## Suggested Solutions



# DUNMAN HIGH SCHOOL Preliminary Examination Year 6

**H2 CHEMISTRY** 

Paper 4 Practical

9729/04 19 August 2024 2 hours 30 minutes

Candidates answer on the Question Paper.

### READ THESE INSTRUCTIONS FIRST

Write your centre number, index number, name and class at the top of this page.

Give details of the practical shift and laboratory where appropriate, in the boxes provided. Write in dark blue or black pen.

You may use an 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 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 20 and 21.

At the end of the examination, fasten all your work securely together. The number of marks is given in brackets [] at the end of each question or part question.

Shift	
Laboratory	

For Examiner's Use		
1		
	16	
2		
_	11	
3		
5	13	
4		
-	15	
Total		
. otai	55	

This document consists of **15** printed pages.

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

#### 1 Determination of the enthalpy change of decomposition of magnesium carbonate

The enthalpy change of decomposition of magnesium carbonate,  $\Delta H_1$ , cannot be determined experimentally.

Reaction 1MgCO<sub>3</sub>(s) 
$$\rightarrow$$
 MgO(s) + CO<sub>2</sub>(g) $\Delta H_1$ 

However, the enthalpy changes for **Reaction 2** and **Reaction 3** can be determined experimentally as  $\Delta H_2$  and  $\Delta H_3$  respectively.

**Reaction 2** 
$$MgCO_3(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2O(l) + CO_2(g)$$
  $\Delta H_2$ 

**Reaction 3**  $MgO(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2O(l)$   $\Delta H_3$ 

You will carry out an experiment to determine the enthalpy change for **Reaction 3**,  $\Delta H_3$ , and use this value, together with  $\Delta H_2$ , to calculate the enthalpy change of decomposition of magnesium carbonate,  $\Delta H_1$ .

**FA 1** is solid magnesium oxide powder, MgO. **FA 2** is 1.0 mol dm<sup>-3</sup> sulfuric acid, H<sub>2</sub>SO<sub>4</sub>.

#### (a) Determination of $\Delta H_3$

In this experiment, you will be adding solid magnesium oxide powder to sulfuric acid in a Styrofoam cup. You will then measure the temperature of the reaction mixture over time. Plotting an appropriate graph using the data obtained will allow you to determine  $\Delta H_3$ .

Prepare a table in the space provided on page 3 in which to record:

- all weighings to an appropriate level of precision,
- all values of temperature, *T*, to an appropriate level of precision,
- all values of time, *t*, recorded to 0.5 min.

#### Procedure

- 1. Weigh the capped bottle containing solid **FA 1**. Record this mass.
- 2. Place a clean and dry Styrofoam cup on the 250 cm<sup>3</sup> glass beaker.
- 3. Using a 25 cm<sup>3</sup> measuring cylinder, add 25 cm<sup>3</sup> of **FA 2** into the Styrofoam cup.
- 4. Stir the solution in the cup with the thermometer. Read and record its temperature, T (time, t = 0.0 min).
- 5. Continue to stir the solution. Read and record *T* every 0.5 min.
- 6. At exactly 2.0 minutes, transfer all the solid **FA 1** into the Styrofoam cup. Stir the mixture but do not read *T*.
- 7. Read and record *T* at t = 2.5 min and then every 0.5 min until t = 7.0 min.
- 8. Continue stirring occasionally throughout this time.
- 9. Reweigh the emptied bottle and its cap. Record this mass.

#### 3

#### (i) Results

Mass of capped bottle containing solid FA 1 / g	5.918
Mass of emptied bottle and cap / g	5.420
Mass of FA 1 used / g	0.498

t / min	T/°C	
0.0	30.0	
0.5	30.0	
1.0	30.0	
1.5	30.0	
2.0	-	
2.5	35.0	
3.0	42.0	
3.5	45.8	
4.0	46.2	
4.5	45.6	
5.0	45.2	
5.5	44.8	
6.0	44.2	
6.5	43.6	
7.0	43.0	

[3]

(ii) Plot a graph of temperature, T, on the y-axis, against time, t, on the x-axis, on the grid in Fig.1.1.

