



CANDIDATE
NAME

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CENTRE
NUMBER

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9701/21

May/June 2024

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

- 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.

- 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. Any blank pages are indicated.

- 1 (a) The elements of Group 17 are called halogens.

Complete Table 1.1.

Table 1.1

halogen	colour at 293 K
chlorine	
bromine	
iodine	

[1]

- (b) State the trend in volatility of the halogens chlorine, bromine and iodine. Explain your answer.

.....

 [3]

- (c) Iodine is made by reacting bromine with sodium iodide.

- (i) Construct an ionic equation for the reaction of bromine with sodium iodide.

..... [1]

- (ii) State the role of bromine in the reaction. Explain your answer.

.....
 [1]

(d) Concentrated sulfuric acid is added to separate samples containing equal amounts of NaCl, NaBr and NaI. All three samples initially react to produce the hydrogen halide.

- (i) Write an equation to describe the acid–base reaction that occurs when concentrated sulfuric acid reacts with NaBr.

..... [1]

- (ii) Deduce which sodium halide, NaCl, NaBr or NaI, produces the largest percentage yield of hydrogen halide when concentrated sulfuric acid is added. Explain your answer by considering the relative reactivity of the halide ions as reducing agents.

identity of sodium halide

explanation

.....

.....

[3]

[Total: 10]

- 2 (a) Sulfur chloride, SCl_2 , is a liquid at room temperature. When SCl_2 is added to water, misty fumes are seen and a solution is made that turns universal indicator red.

(i) Identify the type of reaction that occurs when SCl_2 is added to water.

..... [1]

(ii) Name a chloride of a different Period 3 element that is also a liquid at room temperature and produces misty fumes when added to water.

..... [1]

(b) A molecule of SCl_2 contains two S–Cl covalent bonds.

(i) Complete the dot-and-cross diagram in Fig. 2.1 to show the arrangement of the outer electrons in a molecule of SCl_2 .

Use $\times$ to show electrons from the chlorine atoms.

Use $\bullet$ to show electrons from the sulfur atom.

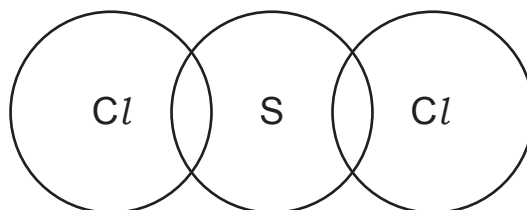


Fig. 2.1

[2]

(ii) Predict the shape of, and bond angle in, a molecule of SCl_2 by using VSEPR theory.

shape

bond angle

[2]

(c) Solid magnesium nitride, Mg_3N_2 , is a crystalline solid.

(i) Deduce the oxidation numbers of magnesium and nitrogen in magnesium nitride to complete Table 2.1.

Table 2.1

	oxidation number in Mg_3N_2
magnesium	
nitrogen	

[1]

- (ii) Magnesium nitride reacts with an excess of water to produce ammonia and magnesium hydroxide only. Construct an equation to describe this reaction.

..... [1]

- (iii) Explain why the solution produced in the reaction in (c)(ii) has a pH greater than 7. Refer to the products of the reaction in your answer.

.....

.....

..... [2]

- (d) Boron nitride is a white solid that melts above 2900 °C.

Fig. 2.2 shows part of the lattice structure of a crystal of boron nitride.

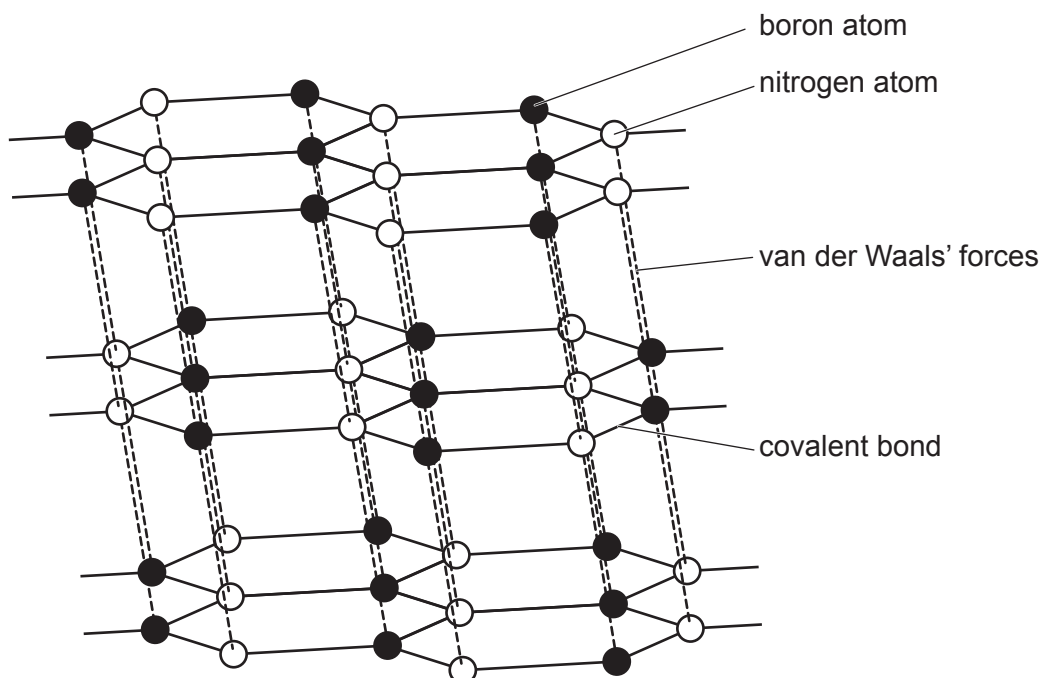


Fig. 2.2

- (i) Use Fig. 2.2 to deduce the empirical formula of boron nitride.

..... [1]

- (ii) Suggest the identity of another crystalline solid that has atoms arranged in layers similar to that of solid boron nitride.

..... [1]

[Total: 12]

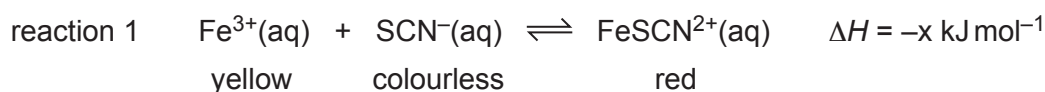
3 (a) Define Le Chatelier's principle.

.....

.....

..... [2]

(b) Reaction 1 describes the reversible reaction between yellow $\text{Fe}^{3+}(\text{aq})$ and colourless $\text{SCN}^{-}(\text{aq})$ to produce red $\text{FeSCN}^{2+}(\text{aq})$.



