydrous sodium hydrogencarbonate, $NaHCO_3$, of greater than 95% purity that has been contaminated with a sodium halide.

You are also provided with an aqueous solution of **FA 4**, labelled **FA 4 solution.**

(a) You will devise and perform a simple test, based on the Qualitative Analysis Notes on pages 23–24, to identify the halide present in the **FA 4 solution.**

(i) Describe a test, using only the bench reagents provided, which will allow you to identify the halide impurity present in **FA 4**.

....

....[1]

(ii) Perform the test you described in **2(a)(i)** using the **FA 4 solution provided.**

Record your observations and hence deduce the identity of the halide **in solid FA 4**.

....

....

....

identity of halide ....

[2]

(b) Thermal decomposition of $NaHCO_3$

When $NaHCO_3$ is heated above 110 °C (but not heated to "red heat") it has been observed that both $H_2O(g)$ and $CO_2(g)$ are evolved, and that after this decomposition is complete, a white solid residue remains. Among possible reactions, the two following reactions seem the ones that are most likely to explain these facts:

reaction 4 $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(g) + CO_2(g)$

reaction 5 $2NaHCO_3(s) \rightarrow Na_2O(s) + H_2O(g) + 2CO_2(g)$

Sodium halides are stable to heat.

In this experiment, solid **FA 4** is heated gently in a boiling tube, over a luminous Bunsen flame, until **all** $NaHCO_3$ has been decomposed. The data will be used to determine

- the percentage mass loss,
- whether the decomposition takes place *via* **reaction 4** or **reaction 5**,
- the amount of CO_2 lost,
- the percentage purity of $NaHCO_3$ in **FA 4**

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

For Examiner's Use

1. Weigh accurately between 2.00 g and 2.50 g of **FA 4** in the boiling tube provided. Record your weighings in the space provided below.

2. Heat the tube and content **gently** for 5 minutes.

Use a **luminous** Bunsen flame with the air-hole **closed** for this purpose. Ensure even heating of the sample and boiling tube.

3. Place the boiling tube into a **dry** 250 cm^3 beaker to cool.

You may wish to proceed with other experiments while waiting for the boiling tube to cool.

4. Weigh and record the mass of the cooled boiling tube containing the residue.

5. Repeat points 2 (heat gently for 2 minutes subsequently) to 4 as necessary until a constant mass is obtained.

6. **Turn off the Bunsen burner**.

(i) In an appropriate format in the space below, record all weighings.

[4]

(ii) Using your results, calculate the mass lost upon decomposition of **FA 4**.

mass lost = ... [1]

(iii) Using your answer to **2(b)(ii)**, calculate the percentage mass lost.

percentage mass lost = ... [1]

For Examiner's Use

(iv) Using your answer to **2(b)(iii)**, determine whether the decomposition occurs *via* **reaction 4** or **reaction 5**

....

....

....

....

....

....

.... [2]

(v) Using your answer to **2(b)(ii)** and **2(b)(iv)**, calculate the amount of CO_2 lost.

amount of CO_2 lost = ... [1]

(vi) Using your answer to **2(b)(v)**, calculate the percentage purity of $NaHCO_3$ in **FA 4**.

percentage purity of $NaHCO_3$ in **FA 4** = ... [2]

For Examiner's Use

(c) Planning

The percentage purity of $NaHCO_3$ in **FA 4** was determined *via* volatilisation gravimetric analysis in **2(b)**. Titrimetric analysis such as the thermometric titration in **1(a)** using **reaction 1** can also be used. In addition, the more usual acid-base titrations based on either **reaction 1** or **reaction 2** are applicable too.

reaction 1 $NaHCO_3(aq) + NaOH(aq) \rightarrow Na_2CO_3(aq) + H_2O(l)$

reaction 2 $NaHCO_3(aq) + \frac{1}{2}H_2SO_4(aq) \rightarrow \frac{1}{2}Na_2SO_4(aq) + H_2O(l) + CO_2(g)$

Plan an investigation to determine the percentage purity of $NaHCO_3$ in **FA 4** using an *acid-base titration* involving **reaction 2**.

You may assume that you are provided with:
- solid **FA 4**, impure $NaHCO_3$ of greater than 95% purity
- 0.200 mol dm^{-3} sulfuric acid, H_2SO_4
- acid-base indicator of your choice
- the equipment normally found in a school or college laboratory

In your plan, you should include brief details of
- the apparatus you would use,
- the quantities you would use,
- the procedure you would follow,
- the indicator you would use, including the colour change at the endpoint,
- the measurements you would make,
- an outline of how you would use your results to determine the percentage purity of $NaHCO_3$ in **FA 4**.

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

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For Examiner's Use

For Examiner's Use

[8]

[Total: 22]

For Examiner's Use

3 Qualitative Analysis

FA 5 contains two unknown cations.

FA 6 contains one unknown anion.

(a) Perform the tests described in Table 3.1, and record your observations in the table. Test and identify any gases evolved. If there is no observable change, write **no observable change**.

