

NATIONAL JUNIOR COLLEGE
SH2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE
NAME

SUBJECT
CLASS

REGISTRATION
NUMBER

CHEMISTRY

Paper 2 Structured Questions

9729/02

16 September 2025

2 hours

Candidates answer on Question Paper.
Additional Materials: Data Booklet

READ THE INSTRUCTIONS FIRST

Write your subject class, registration number and name on all the work you hand in.

Write in dark blue or black pen on both sides of the paper.

You may use a soft pencil for any diagrams, graphs or rough working.

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

Answers **all** questions.

The number of marks is given in brackets [] at the end of each question or part question.

For Examiner's Use	
1	/16
2	/14
3	/17
4	/16
5	/12
Paper 2 Total	/75

	Marks	Weightings
Paper 1	/30	15%
Paper 2	/75	30%
Paper 3	/80	35%
Paper 4	/55	20%

Overall Percentage	
Grade	

This document consists of **19 printed pages and 1 blank page.**

[Turn over

Answer **all** the questions in the spaces provided.

- 1 925 silver, also known as sterling silver, is an alloy that is commonly used to make jewellery. It consists of 92.5% silver and 7.5% other metals, such as copper, by mass. Over time, the alloy can form a tarnish of $\text{Ag}_2\text{S}(\text{s})$ when it reacts with hydrogen sulfide, as represented by the following equation.



- (a) (i) Write the full electronic configuration for copper.

$1\text{s}^2 2\text{s}^2 2\text{p}^6 3\text{s}^2 3\text{p}^6 3\text{d}^{10} 4\text{s}^1$

Note: Cu has a special configuration of $3\text{d}^{10} 4\text{s}^1$

Common mistakes

- Putting 4s^1 before 3d^{10}
- Configuration written as $1\text{s}_2 2\text{s}_2 2\text{p}_6 3\text{s}_2 3\text{p}_6 3\text{d}_{10} 4\text{s}_1$

[1]

- (ii) State and explain the difference in atomic radii for silver and copper.

Ag has one more filled electronic shell than Cu. The distance of its valence electron is further away from nucleus and experience higher shielding effect.

This outweighs the higher nuclear charge in Ag. Nuclear attraction for the outermost electron in Ag is weaker. Thus, atomic radius of Ag is larger.

Common mistakes

- Students mention shielding effect but **did not state the further distance as a factor as well.**
- Another common mistake is that having more electrons/more inner subshells does not always means a further distance of the valence electrons from the nucleus.
- Students mention both nuclear charge and shielding effect being higher for Ag but did not mention that the higher shielding effect and further distance **outweighs** the higher nuclear charge.
- Students also often miss out nuclear attraction for the **valence electrons.**
- Outweigh and **not** offset/nullified/cancelled out.

[2]

- (b) The Ag_2S tarnish on sterling silver can be removed until only sterling silver remains. A student weighs a tarnished sterling silver sample both before and after removing the Ag_2S and records the data in Table 1.1.

Table 1.1

mass before Tarnish Removal /g	54.23
mass after Tarnish Removal /g	52.34

Assuming that only Ag_2S (s) is removed, calculate the number of moles of silver atoms removed.

Mass of Ag_2S removed = $54.23 - 52.34 = 1.89 \text{ g}$.

$$\text{Amount of } \text{Ag}_2\text{S} \text{ removed} = \frac{1.89}{2(107.9) + 32.1} = \frac{1.89}{247.9} = 0.00762 \text{ mol}$$



$$\begin{aligned} \text{Amount of Ag removed} &= 2 \times 0.00762 \\ &= \underline{\underline{0.0152 \text{ mol}}} \end{aligned}$$

Common mistakes

- Students did not use the mole ratio to find the number of mol of Ag removed
- Many students calculated the no of atom instead of no of mole of Ag

[1]

- (c) (i) Suggest and explain the relative magnitude of the lattice energy of the silver compounds Ag_2S , Ag_2O and Ag_2Se .

$|\text{L.E.}| \propto \left| \frac{q_+ \times q_-}{r_+ + r_-} \right|$ **circle but don't penalize if put "="**

- **Product of charges ($q_+ \times q_-$) and the cationic radius (r_+) for Ag_2O , Ag_2S , Ag_2Se are the same**
- **Interionic distance of $\text{Ag}_2\text{O} < \text{Ag}_2\text{S} < \text{Ag}_2\text{Se}$ OR**
Anion radius of $\text{O}^{2-} < \text{S}^{2-} < \text{Se}^{2-}$
- Since $|\text{L.E.}| \propto \left| \frac{q_+ \times q_-}{r_+ + r_-} \right|$, **magnitude of lattice energy of $\text{Ag}_2\text{O} > \text{Ag}_2\text{S} > \text{Ag}_2\text{Se}$**

Common mistakes

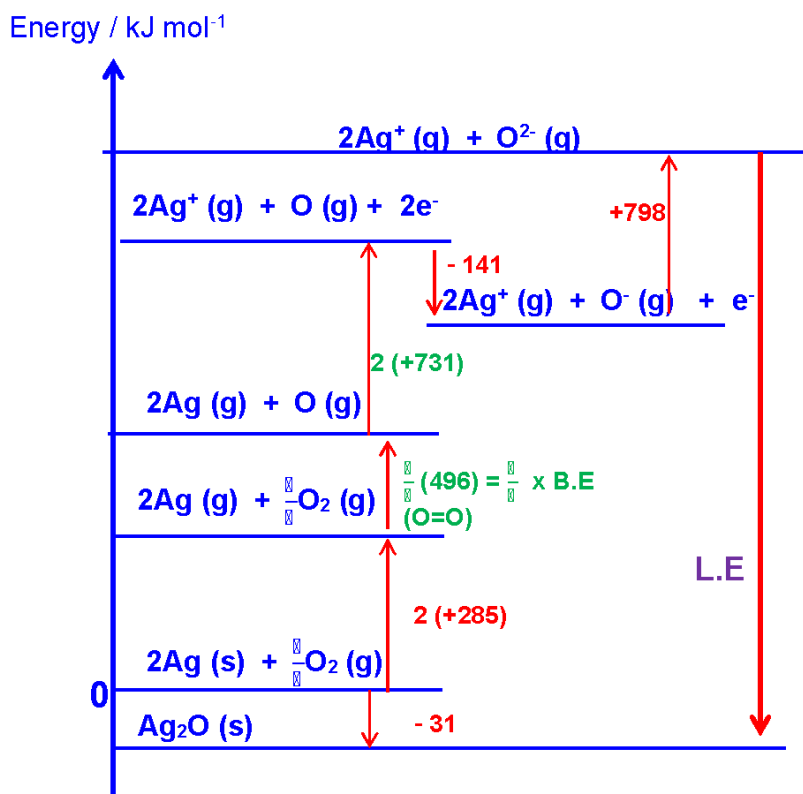
- Students did not state the $|\text{L.E.}| \propto \left| \frac{q_+ \times q_-}{r_+ + r_-} \right|$ in the answer
- Students mention atomic radius comparison rather than the ionic radius.

