



CANDIDATE
NAME

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CENTRE
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NUMBER

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9701/22

February/March 2023

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.

2

- 1 The Pauling electronegativity values of elements can be used to predict the chemical properties of compounds.

Use the information in Table 1.1 to answer the following questions.

Table 1.1

element	H	Li	C	O	S
Pauling electronegativity value	2.1	1.0	2.5	3.5	2.6
first ionisation energy/ kJ mol^{-1}	1310	519	1090	1310	1000
second ionisation energy/ kJ mol^{-1}	—	7300	2350	3390	2260

- (a) (i) Define electronegativity.

.....
..... [1]

- (ii) O and S are in Group 16.

Explain the difference in the Pauling electronegativity values of O and S.

.....
.....
..... [2]

- (b) (i) LiH is an ionic compound.

Draw a dot-and-cross diagram of LiH.

Include **all** electrons.

[2]

- (ii) Suggest the shape of a molecule of H_2S .

..... [1]

3

(c) (i) Write an equation that represents the first ionisation energy of H.

..... [1]

(ii) Explain why there is no information given in Table 1.1 for the second ionisation energy of H.

..... [1]

(iii) Give the full electronic configuration of $S^{2+}(g)$.

..... [1]

(d) CO_2 and SO_2 are acidic gases.

(i) Write an equation for the reaction of SO_2 with H_2O .

..... [1]

(ii) Write an equation for the reaction of SO_2 with $NaOH$.

..... [1]

(iii) Construct an equation for the reaction of CO_2 with $Mg(OH)_2$.

..... [1]

4

- (e) (i) Complete Table 1.2 by placing a tick (✓) to show which of the compounds have molecules with an overall dipole moment.

Table 1.2

compound	O=C=O	O=S=O	S=C=S	S=C=O
overall dipole moment				

[2]

- (ii) At 150 °C and 103 kPa, all of the compounds listed in Table 1.2 are gases.

Under these conditions, 0.284 g of one of the compounds occupies a volume of 127 cm³.

Use this information to calculate the M_r of the compound. Hence, identify the compound from those given in Table 1.2.

Show your working.

M_r = identity of compound = [3]

[Total: 17]

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6

2 The Group 2 elements Mg to Ba are all silvery-white reactive metals.

- (a) (i) Draw a labelled diagram to show the bonding and structure of the Group 2 metals at room temperature.

[2]

- (ii) Explain why Mg has a higher electrical conductivity than Na.

.....
..... [1]

- (b) Write an equation for the reaction of magnesium with cold water.

..... [1]

- (c) Identify a single reagent that can be used to distinguish separate samples of dilute $\text{Mg}(\text{NO}_3)_2(\text{aq})$ and dilute $\text{Ba}(\text{NO}_3)_2(\text{aq})$.

Explain your answer.

reagent

explanation

..... [2]

7

- (d) (i) Describe what is observed when $\text{SrI}_2(\text{aq})$ reacts with concentrated sulfuric acid.

.....
..... [2]

- (ii) Compound **X**, an anhydrous Group 2 bromide, is dissolved in water and titrated against aqueous silver nitrate.

A solution containing 0.250 g of **X** requires 33.65 cm^3 of $0.0500 \text{ mol dm}^{-3} \text{ AgNO}_3(\text{aq})$ for complete reaction.

Identify **X**.

Show your working.

X = [3]

[Total: 11]

8

- 3 Alkenes undergo an addition reaction with a 1:1 mixture of CO and H₂ to form aldehydes.

Fig. 3.1 shows the reaction of propene with a 1:1 mixture of CO and H₂.

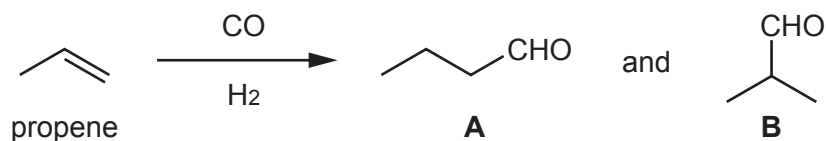


Fig. 3.1

- (a) (i) Define addition reaction.

