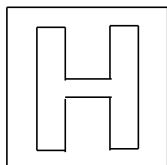


CANDIDATE
NAME

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CLASS

25S0



RAFFLES INSTITUTION
2025 YEAR 6 PRELIMINARY EXAMINATION

Higher 2



CHEMISTRY

9729/04

Paper 4 Practical

27 August 2025

2 hours 30 minutes

Do NOT turn over the Question Booklet until you are told to do so.

READ THESE INSTRUCTIONS FIRST.

Write your name and class on the space provided when instructed to do so.
Give details of the practical shift and laboratory where appropriate, in the space provided.
Write in dark blue or black pen.
You may use a 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 number of marks is given in brackets [] at the end of each question or part question.

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.

Shift	
Laboratory	
Bench Number	

For Examiner's Use	
Question	Marks
1	/ 14
2	/ 19
3	/ 13
4	/ 9
Total	/ 55

This document consists of **21** printed pages and **3** blank pages.

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

1 Investigation of inorganic and organic compounds

- (a) **FA 1** is an aqueous solution containing two cations.
FA 2 is an aqueous solution containing one anion.

You will perform tests to identify

- the two cations present in **FA 1**
- the anion present in **FA 2**.

- (i) Carry out the following tests. Carefully record your observations in Table 1.1.

The volumes given below are approximate and should be estimated rather than measured.

Test and identify any gases evolved.

If there is no observable change, write **no observable change**.

Table 1.1

tests		observations
1	Test FA 1 with Universal Indicator paper.	
2	Add 1 cm depth of FA 1 into a test-tube. Add aqueous sodium hydroxide, slowly with shaking, until no further change is seen. Filter the mixture into a clean test-tube. To the filtrate, add dilute nitric acid drop-wise until in excess.	
3	Add 1 cm depth of FA 2 into a test-tube. Add 1 cm depth of dilute nitric acid.	

[5]

- (ii) Use your observations in Table 1.1 to identify the two cations in **FA 1** and the anion in **FA 2** and state the evidence of each by completing Table 1.2.

Table 1.2

	identity	evidence
cation in FA 1		
cation in FA 1		
anion in FA 2		

[3]

- (b) **FA 3** and **FA 4** are aqueous solutions of two organic compounds **Y** and **Z** respectively. Both **Y** and **Z** contain only two carbon atoms.

You will perform some of the tests described in Table 1.3. You will then deduce the identities of **Y** and **Z** present in **FA 3** and **FA 4** respectively.

In addition to having access to the usual bench reagents, you are also provided with the following:

- magnesium turnings
- iodine solution

Perform the tests described in Table 1.3. Some of the observations have been completed for you. There is no need to carry out these tests. Record your observations in Table 1.3.

Test and identify any gases evolved.

If there is no observable change, write **no observable change**.

Table 1.3

tests		observations with FA 3	observations with FA 4
(i)	Add 1 cm depth of FA 3 to a test-tube. Add all of the magnesium turnings provided in the vial to this test-tube.		no observable change
(ii)	Add about 1 cm depth of FA solution to a test-tube. To this test-tube, add 8 drops of sodium hydroxide solution followed by iodine solution, dropwise, until a permanent orange/red colour is present.		
(iii)	Add 1 cm depth of aqueous silver nitrate to a test-tube. Then slowly add 1 cm depth of aqueous sodium hydroxide. Add aqueous ammonia slowly, with shaking, until the precipitate just dissolves. You may use a clean glass rod to stir the mixture and help dissolve the precipitate. Add 1 cm depth of FA 4 to this mixture, shake the tube and place it in the test-tube rack to stand.	no observable change	

[4]

- (iv) Using your observations in Table 1.3, complete Table 1.4 with the identities of **Y** and **Z** in **FA 3** and **FA 4** respectively.

