Class	Adm No

Candidate Name: _____

H

millennia institute

2022 Preliminary Exams
Pre-University 3

H2 CHEMISTRY **9729/02**

Paper 2 Structured Questions **14 Sep 2022**

2 hours

Candidates answer on the Question paper.

Additional materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Do not turn over this question paper until you are told to do so

Write your name, class and admission number on all the work you hand in.

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.

The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

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.

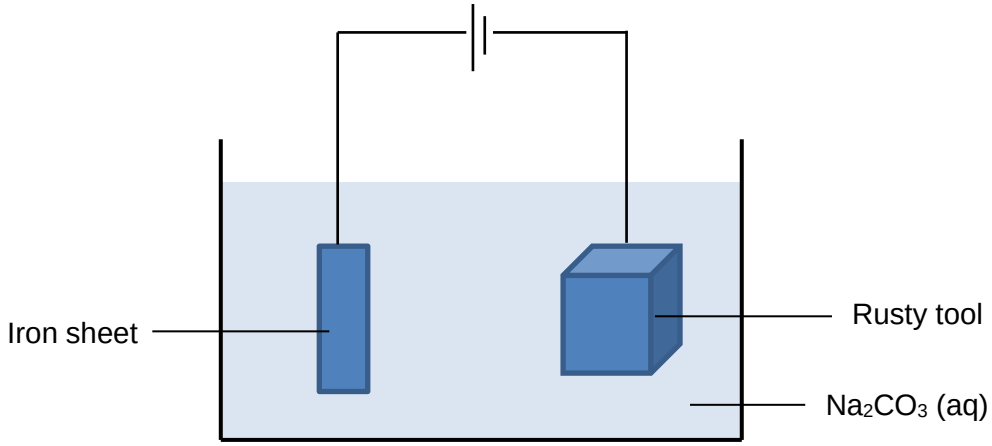
Question	1	2	3	4	5	Total
Marks	/20	/13	/24	/9	/9	/75

Answer all questions in the spaces provided.

1 Many household tools are made from stainless steel as it is highly resistant to corrosion and rust. Stainless steel contains iron, chromium, manganese, nickel, molybdenum, silicon and carbon which interacts with oxygen from water and air to form oxides. Of these elements, chromium has the highest resistance to corrosion.

Despite the high resistance, rusting still occurs in a humid environment. A 'Do-it-Yourself' (DIY) kit has been launched in the market to remove rust from household tools and the set-up is shown in **Figure 1.1**.

Figure 1.1



(a) **(i)** State if the iron sheet is the anode or the cathode.

……[1]

(ii) *Use of Data Booklet is relevant to this question.*
State and explain the observations found at the iron sheet electrode.

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……[2]

(iii) Suggest why carbonate ions from Na_2CO_3 electrolyte cannot be oxidised at the anode.

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……[1]

(iv) A consumer saw the DIY kit and decided to purchase it and try out on his rusted dumbbell. He prepared the set up as shown in **Figure 1.1** with a 20 A power source and switched it on for 6 hours.

Determine the change in mass of the iron sheet.

[2]

(b) Fe_2O_3 is the main constituent of the rust found on household items. The standard electrode potentials involving the iron containing species can be found in **Table 1.1**.

Table 1.1

Half-equations	E^{θ}/V
$3Fe_2O_3 + H_2O + 2e \rightleftharpoons 2OH^- + 2Fe_3O_4$	–0.62
$Fe_2O_3 + 3H_2O + 6e \rightleftharpoons 2Fe + 6OH^-$	–0.88
$Fe_3O_4 + 4H_2O + 8e \rightleftharpoons 3Fe + 8OH^-$	–0.91

A layer was coated around the rusty tool after using the DIY kit.
With reference to the standard electrode potentials given in **Table 1.1**, explain fully whether the layer coated is iron.

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(c) The metal alloy that made up the main components of stainless steel are transition metals.

(i) Define *transition metal*.

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……[1]

(ii) State a physical property of transition metals which makes them a suitable material used for household tools compared to main group metals.

……[1]

(iii) Iron(III) ions catalyse the reaction between I^- ions and $S_2O_8^{2-}$ ions through homogeneous catalysis.

Explain the term *homogeneous catalyst*.

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……...[1]

(iv) By considering relevant $E^{\ominus}$ values from the Data Booklet, and using balanced equations, determine whether chromium(III) ions are suitable catalyst for the reaction between I^- ions and $S_2O_8^{2-}$ ions.

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(v) Describe the structure and bonding in the element chromium. Draw a diagram to illustrate your answer.

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……[2]

(d) Chromium(III) oxide has the same acid-base behaviour as aluminium oxide.

(i) State the type of oxide chromium(III) oxide exists as in terms of its acid-base behaviour.

……[1]

(ii) By quoting relevant data from the *Data Booklet*, explain why chromium(III) oxide and aluminium oxide have the same acid-base behaviour.

