



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]

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- (b) Calcium carbonate is used in flue-gas desulfurisation applications to remove harmful SO_2 and NO_2 emissions from fossil fuels burnt in power stations.

- (i) Draw dot-and-cross diagrams to show the bonding in the molecules of SO_2 and NO_2 . [2]

- (ii) With reference to your answer in (b)(i), explain why the bond angle in SO_2 is found to be 118° while that in NO_2 is 134° . [2]

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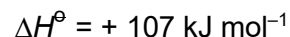
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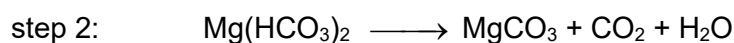
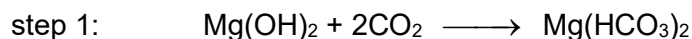


$$\Delta S^\ominus = + 360 \text{ J mol}^{-1} \text{ K}^{-1}$$

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

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- (d) High purity magnesium carbonate, MgCO_3 , is produced industrially at high pressure via a two-step process.



When 150 kg 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 MgCO_3 was produced.

Determine the percentage yield of this industrial process. [2]

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- (e) Titanium dioxide, 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 sublimes at -78°C while titanium dioxide is a crystalline solid with a melting point of 1840°C . [2]

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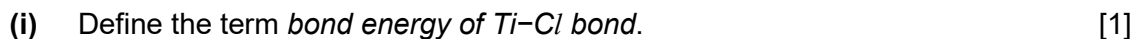
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(ii) Using the ΔH_f° value given above and the data in Table 1.1, together with appropriate data from the *Data Booklet*, construct a fully labelled energy cycle and use it to calculate the average bond energy of the Ti–C/ bond in TiCl_4 .

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

[4]

[illegible]

[Total: 19]

[Turn over

- 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_{cell} for this reaction. [2]
- (ii) Hence, calculate the standard Gibbs free energy change, ΔG^\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 Cr^{3+} ions are kept at 1 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_{cell} , when the cathode is diluted with water. [1]

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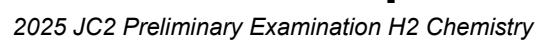
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(b) Fig. 2.1 shows the reactions of the *transition element* chromium and its compounds.

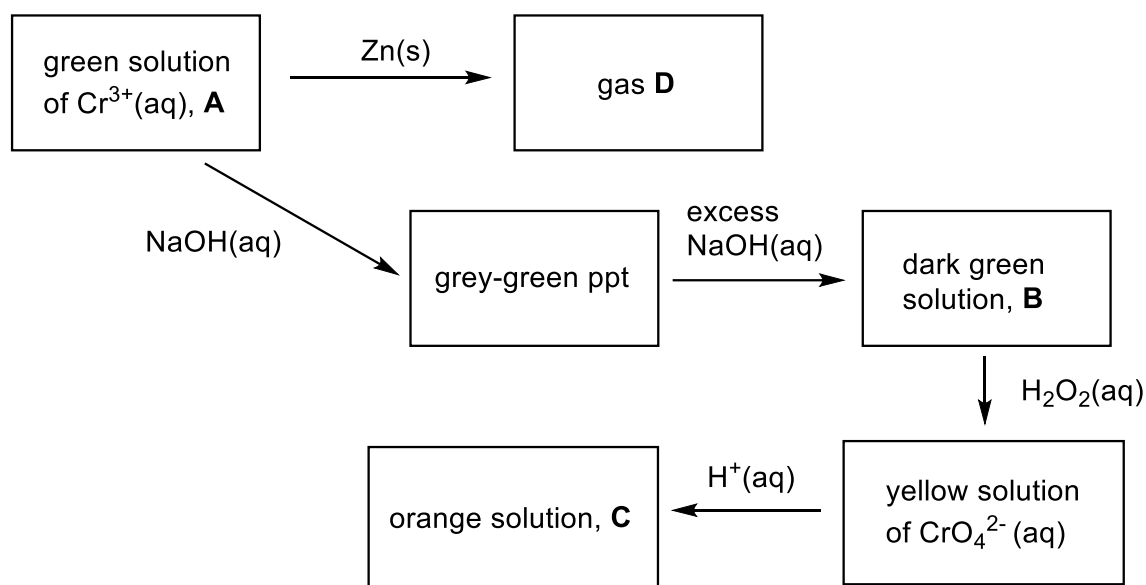


Fig. 2.1

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

[illegible]

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- 3 The Michael addition is a nucleophilic addition reaction where a nucleophile, such as an enolate ion, reacts with an α,β -unsaturated carbonyl compound.

An α,β -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.

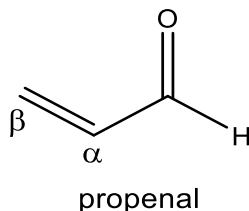


Fig. 3.1

An enolate ion is formed by deprotonating an α -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.

