Candidate Name: _____

Class	Adm No

H

millennia institute

2025 Preliminary Examination
Pre-University 3

H2 CHEMISTRY **9729/03**

Paper 3 Free Response **15 Sep 2025**

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 in the spaces provided on the Question Paper. If additional space is required, you should use the page at the end of this booklet. The question number must be clearly shown.

Section A
Answer **all** questions.

Section B
Answer **one** question.

A Data Booklet is provided.
The use of an approved scientific calculator is expected, where appropriate.

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

Question	A			B	**Total**
	1	2	3	4 / 5	
Marks	21	16	23	20	**80**

Section A

Answer **all** the questions in this section.

1 Copper and iron are transition metals that form a wide array of complexes due to their ability to exhibit multiple oxidation states. Copper and iron complexes showcase diverse chemical and biological roles, ranging from catalysis to electrochemical processes.

(a) **(i)** State two physical properties of transition metals which differ from that of main group elements. [2]

(ii) When copper(I) oxide solid, Cu_2O was added to sulfuric acid, $H_2SO_4(aq)$, and warmed, a blue solution and a pink solid were observed. Identify the blue solution and the pink solid and write a balanced chemical equation for the reaction. [2]

(iii) Ethylenediaminetetraacetic acid (EDTA) is a compound used in chelation therapy. Suggest why $[Cu(EDTA)]^{2-}$ and $[Cu(NH_3)_4(H_2O)_2]^{2+}$ complexes have different colours. [1]

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(b) A sample of copper(II) sulfate solution was added to an excess of aqueous potassium iodide to make a 250 cm^3 solution.

$$2CuSO_4 + 4KI \longrightarrow 2CuI + I_2 + 2K_2SO_4$$

The amount of iodine produced can be found by titrating a sample of this solution with sodium thiosulfate, $Na_2S_2O_3$, solution. 25.0 cm^3 of the iodine-containing solution required 20.00 cm^3 of 0.10 mol dm^{-3} sodium thiosulfate solution for complete reaction.

$$I_2 + 2S_2O_3^{2-} \longrightarrow S_4O_6^{2-} + 2I^-$$

Calculate the amount of copper(II) sulfate present in the original sample. [2]

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(c) Chromium is also a transition metal. Potassium dichromate(VI), $K_2Cr_2O_7$, is commonly used as an oxidising agent in organic chemistry reactions. For example, a solution of $K_2Cr_2O_7$ can be used to oxidise butan-1-ol to butanoic acid.

(i) State the oxidation number of the underlined carbon in butan-1-ol, $CH_3CH_2CH_2\underline{C}H_2OH$.

[1]

(ii) By writing the oxidation and reduction half equations, construct an ionic equation for the reaction between potassium dichromate(VI) and butan-1-ol in an acidic solution. [3]

A student proposed a reaction mechanism for the oxidation of butan-1-ol and suggested that steps 1 and 2 of the mechanism are as follows:

Step 1: Protonation of butan-1-ol to form a better leaving group.

Step 2: Breaking of the C−O bond to form a carbocation.

(iii) Draw the structure of the protonated intermediate in step 1. [1]

(iv) It was found that the proposed mechanism was not feasible as the carbocation formed in step 2 was unstable. Suggest why the carbocation formed was unstable. [1]

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(d) A team of scientists is designing a power source for field sensors. The aim is to develop a sustainable electrochemical cell using abundant and recyclable materials. After consideration, the team narrows their choice of materials to zinc, copper, iron, and silver electrodes.

(i) Propose a combination of two materials that will give rise to the most efficient electrochemical cell with the highest voltage. Explain your answer and justify by means of a calculation. [3]

(ii) Draw a fully labelled diagram of the electrochemical cell proposed in **(d)(i)**, indicating clearly the direction of electron flow. [3]

(iii) State the observations observed over time as the electrochemical cell is allowed to run. [1]

(iv) Suggest one potential challenge the team of scientists might face should they proceed with large scale productions of the electrochemical cells proposed in **(d)(i)**. [1]

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[Total: 21]

2 The cracking of decane, $C_{10}H_{22}$, produces octane and ethene, as shown in the equation below.

$$C_{10}H_{22} \rightarrow C_8H_{18} + C_2H_4$$

Octane is a key chemical component of gasoline, while ethene is a common starting material for the synthesis of many two-carbon containing organic compounds. The straight-chain isomer of octane is known as n-octane and exists in the liquid state at room temperature.

(a) Highly branched alkanes are favoured in gasoline, because the branched structure makes them more resistant to 'knocking' in combustion engines compared to n-octane. This resistance to 'knocking' leads to smoother engine operation.