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……[2]

(iii) *Use of Data Booklet is relevant to this question.*

Describe the observations when dilute NaOH is slowly added to the solution containing chromium(III) ions until in excess.

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……[2]

[Total: 20]

2 **(a)** An aqueous solution of chlorine dioxide undergoes disproportionation in sodium hydroxide to form chlorate(V) ion, ClO_3^-, and hypochlorite ion, ClO^-. The reaction is catalysed by OBr^- ion.

$$4ClO_2(aq) + 4OH^-(aq) \xrightarrow{OBr^-} 3ClO_3^-(aq) + ClO^-(aq) + 2H_2O(l)$$

To study the kinetics of this reaction at 25 °C, initial rates were measured using various concentrations of ClO_2, OH^- and OBr^-.

experiment	$[ClO_2]$/ mol dm^{-3}	$[OH^-]$/ mol dm^{-3}	$[OBr^-]$ / mol dm^{-3}	initial rate/ mol dm^{-3} s^{-1}
1	0.02	0.05	0.01	2.30×10^{-3}
2	0.10	0.02	0.03	6.90×10^{-2}
3	0.02	0.10	0.01	4.60×10^{-3}
4	0.04	0.02	0.03	1.10×10^{-2}

(i) Explain, in terms of oxidation numbers, why this reaction is a disproportionation reaction.

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……[2]

(ii) Determine the orders of reaction with respect to ClO_2, OH^- and OBr^-.

[3]

(iii) Hence, write the rate equation for the reaction.

……...[1]

(iv) Calculate the rate constant, *k*, of the reaction and state its units.

[2]

(v) Determine the initial pH of an aqueous solution of the reaction mixture if the concentration of chlorine dioxide is 0.200 mol dm^{-3} and the concentration of OBr^- is 0.1 mol dm^{-3}, given that the initial rate of reaction is 1.45 mol dm^{-3} s^{-1}.

[2]

(b) With an appropriate sketch of the Maxwell-Boltzmann distribution, explain how a rise in temperature affects the rate of reaction.

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……[3]

[Total: 13]

3 Alpha hydroxy acids (AHA) have a general formula of RCH(OH)COOH. They are a group of plant and animal-derived acids used in a variety of skincare products and are known to tackle hyperpigmentation and signs of skin aging.

(a) **(i)** Explain why AHAs are generally water-soluble.

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……[2]

(ii) Glycolic acid, $CH_2(OH)COOH$, lactic acid, $CH_3CH(OH)COOH$, and mandelic acid, $C_6H_5CH(OH)COOH$, are examples of AHA.
Suggest, with reasoning, which of the three AHAs is the most soluble in water.

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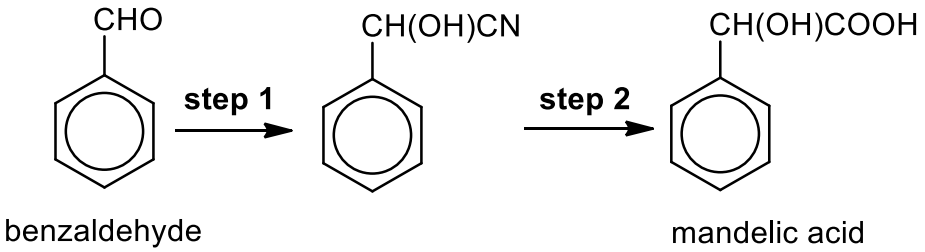
……[1]

(b) Mandelic acid can be synthesised in the laboratory from benzaldehyde by the following reactions.



(i) State the reagent and conditions used in **step 1**.

……[1]

(ii) State the type of reaction that occurs in **step 1** and **2**.

Step 1: ……

Step 2: ……

[2]

(iii) Describe the mechanism of the reaction in **step 1**. Show clearly all charges and the intermediate formed and use curly arrows to indicate the movement of electron pairs.

[3]

(iv) Predict, with reasoning, whether the product of **step 1** is able to rotate plane-polarised light.

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……...[3]

(v) A scientist carrying out the synthesis of mandelic acid would like to check if all the reactants in **step 1** have been used up.

Devise a suitable chemical test which can help him verify if all the reactants in **step 1** have been used up and include observations in your answer.

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……..[2]

(c) Glycolic acid is produced by plants during photorespiration and is recycled by conversion to glycine, H_2NCH_2COOH, within the cytoplasm. The same conversion can be done in the laboratory.

Devise a two-step synthetic route that converts glycolic acid to glycine in a laboratory. Include the reagents and conditions and the structure of the intermediate product. [3]

(d) A polypeptide made up of 10 amino acid residues is partially hydrolysed to give four smaller fragments. The four fragments are:

ala-gly-ser-gln
lys-trp-arg-pro
gln-his-lys
asp-ala-gly.

Deduce the sequence of the peptide chain.

[1]

(e) Amino acids can be neutral, positively or negatively charged, depending on the pH of the solution.

Amino acid exists as zwitterions at the isoelectric point.

