



VICTORIA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME **ANSWERS**

CT GROUP

CHEMISTRY

9729/03

Paper 3 Free Response

17 September 2025

2 hours

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and CT group on this cover page.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Answer all questions in the spaces provided on the Question Paper.
If additional space is required, you should use the pages 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.

For Examiner's Use	
1	/ 20
2	/ 20
3	/ 20
4	/ 20
5	/ 20
Total	/ 80

This document consists of **23** printed pages and **1** blank page.

Section A

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

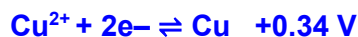
- 1 (a) Potassium is a highly reactive alkali metal that must be stored under oil, while copper is a much less reactive metal that resists corrosion.

Table 1.1 shows the melting points of both metals.

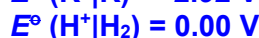
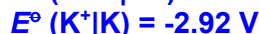
Table 1.1

metal	Melting point / °C
K	63.5
Cu	1085

- (i) Copper does not react with most dilute acids, unlike potassium. With reference to the standard electrode potentials in the *Data Booklet*, explain why this is so. [2]



Or



Copper is unable to react with dilute acids.

For copper, $E^\circ_{\text{cell}} = (0 - 0.34) = -0.34 \text{ V} < 0$ (not spontaneous)

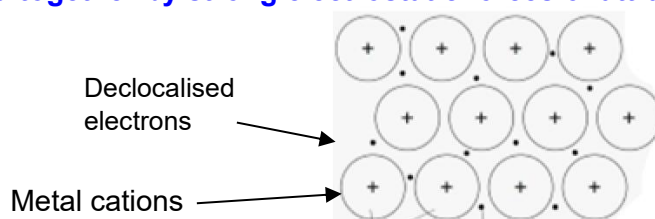
Potassium can react with acid to produce H_2 gas.

For potassium, $E^\circ_{\text{cell}} = (0 - (-2.92)) = 2.92 \text{ V} > 0$ (spontaneous)

- Quote & calculation of E°_{cell}
- Explanation

- (ii) Describe with the aid of a labelled diagram the structure of copper at room temperature. [2]

- Copper has a giant metallic structure which is a three-dimensional arrangement of positive copper ions surrounded by delocalised electrons, held together by strong electrostatic forces of attraction.



- (iii) Suggest why the melting point of copper is significantly higher than that of potassium as shown in Table 1.1. [2]

- Potassium can only delocalise its single 4s electron while copper is able to delocalized electrons from both its 4s and 3d subshells.

- Copper forms ions with smaller ionic radius with greater charge. This leads to the stronger metallic bonds in copper which required more energy to break.

(iv) Fig. 1.1 shows the first ionisation energies for the elements K to Cu.

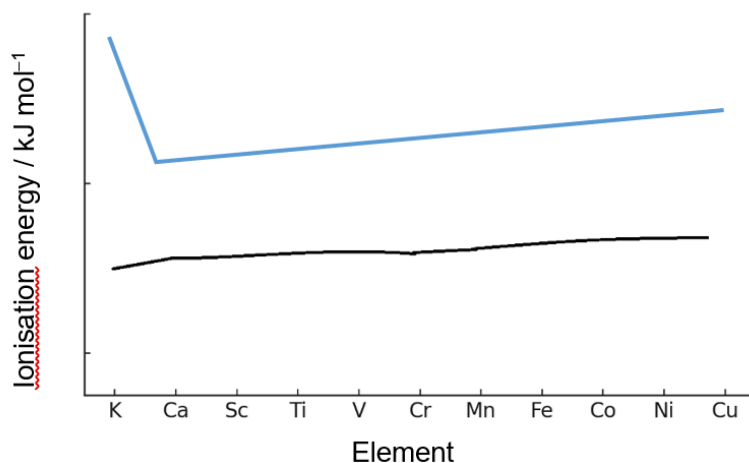


Fig 1.1

Explain why the first ionisation energy remains relatively constant from scandium to copper. [2]

From Sc to Cu,

the number of protons increases, hence the nuclear charge increases.

- Additional electron enters the penultimate 3d subshell and shielding effect increases slightly.
 - The increase in nuclear charge is partially nullified by the increase in shielding effect leading to insignificant increase in effective nuclear charge across the period.
- Hence the 1st ionisation energy remains relatively constant.

(v) Using your knowledge in the variation of first ionisation energy of the elements from potassium to copper, sketch the trend of the second ionisation energies on Fig 1.1. [1]

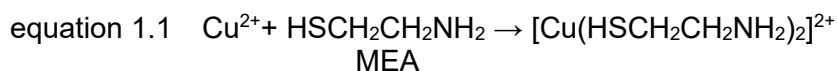
- Shape decrease from K to Ca AND Ca to Cu gentle upward sloped or horizontal line.

(b) Copper is a transition element which form many different complexes.

(i) Explain what is meant by the term *transition element*. [1]

- Transition element is a d-block element which forms one or more stable ions with partially filled d subshell.

(ii) Copper(II) ions form a coloured *complex* with mercaptoethylamine, MEA, a bidentate *ligand* as shown in equation 1.1.



With reference to the complex in equation 1, explain what is meant by the term *ligand*. [1]

- **HSCH₂CH₂NH₂ ligand has lone pair of electrons on S and N atom that can be donated to the empty 3d orbitals of Cu²⁺ by dative covalent bonds to form complex.**

(iii) Explain why complexes of copper(II) are usually coloured. [3]

- **The degenerate 3d orbitals in Cu²⁺ octahedral complex is split into 2 different energy levels due to the presence of ligands (d-d splitting).**
- **d-d transition took place whereby a 3d electron from the lower energy level is promoted to the upper energy level by absorbing energy from the visible region of the electromagnetic spectrum.**
- **The colour seen is the complement of the colour absorbed.**

(c) Polymerisation is a process where small molecules called monomers are combined to form larger polymer chains. Polymers are large molecules made of many repeat units.