(i) Draw the skeletal structure and state the IUPAC name of the most highly branched isomer of n-octane. [2]

(ii) State and explain if the branched isomer in **(a)(i)** will have a higher or lower boiling point compared to n-octane. [2]

(iii) Using bond energy values from the *Data Booklet*, calculate the enthalpy change of combustion of n-octane. [3]

(iv) Suggest why the method in **(a)(iii)** will not be able to give an accurate value of the enthalpy change of combustion of n-octane. [1]

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(b) Ethene is a useful starting material for the synthesis of ethanol. The reagent for the formation of ethanol from ethene includes steam, $H_2O(g)$ and concentrated H_3PO_4 as the acid catalyst. The reaction takes place under conditions of high temperature and pressure. The ethanol produced can subsequently be used to synthesise ethyl ethanoate, in a reversible chemical reaction.

(i) Name the type of reaction when ethanol is synthesised from ethene. [1]

(ii) The reaction mechanism for the synthesis of ethanol from ethene takes place in the following steps.

Step 1: the ethene molecule acts as a nucleophile and attacks a proton from the acid catalyst, forming a carbocation intermediate.

Step 2: the water molecule attacks the carbocation, forming an oxonium ion intermediate, where an oxygen atom carries a positive charge.

Step 3: the oxonium ion from step 2 is unstable and loses a proton, resulting in the formation of ethanol. The acid catalyst is regenerated in the process.

Draw the mechanism of the synthesis reaction based on the steps above, including all curly arrows and intermediates drawn clearly. You may use HA to represent the acid catalyst. [4]

(iii) By reference to the hybridisation of the carbon atoms and orbital overlap, describe the covalent bonding in ethene with the aid of a labelled diagram. [3]

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[Total: 16]

3 Iodine is a Group 17 element that can form several ions with varying oxidation states. Iodine also plays important roles in organic and inorganic reactions.

(a) One such ion, the iodate ion, IO_3^-, contains iodine in an oxidation state of +5, and acts as an oxidising agent in chemical reactions.

(i) Draw the 'dot-and-cross' diagram of an iodate ion, IO_3^-, stating the shape clearly. [2]

The reaction between potassium iodate, KIO_3, and sodium bisulfite, $NaHSO_3$, in acidic solution was studied.

$$IO_3^-(aq) + 3HSO_3^-(aq) \rightarrow I^-(aq) + 3SO_4^{2-}(aq) + 3H^+(aq)$$

(ii) The reaction was found to be first order with respect to iodate and had a rate constant of 3.10 mol^{-1} dm^3 s^{-1} at a particular temperature.
Deduce the rate equation for the reaction between iodate and bisulfite ions. [2]

(iii) In a separate experiment, the bisulfite ions were present in excess. Sketch a labelled graph of concentration of iodate against time for this experiment. [2]

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(b) Iodine can also exhibit the oxidation state of -1, in the form of the iodide ion, I^-.

A solution containing potassium iodide, KI, was electrolysed using inert electrodes. Calculate the mass of iodine, I_2, produced at the anode when a current of 3.2 A is passed through the solution for 45 minutes. [3]

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

Iodine also reacts with chlorine to form gaseous iodine monochloride, IC*l*.

(i) Construct an energy cycle to determine the average bond energy of the I–C*l* bond in iodine monochloride, using the data given below and other data from the *Data Booklet*.

Enthalpy change of formation of IC*l* (g)	− 24 kJ mol^{-1}
Enthalpy change of sublimation of I_2 (s)	+ 62 kJ mol^{-1}

[4]

(ii) State and explain the sign of ΔS for the sublimation of iodine. [2]

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(d) Hydrogen halides can be formed through a reaction between hydrogen gas and the halogen. When sparked, the reaction takes place and eventually reaches an equilibrium. An example of this reaction is the formation of hydrogen iodide.

$$I_2(g) + H_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -11 \text{ kJ mol}^{-1}$$

(i) Platinum could be used as a heterogeneous catalyst for this reaction.
Outline the mode of action of platinum in this reaction. [3]

(ii) In addition to HI, other hydrogen halides such as HBr and HC*l* can also be produced from the reaction in **(d)**. State and explain the trend in thermal stability of the Group 17 hydrogen halides. [3]

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(e) Iodine can react with alkenes via electrophilic addition reactions. The reactivity of iodine with alkenes is lower than that of bromine in electrophilic addition reactions with alkenes. Suggest two reasons why this is so. [2]

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[Total: 23]

Section B

Answer **one** question from this section.