(i) Define *zwitterion*.

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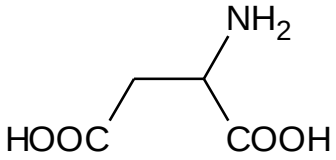
……...[1]

(ii) Aspartic acid is an α-amino acid which has the R group $-CH_2COOH$.



Aspartic acid (asp)

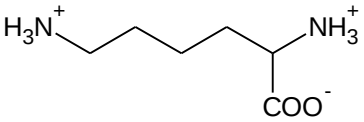
When fully protonated, the pK_a values of the acidic groups are 1.88, 3.65 and 9.60. Draw the fully protonated aspartic acid and assign the pK_a values.

[2]

(iii) Hence, draw the major species of aspartic acid at pH 5.

[1]

(iv) Aspartic acid was accidentally mixed with lysine at pH 5.



lysine at pH 5

Electrophoresis is a technique to separate the amino acids in an electric field. The sample was loaded onto an electrophoresis tank buffered at pH 5.0 and an electric field was applied.

On **Figure 3.1**, draw and label the relative positions of lysine and aspartic acid after the electrophoresis.

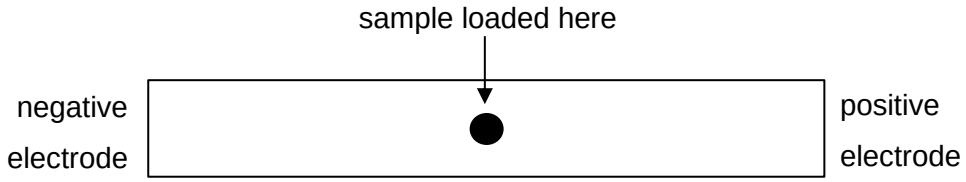


Figure 3.1

[2]

[Total: 24]

4 **(a)** Methane, CH_4 is the second major greenhouse gas after CO_2, exerting a significant influence on the climate and the chemistry of the atmosphere.

Biological methods have also been developed to produce methane from organic acids using bacteria. An example of this reaction where methane is produced from butanoic acid is shown below.

$$\_\_\_ CH_3CH_2CH_2COOH(l) + \_\_\_ H_2O(l) \rightarrow \_\_\_ CH_4(g) + \_\_\_ CO_2(g) \quad \Delta H_r$$

(i) Calculate the average oxidation state of C in each of the following carbon-containing compound.

C in $CH_3CH_2CH_2COOH$: ……..

C in CH_4: …….

C in CO_2: ……. [1]

(ii) Hence, or otherwise, balance the equation by filling in the stoichiometric coefficient in the above equation where methane is produced from butanoic acid in **(a)**. [1]

(iii) Using the thermochemical data shown in **Table 4.1**, draw a fully-labelled energy cycle to calculate the standard enthalpy change of reaction, ΔH_r in **(a)**.

Table 4.1

Standard enthalpy change of formation of liquid butanoic acid	–534 kJ mol^{-1}
Standard enthalpy change of combustion of carbon	–394 kJ mol^{-1}
Standard enthalpy change of combustion of hydrogen	–286 kJ mol^{-1}
Standard enthalpy change of formation of methane	–78.4 kJ mol^{-1}

[3]

(iv) Hence, predict the sign of ΔS for the reaction in **(a)** and explain the spontaneity of the reaction at high temperatures.

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……[2]

(b) Trouton's rule states that the entropy change of vapourisation for liquids such as benzene and hexane at their boiling points is almost the same value at around +85 to +88 J K^{-1} mol^{-1}.

However, the entropy change of vapourisation for butanoic acid is +130 J K^{-1} mol^{-1}.

Compare and explain the difference in the entropy change of vapourisation for butanoic acid and benzene.

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……[2]

[Total: 9]

5 Compounds **P**, **Q**, **R** and **S** are oxides or chlorides of Period 3 elements.

Table 5.1 shows some properties of the compounds.

Table 5.1

Compounds	Melting point	Solubility in water	pH of solution
P	High	Yes	13
Q	Low	Yes	2
R	High	Yes	6.5
S	High	No	

(a) Based on the information from **Table 5.1**, deduce the identities of compounds **P** and **R** and write the equations to justify the pH of the respective solutions.

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……[2]

(b) **S** is only soluble in hot concentrated sodium hydroxide.

Identify compound **S** and write the equation for the reaction with hot concentrated sodium hydroxide.

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……[2]

(c) When water is added to 0.0500 mol of **Q**, the resulting solution requires 0.250 mol of silver nitrate for complete reaction.
Identify compound **Q** and write the equations to show:

- its reaction with water
- the reaction between the resulting solution and silver nitrate

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……[3]

(d) The melting point of compound **P** is 1132 ^{o}C while that of potassium carbonate is 891 ^{o}C. Explain the difference in the melting points in terms of structure and bonding.

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[Total: 9]

END OF PAPER 2

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