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

1 To determine the concentration of NaOH and Na_2CO_3 in FA 1

Aqueous NaOH can be used to remove CO_2 from exhaled air in spacecrafts. NaOH reacts with CO_2 according to the following equation:

$$2NaOH(aq) + CO_2(g) \rightarrow Na_2CO_3(aq) + H_2O(l)$$

A sample of aqueous NaOH was used to absorb CO_2 in the air for some time. The resulting mixture of NaOH and Na_2CO_3 formed was labelled as **FA 1**.

You are to determine the concentration of NaOH and Na_2CO_3 in **FA 1** by titration with an aqueous solution of HC*l*, **FA 2.**

You are provided with the following.
FA 1, is a mixture of NaOH and Na_2CO_3
FA 2, 2.50 mol dm^{-3} of hydrochloric acid, HC*l*
methyl orange indicator
thymol blue indicator
distilled water

(a) Titration of FA 1 against FA 2 using thymol blue indicator.

1. Fill a burette with **FA 2**.
2. Using a pipette, transfer 25.0 cm^3 of **FA 1** into a 250 cm^3 conical flask.
3. Add a few drops of thymol blue indicator into the conical flask.
4. Run **FA 2** from the burette into the flask. The end point is reached when the solution changes from blue to green.
5. Record your titration results in Table 1.1
6. Repeat points 2 to 5 until consistent titre values are obtained.

Table 1.1

	1	**2**	**3**
final burette reading / cm^3	13.80	13.80	
initial burette reading / cm^3	0.00	0.00	
volume of **FA 2** added / cm^3			

[3]

From your titrations, obtain a suitable volume of **FA 2** to be used in your calculations. Show clearly how you obtained this volume.

volume of **FA 2** = ……………………….. [1]

(b) Titration of FA 1 against FA 2 using methyl orange indicator.

Repeat points 1 to 6 in (a) but add methyl orange at point 3 in place of thymol blue. Using this indicator, the end point is reached when the solution changes from yellow to orange. Record your titration results in Table 1.2.

Table 1.2

	1	**2**	**3**
final burette reading / cm^3	18.80	19.00	
initial burette reading / cm^3	0.00	0.20	
volume of **FA 2** added / cm^3			

[3]

From your titrations, obtain a suitable volume of **FA 2** to be used in your calculations. Show clearly how you obtained this volume.

volume of **FA 2** = ……………………….. [1]

(c) Calculation

When **thymol blue** is used as the indicator in part **(a)**, the following reactions occur.

Reaction 1: $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$
Reaction 2: $Na_2CO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + NaHCO_3(aq)$

When **methyl orange** is used as the indicator in part **(b),** the following reactions occur.

Reaction 1: $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$
Reaction 2: $Na_2CO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + NaHCO_3(aq)$
Reaction 3: $NaHCO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$

The $NaHCO_3$ in **Reaction 3** is the product from reaction of Na_2CO_3 with HCl in **Reaction 2**.

(i) Calculate the volume of hydrochloric acid that reacted with $NaHCO_3$ in 25.0 cm^3 of **FA 1** in **Reaction 3.**

volume of hydrochloric acid = ……………………..[1]

(ii) By considering **Reactions 2** and **3**, determine the volume of hydrochloric acid that reacted with sodium carbonate in 25.0 cm^3 of **FA 1** to form $NaHCO_3$.

volume of hydrochloric acid = ……………………….. [1]

(iii) Calculate the volume of hydrochloric acid that reacted with the sodium hydroxide present in 25.0 cm^3 of **FA 1**.

volume of hydrochloric acid = ……………………….. [1]

(iv) Using your answer in **(c)(ii)** and the equation for Reaction **2**, calculate the amount of sodium carbonate present in 25.0 cm^3 of **FA 1**.

amount of sodium carbonate = ……………………….. [1]

(v) Calculate the concentration of sodium carbonate, Na_2CO_3 in **FA 1**.

concentration of sodium carbonate = ……………………….. [1]

(vi) From your answer to **(c)(iii)** and the equation for **Reaction 1**, calculate the amount of sodium hydroxide present in 25.0 cm^3 of **FA 1**.

amount of sodium hydroxide = ……………………….. [1]

(vii) Calculate the concentration of sodium hydroxide, NaOH in **FA 1**.

concentration of sodium hydroxide = ……………………….. [1]

(d) Give **one** reason why after 25.0 cm^3 of **FA 1** is pipetted into a conical flask, the stock solution **FA 1** should be immediately covered with a sealant film.

