



# TAMPINES MERIDIAN JUNIOR COLLEGE

## JC2 PRELIMINARY EXAMINATION

CANDIDATE  
NAME

CIVICS GROUP

**H2 CHEMISTRY**

**9729/03**

**Paper 3 Free Response**

**23 September 2025**

**2 hours**

Candidates answer on the Question Paper.

Additional materials: Data Booklet

### READ THESE INSTRUCTIONS FIRST

Write your name and Civics Group in the spaces at the top of the page.

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 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		Percentage
Paper 1	/ 30	/ 15
Paper 2	/ 75	/ 30
Paper 3		
Section A		
1	/ 19	
2	/ 20	
3	/ 21	
Section B		
4	/ 20	
OR		
5	/ 20	
Paper 3 Total	/ 80	/ 35
Paper 4	/ 55	/ 20
Grand Total		/ 100

## Section A

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

- 1 (a) Describe and explain the trend in the thermal stabilities of the Group 2 carbonates. [2]

(a) Thermal stability of Group 2 carbonates increases down the group.

Down Group 2, size of cations increases, and charge density and polarising power of the cations decreases.

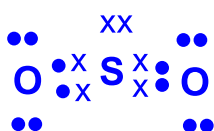
The cations distort the  $\text{CO}_3^{2-}$  / anion electron cloud, and weaken C–O bonds to a smaller extent, and hence more energy is required to decompose the  $\text{CO}_3^{2-}$ .

- (b) Calcium carbonate is used in flue-gas desulfurisation applications to remove harmful  $\text{SO}_2$  and  $\text{NO}_2$  emissions from fossil fuels burnt in power stations.

(i) Draw dot-and-cross diagrams to show the bonding in the molecules of  $\text{SO}_2$  and  $\text{NO}_2$ . [2]

(ii) With reference to your answer in (b)(i), explain why the bond angle in  $\text{SO}_2$  is found to be  $118^\circ$  while that in  $\text{NO}_2$  is  $134^\circ$ . [2]

(b) (i)



(ii) For  $\text{SO}_2$ , as there are 2 bond pairs and 1 lone pair around the central S atom. Since lone pair–bond pair repulsion > bond pair – bond pair repulsion, the bond angle is about  $118^\circ$ .

However, in  $\text{NO}_2$ , the repulsion between the unpaired electron (or lone electron) and a bond pair is weaker compared to the repulsion between a lone pair and a bond pair. This results in a larger bond angle of  $134^\circ$ .



- (c) Magnesium carbonate,  $\text{MgCO}_3$ , can be prepared in the laboratory by the reaction between magnesium chloride solution and aqueous sodium bicarbonate according to the equation:



$$\Delta H^\circ = + 107 \text{ kJ mol}^{-1}$$

$$\Delta S^\circ = + 360 \text{ J mol}^{-1} \text{ K}^{-1}$$

- (i) Explain why the reaction shows an overall positive value for  $\Delta S^\circ$ . [1]
- (ii) Calculate  $\Delta G$ , in  $\text{kJ mol}^{-1}$ , for the reaction at  $50^\circ\text{C}$ . [1]
- (iii) Explain qualitatively how temperature affects the feasibility of this reaction. [2]

(c) (i)  $\Delta S^\circ$  is positive as there is an increase in disorder / entropy. This is due to an increase in the number of moles of gaseous particles from 0 mol to 1 mol, resulting in more ways for the particles to arrange themselves.

(ii)  $\Delta G = \Delta H^\circ - T\Delta S^\circ$   
 $= +107 - (273 + 50) (0.360)$   
 $= \underline{-9.28} \text{ kJ mol}^{-1}$

(iii) Both  $\Delta H$  and  $\Delta S$  are positive, and  $-T\Delta S$  is negative.

At low temperatures,

$|\Delta H| > |T\Delta S|$ . Hence,  $\Delta G = \Delta H - T\Delta S > 0$ . (or  $\Delta G$  is positive)

At high temperatures,

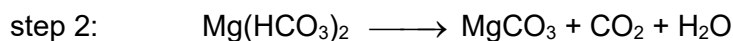
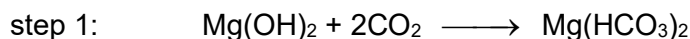
$|\Delta H| < |T\Delta S|$  (or the negative  $-T\Delta S$  outweighs the positive  $\Delta H$ ).

Hence,  $\Delta G = \Delta H - T\Delta S < 0$ . (or  $\Delta G$  becomes negative).

Hence, reaction is non-spontaneous/ not feasible at low temperatures,  
but spontaneous / feasible at high temperatures.



- (d) High purity magnesium carbonate,  $\text{MgCO}_3$ , is produced industrially at high pressure via a two-step process.



When 150 kg  $\text{Mg(OH)}_2$  was reacted with excess carbon dioxide gas, and the resultant  $\text{Mg(HCO}_3)_2$  vacuum dried to remove carbon dioxide and water, 168 kg  $\text{MgCO}_3$  was produced.

Determine the percentage yield of this industrial process.

[2]

(d) Amount of  $\text{Mg(OH)}_2$  reacted  $= \frac{150 \times 1000}{58.3}$   
 $= 2573 \text{ mol}$   
 $= \text{Theoretical amount of } \text{MgCO}_3 \text{ produced}$

Theoretical yield of  $\text{MgCO}_3$   $= 2573 \times 84.3$   
 $= 216900 \text{ g}$   
 $= 216.9 \text{ kg}$

% yield  $= \frac{168}{216.9} \times 100 = 77.5 \%$

- (e) Titanium dioxide,  $\text{TiO}_2$ , is a widely used white pigment employed to provide whiteness and opacity for paints, papers and toothpaste.

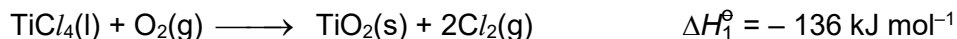
Explain, in terms of structure and bonding, why carbon dioxide sublimates at  $-78^\circ\text{C}$  while titanium dioxide is a crystalline solid with a melting point of  $1840^\circ\text{C}$ .

[2]

- (e)  $\text{CO}_2$  has a simple molecular structure.  
Little energy is required to overcome the weak instantaneous dipole – induced dipole forces of attraction between  $\text{CO}_2$  molecules, resulting in a low sublimation point.
- $\text{TiO}_2$  has a giant ionic structure.  
A lot of energy is required to break the strong ionic bonds / electrostatic forces of attraction between  $\text{Ti}^{4+}$  ions and  $\text{O}^{2-}$  ions / oppositely charged ions, resulting in a high melting point.



- (f) The industrial manufacture of titanium dioxide involves reacting titanium(IV) chloride,  $\text{TiCl}_4$ , with oxygen gas according to the equation as shown.



