Name: ( )	Class: 23S0____

RAFFLES INSTITUTION
2022 Year 5 Term 3 Common Test

HIGHER 2

CHEMISTRY 9729

30 June 2022
2 hours 15 minutes

Additional Materials: Multiple Choice Answer Sheet
Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, 6-digit index number and civics tutorial group in the spaces provided on the OMR sheet and the cover sheet on page **17.** Shade in your 6-digit exam index number on the OMR Answer Sheet.

This paper consists of three sections **A**, **B** and **C**.

Section A (15 marks) consists of 15 multiple-choice questions.
Answer this section first. Your OMR Answer Sheet will be collected after the first 30 minutes. Record your answers to this section in soft pencil on the separate OMR Answer Sheet.

Section B (30 marks) consists of 3 structured questions.
Answer all questions. Answers to this section are to be written in the spaces provided in the question paper.

Section C (35 marks) consists of 2 free-response questions.
Write your answers in the spaces provided in the question paper. If additional space is required, you should use pages 29–30 at the end of the booklet for Section C. The question number must be clearly shown.

The number of marks is given in brackets [ ] at the end of each question or part question.

Write in dark blue or black pen. You may be subject to penalty for writing answers in pencil.

Answers to Sections **B** and **C** are to be handed in **separately**.

Question	Marks
B1	/ 6
B2	/ 8
B3	/ 16

Section A (15 marks)

For each question, there are four possible answers, **A**, **B**, **C**, and **D**. Choose the one you consider to be correct.

1 *Use of the Data Booklet is relevant to this question.*

Which gas contains the greatest number of atoms?

A 2.80 g of nitrogen

B 3.60 g of argon

C 950 cm^3 of C_2H_2 (measured at r.t.p.)

D 5.10×10^{22} molecules of carbon dioxide

2 Chlorine reacts with hot aqueous sodium hydroxide to form chloride ions and another chlorine-containing product.

When 0.03 mol of chlorine were reacted with excess sodium hydroxide, 0.05 mol of chloride ions were formed.

What is the oxidation state of C*l* in the other chlorine-containing product?

A +1 **B** +3

C +5 **D** +7

3 *Use of the Data Booklet is relevant to this question.*

Which statements regarding chromium are correct?

1 The electronic configuration of $Cr^+(g)$ at ground state is [Ar] $3d^4 4s^1$.

2 $Cr^{2+}(g)$ and $Cr^{3+}(g)$ have the same number of paired electrons.

3 The energy required for the process, $Cr^{2+}(g) \longrightarrow Cr^{3+}(g) + e^-$, is 2990 kJ mol^{-1}.

A 1, 2 and 3 **B** 1 and 2 **C** 2 and 3 **D** 2 only

4 The 5th, 6th, 7th and 8th ionisation energies of four consecutive elements in the Periodic Table, W, X, Y and Z, are shown in the table below.

W, X, Y and Z have atomic numbers less than 20.

element	5th ionisation energy / kJ mol^{-1}	6th ionisation energy / kJ mol^{-1}	7th ionisation energy / kJ mol^{-1}	8th ionisation energy / kJ mol^{-1}
W	16 091	19 805	23 780	29 287
X	6274	21 267	25 431	29 872
Y	7004	8496	27 107	31 719
Z	6542	9362	11 018	33 604

Which element has the highest first ionisation energy?

A W **B** X **C** Y **D** Z

5 J is an ionic compound comprising one polyatomic cation and a number of monoatomic anions.

The cation has an overall charge of 2+, and contains platinum at an oxidation state of +4. The platinum is attached, via co-ordinate bonds (dative covalent bonds), to six other species which can be NH_3 or Cl^-.

What is the formula of J?

A $Pt(NH_3)_4Cl_2$

B $Pt(NH_3)_4Cl_4$

C $Pt(NH_3)_6Cl_2$

D $Pt(NH_3)_6Cl_4$

6 In the year 2000, argon fluorohydride, HArF, was synthesised as follows.

$$Ar + HF \longrightarrow HArF$$

Which statement regarding the above molecules is correct?

