TAMPINES MERIDIAN JUNIOR COLLEGE

2019 JC2 H2 Chemistry Prelim Exam Paper 4

(Suggested Answers)

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1 Determination of the concentration of a base and the enthalpy change of the neutralisation reaction

FA 1 is 2.0 mol dm^{-3} sulfuric acid, H_2SO_4.
FA 2 is aqueous sodium hydroxide, NaOH.

The reaction of sulfuric acid and sodium hydroxide is exothermic.
In separate experiments, you will add increasing volumes of **FA 2** to a fixed volume of **FA 1**. In each experiment you will measure the maximum temperature rise, ΔT. As the volume of **FA 2** is increased, this maximum temperature rise, ΔT, will increase and then decrease.

By measuring the maximum temperature rise for different mixtures of the two reagents, you are to determine the following:

- the concentration of sodium hydroxide, NaOH, in **FA 2**
- the enthalpy change when 1 mol of H_2SO_4 is neutralised by NaOH

(a) Method

- Fill the labelled burette with **FA 1**.
- Support a styrofoam cup in the 250 cm^3 beaker.
- Run 10.00 cm^3 of **FA 1** from the burette into the styrofoam cup.
- Measure 20.0 cm^3 of **FA 2** using a measuring cylinder.
- Place the thermometer in the **FA 2** in the measuring cylinder and record the steady temperature of the solution.
- Pour the **FA 2** into the styrofoam cup, stir and record the maximum temperature obtained in the reaction.
- Empty and rinse the styrofoam cup; shake dry the styrofoam cup. Rinse the thermometer.
- Carry out the experiment three more times. Each time use 10.00 cm^3 of **FA 1**.
- Use 30.0 cm^3, 40.0 cm^3 and 50.0 cm^3 of **FA 2** in these different experiments.

Carry out **two further experiments**.
Choose volumes of **FA 2** which will allow you to investigate more precisely the volume of **FA 2** that produces the highest temperature rise when added to 10.00 cm^3 of **FA 1**.

Results

Record your results below in an appropriate form showing, for each experiment, the volumes of solutions used, temperature measurements and the temperature rise, ΔT.

