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	13.80	13.80	

[3]

Students should be mindful to input the burette reading in the correct box.
Students should be careful with the subtraction of the burette readings and all entries must be written to 2 dp (to nearest 0.05 cm^3).
Students should have at least 2 consistent readings within ±0.10 cm^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]

Calculation of average to 2 dp

(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	18.80	18.80	

[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.**

$$NaHCO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$$

Volume of HC*l* used = 18.80 (Reaction 1, 2 and 3) – 13.80 (Reaction 1 and 2)
= 5.00cm^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 $NaHCO_3$.

1 mol $NaHCO_3 \equiv$ 1 mol Na_2CO_3
Volume of HCl used to react with Na_2CO_3 = 5.00 cm^3

Students should be mindful of this statement given "The $NaHCO_3$ in **Reaction 3** is the product from reaction of Na_2CO_3 with HC*l* in **Reaction 2**."

As such the volume of HCl that reacted with $NaHCO_3$ should be equal to the volume of HCl that react with Na_2CO_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 HCl reacted with Na_2CO_3 = 5.00 cm^3 (Reaction 2)

Volume of HCl reacted with NaOH = 13.80 – 5.00
= 8.80 cm^3

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**.

$$Na_2CO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + NaHCO_3(aq)$$

Volume of HCl used to react with Na_2CO_3 = 5.00 cm^3

Amount of HCl reacted with $Na_2CO_3 = 2.50 \times \frac{5.00}{1000} = 0.0125$ mol

Since $Na_2CO_3 \equiv$ HCl
Amount of Na_2CO_3 = 0.0125 mol

amount of sodium carbonate = …….. [1]

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

$$[Na_2CO_3] = 0.0125 \times \frac{1000}{25} = 0.500 \text{ moldm}^{-3}$$

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**.

$NaOH\ (aq) + HCl\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)$

Amount of HCl used = $2.50 \times \frac{8.80}{1000} = 0.0220$ mol

Since NaOH ≡ HCl

Amount of NaOH = 0.0220 mol

amount of sodium hydroxide = …….. [1]

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

$[NaOH] = 0.0220 \times \frac{1000}{25} = 0.880\ moldm^{-3}$

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]

This will prevent atmospheric **carbon dioxide** from reacting further with sodium hydroxide present in **FA 1**. $CO_2 + 2NaOH \rightarrow Na_2CO_3 + H_2O$

If a stopper or sealant is not used, the calculated concentration of NaOH will be **lower** than actual concentration of NaOH in **FA 1** since it reacts with carbon dioxide in the atmosphere.

Note: The calculated concentration of NaOH will be lower while the calculated concentration of Na_2CO_3 will be higher.

[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	30.0	20.0	10.0	25.0	15.0
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	+4.6	+9.0	+11.0	+5.6	+11.4	+8.6

[3]

Total volume of FA 3 and FA 4 should add up to 50 cm^3 for all experiments.
All temperature should be written to 1 dp.
ΔT = final temperature – initial temperature so the correct sign for ΔT should be +ve (for exothermic reaction).
Students should be mindful of the correct calculation ΔT.

(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.

