TAMPINES MERIDIAN JUNIOR COLLEGE

JC2 PRELIMINARY EXAMINATION

H2 CHEMISTRY **9729/01**

Paper 1 Multiple Choice **25 September 2025**

1 hour

Additional materials: Multiple Choice Answer Sheet
Data Booklet

READ THESE INSTRUCTIONS FIRST

Write in soft pencil.

There are **thirty** questions in this paper. Answer **all** questions. For each question, there are four possible answers **A**, **B**, **C** and **D**.
Choose the **one** you consider correct and record your choice in **soft pencil** on the separate Answer Sheet.

Read the instructions on the use of the Answer Sheet very carefully.

You are advised to fill in the Answer Sheet as you go along. No additional time will be given for the transfer of answers once the examination has ended.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.
Any rough working should be done in this booklet.
The use of an approved scientific calculator is expected, where appropriate.

Use of the Answer Sheet

Ensure you have written your name, class, date and subject on the Answer Sheet. Shade the last four digits of your centre/index number on the Multiple Choice Answer Sheet. (e.g. if your centre/index number is 3054**1234**, shade 1234).

Use a **2B** pencil to shade your answers on the Answer Sheet; erase any mistakes cleanly. Multiple shaded answers to a question will not be accepted.

This document consists of **16** printed pages.

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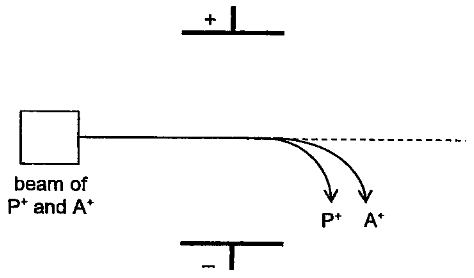
1 *Use of the Data Booklet is relevant to this question.*

In an experiment, a sample containing phosphorus and an unknown element A is vapourised, ionised and passed through an electric field as shown below.



Given that the extent of deflection for A^+ is smaller than P^+, which could be the identity of element A?

A sulfur **B** silicon **C** sodium **D** nitrogen

Answer: A

Angle of deflection $\propto \left|\frac{\text{charge}}{\text{mass}}\right|$

Since the extent of deflection of X^+ is smaller, this implies that X^+ has a larger mass than P^+.

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

Which particle contains the largest number of unpaired electrons?

A O **B** Cl^- **C** K^+ **D** Fe

Answer: D

${}_{8}O$: $1s^22s^22p^4$ (2 unpaired electrons)

${}_{17}Cl^-$: $1s^22s^22p^63s^23p^6$ (0 unpaired electrons)

${}_{19}K^+$: $1s^22s^22p^63s^23p^6$ (0 unpaired electrons)

${}_{26}Fe$: $1s^22s^22p^63s^23p^63d^64s^2$ (4 unpaired electrons)

BP-563

BP-564

3 In a microwave oven, the microwave produced is absorbed by polar molecules.

Which molecules would absorb microwave energy?

1 SO_3

2 CH_2F_2

3 CH_3CH_2OH

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

Answer: C

$SO_3 \Rightarrow$ trigonal planar, non–polar
$CH_3F \Rightarrow$ tetrahedral, polar C–F bond
$CH_3CH_2OH \Rightarrow$ tetrahedral, polar O–H bond

4 The melting point of potassium is lower than the melting point of magnesium.

Which statement is most relevant in explaining the difference?

A Potassium ion has a smaller radius than magnesium ion.

B Potassium ion has a lower charge than magnesium ion.

C Potassium atom contains fewer electrons than magnesium atom.

D Potassium atom is heavier than magnesium atom.

Answer: B

Both potassium and magnesium contain giant metallic structures.

Strength of metallic bond is affected by:
(i) no. of valence electrons delocalised (K < Mg)
(ii) charge density ($K^+ < Mg^{2+}$)

[Turn over

5 Which of the following cannot be explained by hydrogen bonding?

A The existence of hydrogen–difluoride anion, HF_2^-.

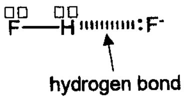
B The difference in volatility between pentan–1–ol and hexan–1–ol.

C The difference in melting point between 2–nitrophenol and 4–nitrophenol.

D The relative molecular mass of ethanoic acid in organic solvent is higher than expected.

Answer: B

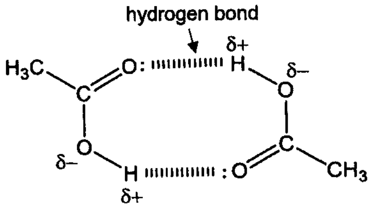
Option A:



Option B: Pentan–1–ol is more volatile (or has a lower boiling point) because it has a smaller electron cloud size than hexan–1–ol. Hence there is a smaller extent of distortion of electron cloud, resulting in weaker instantaneous dipole–induced dipole attraction between pentan–1–ol molecules.

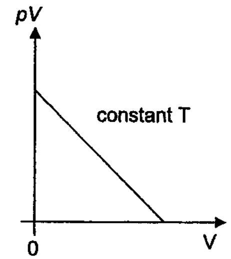
Option C: Due to the proximity of $-NO_2$ and –OH group in 2–nitrophenol, intramolecular hydrogen bonding will occur. Hence less extensive intermolecular hydrogen bonding will be formed between 2–nitrophenol molecules, resulting in lower melting point compared to 4–nitrophenol.

Option D: Ethanoic acid molecules can form a dimer via hydrogen bond in organic solvent.

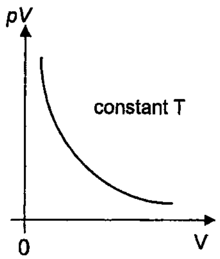


6 Which diagram correctly describes the behaviour of a fixed mass of an ideal gas?

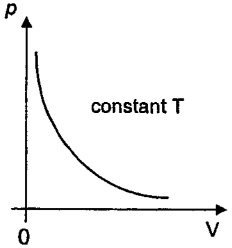
A



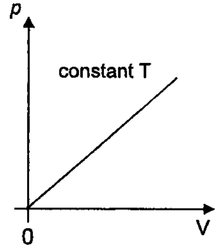
B



C

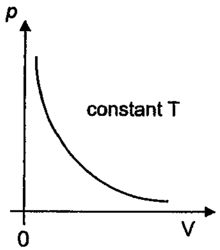


D



Answer: C

Option C is correct



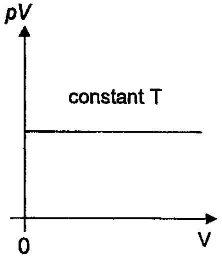
$pV = nRT$

$p = nRT\,(\frac{1}{V})$

since nRT is constant

⇒ $p = k\,(\frac{1}{V})$, where k is a constant

Option A and B is incorrect



since nRT is constant

⇒ $pV = k$, where k is a constant

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

Sodium percarbonate, $(Na_2CO_3)_x{\cdot}y(H_2O_2)$, is an oxidising agent used in laundry cleaning products.

On acidification, 10.0 cm^3 of 0.100 mol dm^{-3} sodium percarbonate releases 48.0 cm^3 of carbon dioxide at room temperature and pressure.

An identical sample, on titration with 0.0500 mol dm^{-3} $KMnO_4$, requires 24.0 cm^3 before the first pink colour appears. 2 moles of $KMnO_4$ reacts with 5 moles of H_2O_2.

What is the ratio of y/x?

A $\frac{1}{3}$ **B** $\frac{2}{3}$ **C** $\frac{3}{2}$ **D** 3

Answer: C

$(Na_2CO_3)_x{\cdot}y(H_2O_2) \equiv xNa_2CO_3 \equiv xCO_2$
$\eta Na_2CO_3 = \frac{10.0}{1000} \times 0.100 = 0.001$
$\eta CO_2 = \frac{48.0}{1000} \div 24 = 0.002$
⇒ $x = 2$

$2KMnO_4 \equiv 5H_2O_2$
$(Na_2CO_3)_x{\cdot}y(H_2O_2) \equiv yH_2O_2$
$\eta KMnO_4 = \frac{24.0}{1000} \times 0.0500 = 0.0012$
$\eta H_2O_2 = \frac{5}{2} \times 0.0012 = 0.003$
⇒ $y = 3$

8 **G**, **H** and **J** are three elements found in Period 3 of the Periodic Table.

Among the elements in Period 3,
- the melting point of **G** is the highest.
- the electrical conductivity of **H** is the highest.
- the melting point of the oxides of **J** is the highest.

Which of the following elements is **not** represented by **G**, **H** or **J**?

A Na **B** Mg **C** A*l* **D** Si

Answer: A
Among the Period 3 elements:
- Silicon has the highest melting point. Hence, **G** is silicon.
- Aluminium has the highest electrical conductivity. Hence, **H** is aluminium.
- Magnesium oxide has the highest melting point. Hence, **J** is magnesium.

9 Which equation defines standard enthalpy change of formation correctly?

A $Na(s) + Cl(g) \rightarrow NaCl(s)$

B $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

C $Mg^{2+}(g) + O^{2-}(g) \rightarrow MgO(s)$

D $H_2(g) + S(s) + 2O_2(g) \rightarrow H_2SO_4(l)$

Answer: D

Standard enthalpy change of formation of a substance is the energy change when 1 mole of the substance is formed from its elements under standard conditions of 298K and 1bar.

[Turn over

10 Hydrogen can be made from steam.

$$H_2O(g) + C(s) \longrightarrow H_2(g) + CO(g)$$

The Gibbs free energy change of reaction at two different temperatures are shown.

At 378 K, $\Delta G_1 = +78$ kJ mol^{-1}
At 1300 K, $\Delta G_2 = -58$ kJ mol^{-1}

Which row gives the correct signs of ΔH and ΔS for this reaction?

	ΔH	ΔS
A	–	+
B	–	–
C	+	–
D	+	+

Answer: D

When T is increased from 378K to 1300K, ΔG is changed from positive to negative.
$\Delta G = \Delta H - T\Delta S$
When ΔH is positive, ΔS is positive such that $-T\Delta S$ is negative,
(i) At lower T, $|\Delta H| > |T\Delta S|$, so ΔG will be positive.
(ii) At higher T, $|\Delta H| < |T\Delta S|$, so ΔG will be negative.

11 The equation for the formation of hexaamminecobalt(III), $[Co(NH_3)_6]^{3+}$ complex ion is shown below.

$$2Co^{2+} + 12NH_3 + H_2O_2 \longrightarrow 2[Co(NH_3)_6]^{3+} + 2OH^-$$

The rate equation is rate = $k\,[Co^{2+}][NH_3]^3[H_2O_2]$.

When the concentration of each reactant is x mol dm^{-3}, the initial rate was found to be y mol dm^{-3} s^{-1}.

What will be the initial rate of the reaction if $[Co^{2+}]$ is 2x, $[NH_3]$ is $\frac{1}{2}$x and $[H_2O_2]$ is 2x?

A $\frac{1}{8}y$ **B** $\frac{1}{2}y$ **C** 2y **D** 8y

Answer: B

Rate = $k\,[Co^{2+}][NH_3]^3[H_2O_2]$

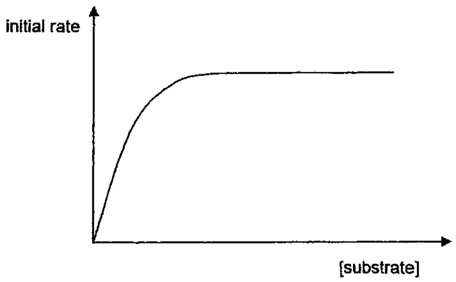
$k = \frac{rate}{[Co2+]\,[NH3]^3\,[H2O2]}$

$= \frac{y}{[x]\,[x]^3\,[x]}$

$= \frac{y}{x^5}$

Rate= $\frac{y}{x^5}\,(2x)(\frac{1}{2}x)^3(2x) = \frac{1}{2}$

12 The Michaelis-Menten graph shows how the initial rate of reaction vary as the concentration of the substrate changes for an enzyme-catalysed reaction.



Which statement could explain the shape of the graph?

A The enzyme is acting as a limiting reagent and is being used up in the reaction.

B Substrate molecules inhibit the enzyme at high concentrations which resulted in a constant rate.

C The reaction will reach a constant rate when all active sites of the enzyme are occupied.

D At high substrate concentration, the order of reaction with respect to substrate is 1

Answer: C

Option A (incorrect): Enzyme is a catalyst so it is not been used up in the reaction.

Option B (incorrect): substrate inhibition does occur in some systems, but that's not the usual explanation for a plateau in Michaelis-Menten kinetics.