- (i) Define the term *bond energy of Ti-Cl bond*. [1]
- (ii) Using the  $\Delta H_1^\ominus$  value given above and the data in Table 1.1, together with appropriate data from the *Data Booklet*, construct a fully labelled energy cycle and use it to calculate the average bond energy of the Ti-Cl bond in  $\text{TiCl}_4$ .

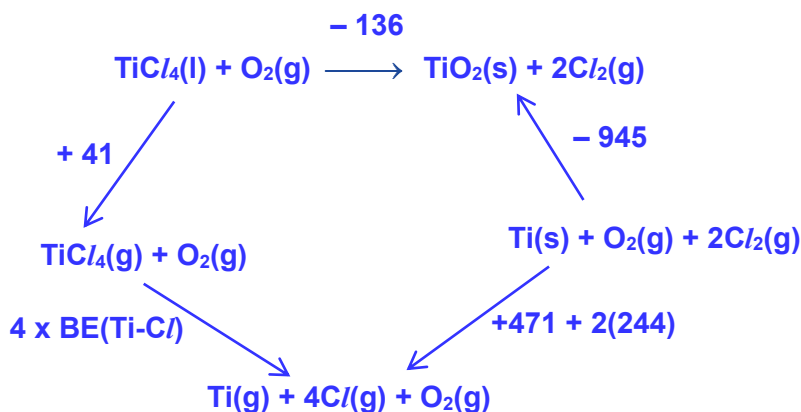
Table 1.1

enthalpy change of vaporisation of $\text{TiCl}_4(\text{l})$	+ 41 kJ mol <sup>-1</sup>
standard enthalpy change of formation of $\text{TiO}_2(\text{s})$	- 945 kJ mol <sup>-1</sup>
standard enthalpy change of atomisation of $\text{Ti}(\text{s})$	+ 471 kJ mol <sup>-1</sup>

[4]

- (f) (i) It is the average energy absorbed when one mole of the Ti-Cl bond is broken in the gaseous phase to form Ti and Cl gaseous atoms.

(ii)



By Hess' Law,

$$4 \times \text{BE}(\text{Ti-Cl}) = -41 -136 - (-945) + (471 + 2(244))$$

$$\text{BE}(\text{Ti-Cl}) = \underline{+ 432 \text{ kJ mol}^{-1}}$$

[Total: 19]



- 2 Chromium is a hard, corrosion-resistant transition metal with variable oxidation states. It is widely used in energy-efficient and long-lasting redox flow batteries. One example would be the zinc dichromate battery, also known as the bichromate cell. The reaction at one of the electrodes is given.



The other electrode in this cell is the zinc electrode in the presence of  $\text{H}_2\text{SO}_4(\text{aq})$  as the electrolyte.

- (a) (i) Construct the overall equation for the reaction when 1 mol of  $\text{Cr}_2\text{O}_7^{2-}$  reacts with zinc. Use relevant data from the *Data Booklet* to calculate the  $E^\ominus_{\text{cell}}$  for this reaction. [2]
- (ii) Hence, calculate the standard Gibbs free energy change,  $\Delta G^\ominus$ , of the reaction. [1]
- (iii) The cathode of the bichromate cell usually operates at pH 3 and 298 K. The concentration of  $\text{Cr}_2\text{O}_7^{2-}$  ions and  $\text{Cr}^{3+}$  ions are kept at  $1 \text{ mol dm}^{-3}$ . The Nernst Equation is often used to calculate the electrode potential,  $E$ , generated under non-standard conditions.

$$E = E^\ominus - \frac{RT}{nF} \ln Q$$

$n$  is the number of moles of electrons transferred per mole of equation,

$R$  is the molar gas constant,

$F$  is the Faraday constant,

$Q$  is the reaction quotient, where  $Q = \frac{[\text{Cr}^{3+}]^2}{[\text{Cr}_2\text{O}_7^{2-}][\text{H}^+]^{14}}$

Show that the electrode potential,  $E$ , at the cathode is +0.916 V. Hence, explain qualitatively why the  $E$  value is less positive than its  $E^\ominus$  value? [2]

- (iv) Suggest, with reasoning, what happens to the cell potential,  $E^\ominus_{\text{cell}}$ , when the cathode is diluted with water. [1]

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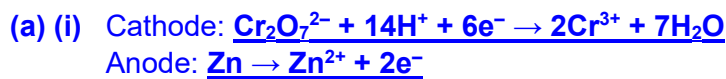
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$$E^\ominus_{\text{cell}} = E^\ominus_{\text{red}} - E^\ominus_{\text{oxid}}$$

$$= +1.33 - (-0.76) = \underline{+2.09 \text{ V}}$$

(ii)  $\Delta G^\ominus = -nFE^\ominus_{\text{cell}}$   
 $= -(6)(96500)(2.09) = \underline{-1.21 \times 10^6 \text{ J mol}^{-1}}$   
 $= \underline{-1210 \text{ kJ mol}^{-1}}$

(a) (iii)  $E = E^\ominus - \frac{RT}{nF} \ln (Q)$   
 $E = (+1.33) - \frac{(8.31)(298)}{(6)(96500)} \ln \left( \frac{1}{(10^{-3})^{14}} \right)$

$E = \underline{+0.916 \text{ V}}$



According to Le Chatelier's principle,  $[\text{H}^+]$  is lower than  $1 \text{ mol dm}^{-3}$ , the equilibrium position will shift/lie more to left, favouring oxidation, E becomes less positive.

(iv) Based on the Nernst Equation, as there is a greater number of aqueous species on the LHS compared to the RHS of the half-equation. OR  $[\text{H}^+]$  decreases, position of equilibrium shift left, E value will become more negative Hence  $E^\ominus_{\text{cell}}$  become more negative (or less positive).



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(b) Fig. 2.1 shows the reactions of the *transition element* chromium and its compounds.