A HArF has a trigonal bipyramidal shape.

B HF is non-polar as it is a linear molecule.

C In HArF, Ar has ten electrons in its valence shell.

D Hydrogen bonds exist between HArF molecules.

7 The boiling points of three gases are given below.

	CH_4	PH_3	NH_3
boiling point / °C	−161.5	–87.7	–77.7

Which statements are **incorrect**?

1 PH_3 has a higher boiling point than CH_4 because strong hydrogen bonds exist between PH_3 molecules.

2 CH_4 has a lower boiling point than NH_3 because the CH_4 molecule has fewer electrons than the NH_3 molecule.

3 NH_3 has a higher boiling point than PH_3 because NH_3 has stronger instantaneous dipole–induced dipole interactions than PH_3.

A 1, 2 and 3 **B** 1 and 2 **C** 1 and 3 **D** 2 and 3

8 The melting point of barium, 727 °C, is much higher than the melting point of potassium, 63.5 °C.

Which statement is most relevant in explaining this difference?

A The barium atom is larger than the potassium atom.

B The barium atom is heavier than the potassium atom.

C The barium ion, Ba^{2+}, has a higher charge than the potassium ion, K^+.

D The barium ion, Ba^{2+}, contains more electrons than the potassium ion, K^+.

9 A piece of dry ice (solid CO_2) weighing 4.40 g is placed in a 1.00 dm^3 rigid bottle filled with air at 1 bar. The bottle is capped and the dry ice sublimes into gas.

Given that the temperature is kept constant at 90.0 °C, what is the final pressure, in bar, inside the bottle?

[You may ignore the volume occupied by the solid dry ice.]

A 1.31 **B** 1.75 **C** 3.98 **D** 4.02

10 Which of the following properties are observed for ideal gases?

1 At the same temperature and pressure, gases of the same volume contain the same number of particles.

2 For a fixed mass of gas at constant volume, the pressure of the gas is directly proportional to its absolute temperature.

3 For a fixed mass of gas at constant temperature, the volume of the gas is directly proportional to its pressure.

A 1 only **B** 2 only

C 1 and 2 **D** 2 and 3

11 The standard enthalpy changes for the following two processes are known.

$$Br(g) + e^- \longrightarrow Br^-(g)$$
$$\tfrac{1}{2}Br_2(l) + e^- \longrightarrow Br^-(aq)$$

What additional data is needed to determine the standard enthalpy change of hydration of $Br^-(g)$?

A first ionisation energy of Br

B enthalpy change of solution of $Br_2(l)$

C enthalpy change of formation of $Br_2(l)$

D enthalpy change of atomisation of $Br_2(l)$

12 When equal volumes of 0.25 mol dm^{-3} sulfuric acid and 0.25 mol dm^{-3} of ethanoic acid were separately neutralised by dilute sodium hydroxide, the heat energy released was p kJ and q kJ respectively.

Which relationship between p and q is correct?

A $p > 2q$ **B** $p = q$

C $p = 2q$ **D** $p = \frac{1}{2}q$

13 Elemental sulfur occurs in two allotropic forms, α-sulfur and β-sulfur. They undergo combustion to form $SO_2(g)$.

The standard enthalpy changes of combustion are shown below.

$\Delta H_c^{\ominus}$ (α-sulfur) = –298 kJ mol^{-1}
$\Delta H_c^{\ominus}$ (β-sulfur) = –300 kJ mol^{-1}

Which deduction can be made from the data above?

A The $\Delta H_f^{\ominus}$ of β-sulfur is 0 kJ mol^{-1}.

B The $\Delta H_f^{\ominus}$ of $SO_2(g)$ is –298 kJ mol^{-1}.

C α-Sulfur is less stable than β-sulfur.

