Class	Adm No

Candidate Name: _____

H

millennia institute

2025 Preliminary Examination
Pre-University 3

H2 CHEMISTRY **9729/01**

Paper 1 Multiple Choice **17 Sep 2025**

1 hour

Additional materials: Multiple Choice Answer Sheet
Data Booklet

READ THESE INSTRUCTIONS FIRST

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

Write in soft pencil.

Do not use staples, paper clips, glue or correction fluid.

Write your name, class and admission number in the spaces provided at the top of this page and on the Multiple Choice Answer Sheet provided.

There are **thirty** questions on this paper. Answer **ALL** questions. For each question there are four possible answers **A**, **B**, **C** and **D**.

Choose the **one** you consider correct and record your choice in **soft pencil** on the Multiple Choice Answer Sheet provided.

Read the instructions on the Multiple Choice Answer Sheet very carefully.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.

Any rough working should be done in this question paper.

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

FOR EXAMINER'S USE	
TOTAL (30 marks)	

1 Sulfur dioxide is a preservative that can be found in small amount in wines. The sulfur dioxide content in wine can be determined through back titration.

A 25 cm^3 sample of wine is reacted with 30.0 cm^3 of 0.01 mol dm^{-3} of excess aqueous iodine, oxidising the sulfur dioxide in the wine to sulfate, SO_4^{2-}, in the process.

$$SO_2 + I_2 + 2H_2O \longrightarrow SO_4^{2-} + 4H^+ + 2I^-$$

The unreacted iodine requires exactly 24.80 cm^3 of 0.02 mol dm^{-3} sodium thiosulfate for complete reaction.

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

What is the concentration of sulfur dioxide, in mol dm^{-3}, in the wine?

A 2.08×10^{-3} **B** 2.48×10^{-3} **C** 9.92×10^{-3} **D** 2.77×10^{-2}

2 Which of the following contains approximately the same number of the stated particles as there are atoms in 18.0 g of water?

1 number of ions in 142.1 g of sodium sulfate, Na_2SO_4
2 number of molecules in 6.0 g of hydrogen gas
3 number of neutrons in 6.0 g of carbon-12

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

3 Ions of the two most common isotopes of zinc are shown below:

$$^{64}_{30}Zn^{2+} \qquad ^{66}_{30}Zn^{2+}$$

Which of the following statements is correct?

A Both these Zn^{2+} ions have the same number of electrons but different number of protons.
B Both these Zn^{2+} ions have the same electronic configuration $1s^22s^22p^63s^23p^63d^84s^2$.
C The $^{64}_{30}Zn^{2+}$ ion has fewer neutrons in its nucleus than the $^{66}_{30}Zn^{2+}$ ion.
D The $^{66}_{30}Zn^{2+}$ ion will be deflected more than the $^{64}_{30}Zn^{2+}$ ion in an electric field of the same strength.

4 The successive ionisation energies (IE) of two elements, **W** and **X**, are given below.

IE / kJ mol^{-1}	1st	2nd	3rd	4th	5th	6th	7th	8th
W	1090	2350	4610	6220	37800	47000	-	-
X	1251	2298	3822	5158	6542	9362	11018	33604

What is the likely formula of the compound that is formed when **W** reacts with **X**?

A **WX** **B** W_2X_3 **C** WX_4 **D** W_4X

5 Which of following statements are **incorrect**?

1 Any covalent compound that contains both hydrogen and oxygen in its molecule can form intermolecular hydrogen bond.

2 Ionic compounds can be distinguished from metals by their electrical conductivity in the liquid states.

3 All substances with covalent bonding have poor electrical conductivity.

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

6 Which of the following species contains the smallest bond angle?

A N_2H_4 **B** BrF_5 **C** XeF_2 **D** SO_2

7 The table below shows the standard thermodynamic values for the synthesis of hydrogen chloride:

$$H_2(g) + Cl_2(g) \longrightarrow 2HCl(g)$$

$\Delta H^{\ominus}$	−184.6 kJ mol^{-1}
$\Delta S^{\ominus}$	+20.0 J K^{-1} mol^{-1}

What is the value of $\Delta G^{\ominus}$ of the reaction?

A +179 kJ mol^{-1} **B** −179 kJ mol^{-1} **C** −185 kJ mol^{-1} **D** −191 kJ mol^{-1}

8 Which of the following has the same value as the standard enthalpy change of formation of carbon monoxide?

A $\frac{1}{2}\Delta H_c^{\ominus}$ (C(graphite))

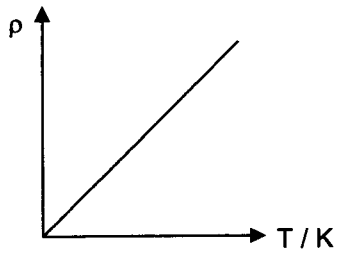
B $\Delta H_f^{\ominus}$ (CO_2) – $\Delta H_c^{\ominus}$ (C(graphite))

C $\Delta H_f^{\ominus}$ (CO_2) – $\frac{1}{2}\Delta H_c^{\ominus}$ (C(graphite))

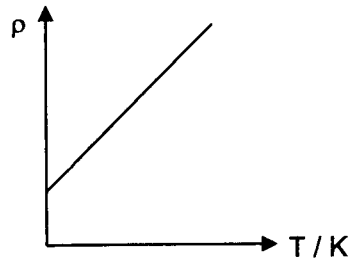
D $\Delta H_c^{\ominus}$ (C(graphite)) – $\Delta H_c^{\ominus}$ (CO)

9 Which of the following graphs shows the correct relationship between the density of a gas (ρ) against temperature (T) for an ideal gas under constant pressure?