A mixture of $\text{Fe}^{3+}(\text{aq})$, $\text{SCN}^{-}(\text{aq})$ and $\text{FeSCN}^{2+}(\text{aq})$ is at equilibrium at 20°C .

The temperature of this mixture is then increased to 50°C and allowed to reach equilibrium.

Deduce the changes that occur, if any, in the equilibrium mixture at 50°C compared to the equilibrium mixture at 20°C .

- change in appearance

.....

- change in relative concentration of $\text{FeSCN}^{2+}(\text{aq})$

.....

- change in value of the equilibrium constant, K_c

.....

[3]

- (c) In another experiment, equimolar amounts of $\text{Fe}^{3+}(\text{aq})$ and $\text{SCN}^{-}(\text{aq})$ are mixed together and allowed to reach equilibrium. The total volume of the mixture is 25.0 cm^3 .



At equilibrium the mixture contains:

- $[\text{SCN}^{-}] = 1.30 \times 10^{-3} \text{ mol dm}^{-3}$
- $[\text{FeSCN}^{2+}] = 0.300 \times 10^{-3} \text{ mol dm}^{-3}$.

- (i) Calculate the initial amount, in mol, of $\text{Fe}^{3+}(\text{aq})$ added to $\text{SCN}^{-}(\text{aq})$ to produce this mixture.

initial amount of $\text{Fe}^{3+}(\text{aq}) = \dots\dots\dots \text{ mol}$ [2]

- (ii) Calculate K_c for reaction 1 and state its units.

Show your working.

$K_c = \dots\dots\dots$

units $\dots\dots\dots$
[2]

[Total: 9]

- 4 (a) Define enthalpy change of formation.

.....

.....

..... [2]

- (b) Iron is made when iron(III) oxide is heated with carbon monoxide, as shown by reaction 2.

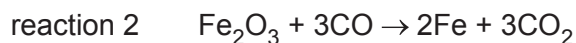


Table 4.1 shows enthalpy change of formation data measured at 298 K and 101 kPa.

Table 4.1

substance	equation	value for $\Delta H_f^\ominus / \text{kJ mol}^{-1}$
Fe_2O_3		–824.2
CO		–110.5
CO_2	$\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$	–393.5

- (i) Complete Table 4.1 by adding equations with relevant state symbols to represent:

- standard enthalpy change of formation for Fe_2O_3
- standard enthalpy change of formation for CO.

[2]

- (ii) Use the data in Table 4.1 to calculate the enthalpy change of reaction, ΔH_r , in kJ mol^{-1} , for reaction 2.

Show your working.

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

[Total: 6]

5 Hydrocarbon molecules contain covalent bonds.

(a) Define covalent bond.

.....
 [1]

(b) A C=C bond in an alkene is made from a σ bond and a π bond.

(i) Identify the hybridisation of the carbon atoms in a C=C bond in an alkene.

..... [1]

(ii) Draw labelled diagrams to show, in terms of orbital overlap, how the σ and π bonds are made in a C=C bond. σ bond π bond

[2]

(c) In electrophilic reactions involving alkenes the π bond of C=C is broken.(i) Suggest **one** difference between σ and π bonds that explains why the π bond is broken in electrophilic addition reactions involving alkenes.

.....
 [1]

(ii) Complete Fig. 5.1 to show the mechanism for the electrophilic addition of hydrogen bromide to 2-methylpropene to produce the major organic product.

Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.



Fig. 5.1

[4]

[Total: 9]

- 6 (a) **V** shows stereoisomerism.

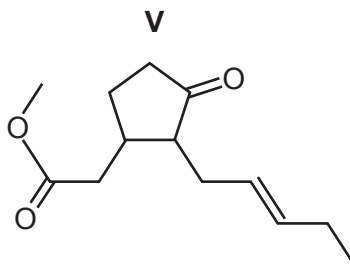


Fig. 6.1

- (i) Explain what is meant by stereoisomerism.

.....

 [1]

- (ii) Deduce the number of stereoisomers of **V**. Explain your reasoning.

.....

 [2]

- (iii) Deduce the molecular formula of **V**.

..... [1]

- (iv) Name **all** the functional groups present in **V**.

.....
 [1]

(b) Fig. 6.2 shows two reactions involving **V**.

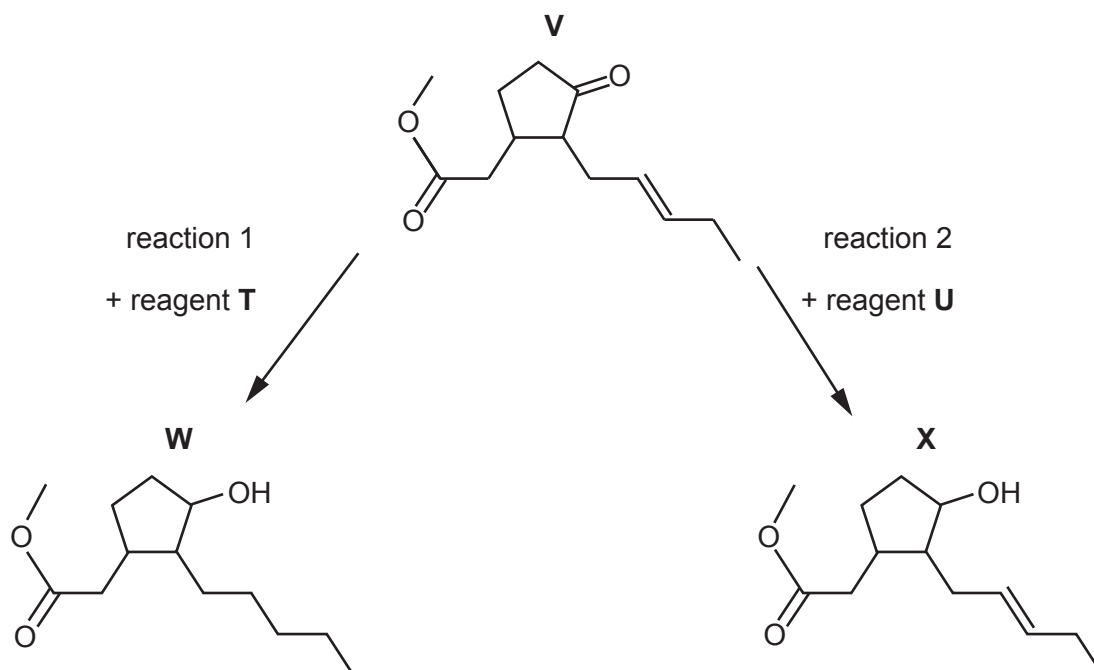


Fig. 6.2

(i) Identify the role of reagent **T** for each functional group that reacts in reaction 1.

.....
 [1]

(ii) Suggest the identity of reagent **U** in reaction 2.