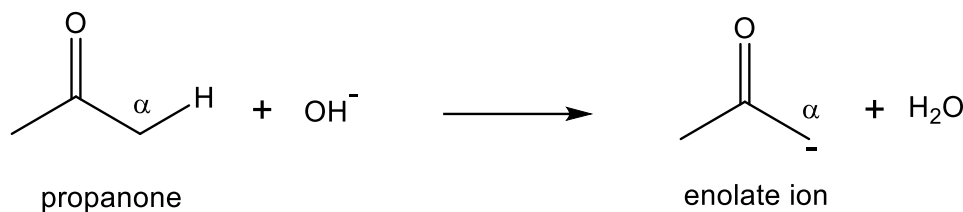


Fig. 3.2

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

Table 3.1

compound	K_a
<p style="text-align: center;">pentane-2,4-dione</p>	1.26×10^{-9}
<p style="text-align: center;">propanone</p>	1.00×10^{-19}

- $$\begin{array}{ccc} \text{O} & & \text{O}^- \\ || & & | \\ \beta \text{C} = \alpha \text{C} - \text{H} & \longleftrightarrow & \text{H} - \alpha \text{C} = \beta \text{C}^+ \end{array}$$

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

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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 OH^- attacks the α -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 β -carbon of propenal, breaking the π bond and pushing electrons towards the α -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 OH^- ion.

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

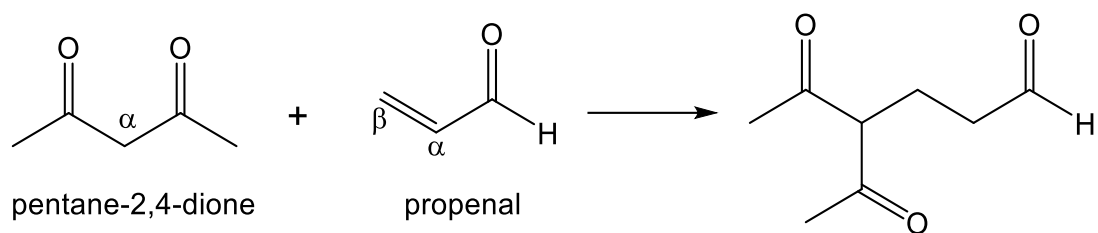


Fig. 3.4

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

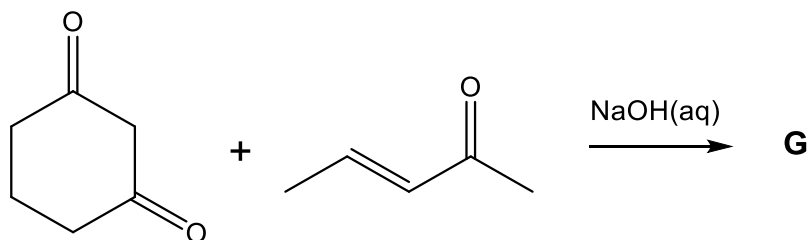
[3]

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]



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

(i) LiAlH_4 in dry ether

(ii) 2,4-dinitrophenylhydrazine

[2]

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(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]

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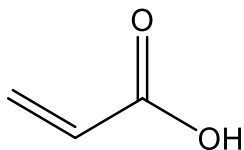
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- (f) Additionally, propenal can undergo oxidation to form propenoic acid. The structure of propenoic acid is shown below in Fig. 3.5.



propenoic acid

Fig. 3.5

- (i) A student suggested the use of hot acidified 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 [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]

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[Total: 21]

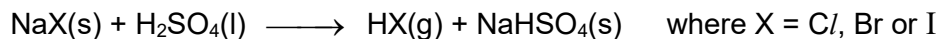
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Section B

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 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 Br_2 liquid and a colourless SO_2 gas.
NaI	White fumes of HI formed. Violet I_2 gas condensed to form a black solid. A pungent H_2S gas is evolved.

- (i) Using Table 4.1, write a balanced equation for the reaction between gaseous HBr and concentrated H_2SO_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]

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- (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.

