



Cambridge International AS & A Level

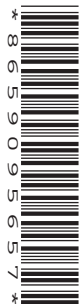
CANDIDATE
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CHEMISTRY

9701/23

Paper 2 AS Level Structured Questions

May/June 2024

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

INFORMATION

- The total mark for this paper is 60.
- The number of marks for each question or part question is shown in brackets [].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **16** pages.

2

- 1 (a) (i) Explain the lack of reactivity of nitrogen gas, $\text{N}_2(\text{g})$.

.....

.....

..... [2]

- (ii) Covalent bonds can be σ bonds or π bonds.

Complete Table 1.1 to show the number of σ and π bonds in a molecule of N_2 and to describe how the orbitals overlap to form σ and π bonds.

Table 1.1

	σ bond	π bond
number of bonds in N_2		
how the orbitals overlap		

[4]

- (b) (i) A sample of Al reacts with an excess of Cl_2 .

State the oxidation number of Al in the product of the reaction.

oxidation number of Al [1]

- (ii) State what determines the maximum oxidation number of the Period 3 elements in their oxides.

.....

..... [1]

- (c) Separate samples of aluminium oxide, Al_2O_3 , and phosphorus(V) oxide, P_4O_{10} , react with an excess of $\text{NaOH}(\text{aq})$ at room temperature.

- (i) Give the state of Al_2O_3 and P_4O_{10} at room temperature.

Al_2O_3

P_4O_{10} [1]

- (ii) Write an equation for the reaction of each oxide with an excess of $\text{NaOH}(\text{aq})$ at room temperature.

Al_2O_3 +

P_4O_{10} + [2]

- (d) The oxide of silicon reacts with calcium oxide in an addition reaction to produce calcium silicate, CaSiO_3 . The oxidation number of calcium in CaSiO_3 is +II.

- (i) Deduce the oxidation number of silicon in calcium silicate.

oxidation number of silicon [1]

- (ii) Calcium oxide can be made from calcium carbonate in a single-step reaction.

Identify the type of reaction that occurs.

..... [1]

[Total: 13]

- 2 $\text{N}_2(\text{g})$ reacts with $\text{H}_2(\text{g})$ in the Haber process, as shown in reaction 1.

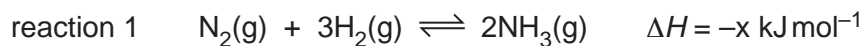


Table 2.1 shows the different conditions used to produce three equilibrium mixtures, **A**, **B** and **C**.

Table 2.1

	A	B	C
initial molar ratio of $\text{N}_2 : \text{H}_2$ added	1 : 3	1 : 3	1 : 3
temperature/ $^{\circ}\text{C}$	500	500	1000
pressure/atm	1000	1000	1000
iron present in mixture	no	yes	no
percentage yield of $\text{NH}_3(\text{g})$ at equilibrium	58	x	y

- (a) Describe and explain the change, if any, to the percentage yield of $\text{NH}_3(\text{g})$ produced in **B** compared to **A**.

.....

 [1]

- (b) (i) Describe and explain the change, if any, to the percentage yield of $\text{NH}_3(\text{g})$ produced in **C** compared to **A**.

.....

 [1]

- (ii) Describe and explain the change to the rate of the forward reaction that occurs to establish the equilibrium in **C** compared to **A**.

You do **not** need to refer to the Boltzmann distribution in your answer.

.....

 [2]

- (c) (i) Write an expression for the equilibrium constant, K_p , for reaction 1. State the units.

$$K_p =$$

units [2]

- (ii) Equilibrium mixture **D** is made when 1.0 mol of $N_2(g)$ and 3.0 mol of $H_2(g)$ are added to a sealed container at $750^\circ C$ and 1000 atm and left to reach equilibrium. This mixture contains 1.16 mol of $NH_3(g)$.

Calculate the mole fraction of $NH_3(g)$ in **D**.

mole fraction of $NH_3(g)$ = [2]

- (iii) The mole fraction of $N_2(g)$ is 0.625 in a new equilibrium mixture, **E**.