Table 3.1

	tests	observations
1.	To 2 cm depth of **FA 5** in a test tube, add aqueous sodium hydroxide. Warm the mixture. Filter the mixture and use the resulting filtrate for **Test 2** and residue for **Test 3**.	
2.	To 1 cm depth of the filtrate from **Test 1**, add dilute nitric acid dropwise with shaking until in excess. Add aqueous ammonia.	
3.	Pour nitric acid onto the residue on the filter paper from **Test 1**. Divide the liquid that filters through into 2 equal portions. To one portion, add aqueous sodium hydroxide slowly with shaking.	
4.	To the other portion of the liquid from **Test 3**, add aqueous ammonia.	
5.	Place about 2 cm depth of the **FA 6** solution in a test-tube. To this solution, add about 2 cm depth of **FA 5.**	

[6]

For Examiner's Use

(b) Deduce the unknown ions present in the following solutions.

(i) **FA 5**

....

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....

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....

....

....[2]

(ii) **FA 6**

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....

....[1]

(c) Write equations to account for the observations in **Test 5**.

....

....

....

....[2]

[Total: 11]

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Qualitative Analysis Notes
[ppt. = precipitate]

(a) Reactions of aqueous cations

cation	*reaction with*	
	NaOH(aq)	NH_3(aq)
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	ammonia produced on heating	–
barium, Ba^{2+}(aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca^{2+}(aq)	white. ppt. with high [Ca^{2+}(aq)]	no ppt.
chromium(III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu^{2+}(aq),	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(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^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(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^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

(b) Reactions of anions

anion	*reaction*
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, $Cl^-(aq)$	gives white ppt. with $Ag^+(aq)$ (soluble in $NH_3(aq)$)
bromide, $Br^-(aq)$	gives pale cream ppt. with $Ag^+(aq)$ (partially soluble in $NH_3(aq)$)
iodide, $I^-(aq)$	gives yellow ppt. with $Ag^+(aq)$ (insoluble in $NH_3(aq)$)
nitrate, $NO_3^-(aq)$	NH_3 liberated on heating with $OH^-(aq)$ and Al foil
nitrite, $NO_2^-(aq)$	NH_3 liberated on heating with $OH^-(aq)$ and Al foil; NO liberated by dilute acids (colourless NO $\rightarrow$ (pale) brown NO_2 in air)
sulfate, $SO_4^{2-}(aq)$	gives white ppt. with $Ba^{2+}(aq)$ (insoluble in excess dilute strong acids)
sulfite, $SO_3^{2-}(aq)$	SO_2 liberated with dilute acids; gives white ppt. with $Ba^{2+}(aq)$ (soluble in dilute strong acids)

(c) Tests for gases

gas	*test and test result*
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine, Cl_2	bleaches damp litmus paper
hydrogen, H_2	"pops" with a lighted splint
oxygen, O_2	relights a glowing splint
sulfur dioxide, SO_2	turns aqueous acidified potassium manganate(VII) from purple to colourless

(d) Colour of halogens

halogen	*colour of element*	*colour in aqueous solution*	*colour in hexane*
chlorine, Cl_2	greenish yellow gas	pale yellow	pale yellow
bromine, Br_2	reddish brown gas / liquid	orange	orange-red
iodine, I_2	black solid / purple gas	brown	purple

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9729/04

Paper 4 Practical

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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 23 and 24.

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.

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FA 2 is sodium hydroxide, NaOH, of concentration between 1.5 mol dm^{-3} and 2.0 mol dm^{-3}
FA 3 is 2.00 mol dm^{-3} sulfuric acid, H_2SO_4

According to the Arrhenius theory, an acid-base neutralisation reaction involves reacting together $H^+(aq)$ and $OH^-(aq)$ to produce water molecules.

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l) \qquad \Delta H_{neutralisation} = -57.1 \text{ kJ mol}^{-1}$$

This task involves two different acid-base reactions.

The first reaction is between sodium hydrogencarbonate, **FA 1**, and sodium hydroxide, **FA 2**.

reaction 1 $NaHCO_3(aq) + NaOH(aq) \rightarrow Na_2CO_3(aq) + H_2O(l)$ $\Delta H_{reaction\ 1}$

The molar enthalpy change for **reaction 1**, $\Delta H_{reaction\ 1}$, is the enthalpy change when 1.00 mol of $NaHCO_3$ reacts completely with NaOH.

Instead of using an indicator to determine the endpoint, you will perform a thermometric titration to determine the equivalence point of the reaction. The equivalence point is that point where $H^+(aq)$ from the acid and $OH^-(aq)$ from the base are present in equal molar amounts.

The second reaction is between sodium hydrogencarbonate, **FA 1**, and sulphuric acid, **FA 3**.

reaction 2 $NaHCO_3(aq) + \frac{1}{2}H_2SO_4(aq) \rightarrow \frac{1}{2}Na_2SO_4(aq) + H_2O(l) + CO_2(g)$ $\Delta H_{reaction\ 2}$

The molar enthalpy change for **reaction 2**, $\Delta H_{reaction\ 2}$, is the enthalpy change when 1.00 mol of $NaHCO_3$ reacts completely with H_2SO_4.

In your first experiment, you will perform a thermometric titration by adding portions of **FA 2** progressively to a known volume of **FA 1**. You will continue adding **FA 2** until the equivalence point is reacted and passed. Throughout the experiment you will note and record the temperature of the mixture after each addition.

You will then analyse your results graphically in order to determine the

- titration volume at the equivalence point, $V_{equivalence}$,
- maximum temperature change, $\Delta T_{maximum\ 1}$,
- molar enthalpy change, $\Delta H_{reaction\ 1}$, for **reaction 1**.

In your second experiment, you will mix together a given volume of **FA 1** with a suitable volume of **FA 3**.