Table 1.4

	identity
Y in FA 3	
Z in FA 4	

[2]

[Total: 14]

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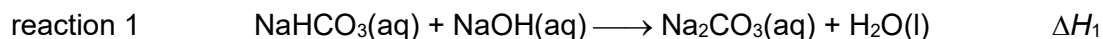
2 Determination of enthalpy change of reaction for some acid-base reactions

FA 5 is 0.60 mol dm^{-3} sodium hydrogencarbonate, NaHCO_3 .

FA 6 is aqueous sodium hydroxide, NaOH , of unknown concentration.

This experiment involves two different acid-base reactions.

The reaction between sodium hydrogencarbonate, **FA 5**, and sodium hydroxide, **FA 6** is shown.



The molar enthalpy change for reaction 1, ΔH_1 , is the enthalpy change when 1.00 mol of NaHCO_3 reacts completely with NaOH .

In this experiment, you will perform a thermometric titration to determine the equivalence point for the reaction of **FA 5** and **FA 6**, where maximum heat is evolved, without the use of an indicator.

You will follow the reaction by measuring the temperature as volumes of **FA 6** are added in regular portions from a burette to a fixed volume of **FA 5** placed in a polystyrene cup.

The data obtained will allow you to determine the temperature change. Then, you will analyse your results graphically in order to determine the equivalence point of the reaction.

(a) Determination of the enthalpy change of reaction between **FA 5** and **FA 6**

Prepare a table in the space provided on page 8 and record, to the appropriate level of precision:

- all volumes of **FA 6** added, $V_{\text{FA 6}}$
- total volume of solution in the cup, V_{total}
- the maximum temperature, T , reached after each addition of base, **FA 6**.

It is important that the volume of **FA 6** recorded is the total volume you have added up to the point when the temperature reading was made.

Note: If you overshoot on an addition, record the actual total volume of **FA 6** added up to that point.

In the same table, you also need to calculate the corresponding values of:

- $\Delta T = T - T_0$, where T_0 is the initial temperature of **FA 5**
- $(V_{\text{total}} \times \Delta T)$ to 3 significant figures.

Procedure

1. Fill the burette labelled **FA 6** to the 0.00 cm³ mark with **FA 6**.
2. Place a polystyrene cup inside a second polystyrene cup and place both cups in a 250 cm³ glass beaker.
3. Use a measuring cylinder to transfer 40.0 cm³ of **FA 5** into the first cup.
4. Measure and record the initial temperature of **FA 5**, T_0 .
5. Run 5.00 cm³ of **FA 6** from the burette into the cup and stir the solution gently with the thermometer. Record both the maximum temperature and the actual total volume of **FA 6** added.
6. Immediately run a further 5.00 cm³ of **FA 6** from the burette into the cup, stir and record the maximum temperature as before.
7. Continue the addition of **FA 6** in 5.00 cm³ portions until a total of 45.00 cm³ of **FA 6** has been added. For each addition of **FA 6**, record both the maximum temperature and the actual total volume of **FA 6** added up to that point.

