Cambridge Assessment International Education

Cambridge International AS & A Level

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

CHEMISTRY **9701/21**

Paper 2 AS Level Structured Questions **May/June 2025**

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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[Turn over

1 **(a)** Solid sodium conducts electricity. Sodium oxide conducts electricity when molten but not when solid.

(i) Name the type of bonding present in sodium and in sodium oxide.

bonding in sodium .....

bonding in sodium oxide .....

[1]

(ii) Explain how solid sodium conducts electricity.

.....

..... [1]

(iii) Explain why sodium oxide conducts electricity when molten.

.....

..... [1]

(b) Separate samples of sodium and sodium oxide are each added to an excess of cold water.

(i) Write an equation for the reaction of sodium with cold water.

..... [1]

(ii) Write an equation for the reaction of sodium oxide with cold water.

..... [1]

(iii) Complete Table 1.1.
Do **not** refer to temperature changes when considering observations for these reactions.

Table 1.1

	sodium	sodium oxide
one similarity in observation on addition to cold water		
one difference in observation on addition to cold water		

[2]

(c) State the oxidation number of the Period 3 elements bonded to Cl in NaCl and PCl_5. Explain the difference in the oxidation number.

.....

.....

..... [2]

(d) Table 1.2 shows melting points of some oxides.

Table 1.2

oxide	melting point / °C
SO_2	–73
H_2O	0
SO_3	17
SiO_2	1610
MgO	2852
Al_2O_3	2072

A student suggests the following hypothesis.

The higher the oxidation number of the element combined with oxygen, the higher the melting point of the oxide.

Use Table 1.2 to deduce if this hypothesis is true or false or if there is **not** enough information to make a conclusion. Explain your answer.

.....

.....

..... [2]

[Total: 11]

2 A sample of iron is analysed using a mass spectrometer. The mass spectrum shows three isotopes of iron are present in the sample.

(a) Define isotopes.

.....

.....

..... [1]

(b) Fig. 2.1 shows the mass spectrum of the sample of iron.

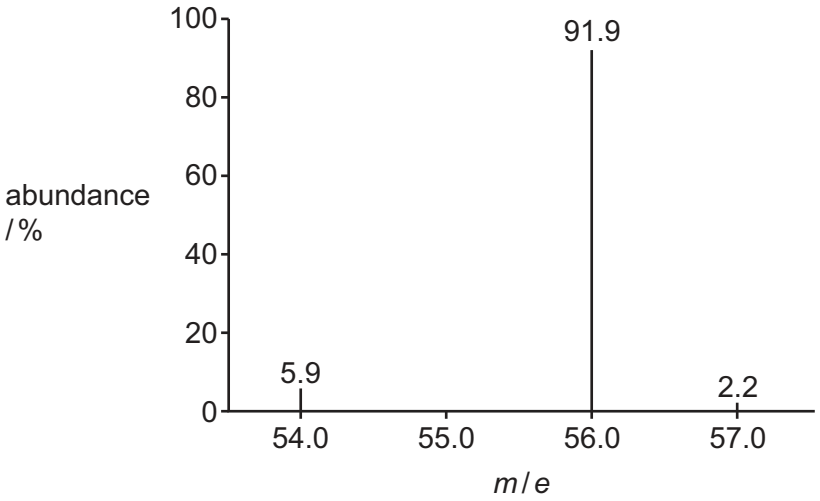


Fig. 2.1

(i) Use Fig. 2.1 to calculate the relative atomic mass, A_r, of iron to **one** decimal place.

Show your working.

A_r of iron = ... [2]

(ii) Complete Table 2.1 to show the number of protons and nucleons in one atom of ^{56}Fe.

Table 2.1

particle	number of particles in one atom of ^{56}Fe
protons	
nucleons	

[2]

(c) Deduce the number of pairs of electrons in the shell with principal quantum number $n = 3$ in an Fe atom.

number of pairs of electrons ..... [1]

(d) Write an equation to represent the first ionisation energy of iron.

..... [1]

(e) Suggest how the value for the first ionisation energy of ^{54}Fe compares to the first ionisation energy of ^{56}Fe. Explain your answer in terms of the factors that affect ionisation energy.