State the effect of not covering **FA 1** with a sealant film on the calculated concentration of NaOH.

……….………………………………………………………………….……………….……….

……….………………………………………………………………….……………….……….

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

[Total: 17]

2 Determination of the identity of the acid and the enthalpy change of neutralisation, ΔH_{neut}

You are provided with the following solutions:

FA 3 is a solution of 1.60 mol dm^{-3} sodium hydroxide, NaOH

FA 4 is a solution of 2.00 mol dm^{-3} of either hydrochloric acid, HC*l* or sulfuric acid, H_2SO_4.

In this question, you are to perform a series of 6 experiments where different volumes of **FA 3** and **FA 4** are mixed to give a total volume of 50 cm^3. The temperature change, ΔT, of the reaction mixture for each experiment will be determined and a graph of ΔT against the volume of **FA 3** will be plotted.

You will then use the data from your graph to determine the identity of the acid and the enthalpy change of neutralization for the reaction between aqueous sodium hydroxide and the acid.

(a) Procedure

Experiment 1

1) Place one polystyrene cup inside a second polystyrene cup. Place these into a 250 cm^3 beaker to prevent them from tipping over.

2) Use a measuring cylinder to transfer 10.0 cm^3 of **FA 3** into the polystyrene cup.

3) Measure the temperature of **FA 3** in the polystyrene cup and record the initial temperature of **FA 3**, T_1, in Table 2.1 on the next page.

4) Use another measuring cylinder to transfer 40.0 cm^3 of **FA 4** into the same polystyrene cup.

5) Stir the mixture in the polystyrene cup with the thermometer. Measure and record the highest temperature, T_2 in Table 2.1 on the next page.

6) Rinse the polystyrene cup and thermometer with distilled water and dry them with paper towels.

Experiment 2 to 4

7) Repeat steps **1** to **6** using 20.0 cm^3, 30.0 cm^3 and 40.0 cm^3 of **FA 3**, each time using an appropriate volume of **FA 4**, such that the total volume of the reaction mixture is 50.0 cm^3.

8) Record all measurements of volumes of **FA 3** and **FA 4**, temperature (T_1 and T_2) and temperature change, ΔT, in Table 2.1 on the next page.

(b) Results

Table 2.1

	experiment					
	1	2	3	4	5	6
volume of **FA 3** / cm^3	10.0	20.0	30.0	40.0	25.0	35.0
volume of **FA 4** / cm^3	40.0					
initial temperature, T_1 / °C	31.0	31.0	31.0	31.0	31.0	31.0
final temperature, T_2 / °C	35.6	40.0	42.0	36.6	42.4	39.6
temperature change, ΔT / °C						

[3]

(c) (i) Plot a graph of ΔT (y–axis) against volume of **FA 3** used (x–axis) in Fig 2.1 using the four experimental results that you have obtained.

The scales for both axes must be chosen to provide an origin.