Results

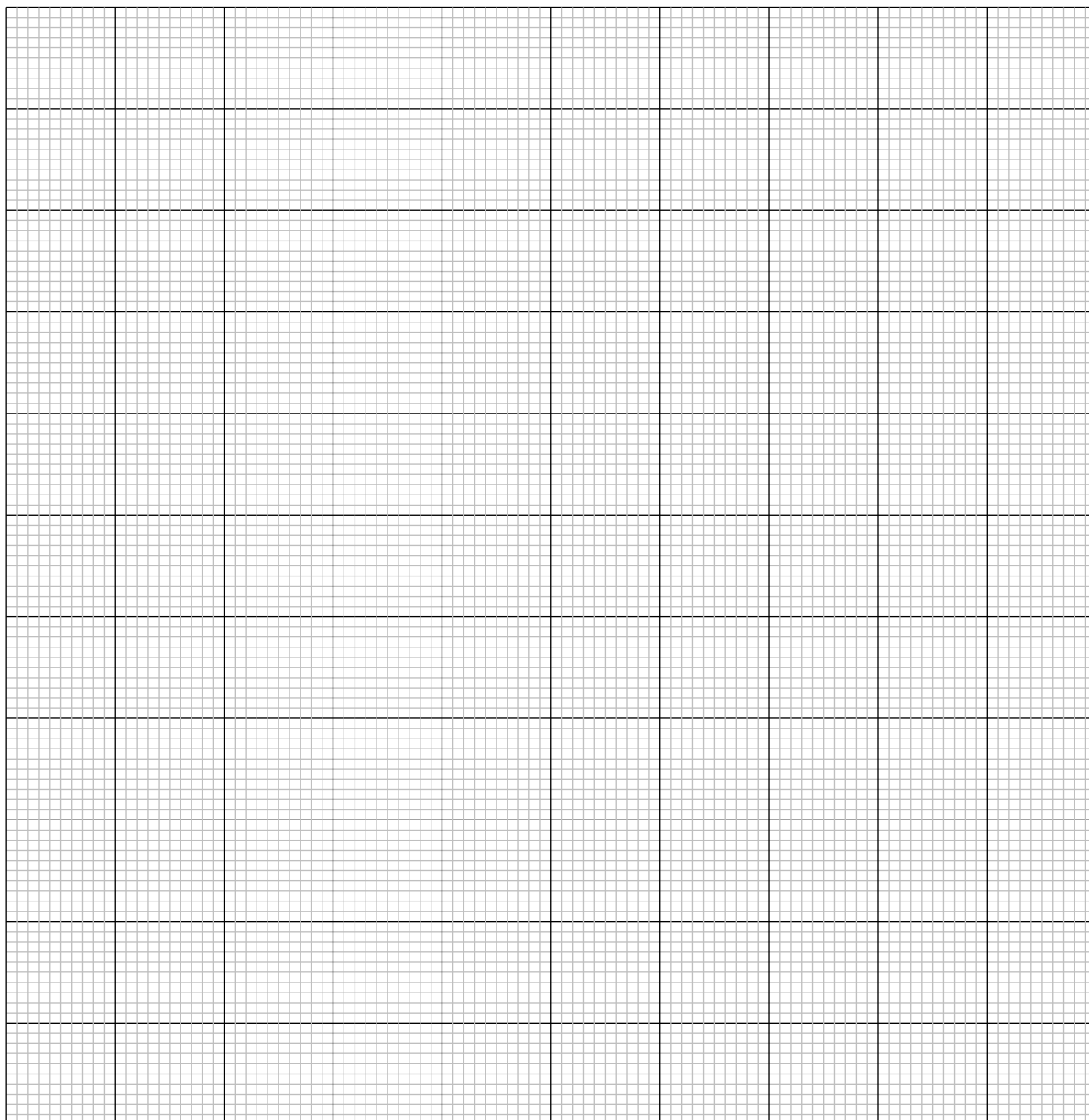
[3]

- (b) (i) Plot a graph of $(V_{\text{total}} \times \Delta T)$, on the y-axis, against total volume of **FA 6** added, $V_{\text{FA 6}}$, on the x-axis.

Draw two best-fit lines, taking into account the points when $(V_{\text{total}} \times \Delta T)$ was rising and the points when $(V_{\text{total}} \times \Delta T)$ was falling.

Extrapolate both lines until they intersect to determine the:

- equivalence point of the reaction, V_{eq}
- maximum value of $(V_{\text{total}} \times \Delta T)$.



$V_{\text{eq}} = \dots\dots\dots$

maximum value of $(V_{\text{total}} \times \Delta T) = \dots\dots\dots$

[5]

- (ii) Calculate the concentration of NaOH in **FA 6**.