4 (a) Sodium fluoride reacts with concentrated sulfuric acid to form hydrogen fluoride which dissolves in water to form hydrofluoric acid, HF.

(i) An aqueous solution of HF with a concentration of 0.0100 mol dm^{-3} has a pH of 3.2 at 25 °C. Show that HF is a weak acid. Explain your answer. [2]

(ii) Suggest how the addition of sodium fluoride, NaF(s), to a solution of hydrofluoric acid, HF(aq), affects the pH of the resulting solution. [2]

(iii) A buffer solution can be made from sodium fluoride and hydrofluoric acid.

Write two equations to show how this buffer solution will react when small amount of acid or alkali are added separately to two portions of the buffer solution. [2]

(iv) Suggest why a mixture of NaC*l*(aq) and HC*l*(aq) cannot form a buffer solution. [1]

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(b) **(i)** Propose a 3-step synthesis route to synthesise phenylethylamine, $C_6H_5CH_2CH_2NH_2$, from benzene and CH_3CH_2Cl. Include all reagents and conditions used in each step and draw the structures of the intermediates clearly. [5]

(ii) Based on your answer in **(b)(i)**, suggest one reason why the yield of phenylethylamine tends to be low. [1]

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(c) **(i)** Describe the reactions of the chlorides of silicon and aluminium with water. Include the pH value of the resulting solutions and write equations where appropriate. [4]

(ii) Predict and explain the difference in melting points between Na_2O and MgO. [3]

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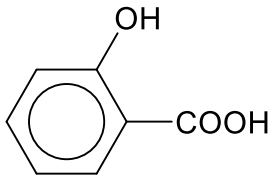
[Total: 20]

5 2-hydroxybenzoic acid, commonly known as salicylic acid, is primarily used in medicine as a key ingredient in skincare.



2-hydroxybenzoic acid

(a) Describe two simple chemical tests and state the positive observations expected, to confirm the presence of the two functional groups present in 2-hydroxybenzoic acid. [3]

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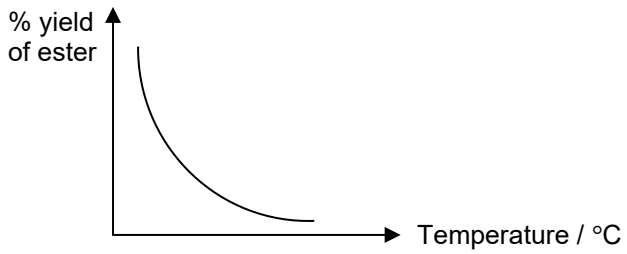
(b) 2-hydroxybenzoic acid reacts with ethanol, in the presence of concentrated H_2SO_4 catalyst in an esterification process. The esterification process is reversible and results in low yield of the ester product.

(i) Write a balanced chemical equation for the esterification process. [1]

(ii) Suggest two **different methods** to increase the yield of the ester product. Explain the chemistry behind the methods. [3]

(iii) The thermodynamics of the esterification process was investigated, and the following graph was obtained.



Use Le Chatelier's Principle to explain if the esterification process was exothermic or endothermic. [2]

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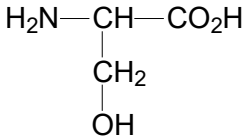
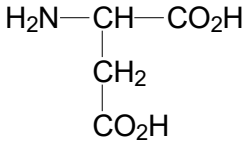
(c) The pK_a values of two amino acids are given in Table 5.1 below.

Table 5.1

	structure	pK_{a1}	pK_{a2}	pK_{a3}
ethanoic acid	CH_3COOH	4.7	–	–
serine (ser)		2.2	9.2	–
aspartic acid (asp)		1.9	3.7	9.6

(i) Suggest one reason why the pK_{a1} of serine is smaller than the pK_{a1} of ethanoic acid. [1]

(ii) Draw the structure for the dipeptide, asp–ser. [1]

(iii) A sample consisting of serine and aspartic acid was analysed by electrophoresis using a gel buffered at pH 5.7. Draw the structures of the major species present in the buffer solution at pH 5.7. [2]

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(d) **(i)** Al_2O_3 is an amphoteric oxide that can react with both acids and bases. By writing suitable balanced chemical equations, illustrate the amphoteric property of Al_2O_3 and explain why Al_2O_3 is amphoteric. [4]

(ii) Predict and explain the difference in melting points between NaC*l* and A*l*C*l*$_3$. [3]

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[Total: 20]

End of Paper 3

Additional answer space

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