



CANDIDATE
NAME

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CENTRE
NUMBER

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NUMBER

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9701/21

May/June 2022

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 Calcium, magnesium and radium are Group 2 elements. Radium follows the same trends as the other members of Group 2.

- (a) Identify the highest energy orbital which contains electrons in a calcium atom. Sketch the shape of this orbital.

identity of highest energy orbital in Ca

shape

[1]

- (b) (i) Write the equation for the thermal decomposition of calcium nitrate.

..... [1]

- (ii) Suggest which of the Group 2 nitrates, calcium, magnesium or radium, requires the highest temperature to decompose. Explain your answer.

.....

.....

..... [1]

- (c) Predict what you would observe when aqueous radium chloride is added to aqueous sodium sulfate.

Do **not** refer to temperature changes in your answer.

.....

..... [1]

- (d) (i) $^{25}_{12}\text{Mg}$ is an isotope of magnesium.

Determine the number of protons and neutrons in an atom of $^{25}_{12}\text{Mg}$.

number of protons

number of neutrons

[1]

- (ii) State the full electronic configuration of an atom of $^{25}_{12}\text{Mg}$.

..... [1]

- (e) A sample of magnesium contains three isotopes, ^{25}Mg , ^{26}Mg and **X**.

The percentage abundance of the three isotopes is shown in Table 1.1.

Table 1.1

isotope of Mg	mass/a.m.u.	percentage abundance/%
X		78.99
^{25}Mg	24.99	10.00
^{26}Mg	25.98	11.01

- (i) The relative atomic mass, A_r , is calculated by comparing the average mass of the isotopes of an element to the unified atomic mass unit.

Define the unified atomic mass unit.

..... [1]

- (ii) Calculate the mass of **X**. Use data from Table 1.1 and A_r (magnesium) = 24.31 in your calculation. Show your working.

mass of **X** = ... [2]

- (iii) State **one** similarity and **one** difference in the properties of these isotopes of magnesium. Explain your answer.

.....

.....

..... [2]

- (f) Magnesium, Mg, burns in oxygen, O₂.
The activation energy, E_a , for this reaction is +148 kJ mol⁻¹.

- (i) State **one** observation when magnesium burns in oxygen.
Do **not** refer to temperature changes in your answer.

..... [1]

- (ii) On Fig. 1.1:

- sketch a reaction pathway diagram for the reaction that occurs when Mg burns in O₂
- label the diagram to show the enthalpy change, ΔH , and the activation energy, E_a , for the reaction.

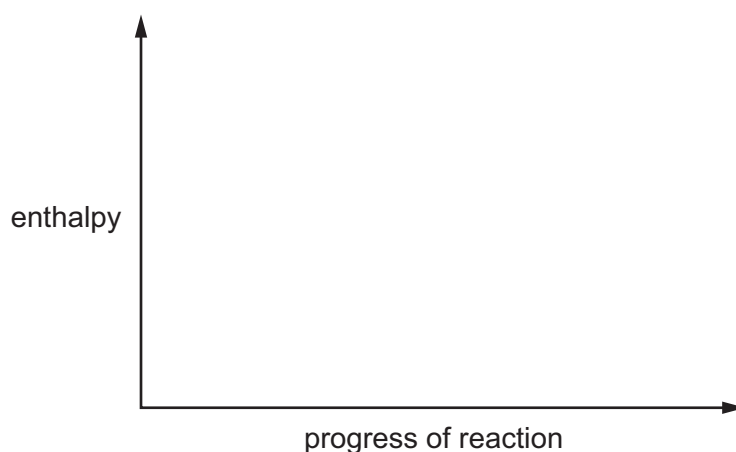
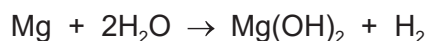


Fig. 1.1

[3]

- (g) Cold water reacts slowly with a piece of Mg to produce bubbles of H₂(g).
Cold water reacts rapidly with burning Mg to produce H₂(g) in an explosive mixture.



Explain why the rate of reaction of cold water with burning magnesium is greater.

