1 Strong acids, such as hydrochloric acid, HCl, are completely ionised in aqueous solution. Weak acids, such as ethanoic acid, CH_3COOH, are partially ionised in aqueous solution.

You will investigate the enthalpy change for the reaction of an excess of each of these acids with magnesium and hence determine the energy needed to cause the weak acid to ionise completely.

(a) Reaction 1 Enthalpy change of a weak acid

FB 1 is ethanoic acid, CH_3COOH.
FB 2 is magnesium, Mg.

Method 1

- Weigh the strip of magnesium and record the balance reading in the space below.
- Support the plastic cup in the 250 cm^3 beaker.
- Coil the magnesium ribbon loosely so that it fits into the bottom of the plastic cup and then remove the ribbon.
- Use the measuring cylinder to transfer 25 cm^3 of the acid, **FB 1**, into the plastic cup.
- Place the thermometer in the acid and read the initial temperature. This is the temperature at time zero (t = 0).
- Start timing and do not stop the clock until the whole experiment has been completed.
- Read the temperature of the acid every half minute for two minutes.
- At time $t = 2\frac{1}{2}$ minutes drop the magnesium, **FB 2**, into the acid and stir the mixture.
- Measure and record, in the table below, the temperature of the mixture at t = 3 minutes and then every half minute until t = 10 minutes. Stir the mixture continuously between thermometer readings.
- Rinse the plastic cup for use in **Method 2**. Shake to remove excess water.

Results

Mass of magnesium	0.16 g

Temperature

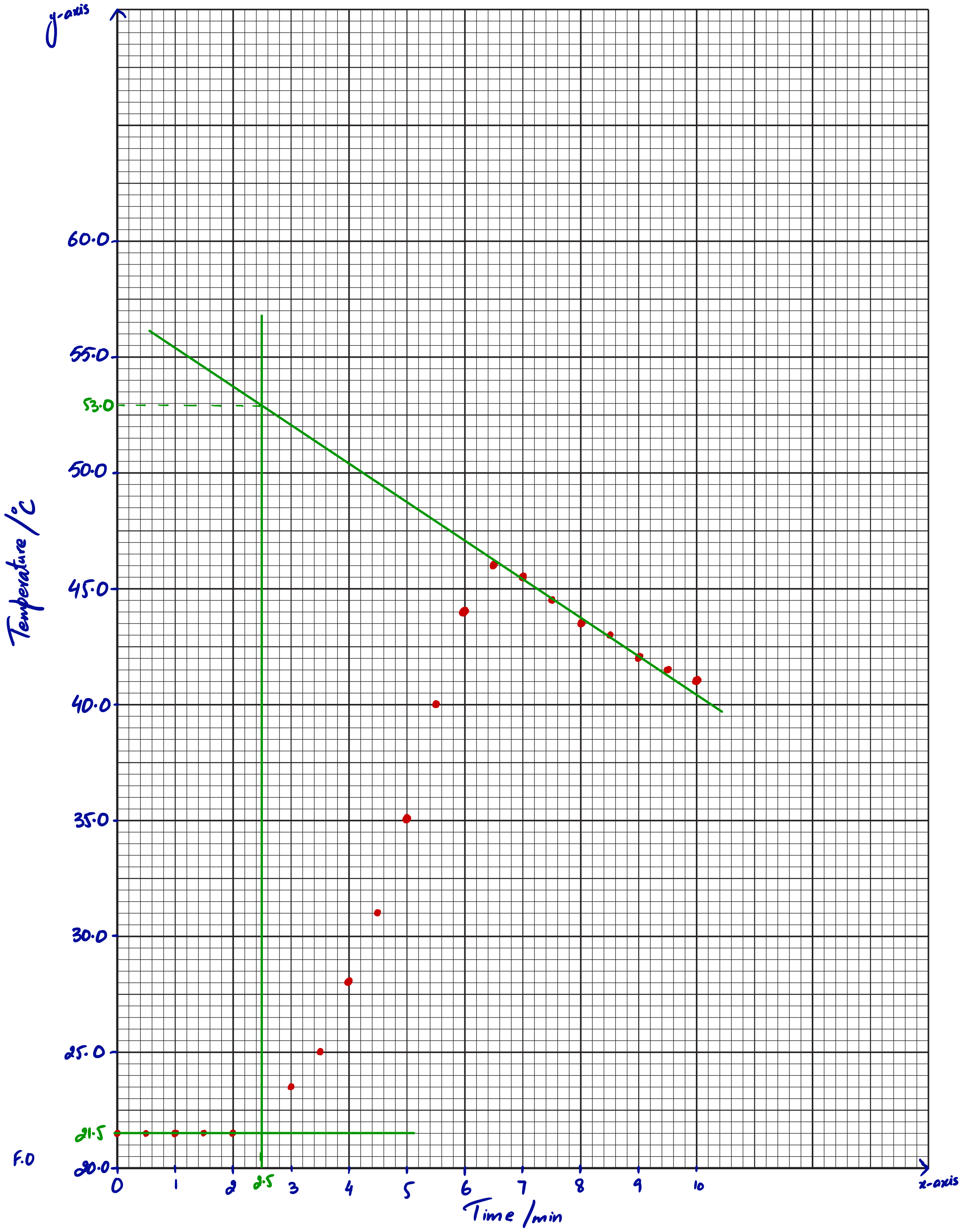
time / minutes	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5
temperature / °C	21.5	21.5	21.5	21.5	21.5		23.5	25.0	28.0	31.0	35.0