D Energy is absorbed to convert β-sulfur to α-sulfur.

14 1 mol of CH_4 reacts with 1 mol of steam to form carbon monoxide and gas **R**. The enthalpy change of this reaction is +210 kJ mol^{-1} and the entropy change of this reaction is +215 J mol^{-1} K^{-1}.

Which statements are correct for this reaction?

1 Gas **R** is flammable.

2 At 1000 °C, ΔG of the reaction is −5 kJ mol^{-1}.

3 The minimum temperature for the reaction to be spontaneous is 704 °C.

A 1 only

B 2 only

C 1 and 3 only

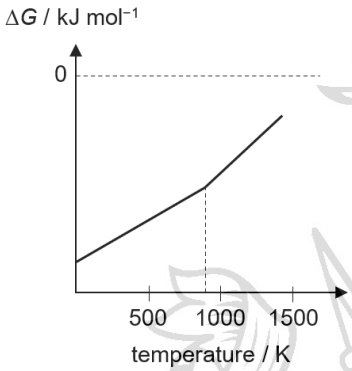
D 1, 2 and 3

15 Magnesium reacts with oxygen gas to form magnesium oxide. The melting point of magnesium is 900 K.

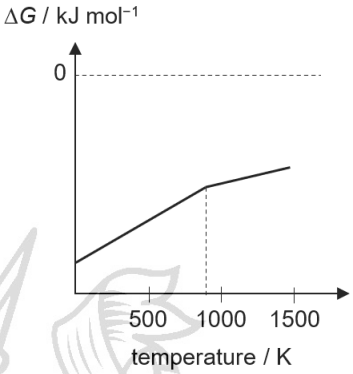
$$2Mg + O_2 \longrightarrow 2MgO$$

Which diagram correctly shows how ΔG of the reaction changes with temperature?

A



B



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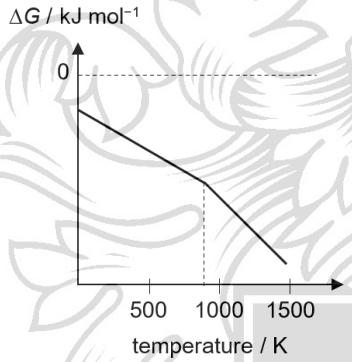
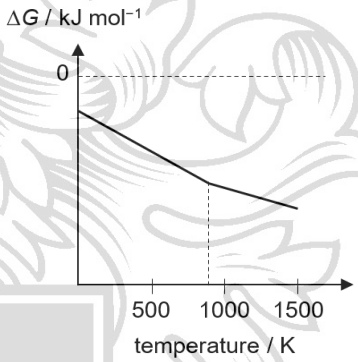


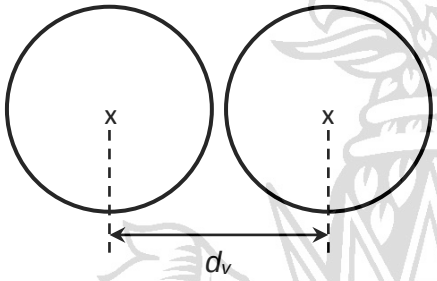
D



Section B (30 marks)

This section consists of **3** questions.
Answer **all** the questions in this section.

B1 The van der Waals radius, r, of an atom is half the inter–nuclear distance between atoms which are not chemically bonded, i.e. $r = ½\ d_v$.



x nucleus
d_v inter–nuclear distance

(a) Table 1.1 shows the data for the van der Waals radius for some noble gases.

Table 1.1

element	He	Ne	Ar	Kr	Xe
r / nm				0.202	0.216

(i) With reference to the *Data Booklet,* fill in the van der Waals radii for He, Ne and Ar, in Table 1.1. [1]

(ii) State and explain how r varies down Group 18.