Option C (correct): when all active sites are occupied, the enzyme is saturated, and increasing [S] further does not increase the rate

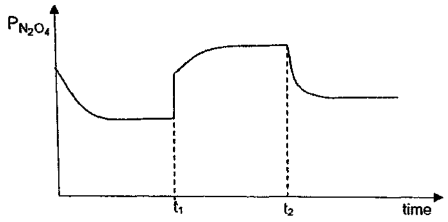
Option D (incorrect): Order of reaction at high substrate concentration is 0.

[Turn over

13 A sample of N_2O_4 was placed in a closed vessel and allowed to reach equilibrium as shown below.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \quad \Delta H^\circ = +57.3\ \text{kJ mol}^{-1}$$

When the partial pressure of a sample of N_2O_4 in a closed vessel was investigated, the following graph was obtained.



Which row correctly describes the changes applied to the reaction vessel at times t_1 and t_2?

	t_1	t_2
A	Volume decreased	Temperature increased
B	Volume decreased	Temperature decreased
C	Volume increased	Temperature increased
D	Volume increased	Temperature decreased

Answer: A

At t_1, there is a sharp increase in partial pressure of N_2O_4 followed by further increase in partial pressure of N_2O_4. With an decrease in volume, it will leads to formation of less moles of gaseous molecules and thus backward reaction is favoured.

At t_2, gradual decrease in partial pressure of N_2O_4 implies that the forward reaction is favoured. Since the forward reaction is given to be endothermic, increase in temperature will favour the forward endothermic reaction.

14 10.0 cm^3 of 8.00×10^{-3} mol dm^{-3} $HCl(aq)$ is added to 10.0 cm^3 of 6.00×10^{-3} mol dm^{-3} $Ba(OH)_2(aq)$.

What is the pH of the resulting solution?

A 3.0 **B** 4.7 **C** 9.6 **D** 11.3

Answer: D

BP-568

Amt of HC*l* = 8.00 x 10^{-5} mol Amt of $Ba(OH)_2$ = 6.0 x 10^{-5} mol

2HC*l* + $Ba(OH)_2$ → $BaCl_2 + 2H_2O$
Limiting reagent: HC*l*

Amt of $Ba(OH)_2$ used = 8.00 x 10^{-5} /2 = 4.00 x 10^{-5} mol
Amt of $Ba(OH)_2$ left = 6.00 x 10^{-5} – 4.00 x 10^{-5} = 2.00 x 10^{-5}
$Ba(OH)_2 \rightarrow Ba^{2+} + 2OH^-$
$[OH^-]$ = [2.00 x 10^{-5} x 2] / 0.02 = 2.00 x 10^{-3} mol

pOH = -lg $[OH^-]$ = 2.70
pH = 14 – 2.70 = 11.3

15 A saturated solution of $Ca(OH)_2$ is found to have a pH of 12.4 at 25 °C.

Which statements are correct?

1 The K_{sp} of $Ca(OH)_2$ is 7.92×10^{-6} mol³ dm⁻⁹.

2 The solubility of $Ca(OH)_2$ will increase when aqueous HC*l* is added.

3 The solubility of $Ca(OH)_2$ would increase when temperature is raised to 40 °C.

4 The pH of the solution would increase when solid $Ca(NO_3)_2$ is added.

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

Answer: D

A saturated solution of $Ca(OH)_2$ is found to have a pH of 12.4 at 25 °C.

$Ca(OH)_2 \rightleftharpoons Ca^{2+} + 2OH^-$ —— (1)

Option A is correct:
K_{sp} of $Ca(OH)_2$ = $[Ca^{2+}][OH^-]^2 = (\frac{1}{2} \times 10^{-1.6})(10^{-1.6})^2 = 7.92 \times 10^{-6}$ mol³ dm⁻⁹.

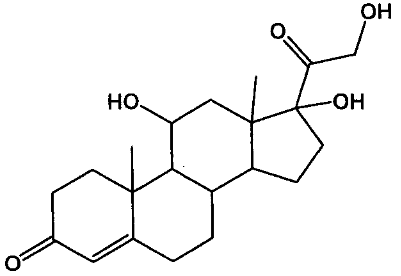
Option B is correct: When HC*l* is added, $[OH^-]$ decreases. As such, eqm position of (1) above will shift to the right to increase $[OH^-]$. The solubility of $Ca(OH)_2$ will increase.

Option C is correct: The solubility of $Ca(OH)_2$ would increase when temperature is increased.

Option D is incorrect: When $Ca(NO_3)_2$ is added, $[Ca^{2+}]$ increases. As such, eqm position of (1) will shift to the left, hence $[OH^-]$ decrease. The pH of the solution would decrease.

[Turn over

16 Cortisol is a hormone that plays a critical role in regulating glucose metabolism.

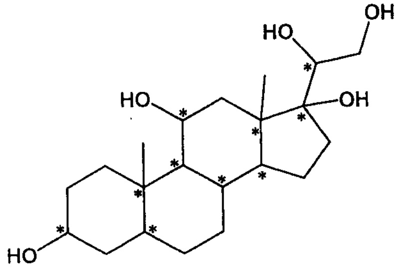


cortisol

After cortisol is reacted with an excess of hydrogen gas in the presence of platinum catalyst, how many chiral carbon atoms would there be in the product?

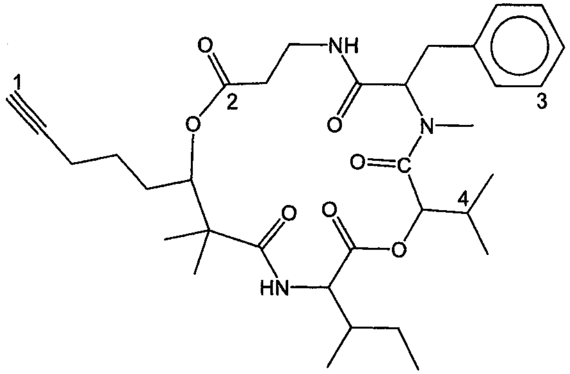
A 8 **B** 9 **C** 10 **D** 11

Answer: C



(10 chiral carbons)

17 Yanucamide B can be extracted from a marine sponge.



yanucamide B

What is the hybridisation of each of the carbon atoms, C-1 to C-4?

	C-1	C-2	C-3	C-4
A	sp^2	sp^2	sp	sp^3
B	sp	sp^2	sp^2	sp^3
C	sp^2	sp^3	sp^2	sp^2
D	sp	sp^2	sp	sp^2

Answer: B

C-1 (alkyne carbon / ≡C—H) forms 2 σ bonds ⇒ sp hybridisation
C-2 (carbonyl C atom) forms 3 σ bonds ⇒ sp^2 hybridisation
C-3 (C on benzene ring) forms 3 σ bonds ⇒ sp^2 hybridisation
C-4 forms 4 σ bonds ⇒ sp^3 hybridisation

[Turn over

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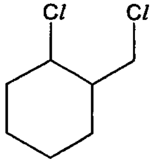
18 Which compounds, on heating with ethanolic sodium hydroxide, produce **only one** product with molecular formula C_7H_{10}?

1


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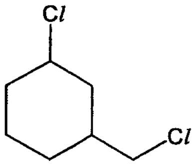

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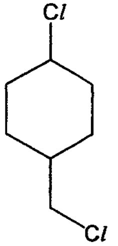
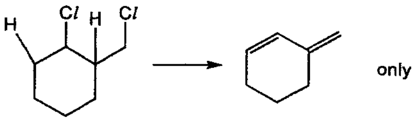


A 1 and 2 only **B** 1 and 3 only **C** 2 and 3 only **D** 1,2 and 3

Answer: B (1 and 3 only)

1


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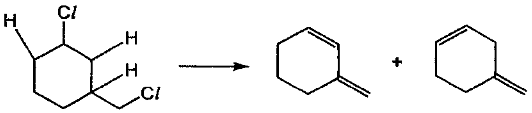

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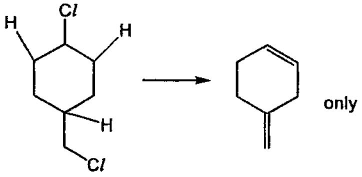


BP-570

19 A catalytic converter is part of the exhaust system of many modern cars.

Which reaction does **not** occur in a catalytic converter?

A $CO_2 + NO \longrightarrow CO + NO_2$

B $2CO + 2NO \longrightarrow 2CO_2 + N_2$

C $2CO + O_2 \longrightarrow 2CO_2$

D $2C_8H_{18} + 25O_2 \longrightarrow 16CO_2 + 18H_2O$

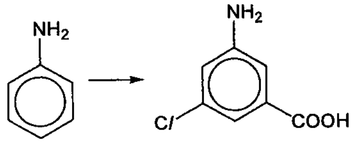
Answer: A

A catalytic converter in the exhaust system of motor vehicles speeds up the conversion of harmful pollutants such as CO, NO_x and unburnt hydrocarbons (C_xH_y) into harmless products such as H_2O, CO_2 and N_2.

Option A is incorrect as CO is formed as one of the products.

20 Use of the Data Booklet is relevant to this question.

Which of the following routes is most suitable to synthesise 3-amino-5-chlorobenzoic acid from phenylamine?



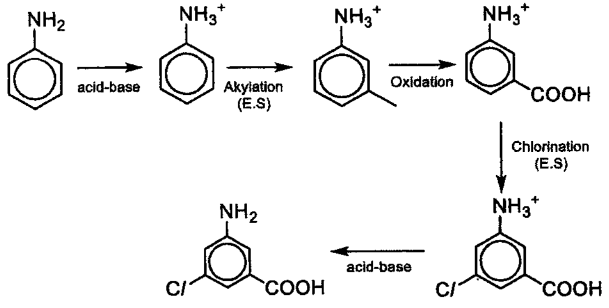
A neutralisation → chlorination → alkylation → oxidation → neutralisation

B neutralisation → alkylation → oxidation → chlorination → neutralisation

C reduction → alkylation → chlorination → oxidation → neutralisation

D reduction → alkylation → oxidation → chlorination → neutralisation

Answer: B



21 The molecular formula of compound **X** is $C_5H_{12}O$. The following shows the reactions compound **X** undergoes:

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

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

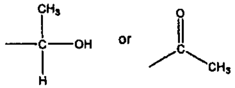
A $(CH_3)_2CHCH(OH)CH_3$

B $(CH_3)_2C(OH)CH_2CH_3$

C $CH_3CH_2CH(CH_3)CH_2OH$

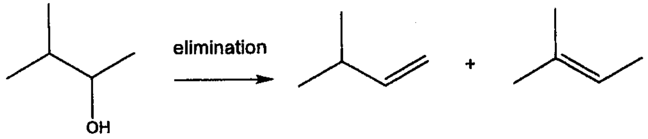
D $CH_3CH_2CH_2CH(OH)CH_3$

Answer: A

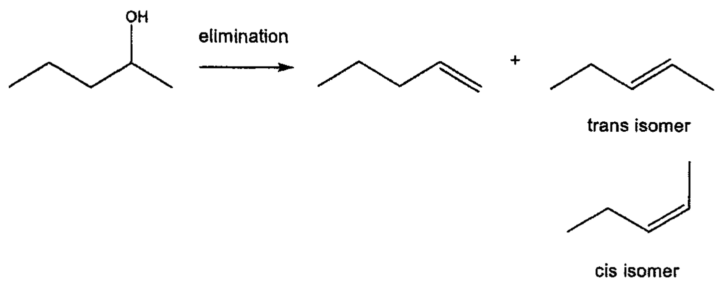


Options B and C does not contain the or group that undergoes iodoform test / oxidation with alkaline aqueous iodine.

Alkenes formed after elimination for option A:



Alkenes formed after elimination for option D:



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22 A sample of bromoethane was warmed with ethanolic silver nitrate, and a cream precipitate was observed after about 4 minutes.

Under similar reaction conditions, which of the following compounds will result in precipitate formation only after 8 minutes?

A chlorobenzene

B chloroethane

C iodoethane

D ethanoyl bromide

Answer: B

Chlorobenzene would not release chloride ions as the lone pair of electrons on the chlorine atom is delocalized into the benzene ring, resulting in the strengthening of the carbon-chlorine bond. Hence no precipitation would occur.

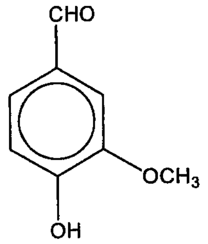
Iodoethane has a weaker carbon-halogen bond than bromoethane, hence it will result in nucleophilic substitution more readily and precipitation occurs in less than 4 minutes.