[2]

- (ii) Using relevant data from the *Data Booklet* and Table 1.2, calculate the lattice energy of Ag_2O .

Table 1.2

standard enthalpy change of atomisation of silver	+285 kJ mol ⁻¹
1 st electron affinity of oxygen	-141 kJ mol ⁻¹
2 nd electron affinity of oxygen	+798 kJ mol ⁻¹
standard enthalpy change of formation of $\text{Ag}_2\text{O}(\text{s})$	-31 kJ mol ⁻¹



By Hess Law,

$$-31 = 2(285) + \frac{1}{2}(496) + 2(731) + (-141) + 798 + \text{L.E.}$$

$$\text{L.E.} = -2968 = \underline{\underline{-2970 \text{ kJ mol}^{-1}}}$$

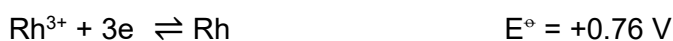
Common mistakes

- Axis not drawn
- Putting Electron affinity before Ionisation energy in the energy level diagram
- Bond energy for the oxygen is left out.
- Students forget to x2 to the ionisation energy of Ag but instead include in 2nd I.E for Ag
- Students are not familiar with the use of Hess's law. Many students changed the ΔH_f sign for $\text{Ag}_2\text{O}(\text{s})$ to $+31 \text{ kJ mol}^{-1}$ and 1st EA of O to $+141 \text{ kJ mol}^{-1}$.

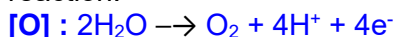
[4]

- (d) Rhodium plating is a process used to protect sterling silver from tarnishing. This involves electroplating (depositing) solid rhodium, $\text{Rh}(\text{s})$, onto the surface of the metal from an acidified solution of $\text{Rh}_2(\text{SO}_4)_3(\text{aq})$. Oxygen gas is produced during this process.

One of the half equations involved in this reaction is



- (i) Write the half equation for the reaction that has resulted in the formation of oxygen gas in this reaction and hence, write the balanced ionic equation for the overall reaction.



cannot accept reversible arrow.



must have state symbol for ionic equation

Common mistakes

- **[O]** equation not written with \square
- The basic equation is chosen instead.
- The balanced equation does not have state symbol

[2]

- (ii) Calculate the value of E°_{cell} for the overall reaction in part (i).

$$E^\circ_{\text{cell}} = E^\circ_{\text{Red}} - E^\circ_{\text{Ox}}$$

$$= +0.76 \text{ V} - 1.23 \text{ V}$$

$$= \underline{\underline{-0.47 \text{ V}}}$$

[1]

- (iii) Based on your answer to part (ii), explain why this process requires the use of an external power source.

E°_{cell} **is negative**, which means the reaction is **not energetically feasible** and thus **energy must be supplied for the reaction to occur**.

Generally, well done

[1]

- (iv) Calculate the current that must be supplied for 3.5 g of Rh to be plated onto a piece of sterling silver in 3 minutes.



$$\text{Amount of Rh deposited} = \frac{3.5}{102.9} = 0.0340 \text{ mol}$$

$$\eta_{\text{e}} = 3 \times 0.0340 = 0.102 \text{ mol}$$

$$\mathbf{I \times t = \eta_{\text{e}} \times F}$$

$$\mathbf{I = \frac{\eta_{\text{e}} \times F}{t} = \frac{0.102 \times 96500}{3 \times 60} = \underline{\underline{54.7 \text{ A}}}$$

Generally, well done

[2]

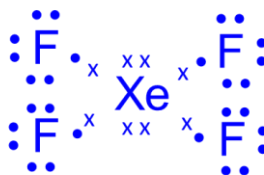
[Total : 16]

- 2 (a) Xenon is a noble gas and forms various fluorides with fluorine. Two of these are xenon difluoride, XeF_2 , and xenon tetrafluoride, XeF_4 , which are crystalline solids with melting points of 140°C and 112°C respectively.

- (i) Draw the dot-and-cross diagrams for XeF_2 and XeF_4 and hence state their molecular shapes.



XeF_2 : linear



XeF_4 : square planar

[3]

Common mistakes

- Students missed out drawing the 3 lone pair electrons on F atom.
- Students are still unsure of the molecular shapes associated with the different number of lone pairs & bond pairs.

- (ii) Even though XeF_4 has more electrons and is hence expected to have greater intermolecular forces than XeF_2 , its melting point is lower. Suggest why XeF_2 has a higher melting point than XeF_4 .

There is higher packing efficiency in the linear XeF_2 molecules compared to the square planar XeF_4 molecules, thus intermolecular forces are stronger between XeF_2 molecules, requiring more energy to overcome, hence higher melting point.

[1]

Common mistakes

- Students incorrectly identified XeF_2 as a polar molecule and explained that the pd-pd interactions are stronger than id-id between the non-polar XeF_4 .

- (iii) Using your knowledge of covalent bond formation, explain why

- Xenon reacts with fluorine but neon does not
- Xenon reacts with fluorine but not with iodine

Xenon is in Period 5, hence able to expand octet due to availability of vacant energetically accessible orbitals (empty low-lying orbitals) to accommodate additional electrons from fluorine during covalent bond formation but neon is unable to expand octet as it is in Period 2.

Common mistakes

- Common misconception is that neon already has a full octet structure hence does not undergo reaction with other elements while xenon has not fulfilled octet structure yet.