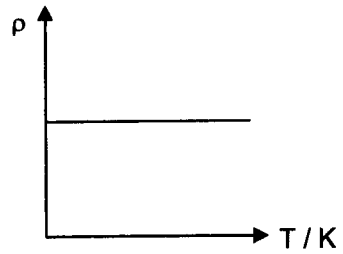
A



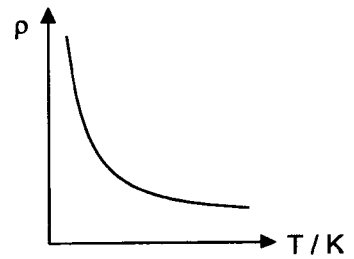
B



C



D



10 Steam reforming of methane is the main source of production of hydrogen in the industry. There are two steps in the process, both being in equilibrium in closed systems:

Step 1 $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H = +210$ kJ mol^{-1}

Step 2 $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ $\Delta H = -42$ kJ mol^{-1}

Which statement about **Step 1** and **Step 2** is correct?

A Increasing the pressure increases the equilibrium constant for **Step 2**.

B Increasing the temperature increases the equilibrium constant for **Step 1**.

C Addition of a catalyst increases both the yield and rate of production of hydrogen gas.

D Increasing the temperature decreases the rate constant for the forward reaction in **Step 2**.

11 The Contact process is an industrial process to produce sulfuric acid. One of the reactions involved is the reaction of sulfur dioxide with oxygen.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H < 0$$

Which of the following pair of changes will increase the amount of SO_3 present at equilibrium?

	temperature	pressure
A	increase	increase
B	increase	decrease
C	decrease	increase
D	decrease	decrease

12 Zinc oxide reacts with hydrogen according to the following equation.

$$ZnO(s) + H_2(g) \rightleftharpoons Zn(s) + H_2O(g)$$

At temperature T and a total pressure of 10 atm, it is found that initial amounts of 1 mole of zinc oxide and hydrogen gas each produce 0.01 mole of zinc and steam at equilibrium.

What is the approximate value of K_p at temperature T?

A 10^{-4} **B** 10^{-2} **C** 10 **D** 100

13 The reaction between hydrogen peroxide and acidified iodide ions produces iodine. This reaction can be represented by the following equation:

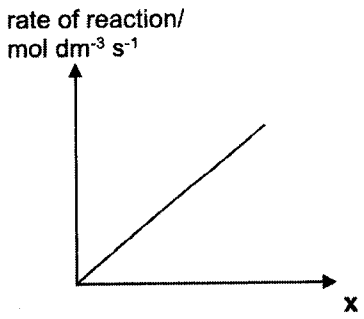
$$H_2O_2(aq) + 2H^+(aq) + 2I^-(aq) \longrightarrow I_2(aq) + 2H_2O(l)$$

Investigation of the reaction kinetics revealed that the rate equation takes the form:

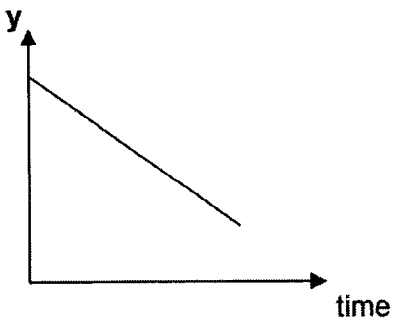
$$\text{rate} = k[H_2O_2][I^-]$$

The results of two separate series of experiments are displayed in Graph **A** and Graph **B**.

Graph **A**



Graph **B**



Which of the following shows the correct labeling of the x-axis for Graph **A** and y-axis for Graph **B**?

	x-axis for Graph **A**	y-axis for Graph **B**
A	$[H_2O_2][I^-]$ / mol^2 dm^{-6}	$[H^+]$ / mol dm^{-3}
B	$[I^-][H^+]$ / mol^2 dm^{-6}	$[I_2]$ / mol dm^{-3}
C	$[H_2O_2]$ / mol dm^{-3}	$[I^-]$/ mol dm^{-3}
D	$[H^+]$ / mol dm^{-3}	$[H_2O_2]$ / mol dm^{-3}

14 The reaction between substances **A** and **B** is found to follow the rate law

$$\text{rate} = k[\mathbf{A}]^m[\mathbf{B}]$$

where k is the rate constant and has units of $\text{mol}^{-2}\ \text{dm}^6\ \text{s}^{-1}$.

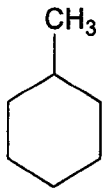
Two experiments to study the kinetics of this reaction were carried out and the data obtained are tabulated below.

Experiment	Initial [**A**] / mol dm^{-3}	Initial [**B**] / mol dm^{-3}	Initial rate / mol $\text{dm}^{-3}\ \text{s}^{-1}$
1	0.040	0.080	R
2	0.020	y	$\frac{R}{2}$

What is the value of y in experiment 2?