..... [1]

- (c) Both functional groups in one molecule of **Y** react with an inorganic reagent to form one molecule of **Q** and one molecule of methanol, CH_3OH , as shown in Fig. 6.3.

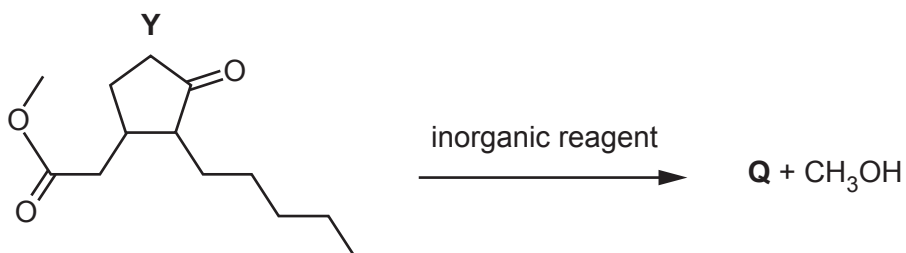


Fig. 6.3

- (i) Part of the mass spectrum for **Q** is shown in Fig. 6.4. Only peaks with m/e greater than 198 are shown.

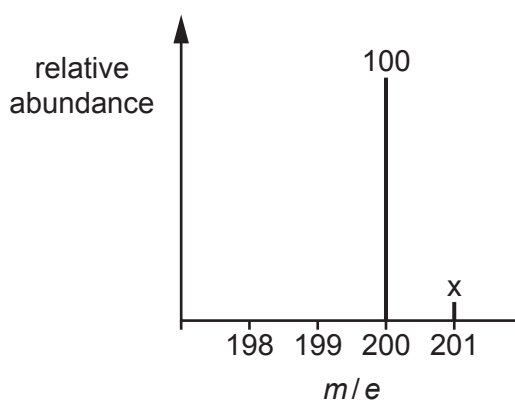


Fig. 6.4

Calculate the relative abundance, x , of the peak at $m/e = 201$.

Show your working.

$x = \dots\dots\dots$ [2]

- (ii) **Q** contains **only** hydroxyl functional groups.

Complete Table 6.1 to show the observations that occur when 2,4-dinitrophenylhydrazine (2,4-DNPH reagent) is added to separate samples of **Y** and **Q**.

Table 6.1

	observation on addition of 2,4-DNPH reagent
Y	
Q	

- (iii) Under certain conditions, 0.0020 mol of **Q** reacts with an excess of sodium to produce a total of 44.8 cm³ of gas at s.t.p.

Calculate the number of hydroxyl groups present in a molecule of **Q**.

Show your working.

number of hydroxyl groups = ... [2]

- (iv) Use Table 6.2 to describe and explain **two** differences between the infrared spectrum of **Y** and **Q** in the region above 1500 cm⁻¹.

.....

 [2]

Table 6.2

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

[Total: 14]

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

Group																																																											
1	2													13	14	15	16	17	18																																								
1 H hydrogen 1.0 Key atomic number atomic symbol name relative atomic mass 3 Li lithium 6.9 4 Be beryllium 9.0 11 Na sodium 23.0 12 Mg magnesium 24.3 19 K potassium 39.1 20 Ca calcium 40.1 21 Sc scandium 45.0 22 Ti titanium 47.9 23 V vanadium 50.9 24 Cr chromium 52.0 25 Mn manganese 54.9 26 Fe iron 55.8 27 Co cobalt 58.9 28 Ni nickel 58.7 29 Cu copper 63.5 30 Zn zinc 65.4 31 Ga gallium 69.7 32 Ge germanium 72.6 33 As arsenic 74.9 34 Se selenium 79.0 35 Br bromine 79.9 36 Kr krypton 83.8 37 Rb rubidium 85.5 38 Sr strontium 87.6 39 Y yttrium 88.9 40 Zr zirconium 91.2 41 Nb niobium 92.9 42 Mo molybdenum 95.9 43 Tc technetium — 44 Ru ruthenium 101.1 45 Rh rhodium 102.9 46 Pd palladium 106.4 47 Ag silver 107.9 48 Cd cadmium 112.4 49 In indium 114.8 50 Sn tin 118.7 51 Sb antimony 121.8 52 Te tellurium 127.6 53 I iodine 126.9 54 Xe xenon 131.3 55 Cs caesium 132.9 56 Ba barium 137.3 57–71 lanthanoids — 72 Hf hafnium 178.5 73 Ta tantalum 180.9 74 W tungsten 183.8 75 Re rhenium 186.2 76 Os osmium 190.2 77 Ir iridium 192.2 78 Pt platinum 195.1 79 Au gold 197.0 80 Hg mercury 200.6 81 Tl thallium 204.4 82 Pb lead 207.2 83 Bi bismuth 209.0 84 Po polonium — 85 At astatine — 86 Rn radon — 87 Fr francium — 88 Ra radium — 89–103 actinoids — 104 Rf rutherfordium — 105 Db dubnium — 106 Sg seaborgium — 107 Bh bohrium — 108 Hs hassium — 109 Mt meitnerium — 110 Ds darmstadtium — 111 Rg roentgenium — 112 Cn coppernium — 113 Nh nihonium — 114 Fl flerovium — 115 Mc moscovium — 116 Lv livermorium — 117 Ts tennessine — 118 Og oganesson —																																																											
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57	La	lanthanum	138.9	58	Ce	cerium	140.1	59	Pr	praseodymium	140.9	60	Nd	neodymium	144.2	61	Pm	promethium	—	62	Sm	samarium	150.4	63	Eu	euporium	152.0	64	Gd	gadolinium	157.3	65	Tb	terbium	158.9	66	Dy	dysprosium	162.5	67	Ho	holmium	164.9	68	Er	erbium	167.3	69	Tm	thulium	168.9	70	Yb	yterbium	173.1	71	Lu	lutetium	175.0
actinoids																																																											
89	Ac	actinium	—	90	Th	thorium	232.0	91	Pa	protactinium	231.0	92	U	uranium	238.0	93	Np	neptunium	—	94	Pu	plutonium	—	95	Am	americium	—	96	Cm	curium	—	97	Bk	berkelium	—	98	Cf	californium	—	99	Es	einsteinium	—	100	Fm	fermium	—	101	Md	mendelevium	—	102	No	nobelium	—	103	Lr	lawrencium	—

lanthanoids

actinoids



Cambridge International AS & A Level

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CHEMISTRY

9701/22

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.
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- 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. Any blank pages are indicated.



- 1 (a) Complete Table 1.1 using relevant information from the Periodic Table.

Table 1.1

	nucleon number	proton number	number of electrons
Mg^{2+}	24		
Al^{3+}	27		

[2]

- (b) State and explain the difference in the ionic radius of Al^{3+} compared to Mg^{2+} .