Fluorine has smaller atomic radius than iodine, Xe-F bond hence has shorter bond length and is stronger than Xe-I bond

Common mistakes

- Many students explained that since fluorine is more electronegative than iodine, hence it can better attract the electrons from xenon towards itself, forming a stronger bond.
- Do note that when we compare covalent bond strength, we look at the following factors:
 1. Bond order (strength of triple bond > double bond > single bond)
 2. Effectiveness of orbital overlap (smaller orbitals are less diffused, hence generally have more effective orbital overlap resulting in a stronger bond)
 3. Bond Polarity (this factor is used only when comparing 2 bonds with similar bond order, similar effectiveness of orbital overlap, eg comparing between C-C and C-F bond. C-F bond is stronger due to difference in electronegativity between C & F)

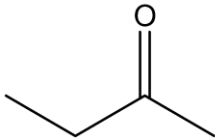
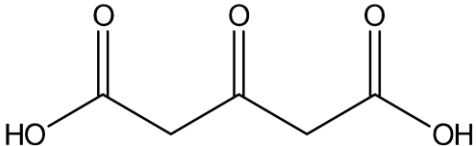
[2]

(b) **P** and **Q** are compounds containing the same functional groups.

Both compounds

- readily decolourise bromine in the dark
- liberate a gas with sodium metal
- do not have O atom bonded to an unsaturated carbon atom
- react with hot acidified potassium manganate(VII) to give the products as shown in Table 2.1.

Table 2.1

compound	products of oxidation
P ($C_6H_{12}O$)	 and CO_2
Q (C_5H_8O)	

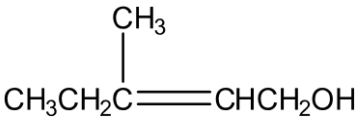
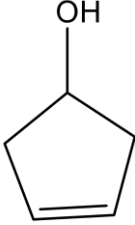
- (i) Considering the molecular formulae of the two compounds together with the information given above, name the two functional groups that are present in compounds **P** and **Q**.

Alkene and alcohol

[2]

Generally well done

- (ii) Suggest the structures of compounds **P** and **Q**.

Compound P	Compound Q
	

Note: For compound **P**, $=CHCH_2OH$ oxidises to give ethanedioic acid, $HOOC-COOH$, which is further oxidized by $KMnO_4$ to give $2CO_2 + H_2O$

Note: From Table 2.1, oxidation of **Q** gives only one product with same number of carbon atoms as **Q**, we can deduce that **Q** contains $C=C$ in a cyclic ring.

Common mistakes

- Students incorrectly drew terminal alkene for **P** without realising that although terminal alkenes can give rise to CO_2 product, it will also give a carboxylic acid product, which does not tally with the products given in Table 2.1.

- (c) Compound **R**, $C_9H_{18}O_2$, has the same two functional groups as **P** and **Q** in (b). Upon strong oxidation by hot acidified $KMnO_4$, compound **S**, $C_6H_{12}O_2$, and compound **T**, $C_3H_4O_3$, are obtained.

The following four reagents were used to test compounds **S** and **T** and the results are shown in the table below.

test reagent	result of test with	
	compound S	compound T
Na(s)	fizzes	fizzes
$NaHCO_3(aq)$	no reaction	fizzes
$I_2(aq) + OH^-(aq)$, warm	no reaction	yellow ppt
2,4-DNPH	orange ppt	orange ppt

- (i) By considering the test results with Na(s) and $NaHCO_3(aq)$, name the functional group that is present in **S** and **T**.

Functional group present in **S**: Alcohol

Functional group present in **T**: Carboxylic acid

[2]

Generally well done

- (ii) Suggest the structures of compounds **S** and **T**.

Compound S	Compound T
$ \begin{array}{c} \text{CH}_3 \quad \text{O} \\ \quad \\ \text{CH}_3\text{C} - \text{C} - \text{CH}_2\text{CH}_3 \\ \\ \text{OH} \end{array} $	$ \begin{array}{c} \text{O} \\ \\ \text{CH}_3\text{CCOOH} \end{array} $

Note: **S** must contain a tertiary alcohol (remains unaffected by oxidation of **R** with hot acidified $KMnO_4$). **S** cannot have $-COCH_3$ group as it does not give yellow ppt with warm alkaline I_2 .

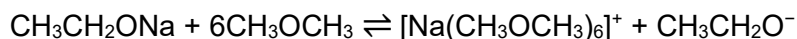
[2]

Common mistakes

- Many incorrect structures for **S** were drawn, including those having aldehyde (which should not be present since **R** was oxidised by strong oxidising agent $KMnO_4$)

[Total : 14]

- 3 (a) A sodium ethoxide slurry is prepared by dissolving sodium in dry ethanol. When this slurry is transferred into liquid dimethyl ether, CH_3OCH_3 , at 40°C , the following equilibrium is established.



- (i) Write a balanced equation for the reaction of ethanol with sodium.



[1]

Common mistakes

1. Writing H^+ as product.
2. Mistaking ethanol ($\text{CH}_3\text{CH}_2\text{OH}$) as CH_3COOH

- (ii) Using your knowledge of VSEPR theory, state and explain the bond angle around the oxygen atom in CH_3OCH_3 .

For CH_3OCH_3 , there are 2 bond pairs and 2 lone pairs of electrons around the O atom.

By VSEPR theory, electron regions around the central O atom are spread out to minimise mutual repulsion. Since lone pair – lone pair repulsion > lone pair – bond pair repulsion > bond pair – bond pair repulsion, the bond angle is 105° or (104.5°)

Common mistakes

1. Not stating clearly the order of lone pair-lone pair, lone pair-bond pair and bond pair-bond pair repulsions.
2. Not mentioning the idea that electron regions are “spread out” or “arranged as far as possible” to “minimise repulsion”.

[2]

- (b) The strongly basic ethoxide ion, $\text{CH}_3\text{CH}_2\text{O}^-$ then removes a proton from compound A, giving the anion shown in Fig. 3.1.

Intramolecular attack of the anion on the C–Cl bond forms compound B.