A 0.020 **B** 0.040 **C** 0.160 **D** 0.320

15 Methylcyclohexane can react with chlorine gas to form monochlorinated products.

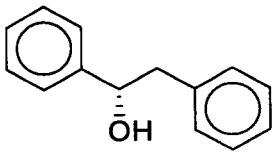


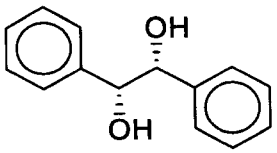
methylcyclohexane

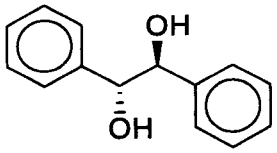
How many different constitutional isomers of monochlorinated products can be formed?

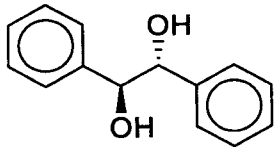
A 4 **B** 5 **C** 6 **D** 7

16 Which molecules rotate plane polarised light?

1 

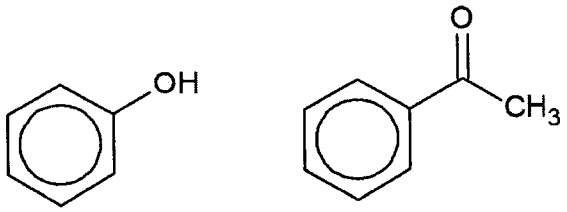
2 

3 

4 

A 1 and 2 only **B** 3 and 4 only **C** 1, 3 and 4 only **D** 1, 2, 3 and 4

17 Which of the following reagents can be used to distinguish between the two compounds below?



1 alkaline I_2(aq)

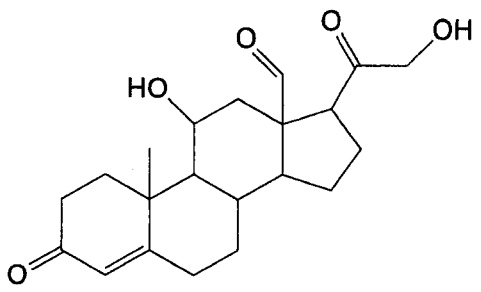
2 neutral $FeCl_3$(aq)

3 Na_2CO_3(aq)

4 2,4-dinitrophenylhydrazine

A 1 and 3 only **B** 2 and 4 only **C** 1, 2 and 4 only **D** 1, 2, 3 and 4

18 Aldosterone is a hormone essential for sodium conservation in the kidney and colon.



aldosterone

How many chiral carbons are there in the product of the reaction between aldosterone and $LiAlH_4$ in dry ether?

A 7 **B** 8 **C** 9 **D** 10

19 The molecular formula of compound **X** is $C_5H_{12}O$. **X** has the following properties:

- reacts with alkaline aqueous iodine
- can be dehydrated to form two alkenes only.

What could be the identity of **X**?

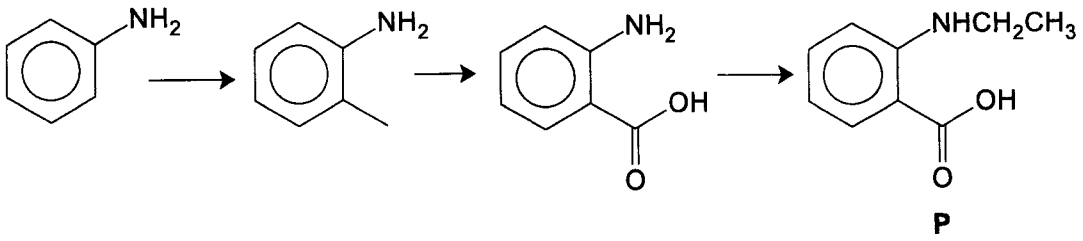
A $CH_3CH_2CH(CH_3)CH_2OH$

B $(CH_3)_2C(OH)CH_2CH_3$

C $(CH_3)_2CHCH(OH)CH_3$

D $CH_3CH_2CH_2CH(OH)CH_3$

20 The reaction scheme below shows the synthesis of compound **P** from phenylamine.



P

Which of the following types of reaction is **not** involved in the reaction scheme shown?

A electrophilic substitution
B nucleophilic addition
C nucleophilic substitution
D oxidation

21 What is produced when $CH_3NHCH_2CONH_2$ is added to an excess of $H_2SO_4(aq)$ and heated?

A $CH_3\overset{+}{N}H_2CH_2CONH_2$
B $CH_3\overset{+}{N}H_2CH_2CO_2H$
C $CH_3NHCH_2C\overset{+}{O}NH_3$
D $CH_3\overset{+}{N}H_2CH_2COO^-$

22 Which of the following statements about the theories of acids and bases is true?

A All Arrhenius acids can behave as Lewis acids.
B All Brønsted-Lowry bases can behave as Arrhenius bases.
C All Lewis acids can behave as Arrhenius acids.
D All Lewis bases can behave as Arrhenius bases.

23 Paracetamol (pK_a = 9.5) is a widely used over-the-counter pain reliever and fever reducer. Its solubility in water is 12.78 g dm^{-3} at 25 °C.