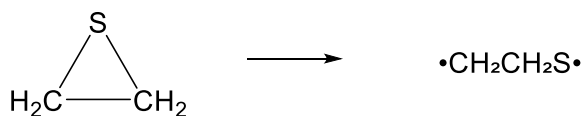
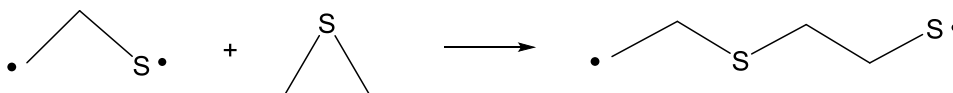
Thiirane, , can undergo free radical ring-opening polymerisation in the presence of a radical initiator, benzoyl peroxide and an excess of dodecanol, CH₃(CH₂)₁₀CH₂OH.

Fig. 1.2 shows a proposed mechanism via three reactions.

Reaction 1: Homolytic fission of a C–S bond in thiirane, generating a ‘double-ended’ free radical, •CH₂CH₂S•, that initiates a chain reaction.



Reaction 2: A chain reaction occurs where the ring opens and units of •CH₂CH₂S• adds to a growing chain. Repeated steps involve production of other free radicals.

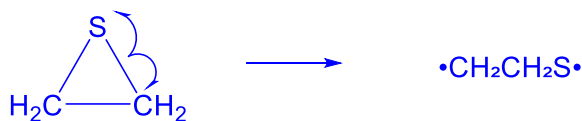


Reaction 3: Termination with dodecanol to form CH₃(CH₂)₁₀CH₂–O–(CH₂CH₂S)_n–H.

Fig 1.2

(i) Use curly arrows to show the movement of electrons which occur in reactions 1 and reaction 2 on Fig. 1.2. [2]

Reaction 1:



Reaction 2:



Correct arrows for each step 1 mark.

- (ii) Suggest why thiirane undergoes the reaction more easily as compared to $(\text{CH}_3)_2\text{S}$. [1]

- Three membered ring is unstable due to ring strain.

- (e) The three compounds in Table 1.1 behave as monoprotic acids in aqueous solution.

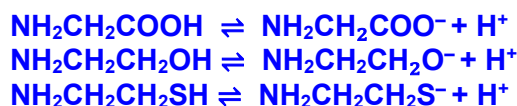
Table 1.2

name	formula
MEA	$\text{NH}_2\text{CH}_2\text{CH}_2\text{SH}$
glycine	$\text{NH}_2\text{CH}_2\text{COOH}$
ethanolamine	$\text{NH}_2\text{CH}_2\text{CH}_2\text{OH}$

Arrange the compounds in order of increasing acidity. Explain your answer.

[3]

Glycine < MEA < ethanolamine



- Glycine is acidic as the negative charge is dispersed over COO^- . Conjugate base ($-\text{COO}^-$) is stabilised and position of equilibrium lies most to the right favouring formation of more H^+ .
- The conjugate bases of ethanolamine and MEA are less stable as negative charge is intensified on O and S atoms by electron donating inductive effect of alkyl group.
- The negative charge on S atom in MEA is dispersed to a greater extent due to the larger atomic radius as compared to O in ethanolamine. $\text{NH}_2\text{CH}_2\text{CH}_2\text{S}^-$ is more stable than $\text{NH}_2\text{CH}_2\text{CH}_2\text{O}^-$. Hence $\text{NH}_2\text{CH}_2\text{CH}_2\text{SH}$ is more acidic than $\text{NH}_2\text{CH}_2\text{CH}_2\text{OH}$.

1m for strong acid forms more stable anions, hence greater dissociation.
1m for anions being most stabilised by charge dispersal in carboxylate
1m for correctly comparing O and S in dispersing the charge and hence correct sequence.

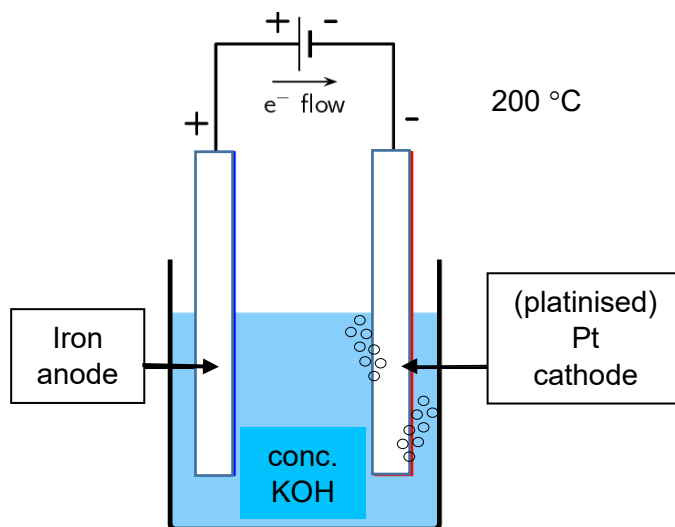
[20 marks]

- 2 Oxidation is one of the important processes for the disinfection of water and wastewater treatment.

Ferrate ions, FeO_4^{2-} , are effective disinfectants, superior to many common oxidants, such as chlorine dioxide, hydrogen peroxide and manganate(VII) ions.

- (a) The electrochemical synthesis of ferrate ions usually consists of a sacrificial iron anode and an inert cathode in an electrolytic cell containing a highly concentrated alkaline solution of potassium hydroxide.