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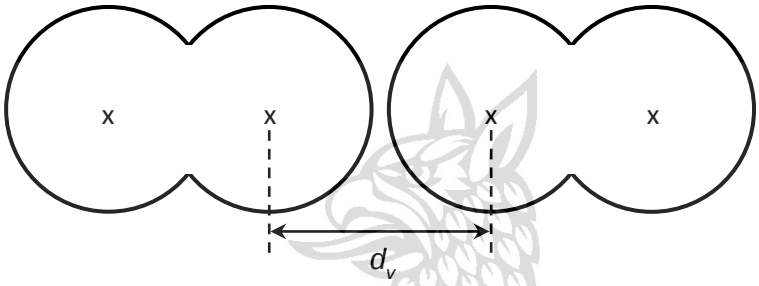
……[3]

The following diagram represents two neighbouring chlorine molecules, Cl_2, in the solid state.



x nucleus

(b) Indicate clearly on the diagram, what is meant by the covalent radius, *R*, of C*l*.

[1]

(c) "The covalent radius of an element is always smaller than its van der Waals radius."

Explain why the above statement is correct.

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……[1]

[Total: 6]

B2 The two most common allotropes of carbon are diamond and graphite.
Carbon also exists as fullerenes, which are a series of carbon molecules with hollow structures.

As shown in Fig. 2.1, buckminsterfullerene, C_{60}, is a molecule with 60 carbon atoms arranged in pentagons and hexagons that are similar to those in a football.

buckminsterfullerene, C_{60}

Fig. 2.1

(a) Table 2.1 provides some information about buckminsterfullerene and graphite.

Table 2.1

allotrope	buckminsterfullerene	graphite
melting point	~300 °C (sublimes)	~3700 °C
solubility in water	insoluble	insoluble

(i) In terms of structure and bonding, explain why graphite has a high melting point.

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……[2]

(ii) Explain why buckminsterfullerene, C_{60}, is insoluble in water.

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……[2]

(b) Each molecule of buckminsterfullerene, C_{60}, comprises carbon atoms connected by single and double bonds.

(i) A π (pi) bond can be formed between two carbon atoms.

Draw a labelled diagram to show how the orbitals overlap to form a π bond.

[1]

(ii) Given that each carbon in C_{60} forms three σ (sigma) bonds, state the number of π bonds in C_{60}.

number of π bonds …… [1]

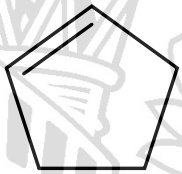
Further information about C_{60} is given as follows.

- Each molecule of C_{60} comprises 12 pentagons and 20 hexagons (see Fig. 2.1).
- The two bond lengths in C_{60} are 0.138 nm and 0.145 nm.
- The bond length between any two carbon atoms shared by a pentagon and a hexagon is 0.145 nm.

(iii) To illustrate the presence of **all** the π bonds in C_{60}, a student proposed the following method of drawing.

All π bonds are to be drawn *within* the pentagons.

An example of a drawn π bond is shown below.



Suggest if the proposed method will result in a correct illustration for C_{60}.

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……[1]

(iv) Draw on Fig. 2.1 to indicate the locations of at least 6 π bonds. [1]

[Total: 8]

B3 The troposphere is the lowest layer of Earth's atmosphere. The atmospheric concentration, in parts per billion (ppb), and atmospheric lifetime of some gases present in the troposphere can be found in Table 3.1.

Table 3.1

gas	atmospheric concentration / ppb	atmospheric lifetime / years
CCl_2F_2	530	55
H_2	600	3
N_2O	325	115
NF_3	4.5×10^{-7}	550

[1 ppb = 1 molecule of that gas in every 10^9 gaseous molecules]

(a) Assuming ideal gas behaviour, calculate the number of moles of CCl_2F_2 in 1 dm^3 of air at a tropospheric temperature and pressure of −50 °C and 10^5 Pa.