What is its pH of a saturated solution of paracetamol at 25 °C?

[M_r of paracetamol = 151.0]

A 4.20 **B** 5.29 **C** 6.79 **D** 8.71

24 Soap scum is a white residue that forms when soap reacts with minerals such as Ca^{2+} in hard water. Soap scum forms when the concentration of Ca^{2+} ions in water is greater than 10^{-5} mol dm^{-3}.

What is the minimum mass of sodium carbonate that should be added to 1 dm^3 of water to prevent soap scrum from being formed?

[K_{sp} $CaCO_3$ = 5.0 × 10^{-9} mol^2 dm^{-6}]

A 0.037 g **B** 0.042 g **C** 0.050 g **D** 0.053 g

25 Which compound dissolves in water to give a solution with the lowest pH?

A SO_3 **B** P_4O_{10} **C** $MgCl_2$ **D** Al_2O_3

26 Which property generally increases down for elements in Group 2?

A charge density of the M^{2+} ion
B electronegativity
C first ionisation energy
D thermal stability of the carbonate

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

Electric cars use zinc-air battery with one electrode made up of zinc and the other is a carbon electrode. During discharge, zinc dissolves as ions. At the carbon electrode, hydroxide ions are formed. Zinc ions then react with the hydroxide ions, forming solid zinc hydroxide.

Which statements about this cell are correct?

1 The e.m.f of the cell is +1.16V.
2 The overall cell reaction is $2Zn + O_2 + 2H_2O \rightarrow 2Zn(OH)_2$.
3 Overall pH of the solution does not change at the end of the reaction.

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

28 Electrolysis of a dilute hydrochloric acid solution was carried out by passing a current of 0.1 A through it.

How long will it take to liberate 0.01 mol of H_2 gas at the cathode?

A 9.65×10^3 s
B 1.93×10^4 s
C 2.90×10^4 s
D 3.86×10^4 s

29 Which of the following species cannot act as a ligand in the formation of complexes?

A CH_3NH_2 **B** Cl^- **C** NH_4^+ **D** OH^-

30 When drops of $NH_3(aq)$ are added to $Cu(NO_3)_2(aq)$, a pale blue precipitate is formed. This precipitate dissolves when an excess of $NH_3(aq)$ is added, giving a dark blue solution.

Which of the following process does **not** occur?

A ligand exchange
B acid-base reaction
C reduction of Cu^{2+} ions
D formation of a complex ion

END OF PAPER 1

Class Adm No

Candidate Name: _____

H

millennia institute

2025 Preliminary Examination
Pre-University 3

H2 CHEMISTRY **9729/02**

Paper 2 Structured Questions **3 September 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.

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	/13	/14	/12	/12	/24	/75

For Examiners' Use

1 The fire triangle (Fig 1.1), shows the three components necessary for combustion. Disrupting any one of these components can suppress or extinguish a fire.

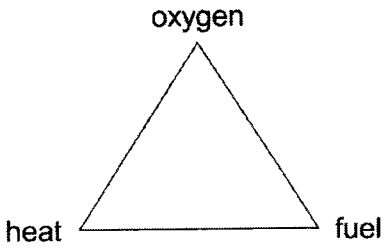


Fig 1.1

Fire retardants are substances added to materials to reduce flammability by disrupting the fire triangle.

(a) Magnesium hydroxide, $Mg(OH)_2$, is an example of an inorganic fire retardant. It undergoes thermal decomposition upon heating and releases water vapour in the process.

(i) Write a balanced equation for the thermal decomposition of magnesium hydroxide. State symbols are **not** required.

.....[1]

(ii) With reference to the components in Fig 1.1, suggest one way in which this decomposition reaction helps to suppress a fire.

.....

.....

.....

.....[1]

Aluminium hydroxide, $Al(OH)_3$ is also a good fire retardant. It undergoes thermal decomposition in the same way as magnesium hydroxide.

(iii) Explain why the thermal decomposition temperature of $Al(OH)_3$ is lower than that of $Mg(OH)_2$.

.....

.....

.....

.....

.....[2]

(iv) Hence, explain whether $Al(OH)_3$ would be a better fire retardant compared to $Mg(OH)_2$.

.....

.....

.....[1]

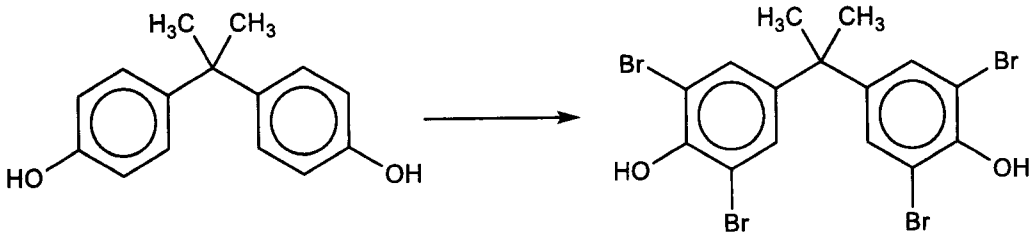
(b) Halogenated fire retardants often use bromine or chlorine derivatives and they release hydrogen halides or halogen radicals upon decomposition which disrupt free radical chain reactions that sustain combustions.