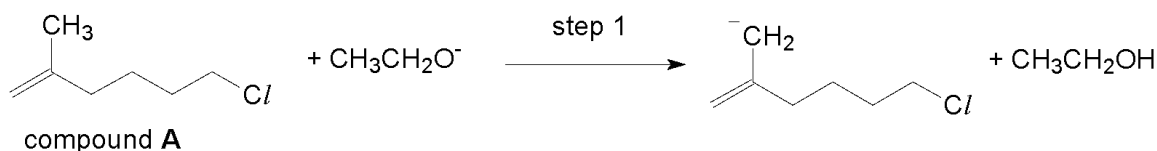
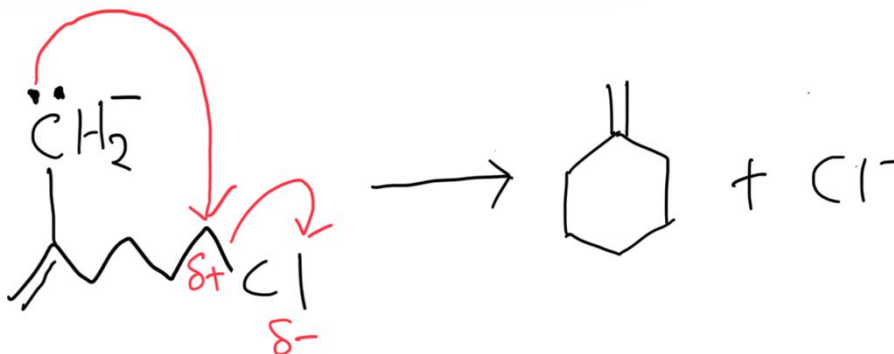


Fig. 3.1

Show the mechanism for step 2 on Fig. 3.1 by adding a lone pair, curly arrows and dipoles.

State the name of the mechanism involved.

Nucleophilic substitution

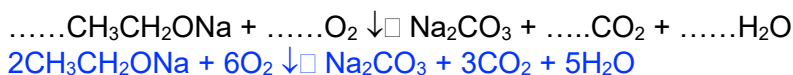


This was generally well done. Common mistake is to forget to draw the lone pair on the carbon atom of the $-\text{CH}_2^-$ group.

[2]

- (c) Finely powdered sodium ethoxide burns in excess oxygen to give sodium carbonate, carbon dioxide and water as the only products.

Balance the chemical equation for this combustion.

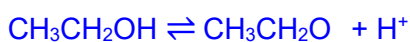


Many students found it difficult to balance this equation.

[1]

- (d) Given the pK_a values, explain the order of acidity of the following compounds in aqueous medium.

compound	pK_a
ethanol	15.9
phenol	10.0
ethanoic acid	4.76



The electron-donating alkyl group (CH_3CH_2-) destabilize $\text{CH}_3\text{CH}_2\text{O}^-$ by intensifying its negative charge. The negative charge of $\text{C}_6\text{H}_5\text{O}^-$ is dispersed into the benzene ring via resonance. The negative charge of CH_3COO^- is dispersed **significantly** over 2 highly electronegative O atoms via resonance.

Stability of $\text{CH}_3\text{COO}^- > \text{C}_6\text{H}_5\text{O}^- > \text{CH}_3\text{CH}_2\text{O}^-$

Ethanoic acid dissociates most readily into H^+ and its conjugate base, followed by phenol and lastly ethanol. Hence acidity of ethanoic acid $>$ phenol $>$ alcohol.

This question was not well done.

Common mistakes

1. Referring to the acid molecules when talking about “dispersal of negative charges” and the “intensification of negative charge” or when talking about “stability”. Students should be referring to their respective conjugate bases instead.

Many students are ambiguously using the name of the acid and its conjugate base interchangeably as if they are referring to the same thing. Also, many are using the pronoun “it” in an ambiguous manner to refer to the acid and its conjugate base in the same sentence. This makes it hard for the marker to award marks.

2. Focusing on “delocalization of the lone pair electrons on O atom” in the phenol and ethanoic acid molecules, rather than to focus on the “dispersal of negative charge” in the phenoxide and ethanoate ions.

3. Not clearly stating the orders of “stability of conjugate bases” and the “extent of dissociation of the acid molecules”.

4. A number of students used incorrect terms to refer to the conjugate base of ethanol and do not seem to know that the conjugate base of ethanol is called “ethoxide”, despite the name of the salt “sodium ethoxide” being used in the question stems in 3(a) and 3(c).

[3]

- (e) 2-bromobutane can be used to synthesise propanoic acid by the three-step route shown in Fig. 3.2.

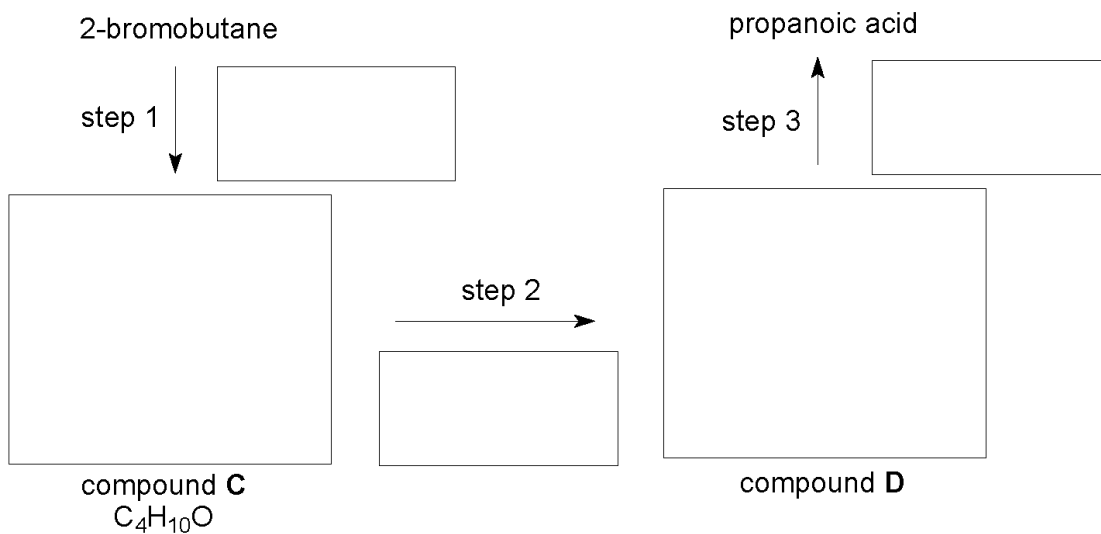
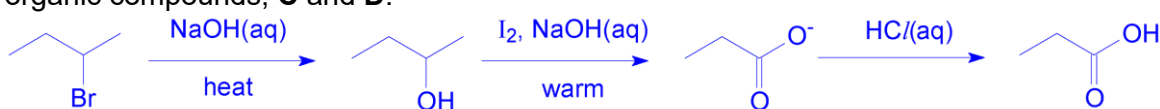
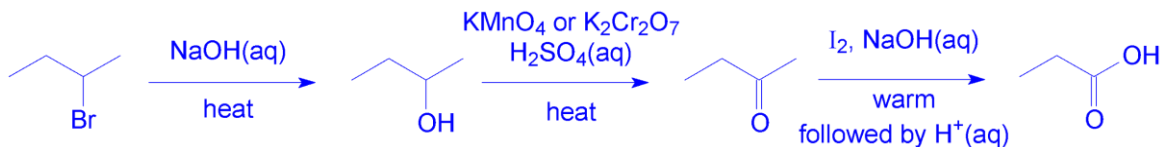