Calculate the partial pressure of $N_2(g)$ in **E** when the total pressure is 1000 atm.

partial pressure of $N_2(g)$ = atm [1]

(d) When oxides of nitrogen escape into the atmosphere they may be involved in:

- formation of acid rain from sulfur dioxide
- formation of photochemical smog.

(i) Identify the role of NO and NO₂ in the formation of H₂SO₄ from SO₂ in the atmosphere to produce acid rain.

Use relevant equations to support your answer.

.....

.....

.....

.....

.....

..... [3]

(ii) Outline how NO and NO₂ may contribute to the formation of photochemical smog.

.....

.....

..... [2]

[Total: 14]

- 3 (a) Write an equation to show the reaction for the standard enthalpy change of formation of H_2O . Include state symbols.

..... [2]

- (b) Water is one of the products in the reaction of B_2O_3 and NH_3 , as shown in reaction 2.

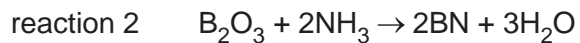


Table 3.1 shows information about the standard enthalpy change of formation, ΔH_f^\ominus , of some substances.

Table 3.1

substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
B_2O_3	–1264
NH_3	–46
BN	–134
H_2O	–286

Calculate the enthalpy change, ΔH , for reaction 2 using the data from Table 3.1.

$\Delta H = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

(c) Boron carbide is a hard crystalline solid that has a melting point greater than 2000 °C.

(i) Suggest the structure and bonding in boron carbide.

..... [1]

(ii) 100 g of pure boron carbide contains 78.26 g of boron.

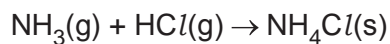
Calculate the empirical formula of boron carbide.

Show your working.

empirical formula of boron carbide [2]

[Total: 7]

- 4 (a) $\text{NH}_3(\text{g})$ reacts with $\text{HCl}(\text{g})$ to produce $\text{NH}_4\text{Cl}(\text{s})$, as shown.



Draw a diagram to show the ionic, covalent and coordinate bonding present in a formula unit of NH_4Cl .

[2]

- (b) An exothermic reaction occurs when $\text{NH}_4^+(\text{aq})$ is added to $\text{OH}^-(\text{aq})$.

- (i) Identify the type of reaction.

..... [1]

- (ii) Construct an ionic equation for the reaction of NH_4^+ and OH^- .

..... [1]

- (c) Substitution reactions of NH_3 and OH^- with halogenoalkanes both involve a lone pair of electrons.

- (i) Name the role of NH_3 and OH^- in these reactions.

..... [1]

- (ii) Suggest which species, NH_3 or OH^- , is more reactive during these reactions. Explain your answer.

.....

.....

..... [1]

- (d) When 2-bromo-2-methylpropane reacts with OH^- , two mechanisms, $\text{S}_{\text{N}}1$ and $\text{S}_{\text{N}}2$, both occur. The $\text{S}_{\text{N}}2$ mechanism has a slower rate.

Fig. 4.1 shows the reaction pathway diagram for the $\text{S}_{\text{N}}1$ mechanism.

Sketch a graph on Fig. 4.1 to show the reaction pathway for the $\text{S}_{\text{N}}2$ mechanism.