time / minutes	$5\frac{1}{2}$	6	$6\frac{1}{2}$	7	$7\frac{1}{2}$	8	$8\frac{1}{2}$	9	$9\frac{1}{2}$	10
temperature / °C	40.0	44.0	46.0	45.5	44.5	43.5	43.0	42.0	41.5	41.0

[4]

I	
II	
III	
IV	

(b) Plot a graph of temperature on the *y*-axis against time on the *x*-axis on the grid below.
The scale for temperature should extend 10 °C above your highest recorded temperature.
You will use this graph to determine the theoretical maximum temperature rise at $2\frac{1}{2}$ minutes.



I	
II	
III	
IV	
V	

Draw two lines of best fit through the points on your graph. The first line should be for the temperature before adding **FB 2** and the second for the cooling of the mixture once the reaction is complete.

Extrapolate the two lines to $2\frac{1}{2}$ minutes, draw a vertical line between the two and determine the theoretical rise in temperature at this time.

theoretical rise in temperature at $2\frac{1}{2}$ minutes = ...31.5........... °C [5]

(c) Calculations

Show your working and appropriate significant figures in the final answer to **each** step of your calculations.

Magnesium reacts with ethanoic acid according to the equation shown.

$$Mg(s) + 2CH_3COOH(aq) \rightarrow Mg(CH_3COO)_2(aq) + H_2(g)$$

(i) Use your answer to **(b)** to calculate the heat energy, in joules, given out when **FB 2** is added to the acid.
[Assume 4.2 J of heat energy raises the temperature of 1.0 cm^3 of the mixture by 1.0 °C.]

$Q = mc\Delta T$
$= 25.0 \times 4.2 \times 31.5$
3308 J

heat energy evolved = 3308 J

(ii) Use the Periodic Table and your answer to **(i)** to calculate the enthalpy change, in kJ mol^{-1}, when 1 mole of **FB 2**, Mg, reacts with ethanoic acid.

$\frac{0.16}{24.3} = 6.58 \times 10^{-3}$ mol

6.58×10^{-3} mol — 3308 J
1 mol — x

$= \frac{502736 \text{ J}}{1000}$

$= 502.7$ kJ mol^{-1}

enthalpy change, ΔH = – (sign) 503 (value) kJ mol^{-1}

[3]

(d) Reaction 2 Enthalpy change of a strong acid.

FB 3 is hydrochloric acid, HC*l*.
The tube labelled **FB 4** contains two strips of magnesium, Mg. One strip is longer than the other strip.

Method 2

Read the whole method before starting any practical work and prepare a table for your results in the space below.

- Weigh the longer strip of magnesium and record the balance reading.
- Support the plastic cup in the 250 cm^3 beaker.
- Coil the magnesium ribbon loosely so that it fits into the bottom of the plastic cup and then remove the ribbon.
- Use the measuring cylinder to transfer 25 cm^3 of the acid, **FB 3**, into the plastic cup.
- Place the thermometer in the acid and measure and record the initial temperature of the acid.
- Add the piece of magnesium into the acid in the cup.
- Stir constantly until the maximum temperature is reached.
- Measure and record the maximum temperature.
- Rinse the plastic cup for use in the next experiment.
- Calculate and record the temperature rise.

