Cambridge Assessment International Education

Cambridge International AS & A Level

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

3464830537

CHEMISTRY **9701/21**

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. Any blank pages are indicated.

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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 × to show electrons from the chlorine atoms.
Use ● to show electrons from the sulfur atom.

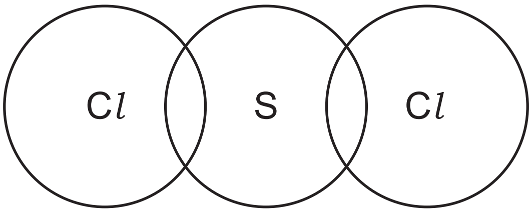

Fig. 2.1

[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.

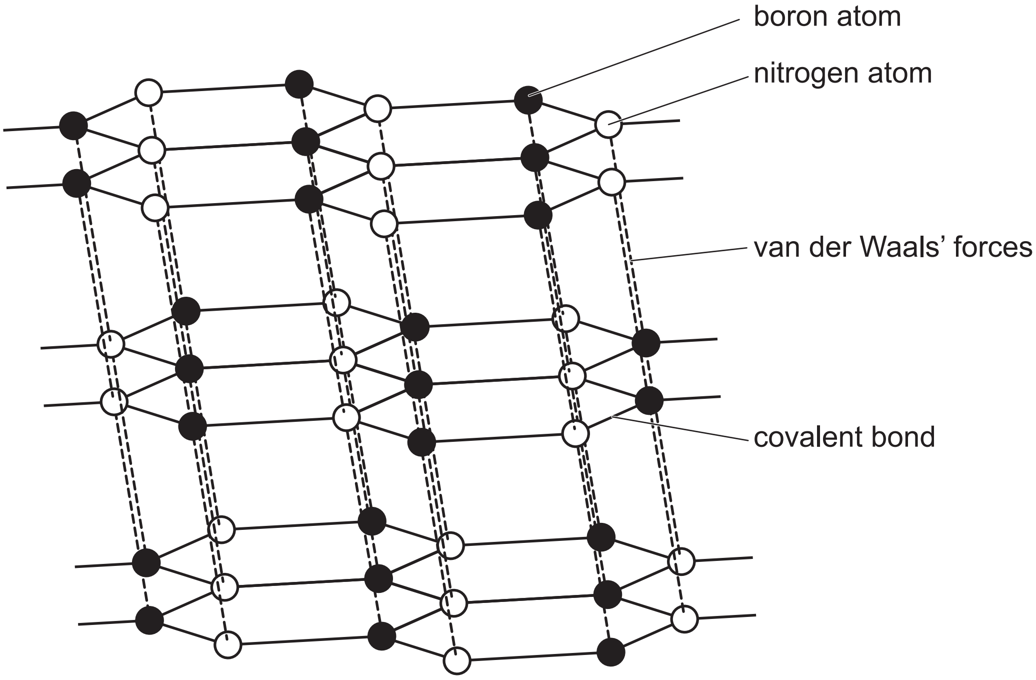

Fig. 2.2

(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 Fe^{3+}(aq) and colourless SCN^{-}(aq) to produce red $FeSCN^{2+}$(aq).

reaction 1 $\quad Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq) \qquad \Delta H = -x\ kJ\,mol^{-1}$

yellow colourless red

A mixture of Fe^{3+}(aq), SCN^{-}(aq) and $FeSCN^{2+}$(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 $FeSCN^{2+}$(aq)

  ....

- change in value of the equilibrium constant, K_c

  ....

[3]

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

reaction 1 $\quad Fe^{3+}(aq) + SCN^-(aq) \rightleftharpoons FeSCN^{2+}(aq)$

At equilibrium the mixture contains:

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

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

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

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

Show your working.

K_c = ...

units ....
[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.

reaction 2 $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

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

Table 4.1

substance	equation	value for $\Delta H_f^\ominus$ / kJ mol^{-1}
Fe_2O_3		–824.2
CO		–110.5
CO_2	$C(s) + O_2(g) \rightarrow CO_2(g)$	–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.

ΔH_r = ... 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.

V

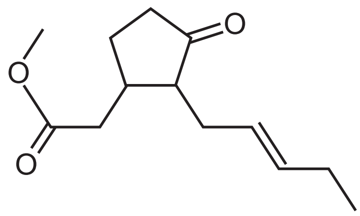

Fig. 6.1

(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**.