Ethanoyl bromide has the carbonyl bonded to two electronegative atoms O and Br. This makes the carbonyl C highly electron deficient, and is hence very susceptible to nucleophilic substitution, releasing Br^- readily. Hence precipitation will occur in less than 4 minutes.

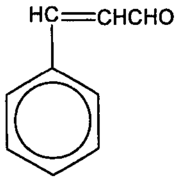
Chloroethane has a stronger carbon-halogen bond than bromoethane, hence it will result in nucleophilic substitution les readily and precipitation occurs in more than 4 minutes.

BP~572

23 Vanillin and cinnamaldehyde are found in natural products and have very pleasant fragrances.



vanillin



cinnamaldehyde

Which reagents could be used to distinguish between the two compounds? You may assume that the –OCH_3 group in vanillin is inert.

1 2,4-dinitrophenylhydrazine

2 Fehling's solution

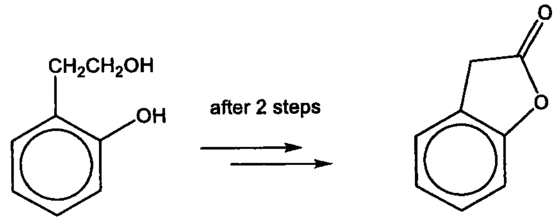
3 Tollen's reagent

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

Answer: B

	Vanillin	Cinnamaldehyde
2,4-dinitrophenylhydrazine	✓	✓
Fehling's solution	×	✓
Tollen's solution	✓	✓

24 Compound **B** can be converted to compound **C** as shown below.



Which reagents are involved in the 2-steps synthesis?

1 hot acidified $KMnO_4$

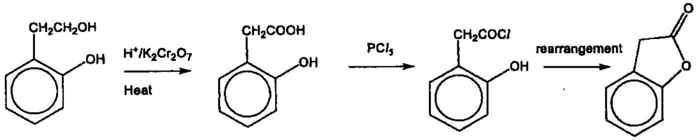
2 hot acidified $K_2Cr_2O_7$

3 PCl_5

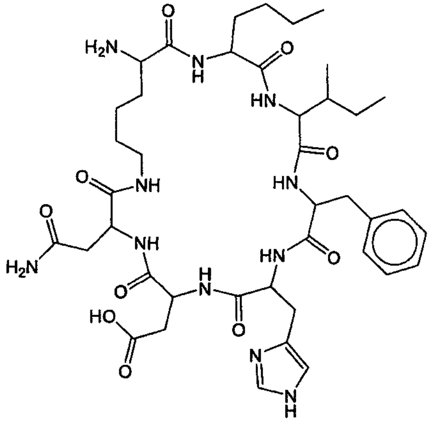
4 concentrated H_2SO_4

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

Answer: C

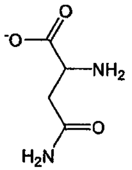


25 Consider the structure of the following cyclic polypeptide.

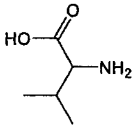


Which one of the following is a product of hydrolysis with hot NaOH(aq)?

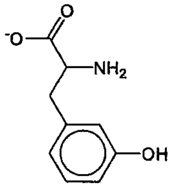
A



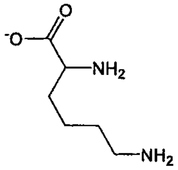
B



C



D



Answer: D

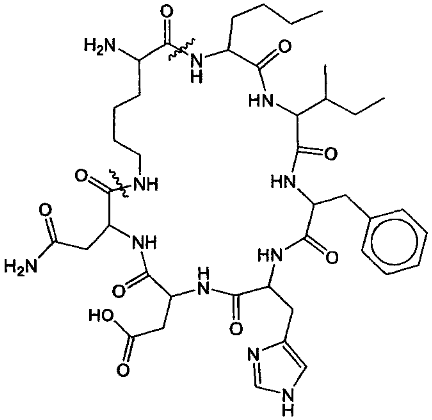
Option A is wrong as amide functional group would undergo basic hydrolysis to form a carboxylate salt.

Option B is wrong as carboxylic acid group would undergo neutralisation to form a carboxylate salt.

Option C is wrong as no such amino acid would be formed upon hydrolysis of all amide bonds. Additionally phenol would undergo neutralisation to form phenoxide.

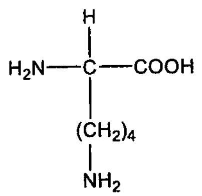
Option D is formed from this amino acid fragment.

[Turn over



BP~574

26 Lysine is an amino acid. The structure of lysine is shown below.



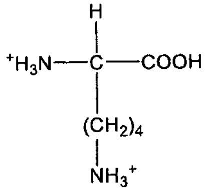
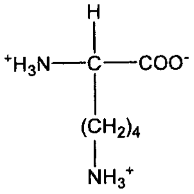
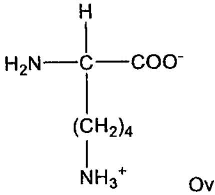
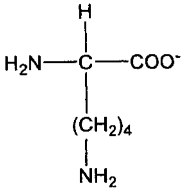
$H_2N-CH((CH_2)_4NH_2)-COOH$

The pKa values of lysine are 2.18, 8.25 and 10.53.

Which of the following pH would result in a zwitterion to be predominantly formed?

A pH 1 **B** pH 5 **C** pH 9 **D** pH 13

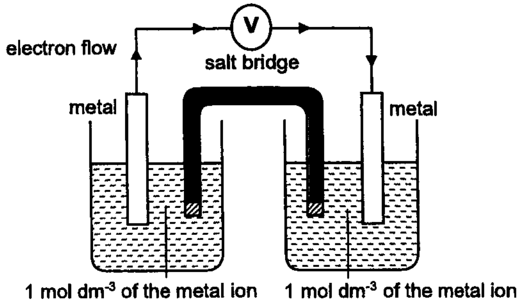
Answer: C

pH 1	pH 5
 $^+H_3N-CH((CH_2)_4NH_3^+)-COOH$ Overall: 2+ charge	 $^+H_3N-CH((CH_2)_4NH_3^+)-COO^-$ Overall: 1+ charge
pH 9	**pH 13**
 $H_2N-CH((CH_2)_4NH_3^+)-COO^-$ Overall: 0 charge	 $H_2N-CH((CH_2)_4NH_2)-COO^-$ Overall: 1- charge

[Turn over

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

The half-cells for three metals: Ag, **X** and **Y** were in turn connected in pairs and the value of the potential difference was recorded at 298 K.



The results obtained are as shown in the table below.

negative electrode	positive electrode	e.m.f /V
X	Ag	+ 0.46
Y	X	+ 0.47

What is the identity of metal Y?

A Co **B** Ni **C** Pb **D** Zn

Answer: C

Negative electrode is anode (oxidation) while positive electrode is cathode (reduction).

In the reaction between metal X and Ag half-cells,
Since $E^\circ_{red} = E^\circ_{Ag+/Ag}$,
$E^\circ_{cell} = E^\circ_{red} - E^\circ_{oxid}$

$+0.46 = +0.80 - E_{oxid}$
$E^\circ_{oxid} = +0.34$ V

In the reaction between metal Y and X, $E_{red} = +0.34$ V
$+0.47 = +0.34 - E^\circ_{oxid}$
Hence, $E^\circ_{oxid} = -0.13$ V

Hence metal Y is Pb since $E^\circ_{Pb2+/Pb} = -0.13$ V from Data Booklet

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

A current of 8 A is passed for 100 minutes through molten aluminium oxide using inert electrodes.

What is the approximate volume of gas liberated, measured at s.t.p.?

A	2.8 dm^3	**B**	3.0 dm^3	**C**	8.4 dm^3	**D**	11.2 dm^3

Answer: A

$2O^{2-} \rightarrow O_2 + 4e^-$
Amount of O_2 = (8 x 100 x 60) / (4 x 96500) = 0.124
Volume of O_2 = 0.124 x 22.7 = 2.8 dm^3

29 Copper is a typical transition element and calcium is an s-block element.

Which property is greater for calcium than for copper?

- **A** density
- **B** melting point
- **C** reducing power
- **D** electrical conductivity

Answer: C

Density: Due to its greater nuclear charge, Cu has a higher atomic mass and smaller atomic volume. Hence, its density is higher than Ca.

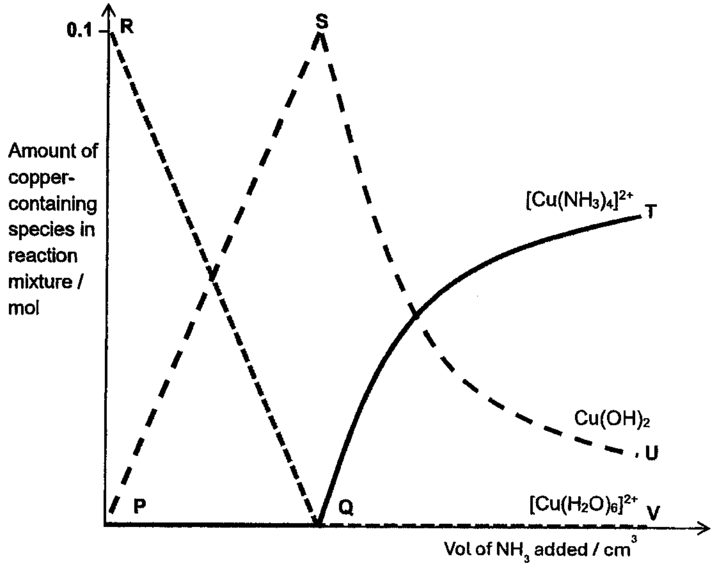
Melting point: Metallic bond for Cu is stronger since both 3d and 4s electrons are delocalised compared to the 4s electrons only for Ca. Hence, more energy is needed during melting accounting for its higher melting point.

Reducing power:
$E^{\circ}_{Cu2+/Cu}$ = + 0.34 V while $E^{\circ}_{Ca2+/Ca}$ = -2.87 V
The more negative the E° value, the more tendency for the metal to undergo oxidation (while it reduces others). Ca will have greater reducing power while itself undergoes oxidation.
OR
The sum of first and second IE for Cu is higher than that for Ca. It is harder for Cu to lose 2 e^- to form Cu^{2+} than that for Cu^{2+}. Hence, Cu has a lower reducing power than Ca.

Electrical conductivity: Cu has higher electrical conductivity since it has a greater number of delocalised electrons (both 3d and 4s) to conduct electricity compared to the 4s electrons only for Ca.

[Turn over

30 An experiment was conducted by adding NH_3(aq) gradually to $CuSO_4$(aq) in a beaker. The amounts of three major copper-containing species, $[Cu(H_2O)_6]^{2+}$, $Cu(OH)_2$ and $[Cu(NH_3)_4]^{2+}$ were determined and plotted against the volume of NH_3(aq) added.



Which portion of the graph best represents each of the processes described?

	precipitation	dissolution	complex formation
A	QT	SU	QT
B	PS	RQ	SU
C	QT	RQ	SU
D	PS	SU	QT

Answer: D

NH_3(aq) is a weak base which contains OH^-(aq).$Cu(OH)_2$ will be precipitated according to the following equation: $Cu^{2+}(aq) + 2OH^-(aq) \longrightarrow Cu(OH)_2(s)$. Therefore, Cu^{2+}(aq) amount will decrease and the $Cu(OH)_2$(s) amount will increase. **RQ**, would refer to Cu^{2+}(aq) decreasing. **PS** would refer to precipitation of $Cu(OH)_2$(s).

Beyond point **Q**, further addition of NH_3(aq) result in formation of the $[Cu(NH_3)_4(H_2O)_2]^{2+}$ complex (blue ppt soluble in excess aq. NH_3 to give dark blue solution according to the QA Notes). More NH_3 added means more complex formed, so **QT** would refer to complex formation. The formation of the complex also results in the dissolution of $Cu(OH)_2$(s) which would be represented by **SU**.

Answers:

1	2	3	4	5	6	7	8	9	10
A	D	C	B	B	C	C	A	D	D
11	12	13	14	15	16	17	18	19	20
B	C	A	D	D	C	B	B	A	B
21	22	23	24	25	26	27	28	29	30
A	B	B	C	D	C	C	A	C	D

6A 8B 9C 7D

[Turn over

TAMPINES MERIDIAN JUNIOR COLLEGE
JC2 PRELIMINARY EXAMINATION

CANDIDATE NAME

CIVICS GROUP

H2 CHEMISTRY **9729/02**

Paper 2 Structured Questions **18 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 this page.

Write in dark blue or black pen.

You may use an HB pencil for any diagrams and graphs.

Do not use paper clips, glue or correction fluid.

Answer **all** questions in the spaces provided on the Question Paper.

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

A *Data Booklet* is provided.