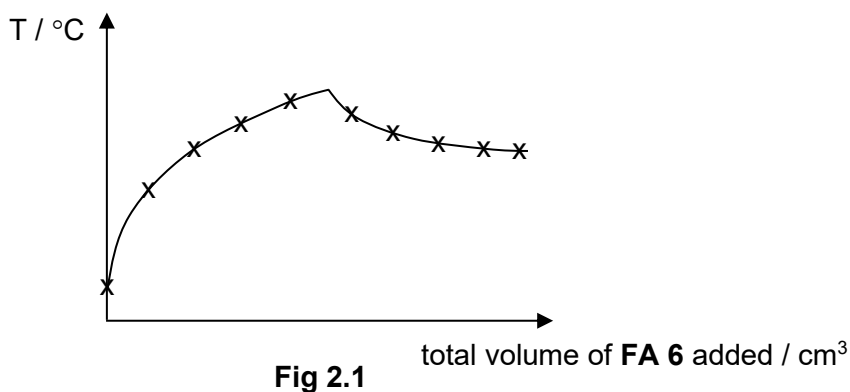
concentration of NaOH in **FA 6** = [1]

- (iii) Using your answer in **(b)(i)**, calculate the heat change, q , for your experiment in **(a)** and hence calculate the molar enthalpy change for reaction 1, ΔH_1 .

You should assume that the specific heat capacity of the solution is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$, and that the density of the solution is 1.0 g cm^{-3} .

ΔH_1 = [2]

- (iv) A student plotted a graph of T against total volume of **FA 6** added and the graph obtained is shown in Fig 2.1.



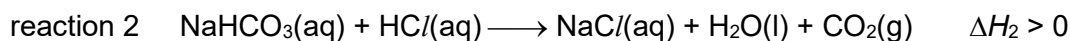
Explain why plotting the graph of $(V_{\text{total}} \times \Delta T)$ against total volume of **FA 6** added in **(b)(i)** yields a more accurate result for the equivalence point compared to the graph in Fig 2.1.

.....

[1]

(c) The reaction between sodium hydrogencarbonate and hydrochloric acid

The acid–base reaction between sodium hydrogencarbonate, NaHCO_3 and hydrochloric acid, HCl is shown.



A student carried out an experiment to determine the molar enthalpy change for reaction 2, ΔH_2 , by mixing 40.0 cm^3 of 0.60 mol dm^{-3} NaHCO_3 with 50.0 cm^3 of 1.00 mol dm^{-3} HCl . HCl is in excess.

The data collected for this experiment is recorded in Table 2.1.

Table 2.1

initial temperature of NaHCO_3 / $^{\circ}\text{C}$	28.6
initial temperature of HCl / $^{\circ}\text{C}$	28.9
lowest temperature of mixture / $^{\circ}\text{C}$	26.2

- (i) The weighted average initial temperature, T_{average} , of two solutions of different temperatures may be calculated using the formula below.

$$T_{\text{average}} = \frac{(V_1 \times T_1) + (V_2 \times T_2)}{(V_1 + V_2)}$$

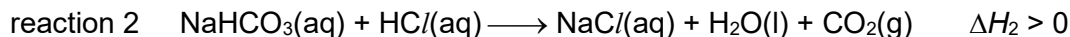
Calculate the T_{average} for this experiment.

$$T_{\text{average}} = \dots\dots\dots [1]$$

- (ii) Hence, calculate the molar enthalpy change for reaction 2, ΔH_2 .

You should assume that the specific heat capacity of the solution is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$, and that the density of the solution is 1.0 g cm^{-3} .

$$\Delta H_2 = \dots\dots\dots [1]$$

(d) Planning

The molar enthalpy change for reaction 2, ΔH_2 , may be determined more accurately by taking temperature measurements at regular time intervals and analysing the results graphically. The maximum temperature change, ΔT_{max} , obtained from the graph can be used to calculate the heat change, q , for the experiment. By using q , another value for ΔH_2 may be determined.

An outline of the experimental procedure proposed is given.

- Measure $Y \text{ cm}^3$ of 2.00 mol dm^{-3} HCl solution using a measuring cylinder. HCl is in excess.
- Use an analytical balance, weigh accurately about 5.0 g of solid NaHCO_3 in a weighing bottle.
- Transfer and dissolve the weighed NaHCO_3 in 50.0 cm^3 of water contained in a polystyrene cup. Place the lid on.
- Record the temperature at time = 0 min. Start timing using the stopwatch.
- Record the temperature of the NaHCO_3 solution at time = 1 min and time = 2 min.
- At exactly 2.5 min, transfer the $Y \text{ cm}^3$ HCl solution into the polystyrene cup. Place the lid on and stir the solution.
- Record the temperature of the solution at every 1-minute interval until time = 9 min.
- Reweigh the weighing bottle.