- (i) Draw a labelled diagram of the electrolytic cell used to synthesise ferrate ions. Include details of the electron flow, cathode, anode and electrolyte. [3]



- **Electrolytic cell with battery shown**
- **Correct labelling of anode, cathode, conc. KOH**
- **Correct electron flow**

- (ii) Write the half-equation for the formation of FeO_4^{2-} at the anode. [1]

- **Anode: $\text{Fe} + 8\text{OH}^- \rightarrow \text{FeO}_4^{2-} + 4\text{H}_2\text{O} + 6\text{e}^-$**

- (iii) Effervescence was observed at the cathode.

Suggest the product formed at the cathode, including the relevant half-equation. Explain your answer. [2]

- **H_2 is formed at the cathode as H_2O undergoes reduction more readily compared to K^+ as indicated by its more positive E° value.**
- **$2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$**

- (iv) Hence construct the equation for the overall reaction for the electrochemical synthesis of ferrate ions. [1]

- **$\text{Fe} + 2\text{OH}^- + 2\text{H}_2\text{O} \rightarrow \text{FeO}_4^{2-} + 3\text{H}_2 + \text{H}_2\text{O}$**

- (v) In an electrolytic cell above, mass of anode decreased by 0.605 g after 30 minutes.

Assume 100% purity of iron at the anode, determine the current of this cell. [2]

- amount of Fe oxidised = $\frac{0.605}{55.8} = 1.08 \times 10^{-2} \text{ mol}$

Mole ratio of Fe : e^- = 1 : 6

- $Q = n_e \times F = 1.08 \times 10^{-2} \times 6 \times 96500 = 6277.7 \text{ C}$

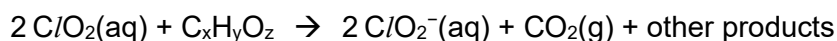
- $I = \frac{Q}{t} = \frac{6277.7}{30 \times 60} = 3.49 \text{ A}$

- (vi) Numerous research reported a maximum current efficiency of ferrate ion production in 14 mol dm^{-3} KOH solution. When the concentration of KOH approaches its saturated value of around 20 mol dm^{-3} , the electrolyte solution will become very viscous, resulting in a lower rate of ferrate ion produced.

Suggest a reason for the lower rate of production of ferrate ions. [1]

- The electrical conductivity of the solution declines as it is more viscous, the electron carriers are less mobile.

- (b) Chlorine dioxide, ClO_2 , is also used in the treatment of wastewater to oxidise organic pollutants. A simplified overall reaction is:



To investigate the kinetics of this reaction, x mol of ClO_2 was reacted with a large excess of $\text{C}_x\text{H}_y\text{O}_z$ in 400 cm^3 of solution. Fig 2.1 shows the volume of CO_2 , measured at r.t.p., produced over time by this reaction.