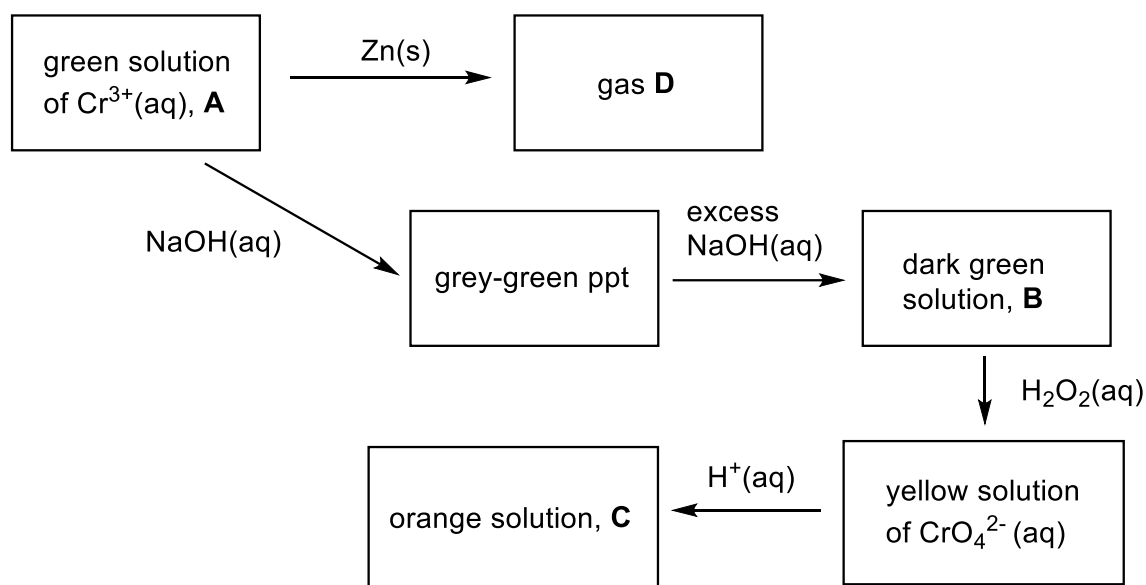


Fig. 2.1

- (i) Define the term *transition element*. [1]
- (ii) Explain why chromium complexes are usually coloured. [3]
- (iii) State the identities of **B**, **C** and **D**. [3]
- (iv) Chromium(II) ions form octahedral complexes. There are two isomeric complexes with the formula  $\text{Cr}(\text{H}_2\text{O})_4(\text{Cl})_2$ . Suggest the structures of the two isomers. [1]
- (v) Write an equation to account for why solution **A** is acidic. [1]

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(b) (i) A d-block element that forms at least one stable ion with partially-filled d subshell.

(ii) A transition metal ion has partially-filled d orbitals. In the presence of ligands, the d orbitals are split into two groups with an energy gap,  $\Delta E$ . This effect is known as d orbital splitting.

During d-d transition, the d electrons from the lower energy d orbitals absorb a certain wavelength of light from the visible spectrum and gets promoted to a higher energy d orbital.

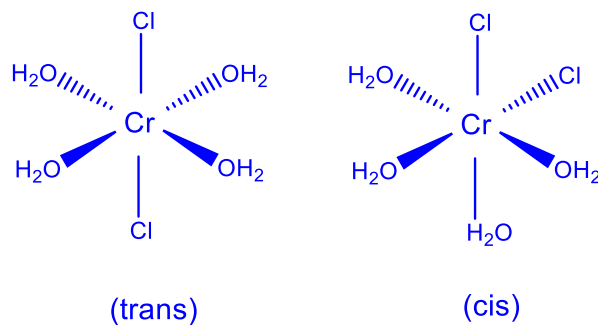
The colour observed is complementary to the colour absorbed.

(b) (iii) B:  $[\text{Cr}(\text{OH})_6]^{3-}$

C:  $\text{Cr}_2\text{O}_7^{2-}$

D:  $\text{H}_2$

(iv)



(v)  $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} \rightleftharpoons [\text{Cr}(\text{H}_2\text{O})_5(\text{OH})]^{2+} + \text{H}^+$

- (c) Acidified  $\text{K}_2\text{Cr}_2\text{O}_7$  can oxidise both  $\text{M}^{2+}$  and  $\text{C}_2\text{O}_4^{2-}$  in  $\text{MC}_2\text{O}_4$ . One of the products formed is  $\text{CO}_2$ .  $25.00 \text{ cm}^3$  of  $0.0200 \text{ mol dm}^{-3}$  acidified  $\text{K}_2\text{Cr}_2\text{O}_7$  is required to completely oxidise  $15.0 \text{ cm}^3$  of  $0.0500 \text{ mol dm}^{-3}$   $\text{MC}_2\text{O}_4$ .

(i) Show that the volume of  $\text{K}_2\text{Cr}_2\text{O}_7$  required to oxidise  $\text{C}_2\text{O}_4^{2-}$  **only** is  $12.5 \text{ cm}^3$ . [2]

(ii) Hence, calculate the oxidation state of **M** in the final product. [3]

(c) (i) Reduction:  $\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$

Oxidation:  $\text{C}_2\text{O}_4^{2-} \rightarrow 2\text{CO}_2 + 2\text{e}^-$

Oxidation:  $\text{M}^{2+} \rightarrow ?$

Amount of  $\text{C}_2\text{O}_4^{2-} = 15/1000 \times 0.0500 = 0.00075 \text{ mol}$

$\text{Cr}_2\text{O}_7^{2-} \equiv 3\text{C}_2\text{O}_4^{2-}$

Amount of  $\text{Cr}_2\text{O}_7^{2-}$  reacted w  $\text{C}_2\text{O}_4^{2-} = 0.00075 / 3 = 0.00025 \text{ mol}$

Vol of  $\text{Cr}_2\text{O}_7^{2-}$  needed =  $0.00025/0.0200 = 0.0125 \text{ dm}^3 = \underline{12.5 \text{ cm}^3}$

(ii) Amount of  $\text{Cr}_2\text{O}_7^{2-}$  reacted with  $\text{M}^{2+}$

=  $(25/1000 \times 0.0200) - (0.00025) = 0.00025 \text{ mol}$

Amount of  $\text{M}^{2+} = 0.00075 \text{ mol}$

	Reduction ( $\text{e}^-$ gained)	Oxidation ( $\text{e}^-$ lost)
Species involved	$\text{Cr}_2\text{O}_7^{2-} \rightarrow \text{Cr}^{3+}$	$\text{M}^{2+} \rightarrow ?$
Reacting Moles	$(12.5/1000)(0.02) = 0.00025$	0.00075
Number of moles of electrons gained or lost per mole	6	y
Total number of moles of electrons gained or lost	0.0015	$0.00075(y)$

$$0.0015 = 0.00075y$$

$$y = \underline{2}$$

1 mole of  $\text{M}^{2+}$  loses  $2\text{e}^-$

=> Final oxidation state of **M** = +4

[Total: 20]

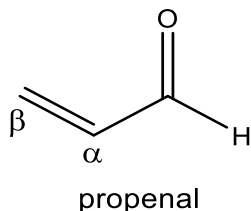


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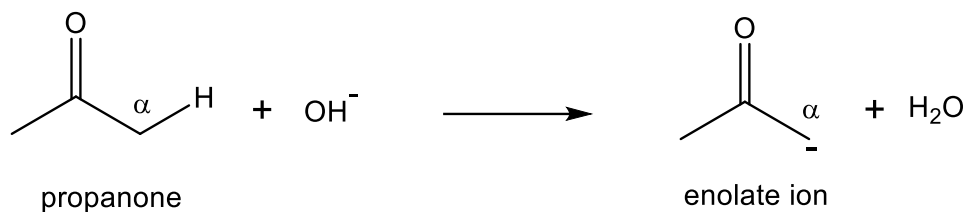
- 3 The Michael addition is a nucleophilic addition reaction where a nucleophile, such as an enolate ion, reacts with an  $\alpha,\beta$ -unsaturated carbonyl compound.