..... [1]

- (ii) Aldehydes **A** and **B** are structural isomers.

State the type of structural isomerism shown by **A** and **B**.

..... [1]

- (iii) Name **A**.

..... [1]

- (iv) The complete reaction of propene with a 1:1 mixture of CO and H₂ produces **A** and **B** only. The product mixture contains 96% **A** and 4% **B**.

Calculate the mass of **A** produced in this reaction when 5.00×10^3 kg of propene is used.

mass of **A** = kg [1]

9

(b) **A** and **B** show reactions typical of aliphatic aldehydes.

- (i) **A** undergoes a nucleophilic addition reaction with a mixture of HCN and KCN, forming compound **C**.

Complete the diagram to show the mechanism for this reaction.

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

Draw the structure of the organic intermediate.



[4]

- (ii) Table 3.1 shows information about three experiments involving **B**.

Complete Table 3.1.

Table 3.1

experiment	reagents	observation with B
1		solution turns from orange to green
2		a silver mirror forms on the sides of the reaction vessel
3	$\text{Br}_2(\text{aq})$	

[3]

- (iii) **B**, $\text{C}_4\text{H}_8\text{O}$, is oxidised by acidified potassium manganate(VII).

Complete the equation for this reaction. Use [O] to represent one atom of oxygen from the oxidising agent.



10

- (iv) **C** is a chiral molecule.

Circle any chiral centres in the structure of **C** shown in Fig. 3.2.

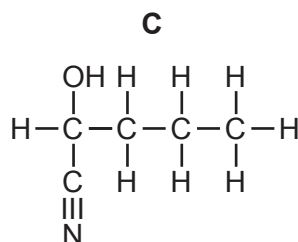


Fig. 3.2

[1]

- (c) When propene reacts with CO and an excess of H_2 , an alkane and a mixture of alcohols are formed instead. The alcohols are isomers of each other.

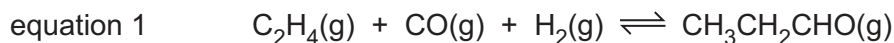
Suggest the molecular formulae of the alkane and the alcohols that are formed under these conditions.

molecular formula of alkane

molecular formula of alcohols

[2]

- (d) The reaction of ethene, C_2H_4 , with a 1:1 mixture of CO and H_2 is shown in equation 1.



At atmospheric pressure a cobalt-based catalyst is used in this reaction.

- (i) State and explain the effect of using a catalyst on this reaction.

.....

.....

.....

..... [2]

11

- (ii) Explain why the yield of $\text{CH}_3\text{CH}_2\text{CHO}(\text{g})$ increases when the overall pressure of the reaction mixture is increased.

.....
 [1]

- (iii) Use the information in Table 3.2 to calculate the enthalpy change, ΔH_r , of the reaction in equation 1.

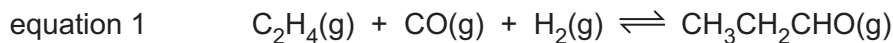


Table 3.2

compound	enthalpy change of formation, $\Delta H_f / \text{kJ mol}^{-1}$
$\text{C}_2\text{H}_4(\text{g})$	+52
$\text{CO}(\text{g})$	−111
$\text{CH}_3\text{CH}_2\text{CHO}(\text{g})$	−187

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

- (iv) The reaction mixture is cooled to collect $\text{CH}_3\text{CH}_2\text{CHO}$ as a liquid.

Identify all types of van der Waals' forces that are present between molecules of $\text{CH}_3\text{CH}_2\text{CHO}$.