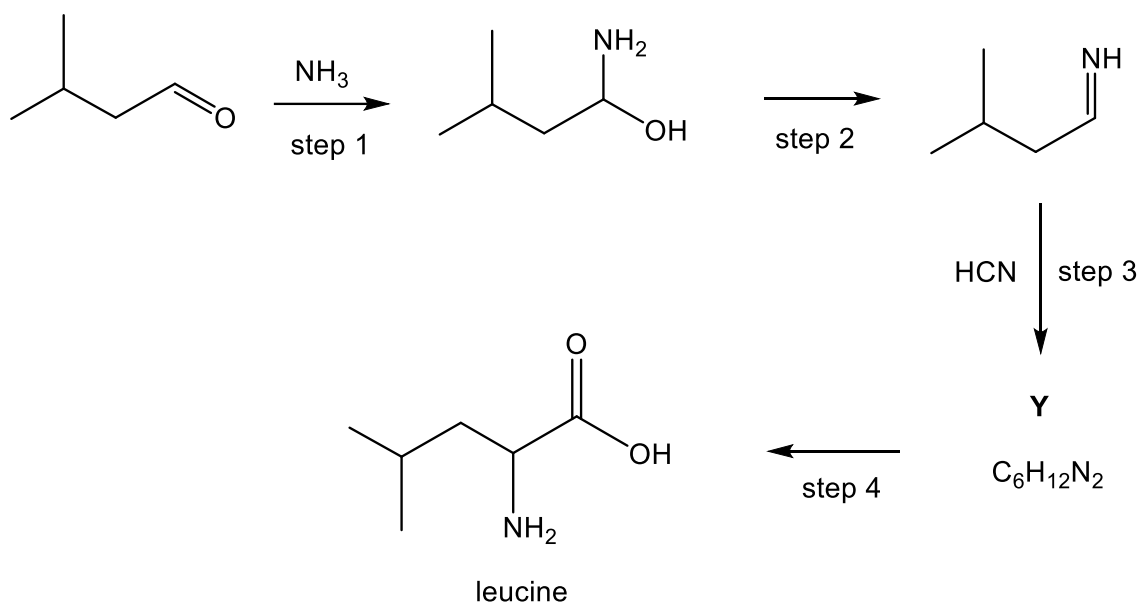
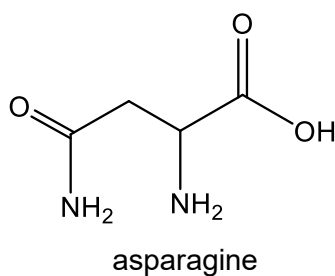


Fig. 4.1

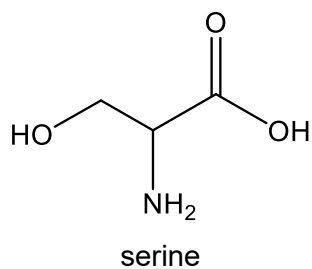
- (i) Suggest the type of reaction occurring in steps 1 and 2. [2]
- (ii) Draw the structure of compound **Y**. [1]
- (iii) State the reagents and conditions for step 4. [1]
- (iv) Asparagine, a non-essential amino acid, is crucial for protein synthesis and various metabolic processes.



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

- (v) 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]

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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 3.00×10^{-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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[Turn over



- 5 (a) The acid-base behaviour of aluminium oxide, Al_2O_3 , shows similarities to that of sodium oxide, Na_2O , on one hand, and sulfur trioxide, 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, BeO , exhibits similar acid-base properties as Al_2O_3 . [1]

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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 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]





- (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.

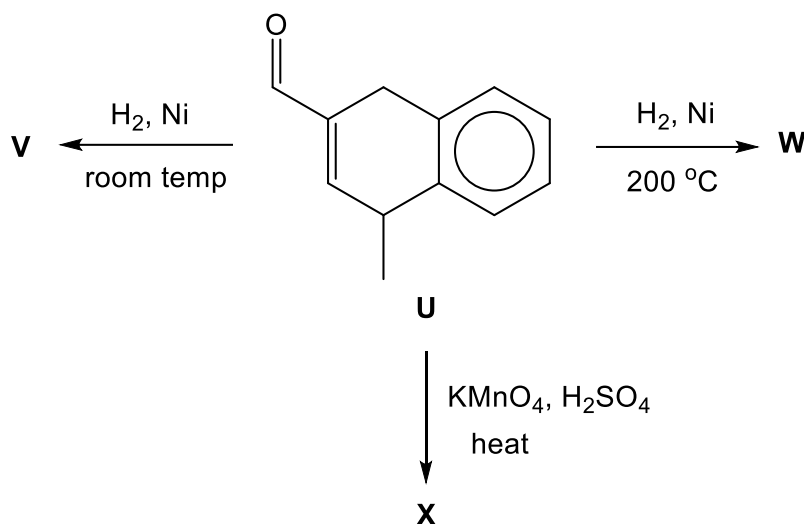


Fig. 5.1

Both **V** and **W** form salts with sodium. **W** does not contain π electrons.

U can undergo oxidation with hot acidified 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 π electrons in compound **U**. [1]
- (iii) Suggest the identities of **V**, **W** and **X**. [3]

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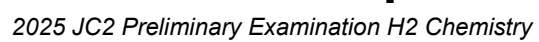
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Additional answer space

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