(i) $Y \text{ cm}^3$ is the volume of 2.00 mol dm^{-3} HCl solution used in the experiment.

Suggest a suitable value for Y .

[M_r : NaHCO_3 , 84.1]

$Y = \dots\dots\dots \text{cm}^3$ [1]

- (ii) Sketch, on Fig. 2.2, the graph you would expect to obtain using the measurements made in (d) and label on the graph the maximum temperature change, ΔT_{\max} .

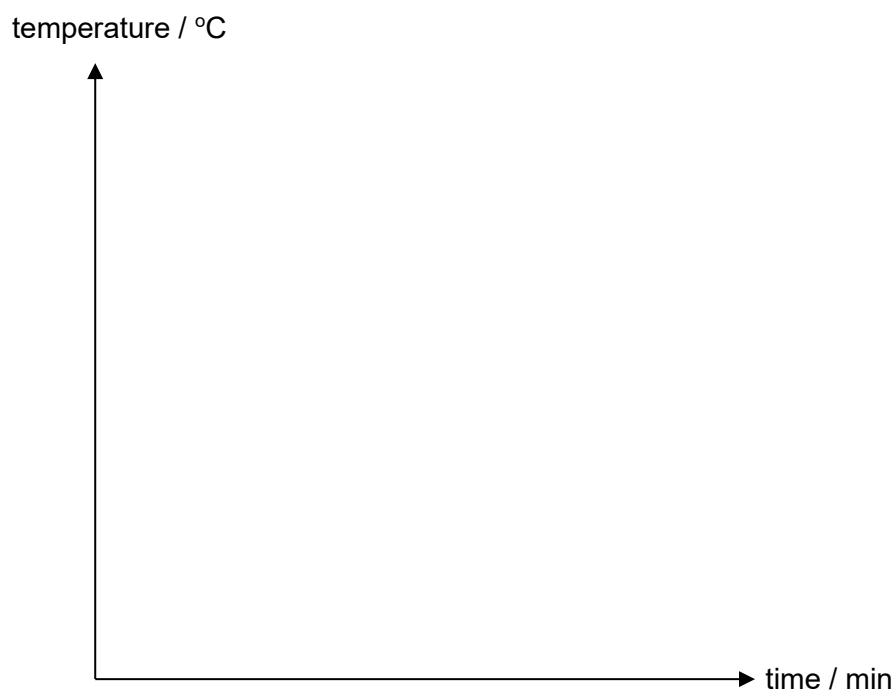


Fig. 2.2

[2]

- (iii) Explain why the graphical method is likely to give a more accurate value of ΔT_{\max} than the method used in (c).

.....
[1]

- (iv) Suggest why HC^{\ominus} solution should be added in gradually rather than all at once at 2.5 min.

.....
[1]

[Total: 19]

3 Standardisation of sodium hydroxide

Sodium hydroxide pellets cannot be obtained pure as they absorb moisture and carbon dioxide from the air. Hence, sodium hydroxide solutions are always standardised before use to determine its exact concentration.

Potassium hydrogen phthalate, $\text{KHC}_8\text{H}_4\text{O}_4$, is an organic acid of high purity that is used to standardise sodium hydroxide solutions. The M_r of $\text{KHC}_8\text{H}_4\text{O}_4$ is 204.2.

FA 8 is an aqueous solution of 8.15 g dm^{-3} $\text{KHC}_8\text{H}_4\text{O}_4$.

FA 6 is aqueous sodium hydroxide, NaOH , which you used in Question 2.

You are to dilute a sample of **FA 6** and titrate **FA 8** with this diluted solution to find the concentration of NaOH in **FA 6**.

Solution **I** is thymolphthalein.