[2]

(b) Some of the infrared radiation emitted from the Earth's surface gets absorbed by greenhouse gases and is re-emitted back towards the Earth's surface, causing further warming. This is known as the greenhouse effect.

Molecules with a permanent dipole moment can absorb infrared radiation.

(i) By considering the information above and in Table 3.1, evaluate the contribution to the greenhouse effect by all the gases listed in Table 3.1.

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……[3]

Although the CO_2 molecule does not have a permanent dipole moment, it can also absorb infrared (IR) radiation.

This is because covalent bonds are not static. The bond between the carbon and oxygen atoms stretches and compresses back and forth. Some of these motions give rise to a change in the net dipole moment and lead to the absorption of IR radiation.

Table 3.2 features two motions, as illustrated by CO_2.

Table 3.2

Asymmetric stretching One bond stretches while the other bond compresses at the same time. For example:    Asymmetric stretching leads to the absorption of IR radiation.
Symmetric stretching Both bonds stretch together, or compress together, at the same time. For example:    Symmetric stretching does not lead to the absorption of IR radiation.

(ii) Explain why asymmetric stretching in the CO_2 molecule leads to absorption of IR radiation.

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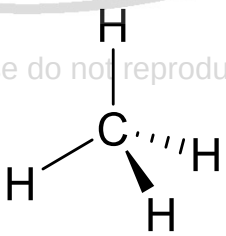
……[1]

(iii) Methane, CH_4, is also a greenhouse gas.

On the structure of CH_4 given below, draw four arrows to show the stretching and/or compression of bonds that lead to the absorption of IR radiation.



[1]

(c) Nitrogen trifluoride, NF_3, is used during the manufacturing process of semiconductors and solar panels.

Metals such as copper can be fluorinated by reacting with nitrogen trifluoride.

$$Cu(s) + 2NF_3(g) \longrightarrow N_2F_4(g) + CuF_2(s)$$

(i) Using the standard enthalpy change of formation data provided in Table 3.3, calculate $\Delta H^{\ominus}$ of the above reaction.

Table 3.3

	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$NF_3(g)$	−132.1
$N_2F_4(g)$	−8.4
$CuF_2(s)$	−538.8

[1]

(ii) State the sign for $\Delta S^{\ominus}$ of the reaction and explain your answer.

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……[1]

(iii) Hence, explain why a low temperature is recommended for the reaction.

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(iv) By considering the Valence Shell Electron Pair Repulsion theory, explain the shape of N_2F_4 about each N atom.

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……[2]

(v) Explain why N_2F_4 is a gas whereas N_2H_4 is a liquid at room temperature.

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…….[2]

(d) BH_3 and NF_3 react readily in a 1:1 ratio to form only one product.

(i) By considering the numbers of bonding and non-bonding electron pairs, draw the 'dot-and-cross' diagram to show the bonding in the product.

[1]

(ii) State the change in the F−N−F bond angle in this reaction.

…… to …… [1]

[Total: 16]

RAFFLES INSTITUTION
2022 Year 5 Term 3 Common Test
H2 Chemistry

C

Name: ( )	**Class: 23S0____**

For Examiner's Use Only

Section		**Marks**
A		**/ 15**
B	**B1**	**/ 6**
	B2	**/ 8**
	B3	**/ 16**
C	**C1**	**/ 16**
	C2	**/ 19**
	Total	**/ 80**
	Percentage	**/ 100**
	Grade	

Section C (35 marks)

This section consists of **2** questions.
Answer **all** the questions in this section.

C1 Limestone is primarily made up of minerals containing calcium carbonate.

(a) **(i)** Draw a 'dot-and-cross' diagram to show the type(s) of bonding present within a formula unit of calcium carbonate. [2]

(ii) Calcium carbonate exists in crystalline form as the mineral calcite. When compared to other minerals, calcite is not as hard as quartz (silicon dioxide) or diamond.