An  $\alpha,\beta$ -unsaturated carbonyl compound is a compound that contains both a carbonyl group and an alkene double bond that are adjacent to each other. An example is propenal, as shown in Fig. 3.1.



**Fig. 3.1**

An enolate ion is formed by deprotonating an  $\alpha$ -hydrogen of a carbonyl compound with a base such as NaOH(aq). An example of an enolate ion formed from the reaction using propanone, is shown below in Fig. 3.2.



**Fig. 3.2**

- (a) The  $K_a$  value of the  $\alpha$ -hydrogen for pentane-2,4-dione and propanone are shown in Table 3.1.

**Table 3.1**

compound	$K_a$
<p>pentane-2,4-dione</p>	$1.26 \times 10^{-9}$
<p>propanone</p>	$1.00 \times 10^{-19}$

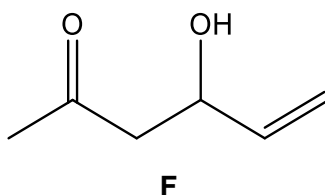
- (i) Explain why pentane-2,4-dione is a stronger acid as compared to propanone. [2]

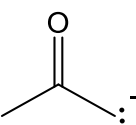
Weakly basic enolate ions would attack the  $\beta$ -carbon of the  $\alpha,\beta$ -unsaturated carbonyl compound, while strongly basic enolate ions would attack the carbonyl carbon of the  $\alpha,\beta$ -unsaturated carbonyl compound.

- (ii) The reaction between propanone and propenal resulted in the carbonyl carbon to be attacked by the enolate ion, while the reaction between pentane-2,4-dione and propenal resulted in the  $\beta$ -carbon to be attacked by the enolate ion.

Using Fig. 3.1 and Table 3.1, explain for the above observations. [1]

- (iii) The enolate ion of propanone reacts with propenal in NaOH(aq) to give compound **F** in a nucleophilic addition reaction.

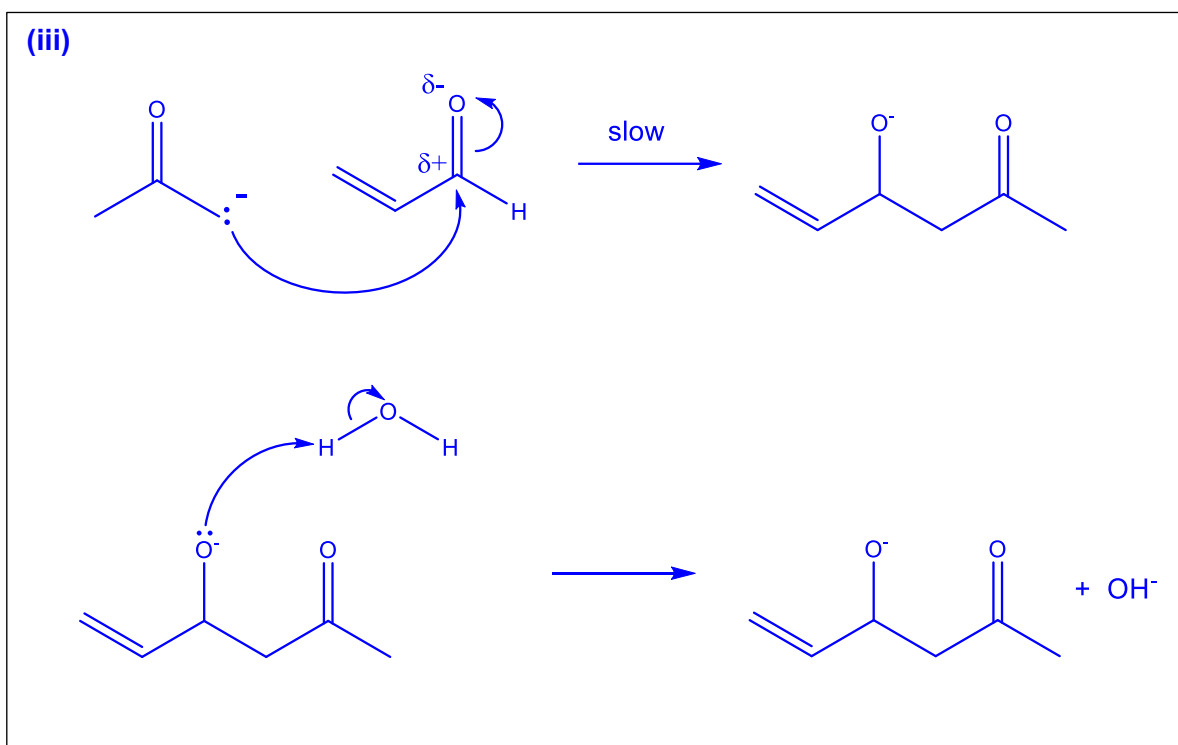


Describe the mechanism for this reaction, using  as the nucleophile. Include all relevant lone pairs, dipoles, curly arrows and charges. [3]

- (a) (i) The lone of pair of electrons on the conjugate base of pentadione can delocalise across both carbonyl groups OR  $O=C-CH^- -C=O$  system.

This leads to a greater extent of dispersal of negative charge on the conjugate base OR enolate ion of pentadione, stabilising the anion. Hence pentadione has a greater tendency to lose protons and is a stronger acid as compared to propanone.

- (ii) The enolate ion of propanone is a stronger base compared to the enolate ion of pentadione.  
(As propanone is a weaker acid than pentadione, the conjugate base OR enolate ion formed would result in a stronger base)



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- (b) The structure of propenal can be represented by two different structures as shown in Fig. 3.3. The  $\longleftrightarrow$  indicates that the actual structure of propenal is somewhere between these two structures, with the potential formation of a carbocation on the  $\beta$ -carbon.

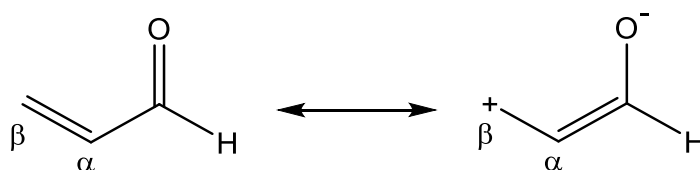


Fig. 3.3

Explain, by considering the orbitals involved, how delocalisation of electrons occurs in propenal. [1]

- (b) The 2p orbitals of O and C orbitals side-on overlap with each other, so that the 2p electrons are completely free to move/ delocalise across the O and C atoms.

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- (c) The following description describes the mechanism of the Michael addition reaction between propenal and pentane-2,4-dione in NaOH(aq).

Step 1: The lone pair of electrons of  $\text{OH}^-$  attacks the  $\alpha$ -hydrogen of pentane-2,4-dione, resulting in the formation of water and an enolate ion.