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		
1	**/ 7**	
2	**/ 16**	
3	**/ 11**	
4	**/ 12**	
5	**/ 16**	
6	**/ 13**	
Paper 2 Total	**/ 75**	**/ 30**
Paper 3	**/ 80**	**/ 35**
Paper 4	**/ 55**	**/ 20**
Grand Total		**/ 100**

This document consists of **24** printed pages.

1(a) The graph in Fig. 1.1 shows the atomic radii of some Period 4 metals.

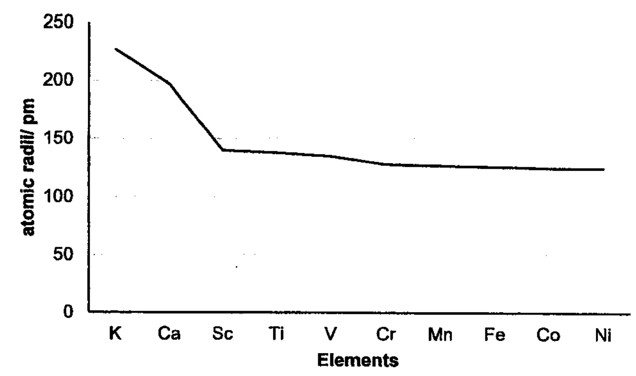


Fig. 1.1

(i) With reference to Fig 1.1, explain briefly why the atomic radius of Ca is smaller than K.

Ca has greater nuclear charge than K while **shielding effect remains relatively constant**. Hence, **Ca has a stronger electrostatic forces of attraction between nucleus and valance electrons** than K, and the valence electrons of Ca are closer to the nucleus.

[1]

(ii) With reference to Fig 1.1, describe and explain why the atomic radii from Cr to Ni are relatively constant.

From Cr to Ni,
- **Nuclear charge increases.**
- **Electrons are added to the inner 3d orbitals** and **provide shielding for the 4s / valence electrons.**
- **Effective nuclear charge varies slightly OR Increase in nuclear charge is offset by the increase in shielding effect.**

Atomic radius remains relatively invariant/ relatively constant.

[2]

BP~577

BP-578

(b) (i) Shibuichi is an alloy of copper and silver and is used in traditional Japanese sword fittings. A particular sample of Shibuichi produced the following peaks in its mass spectrum as shown in Fig 1.2.

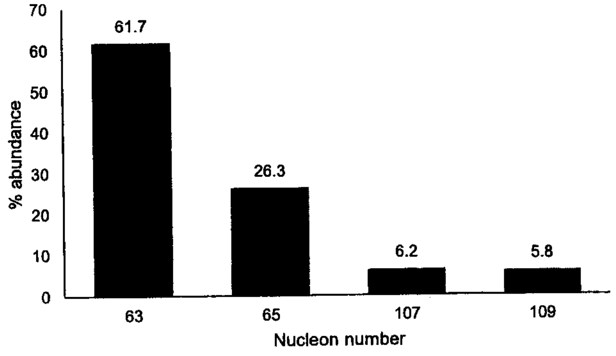


Fig. 1.2

Calculate the average A_r of copper from these data. [1]

$$A_r = \frac{[63 \times 61.7]+[65 \times 26.3]}{88} = \underline{\mathbf{63.6}}$$

(ii) With reference to Fig. 1.2, state the number of protons and neutrons present in the atom with nucleon number 109.

Number of protons: **47**

Number of neutrons: **62**

[1]

(c) Table 1.2 shows the successive ionisation energies of element **B**.

Table 1.2

	1st	2nd	3rd	4th	5th	6th	7th	8th
I.E. / kJ mol^{-1}	900	1800	3250	4900	6050	12690	14200	16250

(i) State which group does element **B** belongs to.

Group 15 [1]

(ii) Both element **A** and element **B** are consecutive elements in the Periodic Table and that element **A** is positioned to the left of element **B**.

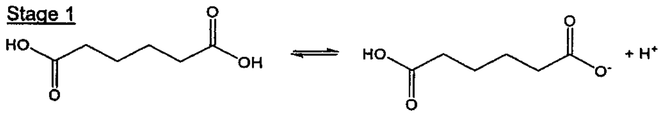
Explain why the 3rd ionisation energy of element **B** is lower than element **A**.

The 3rd I.E. of element B is lower as **the *np* electron to be removed from B has higher energy compared to the *ns* electron to be removed from element A.** Less energy is needed to remove 3rd electron of element B. [1]

[Total: 7]

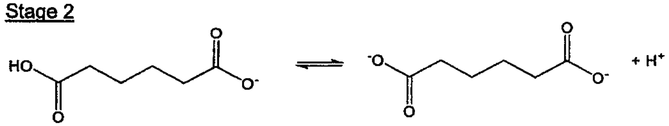
2 Adipic acid, $HOOC(CH_2)_4COOH$, is a flexible food additive used as a gelling aid, firming and buffering agent and can be found in many foods. It is a dibasic acid that ionises in 2 stages.

Stage 1



$K_{a1} = 3.72 \times 10^{-5}$

Stage 2



$K_{a2} = 3.89 \times 10^{-6}$

(a) (i) Write an expression for the first acid dissociation constant of adipic acid, K_{a1}.

$$K_{a1} = \frac{[HO_2C(CH_2)_4CO_2^-][H^+]}{[HO_2C(CH_2)_4CO_2H]}$$

[1]

(ii) Suggest a reason why the value of K_{a2} is lower than that of K_{a1}.

<u>More energy is required to remove a H⁺ from a negatively charged anion after the 1st H⁺ is removed from the acid</u>.

.... [1]

A mixture of adipic acid and its potassium salt can function as a buffer.

(iii) With the aid of a chemical equation, briefly explain how this mixture can act as a buffer when a small amount of base is added.

The effects of K_{a2} can be ignored in any buffer action.

When a small amount of OH^- is added:
$OH^- + HOOC(CH_2)_4COOH \rightarrow HOOC(CH_2)_4COO^- + H_2O$
(or $OH^- + H_2A \rightarrow HA^- + H_2O$)
The added OH^- is removed as H_2O.
<u>$[H^+]$ is slightly changed</u> hence **<u>pH remains fairly constant</u>.**

[2]

(iv) Determine the volume of 0.200 mol dm^{-3} KOH(aq) that needs to be added to 100 cm^3 of 0.200 mol dm^{-3} adipic acid to form a buffer of pH 4.7.

Let the volume of KOH be v dm^3 and total buffer volume be v_t dm^3.

After neutralisation with KOH, the remaining excess acid will form a buffer with the conjugate base of the salt formed.

No of mol of salt = no of mol of KOH added = 0.200 v

No of mol of remaining acid = 0.200 (0.100 – v)

$$pH = -\lg K_{a1} + \lg \frac{[salt]}{[acid]}$$

$$4.7 = 4.43 + \lg \frac{\frac{0.2v}{V_t}}{\frac{0.2(0.1-v)}{V_t}}$$

$$0.27 = \lg \frac{\frac{0.2v}{V_t}}{\frac{0.2(0.1-v)}{V_t}} = \lg \frac{v}{(0.1-v)} \rightarrow 10^{0.27} = \frac{v}{(0.1-v)} = 1.862$$

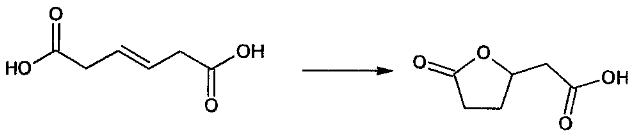
v = 0.1862 – 1.862v → 2.862v = 0.1862

Volume of KOH added, v = **<u>0.0651dm³</u>**

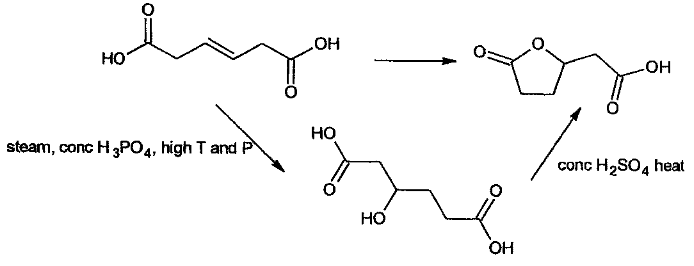
[2]

3-hexenedioic acid can be converted to adipic acid and 3-bromohexanedioic acid which serve as precursors or intermediates for organic synthesis.

(b) (i) Propose a 2-step reaction synthesis to convert 3-hexenedioic acid to **D**. Show clearly all reagents and conditions and the structures of intermediates for each step.



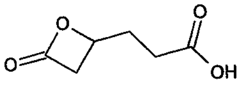
3-hexenedioic acid **D**



[3]

BP-579

(ii) Another possible product that could be produced from the synthesis method in **(i)** is shown below. Suggest why **D** is more likely to be formed than **E**.

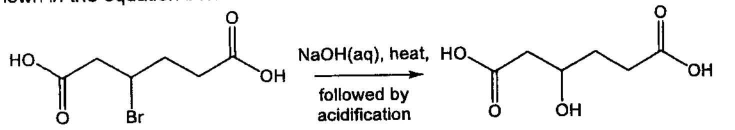


E

Compound **B** will experience **ring strain / angle strain** due to creation of a 4-membered ring and is thus less stable to be formed.

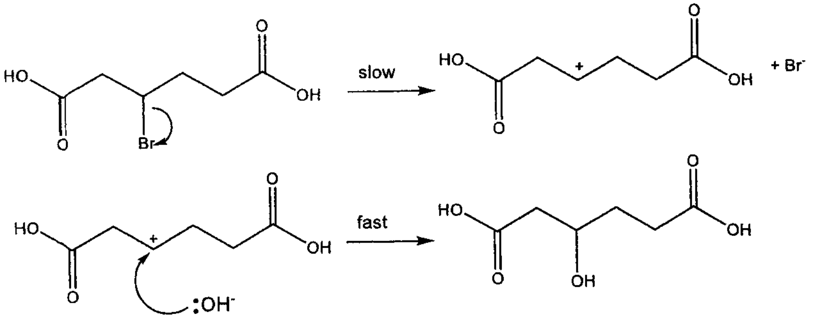
[1]

(c) A sample of 3-bromohexanedioic acid was able to rotate plane polarised light. After reacting with hot NaOH(aq) followed by acidification, the product obtained was no longer able to rotate plane polarised light. The reaction between 3-bromohexanedioic acid and NaOH(aq) is shown in the equation below.



(i) Describe the mechanism for the reaction between 3-bromohexanedioic acid and NaOH(aq). Include all relevant lone pairs, dipoles, curly arrows and charges.

Nucleophilic Substitution (S_N1)

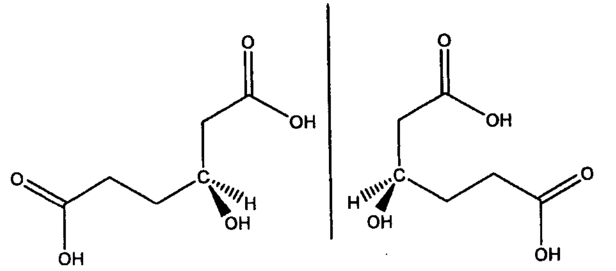


[3]

(ii) State the type of isomerism displayed by the products of the above reaction.

enantiomerism [1]

(iii) Draw the isomers produced in the above reaction.



[2]

[Total: 16]

3(a) Chlorate(V), ClO_3^-, reacts with chloride ions according to the equation as shown below.

$$2ClO_3^-(aq) + 2Cl^-(aq) + 4H^+(aq) \longrightarrow Cl_2(g) + 2ClO_2(aq) + 2H_2O(l)$$

An experiment was conducted using a mixture in which the concentrations of the reactants are as follows: 4.80 x 10^{-4} mol dm^{-3} of ClO_3^-, 0.1 mol dm^{-3} of Cl^- and 0.4 mol dm^{-3} of H^+.

At five-minute intervals, small samples of the reaction mixture were withdrawn, quenched and placed into the UV–vis spectrometer to record its absorbance value. The absorbance value corresponds to the concentration of the product ClO_2.

The graph of absorbance against time is shown in Fig. 3.1.