Consider the structure and bonding of calcium carbonate and suggest why it is not as hard as quartz or diamond. [2]

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(b) One of the primary uses of limestone is to produce lime, calcium oxide. The process involves heating the limestone above 2000 °C, where calcium carbonate undergoes decomposition to form carbon dioxide and calcium oxide.

(i) Define what is meant by the term *lattice energy* of an ionic compound. [1]

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(ii) Use the data in Table 4.1, together with data from the *Data Booklet*, to calculate the enthalpy change of the following reaction.

$$C(g) + \frac{3}{2}O_2(g) + 2e^- \longrightarrow CO_3^{2-}(g) \quad \Delta H_r$$

Show your working.

Table 4.1

	value / kJ mol^{-1}
standard enthalpy change of decomposition of calcium carbonate	+178
lattice energy of calcium carbonate	–2810
lattice energy of calcium oxide	–3505
1st electron affinity of oxygen	–142
2nd electron affinity of oxygen	+844

[4]

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(iii) Explain why the lattice energy of calcium oxide has a greater magnitude than that of calcium carbonate. [2]

(iv) The theoretical lattice energy of calcium carbonate was calculated to be –2920 kJ mol^{-1}.

Explain why there is difference in the theoretical and experimental values. [1]

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(c) Scientists have investigated the use of calcium carbonate to produce hydrocarbons such as methane. In the presence of a catalyst, hydrogen gas was passed through calcium carbonate at high temperatures to produce methane (CH_4), calcium hydroxide and steam.

(i) Write an equation which describes the reaction between hydrogen gas and calcium carbonate. Explain whether it is a redox reaction. [2]

(ii) During an experiment, excess hydrogen gas was passed through 20.0 g of calcium carbonate.

If the yield of the reaction was 80%, calculate the volume of methane produced at room temperature and pressure. [2]

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[Total: 16]

C2 This question examines some properties of magnesium and the various applications of the reaction between magnesium and hydrochloric acid.

(a) **(i)** State the electronic configuration of magnesium. [1]

(ii) For each pair of elements listed below, state and explain which element has the higher first ionisation energy.

(I) magnesium and sodium
(II) magnesium and aluminium [3]

(b) (i) State the two main assumptions of the kinetic theory as applied to an ideal gas. [2]

(ii) In reality, real gases do not obey the ideal gas law exactly.

The graphs of pV against p for an ideal gas and hydrogen gas are provided on the axes below.

Sketch, on the same axes provided, a labelled graph of pV against p for carbon dioxide, CO_2. Give two reasons for the differences in the extent of deviation from ideality for CO_2 compared to H_2. [3]

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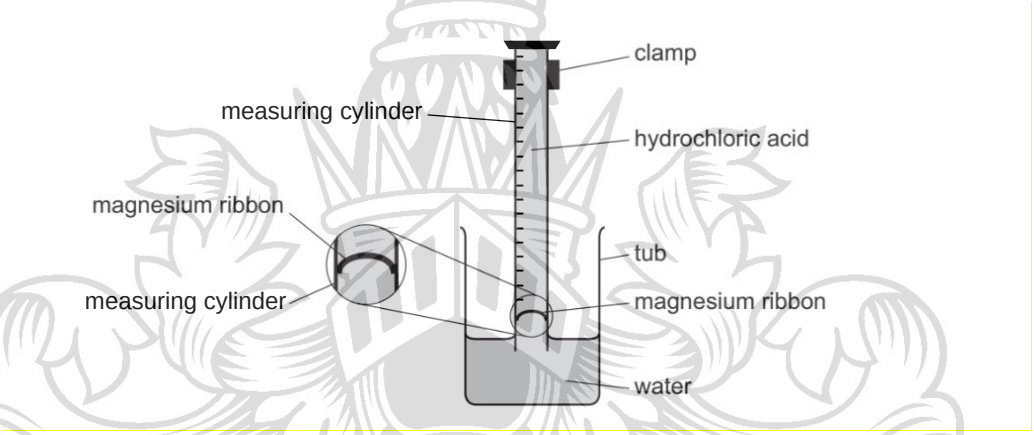
(c) In the ideal gas equation, R is the molar gas constant, which is a constant of proportionality.