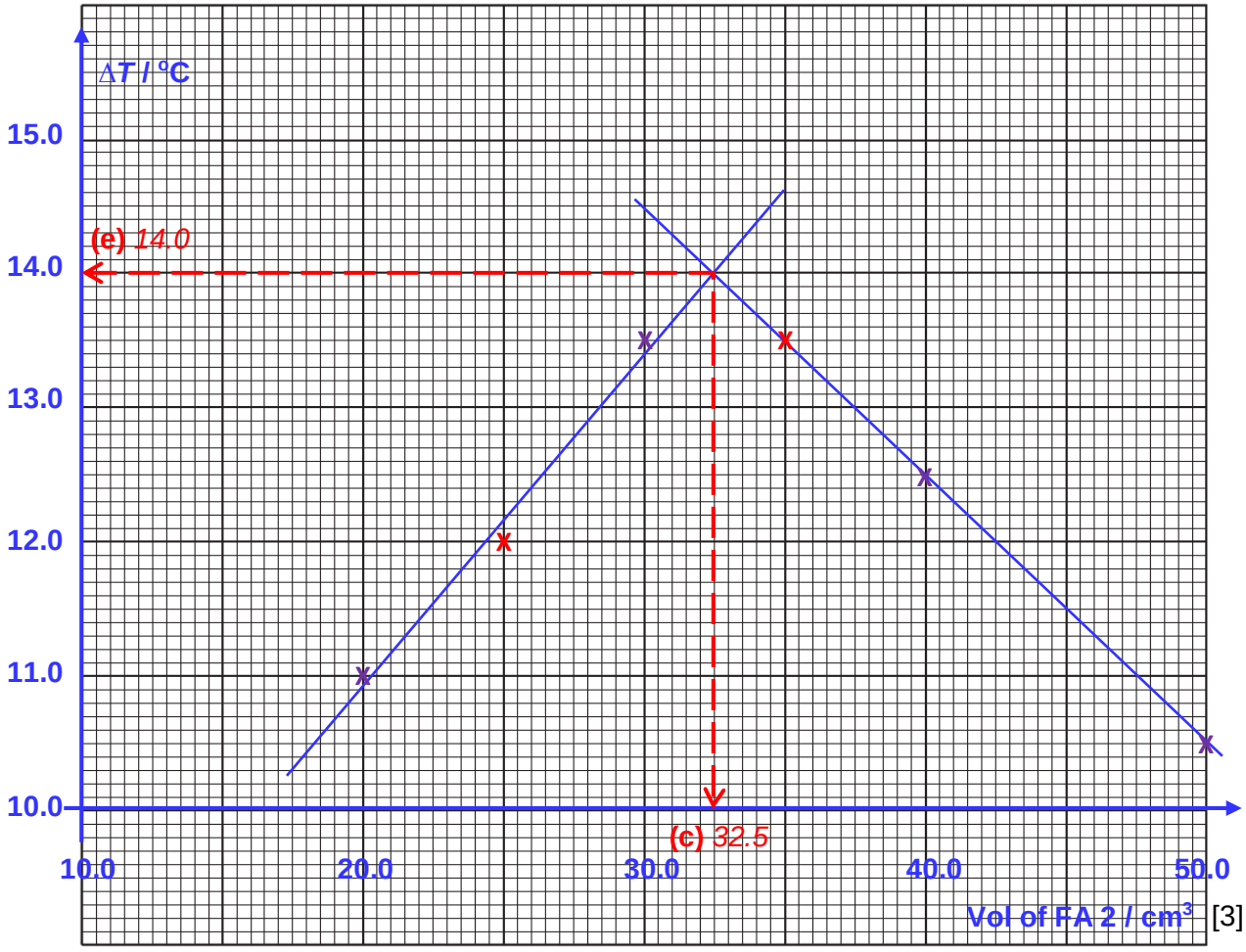
Expt	Volume of FA 1 / cm^3	Volume of FA 2 / cm^3	T_i / °C	T_f / °C	ΔT / °C
1	10.00	20.0	31.5	42.5	11.0
2	10.00	30.0	31.5	45.0	13.5
3	10.00	40.0	31.5	44.0	12.5
4	10.00	50.0	31.5	42.0	10.5
5	10.00	25.0	31.5	43.5	12.0
6	10.00	35.0	31.5	45.0	13.5

[4]

(b) Plot a graph of temperature rise, ΔT, on the y-axis against the volume of **FA 2** added on the x-axis.

Draw a line of best fit through the points where the temperature rise is increasing and another line through the points where the temperature rise is decreasing.

The intersection of these lines represents the temperature rise for the volume of **FA 2** that exactly neutralises the sulfuric acid present in 10.00 cm^3 of **FA 1**.



[3]

(c) Read from the graph the volume of **FA 2** that gives the maximum temperature rise.

Volume of **FA 2** giving the maximum temperature rise = ... **32.5** ..... cm^3 [1]

(d) **(i)** Calculate the amount of NaOH required to neutralise the amount of H_2SO_4 at the maximum temperature rise.

Amount of $H_2SO_4 = 2.0 \times 0.010$
$= 0.0200$ mol

$H_2SO_4 \equiv 2$ NaOH

Amount of $NaOH = 2 \times 0.020$
$=$ **0.0400** mol

Amount of NaOH required = ... **0.0400** ..... mol
[1]

(ii) Hence, calculate the concentration of NaOH in **FA 2**.

Concentration of NaOH in **FA 2** $= 0.0400 \div \frac{32.5}{1000}$
$=$ **1.23** $mol\ dm^{-3}$

Concentration of NaOH in **FA 2** = ... **1.23** ..... $mol\ dm^{-3}$
[1]

(e) Read the maximum temperature rise from the graph and use this to calculate the enthalpy change when 1 mol of H_2SO_4 is neutralised by NaOH. Give your answer in $kJ\ mol^{-1}$.

[4.18 J are absorbed or released when the temperature of 1 cm^3 of solution changes by 1 °C.]