Draw a best-fit straight line taking into account all of the points before t = 2.0 min.

Draw another best-fit straight line taking into account all of the points after the temperature of the mixture has started to decrease steadily.

Extrapolate both lines to t = 2.0 min.



- [3]
- (iii) From your graph, read the minimum temperature,  $T_{min}$ , and the maximum temperature  $T_{max}$ , at 2.0 min. Record these values in the spaces provided below.

Deduce the temperature change,  $\Delta T$ , at t = 2.0 min.

 $T_{min} = 30.0 \ ^{\circ}\text{C}$  $T_{max} = 48.2 \ ^{\circ}\text{C}$  $\Delta T = 18.2 \ ^{\circ}\text{C}$  [1] (iv) Excess sulfuric acid was used in (a). Without carrying out any additional tests, what observation could you have made during your experiment to confirm this?

All the magnesium oxide has completely/all dissolved or no more solid remaining.

(v) Calculate the heat change, q, that occurred during the reaction in (a).

You should assume that the specific heat capacity of the solution is 4.18 J  $g^{-1}$  K<sup>-1</sup>, and that the density of the solution is 1.00 g cm<sup>-3</sup>.

 $q = \text{mc}[\Delta T] = (25)(4.18)[+18.2] = 1901.9 \text{ J} = 1.90 \text{ kJ} (3\text{sf})$ 

[1]

[1]

(vi) Use your answer to (a)(v) to calculate  $\Delta H_3$ , the enthalpy change for the reaction between magnesium oxide and sulfuric acid.

[*A*<sub>r</sub>: Mg, 24.3; O, 16.0]

Moles of MgO used =  $\frac{0.498}{40.3}$  = 0.01235 mol

 $\Delta H_3 = -\frac{1.9019}{0.01235} = -153.908 = -154 \text{ kJ mol}^{-1}$ 

[1]

#### (b) Determination of $\Delta H_2$

Note: You do **not** need to perform this experiment.

In this experiment, the initial temperature of 25 cm<sup>3</sup> of sulfuric acid in a Styrofoam cup is measured and recorded as 30 °C. After which, 2.00 g of solid magnesium carbonate powder is added to the sulfuric acid in the cup. The maximum temperature reached during the reaction is measured and recorded as 40 °C.

(i) Using suitable calculations, show that sulfuric acid is in excess.

[*A*<sub>r</sub>: Mg, 24.3; C, 12.0; O, 16.0]

Moles of MgCO<sub>3</sub> used =  $\frac{2.00}{84.3}$  = 0.02372 mol Moles of H<sub>2</sub>SO<sub>4</sub> used =  $\frac{25}{1000}$  × 1.00 = 0.025 mol MgCO<sub>3</sub> = H<sub>2</sub>SO<sub>4</sub> Hence, H<sub>2</sub>SO<sub>4</sub> is in excess.

[1]

[2]

(ii) Hence, calculate  $\Delta H_2$ , the enthalpy change for the reaction between magnesium carbonate and sulfuric acid.

 $q = \text{mc}|\Delta T| = (25)(4.18)|+10.0| = 1045 = 1.045 \text{ kJ} (3\text{sf})$ 

 $\Delta H_2 = -\frac{1.045}{0.02372} = -44.046 = -44.0 \text{ kJ mol}^{-1}$ 

© DHS 2024

(c) Using your answers in (a)(vi) and (b)(ii), construct an energy cycle to calculate  $\Delta H_1$ , the enthalpy change for **Reaction 1**.



By Hess' Law,  $\Delta H_1 = \Delta H_2 - \Delta H_3$  $\Delta H_1 = -44.055 - (-153.908) = +109.853 = +110 \text{ kJ mol}^{-1}$ 

- [2]
- (d) The method used to determine  $\Delta H_3$  in (a) was more accurate than the method used to determine  $\Delta H_2$  in (b). Suggest why the method used for **Reaction 2** was less accurate.