(i) One method of preparing brominated organic compounds is free radical substitution.

Draw the mechanism for the formation of bromomethane from methane.

[3]

Tetrabromobisphenol A (TBBPA) is a common brominated flame retardant. It can be made from bisphenol A (BPA) in a single step reaction, as shown in Fig. 1.2.

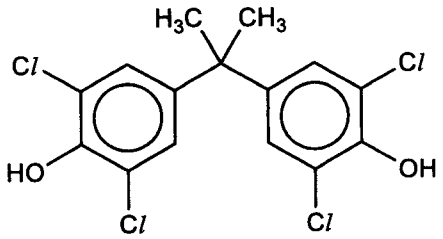


BPA TBBPA

Fig 1.2

(ii) State the reagent and conditions required to convert BPA to TBBPA.

.....[1]



TCBPA

Tetrachlorobisphenol (TCBPA) is the chlorinated analogue of TBBPA, where the bromine atoms are replaced with chlorine.

(iii) Using relevant data from the *Data Booklet*, explain the difference in strength between C–C*l* and C–Br.

.....

.....

.....

.....

.....[2]

(iv) Hence, explain whether TCBPA would be a better flame retardant than TBBPA.

.....

.....

.....[1]

(c) Despite their effectiveness, halogenated fire retardants such at TBBPA are being phased out due to concerns over the release of toxic persistent organic pollutants during fires.

Suggest one reason why $Mg(OH)_2$ is considered a safer alternative to halogenated fire retardants.

.....

.....

.....[1]

[Total: 13]

For Examiners' Use

2 **(a)** Lead(II) sulfate, $PbSO_4$, is a sparingly soluble white solid that was historically used as a pigment in paints.

(i) Write an expression for the solubility product, K_{sp}, of $PbSO_4$, stating its units.

.....[1]

(ii) Calculate the solubility of $PbSO_4$ in pure water, given the value of K_{sp} is 1.60×10^{-8}.

[1]

(iii) A common method used by early artists to prepare $PbSO_4$ was to mix solutions of Na_2SO_4 and $Pb(NO_3)_2$.

A solution of 0.0200 mol dm^{-3} $Pb(NO_3)_2$ was mixed with an equal volume of Na_2SO_4 to prepare $PbSO_4$.

Calculate the minimum concentration of Na_2SO_4 required for $PbSO_4$ to be formed.

[2]

(b) Due to the increased awareness of the toxicity of lead compounds, titanium dioxide, TiO_2, is now widely used as a non-toxic alternative to $PbSO_4$ in white pigments by modern artists.

(i) Write the full electronic configuration of the titanium ion in TiO_2.

.....[1]

(ii) Explain what is meant by the term *transition element*.

.....

.....[1]

(iii) Explain why TiO_2 appears white despite containing a transition element.

.....

.....

.....

.....

.....[2]

(c) Copper obtained from the extraction of copper ores is often impure and contains small amounts of other metals such as zinc, silver and lead.

To obtain high purity copper for electrical use, impure copper is placed at the anode and a pure copper rod is placed at the cathode in an electrolytic cell. The electrolyte used is aqueous copper(II) sulfate.

(i) Write the half equation for the reaction occurring at the anode for copper.

.....[1]

(ii) Using relevant data from the *Data Booklet*, explain how zinc and silver impurities are removed during the purification process.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....[3]

While the lead impurity was expected to dissolve into the electrolyte as Pb^{2+} ions, it was instead found in the anodic sludge as a compound.

(iii) State the identity of the compound and explain how it was formed.

.....

.....

.....[2]

[Total: 14]

3 Advanced Oxidation Processes (AOPs) are used to degrade organic pollutants in wastewater through the formation of highly reactive hydroxyl radicals (•OH).

For Examiners' Use

Two examples of AOPs are the Fenton reaction and the UV/H_2O_2 process which generate hydroxyl radicals (•OH) from H_2O_2 that is mixed in with the wastewater.

In the Fenton reaction, hydrogen peroxide reacts with iron(II) ions in acidic solution to generate hydroxyl radicals (•OH) as well as hydroperoxyl radicals (•OOH).

step 1: $Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + \bullet OH$

step 2: $Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + H^+ + \bullet OOH$

It is known that •OH is much more reactive than •OOH and is mainly responsible for the oxidation of organic pollutants.

In fact, •OH is so reactive that it reacts with hydrogen peroxide to form •OOH (reaction 3.1).

reaction 3.1 $\bullet OH + H_2O_2 \rightarrow \bullet OOH + H_2O$

(a) Write the overall equation for the Fenton reaction.

.....[1]

(b) It is said that Fe^{2+} acts as a catalyst in the Fenton reaction.

(i) Explain how you can tell that Fe^{2+} is acting as a catalyst in this reaction.

.....

.....[1]

(ii) State whether Fe^{2+} acts as a homogeneous or heterogeneous catalyst in the Fenton reaction. Explain your answer.

.....

.....[1]

(c) Suggest a reason why the Fenton reaction is less effective at high pH values.

.....

.....

.....[1]

(d) Explain, with the aid of a labelled Boltzmann distribution curve, how increasing the temperature increases the effectiveness of the Fenton reaction.

.....