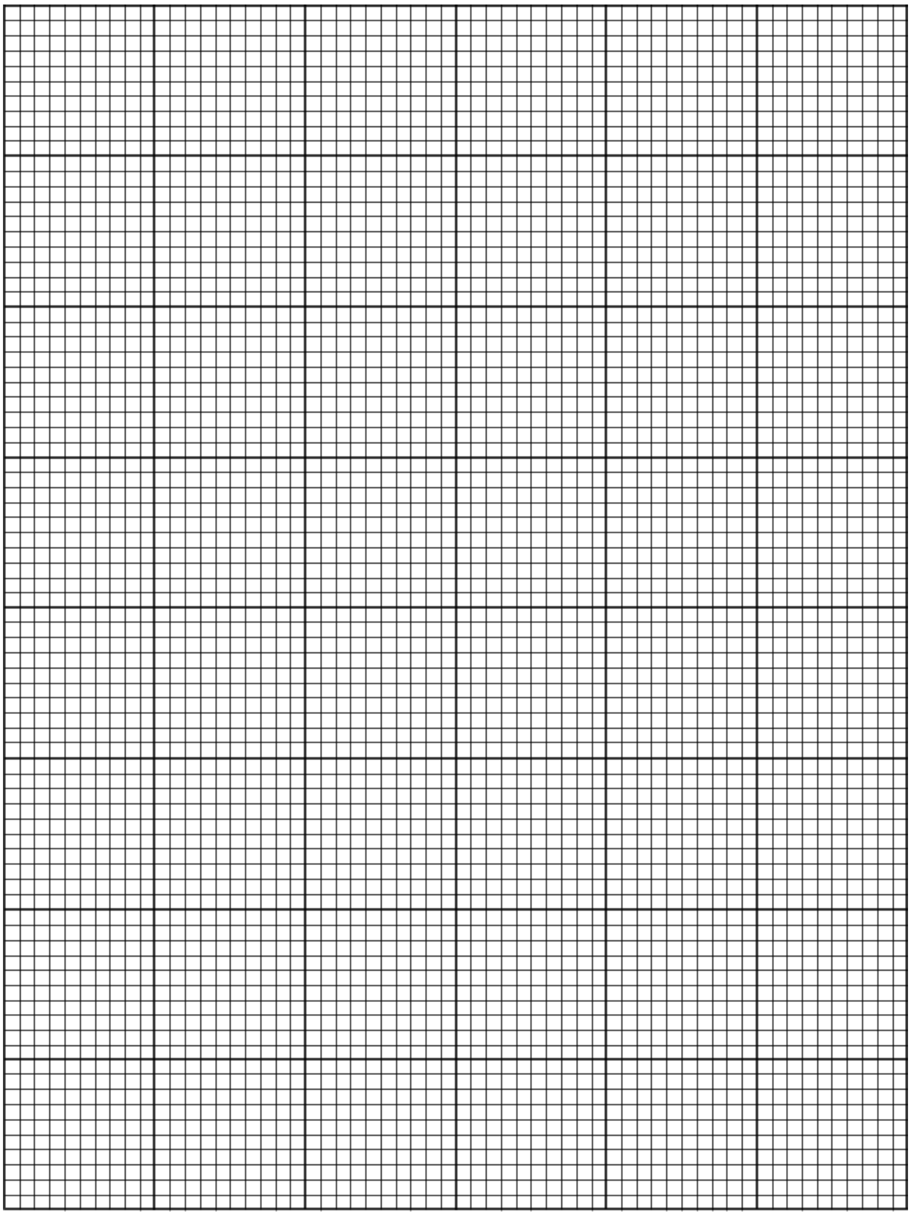

Fig. 2.1

By considering your plotted points, select two other volumes of **FA 3** that will allow you to draw two best fit lines to identify the volume of **FA 3** needed to produce the maximum temperature change, ΔT_{max}.
In each experiment, ensure that the total volume of the reaction mixture is 50.0 cm^3. You may find it helpful to plot the results from experiment 1 to 4 before choosing the volumes to use in experiment 5 and 6.
Record all measurements of volume, temperature (T_1 and T_2) and temperature change, ΔT, in Table 2.1 on page 8. [2]

(ii) Draw two straight lines of best fit. The first best fit line should be drawn using the plotted points where ΔT is increasing and the second best fit line should be drawn using the plotted points where ΔT is decreasing.
Extrapolate these two lines until they cross. [1]

(d) (i) Use your graph in Fig 2.1 to determine the maximum temperature change, ΔT_{max}, as well as the volume of **FA 3,** $V_{\text{FA 3}}$**,** used to obtained it.