.....

.....

.....

.....

..... [4]

[Total: 11]

3 **(a)** Hexene reacts with hydrogen gas to produce hexane.

reaction 1 $C_6H_{12}(l) + H_2(g) \rightarrow C_6H_{14}(l)$

Fig. 3.1 shows the distribution of energies of $H_2(g)$ molecules at temperature *T*.

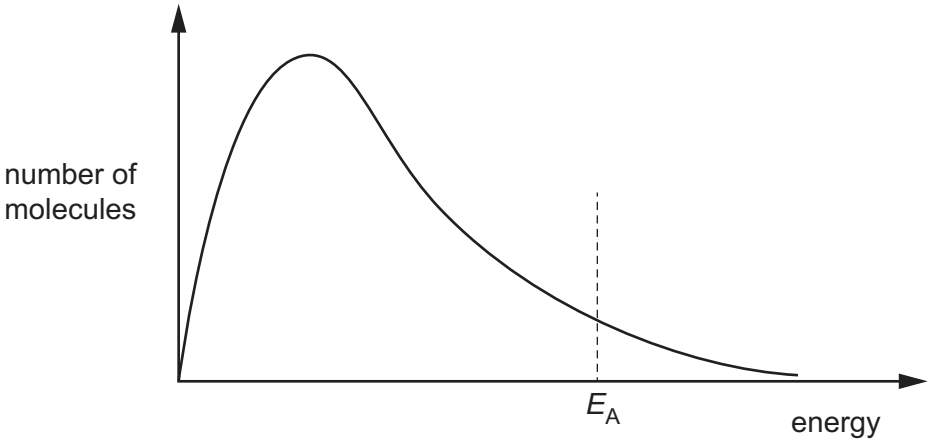


Fig. 3.1

(i) Sketch on Fig. 3.1 the shape of the curve for the same sample of $H_2(g)$ molecules when the temperature is increased. [2]

(ii) Explain why increasing the temperature increases the rate of reaction 1.

.....

.....

..... [2]

(iii) State the role of nickel when it is added to reaction 1.

..... [1]

(iv) Annotate Fig. 3.2 to show the effect of adding nickel to reaction 1 at temperature *T*.

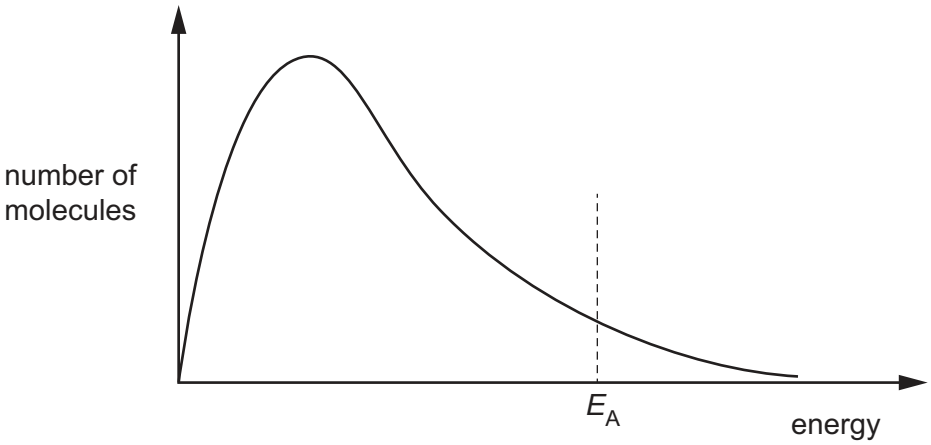


Fig. 3.2

[1]

(b) Define Le Chatelier's principle.

.....

.....

..... [2]

(c) Reaction 2 shows the equilibrium reaction between X(g) and Y(g) to produce Z(g) in a sealed container.

reaction 2 $aX(g) + bY(g) \rightleftharpoons cZ(g)$

Fig. 3.3 shows the effect of changing pressure on the percentage yield of Z(g) at two different temperatures, 300 K and 350 K.