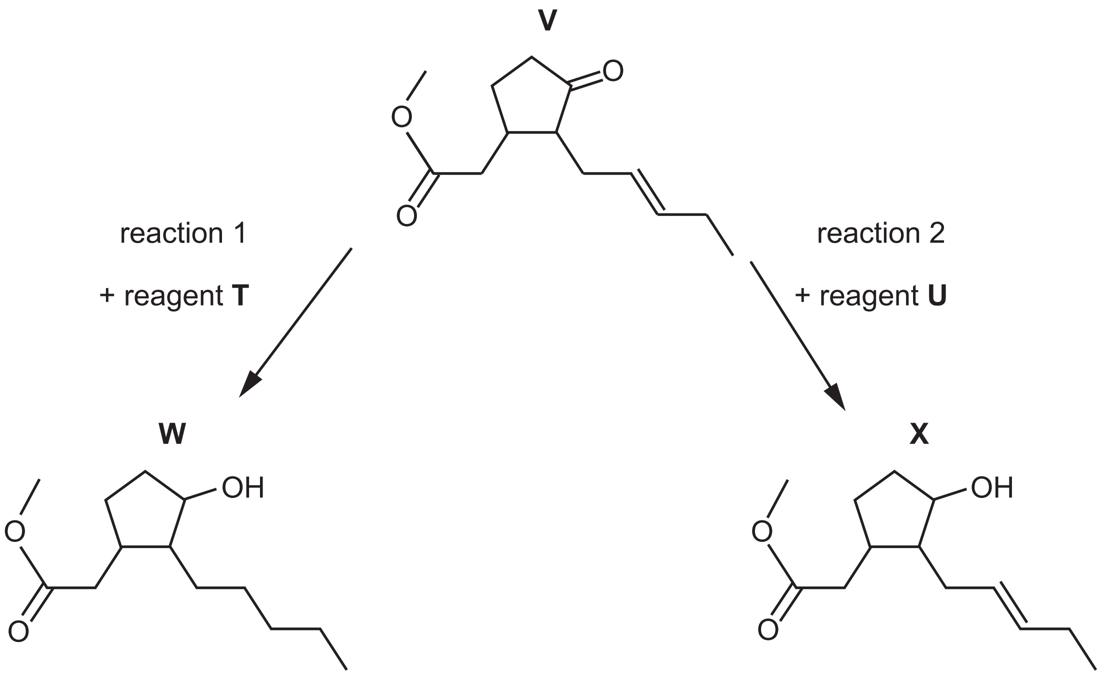

Fig. 6.2

(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.

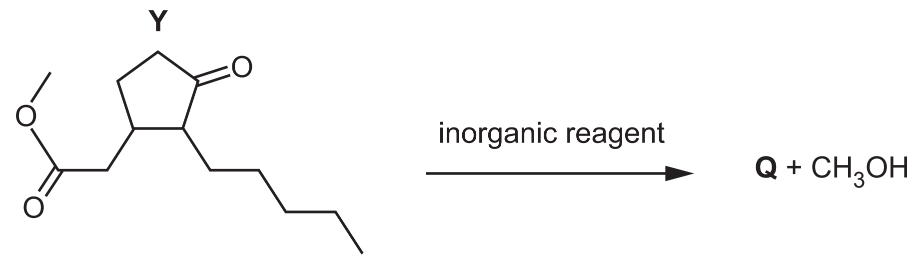

Fig. 6.3

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

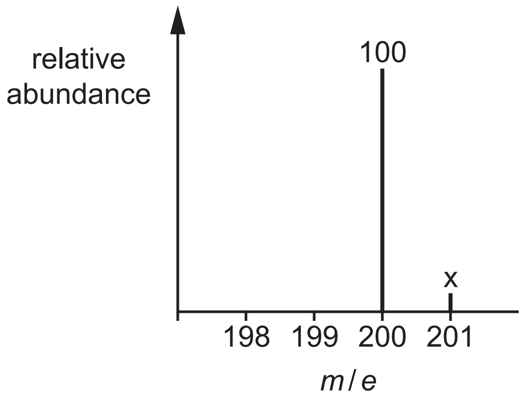

Fig. 6.4

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

Show your working.

x = ... [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	

[1]

(iii) Under certain conditions, 0.0020 mol of **Q** reacts with an excess of sodium to produce a total of 44.8 cm^3 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]

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Important values, constants and standards

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

The Periodic Table of Elements

Key

atomic number atomic symbol name relative atomic mass

Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3											13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
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 oganesson –

lanthanoids	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
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 –