.....
 [1]

[Total: 21]

12

4 Fig. 4.1 shows some reactions of compound **D**, 2-bromobutane.

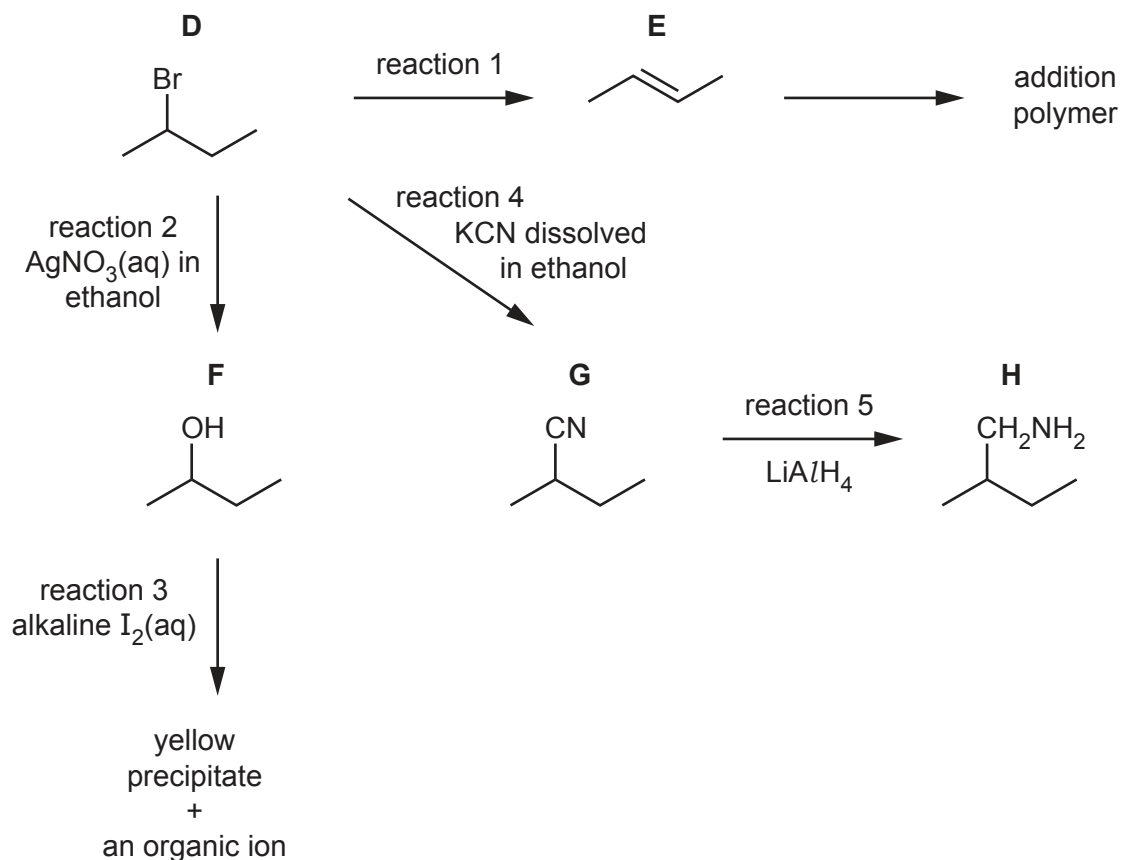


Fig. 4.1

(a) (i) State the reagent and conditions used to form **E** in reaction 1.

..... [1]

(ii) Draw the structure of **one** repeat unit of the addition polymer that forms from **E**.

[1]

(iii) **E** also forms when **F** is heated strongly in the presence of an Al_2O_3 catalyst.

Write an equation for this reaction.

..... [1]

(b) (i) Predict what is observed in reaction 2.

..... [1]

(ii) Identify the yellow precipitate and the organic ion formed in reaction 3.

yellow precipitate

organic ion [2]

(c) (i) State the type of reaction that occurs in reaction 4.

..... [1]

(ii) Reaction 5 is similar to the reaction of LiAlH_4 with carboxylic acids to form alcohols.

Suggest the role of LiAlH_4 in reaction 5.

..... [1]

(d) (i) Fig. 4.2 shows the infrared spectrum of one of the compounds **D**, **E**, **F**, **G** or **H**.