.....

.....

.....

..... [3]

- (c) Draw a labelled diagram to show the structure and bonding in sodium.

[1]

- (d) Fig. 1.1 shows the variation in melting point of some Period 3 elements in their standard states at room temperature and pressure.

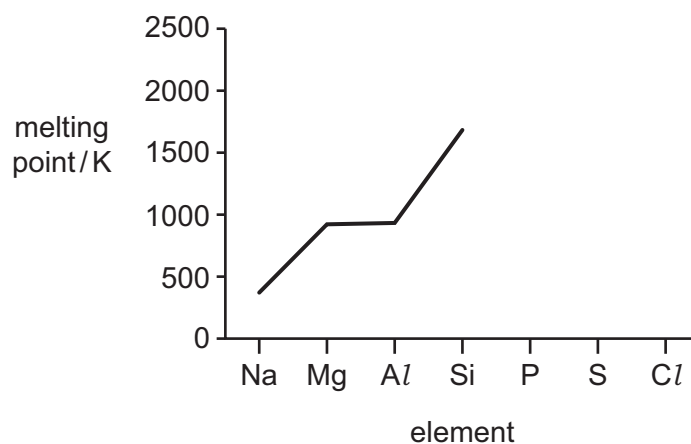


Fig. 1.1



- (i) Explain why Si has a high melting point.

.....

 [1]

- (ii) Complete Fig. 1.1 to show the variation in the melting points of the elements P, S and Cl. [2]

- (e) Two Period 3 elements react with an excess of oxygen at room pressure.

- (i) Complete Table 1.2.

Table 1.2

1	2	3
Period 3 element	state of oxide at room temperature and pressure	approximate pH of solution made when oxide is added to water
Na		
S		

[2]

- (ii) The solutions made in column 3 of Table 1.2 are mixed together. Name the type of reaction that occurs.

..... [1]

- (iii) Write an equation to describe the reaction between P_4O_{10} and an excess of water.

..... [1]

- (f) Aluminium hydroxide is amphoteric.

- (i) Explain what is meant by amphoteric.

.....
 [1]

- (ii) Write an equation to describe the reaction that occurs when aluminium hydroxide, $Al(OH)_3$, reacts with $NaOH(aq)$.

..... [1]

[Total: 15]



- 2 Separate samples of Na_2CO_3 and NaHCO_3 react with $\text{HCl}(\text{aq})$ to produce the same products, as shown in Table 2.1.

Table 2.1

reaction	equation	$\Delta H/\text{kJ mol}^{-1}$
1	$\text{Na}_2\text{CO}_3 + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$	ΔH_1
2	$\text{NaHCO}_3 + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$	$\Delta H_2 = +27.2$

- (a) Complete the reaction pathway diagram in Fig. 2.1 for reaction 2.

Label the diagram to show the enthalpy change, ΔH_2 , and the activation energy, E_A .

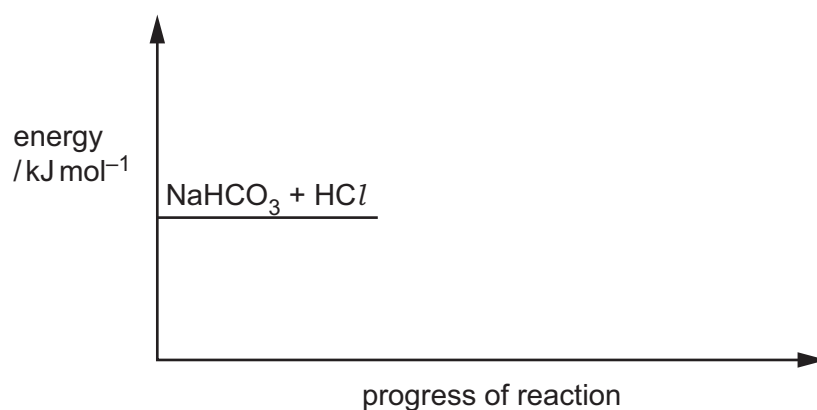


Fig. 2.1

[2]

- (b) The value for ΔH_1 is determined by experiment using the following method.

- 50.0 cm^3 of 2.00 mol dm^{-3} $\text{HCl}(\text{aq})$ is added to a polystyrene cup.
- The initial temperature of the acid is recorded as 19.6°C .
- 0.0400 mol of Na_2CO_3 is added and the mixture is stirred.
- All the solid Na_2CO_3 disappears and a colourless solution is produced.

The maximum temperature recorded during the reaction is 26.2°C .

- (i) Describe **one** other observation that shows the reaction is complete.

..... [1]





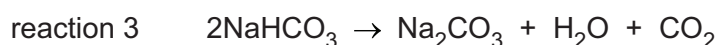
(ii) Calculate the value of ΔH_1 in kJ mol^{-1} .

Assume the specific heat capacity of the reaction mixture is the same as for water and no heat is lost to the surroundings.

Show your working.

$$\Delta H_1 = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$

(iii) Thermal decomposition occurs when NaHCO_3 is heated.



Calculate the enthalpy change for reaction 3, ΔH_r , using the data in Table 2.1 and the value of ΔH_1 calculated in (b)(ii).

(If you were unable to calculate a value for ΔH_1 in (b)(ii), assume the enthalpy change is $-38.4 \text{ kJ mol}^{-1}$. This is **not** the correct value.)

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

(c) **Z** is a salt that contains a Period 4 element from Group 2. When **Z** is heated brown gas forms.

Identify the formula of **Z** and use it to write an equation for the reaction.

..... [2]

[Total: 10]





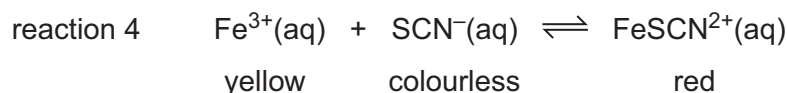
3 (a) Describe what is meant by dynamic equilibrium.

.....

.....

..... [2]

(b) Reaction 4 describes the reversible reaction between yellow $\text{Fe}^{3+}(\text{aq})$ and colourless $\text{SCN}^{-}(\text{aq})$ to produce red $\text{FeSCN}^{2+}(\text{aq})$.



An equilibrium mixture contains $\text{Fe}^{3+}(\text{aq})$, $\text{SCN}^{-}(\text{aq})$ and $\text{FeSCN}^{2+}(\text{aq})$. A few colourless crystals of soluble $\text{KSCN}(\text{s})$ are added. The mixture is then left until it reaches equilibrium again. The temperature of both equilibrium mixtures is the same.

(i) Deduce the changes that occur, if any, in the equilibrium mixture after $\text{KSCN}(\text{s})$ is added compared to the original equilibrium mixture.

- change in appearance

.....