Quantity of heat absorbed by solution $= (32.5 + 10.0) \times 4.18 \times 14.0$
$=$ **2487 J** *OR* **2.487 kJ**

Enthalpy change $= -\frac{2.487}{0.0200}$
$=$ **–124 kJ mol^{-1}**

Enthalpy change = ... **–124** ..... $kJ\ mol^{-1}$
[2]

(f) The enthalpy change of neutralisation, ΔH_{neut}, between a strong acid and a strong base is $-57\ kJ\ mol^{-1}$.

Explain why the enthalpy change calculated in **(e)** is significantly more exothermic than ΔH_{neut}.

Enthalpy change in **(e)** is based on **1 mol of H_2SO_4** (or **2 mol of water** formed) while the enthalpy change of neutralisation, ΔH_{neut} ($-57\ kJ\ mol^{-1}$), is based on **1 mol of water** formed.
[1]

(g) A student suggested that the experiments carried out in **(a)** would be more accurate if volumes of 20.00 cm^3 of 1.0 mol dm^{-3} H_2SO_4 were used instead.

State and explain whether you agree or disagree with the student's suggestion.

Accept any of the following:
• Agree –
Lower (percentage) error as: acid spray is reduced (since reaction will be slower) *OR* smaller temperature rise so less heat loss *OR* larger volume used *(accept other reasons)*
• Disagree –
Higher (percentage) error as: smaller temperature change, so higher (percentage) error of reading *OR* reaction slower so more heat loss *(accept other reasons)*

[1]

[Total: 14]

2 Determination of the percentage by mass of sodium carbonate in a mixture of sodium hydroxide and sodium carbonate

Sodium carbonate is neutralised by hydrochloric acid in two steps:

$Na_2CO_3 + HCl \rightarrow NaCl + NaHCO_3$
$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$

This step-wise neutralisation can be observed when the acid is added slowly to the sodium carbonate.

The percentage by mass of sodium carbonate in a mixture of sodium hydroxide and sodium carbonate can be determined by carrying out titrations using two different indicators. Since both sodium hydroxide and sodium carbonate react with acids, through careful selection of the indicators used for the titration, the volume of acid required to react with only the sodium carbonate can be found.

FA 3 is 0.125 mol dm^{-3} hydrochloric acid, HCl.
FA 4 is an aqueous solution containing sodium hydroxide, NaOH, and sodium carbonate, Na_2CO_3.

You are also provided with bromophenol blue indicator.

In this question, you will carry out titrations to determine the percentage by mass of sodium carbonate in the mixture of sodium hydroxide and sodium carbonate in solution **FA 4**.

(a) (i) Titration of FA 4 against FA 3 using bromophenol blue

1. Fill a burette with **FA 3**.
2. Pipette 25.0 cm^3 of **FA 4** into a conical flask.
3. Add four to five drops of bromophenol blue indicator.
4. Titrate the mixture in the flask with **FA 3** until the blue-violet colour of the solution changes to yellow.
5. Record your titration results, to an appropriate level of precision, in the space provided.

Repeat steps 2 to 5 to obtain consistent results.

Titration results

	1	2	3
Final burette reading / cm^3	20.70	30.55	20.45
Initial burette reading / cm^3	0.00	10.00	0.00
Volume of **FA 3** / cm^3	20.70	20.55	20.45
		✓	✓

[6]

(ii) From your titration results, obtain a suitable volume of **FA 3**, $V_{FA\,3}$, to be used in your calculations. Show clearly how you obtained this volume.

Volume of **FA 3**, $V_{FA\,3} = \frac{20.55 + 20.45}{2}$

$= \underline{\mathbf{20.50\ cm^3}}$ **(2 d.p.)**

$V_{FA\,3}$ = **20.50 cm^3** [1]

(b) When the titrations in **(a)** were repeated using **phenolphthalein** as the indicator, 25.0 cm^3 of **FA 4** required 15.00 cm^3 of **FA 3**.

The following explains why different results are obtained using two different indicators.

- When phenolphthalein is used as the indicator, the following reactions have taken place at the end-point of the titration.

Reaction 1 $NaOH + HCl \rightarrow NaCl + H_2O$

Reaction 2 $Na_2CO_3 + HCl \rightarrow NaCl + NaHCO_3$

- When bromophenol blue is used as the indicator in **(a)**, the following reactions have taken place at the end-point of the titration.