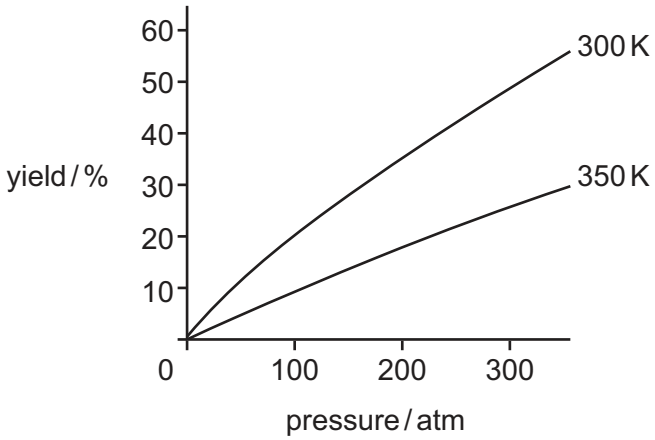


Fig. 3.3

Deduce **two** conclusions about reaction 2 using Fig 3.3.

.....

.....

..... [2]

[Total: 10]

4 The structure of vitamin C is shown in Fig. 4.1.

vitamin C

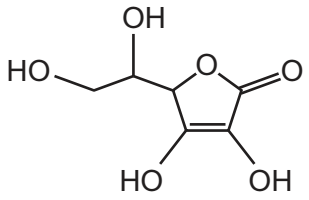


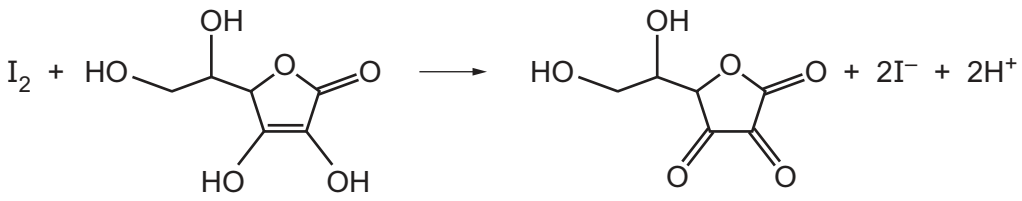
Fig. 4.1

(a) Deduce the empirical formula of vitamin C.

..... [1]

(b) The concentration of vitamin C is found by titration with I_2(aq).

vitamin C



Q

Fig. 4.2

A vitamin C tablet is dissolved in water to produce 200.0 cm^3 of vitamin C solution.
5.00 cm^3 of this vitamin C solution is added to a flask with approximately 150 cm^3 of water and an indicator.
Exactly 28.40 cm^3 of 5.00×10^{-4} mol dm^{-3} I_2(aq) reacts with the sample of vitamin C solution in the flask.

[M_r: vitamin C, 176]

(i) Calculate the amount, in mol, of I_2(aq) added to the flask in this titration.

amount of I_2(aq) = ... mol [1]

(ii) Use your answer to **(b)(i)** to calculate the mass, in g, of vitamin C in the tablet. Show your working.

(If you were unable to calculate a value for the amount of $I_2(aq)$ in **(b)(i)**, use the value 2.64×10^{-4} mol. This is **not** the correct value.)

mass of vitamin C in tablet = ... g [2]

(iii) Deduce the role of $I_2(aq)$ in the reaction in Fig. 4.2.

..... [1]

(iv) Suggest **two** reasons why hot concentrated acidified potassium manganate(VII) is **not** a suitable reagent for producing **Q** from vitamin C.

1 .....

.....

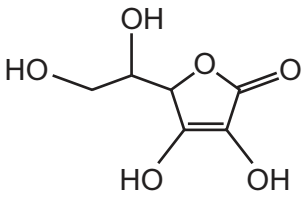
2 .....

.....

[2]

(c) Predict **two** absorptions that will be seen in the infrared spectra of both vitamin C and **Q**. Describe the relevant bond and the specific functional group that is responsible for each absorption identified.

vitamin C



Q

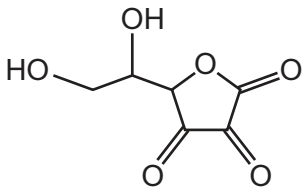


Fig. 4.3

.....