- change in relative concentration of $\text{Fe}^{3+}(\text{aq})$

.....

- change in value of the equilibrium constant, K_c

.....

[3]





(ii) The expression for the equilibrium constant, K_c , for reaction 4 is shown.

$$K_c = \frac{[\text{FeSCN}^{2+}(\text{aq})]}{[\text{Fe}^{3+}(\text{aq})] \times [\text{SCN}^{-}(\text{aq})]}$$

$5.00 \times 10^{-5} \text{ mol}$ of $\text{Fe}^{3+}(\text{aq})$ and $5.00 \times 10^{-5} \text{ mol}$ of $\text{SCN}^{-}(\text{aq})$ are added together and allowed to reach equilibrium. The total volume of the mixture is 25.0 cm^3 .

At equilibrium the concentration of $\text{FeSCN}^{2+}(\text{aq})$ is $4.23 \times 10^{-4} \text{ mol dm}^{-3}$.

Calculate the equilibrium constant, K_c , for reaction 4.

Include the units in your answer.

$K_c = \dots\dots\dots$

units $\dots\dots\dots$
[4]





(c) Determine the full electronic configuration of Fe^{3+} .

..... [1]

(d) $\text{SCN}^{-}(\text{aq})$ is colourless.

Complete the dot-and-cross diagram in Fig. 3.1 to show the arrangement of outer electrons in an SCN^{-} ion.

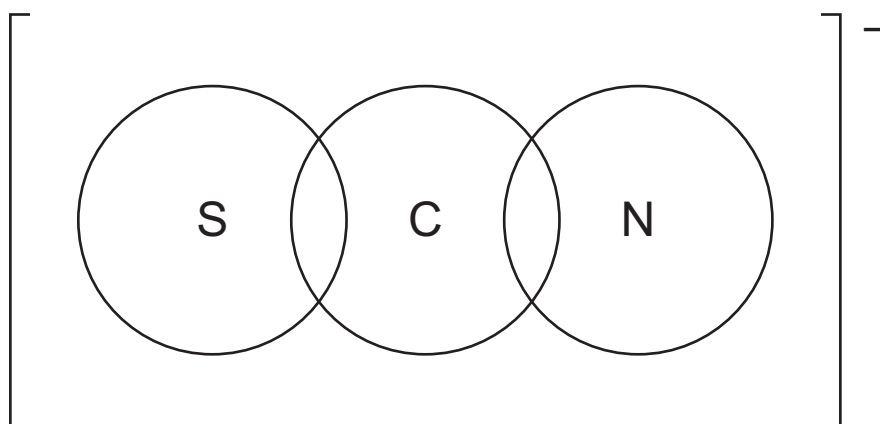


Fig. 3.1

[2]

[Total: 12]



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$$\text{CH}_3(\text{CH}_2)_5-\overset{\text{H}}{\underset{\text{CH}_3}{\text{C}}}-\text{Br} \longrightarrow \text{CH}_3(\text{CH}_2)_5-\overset{\text{H}}{\underset{\text{CH}_3}{\text{C}}}-\text{OH}$$

[3]

- Complete Table 4.1. If no reaction occurs, write x in the relevant box.

reagent added	observation with $\text{CH}_3(\text{CH}_2)_5\text{CHBrCH}_3$	observation with $\text{CH}_3(\text{CH}_2)_5\text{CH}(\text{OH})\text{CH}_3$	observation with $\text{CH}_3(\text{CH}_2)_5\text{CHCH}_2$
$\text{Br}_2(\text{l})$ in the dark			
$\text{PCl}_5(\text{s})$			
$\text{AgNO}_3(\text{aq})$			

[3]

(d) $\text{CH}_3(\text{CH}_2)_5\text{CHBrCH}_3$ is heated with **D** to produce three different molecules, **E**, **F** and **G**.

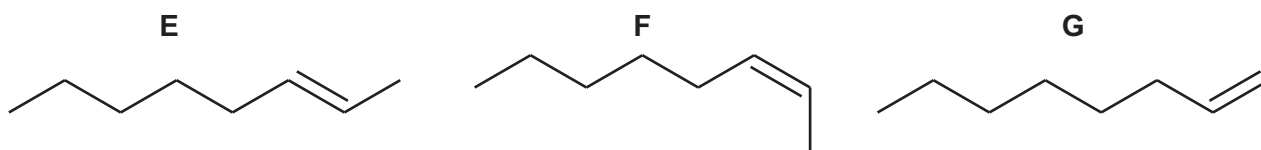


Fig. 4.2

(i) Name the type of reaction.

..... [1]

(ii) Identify **D** and the conditions used.

..... [1]

(e) (i) Both σ and π bonds are present in a molecule of **E** as a result of different types of hybridisation in the carbon atoms.

Complete Table 4.2 to show the number of carbon atoms with each type of hybridisation in a molecule of **E**.

Table 4.2

	number of carbon atoms		
	sp hybridised	sp ² hybridised	sp ³ hybridised
E			

[2]

(ii) Describe the essential feature of an unbranched hydrocarbon that causes its molecules to show stereoisomerism. Explain how this feature leads to stereoisomerism.

.....

.....

..... [3]

[Total: 15]





5 Compound **W** has molecular formula $C_4H_{10}O$. It contains only **one** functional group.

(a) Table 5.1 shows the two peaks with the greatest m/e values in the mass spectrum of **W**.

Table 5.1

m/e	relative abundance
74	50
75	x

(i) Calculate the relative abundance, x, of the peak at $m/e = 75$ using the information from Table 5.1.

x = ... [1]

(ii) The mass spectrum of **W** also shows peaks at $m/e = 29$ and $m/e = 59$.

Suggest the molecular formulae of these fragments.

$m/e = 29$

$m/e = 59$

[2]

(b) A sample of **W**, $C_4H_{10}O$, is heated under reflux with an excess of acidified $K_2Cr_2O_7$ until there is no further reaction. Only **one** organic product, **X**, is present in the mixture at the end of the reaction.

Fig. 5.1 shows the infrared spectrum of **W**.