No correction made for loss of heat on cooling in Reaction 2.

[1]

[Total: 16]

#### 2 Planning

Calcium hydroxide, Ca(OH)<sub>2</sub>, is a white powder which is produced when calcium oxide is mixed with water. Calcium hydroxide is poorly soluble in water and its solubility is described by the following equilibrium.

7

 $Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2OH^{-}(aq)$ 

(a) A 25.0 cm<sup>3</sup> saturated solution containing Ca(OH)<sub>2</sub> dissolved in 0.020 mol dm<sup>-3</sup> NaOH at 25 °C was titrated with HC*l*.

Given the average titre volume of HC*l* is 20.00 cm<sup>3</sup> and the solubility of Ca(OH)<sub>2</sub> in 0.020 mol dm<sup>-3</sup> NaOH at 25 °C is approximately 5.00 x  $10^{-3}$  mol dm<sup>-3</sup>, show that a suitable concentration of HC*l* needed for this titration is 0.0375 mol dm<sup>-3</sup>.

 $Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2OH^{-}(aq)$ 

 $NaOH \rightarrow Na^{+} + OH^{-}$ 

Total  $[OH^-] = 0.020 + 2(0.005) = 0.0300 \text{ mol } dm^{-3}$ 

Amount of OH<sup>-</sup> in 25.0 cm<sup>3</sup> =  $0.03 \times (25.0/1000) = 7.50 \times 10^{-4} \text{ mol}$ 

Amount of HCl required =  $7.50 \times 10^{-4}$  mol

 $[HCl] = 7.50 \times 10^{-4} / 0.0200 = 0.0375 \text{ mol dm}^{-3}$ 

[2]

(b) Using the concentration of HCl from (a), you are to plan an investigation to determine the solubility of Ca(OH)<sub>2</sub> in 0.020 mol dm<sup>-3</sup> aqueous sodium hydroxide at 25 °C and hence, the solubility product of Ca(OH)<sub>2</sub> at 25 °C.

You may assume that you are provided with:

- solid calcium hydroxide, Ca(OH)<sub>2</sub>
- 0.020 mol dm<sup>-3</sup> aqueous sodium hydroxide, NaOH
- 0.0375 mol dm<sup>-3</sup> aqueous hydrochloric acid, HCl
- methyl orange (yellow colour in alkaline medium and red colour in acidic medium)
- the equipment normally found in a school laboratory.

In your plan you should include brief details of:

- the procedure you would follow,
- the appropriate apparatus you would use,
- the measurements you would take.
- 1. Using a measuring cylinder, transfer 100 cm<sup>3</sup> of aqueous sodium hydroxide into a dry 250 cm<sup>3</sup> beaker.
- 2. Using a spatula, add solid Ca(OH)<sub>2</sub> into the beaker. Stir the contents in the beaker using a glass rod until no more solid can dissolve.
- **3.** Allow the mixture to stand for a few minutes in a thermostatic water bath maintained at 25 °C.
- **4.** Filter the solution through a dry filter paper into a dry 250 cm<sup>3</sup> beaker.
- **5.** Pipette 25.0 cm<sup>3</sup> of the filtrate into a 100 cm<sup>3</sup> conical flask.

- 6. Add a few drops of methyl orange indicator to the conical flask.
- 7. Fill a burette with aqueous hydrochloric acid.
- **8.** Titrate the solution in the conical flask with hydrochloric acid. The end-point for this titration is reached when the solution changes colour from yellow to orange.
- 9. Record all burette readings, to an appropriate level of precision.
- 10. Repeat steps 5 to 9 until consistent results are obtained.

[5]

(c) (i) Calculate the solubility of Ca(OH)<sub>2</sub> in 0.020 mol dm<sup>-3</sup> NaOH at 25 °C, assuming that the titre volume of HC*l* obtained in (b) is 19.80 cm<sup>3</sup>.