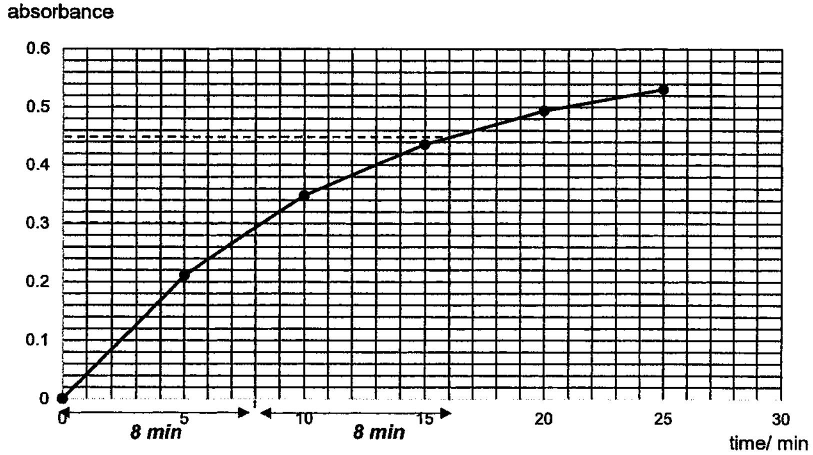


Fig. 3.1

(i) Beer-Lambert's Law states that the absorbance values is directly proportional to the concentration of absorbing species, c, as shown below.

$$A = \varepsilon c l$$

where ε is the molar extinction coefficient and l is the path length, which is usually 1.0 cm.

This equation can be used to calculate the absorbance value when maximum amount of ClO_2 was formed.

Calculate the concentration of ClO_2 in the reaction mixture. Show that the maximum absorbance value of the reaction is 0.600, given that ε of ClO_2 is 1250 mol^{-1} dm^3 cm^{-1}.

Since there are 4.80 x 10^{-4} mol dm^{-3} of ClO_3^-, 0.1 mol dm^{-3} of Cl^- and 0.4 mol dm^{-3} of H^+,
⇒ ClO_3^- is the limiting reagent.

$ClO_3^- \equiv ClO_2$

$[ClO_2]$ = **<u>4.80 x 10^{-4} mol dm^{-3}</u>**

Absorbance value = 1250 x 0.000480 x 1.0 = 0.600 (shown)

[2]

(ii) With reference to Fig. 3.1, show that the reaction is first order with respect to ClO_3^-. Draw clearly any construction lines on the graph.

Since **<u>t½ is relatively constant at 8 min</u>**, the **order of reaction w.r.t ClO_3^-** is <u>1</u>.
At At first t½ (50%), absorbance = $\frac{1}{2}$ x 0.6 = 0.3
At second t½ (75%), absorbance = $\frac{3}{4}$ x 0.6 = 0.45

(iii) Another experiment was carried out using 2.40 x 10^{-4} mol dm^{-3} of ClO_3^- while keeping concentration of Cl^- and H^+ the same.

Deduce the half–life of ClO_3^- in this experiment.

t½ would remain constant at **<u>8 min</u>**.

For first order reaction, **<u>t½ is independent of the initial concentration of reactant</u>**.

[1]

(b) A series of experiments were carried out to investigate the order of reaction with respect to H^+. The results are shown in Table. 3.2.

Table 3.2

Experiment	$[ClO_3^-]$ / mol dm^{-3}	$[Cl^-]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.050	0.100	0.300	3.38 x 10^{-4}
2	0.100	0.100	0.100	7.50 x 10^{-5}

(i) Using the information in Table. 3.2, determine the order of reaction with respect to H^+.

Let rate = $k\,[ClO_3^-]\,[Cl^-]^x[H^+]^y$

Comparing Expt 1 & 2,

$$\frac{\text{rate}_1}{\text{rate}_2} = \frac{k\,[ClO_3^-]_1[Cl^-]_1^x[H^+]_1^y}{k\,[ClO_3^-]_2[Cl^-]_2^x[H^+]_2^y}$$

$$\frac{3.38\times10^{-4}}{7.50\times10^{-5}} = \frac{k(0.050)(0.100)^y(0.300)^z}{k(0.100)(0.100)^y(0.100)^z}$$

$z = 2$

Order of reaction w.r.t. H^+ is <u>**2**</u>.

[2]

BP-581

(ii) The rate of reaction was measured using different initial [H^+] and keeping [ClO_3^-] and [Cl^-] constant. Sketch the graph of rate against initial [H^+] in Fig. 3.3.

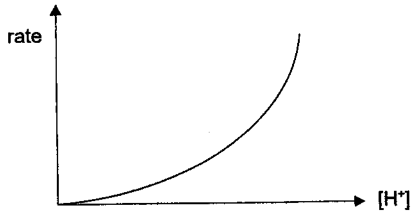
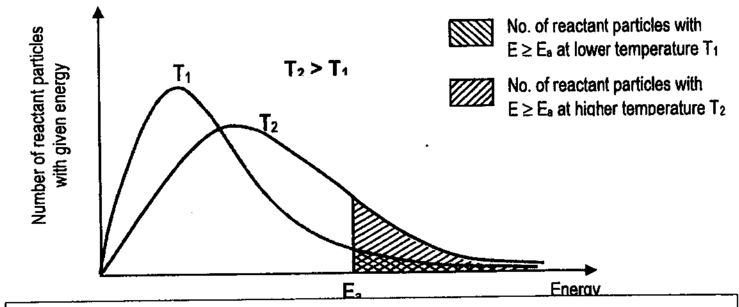


Fig. 3.3

[1]

(iii) Explain, with the aid of a labelled Boltzmann distribution diagram, the effect on a rate constant of increasing temperature.

Maxwell–Boltzmann distribution



When temperature increases,

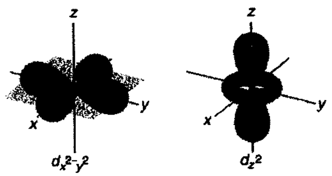
- **number of reactant particles with energy ≥ Ea increases,**
- **frequency of effective collisions increases**,
- resulting in **larger rate constant,** and hence **rate of reaction increases.**.

[2]

(iv) **The reaction between ClO_3^- and Cl^- can take place in the presence of Mn^{2+} catalyst. The five d orbitals in Mn^{2+} ion are degenerated but split into two levels when it is in an octahedral complex.**

Sketch and label one d orbitals that is found in the higher energy level.

Either one of the two orbitals:



[1]

[Total: 11]

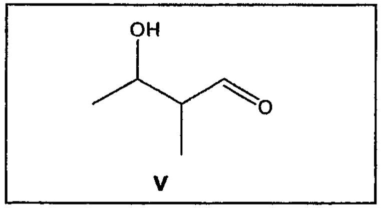
4(a) Compounds **V** and **W** both have molecular formula $C_5H_{10}O_2$. **V** has 2 chiral centres whereas **W** has none.

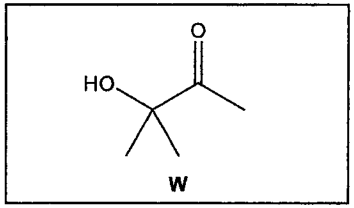
Table 4.1 shows the observations that occurred when separate samples of **V** and **W** were added to different reagents under specific conditions in two separate tests.

Table 4.1

test	reagents and conditions	observations with **V**	observations with **W**
1	heat with acidified $KMnO_4$ (aq)	mixture changes from purple to colourless single organic product made that • forms an orange precipitate with 2,4-dinitrophenylhydrazine • forms effervescence with Na_2CO_3 (aq)	no change
2	heat with alkaline I_2(aq)	pale yellow precipitate forms	pale yellow precipitate forms

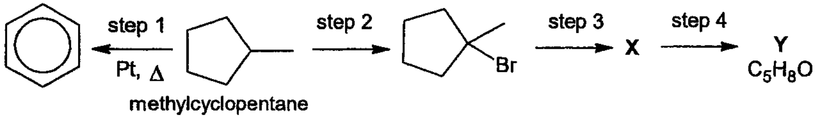
Draw a structure for **V** and for **W**.





[2]

(b) The following flowchart shows reactions of methylcyclopentane.



(i) In Step 1, methylcyclopentane is converted into benzene for the production of gasoline from petroleum. Suggest the type of reaction of Step 1.

Elimination / Oxidation [1]

(ii) Name and describe the mechanism in step 2.

Free radical substitution

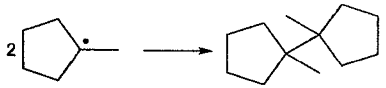
Initiation:

$$Br{-}Br \xrightarrow[\text{(or Heat)}]{\text{UV light}} 2\,Br\bullet$$

Propagation:

Termination:

$$2Br\bullet \longrightarrow Br_2$$



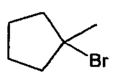
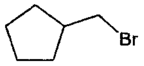
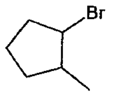
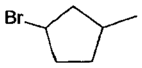
[3]

(iii) Other than the product shown in step 2, three other mono-substituted bromo-alkanes can also be formed in step 2.

Complete Table 4.2 with

- the structures of the three other bromo-alkanes
- the expected ratio in which the four bromo-alkanes will be formed

Table 4.2

Bromo -alkane				
Ratio	1	3	4	4

[2]

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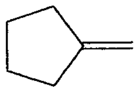
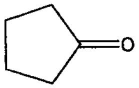
BP-584

(iv) Given that **Y** reacts with 2,4–DNPH, draw the structures of **X** and **Y**. Suggest the reagents and conditions for steps 3 and 4.



X



Y

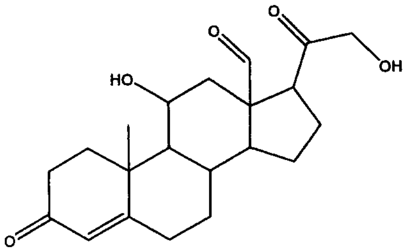
	reagents and conditions
Step 3	**Alcoholic KOH, heat**
Step 4	**Dilute H_2SO_4, $KMnO_4$, heat (cannot use $K_2Cr_2O_7$)**

[4]

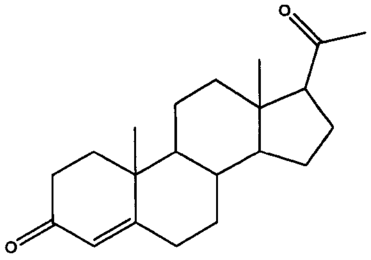
[Total: 12]

5 Steroids are a class of natural or synthetic organic compounds characterised by a molecular structure of 17 carbon atoms arranged in four rings. Natural-occurring steroids are found in hormones in living organisms while synthetic steroids have anti-inflammatory properties.

(a) The chemical structures of some of the naturally occurring steroids are shown below.



aldosterone



progesterone

(i) Identify all the functional groups found in aldosterone

2° alcohol, 1° alcohol, alkene, ketone and aldehyde [2]

(ii) Describe a chemical test that can be performed to distinguish between aldosterone and progesterone.

1. Add **Fehlings' reagent** to each of the compound and **heat**. Aldosterone – **brick red ppt** observed; Progesterone - **No brick red ppt** observed.

2. Add **aq iodine, NaOH** to each compound and **heat**.

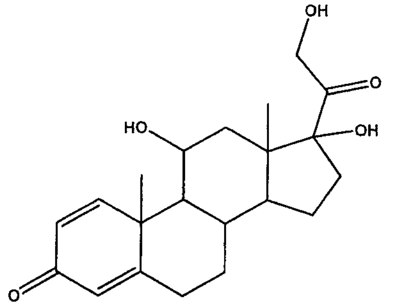
Progesterone - **pale yellow ppt** of CHI_3 observed; Aldosterone - **no pale yellow ppt** observed.

3. Add **Tollens' reagent** to each compound and **heat**.

Aldosterone – **silver mirror/black ppt** observed; Progesterone – **No silver mirror/black ppt** observed.

[2]

Another steroid prednisolone (M_r = 360.4) is a medicine used to treat allergies, blood disorders and inflammation. However, prolonged use of prednisolone comes with side-effects like fatigue and mood swings.



prednisolone

Prednisolone tends to be more fat-soluble than water soluble. When a medicine, such as prednisolone, is not very soluble in blood stream, it will have a low bioavailability, which gives a low efficiency. Bioavailability is defined as the percentage of the administered drug that reaches the blood circulation system. To increase the bioavailability of predinisolone, it is micronised into a smaller size than a conventional drug particle. On average, micronized prednisolone has a bioavailability of 86%.

The prescription of prednisolone depends on the severity of the patient's condition and body weight. The maximum intake of prednisolone each day should not exceed 0.5 mg per kg of the body weight of the patient. [1 mg = 0.001 g]

(b) A patient who weighs 60kg was put on a prednisolone course for four weeks. He was told to consume the maximum intake of prednisolone each day for the first week. This is what his prescription looked like on his medication packaging.

Tampines Meridian Clinic

Prescription:

First Week	**X** tablets each day, taken after breakfast
Second Week	4 tablets each day, taken after breakfast
Third Week	2 tablets each day, taken after breakfast
Fourth Week	1 tablet each day, taken after breakfast

Each tablet contains 5 mg of prednisolone.