Reaction 1 $NaOH + HCl \rightarrow NaCl + H_2O$

Reaction 2 $Na_2CO_3 + HCl \rightarrow NaCl + NaHCO_3$

Reaction 3 $NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$

For the titration using **bromophenol blue**, the amount of Na_2CO_3 reacted in *Reaction 2* is equal to the amount of sodium bicarbonate, $NaHCO_3$, reacted in *Reaction 3*. Both the amounts of Na_2CO_3 reacted in *Reaction 2* using **phenolphthalein or bromophenol blue** are the same.

Show your working and use appropriate significant figures in the final answers to all steps of your calculations.

(i) Calculate the amount of HCl in the volume of **FA 3**, $V_{FA\,3}$, determined in **(a)(ii)**.

Amount of HCl = ***0.125 × ($V_{FA\,3}$ in dm^3) mol***

$= 0.125 \times \frac{20.50}{1000}$ **mol** $= \underline{\mathbf{2.56 \times 10^{-3}\ mol}}$

Amount of HCl in $V_{FA\,3}$ = **2.56×10^{-3} mol**

(ii) Calculate the amount of HCl in 15.00 cm^3 of **FA 3**.

Amount of HCl = **0.125** $\times \frac{15.00}{1000} = \underline{\mathbf{1.88 \times 10^{-3}\ mol}}$

Amount of HCl in 15.00 cm^3 of **FA 3** = **1.88×10^{-3} mol**

[1]

(iii) With reference to the information given in **(b)** and your answers to **(b)(i)** and **(b)(ii)**, calculate the amount of HC*l* that reacted with Na_2CO_3 in *Reaction 2* using **phenolphthalein** indicator.

Amount of HC*l* reacted with Na_2CO_3 = ***ans (b)(i) – (1.88 × 10^{-3}) mol***
= 2.56×10^{-3} **–** 1.88×10^{-3} = **6.83×10^{-4} mol**

Amount of HC*l* reacted with Na_2CO_3 in *Reaction 2* using phenolphthalein = **6.83×10^{-4} mol** [1]

(iv) Use your answer to **(b)(iii)** to calculate the mass of Na_2CO_3 present in 25.0 cm^3 of **FA 4**.
[A_r : C, 12.0; O, 16.0; Na, 23.0]

Mass of Na_2CO_3 = ***ans (b)(iii) × 106.0 g***
= $6.83 \times 10^{-4} \times 106.0$ = **0.0723 g**

Mass of Na_2CO_3 in 25.0 cm^3 of **FA 4** = **0.0723 g** [1]

(v) The **overall** equation for the reaction of Na_2CO_3 with HC*l* when **bromophenol blue** is used as indicator is given below.

$$Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$$

Calculate the amount of HC*l* that reacted with Na_2CO_3 in the above equation in 25.0 cm^3 of **FA 4**.

Amount of HC*l* = ***ans (b)(iii) × 2 mol***
= $6.83 \times 10^{-4} \times 2$ = **1.37×10^{-3} mol**

Amount of HC*l* reacted with Na_2CO_3 using bromophenol blue = **1.37×10^{-3} mol** [1]

(vi) Use your answers to **(b)(i)** and **(b)(v)** to calculate the mass of NaOH in 25.0 cm^3 of **FA 4**.
[A_r : H, 1.0; O, 16.0; Na, 23.0]

Amount of HC*l* reacted with NaOH = ***(ans (b)(i)) – (ans (b)(v)) mol***

Mass of NaOH = ***[(ans (b)(i)) – (ans (b)(v))] × 40.0 g***
= $(2.56 \times 10^{-3} - 1.37 \times 10^{-3}) \times 40.0 = 1.20 \times 10^{-3} \times 40.0$ = **0.0478 g**

Mass of NaOH in 25.0 cm^3 of **FA 4** = **0.0478 g** [1]

(vii) Calculate the percentage by mass of Na_2CO_3 in the mixture of NaOH and Na_2CO_3 in **FA 4**.