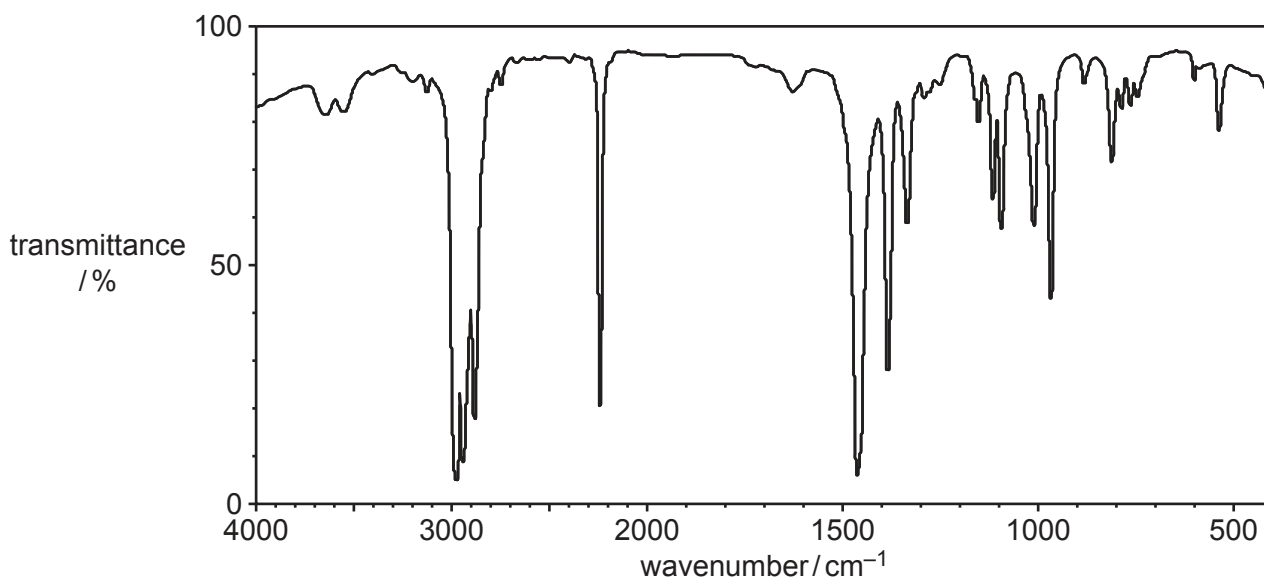


Fig. 4.2

Use information from Table 4.1 (on page 14) to identify which of the compounds **D**, **E**, **F**, **G** or **H** produces the infrared spectrum in Fig. 4.2.

Explain your answer.

.....
.....
..... [2]

14

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 3200–3600

- (ii) In the mass spectrum of **D**, the relative abundance of the molecular ion peak is 3.4.

Predict the relative abundance of the M+2 peak for **D**.

Explain your answer.

.....

 [1]

[Total: 11]

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)

Group																									
1	2	Key												13	14	15	16	17	18						
		atomic number atomic symbol name relative atomic mass																							
3 Li lithium 6.9	4 Be beryllium 9.0													1 H hydrogen 1.0											
11 Na sodium 23.0	12 Mg magnesium 24.3	3	4	5	6	7	8	9	10	11	12							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										
												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 oganeson —								

57	La	lanthanum	138.9
58	Ce	cerium	140.1
59	Pr	praseodymium	140.9
60	Nd	neodymium	144.4
61	Pm	promethium	—
62	Sm	samarium	150.4
63	Eu	europlum	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
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	—
104	Rf	rutherfordium	—
105	Db	bohrium	—
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	—

57	La	lanthanum	138.9
58	Ce	cerium	140.1
59	Pr	praseodymium	140.9
60	Nd	neodymium	144.4
61	Pm	promethium	—
62	Sm	samarium	150.4
63	Eu	europlum	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
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	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	—
104	Rf	rutherfordium	—
105	Db	bohrium	—
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	—