(i) Based on the information given, show that the number of tablets, **X**, the patient ingested each day during the first week is 6.

No. of tablet taken each day during first week = (60 x 0.5) ÷ 5 = **6**

[1]

(ii) Taking into consideration the bioavailability of prednisolone, calculate the total amount of prednisolone that reaches the blood circulation system of the patient in the four weeks.

Number of tablets taken during the 4 weeks = (6+4+2+1) x 7 = 91

Amount of prednisolone = [91 x (5 x 10^{-3}) ÷ 360.4] x 0.86 = **1.127 x 10^{-3} mol**

[2]

(iii) In theory, if two patients have the same body weight and severity of the same condition, suggest why the patient who has higher percentage of body fat will require a higher dosage of prednisolone.

It is because as prednisolone is more fat-soluble, there will be **less prednisolone in the blood circulation system of the patient with higher percentage fat mass**, resulting in a decrease of the efficiency of the medication.

[1]

(iv) Suggest why micronising a medicine into particles with a smaller size can increase its bioavailability and lead to higher efficiency.

Micronised particles **have a greater surface area** allowing the medicine to dissolve more readily in blood/more extensive interactions with water in the body to get better dissolved. This enhances absorption.

[1]

(c) The following Table 5.1 shows the solubility of prednisolone in some common solvents.

Table 5.1

solvent	solubility of prednisolone
water	sparingly soluble
ethanol	soluble

(i) By considering all types of interactions between the solute and solvent, explain why ethanol is a better solvent than water to dissolve prednisolone.

Both water and ethanol can form **hydrogen bond** with the hydroxy group of prednisolone. On top of this, the presence of the ethyl group in ethanol allows **instantaneous dipole – induced dipole interaction** extensively with (the non-polar and bulky hydrophobic carbons rings) prednisolone to allow them to dissolve in ethanol better.

(ii) Another way to increase the solubility of prednisolone in water is to synthesise prednisolone as prednisolone phosphate salt without compromising its anti-inflammatory property.

Using Fig. 5.1, illustrate how a water molecule interacts with the prednisolone phosphate ion to increase its solubility. Label the main type of interaction involved.

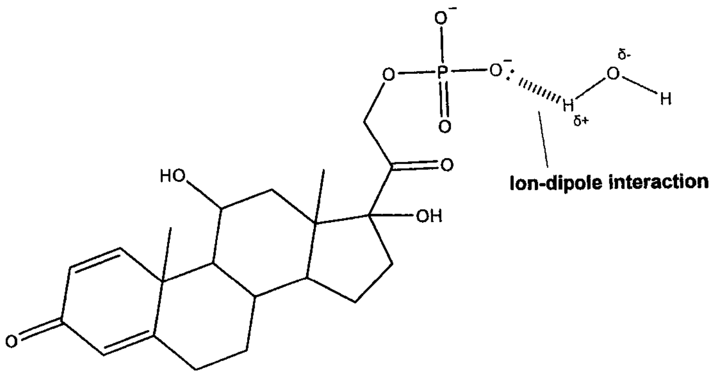


Fig. 5.1

[1]

(d) The half-life of a drug refers to the amount of time it takes for the concentration of its active component in the body to decrease by 50%. A drug is generally regarded as eliminated from the body, with no remaining clinical effect, after 5.5 half-lives.

(i) Calculate the half-life of prednisolone given that the effect of prednisolone will last 16.5 hours after ingestion.

Half-life of prednisolone = 16.5 ÷ 5.5 = **3 hours**

[1]

(ii) Calculate the percentage of prednisolone that remained in the body after 5.5 half-lives.

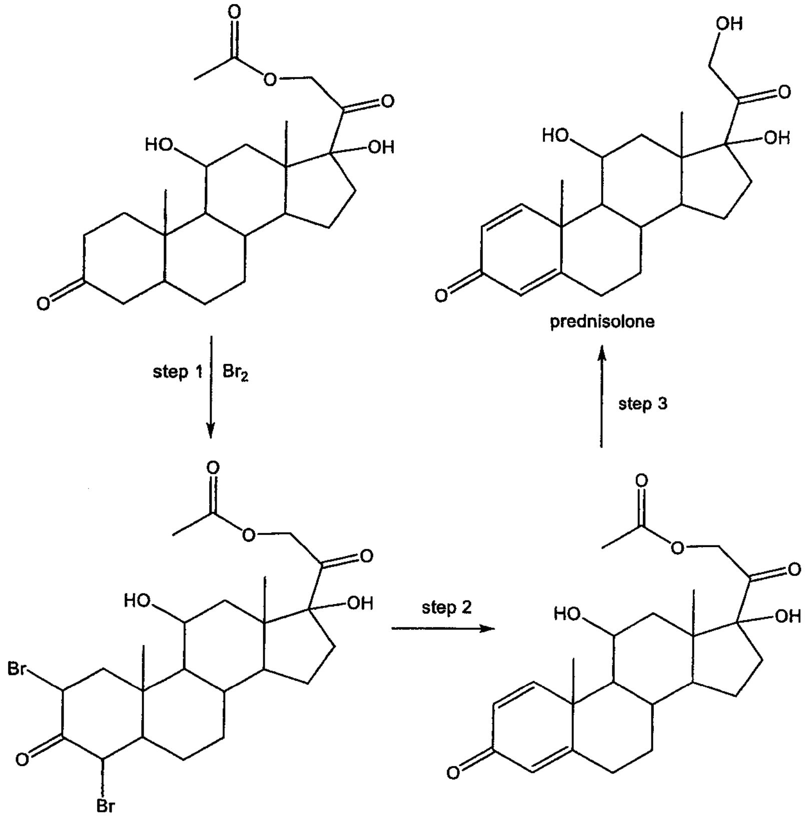
$[A]_t = [A]_0 \times (\frac{1}{2})^n$

where $[A]_t$ is concentration of prednisolone remained; $[A]_0$ is the concentration of prednisolone at the start

Percentage of prednisolone remained = $(\frac{1}{2})^{5.5} \times 100\ \%$ = **2.21%**

[1]

(e) The reaction scheme below shows the synthesis of prednisolone in the pharmaceutical industry.



Identify the type of reaction, and suggest the reagents and conditions for each of the steps 2 and 3.

	reagents and conditions	type of reaction
step 2	**ethanolic KOH, heat**	**elimination**
step 3	**sulfuric acid (aq), heat**	**acidic hydrolysis**

[2]

[Total: 16]

---

6 Dimethyl ether, CH_3OCH_3, is a colourless gas commonly used as a fuel, a spray and a refrigerant. It can react with carbon dioxide to produce carbon monoxide and hydrogen gas as shown in the equation below:

$$CH_3OCH_3(g) + CO_2(g) \rightleftharpoons 3CO(g) + 3H_2(g) \qquad \Delta H = +245 \text{ kJ mol}^{-1}$$

In an experiment, a mixture of CH_3OCH_3 and CO_2 was introduced into a 2500 dm^3 sealed vessel at 600 K and the initial total pressure was 15 atm. The reaction was allowed to reach dynamic equilibrium.

(a) **(i)** Explain what is meant by *dynamic equilibrium*.

A reversible reaction is at dynamic chemical equilibrium when:

- **Rate of forward reaction = Rate of backward reaction** ✓
- the substances are **still reacting together** although the **concentrations** of the **reactants and products** remain **constant.** ✓

[1]

(ii) Write an expression for the equilibrium constant, K_p, stating its units.

$$K_p = \frac{(P_{CO})^3(P_{H_2})^3}{P_{CH_3OCH_3}P_{CO_2}} \qquad \text{atm}^4 \text{ or Pa}^4$$

[2]

(iii) At equilibrium, the amount of H_2 was found to be 280 mol. Show that the equilibrium partial pressure of H_2 in the vessel was 5.5 atm.

$pV = nRT$

Partial pressure of H_2 at equilibrium = $\frac{280 \times 8.31 \times 600}{2500 \times 10^{-3}}$ = 558432 Pa

101325 Pa = 1 atm

558432 Pa = $\frac{558432}{101325}$ = **<u>5.5 atm (shown)</u>**

[1]

BP-587

BP-588

(b)(i) It was found that 75% of the CH_3OCH_3 had dissociated at equilibrium at 600K. Calculate the equilibrium pressures of CH_3OCH_3 and CO_2 in atm.

Let x be the initial pressure of CH_3OCH_3.

	CH_3OCH_3	CO_2	$\rightleftharpoons$	3CO	$3H_2$
Initial partial pressure/atm	x	15 – x		0	0
Change in partial pressure/atm	– 0.75 x	– 0.75 x		+3(0.75)x	+3(0.75)x
Eqm partial pressure / atm	**0.25 x**	**15 – 1.75 x**		**2.25 x**	**2.25 x**

Since equilibrium partial pressure of H_2 in the vessel was 5.5 atm,
2.25 x = 5.5 ⇒ x = 2.44 atm

$P_{CH_3OCH_3}$ at equilibrium = 0.25 x 2.44 = **0.611 atm**

P_{CO_2} at equilibrium = 15 – 1.75(2.44) = **10.7 atm**

[3]

(ii) Hence, calculate the value of K_p, for this reaction. Express your answer to 2 significant figures.

$P_{CH_3OCH_3}$ at equilibrium = 0.611 atm

$P_{H2} = P_{co}$ at equilibrium = 5.5 atm

$$K_p = \frac{(P_{CO})^3(P_{H_2})^3}{P_{CH_3OCH_3}P_{CO_2}}$$

$$K_p = \frac{(5.5)^3\times(5.5)^3}{0.611\times10.7} = \mathbf{4.2\ x\ 10^3\ atm^4}\ \text{(2 s.f.)}$$

[1]

(c)(i) At constant temperature and volume, partial pressure of a gas is proportional to mole fraction. Hence, calculate the average M_r of the gaseous mixture at 600K.

$pV = nRT \Rightarrow p \propto n$

Average M_r

$$= \left(\frac{0.611}{22.311}\times M_r \text{ of } CH_3OCH_3 + \frac{10.7}{22.311}\times M_r \text{ of } CO_2 + \frac{5.5}{22.311}\times M_r \text{ of CO} + \frac{5.5}{22.311}\times M_r \text{ of } H_2\right)$$

= **29.8** (no units and 1 d.p.)

[1]

(ii) Explain the effect on the equilibrium position and the average M_r of the gaseous equilibrium mixture when the experiment was conducted at 700K instead of 600K.

When temperature was increased, the **equilibrium position shifted right towards the endothermic reaction to absorb heat.**

Lower amount of reactants (CH_3OCH_3 and CO_2) with higher M_r and higher amount of products (CO and H_2) with lower M_r were formed. **Hence, the mixture contains a greater proportion of low M_r gases. Therefore,** the **average M_r** of the gaseous mixture **will decrease.**

(d) A key property of an aerosol propellant is that it must exist as a gas under room temperature and pressure conditions.

The behaviour of 1 mol of ideal gas and 1 mol of CH_3OCH_3 at 293 K is shown in Fig. 6.1.

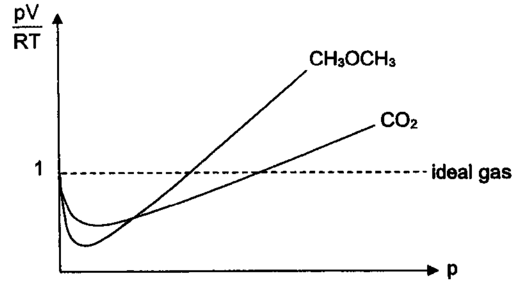


Fig. 6.1

On the **same** axes in Fig. 6.1, sketch and label the graph for 1 mol of CO_2 at 293 K. Explain your answer.

It is observed that at the same temperature, the graph for CO_2 will show a smaller deviation from ideal gas behaviour than CH_3OCH_3 gas.

Both CH_3OCH_3 (M_r = 46.0) and CO_2 (M_r = 44.0) have similar electron cloud size. The **instantaneous dipole – induced dipole attractions between** non-polar **CO_2 molecules** is **weaker /less significant** compared to the **permanent dipole - permanent dipole attractions between the** polar **CH_3OCH_3 molecules.**

[2]

[Total: 13]

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**

This document consists of **30** printed pages and **2** blank pages.

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 CO_3^{2-} / anion electron cloud, and weaken C–O bonds to a smaller extent**, and hence more energy is required to decompose the CO_3^{2-}.

(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]

(b) (i)

(ii) For 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°.

However, in 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°.