Step 2: The lone pair of electrons of the enolate ion attacks the  $\beta$ -carbon of propenal, breaking the  $\pi$  bond and pushing electrons towards the  $\alpha$ -carbon of propenal, leading to the formation of a carbanion intermediate.

Step 3: The lone pair of electrons on the carbanion deprotonates the hydrogen from a water molecule, leading to the final Michael addition product and an  $\text{OH}^-$  ion.

The overall equation for the Michael addition reaction is shown below in Fig. 3.4.

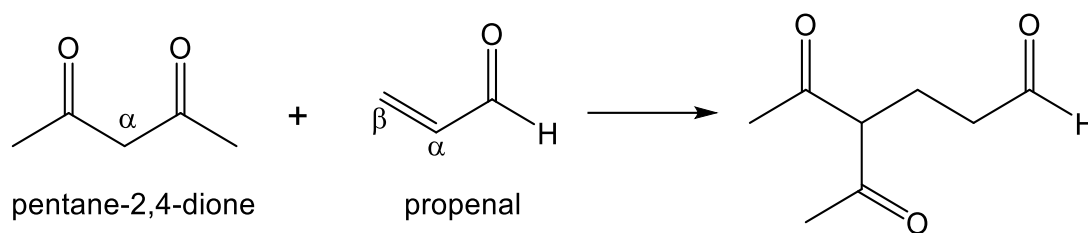


Fig. 3.4

- (i) Complete the mechanism by adding **two** curly arrows to **each** step in Table 3.2.

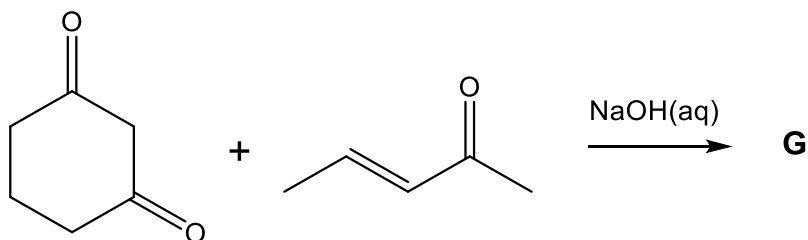
[3]

Table 3.2

step	mechanism
1	
2	
3	

(ii) Suggest a chemical test to confirm that all the propenal in the reaction mixture in (c)(i) has completely reacted. [2]

(iii) Based on the mechanism in (c)(i), suggest the structure of the final organic product **G** for the Michael addition reaction between the following compounds. [1]



(c)(ii) Add  $\text{Br}_2(\text{aq})$  to the final reaction mixture.

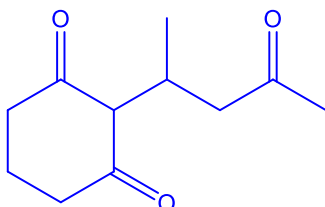
If the reaction is completed, orange  $\text{Br}_2(\text{aq})$  solution should not decolourise.

OR

Add cold alkaline  $\text{KMnO}_4$  to the final reaction mixture

If the reaction is completed, the purple  $\text{KMnO}_4$  solution should not decolourise.

(iii) **G**:



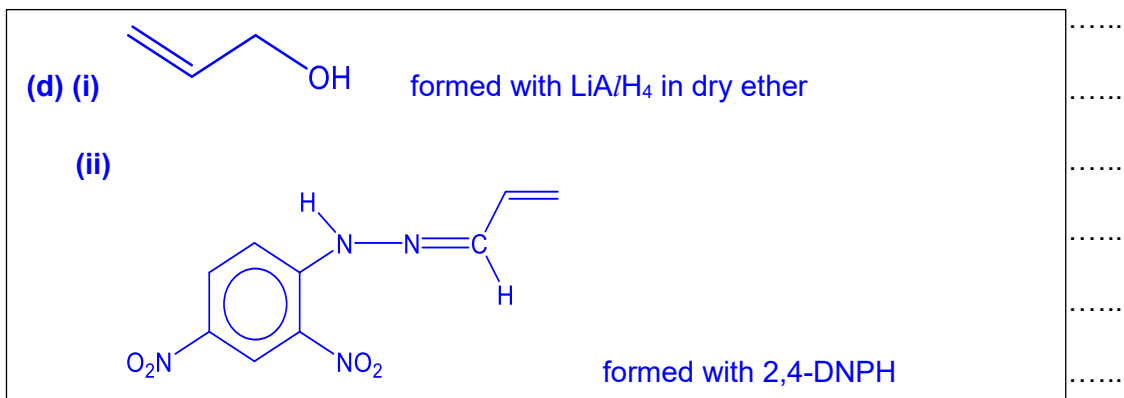


(d) Draw the organic product formed when propenal reacts with

(i)  $\text{LiAlH}_4$  in dry ether

(ii) 2,4-dinitrophenylhydrazine

[2]

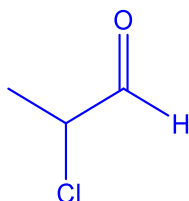


(e) Propenal can react with dry hydrogen chloride gas.

(i) State the mechanism and draw the structure of the organic product formed. [2]

(ii) By considering the mechanism stated in (e)(i), explain why the product formed does not rotate plane-polarised light. [2]

(e) (i) Type of reaction: Electrophilic addition

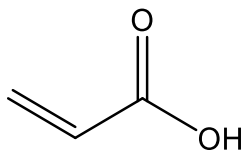


(ii) In step 2 of the electrophilic addition mechanism, the  $\text{Cl}^-$  nucleophile attacks the trigonal planar  $\text{sp}^2$  hybridised C atom of the carbocation intermediate from above and below the plane with equal probability.

This leads to the formation of a racemic mixture OR equal amounts of the (+) and (–) enantiomer and hence does not rotate plane polarised light.



- (f) Additionally, propenal can undergo oxidation to form propenoic acid. The structure of propenoic acid is shown below in Fig. 3.5.

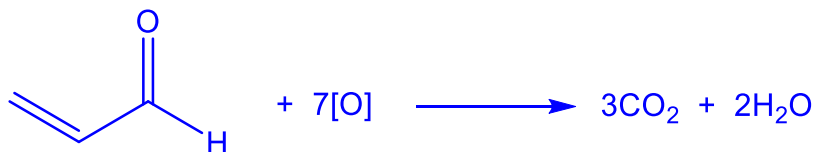


propenoic acid

**Fig. 3.5**

- (i) A student suggested the use of hot acidified  $\text{KMnO}_4$  to oxidise propenal to propenoic acid. However, it was observed that no organic compound was produced. Suggest a balanced equation for the reaction that occurred. Use  $[\text{O}]$  to represent the oxidising agent in the reaction. [1]
- (ii) Hence, state a suitable reagent and condition that could be used for the conversion of propenal to propenoic acid. [1]

(f) (i)



(When using  $\text{H}^+/\text{KMnO}_4$ , both vigorous oxidation of a terminal alkene and oxidation of aldehyde occurred, leading to the formation of  $\text{CO}_2$ ,  $\text{H}_2\text{O}$  and ethanedioic acid. Ethanedioic acid would then undergo further oxidation to form  $\text{CO}_2$  and  $\text{H}_2\text{O}$ .)