You will then determine the

- maximum temperature change, $\Delta T_{maximum\ 2}$,
- molar enthalpy change, $\Delta H_{reaction\ 2}$, for **reaction 2**.

For Examiner's Use

(a) The reaction between FA 1 and FA 2

In this task you will need to record the maximum temperature of the reaction mixture when specified volumes of **FA 2** have been added. It is important that the volume of **FA 2** recorded is the total volume you have added up to that point when the temperature reading was made.

Note: If you overshoot on an addition, record the **actual** total volume of **FA 2** added up to that point.

In an appropriate format in the space provided on page 4, record all values of temperature, *T*, and each total volume of **FA 2** added.

(i) 1. Fill a burette with **FA 2**.

2. Place a Styrofoam cup inside a second Styrofoam cup which is held in a glass beaker to prevent it tipping over.

3. Using a pipette, transfer 25.0 cm^3 of **FA 1** to the first Styrofoam cup.

4. Stir the **FA 1** solution in the cup with the thermometer. Read and record its temperature.

5. From the burette, add 2.00 cm^3 of **FA 2** to the cup and stir the mixture thoroughly.

6. Read and record the maximum temperature of the mixture, *T*, and the volume of **FA 2** added.

7. Repeat points 5 and 6 until a total of 30.00 cm^3 of **FA 2** has been added. After each addition of **FA 2**, record the maximum temperature of the mixture and the total volume of **FA 2** added up to that point.

For Examiner's Use

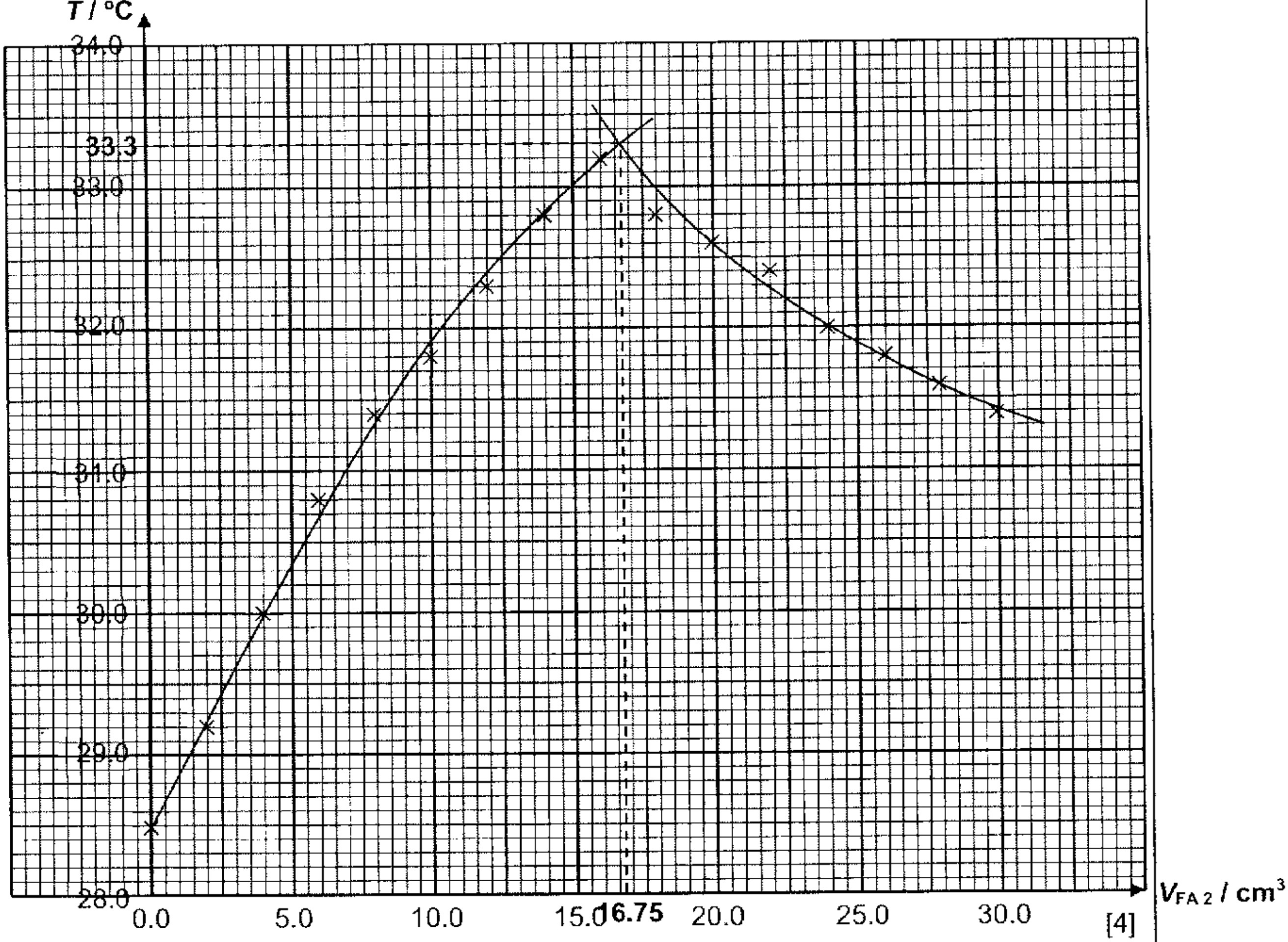
Results

Total vol of **FA2** added/ cm^3	*T* / °C
0.00	28.5
2.00	29.2
4.00	30.0
6.00	30.8
8.00	31.4
10.00	31.8
12.00	32.3
14.00	32.8
16.00	33.2
18.00	32.8
20.00	32.6
22.00	32.4
24.00	32.0
26.00	31.8
28.00	31.6
30.00	31.4

[2]

(ii) On the grid below, plot a graph of temperature, T (*y-axis*) against volume of **FA 2** added (*x-axis*).