.....

.....

.....[3]

(e) It was observed that the effectiveness of the degradation of organic pollutants decreased when the concentration of H_2O_2 exceeded its optimal level.

Suggest a reason for this observation.

.....

.....

.....[1]

In the UV/H_2O_2 process, short wavelength UV C radiation produced by UV lamps penetrates the solution and decomposes H_2O_2 to form hydroxyl radicals (reaction 3.2).

reaction 3.2 $H_2O_2 \rightarrow 2\ {\bullet}OH$

(f) State the type of bond fission that occurs in reaction 3.2 when hydrogen peroxide is decomposed by UV light to form hydroxyl radicals.

.....[1]

(g) At times, the wastewater may be turbid due to the presence of suspended particles.

Explain why the UV/H_2O_2 process may be less effective in turbid water.

.....

.....

.....[1]

Table 3.1 compares selected characteristics of the two processes.

Table 3.1

process	reagents required	pH range	byproduct
Fenton	Fe^{2+} and H_2O_2	~2.8	$Fe(OH)_3$ sludge
UV/H_2O_2	H_2O_2	5–9	None

(h) State one advantage and one disadvantage that the UV/H_2O_2 process has over the Fenton reaction.

.....

.....

.....

.....

.....[2]

[Total: 12]

For Examiners' Use

4 **(a)** The process of rusting begins with the formation of iron(II) hydroxide when iron is exposed to air and moisture. The iron(II) hydroxide is further oxidised to iron(III) hydroxide and eventually forms iron(III) oxide, Fe_2O_3, commonly known as rust.

(i) Explain why the Fe^{2+} ion is smaller than the Fe atom.

.....

.....

.....[1]

(ii) Using relevant data from the *Data Booklet*, explain why the oxidation of iron to iron(II) ions is spontaneous in the presence of air and moisture.

.....

.....

.....

.....

.....

.....

.....[2]

(iii) Explain how the formation of $Fe(OH)_2$ causes the actual cell potential to be more positive than the value you calculated in **(a)(ii)**.

.....

.....

.....

.....

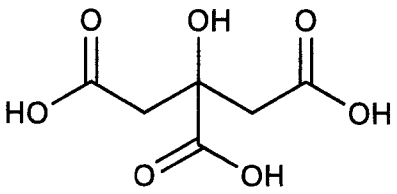
.....

.....

.....[2]

(b) A student investigates if lemon juice can be used to clean rusted iron surfaces.

Lemon juice contains citric acid, a weak acid.



citric acid

(i) Explain what is meant by a *weak acid*.

.....

.....[1]

(ii) Rust reacts with citric acid to form soluble iron(III) ions.

Write a balanced equation for the reaction of Fe_2O_3 with citric acid. Include state symbols in your equation. You may use H^+ to represent the acid from citric acid.

.....[1]

Subsequently, citrate ions (Cit) act as tridentate ligands and bind to the iron(III) ions to form a soluble iron(III) citrate complex, $[Fe(Cit)_2]^{x-}$.

Fig 4.1 shows the structure of $[Fe(Cit)_2]^{x-}$.

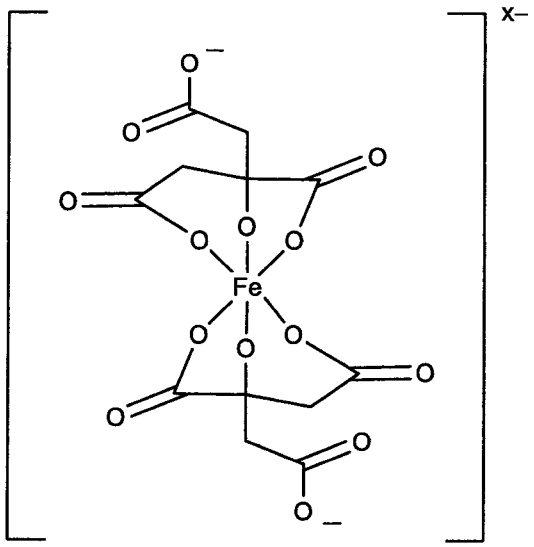


Fig. 4.1

(iii) Give two reasons why Fe^{3+} is able to form complexes with ligands such as citrate ions.

.....

.....

.....

.....

.....

.....[2]

(iv) State the coordination number of Fe^{3+} in $[Fe(Cit)_2]^{x-}$.

.....[1]

(v) State the charge on the citrate ligand in $[Fe(Cit)_2]^{x-}$.

.....[1]

(vi) Hence, determine the value of x in $[Fe(Cit)_2]^{x-}$.

.....[1]

[Total: 12]

For Examiners' Use

5 (a) Ring strain in cycloalkanes arises when the bond angles in the molecules deviate from their ideal tetrahedral angle of 109.5°.

Cyclohexane, C_6H_{12}, is considered largely strain free while smaller cycloalkanes like cyclopropane, C_3H_6, experience significant ring strain.

The ring strain represents stored potential energy that contributes to the molecule's enthalpy change of combustion, a factor of significant interest in fuel research aimed at identifying high-energy-density compounds.

Table 5.1 shows the enthalpy change of combustion of gaseous cyclohexane and cyclopropane.