- Repeat this experiment using the shorter strip of magnesium and record all results.

mass of magnesium / g	0.22	0.09
initial temperature of acid / °C	24.0	24.0
maximum temperature reached / °C	54.5	38.5
temperature rise / °C	30.5	14.5

[3]

(e) Calculations

Show your working and appropriate significant figures in the final answer to **each** step of your calculations.

Use your results from **(d)** for the **longer strip** of magnesium and the Periodic Table to calculate the enthalpy change, in kJ mol^{-1}, when 1 mole of **FB 4**, Mg, reacts with hydrochloric acid.
[Assume 4.2 J of heat energy changes the temperature of 1.0 cm^3 of the mixture by 1.0 °C.]

Q = mCΔT
= 25 × 4.2 × 30.5
= 3203 J

0.22 g Mg — 3203 J
24.3 g — x

353786 J/mol / 1000
= 354 kJ mol^{-1}

enthalpy change, ΔH = – (sign) 354 (value) kJ mol^{-1}

[2]

(f) (i) A student suggested that the experiment carried out in **(d)** could be improved by using a catalyst.

Would the use of a catalyst improve the accuracy of the results in this experiment? Give a reason for your answer.

Yes because the reaction would be faster so less heat loss.
OR
No because a catalyst does not alter ΔH / ΔT.

(ii) Another student could not find the hydrochloric acid, **FB 3**, so used sulfuric acid, H_2SO_4, instead. He used the same volume and the same concentration as the hydrochloric acid in **FB 3**.

What effect would this change have on the temperature rise in the experiment? Give a reason for your answer.

No effect because the acid is in excess and magnesium is the limiting reagent.

[2]

(g) Ethanoic acid is a weak acid. It is partially ionised in aqueous solution.

$$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$$

You are to determine the energy needed to cause the molecules of ethanoic acid to ionise completely.

$$CH_3COOH(aq) \rightarrow CH_3COO^-(aq) + H^+(aq)$$

Hydrochloric acid is a strong acid; it is fully ionised in aqueous solution.

The values for the enthalpy changes you obtained in **(c)(ii)** and **(e)** could be used to calculate the energy change for the ionisation **but** more accurate experiments give the results in Table 1.

Table 1

reaction	equation	ΔH / kJ mol^{-1}
1	$Mg(s) + 2CH_3COOH(aq) \rightarrow Mg(CH_3COO)_2(aq) + H_2(g)$	−460.3
2	$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$	−464.1

(i) Write the **ionic** equation, including state symbols, for the reaction of magnesium with aqueous hydrochloric acid.

$Mg_{(s)} + 2H^+_{(aq)} \longrightarrow Mg^{2+}_{(aq)} + H_{2(g)}$

(ii) Use the data in **Table 1** to calculate the enthalpy change for the ionisation of ethanoic acid.

$$CH_3COOH(aq) \rightarrow CH_3COO^-(aq) + H^+(aq)$$

Show clearly how you obtained your answer.

$Mg + 2CH_3COOH \longrightarrow Mg^{2+} + 2CH_3COO^- + 2Cl^- + H_2$

$Mg + 2H^+ + 2Cl^-$

$Mg + 2CH_3COOH \longrightarrow Mg^{2+} + 2CH_3COO^- + H_2$

$\Delta H_i = \frac{x}{2}$ because of 2 moles

−464.1

$Mg + 2H^+$

$\Delta H_i - 464.1 = -460.3$

$\Delta H_i = -460.3 + 464.1$

$\Delta H_i = 3.8$ for 2 moles

$\Delta H_i = 1.9$ for one mole

ΔH = + (sign) 1.9 (value) kJ mol^{-1}

[4]

(h) The experiment in **(a)** was repeated using trichloroethanoic acid instead of ethanoic acid.

$$Mg(s) + 2CCl_3COOH(aq) \rightarrow Mg(CCl_3COO)_2(aq) + H_2(g)$$ **reaction 3**

Trichloroethanoic acid, CCl_3COOH, is a weak acid that is however stronger than ethanoic acid.