% by mass of Na_2CO_3 = ***(ans (b)(iv))*** ÷ ***[(ans (b)(iv))*** + ***(ans (b)(vi))]*** × ***100*** %

$$= \frac{0.0723}{0.0723+0.0478} \times 100 = \frac{0.0723}{0.1201} \times 100 = \mathbf{60.2\%}$$

FA 4 contains ..... **60.2** ..... % by mass of Na_2CO_3

[2]

(c) The error (uncertainty) associated with **each reading** is given as follows:

50.00 cm^3 burette:	±0.05 cm^3
25.0 cm^3 pipette:	±0.06 cm^3

Calculate the percentage error (uncertainty) when a

- 50.00 cm^3 burette
- 25.0 cm^3 pipette

is used to measure 25 cm^3 of **FA 4** into the conical flask.

Hence explain whether the 50.00 cm^3 burette or the 25.0 cm^3 pipette will be a more accurate apparatus to measure 25 cm^3 of **FA 4**.

% error (uncertainty) of burette = (2 × 0.05)/25 × 100% = **0.40%**
% error (uncertainty) of pipette = 0.06/25 × 100% = **0.24%**
A **25.0 cm^3 pipette** has a **lower % error/uncertainty** and hence is **more accurate** to measure 25 cm^3 of **FA 2**.

[2]

(d) Planning

You are to plan an experiment to determine the percentage by mass of sodium carbonate in an unknown solid sample by measuring the volume of carbon dioxide gas evolved on reaction with excess acid at room temperature and pressure.

$$Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$$

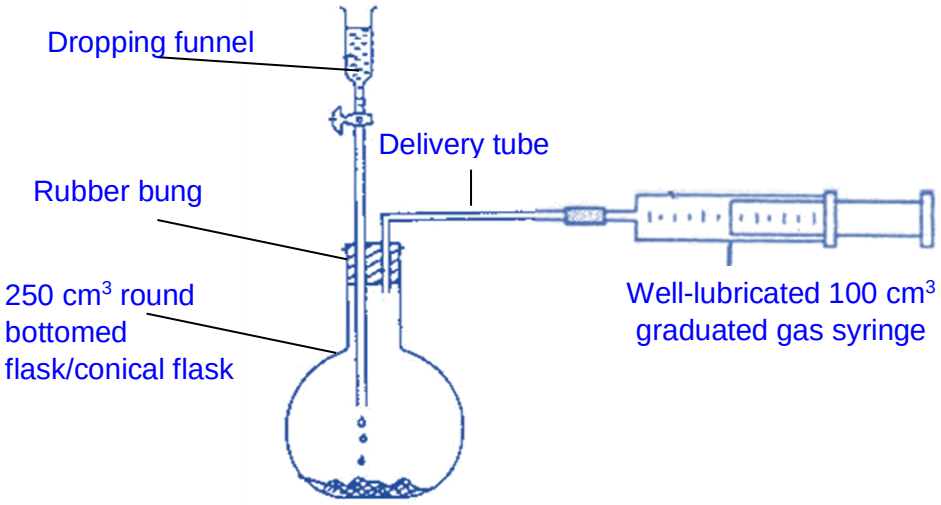
You may assume that you are provided with:
- 0.5 mol dm^{-3} hydrochloric acid, HC*l*;
- 0.5 g impure solid sample containing sodium carbonate, Na_2CO_3. Other impurities present are assumed to have no reaction with acid;
- 100 cm^3 gas syringe for gas collection;
- apparatus normally found in a school laboratory.

Your plan should include:
- calculations of suitable mass of impure sample and volume of excess hydrochloric acid to be used, based on a 100 cm^3 gas syringe;
- a fully-labelled diagram of the experimental set-up;
- practical details of how you would
  - ensure a known mass of solid sample and volume of acid are measured;
  - determine the volume of carbon dioxide evolved, including the measurements to be made;
  - ensure that an **accurate** and **reliable** volume of gas is obtained.