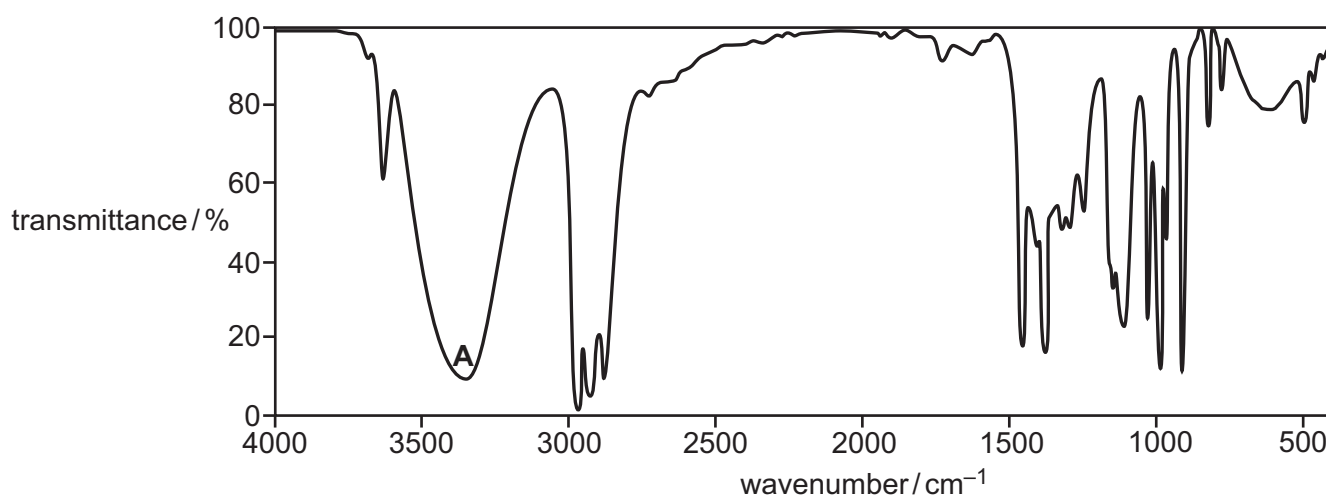


Fig. 5.1



Fig. 5.2 shows the infrared spectrum of **X**.

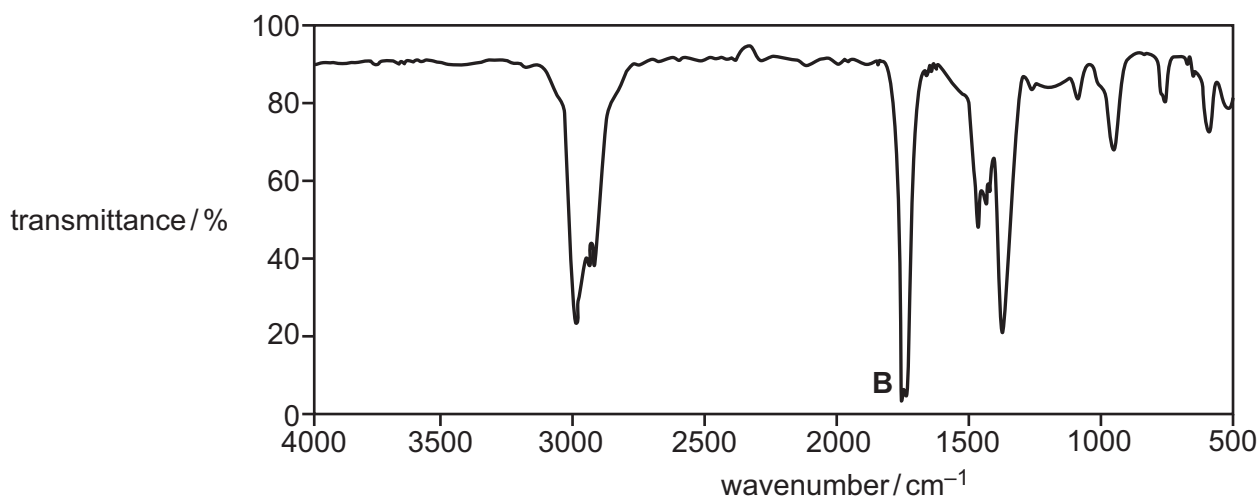


Fig. 5.2

Table 5.2

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

- (i) Absorption **A** is shown in Fig. 5.1.
Absorption **B** is shown in Fig. 5.2.

Complete Table 5.3 using the information given in Fig. 5.1, Fig. 5.2 and Table 5.2.

Table 5.3

absorption	bond	functional group containing the bond
A		
B		

[1]





(ii) Use the information in (a) and (b)(i) to draw the structure of **X** in the box in Fig. 5.3.

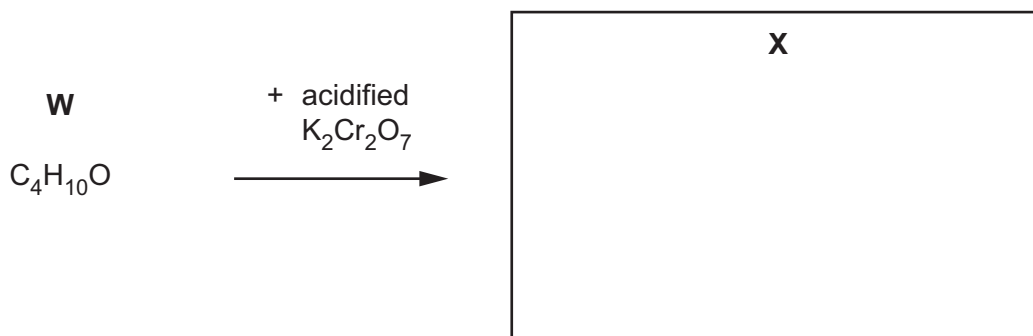


Fig. 5.3

[1]

(c) **Y** is a structural isomer of **W**.

Both **W** and **Y** produce colourless bubbles when sodium is added to them.

Y does **not** react when heated with acidified $\text{K}_2\text{Cr}_2\text{O}_7$.

Y does **not** react when warmed with alkaline $\text{I}_2(\text{aq})$.

(i) Name the functional group present in **Y**.

..... [1]

(ii) Complete the equation to describe the reaction of **W** or **Y** with sodium.

..... $\text{C}_4\text{H}_{10}\text{O}$ + ... Na → [1]

(iii) Draw the structure of **Y**.

[1]

[Total: 8]



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

Group																				
1	2	1 H hydrogen 1.0												13	14	15	16	17	18	
		Key																		
		atomic number atomic symbol name relative atomic mass																		
3 Li lithium 6.9	4 Be beryllium 9.0																			
11 Na sodium 23.0	12 Mg magnesium 24.3																			
3		4		5		6		7		8		9		10		11		12		
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8			
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium —	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3			
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids		72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium —	85 At astatine —	86 Rn radon —		
87 Fr francium —	88 Ra radium —	89–103 actinoids		104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —	113 Nh nihonium —	114 Fl flerovium —	115 Mc moscovium —	116 Lv livermorium —	117 Ts tennessine —	118 Og oganeson —		

lanthanoids

actinoids

57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium —	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
89 Ac actinium —	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium —	94 Pu plutonium —	95 Am americium —	96 Cm curium —	97 Bk berkelium —	98 Cf californium —	99 Es einsteinium —	100 Fm fermium —	101 Md mendelevium —	102 No nobelium —	103 Lr lawrencium —





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9701/23

May/June 2024

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

- 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.