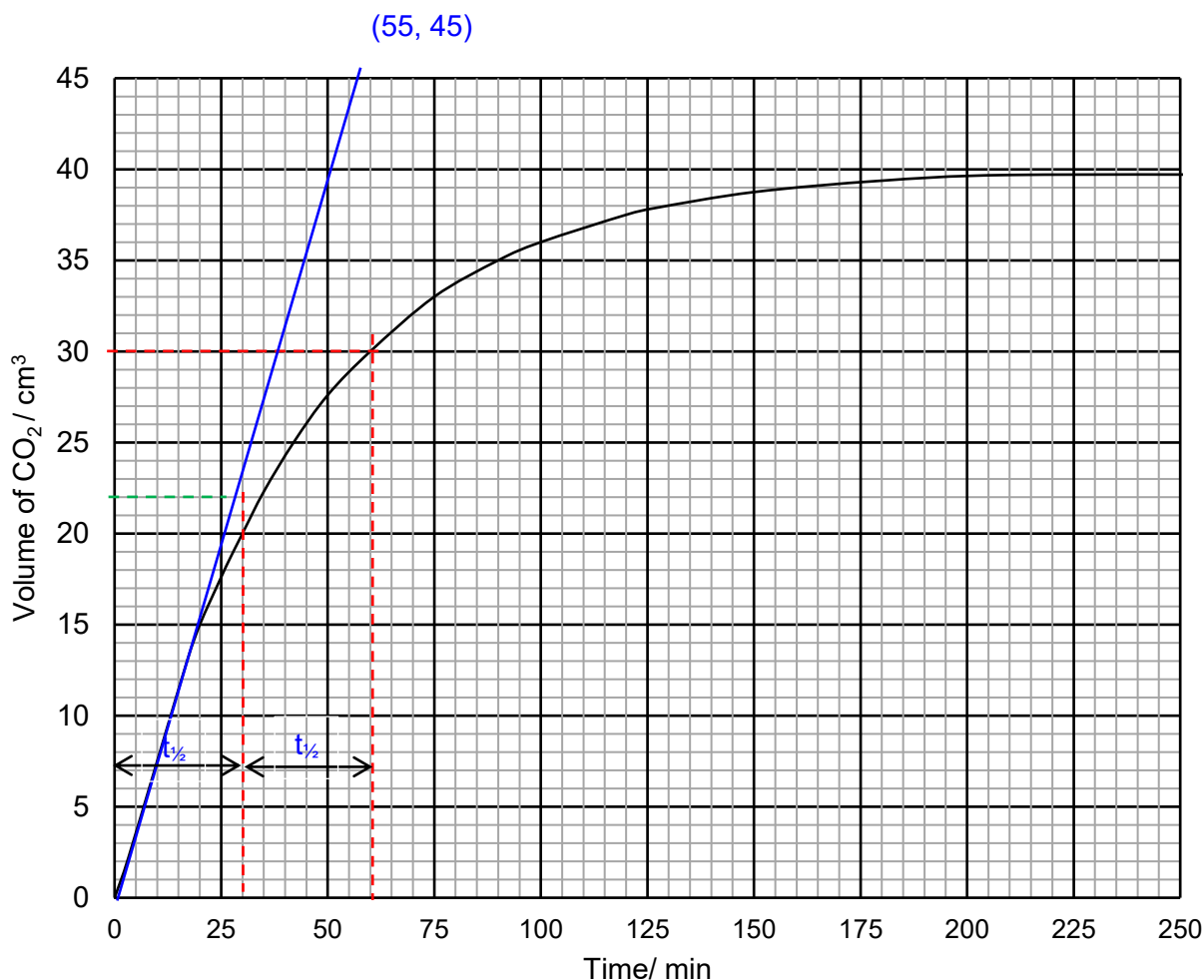


Fig. 2.1

- (i) The maximum volume of CO_2 evolved is 40 cm^3 .

Use Fig. 2.1 to show that the reaction is overall first order.

[1]

- **Show at least TWO $t_{1/2}$ is constant**

- (ii) Calculate the initial rate of CO_2 formation and hence determine the initial change in concentration of ClO_2 per min.

[3]

- **At $t = 0 \text{ s}$, gradient = $(0 - 45) / (0 - 55) = 0.818 \text{ cm}^3 \text{ min}^{-1}$**
- **Rate of volume of CO_2 formed per min = $0.818 \text{ cm}^3 \text{ min}^{-1}$**
- **n_{CO_2} formed per min = $0.818 / 24000 = 3.41 \times 10^{-5} \text{ mol}$**
- **n_{ClO_2} used per min = $3.41 \times 10^{-5} \times 2 = 6.82 \times 10^{-5} \text{ mol}$**
- **$[\text{ClO}_2]$ reacted per min = $6.82 \times 10^{-5} / 0.4 = 1.71 \times 10^{-4} \text{ mol dm}^{-3}$**

- (iii) Assume that the reaction is also first order with respect to $C_xH_yO_z$, state and explain the two changes you would expect to observe in the graph in Fig. 2.1, when the above experiment is repeated using twice the concentration of $C_xH_yO_z$. [2]

- **Double the concentration of $C_xH_yO_z$ doubles (increase) the initial rate as indicated in the steeper gradient.**
- **$t_{1/2}$ will be halved of the original value since $t_{1/2} = \ln 2 / k'$ where $k' = k[C_xH_yO_z]$**

- (c) Chlorine gas is commonly used to disinfect drinking water. However, it can react with naturally occurring organic matter to form trihalomethanes, THMs. THMs are harmful at high levels because they may cause cancer.

The common THMs found in treated water and their boiling points are listed in Table 2.1. The average concentrations detected in a particular sample of treated water are also listed.

Table 2.1

THMs	M_r	Boiling point / °C	Average concentration / $\times 10^{-6} \text{ g dm}^{-3}$
$CHCl_3$	119.5	61	54.9
$CHBrCl_2$	163.9	90	10.7
$CHBr_2Cl$	208.3	120	7.7
$CHBr_3$	252.7	149	3.0

- (i) State the most volatile THMs in Table 2.1.

Using data in Table 2.1, explain your answer with reference to the type and relative strength of intermolecular interactions. [2]

- **$CHCl_3$ is the most volatile since it has the lowest boiling point.**
- **$CHCl_3$ having the smallest M_r and contains the least number of electrons with smallest electron clouds. Instantaneous dipole-induced dipole attractions between the $CHCl_3$ molecules are the weakest and hence required the least energy to overcome.**

1m correctly identify M_r and boiling points as pertinent data

1m correctly explain in terms of strength of instantaneous dipole-induced dipole interaction.

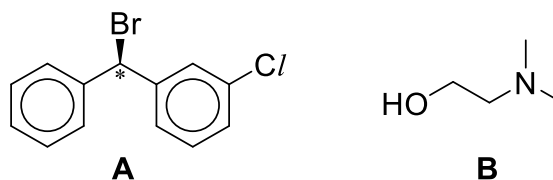
- (ii) Suggest one reason for the trend of the average concentrations of THMs. [1]

- **THMs with increasing number of Br atom are less polar due to lower polarity of C-Br, leading to weaker permanent dipole-permanent dipole interactions with water molecules. Solubility of THMs decreases and hence their average concentrations decreases.**
 - **$CHCl_3$ formed most readily since Cl_2 is used to disinfect OR Br^- concentration in organic matter/waste water is relatively low.**
 - **C-Br is weaker and hence less stable, resulting to it being easily reacted away.**
- 1m for any one reason

- (iii) Rising global temperatures, a consequence of the enhanced greenhouse effect, directly influence THMs formation.

Describe what is meant by the term *enhanced greenhouse effect*. [1]

3 (a) A drug can be synthesised by a reaction between **A** and **B** as the first step. The halogenoalkane in **A** undergoes nucleophilic substitution via S_N2 with the alcohol functional group in **B** to form an ether.



(i) Explain why S_N2 reactions do not occur at the C-Cl bond in **A**. [2]

- The p-orbital of the halogen atom overlaps with the p-orbitals of carbon atom in benzene ring, leading to delocalisation of the lone pair of electrons on C/ atom into the ring. This leads to partial double bond character on the C-C/ bond, thus making the bond stronger and harder to break.
- The benzene ring poses steric hindrance, making it difficult for the nucleophile to approach the electron-deficient carbon. It also hindered the rear attack of the nucleophile.