  [M_r : Na_2CO_3, 106.0]

[7]

Diagram



Pre-calculations

Assuming conditions of r.t.p. and 50 to 100 cm^3 of gas collected, eg. 80 cm^3 of CO_2 gas to be collected:

No of mole of CO_2 = $\frac{80}{24000}$ = 3.33×10^{-3} mol

$Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$

$Na_2CO_3 \equiv CO_2$

Mass of $Na_2CO_3 = 3.33 \times 10^{-3} \times 106 = 0.353$ g

Assuming that impure sample is 100% pure, mass of sample required = **0.353 g** ***(about 0.35g)***

$Na_2CO_3 \equiv 2HCl$

Minimum volume of HCl = $\frac{3.33 \times 10^{-3} \times 2}{0.5}$ = **13.32 cm^3** ***(excess acid; any vol > 13.32 cm^3)***

Procedure

Weighing by difference

1. Weigh about **0.35 g** of impure solid sample in a weighing bottle using a mass balance.
2. Transfer the impure sample to a 250 cm^3 round bottom flask/conical flask.
3. Re–weigh the weighing bottle to obtain mass of residual solid.

Alternative

1. Weigh about **0.35 g** of impure solid sample and transfer into a 250 cm^3 round bottom flask/conical flask.

Gas collection

2. Using a **25 cm^3** measuring cylinder, transfer **20** cm^3 of solution into a dry dropping funnel.
3. Read the initial reading of the 100 cm^3 **gas syringe** (or other appropriate apparatus).
4. Run the solution from the dropping funnel into the 250 cm^3 conical flask. Close the tap when all the solution has flowed into the conical flask.
5. Swirl the flask once and leave it to stand.
6. Read the final reading of the **gas syringe** after the reaction is completed, **when there is no further change to the reading of the gas syringe**.

[Total: 23]

3 Qualitative Analysis

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

Unless otherwise stated, the volumes given below are approximate and should be estimated rather than measured.

You should indicate clearly at what stage in a test a change occurs.
If there is no observable change, write **no observable change**.

Rinse and reuse test-tubes and boiling tubes where possible.

(a) **FA 5** contains **two** cations and **two** anion from the lists on pages 17 and 18.

- To approximately half a boiling tube of distilled water, add all the **FA 5**.
- Stopper and shake the boiling tube thoroughly for one minute to make sure that no more of the solid will dissolve.
- Filter the mixture into a clean boiling tube.
- Place the filter funnel in a conical flask and wash the residue well with distilled water.
- **Keep both filtrate and residue for (a)(i) and (a)(ii) respectively.**

While you are waiting for the mixture to filter, continue with (b) or (c).

(i) Tests on the filtrate

Carry out the following tests and record your observations in Table 3.1 below.

Table 3.1

	test	observations
1.	To a 1 cm depth of the filtrate in a test-tube, add aqueous ammonia, slowly with shaking until no further change is seen;	• **Off-white / beige / pale or light brown** (not cream) **ppt** • Ppt rapidly **turns brown on contact with air / darkens on standing** *OR* **Ppt insoluble in excess NH_3** [1]
	then add aqueous hydrogen peroxide.	• Ppt / solid turns **brown / darker brown / brown-black** • **Effervescence / bubbling** *OR* **Gas evolved relights glowing splint** [1]

(ii) Tests on the residue

Carry out the following tests and record your observations in Table 3.2 below.

Table 3.2

	test	observations
2.	Place the funnel containing the residue into a clean test-tube. Pour approximately 5 cm^3 of dilute nitric acid onto the residue. Collect the resultant filtrate. Discard the first 1 cm depth of this resultant filtrate and collect the remaining filtrate in another clean test-tube for test 3.	• **Effervescence** observed when acid is poured onto the residue • **Colourless filtrate** obtained [1]
3.	To 1 cm depth of the solution in a test-tube, add aqueous sodium hydroxide, slowly with shaking until no further change is seen.	• **White ppt** • Ppt **insoluble in excess NaOH** [1]

(iii) Identify the **two** cations present in **FA 5**. Use evidence from your observations in **(a)(i)** and **(a)(ii)** to support your deduction.

cations present ..... **Mn^{2+}** ..... and ..... **Mg^{2+}** .....

evidence

In test **1**, **addition of NH_3 formed off-white ppt which turned brown / insoluble in excess**, indicating presence of **Mn^{2+}**.

In test **3**, **addition of NaOH formed white ppt which was insoluble in excess**, indicating presence of **Mg^{2+}**.

[2]

(iv) The tests you have carried out in **(i)** and **(ii)** would have enabled you to identify only one of the two anions present in **FA 5**. Identify this anion.

anion present ..... **CO_3^{2-}** ..... [1]

(v) Suggest what type of reaction is happening when hydrogen peroxide is added in test **(b)(i)**.