- 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.

- 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.

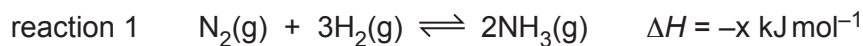


Table 2.1 shows the different conditions used to produce three equilibrium mixtures, **A**, **B** and **C**.

Table 2.1

	A	B	C
initial molar ratio of N_2 : H_2 added	1 : 3	1 : 3	1 : 3
temperature / °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.

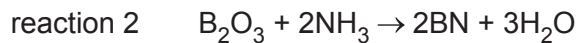


Table 3.1 shows information about the standard enthalpy change of formation, $\Delta H_f^\ominus$, of some substances.

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.

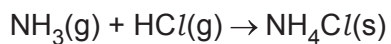
Calculate the empirical formula of boron carbide.

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.

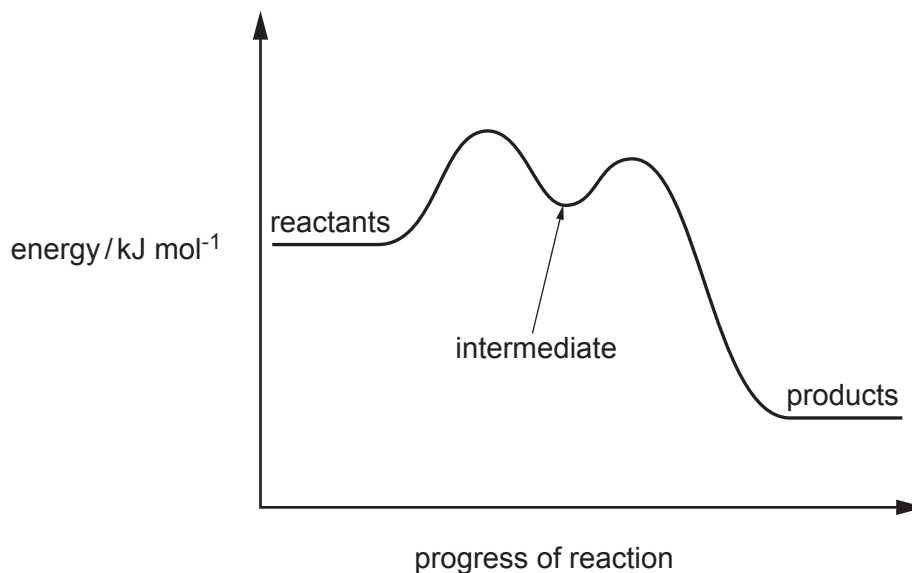


Fig. 4.1

[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.

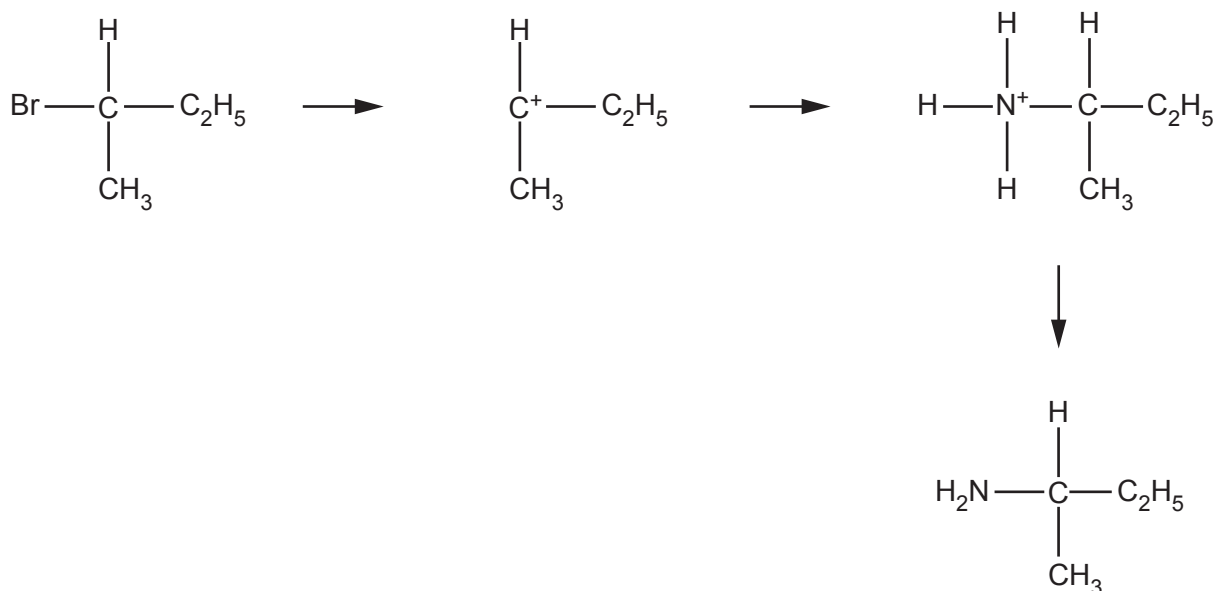


Fig. 4.2

[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.

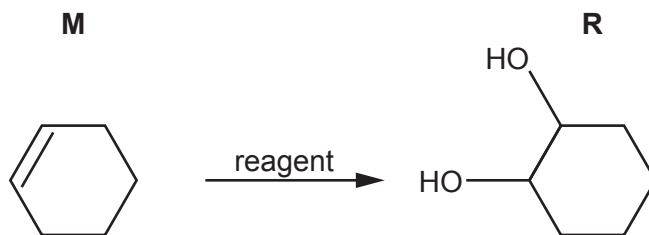


Fig. 5.1

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.

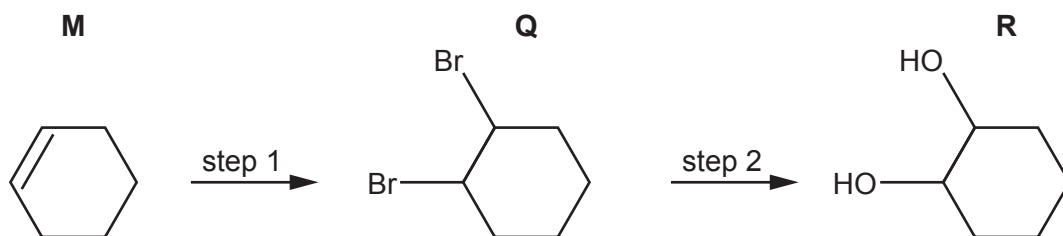


Fig. 5.2

- (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.