BP-589

(c) Magnesium carbonate, $MgCO_3$, can be prepared in the laboratory by the reaction between magnesium chloride solution and aqueous sodium bicarbonate according to the equation:

$$MgCl_2(aq) + 2\,NaHCO_3(aq) \longrightarrow MgCO_3(s) + 2\,NaCl(aq) + H_2O(l) + CO_2(g)$$

$$\Delta H^\ominus = +\,107\ \text{kJ mol}^{-1}$$
$$\Delta S^\ominus = +\,360\ \ \text{J mol}^{-1}\ \text{K}^{-1}$$

(i) Explain why the reaction shows an overall positive value for $\Delta S^\ominus$. [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]

(c) (i) $\Delta S^\ominus$ 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) $\Delta G = \Delta H^\ominus - T\Delta S^\ominus$

$= +107 - (273 + 50)\,(0.360)$

$= \underline{-\,9.28}$ kJ mol^{-1}

(iii) Both ΔH and ΔS 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 ΔH**.

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**.

[Turn over

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

step 1: $Mg(OH)_2 + 2CO_2 \longrightarrow Mg(HCO_3)_2$

step 2: $Mg(HCO_3)_2 \longrightarrow MgCO_3 + CO_2 + H_2O$

When 150 kg $Mg(OH)_2$ was reacted with excess carbon dioxide gas, and the resultant $Mg(HCO_3)_2$ vacuum dried to remove carbon dioxide and water, 168 kg $MgCO_3$ was produced.

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

(d) Amount of $Mg(OH)_2$ reacted $= \dfrac{150 \times 1000}{58.3}$

= 2573 mol

= Theoretical amount of $MgCO_3$ produced

Theoretical yield of $MgCO_3$ = 2573 x 84.3

= 216900 g

= 216.9 kg

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

(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]

(e) CO_2 has a **simple molecular structure**.

Little energy is required to overcome the **weak instantaneous dipole – induced dipole forces of attraction between CO_2 molecules**, resulting in a low sublimation point.

TiO_2 has a **giant ionic structure**.

A lot of energy is required to break the **strong ionic bonds / electrostatic forces of attraction between Ti^{4+} ions and O^{2-} ions / oppositely charged ions**, resulting in a high melting point.

(f) The industrial manufacture of titanium dioxide involves reacting titanium(IV) chloride, $TiCl_4$, with oxygen gas according to the equation as shown.

$$TiCl_4(l) + O_2(g) \longrightarrow TiO_2(s) + 2Cl_2(g) \qquad \Delta H_r^{\ominus} = -136\ \text{kJ mol}^{-1}$$

(i) Define the term *bond energy of Ti–Cl bond.* [1]

(ii) Using the $\Delta H_r^{\ominus}$ 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 $TiCl_4$.

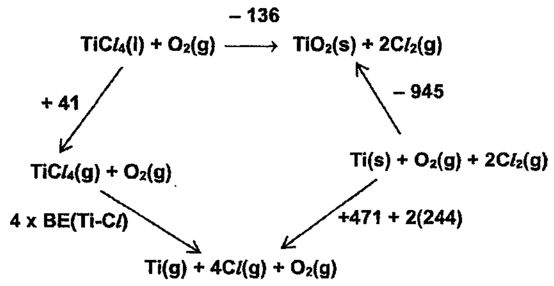
Table 1.1

enthalpy change of vaporisation of $TiCl_4(l)$	+ 41 kJ mol^{-1}
standard enthalpy change of formation of $TiO_2(s)$	– 945 kJ mol^{-1}
standard enthalpy change of atomisation of Ti(s)	+ 471 kJ mol^{-1}

[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 x BE(Ti-Cl) = – 41 –136 – (–945) + (471 + 2(244))

BE(Ti-Cl) = <u>+ 432 kJ mol^{-1}</u>

[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.

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$$

The other electrode in this cell is the zinc electrode in the presence of $H_2SO_4(aq)$ as the electrolyte.

(a) (i) Construct the overall equation for the reaction when 1 mol of $Cr_2O_7^{2-}$ 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, $\Delta G^{\ominus}$, of the reaction. [1]

(iii) The cathode of the bichromate cell usually operates at pH 3 and 298 K. The concentration of $Cr_2O_7^{2-}$ 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 $Q = \dfrac{[Cr^{3+}]^2}{[Cr_2O_7^{2-}][H^+]^{14}}$

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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(a) (i) Cathode: **$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$**
Anode: **$Zn \rightarrow Zn^{2+} + 2e^-$**

Overall eqn: **$Cr_2O_7^{2-} + 14H^+ + 3Zn \rightarrow 2Cr^{3+} + 7H_2O + 3Zn^{2+}$**

$E^{\ominus}_{cell} = E^{\ominus}_{red} - E^{\ominus}_{oxid}$
$= +1.33 - (-0.76) =$ **$+2.09$ V**

(ii) $\Delta G^{\ominus} = -nFE^{\ominus}_{cell}$
$= -(6)(96500)(2.09) =$ **-1.21×10^6 J mol^{-1}**
$=$ **-1210 kJ mol^{-1}**

(a) (iii) $E = E^{\ominus} - \frac{RT}{nF}\ln(Q)$

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

$E =$ **$+0.916$ V**

$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$

According to Le Chatelier's principle, **$[H^+]$ is lower** than 1 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 $[H^+]$ decreases, position of equilibrium shift left, E value will become more negative** Hence **$E^{\ominus}_{cell}$ become more negative (or less positive).**

[Turn over

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

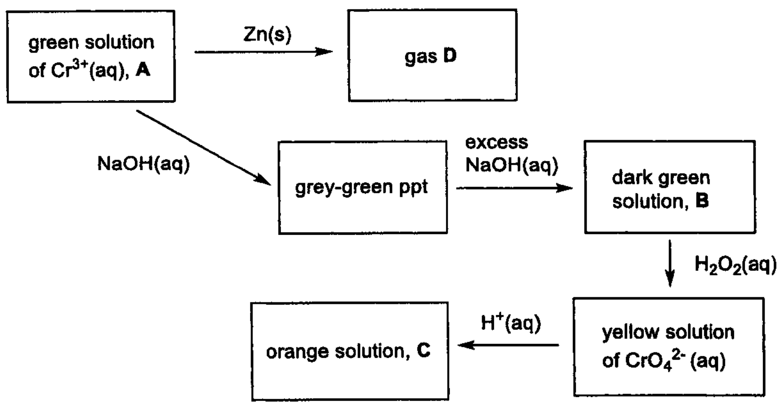


Fig. 2.1

(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 $Cr(H_2O)_4(Cl)_2$. Suggest the structures of the two isomers. [1]

(v) Write an equation to account for why solution **A** is acidic. [1]

(b) (i) A **<u>d–block element that forms at least one stable ion with partially-filled d subshell.</u>**

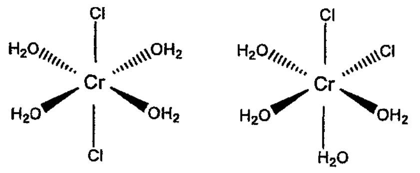
(ii) A transition metal ion has **partially-filled d orbitals**. In the **presence of ligands**, the **d orbitals are split into two groups** with an energy gap, ΔE. This effect is known as **d orbital splitting**.

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: $[Cr(OH)_6]^{3-}$
C: $Cr_2O_7^{2-}$
D: H_2

(iv)



(trans) (cis)

(v) $[Cr(H_2O)_6]^{3+} \rightleftharpoons [Cr(H_2O)_5(OH)]^{2+} + H^+$

(c) Acidified $K_2Cr_2O_7$ can oxidise both M^{2+} and $C_2O_4^{2-}$ in MC_2O_4. One of the products formed is CO_2. 25.00 cm³ of 0.0200 mol dm⁻³ acidified $K_2Cr_2O_7$ is required to completely oxidise 15.0 cm³ of 0.0500 mol dm⁻³ MC_2O_4.

(i) Show that the volume of $K_2Cr_2O_7$ required to oxidise $C_2O_4^{2-}$ **only** is 12.5 cm³. [2]

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

(c) (i) Reduction: $Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$
Oxidation: $C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$

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

Amount of $C_2O_4^{2-}$ = 15/1000 x 0.0500 = 0.00075 mol

$Cr_2O_7^{2-} \equiv 3C_2O_4^{2-}$

Amount of $Cr_2O_7^{2-}$ reacted w $C_2O_4^{2-}$ = 0.00075 / 3 = 0.00025 mol

Vol of $Cr_2O_7^{2-}$ needed = 0.00025/0.0200 = 0.0125 dm³ = **<u>12.5 cm³</u>**

(ii) Amount of $Cr_2O_7^{2-}$ reacted with M^{2+}
= (25/1000 x 0.0200) – (0.00025) = 0.00025 mol

Amount of M^{2+} = 0.00075 mol

	Reduction (e⁻ gained)	**Oxidation (e⁻ lost)**
Species involved	$Cr_2O_7^{2-} \rightarrow Cr^{3+}$	$M^{2+} \rightarrow$?
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 = **<u>2</u>**

<u>1 mole of M^{2+} loses 2e-</u>

=> Final oxidation state of M = <u>+4</u>

[Total: 20]

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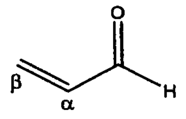
3 The Michael addition is a nucleophilic addition reaction where a nucleophile, such as an enolate ion, reacts with an α,β-unsaturated carbonyl compound.

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.



propenal

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.

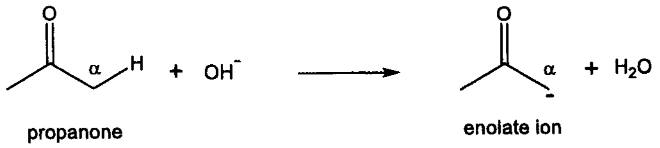
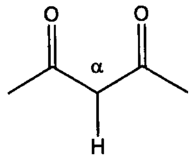
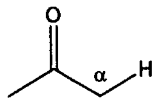


Fig. 3.2

(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
 pentane-2,4-dione	1.26×10^{-9}
 propanone	1.00×10^{-19}

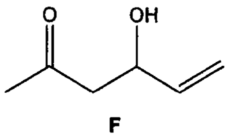
(i) Explain why pentane-2,4-dione is a stronger acid as compared to propanone. [2]

Weakly basic enolate ions would attack the β-carbon of the α,β-unsaturated carbonyl compound, while strongly basic enolate ions would attack the carbonyl carbon of the α,β-unsaturated carbonyl compound.

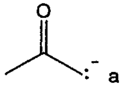
(ii) The reaction between propanone and propenal resulted in the carbonyl carbon to be attacked by the enolate ion, while the reaction between pentane-2,4-dione and propenal resulted in the β-carbon to be attacked by the enolate ion.

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.



F

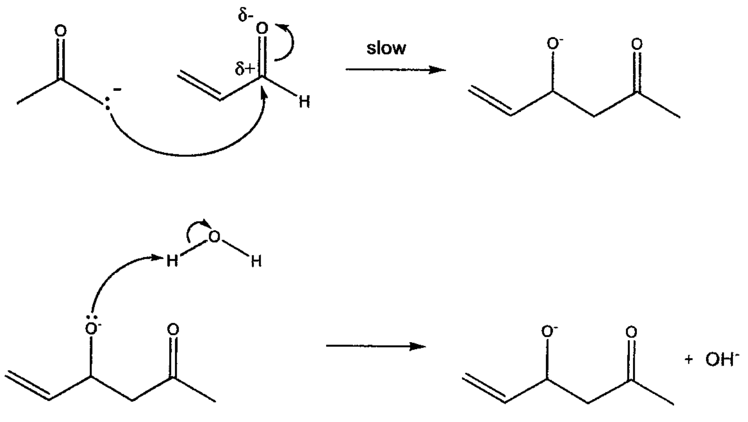
Describe the mechanism for this reaction, using  as the nucleophile. Include all relevant lone pairs, dipoles, curly arrows and charges. [3]

(a) (i) The **<u>lone of pair of electrons on the conjugate base of pentadione can delocalise across both carbonyl groups OR O=C–CH⁻–C=O system</u>**.

This leads to a **<u>greater extent of dispersal of negative charge</u>** on the conjugate base OR enolate ion of pentadione, **<u>stabilising the anion</u>**. 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 **<u>stronger base</u>** 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)

(iii)



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

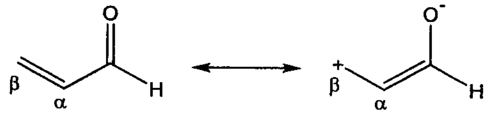


Fig. 3.3

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

(b) The **<u>2p orbitals of O and C orbitals side-on overlap</u>** 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 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.