(ii)  $\text{K}_2\text{Cr}_2\text{O}_7$ ,  $\text{H}_2\text{SO}_4(\text{aq})$ , heat

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[Total: 21]

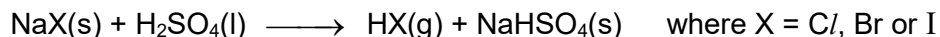
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## Section B

Answer **one** question from this section.

- 4 (a) When solid sodium halides react with concentrated sulfuric acid, an acid-base reaction occurs. This results in the formation of white fumes of hydrogen halide, HX.



The HX formed can undergo further reaction with concentrated sulfuric acid. Depending on the reducing strength of HX, the reaction may result in the formation of  $\text{X}_2$ , a sulfur-containing product and water.

The observations for the reaction of the different sodium halides with concentrated sulfuric acid are shown in Table 4.1.

Table 4.1

sodium halide	observations
NaCl	White fumes of HCl formed.
NaBr	White fumes of HBr formed, followed by the formation of a red-brown $\text{Br}_2$ liquid and a colourless $\text{SO}_2$ gas.
NaI	White fumes of HI formed. Violet $\text{I}_2$ gas condensed to form a black solid. A pungent $\text{H}_2\text{S}$ gas is evolved.

- (i) Using Table 4.1, write a balanced equation for the reaction between gaseous HBr and concentrated  $\text{H}_2\text{SO}_4$ . [1]
- (ii) Using relevant data from the *Data Booklet* and by considering the change in oxidation state, explain the observations in Table 4.1 in terms of the relative reducing powers of HX. [4]
- (iii) Explain the variation for the thermal stabilities of hydrogen halides. [2]



- (ii) In order of increasing reducing strength:  $\text{HCl} < \text{HBr} < \text{HI}$

From *Data Booklet*,



From Cl to I,  $E^\circ(\text{X}_2/\text{X}^-)$  becomes less positive.

Hence, the reducing strength of halides increases  
or reducing strength:  $\text{HCl} < \text{HBr} < \text{HI}$ .

HCl, the weakest reducing agent, cannot reduce S in  $\text{H}_2\text{SO}_4$ .

HBr, a stronger reducing agent, can reduce S from +6 ( $\text{H}_2\text{SO}_4$ ) to +4 ( $\text{SO}_2$ ).

HI, the strongest reducing agent, can reduce S from +6 ( $\text{H}_2\text{SO}_4$ ) to -2 ( $\text{H}_2\text{S}$ ).

(iii) Thermal stability decreases from  $\text{HCl}$  to  $\text{HI}$ .

Down the group from  $\text{Cl}$  to  $\text{I}$ ,

- Extent of orbital overlap between  $\text{H}$  and  $\text{X}$  atoms decreases.
- Bond length of  $\text{H-X}$  increases.
- Bond strength of  $\text{H-X}$  decreases.
- **OR** Bond energy of  $\text{H-X}$  decreases.



- (b) The Strecker synthesis is a method used to produce amino acids through the reaction of an aldehyde with ammonia and hydrogen cyanide. The amino acid, leucine, can be synthesised using this approach, as illustrated in Fig. 4.1.

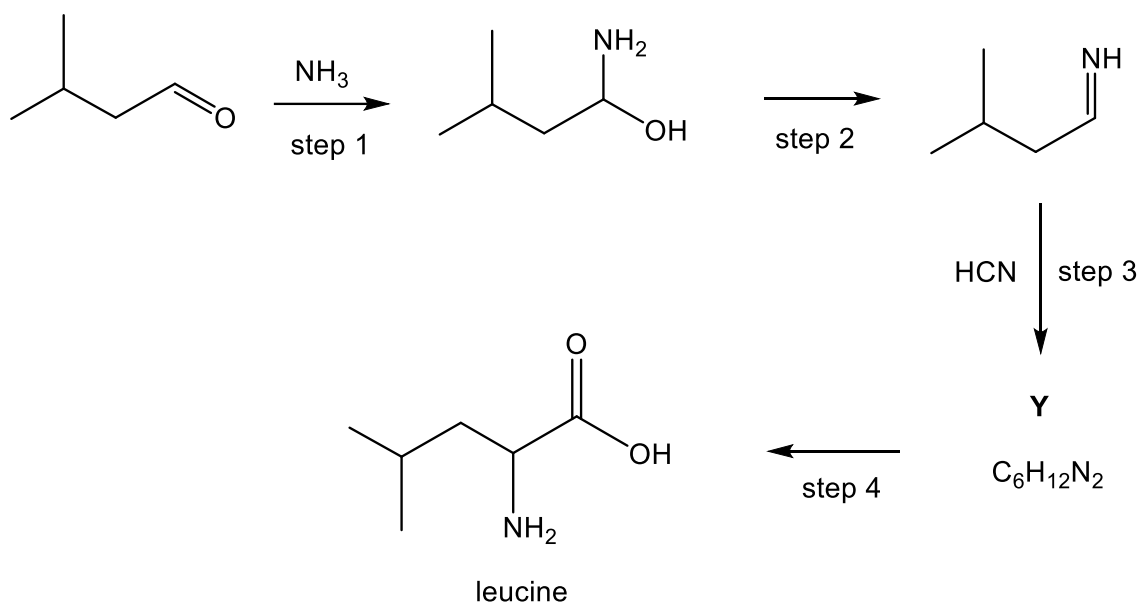
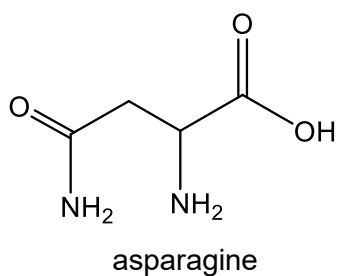


Fig. 4.1

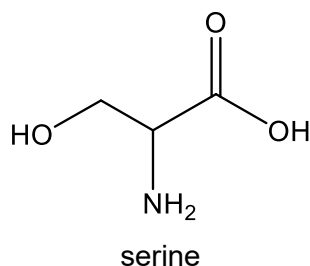
- Suggest the type of reaction occurring in steps 1 and 2. [2]
- Draw the structure of compound **Y**. [1]
- State the reagents and conditions for step 4. [1]
- Asparagine, a non-essential amino acid, is crucial for protein synthesis and various metabolic processes.