For Examiner's Use



[4]

(iii) Draw **two** smooth lines of best fit.

- The first best-fit line should be drawn using the plotted points where the temperature is **rising**.
- The second best-fit line should be drawn using the plotted points where the temperature is **falling**.
- Extrapolate these lines until they cross.

Note: Each line should have a shape best suited to its plotted points.

For Examiner's Use

(iv) Determine from your graph

- the maximum temperature reached, $T_{maximum}$,
- the maximum temperature change, $\Delta T_{maximum\ 1}$,
- the volume, $V_{equivalence}$, of **FA 2** needed to completely react with 25.0 cm^3 of **FA 1**.

Show on your graph how you obtained these values.

Record these values in the spaces provided below.

maximum temperature reached, $T_{maximum}$ = 33.3 °C

maximum temperature change, $\Delta T_{maximum\ 1}$ = 4.8 °C

volume of **FA 2** used, $V_{equivalence}$ = 16.75 cm^3

[3]

(b) Ideally, the graph line **before** the equivalence point should be an *increasing* curve that *concaves downward* (that is, gradient of the curve decreases).

(i) Explain why the graph line is increasing.

As the reaction is **exothermic**, heat energy is released for each addition, hence **temperature** increases with each addition.

[1]

(ii) Explain why the graph line concaves downward.

The **same amount of heat energy** is **released** for each addition. However, **mass of the mixture increases**, hence causing a **smaller temperature rise** for each addition, leading to the graph line concaving downward.

[1]

For Examiner's Use

(c) The reaction between FA 1 and FA 3

The molar enthalpy change for **reaction 2**, $\Delta H_{reaction2}$, is the enthalpy change when 1.00 mol of $NaHCO_3$ reacts completely with H_2SO_4.

In this task you will calculate a value for the molar enthalpy change, $\Delta H_{reaction\ 2}$. To do this, you will need to determine the maximum temperature change produced when measured volumes of **FA 1** and **FA 3** are mixed.

Upon considering the concentrations of **FA 1** and **FA 3**, 15 cm^3 of **FA 3** was chosen to add to 40 cm^3 of **FA 1**.

Note: You should be aware that the reaction mixture will produce considerable frothing.

(i) Explain why 15 cm^3 of **FA 3** was chosen to add to 40 cm^3 of **FA 1**.

There must be **an excess of acid** to **completely react** with the $NaHCO_3$, although too large a volume would diminish the temperature change caused by the reaction

[1]

(ii) Identify the apparatus you intend to use to measure the volume of **FA 1**.

Explain your choice.

apparatus burette

explanation $NaHCO_3$ is the limiting reagent, so accurate/precise measurement of its volume is essential

[1]

For Examiner's Use

(iii) In an appropriate format in the space provided below, record all values of measured temperature for this experiment.

1. Place a Styrofoam cup inside a second Styrofoam cup which is held in a glass beaker to prevent it tipping over.
2. Transfer 40 cm^3 of **FA 1** into the first Styrofoam cup using the apparatus identified in **1(c)(ii)**.
3. Stir the **FA 1** solution in the cup with the thermometer. Read and record its temperature, $T_{FA\,1}$. This is the initial temperature of **FA 1**.
4. Wash and dry the thermometer.
5. Measure 15.0 cm^3 of **FA 3** using an appropriate measuring cylinder. Stir the **FA 3** solution in the measuring cylinder with the thermometer. Read and record its temperature, $T_{FA\,3}$. This is the initial temperature of **FA 3**.
6. Carefully add the contents of the measuring cylinder to the Styrofoam cup in **small** portions to avoid too much frothing.
7. Place the lid on the cup and insert the thermometer through the lid. Stir the mixture.
8. Continue to stir the mixture. Measure and record the temperature, $T_{mixture}$ that shows the maximum change from the initial temperature.

Results

$T_{FA\,1}$ / °C	28.8
$T_{FA\,3}$ / °C	28.8
$T_{mixture}$ / °C	28.4

[1]

For Examiner's Use

Calculations

(d) For the purpose of these calculations, you should assume that the reaction mixture has a density of 1.00 g cm^{-3} and a specific heat capacity, *c*, of 4.18 J g^{-1} K^{-1}.

Use your results from **(a)(iv)** to calculate

(i) the concentration of sodium hydroxide, [NaOH], in **FA 2**,

$$[NaOH] = \frac{25.0 \times 10^{-3}}{16.75 \times 10^{-3}} \times 1.00 = 1.493 \approx 1.49 \text{ mol dm}^{-3} \text{ (3 s.f.)}$$

[NaOH] in **FA 2** = ...1.49 mol dm^{-3}........[1]

(ii) the heat change, *q*, for the reaction occurring in **(a)(i)**, and hence determine a value for the molar enthalpy change for **reaction 1**, $\Delta H_{\text{reaction 1}}$.

$$q = mc\Delta T_{\text{maximum 1}} = (25.0 + 16.75) \times 1.00 \times 4.18 \times 4.8 = 837.672 \approx 838 \text{ J (3 s.f.)}$$

q = ...838 J........