(a) (i) Dilution of FA 6

1. Refill the burette labelled **FA 6** you used in **2(a)** with **FA 6**.
2. Transfer between 12.00 and 13.00 cm^3 of **FA 6** into a 250 cm^3 volumetric flask. Record the volume of **FA 6** used in an appropriate format in the space provided on page 15.
3. Make the solution up to the mark with deionised water and shake well to mix. Label this solution **FA 7**.

Titration of FA 8 against FA 7

4. Fill a clean burette with **FA 7**.
5. Use a pipette to transfer 25.0 cm^3 of **FA 8** into a 250 cm^3 conical flask.
6. Add a few drops of solution **I** into the conical flask. Replace the cap on the container of **I** after use.
7. Titrate the solution in the conical flask with **FA 7**. The end-point is reached when the solution changes from colourless to a permanent **pale** blue colour.
8. Record your titration results, to an appropriate level of precision, in the space provided on page 15.
9. Repeat steps 5 to 8 until consistent results are obtained.

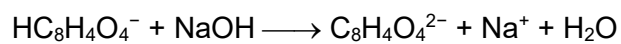
Dilution of FA 6**Titration results**

[6]

- (ii) From your titration results, obtain a suitable volume of **FA 7** to be used in your calculation. Show clearly how you obtained this volume.

volume of **FA 7** =cm³ [1]

- (b) (i) The equation for the reaction in the titration is shown.



Calculate the concentration of NaOH in **FA 7** in mol dm⁻³.

concentration of NaOH in **FA 7** = mol dm⁻³ [3]

- (ii) Hence, calculate the concentration of NaOH in **FA 6**.

concentration of NaOH in **FA 6** = mol dm⁻³ [1]

- (c) (i) The concentration of NaOH in **FA 6** was determined using the equivalence volumes of the two titration methods in Questions 2 and 3.

Calculate the difference between the value you obtained from **2(b)(ii)** and the value from **3(b)(ii)**, as a percentage of the concentration of NaOH in **FA 6** from Question 3. This is the percentage error.

If you were unable to calculate a value for **2(b)(ii)**, you should use 1.50 mol dm⁻³. This is **not** the correct answer.

percentage error = % [1]

- (ii) In Question 2, the equivalence volume, V_{eq} , determined by thermometric titration was used to calculate the concentration of NaOH in **FA 6**. Suggest why the volumetric titration method in Question 3 gives a more accurate equivalence volume for this calculation.

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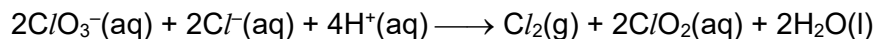
[1]

[Total: 13]

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4 Planning

Chlorate(V), ClO_3^- , reacts with chloride, Cl^- .



The order of reaction with respect to ClO_3^- may be confirmed to be first order by preparing a reaction mixture containing sodium chlorate(V), sodium chloride and sulfuric acid.

At timed intervals, portions of the reaction mixture are removed, quenched in an ice bath and then placed into the UV-vis spectrometer to record its absorbance value. The absorbance value is directly proportional to the concentration of the product ClO_2 .

You should plan to make a 90 cm^3 reaction mixture containing

- 30 cm^3 of $0.400 \text{ mol dm}^{-3}$ dilute sulfuric acid, H_2SO_4 ,
- 30 cm^3 of $0.100 \text{ mol dm}^{-3}$ aqueous sodium chloride, NaCl ,
- 30 cm^3 of $0.00144 \text{ mol dm}^{-3}$ aqueous sodium chlorate(V), NaClO_3 .

- (a) Beer-Lambert's Law states that the absorbance value, A , is directly proportional to the concentration of absorbing species, c , as shown below.

$$A = \epsilon c l$$

where ϵ is a constant and l is the path length, which is usually 1.0 cm . Absorbance has no units.

This equation can be used to calculate the absorbance value when the maximum amount of ClO_2 is formed from the above chlorate(V)-chloride reaction.

Calculate the concentration of NaClO_3 in the 90 cm^3 reaction mixture and hence calculate the maximum absorbance value in the above experiment, given that ϵ of ClO_2 is $1250 \text{ mol}^{-1} \text{ dm}^3 \text{ cm}^{-1}$.