No. of moles of H<sup>+</sup> used = no. of moles of OH<sup>-</sup>(aq) in 25.0 cm<sup>3</sup> saturated solution =  $0.0375 \times (19.80/1000) = 7.425 \times 10^{-4} \text{ mol}$ 

 $Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2OH^{-}(aq)$ 

 $NaOH \rightarrow Na^{+} + OH^{-}$ 

Total [OH<sup>-</sup>] in 25.0 cm<sup>3</sup> saturated solution =  $7.425 \times 10^{-4} / 0.025 = 0.0297 \text{ mol dm}^{-3}$ 

 $[Ca^{2+}] = \frac{1}{2} (0.0297 - 0.020) = 4.85 \times 10^{-3} \text{ mol dm}^{-3}$ 

Solubility of Ca(OH)<sub>2</sub> in 0.020 mol dm<sup>-3</sup> NaOH =  $4.85 \times 10^{-3}$  mol dm<sup>-3</sup>

[2]

(ii) Hence, calculate the solubility product of  $Ca(OH)_2$  at 25 °C.

$$\begin{split} \mathcal{K}_{sp} &= [Ca^{2+}][OH^{-}]^2 \\ &= 4.85 \times 10^{-3} \times (0.0297)^2 \\ &= 4.28 \times 10^{-6} \text{ mol}^3 \text{ dm}^{-9} \end{split}$$

[1]

(iii) Predict and explain how your answer in (c)(i) would compare with the solubility of Ca(OH)<sub>2</sub> in water at 25 °C.

 $Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2OH^{-}(aq)$ 

The solubility of  $Ca(OH)_2$  in NaOH is lower than its solubility in water due to the presence of common OH<sup>-</sup> ion shifting the position of equilibrium to the left.

[1]

[Total: 11]

#### 3 Determination of the basicity of an unknown acid X

The basicity of an acid is defined as the number of hydrogen ions (H<sup>+</sup>) that can be produced when one molecule of the acid completely dissociates in water.

Monobasic acids produce one H<sup>+</sup> per molecule when completely dissociated in water while dibasic acids produce two H<sup>+</sup> per molecule when completely dissociated in water.

In this experiment, an acid-base titration is used to determine whether acid  ${\bf X}$  is monobasic or dibasic.

**FA 3** is a solid sample of acid **X**. **FA 4** is 0.100 mol dm<sup>-3</sup> sodium hydroxide, NaOH. **Solution I** is thymol blue indicator.

#### (a) Preparation of a dilute solution of acid X

- 1. Weigh between 1.2 g and 1.4 g of **FA 3** into a dry 100 cm<sup>3</sup> beaker. Record your mass readings to an appropriate level of precision in the space provided on the next page.
- 2. Use a measuring cylinder to add about 50 cm<sup>3</sup> of deionised water to the beaker. Stir with a glass rod until all the solid has dissolved completely.
- 3. Pour the solution from the beaker into a 100 cm<sup>3</sup> volumetric flask.
- 4. Wash out the beaker thoroughly with deionised water and transfer the washings to the volumetric flask.
- 5. Make the solution up to the mark with deionised water and shake well to mix. This solution is **FA 5**.

#### (b) (i) Titration of FA 5 against FA 4

- 1. Fill a burette with **FA 4**.
- 2. Pipette 10.0 cm<sup>3</sup> of **FA 5** into a 100 cm<sup>3</sup> conical flask.
- 3. Add five drops of **Solution I** to the conical flask. The solution should appear red in colour.
- 4. Titrate the solution in the conical flask with **FA 4**. The solution should gradually turn yellow. The end-point for this titration is reached when the solution changes colour from yellow to blue.
- 5. Record all burette readings, to an appropriate level of precision, in the space provided on the next page.
- 6. Repeat steps 1 to 5 until consistent results are obtained.