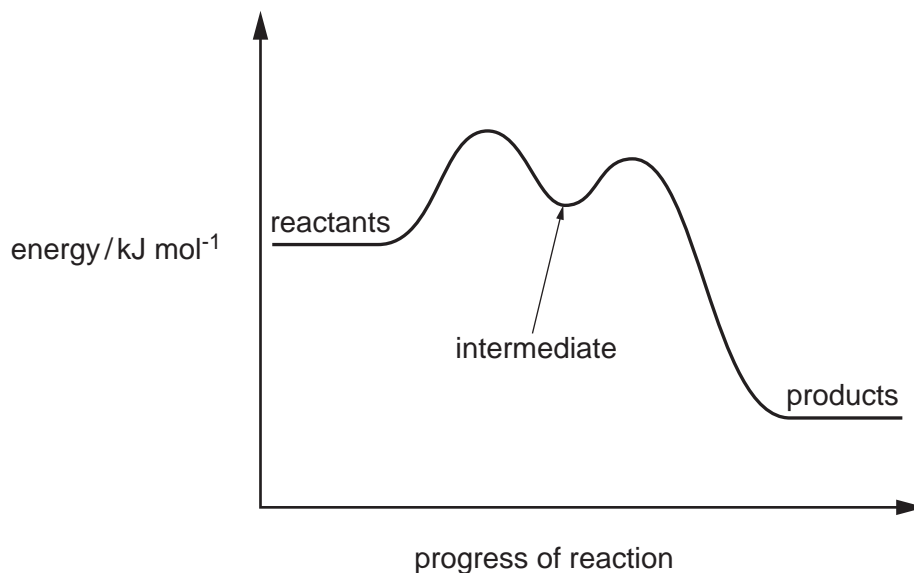


Fig. 4.1

[2]

- (e) (i) Complete Fig. 4.2 to show the mechanism for the $\text{S}_{\text{N}}1$ reaction that occurs when $\text{CH}_3\text{CHBrC}_2\text{H}_5$ reacts with NH_3 to produce $\text{CH}_3\text{CH}(\text{NH}_2)\text{C}_2\text{H}_5$. Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

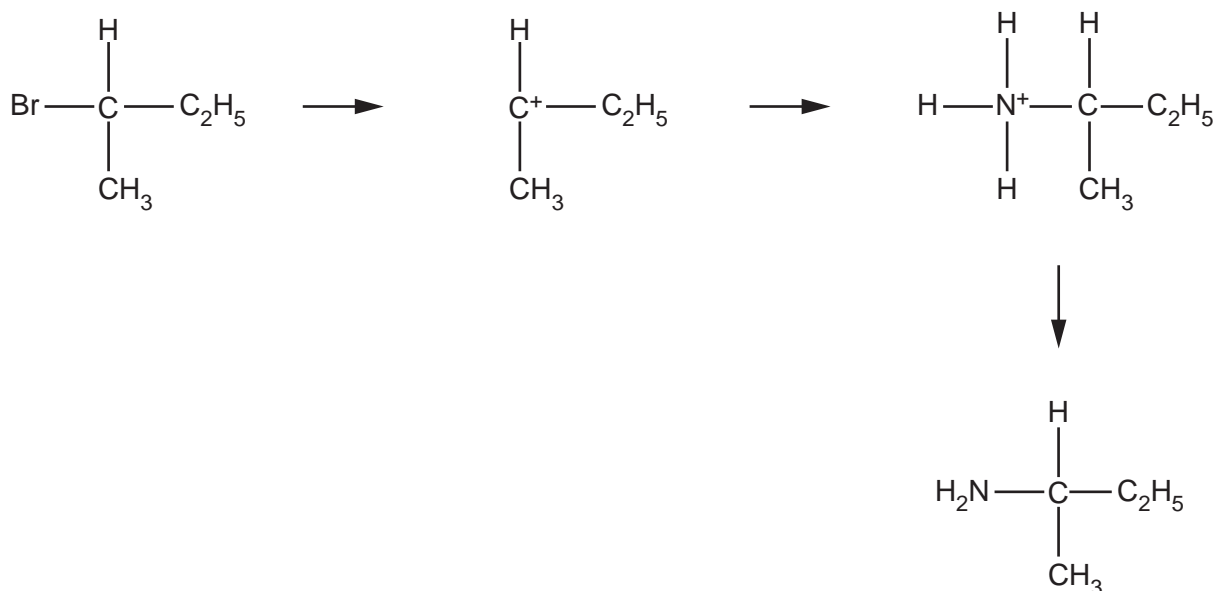


Fig. 4.2

[3]

(ii) Identify the inorganic product that forms in the reaction in Fig. 4.2.

..... [1]

(iii) Give the systematic name for the organic product $\text{CH}_3\text{CH}(\text{NH}_2)\text{C}_2\text{H}_5$.

..... [1]

(f) (i) Complete Table 4.1 by drawing the structural formula of the intermediate that is formed when 2-bromo-2-methylpropane reacts in an $\text{S}_{\text{N}}1$ reaction.