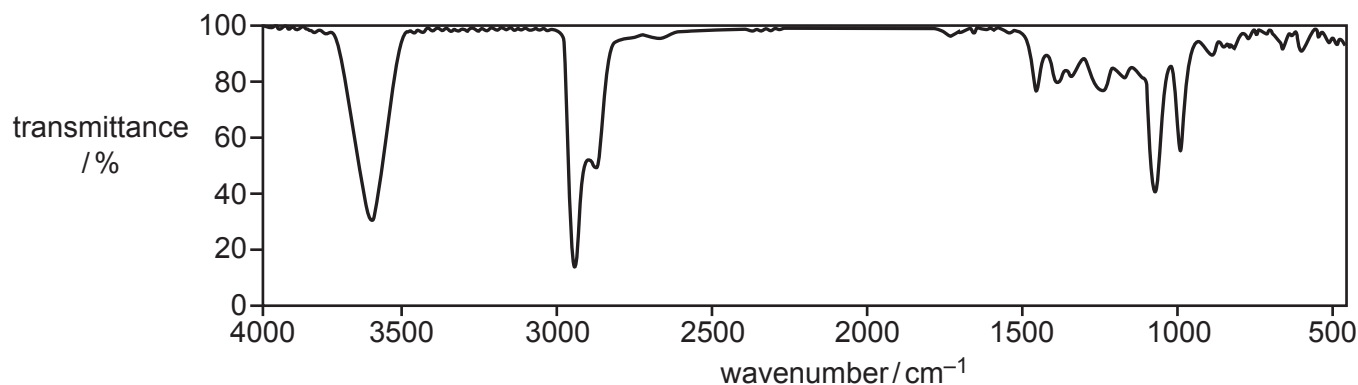


Fig. 5.3

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.

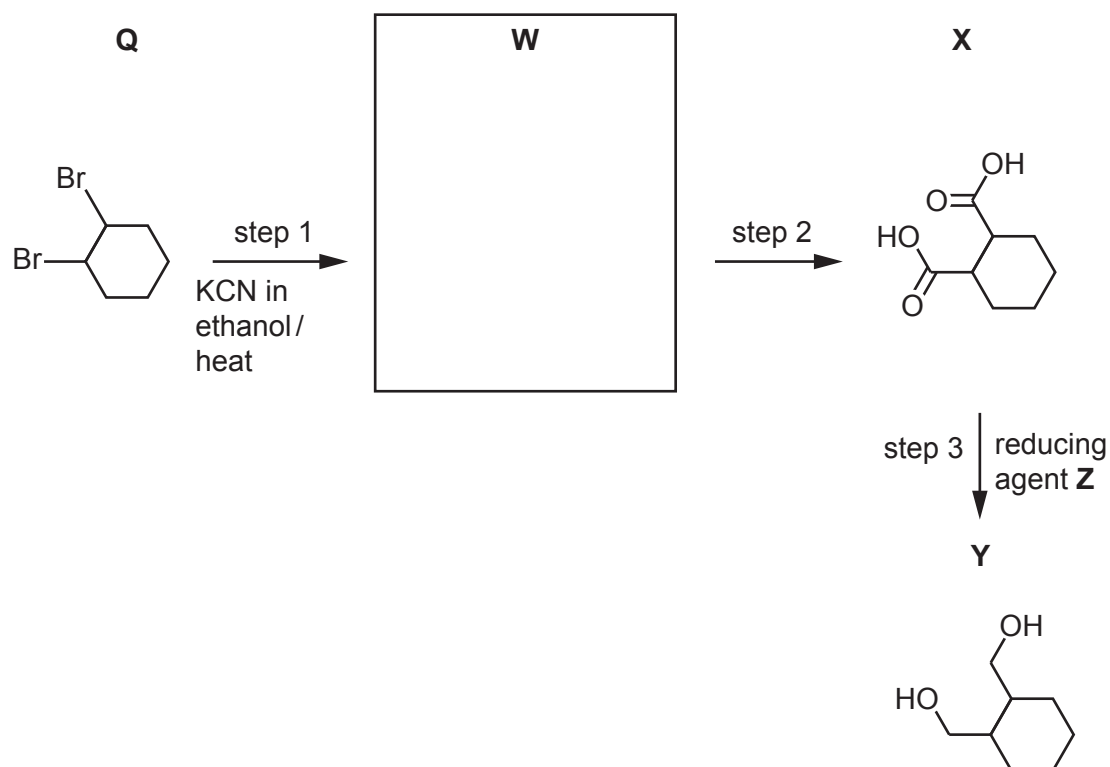


Fig. 5.4

(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

Group																		
1	2	1 H hydrogen 1.0										13	14	15	16	17	18	
		Key																
		atomic number atomic symbol name relative atomic mass																
3	4																	
Li lithium 6.9	Be beryllium 9.0																	
11	12																	
Na sodium 23.0	Mg magnesium 24.3																	
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
K potassium 39.1	Ca calcium 40.1	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8	
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3	
55	56	57–71 lanthanoids		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs caesium 132.9	Ba barium 137.3			Hf hafnium 178.5	Ta tantalum 180.9	W tungsten 183.8	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —	
87	88	89–103 actinoids		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fr francium —	Ra radium —			Rf rutherfordium —	Db dubnium —	Sg seaborgium —	Bh bohrium —	Hs hassium —	Mt meitnerium —	Ds darmstadtium —	Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og ognesson —

Lanthanoids

actinoids

57	La	lanthanum	138.9
58	Ce	cerium	140.1
59	Pr	praseodymium	140.9
60	Nd	neodymium	144.2
61	Pm	promethium	—
62	Sm	samarium	150.4
63	Eu	euroium	152.0
64	Gd	gadolinium	157.3
65	Tb	terbium	158.9
66	Dy	dysprosium	162.5
67	Ho	holmium	164.9
68	Er	erbium	168.9
69	Tm	thulium	168.9
70	Yb	yterbium	173.1
71	Lu	lutetium	175.0
72	Hf	hafnium	178.5
73	Ta	tantalum	180.9
74	W	tungsten	183.8
75	Re	rhenium	186.2
76	Os	osmium	190.2
77	Ir	iridium	192.2
78	Pt	platinum	195.1
79	Au	gold	197.0
80	Hg	mercury	200.6
81	Tl	thallium	204.4
82	Pb	lead	207.2
83	Bi	bismuth	208.9
84	Po	polonium	—
85	At	astatine	—
86	Rn	radon	—
87	Fr	francium	—
88	Ra	radium	—
89	Ac	actinium	—
90	Th	thorium	232.0
91	Pa	protactinium	231.0
92	U	uranium	238.0
93	Np	neptunium	—
94	Pu	plutonium	—
95	Am	americium	—
96	Cm	curium	—
97	Bk	berkelium	—
98	Cf	californium	—
99	Es	einsteinium	—
100	Fm	fermium	—
101	Md	mendelevium	—
102	No	nobelium	—
103	Lr	lawrencium	—

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