- (ii) With reference to the structure, suggest why it is more likely for the alcohol rather than the amine functional group in **B** to undergo S_N2 with the halogenoalkane. [2]

- There are two bulky aryl groups bonded to the secondary halogenoalkane and three alkyl groups bonded to the tertiary amine, compared to just one alkyl group for the primary alcohol.
- This causes steric hindrance for the tertiary amine to approach the electron-deficient carbon from the rear/opposite end of bromine to undergo S_N2 .

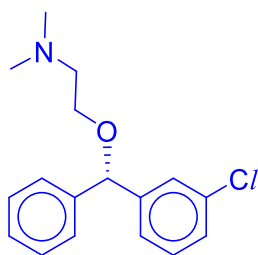
There must be a comparison made between the number of alkyl groups in the tertiary amine and in the primary alcohol as that is the distinguishing factor.

- (iii) For drug **C** to be effective, it must be able to bind to the relevant receptors in the body. Using the other enantiomer of **A** as starting reactant would make the drug ineffective.

Consider the nature of the receptors and the S_N2 mechanism, explain why the drug becomes ineffective. [2]

- The receptors in the body must be chiral and only bind correctly to the drug in a specific 3D spatial arrangement.
- The reaction between A and B via S_N2 would result in an inversion of configuration.
- Using another enantiomeric form of A would result in the formation of an enantiomer of the drug which would not be able to bind effectively to the chiral receptors.

- (iv) Draw the structural formula of the product from the reaction between **A** and **B**. Show the stereochemistry of the compound in your drawing. [1]



- (b) Arrange benzene, nitrobenzene and phenylamine in order of their ease of bromination.

Explain your reasoning by reference to their structures.

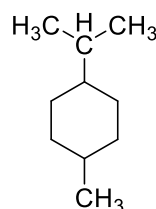
[3]

- **Order of ease of bromination: Nitrobenzene < Benzene < Phenylamine**
- **The $-\text{NO}_2$ group in nitrobenzene is a strong electron-withdrawing group by both inductive and resonance effects, which decreases the electron density in the ring. It deactivates the benzene ring. The benzene ring becomes the least susceptible to electrophilic substitution, making bromination the most difficult.**

Benzene has no activating or deactivating substituents, so it undergoes bromination under normal conditions.

- **The $-\text{NH}_2$ group in phenylamine is electron-donating by resonance, which increases electron density in the ring. This activates the ring. The benzene ring becomes the most susceptible to electrophilic substitution, making bromination the easiest.**

- (c) α -Terpineol, $\text{C}_{10}\text{H}_{18}\text{O}$, contains an alcoholic group which is not readily oxidised. On hydrogenation in the presence of palladium catalyst, it gives **D**, $\text{C}_{10}\text{H}_{20}\text{O}$. **D** reacts readily in the presence of a few drops of concentrated sulfuric acid to give **E**, $\text{C}_{10}\text{H}_{18}$, which can be hydrogenated to give the compound below.



Heating **E** and α -terpineol separately with acidified KMnO_4 gives **F** and **G** respectively.

Table 3.1 shows the observations when **F** and **G** are tested with two different reagents separately under specific conditions.

Table 3.1

test	reagents and conditions	F , $\text{C}_9\text{H}_{16}\text{O}$	G , $\text{C}_{10}\text{H}_{18}\text{O}_4$
1	Na_2CO_3	no effervescence	effervescence
2	Warm alkaline iodine(aq)	yellow ppt	yellow ppt

For each reaction described above, including the tests in Table 3.1, state the type of reaction occurring. For each compound, state what information above tells you about the functional groups it contains. Include your reasoning.

Suggest structures for α -terpineol, **D**, **E**, **F** and **G**.

[10]

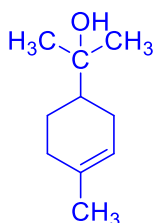
- **α -Terpineol is a tertiary alcohol since it is not readily oxidised.**

- α -Terpineol and E each contain one alkene / C=C bond since it undergoes reduction with H_2 and there is a gain of 2 H atoms.
- D undergoes elimination of one H_2O molecule with a few drops of conc H_2SO_4 to give the resulting molecular formula of E.
- α -Terpineol and E contain undergoes alkene / C=C which undergoes oxidative cleavage with acidified $KMnO_4$.
- F and G contains CH_3CO- since it undergoes oxidation / oxidative cleavage with alkaline aqueous iodine.
- Only G contains $-CO_2H$ which undergoes acid-base reaction with Na_2CO_3 since there is only effervescence of CO_2 with G.

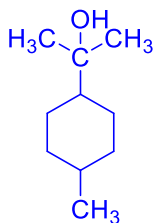
Correct type of reaction and its associated functional group for at least one compound.

Total 6: Max 5 marks

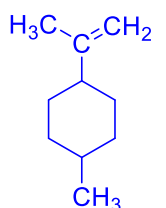
α -Terpineol



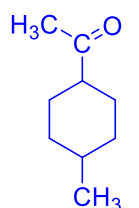
D



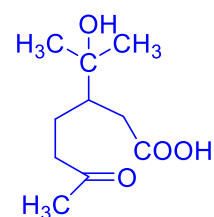
E



F



G



- 1 mark for each structure

Section B

Answer **one** question from this section.

- 4 (a) Describe the variation in the acid-base behaviour of the Period 3 oxides by reference to the reactions of Na_2O , Al_2O_3 and SiO_2 separately with phosphoric acid, H_3PO_4 , and with sodium hydroxide.

Write equations for any reactions described.