Table 5.1

compound	enthalpy change of combustion, ΔH_c / kJ mol^{-1}
cyclohexane(g)	–3887
cyclopropane(g)	–2091

(i) Write a balanced equation for the complete combustion of gaseous cyclohexane.

.....[1]

(ii) Using the information given in Table 5.1, calculate the average heat released per CH_2 group for gaseous cyclohexane in kJ mol^{-1} .

[1]

(iii) Using your answer to **(a)(ii)**, calculate the theoretical enthalpy change of combustion of cyclopropane, assuming it has no ring strain.

[1]

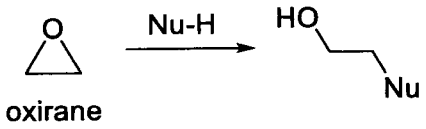
(iv) Hence, calculate the ring strain energy present in one mole of cyclopropane.

[1]

(b) An epoxide contains a three-membered ring compound consisting of two carbon atoms and one oxygen atom. Since it experiences the same ring strain as cyclopropane, it is highly reactive towards nucleophiles. The simplest epoxide is oxirane, C_2H_4O.

When oxirane reacts with nucleophiles, the ring opens as shown in reaction 5.1.

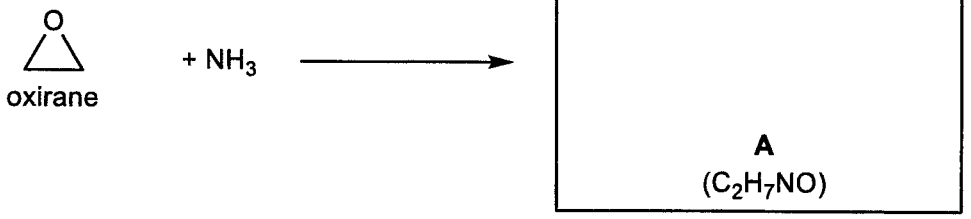
reaction 5.1

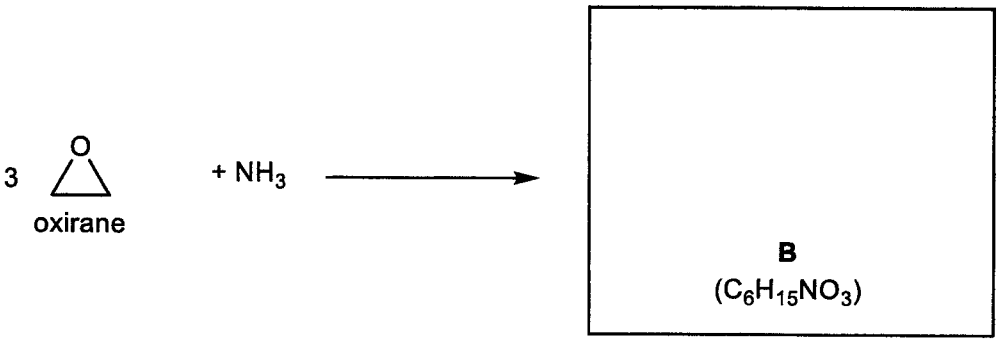


oxirane

(i) When oxirane reacts with NH_3 in a 1:1 ratio, compound **A** (C_2H_7ON) is formed. However, when oxirane reacts with NH_3 in a 3:1 ratio, compound **B** ($C_6H_{15}NO_3$) is formed.

Draw the structures of **A** and **B**.





[2]

Epichlorohydrin is a useful epoxide used in the manufacture of epoxy resins. It can be prepared from 3-chloro-1-propene by a sequence of reactions as shown in Fig 5.1.

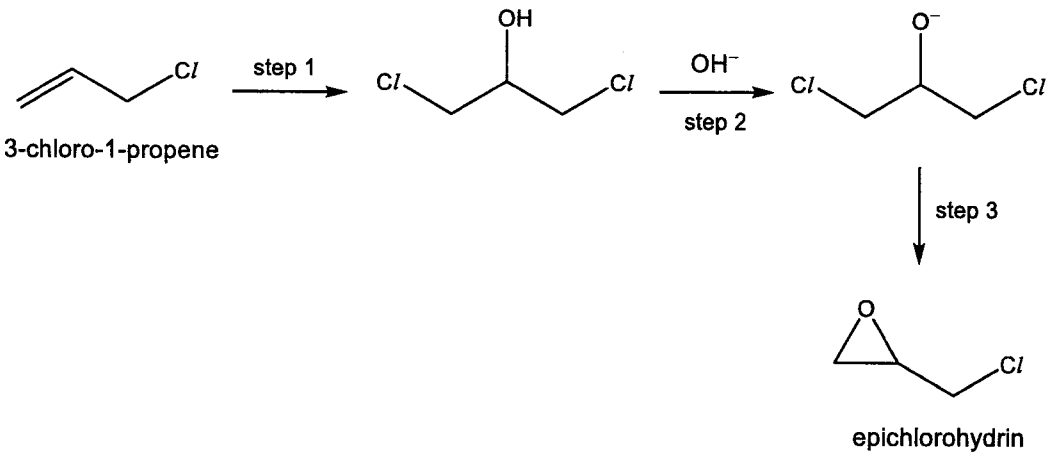


Fig 5.1

(ii) State the reagent and conditions required for step 1.