The setup below was used to determine the value of R by generating hydrogen gas from the reaction between magnesium and hydrochloric acid.

$$Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$$

The measuring cylinder, containing a piece of magnesium ribbon and hydrochloric acid, was inverted carefully into a tub of water and clamped as shown in the diagram below.



During the reaction, the hydrogen gas evolved was collected by the displacement of the liquid in the measuring cylinder. After all the magnesium had reacted, the volume of the gas was measured.

The data collected are presented in Table 5.1.

Table 5.1

mass of Mg / g	0.0382
volume of gas collected / cm^3	37.0
temperature in the lab / °C	28.0
atmospheric pressure in the lab / kPa	101

(i) Calculate the amount, in moles, of magnesium reacted and hence the amount of hydrogen gas evolved in the reaction. [1]

(ii) The total pressure of the gas collected in the measuring cylinder, which included the partial pressure of water vapour, was found to be equal to the atmospheric pressure in the lab.

Given that the partial pressure of water vapour is 3.77 kPa at 28 °C, calculate the partial pressure of hydrogen gas evolved during the reaction. [1]

(iii) Using the ideal gas equation and the experimental data provided, calculate the value of R. [1]

(d) The enthalpy change for the combustion of magnesium, ΔH_c, as shown in the equation below, cannot be determined directly.

$$Mg(s) + \frac{1}{2}O_2(g) \longrightarrow MgO(s) \qquad \Delta H_c$$

However, it is possible to use Hess' Law to determine ΔH_c by considering ΔH_1 and ΔH_2, which are the enthalpy changes for the reactions of magnesium and magnesium oxide with hydrochloric acid.

$$Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g) \qquad \Delta H_1$$
$$MgO(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2O(l) \qquad \Delta H_2$$

The procedure below was used to determine ΔH_1.

1. The initial temperature, $T_{initial}$, of 25.0 cm^3 of 2.0 mol dm^{-3} hydrochloric acid in a Styrofoam cup was measured.
2. The mass of a piece of magnesium ribbon was measured before adding it to the acid in the Styrofoam cup. The Styrofoam cup was quickly covered with a lid and its contents were stirred with the thermometer.
3. The highest temperature reached, $T_{highest}$, was measured.

The data collected are presented in Table 5.2.

Table 5.2

mass of Mg ribbon / g	0.032
$T_{initial}$ / °C	28.6
$T_{highest}$ / °C	34.4

(i) Use the data in Table 5.2 to calculate the heat change during the reaction.

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

(ii) Using your answer to **(d)(i)**, calculate the enthalpy change, ΔH_1, for the reaction between magnesium and hydrochloric acid. [2]

(iii) The values of the enthalpy change for the reaction between magnesium oxide and hydrochloric acid, ΔH_2, and the enthalpy change of formation of water are given below.

$$MgO(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2O(l) \qquad \Delta H_2 = -150 \text{ kJ mol}^{-1}$$
$$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(l) \qquad \Delta H_f = -286 \text{ kJ mol}^{-1}$$

Using your results to **(d)(ii)** and a suitable energy cycle, or otherwise, calculate the enthalpy change for the combustion of magnesium, ΔH_c.

$$Mg(s) + ½\ O_2(g) \longrightarrow MgO(s) \qquad \Delta H_c$$ [3]

(iv) Predict how the temperature change, ΔT, for the reaction between magnesium and hydrochloric acid will change, if the same mass of magnesium was reacted with 50 cm^3 of hydrochloric acid instead of 25 cm^3. Explain your answer. [1]

[Total: 19]

Additional answer space

If you use the following pages to complete the answer to any question, the question number must be clearly shown.

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