[6]

Going across Period 3 from left to right, nature of the oxides changes from basic to acidic as bonding changes from ionic to covalent.

- Na_2O , being ionic, is a basic oxide and reacts with acids but not with bases:
- $3Na_2O + 2H_3PO_4 \rightarrow 2Na_3PO_4 + 3H_2O$
- Al_2O_3 is a predominantly ionic oxide with some covalent character. Hence, it is an amphoteric oxide that reacts with both acids and bases:
- $Al_2O_3 + 2H_3PO_4 \rightarrow 2AlPO_4 + 3H_2O$ and $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$

- **SiO₂ is a covalent oxide. Hence, it is acidic and reacts with concentrated NaOH but not with H₃PO₄**
- **SiO₂ + 2NaOH → Na₂SiO₃ + H₂O**

- (b) Hydration of carbonyl compounds yields gem-diols which are compounds where two hydroxyl groups are bonded to the same carbon atom. Gem-diols are often unstable and exist in equilibrium, as shown in the hydration of propanone.

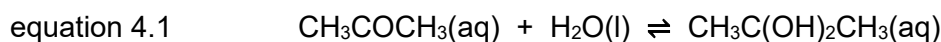


Table 4.1 shows the equilibrium constant, K_c , values for the hydration of propanone at two different temperatures.

Table 4.1

Temperature /K	K_c
298	1.58
318	1.06

- (i) State Le Chatelier's Principle. [1]

- **Le Chatelier's Principle (LCP) states that when a system at equilibrium is subjected to a change in conditions, the system will shift its position of equilibrium to oppose the change and restore a new equilibrium.**

- (ii) Use data in Table 4.1, explain if the formation of gem-diols from propanone is endothermic or exothermic. [2]

- **Since K_c becomes smaller as temperature increases, position of equilibrium shifts to the left to absorb heat, favouring the backward endothermic reaction.**
- **Hence the forward reaction is exothermic.**

- (iii) A sample of 29.5 g of trichloroethanal, CCl_3CHO , is dissolved in 250 cm³ of water and left to reach equilibrium at 298K similar to the reaction shown in equation 4.1.

At equilibrium, it is found that only 0.01% of CCl_3CHO remains.

Determine the equilibrium amount of CCl_3CHO and $\text{CCl}_3\text{C}(\text{OH})_2\text{H}$ and hence calculate the value of K_c for this hydration. [2]

	CCl₃CHO(aq)	+ H₂O	⇌	CCl₃C(OH)₂H(aq)
Initial / mol	$\frac{29.5}{147.5} = 0.200$			0
Change / mol	-0.19998			-0.19998
Equilibrium / mol	$\frac{0.01}{100} \times 0.200 = 2.00 \times 10^{-5}$			0.19998

- **Correct equilibrium amount calculated**

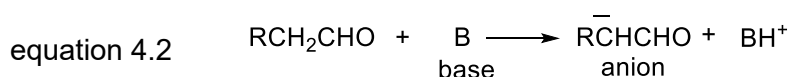
- **$K_c = \frac{0.19998}{2.00 \times 10^{-5}} = 1.00 \times 10^4$ (3sf)**

- (iv) Suggest why CCl_3CHO has a higher K_c value than that of propanone. [1]

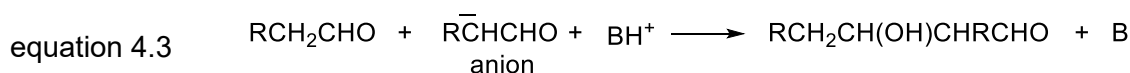
- **Strong electron withdrawing groups of C/ intensify the partial charges on the carbonyl carbon on trichloroethanal, destabilizing it, causing more gem-diol to be formed.**
OR
- **The electron-donating methyl groups in propanone dispersed the positive charge on the carbonyl carbon, stabilizing it, causing less gem-diol to be formed.**

(c) Under certain conditions, carbonyl compounds can also react with each other as shown in equations 4.2 and 4.3.

The hydrogen bonded to a carbon that is adjacent to a carbonyl group can be removed by addition of a catalytic quantity of a strong base.

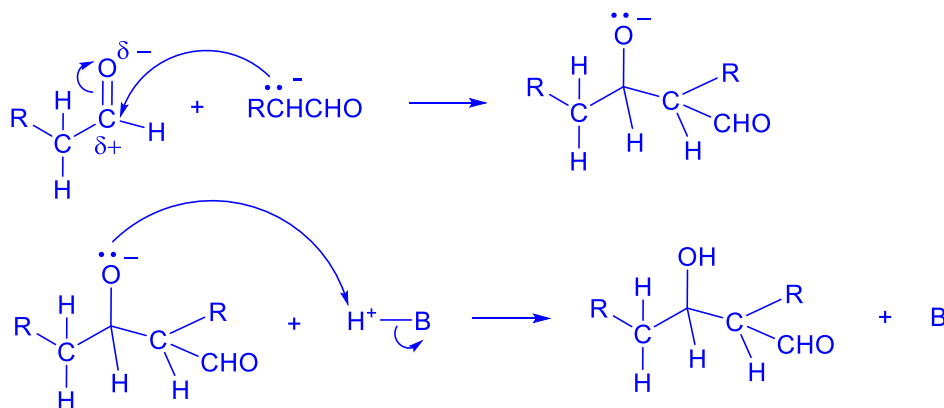


The anion formed then reacts with another molecule of the original carbonyl compound.



(i) Equation 4.3 shows the overall equation for a two-step mechanism where the first step involves the anion attacking the carbonyl molecule.