Fig. 3.2

State the reagents and conditions required for each step and suggest structures for the organic compounds, **C** and **D**.



Alternative answer:



Common mistakes

1. Using ethanolic NaOH to convert 2-bromobutane to butan-2-ol.
2. Forgetting to write (aq) when referring to NaOH (aq). It is important to write the (aq) for step 1 since there is a difference between using aqueous NaOH and ethanolic NaOH.
3. Writing "acidified $KMnO_4$ " instead of writing " $H_2SO_4(aq)$ and $KMnO_4$ ".

[5]

- (d) The K_b of a secondary amine, $R_1(R_2)NH$, is $5.75 \times 10^{-4} \text{ mol dm}^{-3}$. A 1.50 g sample of the amine is dissolved in water and the solution is made up to 1.00 dm^3 . The pH of the resulting solution is 11.55.

Calculate the relative molecular mass of $R_1(R_2)NH$, and suggest a structural formula for $R_1(R_2)NH$. Show your working clearly.

$$\text{Amount of } R_1(R_2)NH = \frac{1.50}{M_r} \text{ mol}$$

$$\text{Initial } [R_1(R_2)NH] = \frac{1.50}{M_r} \text{ mol dm}^{-3}$$

For weak base,

$$[OH^-] = \sqrt{K_b \times [R_1(R_2)NH]}$$

$$\text{Given pH} = 11.55, \text{pOH} = 14 - 11.55 = 2.45$$

$$[OH^-] = 10^{-2.45} \text{ mol dm}^{-3}$$

$$[R_1(R_2)NH] = \frac{[OH^-]^2}{K_b} = \frac{(10^{-2.45})^2}{5.75 \times 10^{-4}} = 0.02189 \text{ mol dm}^{-3}$$

$$\frac{1.50}{M_r} = 0.02189$$

$$M_r = 68.5$$

The secondary amine is $CH_2=CH(CH_2=CH)NH$ ($M_r = 69$).

Alternative method:



$$[OH^-]_{eqm} = 10^{-2.45} = 0.003548 \text{ mol dm}^{-3} = [R_1(R_2)NH_2^+]_{eqm}$$

$$[R_1(R_2)NH]_{eqm} = \frac{1.50}{M_r} - 0.003548$$

$$K_b = \frac{[R_1(R_2)NH_2^+]_{eqm} [OH^-]_{eqm}}{[R_1(R_2)NH]_{eqm}}$$

$$5.75 \times 10^{-4} = \frac{(0.003548)(0.003548)}{\frac{1.50}{M_r} - 0.003548}$$

$$\frac{1.50}{M_r} - 0.003548 = 0.02189$$

$$\frac{1.50}{M_r} = 0.02544$$

$$M_r = 58.9$$

The secondary amine is $CH_3CH_2(CH_3)NH$ ($M_r = 59$).

Many students were able to calculate the M_r of the secondary amine, but few were able to give the correct structural formula of the amine.

A common mistake is to write the unit g mol^{-1} or even g for the M_r calculated.

[3]

[Total : 17]

- 4 Although carbon monoxide, CO, is a poisonous gas, it is an important starting material in the synthesis of many industrially important compounds.

(a) (i) Draw a 'dot-and-cross' diagram to show the bonding in carbon monoxide.



Common mistakes

- The dot and cross drawn shows Oxygen having more than 8 electrons in the outermost shell.

[1]

(ii) Suggest why carbon monoxide is poisonous.

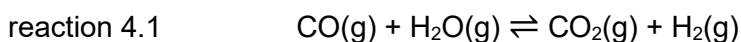
Carbon monoxide **binds more strongly than O₂** with iron ion in haemoglobin to form **very stable complexes**. This **cuts down the supply of oxygen to the body**.

Common mistakes

- Students did not give the idea that carbon monoxide forms a more stable complex relative to oxygen/the more stable complex with CO ligand unlikely to be replaced by the oxygen.

[1]

Carbon monoxide can undergo water-gas shift reaction. The carbon monoxide gas reacts with steam to produce carbon dioxide gas and hydrogen gas.



(b) Explain the difference in boiling points of CO and of CO₂ in terms of the type and relative strength of the intermolecular forces.

species	boiling point/ °C
CO	-191
CO ₂	-78

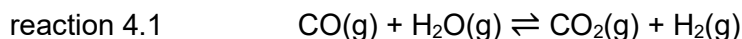
Both CO and CO₂ have simple molecular structure, with **permanent dipole-permanent dipole (pd-pd) interaction and instantaneous dipole-induced dipole (id-id) interaction between the CO molecules** and **id-id interaction between the CO₂ molecules**. CO₂ has a higher *M_r* and a **larger electron cloud than CO, dipole is more easily induced** resulting in **stronger id-id interactions**. More energy is required to overcome the stronger id-id interactions between CO₂ molecules than the intermolecular forces of attraction between CO molecules. Therefore, CO₂ has a higher boiling point than CO.