ΔT_{max} = ……………………………….°C

$V_{\text{FA 3}}$ = ..……..… …………….cm^3 [1]

(ii) Using your results in **(d)(i)**, determine the identity of acid in **FA 4**.

FA 4 is ………………………………..[2]

(iii) Hence, calculate the enthalpy change of neutralisation, ΔH_{neut}.

You may assume that the specific heat capacity of the reaction mixture is 4.18 J g^{-1} K^{-1}, and that the density of the reaction mixture is 1.00 g cm^{-3}.

ΔH_{neut} = ………………………………..[3]

(e) Predict and explain the following:

(i) the effect on ΔT_{max} when the volumes of **FA 3** and **FA 4** used in the reaction are doubled
…………………………………………………………………………………...….[1]

(ii) the effect on ΔH_{neut} if the experiment was repeated with a weak acid of the same concentration and basicity instead of **FA4**.
…………………………………………………………………………………...….[1]

(f) State one significant source of error in the experiment and suggest an improvement that can be made to reduce this error.

……………………………………………………………………………………………[1]

[Total: 15]

3 Qualitative Analysis

FA 5 is an organic compound with molecular formula $C_3H_6O_2$.
Test and identify any gases evolved.

Table 3.1

	test	observations
1.	To 1cm depth of **FA 5**, add aqueous sodium carbonate.	No effervescence √
2.	Place about 2 cm depth of aqueous silver nitrate in a test tube and add to it about 1 cm depth of aqueous sodium hydroxide. Add aqueous ammonia until the precipitate just dissolves. You may use a clean glass rod to help dissolve the precipitate Add 2 cm depth of the **FA 5** and warm in a beaker of hot water until no further change.	Grey/Brown ppt formed √ Brown ppt dissolved to give a colourless solution √ Silver mirror formed. √
3.	Add about 1 cm depth of **FA 5** in 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. Warm the mixture in a beaker of hot water for two minutes.	No (yellow) ppt formed.√ [3]
(b)	Deduce the structure of the organic compound in **FA 5** using your observations. [2] [Total: 5]	

4 Determination of reducing strength of reducing agents

You are provided with samples of 3 metals and 2 aqueous solutions.

Mg powder
Fe powder
Zn powder
$CuSO_4$ solution
$ZnSO_4$ solution

(a) Carry out the tests in Table 4.1. Carefully record your observations in Table 4.1. You are to investigate possible redox reactions and rank the reducing strength of the reducing agents Ag, Cu, Fe, Mg and Zn.

$$Ag^{+} + e^{-} \rightleftharpoons Ag$$
$$Cu^{2+} + 2e^{-} \rightleftharpoons Cu$$
$$Fe^{2+} + 2e^{-} \rightleftharpoons Fe$$
$$Mg^{2+} + 2e^{-} \rightleftharpoons Mg$$
$$Zn^{2+} + 2e^{-} \rightleftharpoons Zn$$

The results of the first test have been given to you and you should use it as an example. Your answers should correspond to the given observations.

Table 4.1

		test	observations	deductions
1	**(i)**	Transfer 2 cm^3 of **Ag^+** to a test-tube. Add 1 spatula of **Cu** powder. Shake the mixture thoroughly and leave it to stand for 3 minutes.	Colourless solution turns pale blue. Reddish brown solid turns grey.	Cu reduces Ag^+ to Ag Cu > Ag
2		Transfer 5 cm^3 of **Zn^{2+}** to a test-tube. Add 1 spatula of **Mg** powder. Shake the mixture thoroughly and leave it to stand for 3 minutes. While waiting, proceed to test 3. Filter the mixture. Add aqueous NaOH dropwise to 1cm depth of the filtrate until in excess.	Solution remains colourless √ Effervescence observed√. Lighted splint extinguishes with a pop sound.√ Filtrate is colourless, residue is grey √ White ppt, insoluble in excess NaOH √	
3		Transfer 5 cm^3 of **Zn^{2+}** to a test-tube. Add 1 spatula of **Fe** powder. Shake the mixture thoroughly and leave it to stand for 3 minutes. While waiting, proceed to the test 4. Filter the mixture. Add aqueous NaOH dropwise to 1cm depth of the filtrate until in excess.	Solution remains colourless √ Filtrate is colourless, residue is grey √ White ppt, soluble in excess NaOH to form a colourless solution √	