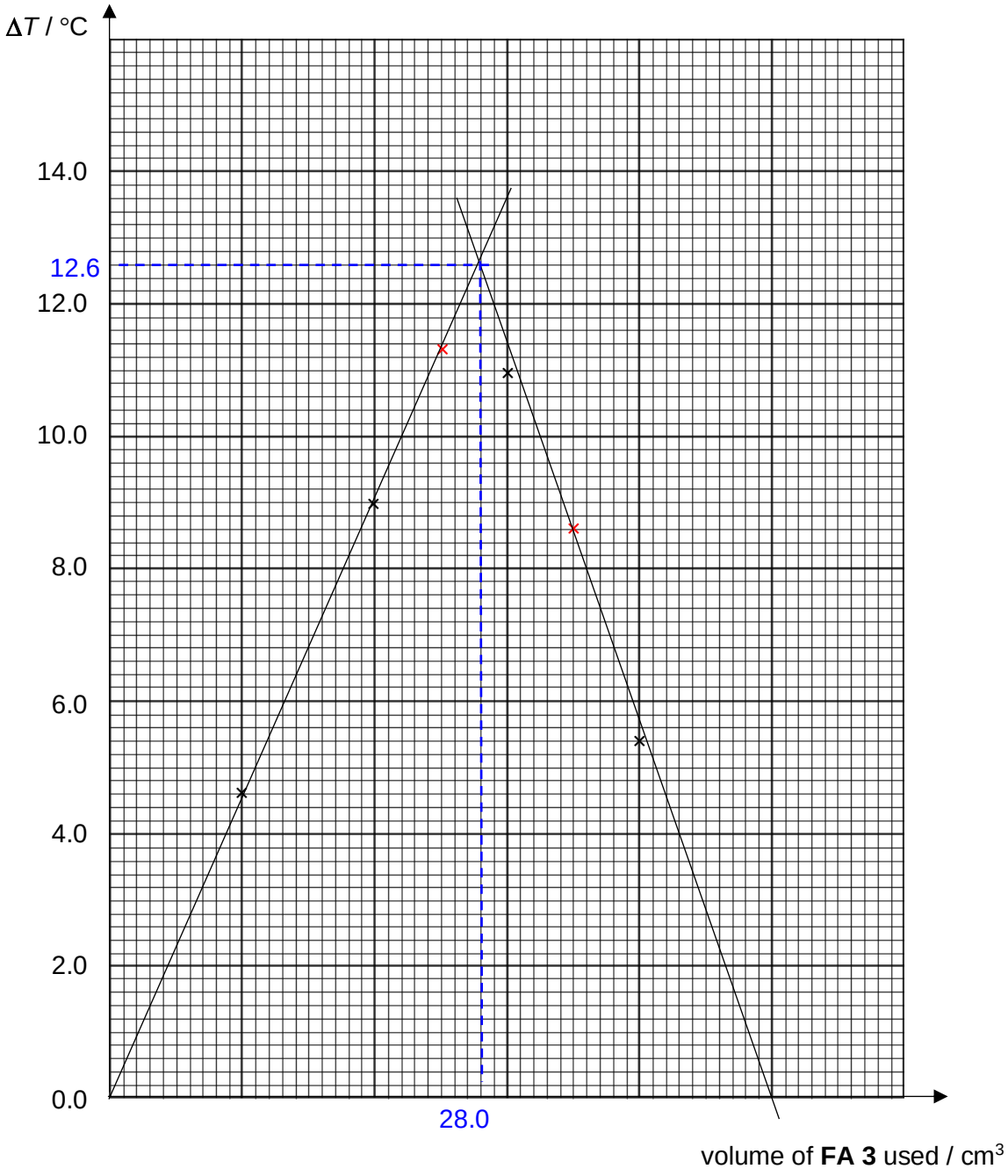


Fig. 2.1

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]

There should be appropriate scale and axes labelled with units.
The choice of values for experiment 5 and 6 should be in a such a way that there is a minimum of 3 points to draw each line.
Students should NOT choose V_{FA3} as 0cm^3 or 50 cm^3.
The line should pass through origin and at V_{FA3} = 50 cm^3.

(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]

2 suitable best-fit lines with extrapolation until they cross.
Extrapolated ΔT must be higher tan the Experimental ΔT.

(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,** $V_{\mathbf{FA\ 3}}$**,** used to obtained it.

ΔT_{max} = ……12.6……°C

$V_{\mathbf{FA\ 3}}$ = ……28.0……cm^3 [1]

Read off ΔT_{max} to 1 dp and V_{FA3} to 1 dp from the graph correctly.
Students should show dotted lines on the graph to show how they determine the intersection point values.

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

volume of acid reacted = 50.0 – 28.0 = 22.0 cm^3
Amount of acid reacted = 22.0/1000 x 2.00 = 0.044 mol

Amount of NaOH reacted = 28.0/1000 x 1.60 = 0.0448 mol

Since the amount of acid reacted is approximately equal to the amount of NaOH, the ratio of acid : NaOH = 1 : 1
Therefore, **FA 4** is hydrochloric acid, HC*l*

Students CANNOT use volume ratio to conclude the identity of the acid.
Volume ratio ≠ Mole ratio in this case unless they are both gases.
Students can only deduce the identity by calculating the amount of the acid and NaOH reacted.