Common mistakes

- Students mistaken identify both CO and CO₂ being polar and compare the difference due to pd-pd
- Students did not identify the presence of id-id between CO on top of the pd-pd.

[2]

- (c) 0.200 mol of carbon monoxide and 0.200 mol of steam was placed in reaction vessel and allowed to react at a temperature of 800 K. The percentage of carbon monoxide reacted was found to be 77.5%.



- (i) Write the expression for the equilibrium constant, K_c , for reaction 4.1.

$$K_c = \frac{[\text{CO}_2][\text{H}_2]}{[\text{CO}][\text{H}_2\text{O}]}$$

Common mistakes

- Students ignore the $[\text{H}_2\text{O}]$ in the expression. It should be included as it is homogenous system. The states of all the species are gas.

[1]

- (ii) Calculate the value of the equilibrium constant, K_c , at 800 K.

	CO(g)	+	H ₂ O(g)	⇌	CO ₂ (g)	+	H ₂ (g)
Initial / mol	0.200		0.200		0		0
change / mol	-0.2×0.775		-0.2×0.775		+0.2×0.775		+0.2×0.775
Eqm / mol	0.045		0.045		0.155		0.155

$$K_c = \frac{\left(\frac{0.155}{V}\right)\left(\frac{0.155}{V}\right)}{\left(\frac{0.045}{V}\right)\left(\frac{0.045}{V}\right)} = 11.86 \approx 11.9$$

Common mistakes

- Students tried to calculate the pressure of each species to calculate the K_c .

[2]

- (iii) The Gibbs free energy change of reaction, ΔG_r , for reaction 4.1 is $-18.4 \text{ kJ mol}^{-1}$ at 600 K. The relationship between the equilibrium constant and the Gibbs free energy change of this reaction can be expressed as:

$$\Delta G = -RT \ln K_c$$

Calculate the value of K_c for the reaction 4.1 at 600 K.

$$-18.4 \times 10^3 = -(8.31)(600) \ln K_c$$

$$\ln K_c = 3.690$$

$$K_c = 40.04 \approx 40.0$$

Note: need to convert ΔG to J mol^{-1}

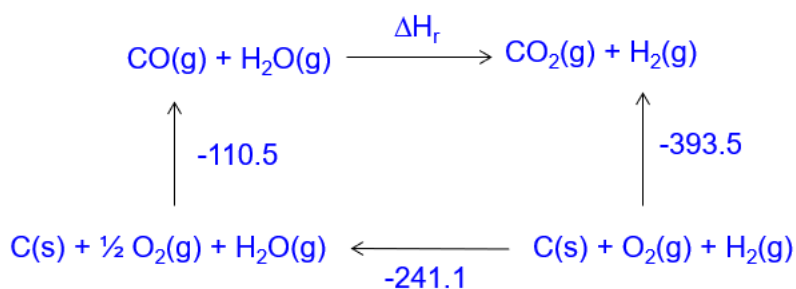
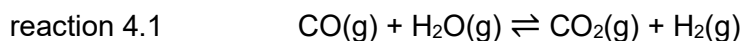
[1]

(d) Table 4.1 gives data relevant to this question.

Table 4.1

$\otimes H_f^\ominus \text{CO(g)}$	$-110.5 \text{ kJ mol}^{-1}$
$\otimes H_f^\ominus \text{CO}_2\text{(g)}$	$-393.5 \text{ kJ mol}^{-1}$
$\otimes H_f^\ominus \text{H}_2\text{O(g)}$	$-241.1 \text{ kJ mol}^{-1}$

Using the data given in Table 4.1, construct an energy cycle to calculate the enthalpy change of reaction for reaction 4.1.



Ok to combine $\otimes H_f^\ominus (\text{CO}) + \otimes H_f^\ominus (\text{H}_2\text{O})$

By Hess' Law,

$$\begin{aligned}
 \Delta H_r &= -(-110.5) - (-241.1) + (-393.5) \\
 &= \underline{\underline{-41.9 \text{ kJ mol}^{-1}}}
 \end{aligned}$$

Most students were able to draw the Hess cycle and calculate the answer correctly. Most common mistakes in the Hess Cycle are to copy the reversible arrow into the Hess Cycle from the question and to omit state symbols in some parts of the cycle.

[2]

- (e) The English chemist William Henry studied the equilibria when an ideal gas dissolves in a liquid. He proposed that the concentration of the gas dissolved in a liquid is proportional to the partial pressure of the gas above the liquid surface. This proportionality factor is called Henry's law constant, K_H . The Henry's law constant, K_H can be represented as the equation below.

$$K_H = \frac{\text{maximum concentration of gas dissolved in mol dm}^3}{\text{partial pressure of gas in atm}}$$

Sealed containers of fizzy drinks contain dissolved CO_2 . This dissolved CO_2 is in equilibrium with a very small quantity of gaseous CO_2 at the top of the container.



The Henry's law constant for CO_2 is $3.3 \times 10^{-2} \text{ mol dm}^{-3} \text{ atm}^{-1}$ at 25°C .

- (i) The partial pressure of CO_2 gas in a can of 250 cm^3 fizzy drink is 3.0 atm at 25°C .

Calculate the concentration of CO_2 in the fizzy drink and hence the mass of CO_2 dissolved in the 250 cm^3 of fizzy drink.

$$K_H = \frac{\text{maximum concentration of gas dissolved in mol dm}^{-3}}{\text{partial pressure of gas in atm}}$$

$$3.3 \times 10^{-2} = \frac{\text{maximum concentration of gas dissolved in mol dm}^{-3}}{3}$$

$$[\text{CO}_2] = 0.0990 \text{ mol dm}^{-3}$$

$$\text{Amount of CO}_2 = 0.0990 \times \frac{250}{1000} = 0.02475 \text{ mol}$$

$$\begin{aligned} \text{Mass of CO}_2 &= 0.02475 \times (12 + 16 + 16) \\ &= 1.089 \\ &= 1.09 \text{ g (3s.f.)} \end{aligned}$$

This question was well done by most. A small number of students forgot to write the unit for the concentration of CO_2 .