$n(NaHCO_3) = 25.0 \times 10^{-3}$ mol

$$\Delta H_{\text{reaction 1}} = -\frac{837.672}{25.0 \times 10^{-3}} = -33506.88 \text{ J mol}^{-1} \approx -33.5 \text{ kJ mol}^{-1} \text{ (3 s.f.)}$$

$\Delta H_{\text{reaction 1}}$ = ...–33.5 kJ mol^{-1}........

[2]

For Examiner's Use

(e) Use your results from **(c)(iii)** to calculate a value for the molar enthalpy change for **reaction 2**, $\Delta H_{reaction\ 2}$. For the experiment in **(c)(iii)**, the weighted average initial temperature, $T_{average}$, of **FA 1** and **FA 3** may be calculated using the formula given below.

$$T_{average} = \frac{(V_{FA1} \times T_{FA1}) + (V_{FA3} \times T_{FA3})}{(V_{FA1} + V_{FA3})}$$

$$T_{average} = \frac{(40\times28.8)+(15\times28.8)}{40+15} = 28.8\ °C$$

$\Delta T_{maximum\ 2} = |28.8 - 28.4| = 0.4\ °C$

$q = mc\Delta T_{maximum\ 2} = (40.0 + 15.0) \times 1.00 \times 4.18 \times 0.4 = 92.0\ J$

$q =$ ....92.0 J........

$n(NaHCO_3) = 40.0 \times 10^{-3}$ mol

$$\Delta H_{reaction\ 2} = +\frac{92.0}{40.0 \times 10^{-3}} = +2300\ J\ mol^{-1} = +2.30\ kJ\ mol^{-1}\ (3\ s.f.)$$

$\Delta H_{reaction\ 2} =$ ....+2.30 kJ mol^{-1}........ [1]

(f) Ionic equations for neutralisation, **reaction 1**, and **reaction 2** are shown below.

$H^+ + OH^- \rightarrow H_2O$	$\Delta H_{neutralisation} = -57.1\ kJ\ mol^{-1}$
$HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$	$\Delta H_{reaction\ 1}$
$HCO_3^- + H^+ \rightarrow H_2O + CO_2$	$\Delta H_{reaction\ 2}$

Carbon dioxide may be removed from stale air by bubbling the air through aqueous alkali. An equation for this reaction is given below.

reaction 3 $\quad 2OH^-(aq) + CO_2(g) \rightarrow CO_3^{2-}(aq) + H_2O(l) \quad \Delta H_{reaction\ 3}$

Use your answers to **(d)(ii)** and **(e)**, together with the molar enthalpy change of neutralisation, $\Delta H_{neutralisation}$, to determine a value for the molar enthalpy change for this reaction, $\Delta H_{reaction\ 3}$.

$HCO_3^-(aq) + OH^-(aq) \rightarrow CO_3^{2-}(aq) + H_2O(l)$	$\Delta H_{reaction\ 1}$
$H_2O(l) + CO_2(g) \rightarrow HCO_3^-(aq) + H^+(aq)$	$-\Delta H_{reaction\ 2}$
$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$	-57.1
$2OH^-(aq) + CO_2(g) \rightarrow CO_3^{2-}(aq) + H_2O(l)$	$\Delta H_{reaction\ 3}$

$\Delta H_{reaction\ 3} = \Delta H_{reaction\ 1} - \Delta H_{reaction\ 2} - 57.1 = -33.5 - (+2.09) - 57.1$

$= -92.69 \approx -92.7\ kJ\ mol^{-1}$

$\Delta H_{reaction\ 3} =$ ....-92.7 kJ mol^{-1}........ [1]

For Examiner's Use

(g) Another student planned a different thermometric titration experiment to determine the value of the titration volume at the equivalence point, $V_{equivalence}$, and the maximum temperature change, $\Delta T_{maximum\ 1}$, for **reaction 1**.

In this other experiment, different volumes of **FA 1** and **FA 2** as shown in Table 1.1 are mixed, and the maximum temperature change, ΔT_{max}, is determined for each mixture.

Table 1.1

experiment	1	2	3	4	5	6	7	8
$V_{FA\ 2}$ / cm^3	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00
$V_{FA\ 1}$ / cm^3	45.00	40.00	35.00	30.00	25.00	20.00	15.00	10.00

ΔT_{max} is plotted against the volume of **FA 2** used, $V_{FA\ 2}$. $V_{equivalence}$ and $\Delta T_{maximum\ 1}$ are determined from the intersection of the two straight lines drawn as shown in Fig. 1.1.

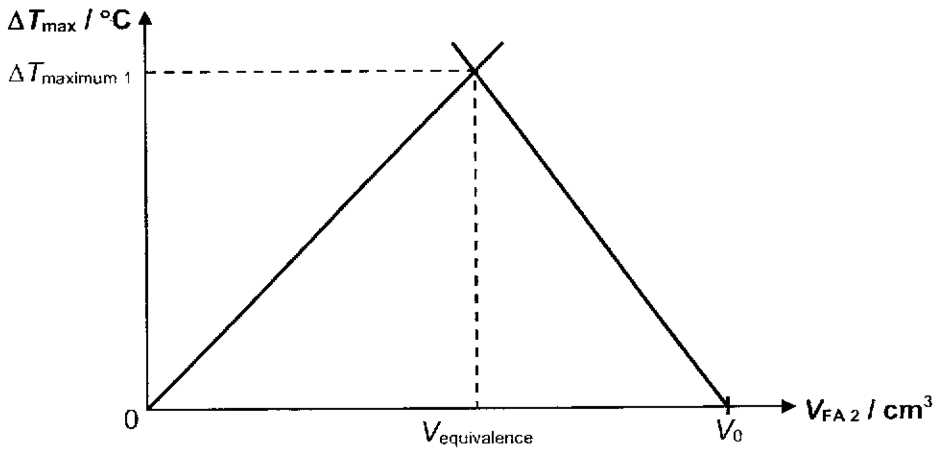


Fig. 1.1

(i) Suggest a value for V_0 in Fig. 1.1.