	test	observations	deductions
4	Transfer 2 cm^3 of $\mathbf{Cu^{2+}}$ to a test-tube. Add 1 spatula of **Fe** powder. Shake the mixture thoroughly and warm the mixture cautiously.	Blue solution fades/turn lighter blue/turn colourless/decolourise. √ Solution turns yellow on heating√ Grey solid turns reddish brown. √	
5	Transfer 2 cm^3 of $\mathbf{Cu^{2+}}$ to a test-tube. Add 1 spatula of **Zn** powder. Shake the mixture thoroughly and warm the mixture cautiously.	Blue solution fades/turns colourless√. Grey solid turns reddish brown. √	

[6]

(b) Explain your deduction in Test 3 of Table 4.1 using evidence from your observations to support your answer.

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(c) Use your information in the above Table 4.1 to rank the order of reducing strengths of the species in decreasing order: Ag, Cu, Fe, Mg, Zn.

Note: In some of the tests performed in part **(a)** there will have been no reaction. Such tests can still help you to deduce the relative reducing powers of the species involved.

……………………………………………………………………………………………………[1]

[Total: 8]

5 Planning: Determine the activation energy for the reaction between ethanedioic acid and acidified potassium manganate(VII).

A solution of ethanedioic acid reduces purple acidified potassium manganate(VII) solution to a colourless solution according to the following equation.

$$2MnO_4^- + 6H^+ + 5H_2C_2O_4 \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$$

You are provided with the following:

- Ethanedioic acid crystals, $H_2C_2O_4$
- Aqueous sulfuric acid
- 0.025 mol dm^{-3} potassium manganate(VII) solution
- deionised water
- the apparatus normally found in a school or college laboratory

Describe how you would make 250 cm^3 of a solution of ethanedioic acid of concentration 0.10 mol dm^{-3}.
[A_r: H, 1.0; C, 12.0; O: 16.0]

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…… [3]

When 10 cm^3 of 0.025 mol dm^{-3} $KMnO_4$ is mixed with equal volumes of 0.10 mol dm^{-3} ethanedioic acid solution and aqueous sulfuric acid at 25 ^oC, it took 54 s for the purple mixture to turn colourless.

In order to determine calculate E_a graphically, the following equation is used

$$\ln\left(\frac{1}{t}\right) = -\frac{E_a}{R}\left(\frac{1}{T}\right) + \ln A$$

where R is the molar gas constant
and ln*A* is the constant for the reaction

The activation energy, E_a, for the reaction may be determined by measuring the time, *t*, for the solution to turn colourless at different temperatures, *T*.

The rate of reaction is proportional to $\frac{1}{t}$ where t is the time taken for the purple mixture to turn colourless.

In all experiments, you need to ensure that potassium manganate(VII) solution is the limiting reagent and the same volume is used.

(a) **(i)** Explain why potassium manganate(VII) solution is the limiting reagent. [1]

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(ii) Explain why the rate of reaction is proportional to $\frac{1}{t}$. [1]

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(b) Plan an experiment to collect sufficient data to plot a graph of ln(1/t) against 1/T where

- t is the time for the reaction mixture to turn colourless
- T is the reaction temperature in kelvin.

In all experiments, you will use 10 cm^3 of potassium manganate(VII) solution and equal volumes of 0.10 mol dm^{-3} ethanedioic acid and aqueous sulfuric acid.

Your plan should include details of:

- the apparatus you would use
- the procedure you would follow
- the measurements you would take
- a sample table of the volume of reagents, the data collected and how the data measured would be used to determine values needed for plotting of the graph.

[5]

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[Total 10]

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 → (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 on warming 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