Suggest a two-step mechanism. Show all charges, relevant lone pairs and the movement of electron pairs by using curly arrows. [2]



- **Correct partial charges**
- **Correct curly arrows**

(ii) Suggest the structure of the final product formed in the reaction of propanone with a strong base. [1]



As shown in Fig. 4.1, carbonyl compound **P** forms **Q** by the same mechanism. **S** can be formed from **Q** via a two-step synthesis.

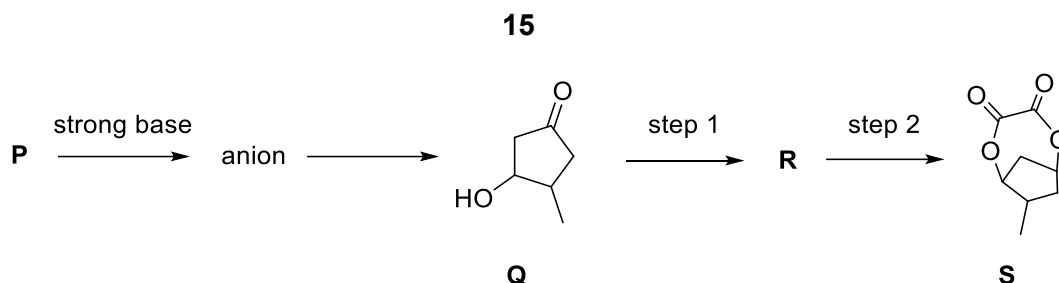
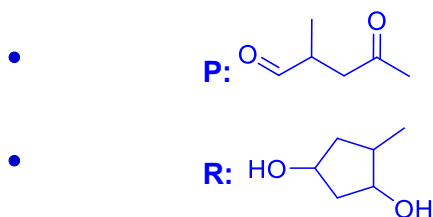


Fig. 4.1

(iii) State one reagent that can be used to distinguish **Q** from **S**. [1]

- **2,4-DNPH or Na**

(iv) Suggest the structures of **P** and **R**. [2]



(v) Suggest reagents and conditions for each of the steps 1 and 2 in Fig. 4.1. [2]

- **Step 1: LiAlH₄ in dry ether or H₂, Ni, Heat**
- **Step 2: H₂SO₄(l), ethanedioic acid OR (COCl)₂**

[Total: 20]

5 (a) Describe and explain the trend in thermal stability of the hydrogen halides HCl, HBr and HI. Include an equation for the thermal decomposition reaction in your answer. [3]

- **2HX → H₂ + X₂**
- **HX decomposes to form hydrogen gas and its corresponding halogen, X₂.**
- **The thermal stability of hydrogen halides (HX) decreases down Group 17 because the halogen atoms get larger, leading to less effective orbital overlap with hydrogen.**
- **This results in longer, weaker H-X bonds, making the compounds less stable to heat.**

(b) The chlorides sodium and phosphorus behave differently when added to water.

State what you would observe when NaCl and PCl₅ are each added separately to water and suggest the pH of the solution formed in each case. [2]

- **NaCl/ dissolves/disappears in water – pH 7.**
- **PCl₅ dissolves/disappears in water with misty/steamy/fumes/vapour – pH 1.**

(c) In the gas phase, the chloride of beryllium exists as a mixture of BeCl₂ and Be₂Cl₄ molecules.

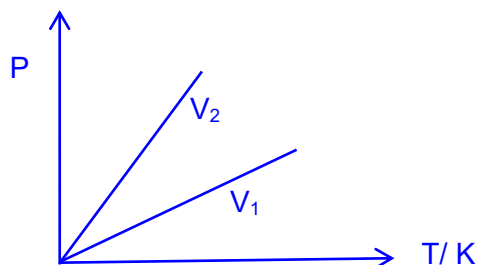


You may assume both BeCl₂ and Be₂Cl₄ behave like ideal gases here.

(i) State three basic assumptions of the kinetic theory as applied to an ideal gas. [2]

- Gas molecules have negligible molecular size.
 - Gas molecules have negligible intermolecular forces of attractions.
 - Collisions between gas molecules are elastic.
- [3 correct, 2 marks; 2 correct, 1 mark]

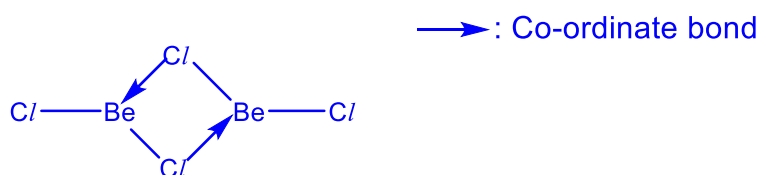
- (ii) Sketch and label a graph showing how the pressure for a given mass of an ideal gas varies with temperature in two different vessels of volumes, V_1 and V_2 , where $V_1 > V_2$. Explain your answer. [2]



1 mark for graph

Since $PV = nRT$ and n is constant, $P = \frac{nR}{V}T$ where P is the y-axis and T is the x-axis and gradient $= \frac{nR}{V}$. $V_1 > V_2$, hence a less steep gradient for bigger volume, V_1 .

- (iii) Draw the structure of Be_2Cl_4 . Label the co-ordinate bonds on your structure. [1]



- (iv) A sample of 0.800 mol of BeCl_2 is allowed to reach equilibrium in a sealed vessel. At equilibrium, it is found that 20% of the original sample of BeCl_2 has reacted. The total pressure in the vessel is 1.50×10^4 Pa.