V_0 = 55.0 cm^3 [1]

(ii) The student claimed that this method gives a more accurate value of $V_{equivalence}$ and $\Delta T_{maximum\ 1}$ compared to the method in **1(a)**.

Do you agree with the student? Explain.

$V_{equivalence}$ Agree. This is because there is greater uncertainty in the extrapolation of a curve than of a straight line. *OR*

Disagree. This is because there are more data points in **1(a)**, allowing for better extrapolation of the line / Both methods uses the same graphical extrapolation treatment to determine $V_{equivalence}$.

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$\Delta T_{maximum\ 1}$ Agree. This is because there is **greater heat lost to the surroundings** for the method in **1(a)** as **FA 2** is added to **FA 1** in fifteen 2 cm^3 portions over a prolonged period of time.

[2]

[Total: 22]

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For Examiner's Use

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2 Determination of identity of the impurity in FA 4, the decomposition route of $NaHCO_3$, the percentage purity of FA 4

Solid FA 4 is anhydrous sodium hydrogencarbonate, $NaHCO_3$, of greater than 95% purity that has been contaminated with a sodium halide.

You are also provided with an aqueous solution of **FA 4**, labelled **FA 4 solution**.

(a) You will devise and perform a simple test, based on the Qualitative Analysis Notes on pages 23–24, to identify the halide present in the **FA 4 solution**.

(i) Describe a test, using only the bench reagents provided, which will allow you to identify the halide impurity present in **FA 4**.

Add $AgNO_3$(aq) dropwise to 1 cm^3 of FA 4 solution. After the ppt is formed, add aqueous ammonia. [1]

(ii) Perform the test you described in **2(a)(i)** using the **FA 4 solution provided.**

Record your observations and hence deduce the identity of the halide in **solid FA 4**.

Upon addition of $AgNO_3$(aq) dropwise, a white ppt is formed which is soluble in excess aqueous ammonia.

identity of halide chloride [2]

(b) Thermal decomposition of $NaHCO_3$

When $NaHCO_3$ is heated above 110 °C (but not heated to "red heat") it has been observed that both H_2O(g) and CO_2(g) are evolved, and that after this decomposition is complete, a white solid residue remains. Among possible reactions, the two following reactions seem the ones that are most likely to explain these facts:

reaction 4 $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(g) + CO_2(g)$

reaction 5 $2NaHCO_3(s) \rightarrow Na_2O(s) + H_2O(g) + 2CO_2(g)$

Sodium halides are stable to heat.

In this experiment, solid **FA 4** is heated gently in a boiling tube, over a luminous Bunsen flame, until **all** $NaHCO_3$ has been decomposed. The data will be used to determine

- the percentage mass loss,
- whether the decomposition takes place *via* **reaction 4** or **reaction 5**,
- the amount of CO_2 lost,
- the percentage purity of $NaHCO_3$ in **FA 4**

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

1. Weigh accurately between 2.00 g and 2.50 g of **FA 4** in the boiling tube provided. Record your weighings in the space provided below.

2. Heat the tube and content **gently** for 5 minutes.

Use a **luminous** Bunsen flame with the air-hole **closed** for this purpose. Ensure even heating of the sample and boiling tube.

3. Place the boiling tube into a **dry** 250 cm^3 beaker to cool.

You may wish to proceed with other experiments while waiting for the boiling tube to cool.

4. Weigh and record the mass of the cooled boiling tube containing the residue.

5. Repeat points 2 (heat gently for 2 minutes subsequently) to 4 as necessary until a constant mass is obtained.

6. **Turn off the Bunsen burner.**

(i) In an appropriate format in the space below, record all weighings.

mass of empty boiling tube / g	30.000
mass of boiling tube + **FA 4** / g	32.290
mass of **FA 4** / g	2.290
mass of boiling tube + residue after first heating / g	31.534
mass of boiling tube + residue after second heating / g	31.530

[4]

(ii) Using your results, calculate the mass lost upon decomposition of **FA 4**.

Mass lost due to decomposition = 2.290 – 1.530 = 0.760 g

mass lost = ...0.760 g........ [1]

(iii) Using your answer to **2(b)(ii)**, calculate the percentage mass lost.

% mass lost = 0.760 / 2.290 × 100% = 33.19 ≈ 33.2 % (3 s.f.)

percentage mass lost = ...33.2 %........ [1]

For Examiner's Use

(iv) Using your answer to **2(b)(iii)**, determine whether the decomposition occurs *via* **reaction 4** or **reaction 5**

via **reaction 4** :

% mass lost = $(18+44) \div (2\times84) \times 100\% = 36.9\%$

via **reaction 5** :

% mass lost = $(18 + 2\times44) \div (2\times84) \times 100\% = 63.1\%$

Since % mass lost is 33.2%, the decomposition occurs via **reaction 4**.