Redox / decomposition of H_2O_2 / disproportionation of H_2O_2 [1]
(allow oxidation of Mn^{2+} / oxidation or reduction of H_2O_2)

(vi) In test 1 of **(a)(i)**, aqueous ammonia behaved as an Arrhenius base:

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

In a separate experiment, an equal volume of aqueous ammonium chloride, NH_4Cl was added to a second portion of the filtrate that was used in **(a)(i)**. When aqueous ammonia was then added to this resultant solution, no precipitate formed.

Suggest an explanation for the results of this experiment.

Presence of ammonium chloride increased $[NH_4^+]$ and **shifted position of equilibrium to the left, decreasing $[OH^-]$**.

$[OH^-]$ insufficient to cause precipitation of the metal hydroxide, $(MnOH)_2$.

[2]

(b) **FA 6** is an aqueous solution containing nickel(II) ion.

Carry out the following tests on **FA 6** and record your observations in Table 3.3 below.

Table 3.3

	test	*observations*
(i)	To a 1 cm depth of **FA 6** in a test-tube, add aqueous ammonia, slowly with shaking, until no further change is seen.	• Solution (**FA 6**) turns from green to **blue** (not dark blue) *(Ignore any ppt)* [1]
(ii)	To a 1 cm depth of **FA 6** in a test-tube, add aqueous sodium hydroxide, slowly with shaking, until no further change is seen.	• **Green ppt** • **Ppt insoluble in excess** [1]

(iii) Nickel(II) ions form complexes with ligands such as ammonia and ethylenediamine as shown:

$$[Ni(H_2O)_6]^{2+}(aq) + 6NH_3(aq) \rightleftharpoons [Ni(NH_3)_6]^{2+}(aq) + 6H_2O(l) \qquad K_c = 4.8 \times 10^7\ mol^{-6}\ dm^{18}$$

$$[Ni(H_2O)_6]^{2+}(aq) + 3en(aq) \rightleftharpoons [Ni(en)_3]^{2+}(aq) + 6H_2O(l) \qquad K_c = 2.0 \times 10^{18}\ mol^{-3}\ dm^{9}$$

purple

[en ≡ ethylenediamine]

The observation in **(b)(i)** is due to the formation of the nickel-ammonia complex.

Suggest, with reason, what might be observed if aqueous ammonia were added to a solution containing $[Ni(en)_3]^{2+}$ ions instead of $Ni^{2+}(aq)$.

No observable change / no colour change / purple solution remained.

Any one of the following:

- **$[Ni(en)_3]^{2+}(aq)$ complex is more stable**
- **$[Ni(NH_3)_6]^{2+}(aq)$ complex is less stable**
- **en is a stronger ligand (**and so unable to be displaced by NH_3)
- **NH_3 is a weaker ligand** (and so unable to displace en)

[2]

(c) **FA 7**, **FA 8** and **FA 9** are 1.0 mol dm^{-3} sulfuric acid, 0.1 mol dm^{-3} sulfuric acid and 1.0 mol dm^{-3} hydrochloric acid, but not necessarily in that order.

You are to plan and carry out **two** simple tests, using only the bench reagents provided, which will enable you to determine the identities of **FA 7**, **FA 8** and **FA 9**.

You should record, in a suitable form in the space below, your tests and observations. You should show clearly the observations for each of **FA 7**, **FA 8** and **FA 9** with all test reagents.

TWO tests only	Test	**FA 7**	**FA 8**	**FA 9**
EITHER (allow identification by elimination, sequence may be swapped)	Add aqueous $BaNO_3$	No ppt	White ppt	White ppt
	Add aqueous $AgNO_3$	White ppt	No ppt	No ppt
AND (accept other correct simple tests)	Add Mg strip	Strong / fast effervescence	Strong / fast effervescence	Weak / slow effervescence

FA 7 is ..**1.0 mol dm^{-3} hydrochloric acid**..

FA 8 is ..**1.0 mol dm^{-3} sulfuric acid**..

FA 9 is ..**0.1 mol dm^{-3} sulfuric acid**..

[4]

[Total: 18]