[2]

- ice bath,
- UV-vis spectrometer,
- the equipment normally found in a school or college laboratory.

- the preparation of the reaction mixture,
- the apparatus you would use,
- the procedure you would follow,
- the measurements you would make.

[illegible]

[5]

(c) Fig. 4.1 shows the graph you would expect to obtain.

Show clearly on the graph how you would confirm the reaction is first order with respect to C/O_3^- .

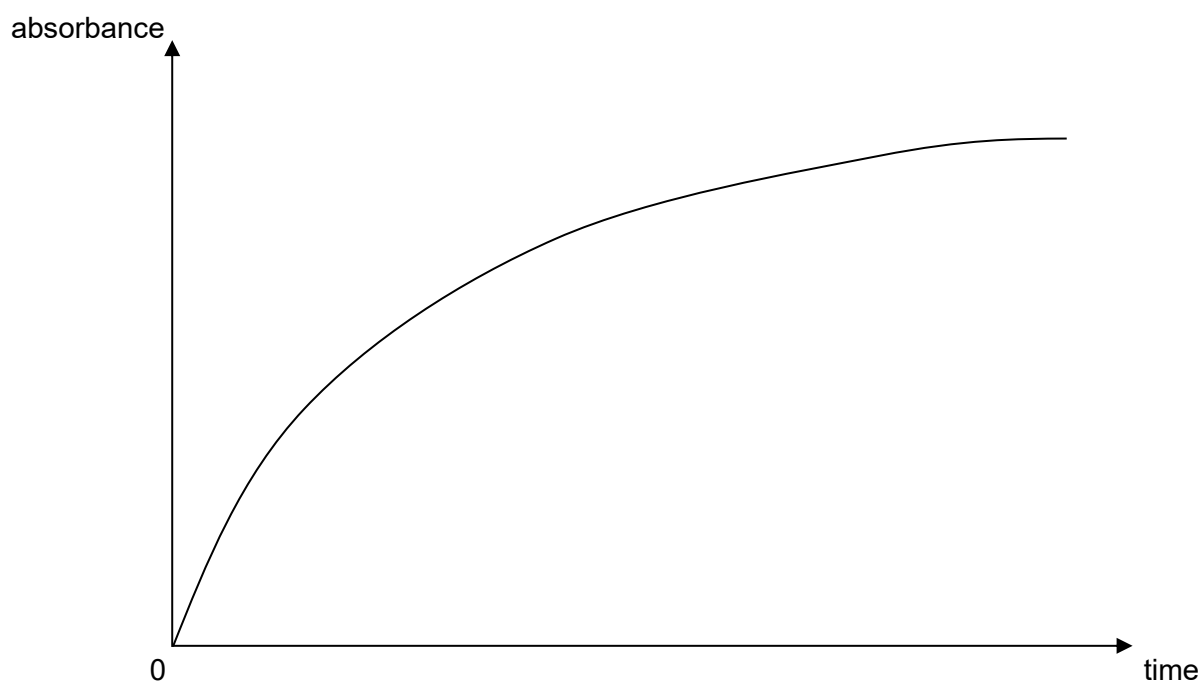


Fig. 4.1

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

[Total: 9]

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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

<i>anion</i>	<i>reaction</i>
carbonate, CO_3^{2-}	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, $\text{NO}_3^-(\text{aq})$	NH_3 liberated on heating with $\text{OH}^-(\text{aq})$ and Al foil
nitrite, $\text{NO}_2^-(\text{aq})$	NH_3 liberated on heating with $\text{OH}^-(\text{aq})$ and Al foil; NO liberated by dilute acids (colourless $\text{NO} \rightarrow$ (pale) brown 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, $\text{SO}_3^{2-}(\text{aq})$	SO_2 liberated on warming 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, 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

<i>halogen</i>	<i>colour of element</i>	<i>colour in aqueous solution</i>	<i>colour in hexane</i>
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