#### Results

Mass of beaker and FA 3 / g	63.383
Mass of empty beaker / g	62.124
Mass of <b>FA 3</b> / g	1.259

Final burette reading / cm <sup>3</sup>	20.10	40.20
Initial burette reading / cm <sup>3</sup>	0.00	20.10
Volume of <b>FA 4</b> used / cm <sup>3</sup>	20.10	20.10

- [3]
- (ii) From your titrations, obtain a suitable volume of **FA 4** to be used in your calculations. Show clearly how you obtained this volume.

Average volume of **FA 4** used =  $\frac{20.10 + 20.10}{2}$  = 20.10 cm<sup>3</sup>

[3]

(c) (i) Calculate the amount of  $H^+$  present in 10.0 cm<sup>3</sup> of FA 5.

Amount of NaOH reacted =  $\binom{20.10}{1000}$  (0.100) = 2.01 x 10<sup>-3</sup> mol

Since  $H^+ \equiv OH^-$ , amount of  $H^+$  in 10.0 cm<sup>3</sup> of **FA 5** = 2.01 x 10<sup>-3</sup> mol

[1]

(ii) Hence, determine the amount of H<sup>+</sup> present in the solid sample of **FA 3** you weighed out in (a).

Amount of H<sup>+</sup> dissociated from solid sample in (a) =  $\binom{100}{10}$  (2.01 x 10<sup>-3</sup>) = 0.0201 mol

[1]

(iii) Given that the molecular mass of acid X is 126.0 g mol<sup>-1</sup>, calculate the amount of acid X weighed out in (a).

Amount of acid X weighed out in (a) =  $\frac{1.259}{126}$ = 0.00999 mol

[1]

(iv) Using your answers in (c)(ii) and (c)(iii), deduce whether acid X is monobasic or dibasic.

Amount of H<sup>+</sup> dissociated per mole of acid  $\mathbf{X} = \frac{0.0201}{0.00999}$ = 2.01  $\approx$  2

Hence, acid **X** is a dibasic acid.

[1]

(d) The pipette used in this experiment is calibrated to  $\pm 0.02$  cm<sup>3</sup>.

Determine whether the pipette or burette used in this experiment would give a larger percentage error when used to measure  $10 \text{ cm}^3$  of **FA 5** needed for the titration.

% error using the pipette =  $\frac{\pm 0.02}{10} \times 100\% = \pm 0.2\%$ 

% error using the burette =  $\frac{2 \times \pm 0.05}{10} \times 100\% = \pm 1.0\%$ 

Hence, using the burette would give a larger percentage error.

[1]

© DHS 2024

(e) The structure of the thymol blue indicator is shown below. The sulfur–containing functional group can be considered inert.



thymol blue

A student used much more thymol blue indicator in the titration than specified in the procedure. Suggest how this student's titre value will compare with the expected titre value. Explain your answer.

The student's titre value will be larger than the expected titre value.

Thymol blue contains the two acidic phenol groups. A significant amount of NaOH will be required to neutralise these groups when a significant amount of thymol blue is used.

[2]

[Total: 13]

#### 4 Analysis of Inorganic and Organic Compounds

(a) FA 6 is an aqueous solution containing one cation.FA 7 is an aqueous solution containing two cations.

You will perform tests to identify the cations in FA 6 and FA 7.

You are **not** expected to identify the anions.

(i) Carry out the following tests. Record your observations in Table 4.1.

Unless otherwise stated, 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**.

test		observations	
1	Add 1 cm depth of <b>FA 6</b> into a boiling tube.		
	Add all the sodium carbonate to this boiling tube	Grey-green ppt seen	
		Effervescence seen	
		Gas forms white ppt with limewater. Gas is CO <sub>2</sub> .	
2	Add 1 cm depth of <b>FA 6</b> into a test-tube.		
	Add aqueous ammonia slowly, with	Grey-green ppt seen	
	shaking, until no further change is seen.	Insoluble in excess NH <sub>3</sub> (aq)	
3	Add 2 cm depth of <b>FA 7</b> into a test-tube.		
	Add aqueous ammonia, slowly with shaking, until 4 cm depth of aqueous ammonia has been added.	Red-brown ppt seen, insoluble in excess NH <sub>3</sub> (aq) Residue is red-brown	
	Filter the mixture into a clean test-tube.	Filtrate is colourless	
4	Add 1 cm depth of the filtrate from test 3 into a test-tube.		
	Add dilute nitric acid, slowly, with shaking, until no further change is seen.	White ppt seen, soluble in excess nitric acid to form a colourless solution.	