[2]

(v) Using your answer to **2(b)(ii)** and **2(b)(iv)**, calculate the amount of CO_2 lost.

$n(CO_2)$ lost = $0.760 \div (18+44) = 0.012258 \approx 0.0123$ mol

amount of CO_2 lost = 0.0123 mol [1]

(vi) Using your answer to **2(b)(v)**, calculate the percentage purity of $NaHCO_3$ in **FA 4**.

$n(NaHCO_3) = 2n(CO_2) = 0.024516$ mol
mass of $NaHCO_3 = n(NaHCO_3) \times 84.0 = 2.0594$ g
% purity = $2.0594 \div 2.290 \times 100\%$ = **89.9%**

percentage purity of $NaHCO_3$ in **FA 4** = 89.9% [2]

For Examiner's Use

(c) Planning

The percentage purity of $NaHCO_3$ in **FA 4** was determined *via* volatilisation gravimetric analysis in **2(b)**. Titrimetric analysis such as the thermometric titration in **1(a)** using **reaction 1** can also be used. In addition, the more usual acid-base titrations based on either **reaction 1** or **reaction 2** are applicable too.

reaction 1 $NaHCO_3(aq) + NaOH(aq) \rightarrow Na_2CO_3(aq) + H_2O(l)$

reaction 2 $NaHCO_3(aq) + \frac{1}{2}H_2SO_4(aq) \rightarrow \frac{1}{2}Na_2SO_4(aq) + H_2O(l) + CO_2(g)$

Plan an investigation to determine the percentage purity of $NaHCO_3$ in **FA 4** using an *acid-base titration* involving **reaction 2**.

You may assume that you are provided with:
- solid **FA 4**, impure $NaHCO_3$ of greater than 95% purity
- 0.200 mol dm^{-3} sulfuric acid, H_2SO_4
- acid-base indicator of your choice
- the equipment normally found in a school or college laboratory

In your plan, you should include brief details of
- the apparatus you would use,
- the quantities you would use,
- the procedure you would follow,
- the indicator you would use, including the colour change at the endpoint,
- the measurements you would make,
- an outline of how you would use your results to determine the percentage purity of $NaHCO_3$ in **FA 4**.

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

Pre-calculation:

Using a **50 cm^3 burette**, a **25 cm^3 pipette**, and a **250 cm^3 volumetric flask**

Assuming that a **titre value** of **25.00 cm^3** of 0.200 mol dm^{-3} H_2SO_4.

$n(H_2SO_4)$ in 25.00 cm^3 = 25.00 × 10^{-3} × 0.200 = 0.00500 mol

$n(NaHCO_3)$ in 25.0 cm^3 aliquot = $2n(H_2SO_4)$ = 0.0100 mol

$n(NaHCO_3)$ in 250 cm^3 solution prepared = 0.100 mol

$m(NaHCO_3)$ present = 0.100 × (23.0+1.0+12.0+16.0×3) = **8.40 g**

maximum mass of **FA 4** measured = 8.40 ÷ 0.95 = **8.84 g**

For Examiner's Use

Procedure:

1. **Weigh out accurately about 8.84 g** of **FA 4** into a clean, dry weighing bottle using an **electronic balance**.
2. **Transfer all** of the solid into a **250 cm^3 beaker** and dissolve it in about **100 cm^3 of deionised water**.
3. Transfer the solution to a **250 cm^3 volumetric flask**, labelled **FA 4 solution**. **Rinse** the beaker with deionised water several times, adding each rinsing to the volumetric flask.
4. Fill a **50 cm^3 burette** with **0.200 mol dm^{-3} H_2SO_4**.
5. Use a **pipette** to transfer **25.0 cm^3** of **FA 4 solution** into a **250 cm^3 conical flask**.
6. Add three drops of **methyl orange indicator** into the conical flask.
7. **Titrate** the **FA 4 solution** in the flask with 0.200 mol dm^{-3} sulfuric acid. The endpoint is reached when the solution changes from **yellow to orange**.
8. **Record** the titration results in a table.

Final burette reading / cm^3			
Initial burette reading / cm^3			
Volume of 0.200 mol dm^{-3} H_2SO_4 added / cm^3			

9. **Repeat** points 5 to 8 until **consistent titre values within ±0.10 cm^3** are obtained.

For Examiner's Use

Calculation:

1. From the consistent titration results, calculate the average volume of 0.200 mol dm^{-3} H_2SO_4, V cm^3.

2. $n(H_2SO_4)$ used = $V \times 10^{-3} \times 0.200 = 2V \times 10^{-4}$ mol

3. $n(NaHCO_3)$ present in 25.0 cm^3 = $2n(H_2SO_4) = 4V \times 10^{-4}$ mol

4. $n(NaHCO_3)$ present in 250 cm^3 = $4V \times 10^{-3}$ mol

5. $m(NaHCO_3)$ present in sample weighed = $n(NaHCO_3) \times 84.0 = 0.336V$ g

6. Assuming m g of **FA 4** weighed out,

   Percentage purity = $0.336V \div m \times 100\%$ = **$33.6V/m$ %**

[8]

[Total: 22]

For Examiner's Use

3 Qualitative Analysis

FA 5 contains two unknown cations.

FA 6 contains one unknown anion.