FA 4 = ……..[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}.

heat released = 50 x 4.18 x 12.6 = 2633 J
Amount of water produced = amount of HCl reacted = 0.044 mol

Students can either use amount of NaOH or amount of HCl or average of the two to calculate amount of water produced.

ΔH_{neut} = –2633.4/0.044 = –59850 J mol^{-1}
= –59.9kJmol^{-1}

If question ask for heat change, q should be +ve for exothermic reaction.
ΔH must give the sign -ve for exothermic reaction & +ve for endothermic reaction.
Students should give correct sf, dp, units and attempt ALL questions.

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]

Heat evolved = $mc\Delta T_{max} = n \times \Delta H_n \Rightarrow \Delta T_{max} = \frac{n \times \Delta H_n}{m \times c}$

When volume of FA 3 and FA 4 are doubled, both n/amount of water produced and m/mass of solution/volume are doubled (ΔH_n and c remain constant). Hence ΔT_{max} is unaffected.

Alternative Answers
Heat change is doubled and mass/volume is doubled, hence ΔT_{max} is unaffected.
OR
Heat change doubled and n/amount of water doubled

Many students incorrectly relate ratio/concentration of acid/base is constant and thus ΔT_{max} is unaffected.
It is insufficient to say that heat change increased when volumes of FA 3 and FA 4 are doubled.

(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]

ΔH_{neut} would be less exothermic/smaller/lower for a weak acid. Energy is absorbed to ionise/dissociate the weak acid completely.

Most students did not explain why ΔH_{neut} would be less exothermic for weak acid.

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

……[1]

Heat is lost to the surrounding, hence a cup with lid can be used to minimise heat exchange with the surrounding air. (insufficient to say use a better insulated cup)
OR
Heat capacity of the styrofoam cup is not accounted for, hence the heat absorbed by the styrofoam cup can be included in the calculation of heat change.

Examples of NOT accepted answers (as they are NOT significant source of error)

Not accepted: use the cooling curve method as cooling curve method will not give equivalence volume (put this comment for your script if they suggest this method)

Not accepted: use more styrofoam cups

Not accepted: 0.2°C thermometer is not precise enough, use digital thermometer

Not accepted: Initial temperature of FA4 not accounted for, should calculate the weighted initial temperature.

[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 √ Grey ppt/grey solid/Black ppt/ 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]

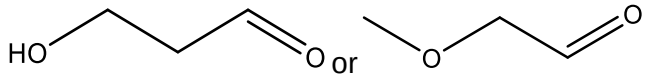
Do align your observations to the test. If there is no reaction, you should try to write the "negative observation", e.g. for test 1, since you are expecting effervescence, you should state "no effervescence.

For test 2, you should record all the observations and since ppt is soluble, you should state the final colour of the solution.

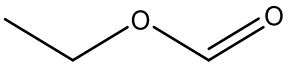
For test 3, you are already told that you should add iodine until a permanent orange red colour is present, hence no marks are awarded for stating the solution of the colour is orange/red.

A common error in test 3 is stating the solution decolourises. Since no further amt of NaOH is added, the colour of the iodine should remain since the decolourisation of iodine is caused by addition of NaOH.

(b) Deduce the structure of the organic compound in **FA 5** using your observations.



(1m) reject



As ethanol from hydrolysis +ve test in (3)

FA5 gave a silver mirror with Tollens' reagent, hence an aldehyde group which undergoes oxidation is present OR aldehyde which reduces Tollens reagent is present. However, since it gives no ppt with aqueous alkaline iodine there is no $-C(OH)HCH_3$ group, hence it is a primary alcohol. [2]

For (b), you should state the functional group and the observations from relevant test. In this case, test 2 and 3 are the most crucial in determining the structure as silver mirror indicates and aldehyde and since there is only one O left, it is likely and alcohol and the placement of the alcohol group is determined by test 3.

For test 2, you should not state that C=O is present as it is not specific enough, since C=O is also present in ketones, carboxylic acids, ester and amides.