[2]

- (ii) The maximum pressure that a can of fizzy drink can withstand is 6.2 atm. Using Fig. 4.1, determine the maximum temperature at which the fizzy drink can be stored safely.

You may assume that the maximum amount of CO₂ that is dissolved remains the same.

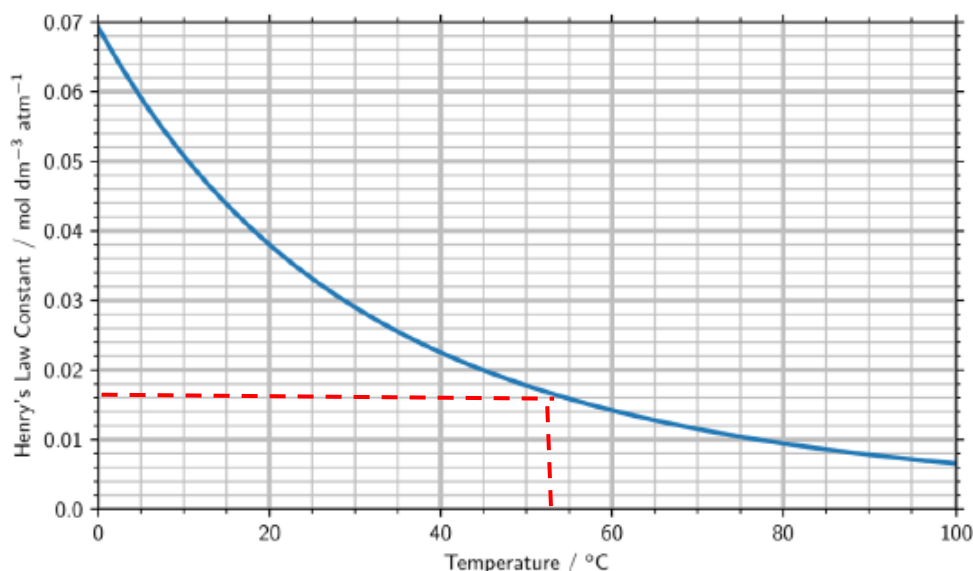


Fig. 4.1

Note : In a sealed container, the gas is essentially trapped within the liquid and the small amount of space above, leading to minimal gas particles in that space. So when the pressure is increased, the change in the concentration in the liquid will be minimal

$$K_H = \frac{0.099}{6.2} \\ = 0.0160 \text{ mol dm}^{-3} \text{ atm}^{-1}$$

From the graph,
Maximum temp = **52°C – 55°C**

This question was well done by most.

[2]

- (iii) Hence, deduce with reasoning, the sign of enthalpy change for reaction 4.2. When the temperature is increased, by *Le Chatelier's Principle*, the system will partially decrease the temperature by absorbing heat. The position of equilibrium will shift to favour endothermic reaction.

As seen from graph, when temperature is increased, the Henry's law constant, K_H decreased, the position of equilibrium has shift left to favour endothermic reaction.

Hence forward reaction is exothermic and the enthalpy change is negative.

Not so well done. Answers that simply stated the enthalpy change as negative without explicitly referring to the forward reaction as being exothermic were not given any credit.

Some students who gave the correct explanation forgot to mention the sign of the enthalpy change.

[2]

[Total : 16]

- 5 Plastic takeaway containers for food are commonly made of polypropene (PP) which is microwave safe and chemically inert.

Polymerisation is a chemical process where small molecules (monomers) combine to form a large molecule (polymer) through the formation of covalent bonds. Fig 5.1 shows the process of joining many propene monomers to form polypropene. The type of polymerisation is known as addition polymerisation as only 1 single product is formed.

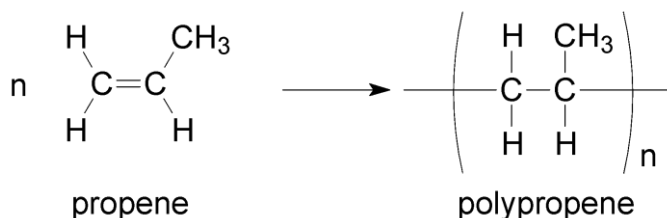


Fig 5.1

- (a) (i) The polymerisation of 1 mole of propene to form polypropene (Fig 5.1) has a standard entropy change of $-110 \text{ J mol}^{-1} \text{ K}^{-1}$.

Account for the negative sign of the standard entropy change for polymerisation.
 Amount of **gaseous** particles decreases from 1 mole to 0 (polypropene is a solid), resulting in **less ways to arrange the particles and their energies**.

[2]

Common mistakes

- Students merely mentioned that there is a decrease in number of particles during polymerisation.
- Recap the factors that we use to explain changes in entropy:
 1. Change in the number of gaseous particles
 2. Mixing of particles (no chemical reaction)
 3. Change in phase (physical change)
 4. Change in temperature

- (ii) Given that the standard enthalpy change of polymerisation of polypropene is $-55.0 \text{ kJ mol}^{-1}$, calculate the maximum temperature for the reaction to be spontaneous.

$$\Delta G = \Delta H - T\Delta S < 0$$

$$-55 - T(-110 \times 10^{-3}) < 0$$

$$T < 500 \text{ K}$$

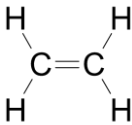
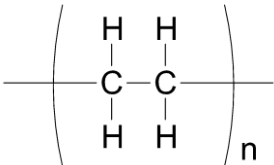
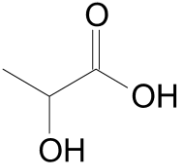
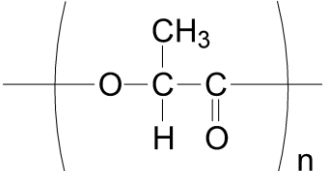
Maximum T is 499 K

Common mistakes

- Many students leave their answer as 500 K without realising that they should suggest a maximum temperature that is less than 500 K.

[2]

The increasing environmental concerns over plastic pollution have led to innovations in food packaging design. Many food establishments now use paper-based takeaway containers coated with either polyethene (PE) or polylactic acid (PLA) instead of conventional plastic containers.

monomer	polymer
 <p>ethene</p>	 <p>polyethene (PE)</p>
 <p>lactic acid</p>	 <p>polylactic acid (PLA)</p>

- (b) (i) State the IUPAC name of lactic acid.
2-hydroxypropanoic acid

[1]

Common mistakes

- Some students put a hyphen between the hydroxy and propanoic acid
- Some students wrote 'hydroxyl' instead. Note that hydroxyl refers to the alcohol functional group.