Asparagine can be prepared from aldehyde **Z** via the Strecker synthesis. Suggest the structure for aldehyde **Z**. [1]

- Explain the difference in basicity of the two nitrogen-containing functional groups present in asparagine. [2]

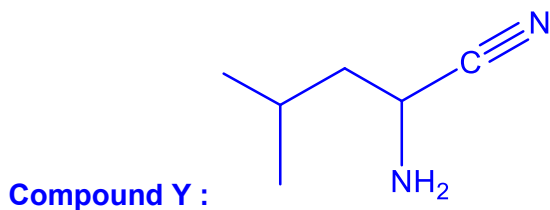
(vi) Serine is a naturally occurring amino acid with the following structure.



Draw the structure of a dipeptide that can be formed between asparagine and serine. [1]

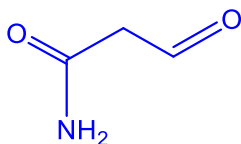
(b) (i) Step 1 is **Nucleophilic Addition**.  
Step 2 is **elimination**

(b) (ii)



(iii) dilute HCl/ or dilute H<sub>2</sub>SO<sub>4</sub>, heat

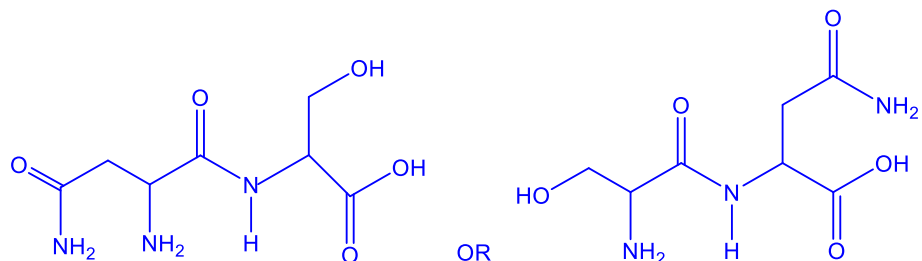
(iv)



(v) The **amine group** in asparagine is more basic as the **lone pair on N atom is more available to accept a proton**, making amine group the stronger base.

For **amide group** in asparagine, **the electron lone pair on N is delocalised into the adjacent C=O**. Hence, the lone pair on N atom is **not available to accept a proton**, making amide **neutral**.

(vi)



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**(c)** Hydrogen cyanide, HCN, can lead to serious health effects when ingested. HCN has a  $pK_a$  value of 9.20 at 25 °C.

- (i)** A solution of HCN was placed in an acidic solution. Calculate the concentration of  $CN^-$  ions when the concentration of HCN is  $0.0500 \text{ mol dm}^{-3}$  at pH 3. [1]

Zinc cyanide,  $Zn(CN)_2$ , is sparingly soluble in water.

The numerical value of its solubility product,  $K_{sp}$ , is  $3.00 \times 10^{-23}$  at 25 °C.

- (ii)** Write an expression for the solubility product of  $Zn(CN)_2$ , stating its units. [1]
- (iii)**  $Zn^{2+}(aq)$  was added to the HCN solution in **(c)(i)**. Determine the minimum concentration of  $Zn^{2+}(aq)$  required to cause the precipitation of  $Zn(CN)_2$  at pH 3.

If you were unable to obtain an answer in **(c)(i)**, use the value of  $[CN^-] = 2.50 \times 10^{-8} \text{ mol dm}^{-3}$ . [2]

- (iv)** Explain how the solubility of  $Zn(CN)_2$  is affected by adding  $HCl(aq)$ . [1]

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$$(c) (i) K_a = \frac{[H^+][CN^-]}{[HCN]}$$

$$10^{-9.20} = \frac{10^{-3}[CN^-]}{0.05}$$

$$[CN^-] = 3.15 \times 10^{-8} \text{ mol dm}^{-3}$$

$$(ii) K_{sp} = [Zn^{2+}][CN^-]^2 \text{ mol}^3 \text{ dm}^{-9}$$

(iii) For precipitation to occur, ionic product  $> K_{sp}$

$$[Zn^{2+}][3.15 \times 10^{-8}]^2 > 3.0 \times 10^{-23}$$

$$[Zn^{2+}] = \underline{3.02 \times 10^{-8}} \text{ mol dm}^{-3}$$

**Alternative answers**

$$[Zn^{2+}][2.50 \times 10^{-8}]^2 > 3.0 \times 10^{-23}$$

$$[Zn^{2+}] = \underline{4.80 \times 10^{-8}} \text{ mol dm}^{-3}$$



Addition of strong acid, HCl, will cause  $H^+$  to react with  $CN^-$  to form HCN. Hence,  **$[CN^-]$  decreases.**

By LCP, **the equilibrium position (1) will shift to the right to increase  $[CN^-]$ .**  
Hence, **solubility of  $Zn(CN)_2$  increases.**

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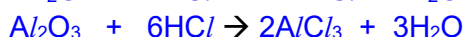
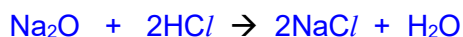


- 5 (a) The acid-base behaviour of aluminium oxide,  $\text{Al}_2\text{O}_3$ , shows similarities to that of sodium oxide,  $\text{Na}_2\text{O}$ , on one hand, and sulfur trioxide,  $\text{SO}_3$ , on the other.

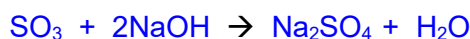
(i) Describe what these similarities are and write equations for all reactions you choose to illustrate your answer. [3]

(ii) Explain why beryllium oxide,  $\text{BeO}$ , exhibits similar acid-base properties as  $\text{Al}_2\text{O}_3$ . [1]

(a) (i)  $\text{MgO}$  is a basic oxide and  $\text{Al}_2\text{O}_3$  is an amphoteric oxide, hence, both reacts with acids.



$\text{SO}_3$  is an acidic oxide and  $\text{Al}_2\text{O}_3$  is an amphoteric oxide, hence, both reacts with bases.



(ii) Both  $\text{Be}^{2+}$  and  $\text{Al}^{3+}$  ions have high/similar charge density, and able to polarize  $\text{O}^{2-}$  anion electron cloud/ induces a partial covalent character.

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- (b) Electroplating uses electrolysis to deposit a layer of metal onto a surface. Nickel plating is widely employed to plate coins, enhancing their durability and resistance to corrosion. In this process, the electrolyte used is a solution of nickel(II) sulfate.