#### Table 4.1

(ii) Identify the cation present in **FA 6**.

Cr<sup>3+</sup>

(iii) Explain your observations in Test 1 of Table 4.1.

[2]

[1]

Cr<sup>3+</sup> has high charge density and undergoes partial hydrolysis by polarising the electron clouds of surrounding water molecules (ligands) and weaken the O–H bonds, hence releasing H<sup>+</sup> ions.

The additional H<sup>+</sup> produced undergoes acid-base reaction with  $CO_3^{2-}$  to form  $CO_2$ /effervescence.

(iv) Identify the two cations in **FA 7** and state the evidence for each cation by completing Table 4.2.

[2]

cation	evidence		
Fe <sup>3+</sup>	In test 3, a red-brown ppt was seen, insoluble in excess $NH_3(aq)$		
Zn <sup>2+</sup>	In test 4, a white ppt was seen (reformed) which is soluble in excess $HNO_3$ to give a colourless solution.		

(b) **FA 8** has the molecular formula  $C_8H_8O$ . **FA 9** has the molecular formula  $C_8H_{10}O$ .

> **Solution 1** is copper(II) sulfate solution. **Solution 2** is potassium sodium tartrate in sodium hydroxide solution.

You will perform tests to identify the functional groups present in **FA 8** and **FA 9**, and hence deduce their possible structures.

Half-fill a 250 cm<sup>3</sup> beaker with water and heat until the water is almost boiling. This is a hot water bath for use in **(b)(i)**. You should turn off the Bunsen burner but reheat the water if it cools excessively.

# Note: Handle all hot apparatus with care and discard all unwanted mixtures in the waste bottle provided.

(i) Carry out the following tests. Some of the observations have been completed for you. There is no need to carry out those tests. Record your observations in Table 4.3.

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

You do **not** need to test and identify any gases evolved.

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

#### Use a fresh sample of each solution in each test.

Table 4	4.3
---------	-----

	test	observations with <b>FA 8</b> , C <sub>8</sub> H <sub>8</sub> O	observations with FA 9, C <sub>8</sub> H <sub>10</sub> O
1	Add about 1 cm depth of the <b>FA</b> solution into a test-tube. To this test-tube add 1 cm depth of aqueous bromine.	no observable change	no observable change
2	Add about 1 cm depth of the <b>FA</b> solution into 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 the hot water bath for two minutes.	solution <b>FA 8</b> turns orange	pale yellow precipitate formed
3	Add 1 cm depth of <b>Solution 1</b> into a test-tube. Then add 1 cm depth of <b>Solution 2</b> into the test-tube.		
	Add 1 cm depth of <b>FA 8</b> to the same test-tube. Shake the test-tube and warm the mixture in the hot water bath. Shake the test-tube occasionally. <b>Repeat test 3 using FA 9 instead of FA 8</b> .	Reddish brown ppt seen	No observable change
4	Add 1 cm depth of <b>FA 8</b> into a test-tube. Add 1 cm depth of 2,4-dinitrophenylhydrazine solution into the test-tube. <b>Repeat test 4 using FA 9 instead of FA 8</b> .	Orange ppt seen	No observable change

[2]

(ii) Based on the observations for test 1 in Table 4.3, state two functional groups that are absent in FA 8 and FA 9. [1]

- Alkene (C=C) and phenol
- (iii) Using the observations in Table 4.3 and your answer in (b)(ii), suggest the structures of FA 8 and FA 9.

[2]



[Total: 15]