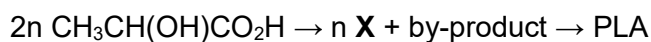
- (ii) Similar to propene, ethene undergoes addition polymerisation to form polyethene. Lactic acid undergoes a different type of polymerisation as a by-product is formed. Identify the by-product and hence state the type of polymerisation undergone by lactic acid to form PLA.

By-product: H₂O

Type of polymerisation: Condensation polymerisation

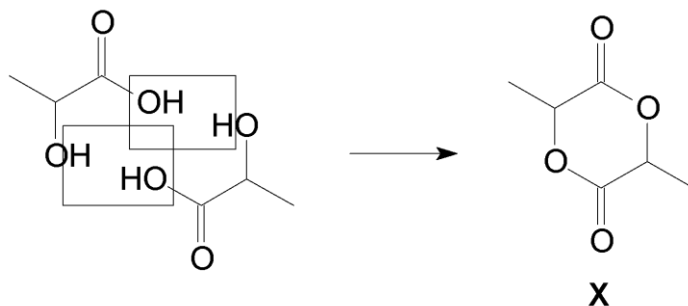
[1]

- (iii) The equation for polymerisation of lactic acid to form PLA is found to be:



X is a cyclic intermediate with the molecular formula of $\text{C}_6\text{H}_8\text{O}_4$.
X does not react with Na.

Draw the skeletal structure of **X**.



[1]

- (c) Tom Yum soup is cooked with Thai bird's eye chilies, lime juice and lemongrass to give the characteristic sour and spicy flavour. A Thai food stall vendor is choosing between takeaway food containers coated with PE or PLA to contain hot Tom Yum soup.

By considering the structures of PE and PLA, and the properties of Tom Yum soup, explain which type of takeaway food container you would recommend to the Thai food stall vendor.

I would recommend PE

As Tom Yum soup is acidic and hot, the ester bond in PLA is likely to undergo acidic hydrolysis.

PE will not undergo acidic hydrolysis.

[2]

Common mistakes

- Some students explained that PLA has pd-pd interactions between polymers, requiring more energy to overcome compared to id-id between PE, hence have higher melting point and can withstand hot food.

- (d) Microplastics are particles with sizes ranging from 1 μm to 5 mm in any dimension (1 mm = 1000 μm).

While PE-coated and PLA-coated paper containers still contain plastic elements, they use significantly less plastic than traditional PP containers, thereby reducing the potential for microplastic generation.

A researcher studied the degradation of samples of PE and PLA in an aqueous condition with a similar salt concentration as seawater and with exposure to UV light after 2 years. He then determined the proportion of particles with various sizes of $\leq 3 \mu\text{m}$, as shown in Fig 5.2.

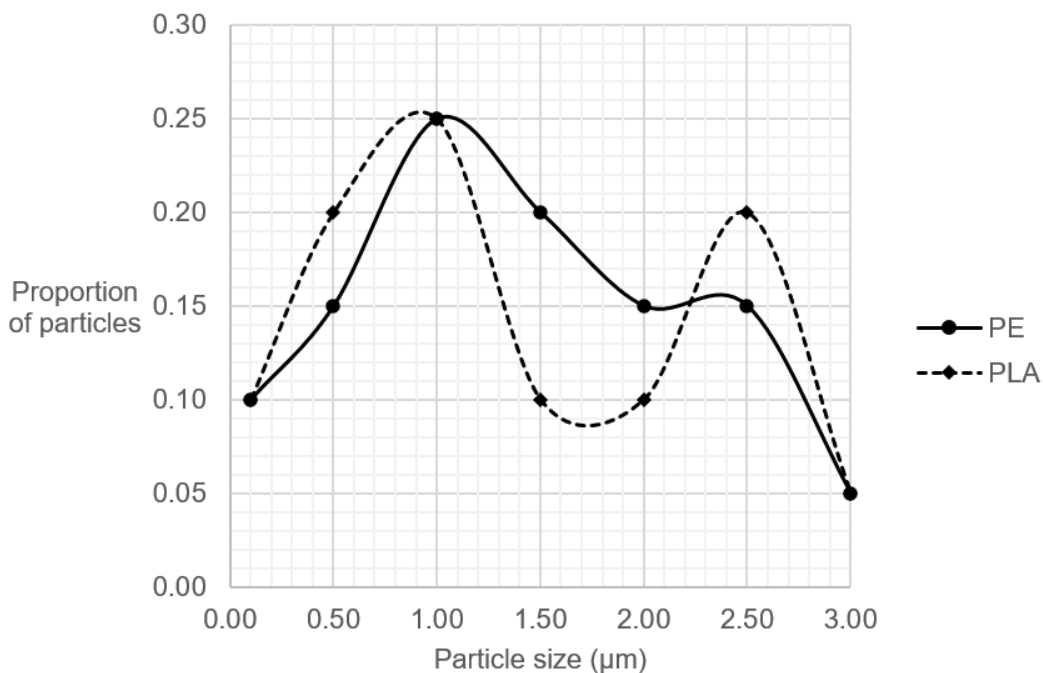


Fig 5.2

- (i) With reference to Fig 5.2, explain whether you would expect PE or PLA to degrade and generate more microplastics in the sea.

There is a greater proportion of particles ($0.25+0.2+0.15+0.15+0.05=0.80$) of particle size greater than from 1 μm to 3 mm from PE than from PLA ($0.25+0.10+0.10+0.2+0.05=0.70$)

Therefore, PE generates more microplastics in the sea.

or

PE generates more microplastics in the sea.

Area under the graph of PE is greater than PLA for sizes from 1 μm to 3 mm.

[2]

- (ii) State one other condition for the degradation of PE and PLA in the sea that the researcher should have considered in his investigation.

Acceptable answers include:

Temperature of seawater

pH of seawater

Wave action

Pressure of seawater

Note that answers given must be related to conditions of the sea

[1]

[Total: 12]