.....

..... [2]

[Total: 9]

Table 4.1

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

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5 Compound **A** contains the elements carbon, hydrogen and oxygen only.
When **A** is heated with $H_2SO_4(aq)$, compounds **B** and **C** are produced, as shown in Fig. 5.1.

$$\mathbf{A} + 2H_2O \xrightarrow[\text{heat}]{H_2SO_4(aq)} \underset{\mathbf{B}}{HOOCCH_2COOH} + \underset{\mathbf{C}}{2CH_3CH_2OH}$$

Fig. 5.1

(a) Draw the structure of **A**.

[2]

(b) Name the type of reaction that occurs when **A** is heated with $H_2SO_4(aq)$.

..... [1]

(c) When aqueous Na_2CO_3 is added to separate samples of **B** and **C**, effervescence is observed with **B** only.

(i) Complete the equation to describe the reaction between **B** and an excess of aqueous Na_2CO_3.

.....$HOOCCH_2COOH$ + ...$Na_2CO_3 \rightarrow$ .....
[1]

(ii) Suggest why **C** does **not** react with aqueous Na_2CO_3 in a similar type of reaction to **B**.

.....

..... [1]

(d) A student suggests a two-step synthesis to produce **B**, as shown in Fig. 5.2.

$$C\mathit{l}CH_2CH_2CH_2C\mathit{l} \xrightarrow{\text{step 1}} HOCH_2CH_2CH_2OH \xrightarrow{\text{step 2}} \underset{\mathbf{B}}{HOOCCH_2COOH}$$

Fig. 5.2

(i) Identify the reagents and conditions required in steps 1 and 2.

step 1 .....

step 2 .....
[2]

(ii) Identify the type of reaction that $HOCH_2CH_2CH_2OH$ undergoes in step 2.

..... [1]

(e) **B** reacts with an excess of reducing agent **R** to produce **D**.

An excess of PCl_5 is added to **D**.

- A vigorous reaction occurs.
- Misty fumes are seen.
- Organic compound **E** is produced.

(i) Identify the formula of the reducing agent **R**.

..... [1]

(ii) Complete the equation to describe the reaction of **B** with an excess of **R**.
Use [H] to represent one atom of hydrogen from **R**.

.....$HOOCCH_2COOH$ + ...[H] → ..... [2]

(iii) Name organic compound **E**.

..... [1]

[Total: 12]

6 Three bottles of colourless liquids labelled **F**, **G** and **H** contain separate pure samples of the compounds ethanal, propanal or propanone but **not** necessarily in that order.

(a) State the functional group in ethanal, propanal and propanone.

..... [1]

(b) State a reagent and the relevant observation that confirm that **F**, **G** and **H** have the same functional group.

reagent .....

observation .....

[2]

(c) Separate samples of **F**, **G** and **H** are each tested with Tollens' reagent and with alkaline I_2(aq). The observations are shown in Table 6.1.

Table 6.1

	Tollens' reagent	alkaline I_2(aq)
F	no observable change	pale yellow precipitate
G	silver mirror	pale yellow precipitate
H	silver mirror	no precipitate

(i) Use Table 6.1 to name the organic compounds in bottles **F**, **G** and **H**.

F = ...

G = ...

H = ...

[2]

(ii) Identify the yellow precipitate produced when alkaline I_2(aq) is added to separate samples of **F** and **G**.

..... [1]

(iii) Compound **J** does **not** contain the same functional group as **F**, **G** and **H**. Compound **J** also reacts with alkaline I_2(aq) to produce a pale yellow precipitate.

Suggest the structure of compound **J**.

[1]

[Total: 7]

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	$L = 6.02 \times 10^{23}\,\text{mol}^{-1}$
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	$c = 4.18\,\text{kJ kg}^{-1}\,\text{K}^{-1}$ ($4.18\,\text{J g}^{-1}\,\text{K}^{-1}$)

The Periodic Table of Elements

Group																	
1	2											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	3	4	5	6	7	8	9	10	11	12	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 –

Key

atomic number
atomic symbol
name
relative atomic mass

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 –