[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.		
		$Ag^+ + e^-$	⇌	Ag
		$Cu^{2+} + 2e^-$	⇌	Cu
		$Fe^{2+} + 2e^-$	⇌	Fe
		$Mg^{2+} + 2e^-$	⇌	Mg
		$Zn^{2+} + 2e^-$	⇌	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 $\mathbf{Ag^+}$ 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 $\mathbf{Zn^{2+}}$ 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 √	Mg reduces Zn^{2+} to Zn Mg > Zn √
3		Transfer 5 cm^3 of $\mathbf{Zn^{2+}}$ 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 √	Fe cannot reduce Zn^{2+} to Zn Zn > Fe √

	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. √	Fe reduces Cu^{2+} to Cu Fe > Cu √
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. √	Zn reduces Cu^{2+} to Cu Zn > Cu √

[6]

Do remember to align your observations to the test.

A common mistake here is not stating the colour of the residue and filtrate in test 2 and 3. Note that whenever the mixture is filtered, you are required to state the colour of the residue and filtrate.

For test 3, since the white ppt was soluble, you are required to state the final colour of the solution.

For test 4 and 5, do note that you should NOT state “ppt” is reddish brown. A ppt is a solid that appears when 2 aq solutions are mixed.

Since the solid was already present to begin with, you should state it as a “solid” and NOT a “ppt”

Note that for deductions, you MUST follow the format in Qn1 since it was clearly stated.

A common mistake was to state the cation as the reducing agent, e.g. for test 5, stating that Zn > Cu^{2+}. Note that the reducing agent is the metal, not the cation. The chemistry behing all these test is a stronger reducing agent, i.e. the metal can reduce the cation of the metal that is a weaker reducing agent.

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

……

……

……

……[1]

As Fe did not reduce Zn^{2+}, the Zn^{2+} remained in solution. When NaOH was added to the filtrate, Zn^{2+} reacted to form a white ppt $Zn(OH)_2$ which dissolved in excess NaOH to form $[Zn(OH)_4]^{2-}$ which is the colourless solution.

OR

As Fe did not reduce Zn^{2+}, Fe^{2+} was not formed. When NaOH was added to the filtrate, a green ppt of $Fe(OH)_2$ was not observed.

For evidence, you are required to identify:
1. Gases
2. Ppt
3. The solution, in this case, the complex.

(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]

Mg > Zn > Fe > Cu > Ag OR in any form that clearly shows the correct trend.

[Total: 8]

Once again, note that the reducing agents are the metals, not the cations.

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]

……[3]

Mass of ethanedioic acid to be used = $\frac{0.10}{1000} \times 250 \times 90$
= 2.25 g [1]

1. Using a mass balance, weigh out 2.25 g of ethanedioic acid in a weighing bottle
2. Transfer the ethanedioic acid to a beaker and add deionised water to dissolve.
3. Rinse the weighing bottle with deionised water and transfer the washings to the beaker.
4. After the solid has dissolved, transfer the ethanedioic acid solution from the beaker into a 250 cm^3 volumetric flask.
5. Rinse the beaker with deionised water and transfer the washings into the volumetric flask.
6. Add deionised water to the mark. Stopper and shake to obtain a homogenous solution of 1.00 mol dm^{-3} ethanedioic acid.

Do note that it is crucial that you should rinse the weighing bottle with deionsed water and transfer the washings into the beaker

Also, you should dissolve the solid in a beaker first rather than transfer the solid directly from the weighing bottle into the volumetric flask.

Code	Marking points	Mark
W	Weighing with mass balance/electronic balance/weighing balance weighing bottle/beaker/container	1
D	250cm^3 volumetric flask Top up to mark with water Stopper and shake Do not accept if students dilute in beaker or conical flask	1

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 °C, 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]

In the experiment, the time taken is for the potassium manganate(VII) to decolourise. If potassium manganate(VII) was in excess, then the purple solution will not decolourise. (words to the effect)

A common mistake was to prove that $KMnO_4$ is the limiting reagent by calculations. The question askes "WHY" $KMnO_4$ is the limiting reagent, not "Show that $KMnO_4$ is the limiting reagent.

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

The time is taken for a fixed/constant amount/volume of purple $KMnO_4$ to turn colourless.

A common mistake was to state that when time increases, rate decreases. Note that for this relationship to be true, you need to be monitoring the time for a fixed amt of product formed or reactant disappearing.
E.g. if it takes 1 min for 1cm^3 of $KMnO_4$ to disappear and 2min for 2cm^3 of $KMnO_4$ to disappear, we cannot say that since the reaction took 2min which is a loger time, it is slower. Because in this case, the rate is the same!