(a) Perform the tests described in Table 3.1, and record your observations in the table. Test and identify any gases evolved. If there is no observable change, write **no observable change.**

Table 3.1

	tests	observations
1.	To 2 cm depth of **FA 5** in a test tube, add aqueous sodium hydroxide. Warm the mixture. Filter the mixture and use the resulting filtrate for **Test 2** and residue for **Test 3**.	White ppt, soluble in excess NaOH Reddish-brown ppt, insoluble in excess NaOH Damp red litmus paper remained red. Colourless filtrate with reddish-brown residue.
2.	To 1 cm depth of the filtrate from **Test 1**, add dilute nitric acid dropwise with shaking until in excess. Add aqueous ammonia.	White ppt, soluble in excess HNO_3 to give a colourless solution. White ppt insoluble in excess NH_3
3.	Pour nitric acid onto the residue on the filter paper from **Test 1**. Divide the liquid that filters through into 2 equal portions. To one portion, add aqueous sodium hydroxide slowly with shaking.	Reddish-brown ppt dissolves to give a yellow solution. Reddish-brown ppt, insoluble in excess NaOH
4.	To the other portion of the liquid from **Test 3**, add aqueous ammonia.	Reddish-brown ppt, insoluble in excess NH_3
5.	Place about 2 cm depth of the **FA 6** solution in a test-tube. To this solution, add about 2 cm depth of **FA 5.**	Pale brown/ beige ppt Effervescence of colourless gas that formed white ppt with $Ca(OH)_2$

[6]

For Examiner's Use

(b) Deduce the unknown ions present in the following solutions.

(i) **FA 5**

The unknown ions are Al^{3+} and Fe^{3+}.

When NaOH is added, **Al^{3+}** forms **white ppt which is soluble in excess NaOH**.

When aqueous ammonia is added, Al^{3+} forms **white ppt which is insoluble in excess ammonia**.

When NaOH and ammonia are added separately to **Fe^{3+}**, a **reddish brown ppt** is formed and is **insoluble in excess base**.

[2]

(ii) **FA 6**

The unknown ion is CO_3^{2-}. Accept HCO_3^-.

When the **acidic FA 5** solution is added, **carbon dioxide** is released.

[1]

(c) Write equations to account for the observations in **Test 5**.

$[Al(H_2O)_6]^{3+} + H_2O \rightleftharpoons [Al(H_2O)_5(OH)]^{2+} + H_3O^+$ or

$[Fe(H_2O)_6]^{3+} + H_2O \rightleftharpoons [Fe(H_2O)_5(OH)]^{2+} + H_3O^+$

$2H^+ + CO_3^{2-} \rightarrow CO_2 + H_2O$

[2]

[Total: 11]

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Qualitative Analysis Notes
[ppt. = precipitate]

(a) Reactions of aqueous cations

cation	*reaction with*	
	$NaOH(aq)$	$NH_3(aq)$
aluminium, $Al^{3+}(aq)$	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, $NH_4^+(aq)$	ammonia produced on heating	–
barium, $Ba^{2+}(aq)$	no ppt. (if reagents are pure)	no ppt.
calcium, $Ca^{2+}(aq)$	white. ppt. with high $[Ca^{2+}(aq)]$	no ppt.
chromium(III), $Cr^{3+}(aq)$	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), $Cu^{2+}(aq)$,	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II), $Fe^{2+}(aq)$	green ppt., turning brown on contact with air insoluble in excess	green ppt., turning brown on contact with air insoluble in excess
iron(III), $Fe^{3+}(aq)$	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, $Mg^{2+}(aq)$	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), $Mn^{2+}(aq)$	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, $Zn^{2+}(aq)$	white ppt. soluble in excess	white ppt. soluble in excess

(b) Reactions of anions

anion	*reaction*
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, $Cl^-(aq)$	gives white ppt. with $Ag^+(aq)$ (soluble in $NH_3(aq)$)
bromide, $Br^-(aq)$	gives pale cream ppt. with $Ag^+(aq)$ (partially soluble in $NH_3(aq)$)
iodide, $I^-(aq)$	gives yellow ppt. with $Ag^+(aq)$ (insoluble in $NH_3(aq)$)
nitrate, $NO_3^-(aq)$	NH_3 liberated on heating with $OH^-(aq)$ and Al foil
nitrite, $NO_2^-(aq)$	NH_3 liberated on heating with $OH^-(aq)$ and Al foil; NO liberated by dilute acids (colourless NO $\rightarrow$ (pale) brown NO_2 in air)
sulfate, $SO_4^{2-}(aq)$	gives white ppt. with $Ba^{2+}(aq)$ (insoluble in excess dilute strong acids)
sulfite, $SO_3^{2-}(aq)$	SO_2 liberated with dilute acids; gives white ppt. with $Ba^{2+}(aq)$ (soluble in dilute strong acids)

(c) Tests for gases

gas	*test and test result*
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine, Cl_2	bleaches damp litmus paper
hydrogen, H_2	"pops" with a lighted splint
oxygen, O_2	relights a glowing splint
sulfur dioxide, SO_2	turns aqueous acidified potassium manganate(VII) from purple to colourless

(d) Colour of halogens

halogen	*colour of element*	*colour in aqueous solution*	*colour in hexane*
chlorine, Cl_2	greenish yellow gas	pale yellow	pale yellow
bromine, Br_2	reddish brown gas / liquid	orange	orange-red
iodine, I_2	black solid / purple gas	brown	purple