The enthalpy change for reaction 3 is between the two values given in Table 1.

Table 1

reaction	equation	ΔH / kJ mol^{-1}
1	$Mg(s) + 2CH_3COOH(aq) \rightarrow Mg(CH_3COO)_2(aq) + H_2(g)$	−460.3
2	$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$	−464.1

(i) Explain why the enthalpy change for reaction 3 is more exothermic than the enthalpy change for reaction 1.

Increased electronegativity of Cl increases strength of trichloroethanoic acid, makes it easier to release H^+ compared to ethanoic acid.

(ii) Explain why the enthalpy change for reaction 3 is less exothermic than the enthalpy change for reaction 2.

A stronger acid i.e. HCl provides a greater concentration of H^+.

[2]

[Total: 25]

2 Qualitative Analysis

At each stage of any test you are to record details of the following.

- colour changes seen
- the formation of any precipitate
- the solubility of such precipitates in an excess of the reagent added

Where reagents are selected for use in a test, the **name** or **correct formula** of the element or compound must be given.

Where gases are released they should be identified by a test, **described in the appropriate place in your observations**.

You should indicate clearly at what stage in a test a change occurs.
No additional tests for ions present should be attempted.

If any solution is warmed, a boiling tube MUST be used.
Rinse and reuse test-tubes and boiling tubes where possible.

(a) (i) **FB 5**, **FB 6** and **FB 7** each contain one anion and one cation.

Carry out the following tests and record your observations.

test	*observations*		
	FB 5	**FB 6**	**FB 7**
To a 1 cm depth of solution in a test-tube, add a few drops of aqueous silver nitrate, then	White ppt	No change	no change
add aqueous ammonia.	ppt soluble	no change	no change
To a 1 cm depth of solution in a test-tube, add a few drops of aqueous barium nitrate, or barium chloride, then	no change	white ppt	no change
add dilute nitric acid.	no change	ppt insoluble	no change
To a 1 cm depth of solution in a test-tube, add a spatula measure of solid sodium carbonate.	effervescence of a colourless gas which formed white ppt with lime water.	effervescence of a colourless gas which formed white ppt with limewater	effervescence of a colourless gas which formed white ppt with limewater

(ii) What cation is present in **FB 5**, **FB 6** and **FB 7**?

H^+ / hydrogen ion

(iii) Suggest another test that you could carry out to confirm the presence of the cation you identified in **(ii)**.

Carry out this test on one of **FB 5**, **FB 6** or **FB 7** and record your observation.

test add Magnesium metal

observation bubbles of a gas which gives pop sound with lighted splint.

(iv) Complete the table to identify, as far as possible, the anions present in **FB 5**, **FB 6** and **FB 7**. If you are not able to identify the anion from the tests you carried out in **(i)**, write 'unknown'.

	FB 5	**FB 6**	**FB 7**
ion present	Cl^-	SO_4^{2-}	unknown

(v) For any **one** anion that you were unable to identify in **(iv)** you are to devise a test or tests that will enable you to identify it. You can assume that it is one of the anions listed in the Qualitative Analysis Notes.

Carry out the test(s), record the observation(s) you obtained and identify the unknown anion.

test(s) add dilute HCl

observation(s) No brown gas produced

Anion present in FB7 is NO_3^- .

[10]

(b) **FB 8** is an aqueous solution of a mixture containing two anions and two cations.

Carry out the following tests and record your observations.

test	*observations*
To a 1 cm depth of **FB 8** in a test-tube, add a 1 cm depth of dilute hydrochloric acid, then	Bubbles of a colourless gas which formed white ppt with limewater
add a few drops of hydrogen peroxide, then	solution turned yellow-brown
add a few drops of starch.	mixture turned blue-black / dark blue
To a 1 cm depth of **FB 8** in a test-tube, add aqueous sodium hydroxide.	no change
To a 1 cm depth of **FB 8** in a test-tube, add a 3 cm depth of aqueous copper(II) sulfate, then	pale-brown ppt
add a 1 cm depth of dilute hydrochloric acid, then	mixture turned brown
add aqueous sodium thiosulfate.	mixture turned off-white

From these observations, identify two ions present in **FB 8**.

ions present in **FB 8** ......I^-...... and ......CO_3^{2-}......

[5]

[Total: 15]