(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]

[Total 10]

1. Using a 50 cm^3 measuring cylinder, transfer 50 cm^3 of ethanedioic acid solution and 50 cm^3 of aqueous sulfuric acid into a 250 cm^3 conical flask.
2. Using a 10 cm^3 measuring cylinder, measure out 10 cm^3 of potassium manganate(VII).
3. Place the conical flask and the measuring cylinder in a water bath. Using a thermometer, ensure that temperature of both solutions are at 25°C.
4. Pour the potassium manganate(VII) into the conical flask. Swirl the mixture and start the stopwatch.
5. Stop the stopwatch and record the time when the mixture decolourises. (or purple/pink colour disappear). Measure the final temperature.
6. Repeat the experiment from step 1 to 5 with the temperatures in the following table.
7. Plot a graph of ln(1/*t*) against $1/T_{avg}$ used where T_{avg} is average of step 3 and 5.
8. The gradient is $-\frac{Ea}{R}$. E_a can be found by multiplying the gradient by R.

+ Table below

Mark scheme:

Code	Marking points	Mark
M	<u>Measurements</u> Measuring cylinders with capcacity (if burette was used, need to transfer 3rd reagent added to a beaker first and poured into conical flask. Measurements of all 3 reagents Use of conical flask/beaker (no capacity required) DNA styrofoam cup	1
S	<u>Swirling and stopwatch</u> Start stopwatch when mixed (last reagent added must be either $KMnO_4$ or $H_2C_2O_4$) Stop stopwatch when mixture decolourises.	1
V	<u>Choice of volumes</u> Volume of ethanedioic acid chosen must ensure that $KMnO_4$ is limiting and must be equal to sulfuric acid i.e. V of ethanedioic acid > 6.25 cm^3, i.e. 7cm^3 $KMnO_4$ must be 10cm^3 H_2SO_4 and $H_2C_2O_4$ must be equal and > 6.25 cm^3 (if students add water to every expt to same volume, ignore as it does not affect the expt)	1
T	<u>Temperature</u> Use of a water bath and thermometer to check temperature.	1
R	<u>Results and repeat 5 times</u> Data required: (in procedure or table form) t/s, (ln1/t), T/degC, 1/T in K^{-1}) At least 5 experiments conducted Choice of temperatures must be reasonably spaced (at least 5°C apart)	1

			(accept any temp range between 1°C tp 99°C)	

Do note that the $KMnO_4$ and $H_2C_2O_4$ MUST be kept separate first as they will still react even without H_2SO_4. The H_2SO_4 can be mixed with either $KMnO_4$ or $H_2C_2O_4$. Hence the two possible combinations are to have $KMnO_4$ and H_2SO_4 in the conical flask then add in $H_2C_2O_4$ OR to have $H_2C_2O_4$ and H_2SO_4 in the conical flask then add in the $KMnO_4$.

A common mistake was to omit the water bath to incubate the reaction mixtures before mixing.
It is also a requirement to use a thermometer to check the temperature IN the reaction mixture even if a thermostatically controlled water bath is used.
The contents should only be mixed to start the reaction when both mixtures have achieved the desired temperature.

Another common mistake was to omit the necessary data to be put in the table.
All primary data collected MUST be included in the table, in this case, the t/s and the temperatures/°C.

Calculated data that are used to plot the graph, in this case, 1/T in K^{-1} and ln(1/t) must also be included in the table.

Do note that all units must be included.

Another mistake was to place the conical flask on a "X" and to stop the stopwatch when the "X" become visible. This is incorrect because "X" will still be visible when solution is pink. You should only stop the stopwatch when the mixture just decolourises.

expt	vol of $KMnO_4$/ cm^3	vol of H_2SO_4 /cm^3	vol of $H_2C_2O_4$ /cm^3	T_{avg} /°C	T/ K	t /s	$1/t$ /s^{-1}	ln(1/*t*)	1/T /K^{-1}
1	10	50	50	25	298	54			
2	10	50	50	35					
3	10	50	50	45					
4	10	50	50	55					
5	10	50	50	65					

*Since the experiment is already taking 54s for 25°C, it is NOT advisable to do experiments with temperatures less than 25°C. (BUT do not penalise)

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