Table 4.1

	2-bromobutane	2-bromo-2-methylpropane
structural formula of intermediate in $\text{S}_{\text{N}}1$ reaction	$\begin{array}{c} \text{H} \\ \\ \text{C}^+ - \text{C}_2\text{H}_5 \\ \\ \text{CH}_3 \end{array}$	

[1]

(ii) Identify the halogenoalkane in Table 4.1 that has the greater tendency to react using the $\text{S}_{\text{N}}1$ mechanism. Explain your answer.

.....

 [2]

[Total: 16]

- 5 (a) **M** reacts to form **R** by the addition of one reagent, as shown in Fig. 5.1.

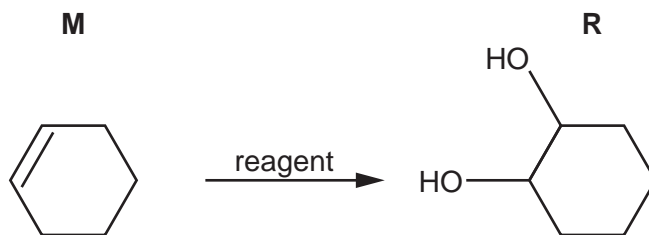


Fig. 5.1

Identify the reagent and conditions for this reaction.

..... [1]

- (b) **R** is also made from **M** by two steps, as shown in Fig. 5.2.

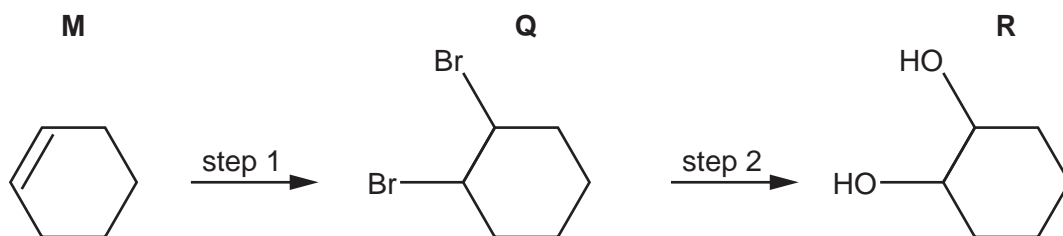


Fig. 5.2

- (i) Identify the reagents and conditions for steps 1 and 2 in Fig. 5.2.

step 1

step 2

[2]

- (ii) Name the mechanism for step 1 in Fig. 5.2.

..... [1]

(c) The infrared spectrum of **R** is shown in Fig. 5.3.

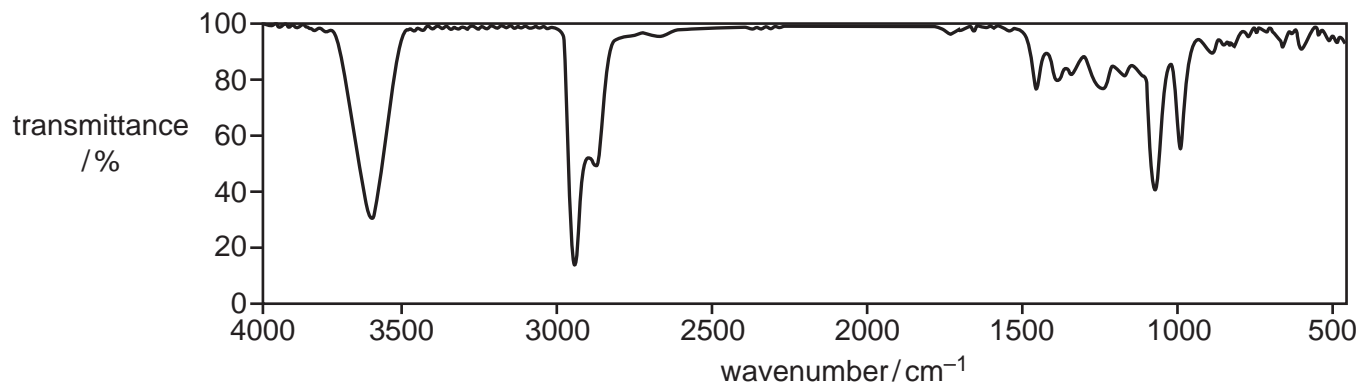


Fig. 5.3

Table 5.1

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers) / cm^{-1}
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

Use the absorptions in the region above 1500 cm^{-1} in Table 5.1 when answering this question.