.....[1]

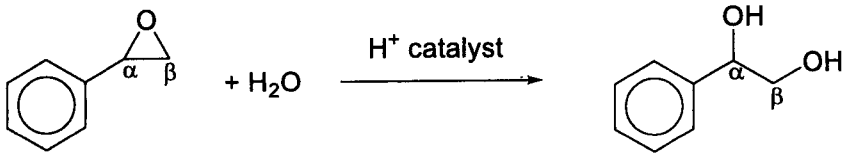
(iii) State the type of reaction for step 2 and step 3.

step 2 : .....

step 3 : .....

[2]

(c) The acid–catalysed hydrolysis of styrene epoxide forms 1-phenyl-1,2-ethanediol as seen in Fig 5.2.



styrene epoxide

1-phenyl-1,2-ethanediol

Fig 5.2

A student proposed that the reaction proceeds via the following mechanism:

step 1: The protonation of the O atom in the epoxide by H^+ catalyst.

step 2: A nucleophilic attack by H_2O on the carbon of the epoxide leading to the opening of the ring.

step 3: The deprotonation of the H_2O^+ group forming the diol and regenerating the H^+ catalyst.

(i) Based on your understanding of steric hindrance, circle the carbon, α or β, on styrene epoxide that would be attacked by the H_2O nucleophile in Fig 5.2. [1]

Isotopic labelling is used in kinetic studies to learn about the mechanisms of a reaction. $H_2{}^{18}O$ is a water molecule that contains ^{18}O instead of ^{16}O. The hydrolysis reaction was carried out with $H_2{}^{18}O$ as the nucleophile.

A study of the hydrolysis products revealed that all ^{18}O were incorporated in the α-position. The conclusion drawn was that a stable carbocation intermediate must have formed before the nucleophilic attack by $H_2{}^{18}O$.

(ii) Suggest the structure of the carbocation intermediate formed and explain why it is stable.

.....

.....

.....

.....[2]

(d) Nitrocellulose is produced by reacting cellulose with a nitrating mixture of concentrated nitric acid and concentrated sulfuric acid.

Sulfuric acid donates a proton to nitric acid from to form an intermediate, $H_2NO_3^+$. This intermediate then decomposes to form the nitronium ion, NO_2^+. The NO_2^+ generated then reacts with the alcohol groups of cellulose to form nitrocellulose.

(i) Write the equation for the decomposition of the intermediate to form the nitronium ion.

.....[1]

(ii) Draw the dot-and-cross diagram of the nitronium ion and hence state its shape.

shape:.....

[2]

The empirical formula of nitrocellulose is $C_6H_7O_{11}N_3$. Complete combustion of nitrocellulose produces carbon dioxide, water vapour and nitrogen.

(iii) Balance the combustion equation of nitrocellulose with the correct stoichiometric coefficients.

$$\ldots\ldots C_6H_7O_{11}N_3 + \ldots\ldots O_2 \rightarrow \ldots\ldots CO_2 + \ldots\ldots H_2O + \ldots\ldots N_2$$

[1]

(iv) During magic performances, magicians often use nitrocellulose as flash paper to produce dramatic flashes of flame without leaving a mess.

Suggest why nitrocellulose is suitable for this purpose.

.....

.....[1]

(v) State two main assumptions of the kinetic theory as applied to an ideal gas.

.....

.....

.....

.....

.....

.....[2]

(vi) Complete Table 5.2 by identifying the most significant type of intermolecular force of attraction present between each of the gas molecules formed during the combustion of nitrocellulose.

Table 5.2

Gas	most significant intermolecular force of attraction
CO_2	
H_2O	
N_2	

[2]

(vii) Arrange the three gases, CO_2, H_2O and N_2, in order of increasing deviation from ideal gas behaviour at 400 K. Explain your answer.

..... < .... < .....

.....

.....

.....

.....

.....

.....

.....

.....[3]

[Total: 24]

BLANK PAGE

Class Adm No

Candidate Name: _____

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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

[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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

[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]

(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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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]

.....

.....

.....

.....

.....

.....

[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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

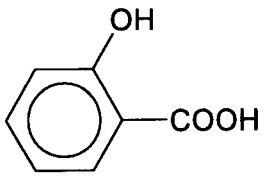
.....

.....

.....

[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]

.....

.....

.....

.....

.....

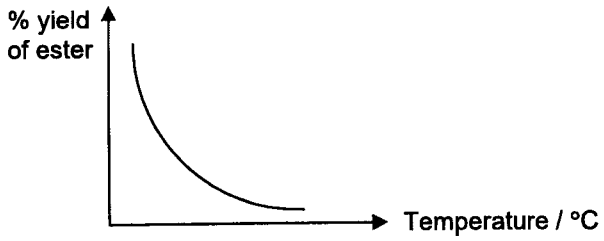
.....

(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]

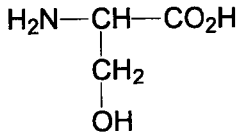
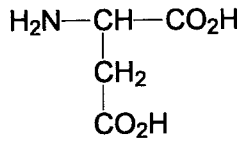
.....

.....

.....

(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]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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 NaCl and $AlCl_3$. [3]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

[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.