Determine the equilibrium amount of BeCl_2 and Be_2Cl_4 and hence calculate the value of K_p for the reaction in equation 5.1. State the units. [3]

	$2\text{BeCl}_2(\text{g})$	\rightleftharpoons	$\text{Be}_2\text{Cl}_4(\text{g})$
Initial / mol	0.800		0
Change / mol	-0.16		+0.08
Equilibrium / mol	0.64		0.08

- Partial pressure of $\text{BeCl}_2 = \frac{0.640}{0.720} \times 1.50 \times 10^4 = 1.33 \times 10^4$ Pa
- Partial pressure of $\text{Be}_2\text{Cl}_4 = 1.50 \times 10^4 - 1.33 \times 10^4 = 0.17 \times 10^4$ Pa
- $K_p = \frac{0.17 \times 10^4}{(1.33 \times 10^4)^2} = 9.61 \times 10^{-6} \text{ Pa}^{-1}$

- (d) Iodomethane, CH_3I , is used as a reagent in the first step of the Hofmann elimination reaction, which converts amines to alkenes. It reacts with an amine to form a quaternary ammonium salt. Upon heating this salt with moist silver(I) oxide, Ag_2O , an elimination reaction occurs, breaking a C – N bond and producing an alkene.

In Hofmann elimination, the less substituted alkene is typically the major product. This is illustrated as the two-stage process of converting 2-aminobutane to but-1-ene in Fig. 5.1.

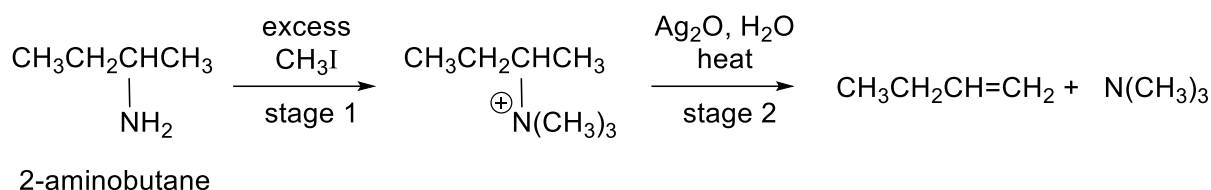
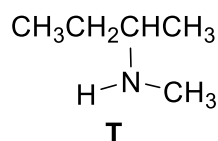


Fig 5.1

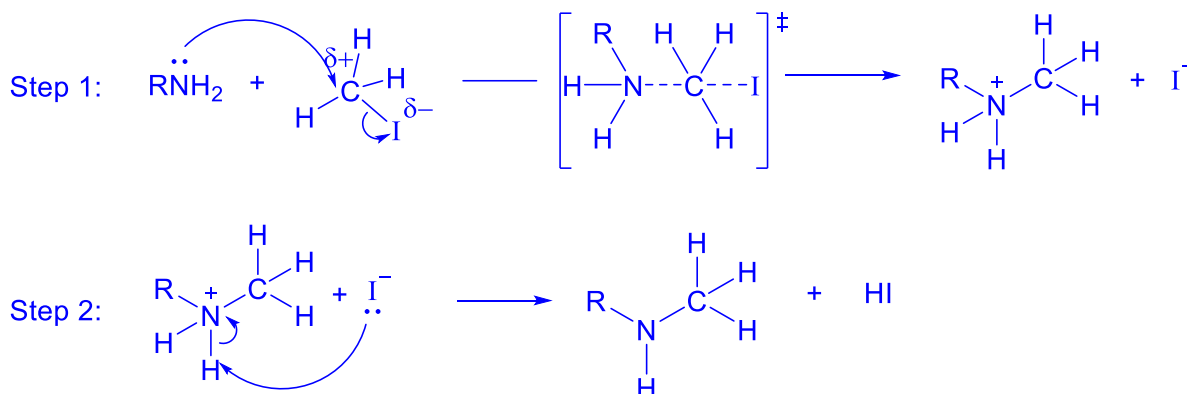
- (i) Compound **T** is an intermediate in stage 1 of Fig. 5.1. It is formed via an $\text{S}_{\text{N}}2$ attack of 2-aminobutane on iodomethane, followed by the removal of a proton on the nitrogen atom by iodide ion.



Suggest the two-step mechanism for the formation of **T**. Show all charges, relevant lone pairs and the movement of electron pairs by using curly arrows.

You may represent 2-aminobutane as RNH_2 .

[2]



- Balanced equation for step 1 with transition state shown with correct curly arrows and charges.
- Balanced equation for step 2, correct curly arrows and charges.

Compound **Z** can be synthesized in 3 steps as shown in Fig. 5.2. Step 2 involves a Hofmann elimination.

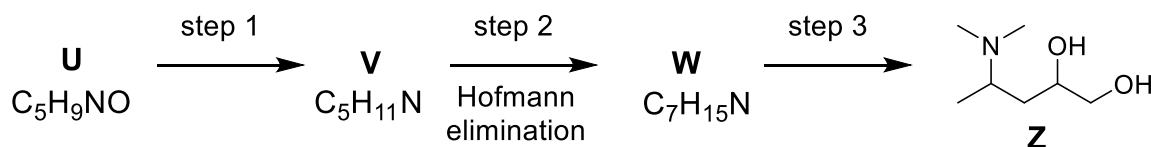
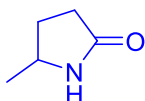


Fig. 5.2

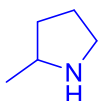
- (ii) Suggest structures of organic compounds **U**, **V** and **W**.

[3]

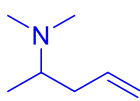
18



U



V



W

- 1 mark for each structure

(iii) Suggest the reagents and conditions required for step 1 and 3.

[2]

- Step 1: LiAlH_4 in dry ether
- Step 3: Cold NaOH(aq) , $\text{KMnO}_4(\text{aq})$

[Total: 20]