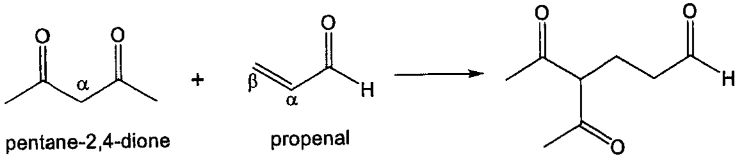
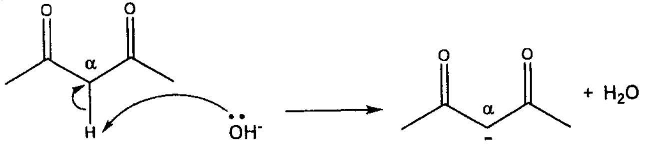
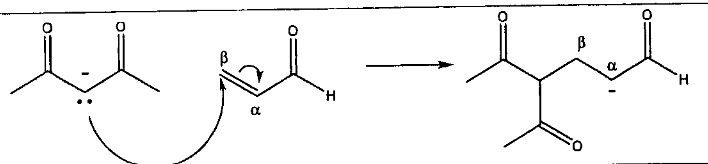
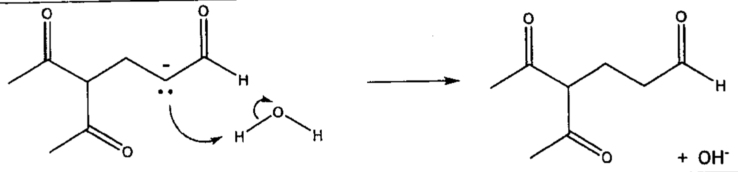


Fig. 3.4

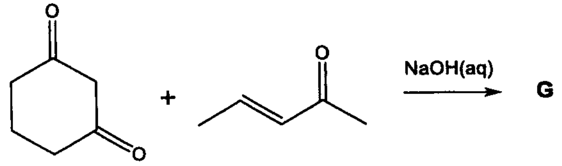
(i) Complete the mechanism by adding **two** curly arrows to **each** step in Table 3.2. [3]

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]

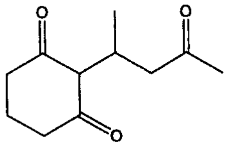


(c)(ii) Add **Br₂(aq)** to the final reaction mixture.
If the reaction is completed, **orange Br_2(aq) solution should not decolourise**.

OR

Add **cold alkaline $KMnO_4$** to the final reaction mixture
If the reaction is completed, the **purple $KMnO_4$ solution should not decolourise**.

(iii) G:

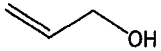


(d) Draw the organic product formed when propenal reacts with

(i) $LiAlH_4$ in dry ether

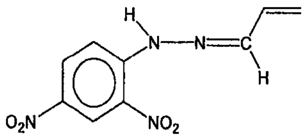
(ii) 2,4–dinitrophenylhydrazine [2]

(d) (i)



formed with $LiAlH_4$ in dry ether

(ii)



formed with 2,4-DNPH

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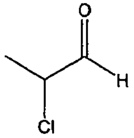
(e) Propenal can react with dry hydrogen chloride gas.

(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]

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



(ii) In step 2 of the electrophilic addition mechanism, the **Cl^- nucleophile attacks the trigonal planar 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.

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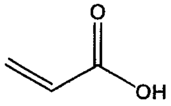
(f) Additionally, propenal can undergo oxidation to form propenoic acid. The structure of propenoic acid is shown below in Fig. 3.5.



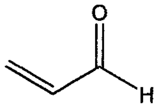
propenoic acid

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]

(f) (i)



$+ 7[O] \longrightarrow 3CO_2 + 2H_2O$

(When using $H^+/KMnO_4$, both vigorous oxidation of a terminal alkene and oxidation of aldehyde occurred, leading to the formation of CO_2, H_2O and ethanedioic acid. Ethanedioic acid would then undergo further oxidation to form CO_2 and H_2O.)

(ii) $K_2Cr_2O_7$, H_2SO_4(aq), heat

....

....

....

....

[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.

$$NaX(s) + H_2SO_4(l) \longrightarrow HX(g) + NaHSO_4(s) \quad \text{where X = C}l\text{, Br or I}$$

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
Na*Cl*	White fumes of H*Cl* 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]

(a) (i) $2HBr + H_2SO_4 \longrightarrow Br_2 + SO_2 + 2H_2O$

(ii) In order of increasing reducing strength: H*Cl* < HBr < HI

From *Data Booklet*,

$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$ $E^\circ = +1.36$ V

$Br_2 + 2e^- \rightleftharpoons 2Br^-$ $E^\circ = +1.07$ V

$I_2 + 2e^- \rightleftharpoons 2I^-$ $E^\circ = +0.54$ V

From C*l* to I, **$E^\circ(X_2/X^-)$ becomes less positive**.
Hence, the **reducing strength of halides increases**
or reducing strength: H*Cl* < HBr < HI.

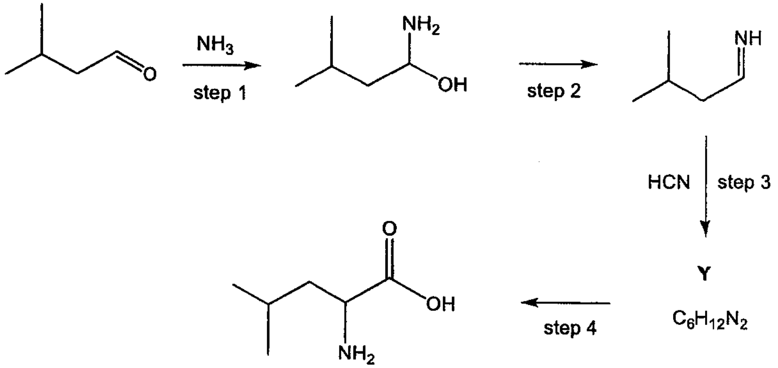
H*Cl*, the weakest reducing agent, **cannot reduce S in H_2SO_4**.
HBr, a stronger reducing agent, can **reduce S from +6 (H_2SO_4) to +4 (SO_2)**.
HI, the strongest reducing agent, can **reduce S from +6 (H_2SO_4) to −2 (H_2S)**.

(iii) **Thermal stability decreases** from HC*l* to HI.

Down the group from C*l* to I,

- Extent of orbital overlap between H and X atoms decreases.
- Bond length of H–X increases.
- **Bond strength** of H–X **decreases**.
- **OR Bond energy of 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.



leucine

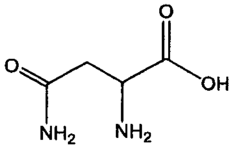
Fig. 4.1

(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

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]

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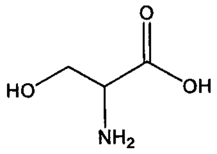
(vi) Serine is a naturally occurring amino acid with the following structure.



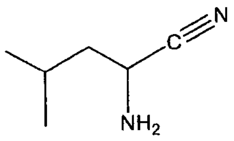
serine

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

(b) (i) Step 1 is **<u>Nucleophilic Addition</u>**.
Step 2 is elimination

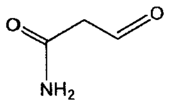
(b) (ii)

Compound Y :



(iii) dilute HC*l* or dilute H_2SO_4, heat

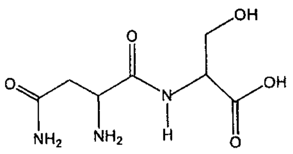
(iv)



(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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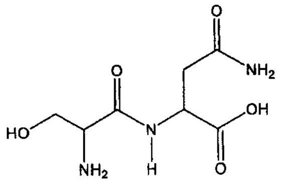

[Turn over

(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 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 $[CN^-] = 2.50 \times 10^{-8}$ mol dm^{-3}. [2]

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

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

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

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

(ii) $K_{sp} = [Zn^{2+}][CN^-]^2$ mol³ dm⁻⁹

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

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

$[Zn^{2+}]$ = **3.02×10^{-8}** mol dm⁻³

Alternative answers

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

$[Zn^{2+}]$ = **4.80×10^{-8}** mol dm⁻³

(c) (iv) $Zn(CN)_2 \rightleftharpoons Zn^{2+} + 2CN^-$ ---- (1)

Addition of strong acid, HC*l*, 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.***

[Total: 20]

[Turn over

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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]

(a) (i) MgO is a **basic oxide** and Al_2O_3 is an **amphoteric oxide**, hence, **both reacts with acids.**

$Na_2O + 2HCl \rightarrow 2NaCl + H_2O$

$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$

SO_3 is an **acidic oxide** and Al_2O_3 is an **amphoteric oxide**, hence, **both reacts with bases**.

$SO_3 + 2NaOH \rightarrow Na_2SO_4 + H_2O$

$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$

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

(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]

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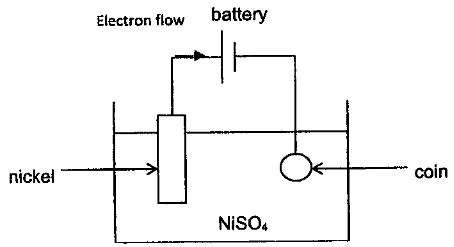
(b) (i)



(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]

$Ni^{2+} + 2e^- \rightarrow Ni$

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

Amount of e^- = 1.312 x 10^{-3} x 2 = 2.624 x 10^{-3} mol

Q = nF

=2.624 x 10^{-3} x 96500

= 253.2 C

Q = It

253.2 = I x (6.5 x 60)

I = 0.649 A

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

(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.

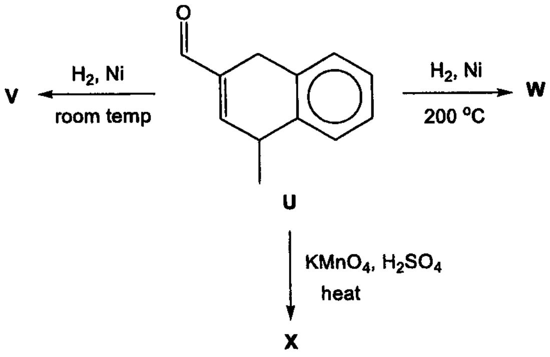


Fig. 5.1

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]

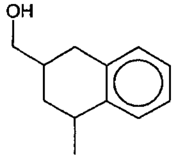
(ii) State the number of π electrons in compound **U**. [1]

(iii) Suggest the identities of **V**, **W** and **X**. [3]

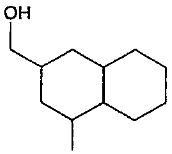
(c) (i) Heterogeneous catalysis, Ni has 3d and 4s electrons for temporary bond formation with reactants.

(ii) 10

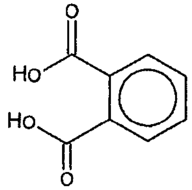
(c) (iii)



V



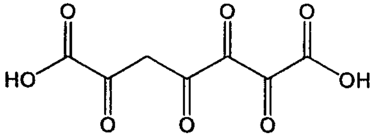
W



X

(d) Compound **P** has the molecular formula, $C_7H_{10}O_5$ and contains a 6-membered ring. **P** gives effervescence with Na_2CO_3. **P** does not produce an orange precipitate with 2,4-DNPH. On treatment with $H_2(g)$ and platinum catalyst, compound **Q** was formed. 1 mole of **P** reacts exactly with 4 moles of PCl_5 to give compound **R**.

P also decolourises hot acidified potassium manganate(VII) solution to give a single compound **S.** The structure of compound **S** is shown below.



compound **S**

Suggest the structures for for **P**, **Q** and **R**, and explain the reactions involved.

[5]

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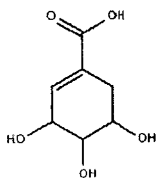
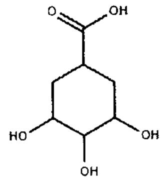
BP~604

(d)

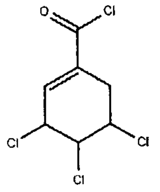
Evidence	Deduction
P does not produce an orange precipitate with 2,4-DNPH.	**P** does not undergoes **condensation** reaction so it does not contain **an aldehyde or a ketone** (carbonyl) functional group.
On treatment of **P** with H_2(g) and platinum catalyst, compound **Q** was formed.	**P** contains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



P

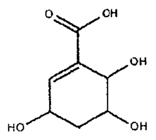


Q

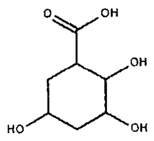


R

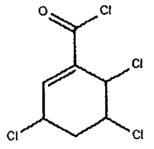
Or



P



Q



R

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Additional answer space

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