- Add **F** to Fig. 5.3 to identify the peak that is present in an infrared spectrum of both **Q** and **R**. Identify the bond that corresponds to the absorption for **F**.

.....

- Add **G** to Fig. 5.3 to identify the peak that is **not** present in an infrared spectrum of **Q**. Identify the bond that corresponds to the absorption for **G**.

.....

[2]

(d) **Y** is made from **Q** in a three-step reaction.

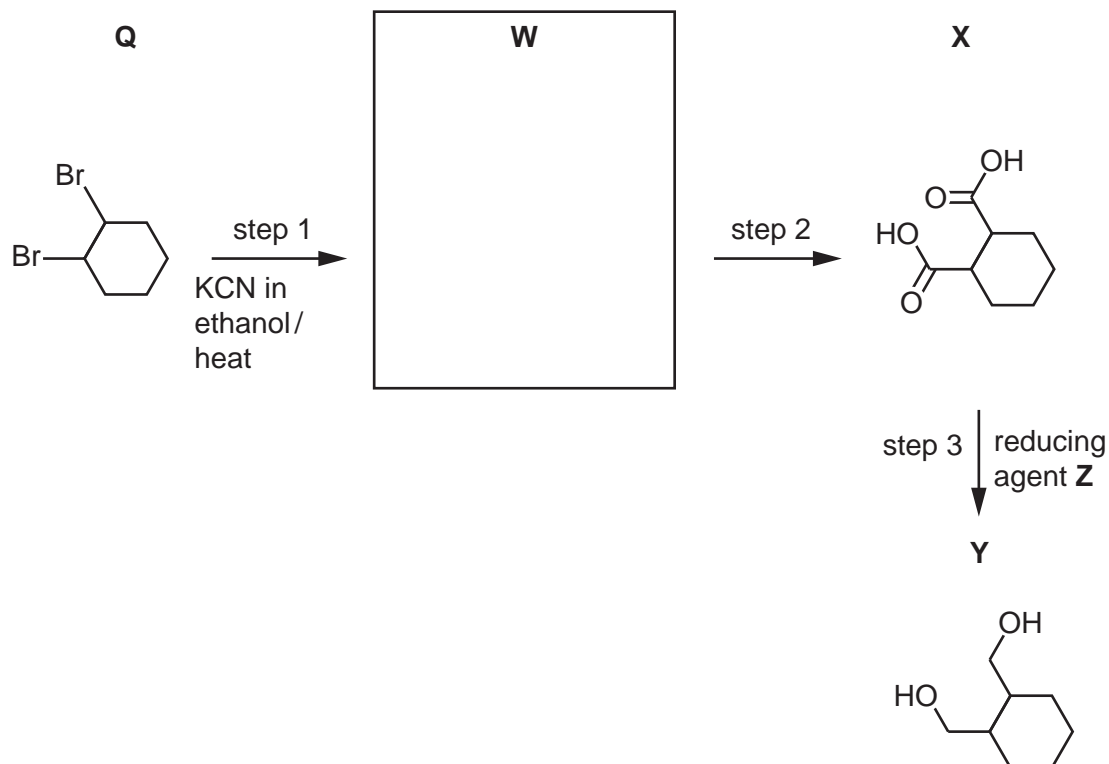


Fig. 5.4

(i) Draw the structure of **W** in the box in Fig. 5.4. [1]

(ii) In step 2, **W** is heated with HCl(aq) to produce **X** and an inorganic product.

Identify the formula of the inorganic product.

..... [1]

(iii) In step 3, **X** reacts with reducing agent **Z** to produce **Y**.

Complete the equation for the reaction of **X** with **Z**.

Use a molecular formula to represent the organic product.

Use $[\text{H}]$ to represent one atom of hydrogen from **Z**.

..... $\text{C}_8\text{H}_{12}\text{O}_4$ + $[\text{H}] \rightarrow$ [1]

(iv) Identify **Z**.

..... [1]

[Total: 10]

Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

The Periodic Table of Elements

[illegible]

lanthanoids

actinoids