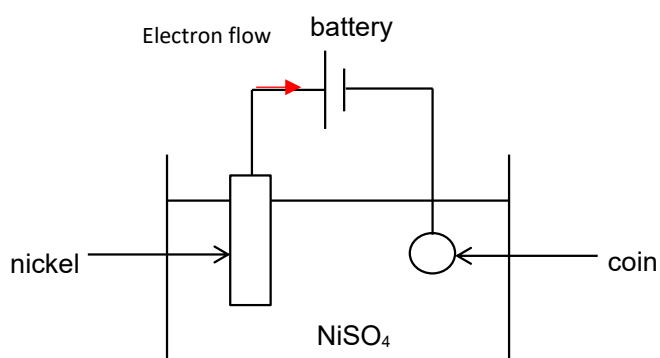
(i) Draw a labelled diagram of the electrolysis cell used to plate coins with nickel. Include details of cathode, anode, electrolyte and the direction of electron flow. [2]

(ii) A constant current is passed through the cell for 6.5 min and 77 mg of Ni is being plated onto the coin. Calculate the current used. [2]

(iii) In another similar set-up, the concentration of the  $\text{NiSO}_4$  solution is doubled while all other conditions remain the same. Explain the effect, if any, on the mass of nickel deposited on the coin. [1]



(b) (i)



(ii) A constant current is passed through the cell for 6.5 minutes and 77 mg of Ni is being plated onto the coin. Calculate the value of current used. [2]



$$\text{Amount of Ni} = \frac{77/1000}{58.7} = 1.312 \times 10^{-3} \text{ mol}$$

$$\text{Amount of e}^{-} = 1.312 \times 10^{-3} \times 2 = 2.624 \times 10^{-3} \text{ mol}$$

$$Q = nF$$

$$= 2.624 \times 10^{-3} \times 96500$$

$$= 253.2 \text{ C}$$

$$Q = It$$

$$253.2 = I \times (6.5 \times 60)$$

$$I = 0.649 \text{ A}$$

(iii) There will be no increase the mass of nickel as the quantity of charge supplied for deposition remains constant with same plating time.

- (c) Reduction and oxidation are important reactions in organic chemistry.

Nickel is an effective catalyst for catalytic hydrogenation, particularly for reducing unsaturated compounds. However, not all possible functional groups can be reduced at room temperature. Applying heat will increase nickel's catalytic activity.

Fig. 5.1. shows some reduction and oxidation reactions that compound **U** can undergo.

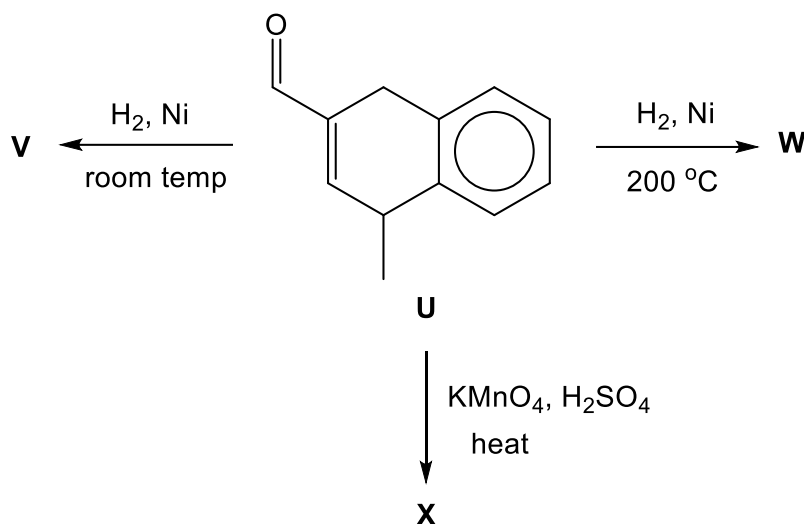


Fig. 5.1

Both **V** and **W** form salts with sodium. **W** does not contain  $\pi$  electrons.

**U** can undergo oxidation with hot acidified  $\text{KMnO}_4$  to give **X**.

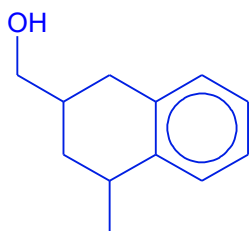
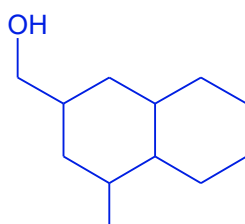
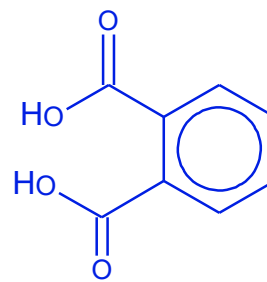
The  $M_r$  values for **V** is 176 and **W** is 182.

- (i) State the type of catalysis for the formation of **V** from **U**. Explain why Ni is a suitable catalyst for this reaction. [2]
- (ii) State the number of  $\pi$  electrons in compound **U**. [1]
- (iii) Suggest the identities of **V**, **W** and **X**. [3]

(c) (i) Heterogeneous catalysis, Ni has 3d and 4s electrons for temporary bond formation with reactants.

(ii) 10

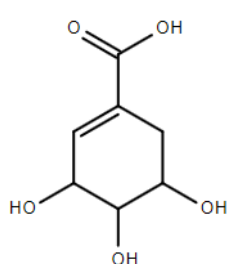
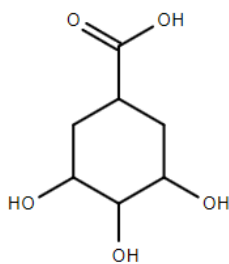
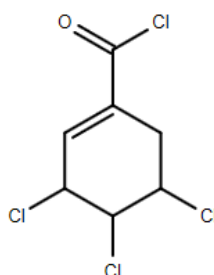
(c) (iii)

**V****W****X**

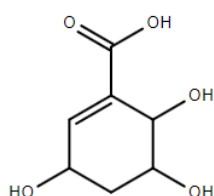
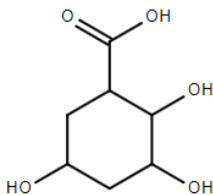
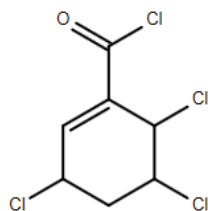


(d)

<u>Evidence</u>	<u>Deduction</u>
<b>P</b> does not produce an orange precipitate with 2,4-DNPH.	<b>P</b> does not undergoes <u>condensation</u> reaction so it does not contain <u>an aldehyde or a ketone</u> (carbonyl) functional group.
On treatment of <b>P</b> with $H_2(g)$ and platinum catalyst, compound <b>Q</b> was formed.	<b>P</b> contains <u>alkene</u> which undergoes <u>reduction</u> to form alkane in <b>Q</b> .
1 mole of <b>P</b> reacts exactly with 4 moles of $PCl_5$ to give compound <b>R</b> .	<b>P</b> contains (4) <u>alcohol or carboxylic acid</u> which undergoes <u>nucleophilic substitution</u> to give <u>chloroalkane or acyl chloride</u> in <b>R</b> .
	Since <b>P</b> is monobasic, it contains <u>1 carboxylic acid and 3 groups of alcohol</u> functional groups
<b>P</b> decolourises hot acidified potassium manganate(VII) solution to give a single compound <b>S</b> .	<b>P</b> contains <u>2° alcohol and alkene</u> which undergoes <u>oxidation</u> to give <u>ketone and carboxylic acid</u> respectively.

**P****Q****R**

Or

**P****Q****R**

**Additional answer space**

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

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