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

[Total: 17]

2 Nitrogen molecules, $\text{N}_2(\text{g})$, contain two atoms attracted to each other by a triple covalent bond.

- (a) Describe how the triple covalent bond forms in a $\text{N}_2(\text{g})$ molecule. Refer to orbital overlap and hybridisation in your answer.

.....
.....
.....
..... [3]

- (b) Nitrogen oxides, NO_2 and NO , are produced in internal combustion engines. Release of these gases into the atmosphere leads to the formation of photochemical smog.

- (i) Outline how nitrogen oxides are involved in the formation of photochemical smog.

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

- (ii) Construct an equation to demonstrate how a catalytic converter reduces the amount of nitrogen oxide gases released into the atmosphere.

..... [1]

- (c) $\text{N}_2(\text{g})$ is very unreactive. It is difficult to make ammonia, $\text{NH}_3(\text{g})$, directly from its elements but it can be made from $\text{NH}_4\text{Cl}(\text{s})$.

Identify a reagent and the conditions required to make $\text{NH}_3(\text{g})$ from $\text{NH}_4\text{Cl}(\text{s})$.

..... [1]

(d) 25 cm^3 of 0.10 mol dm^{-3} HCl(aq) is added to a beaker and its pH is recorded.

50 cm^3 of 0.10 mol dm^{-3} $\text{NH}_3\text{(aq)}$ is added to the HCl(aq) in 5 cm^3 portions.

The pH of the mixture is monitored until all the $\text{NH}_3\text{(aq)}$ is added.

HCl is a strong Brønsted-Lowry acid.

(i) Describe what is meant by a strong Brønsted-Lowry acid.

.....
 [2]

(ii) NH_3 is a weak base.

Construct an equation that shows the behaviour of NH_3 as a weak Brønsted-Lowry base when dissolved in water.

..... [1]

(iii) On Fig. 2.1 sketch a graph to show the change in pH which occurs when HCl(aq) is titrated with $\text{NH}_3\text{(aq)}$ as described in (d).

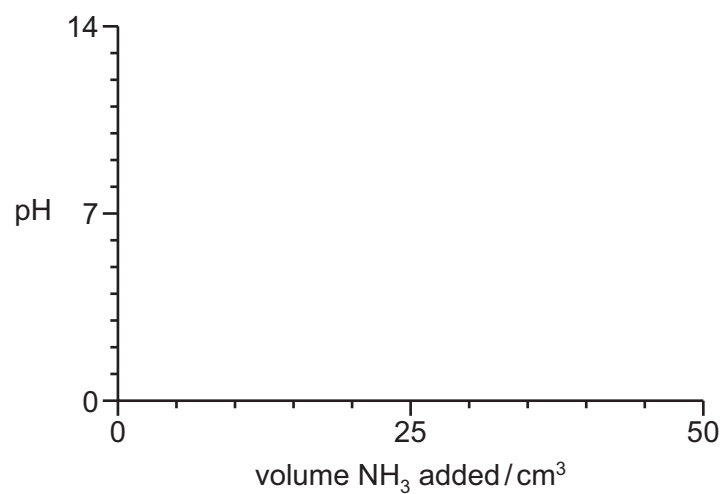


Fig. 2.1

[2]

[Total: 12]

- 3 Liquids that contain molecules of **T** smell like lemons.

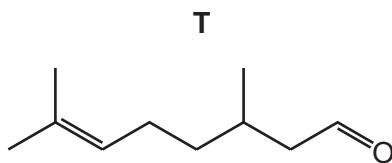


Fig. 3.1

- (a) Molecules of **T** exist as a pair of stereoisomers.

Name the type of stereoisomerism shown by molecules of **T**. Explain your answer.

.....
 [2]

- (b) Two organic products are produced when a sample of **T** is heated under reflux with excess acidified concentrated KMnO_4 .

Draw the structure of the two organic products, from this reaction, in the boxes.



[2]

(c) Fig. 3.2 shows two reactions of **T**.

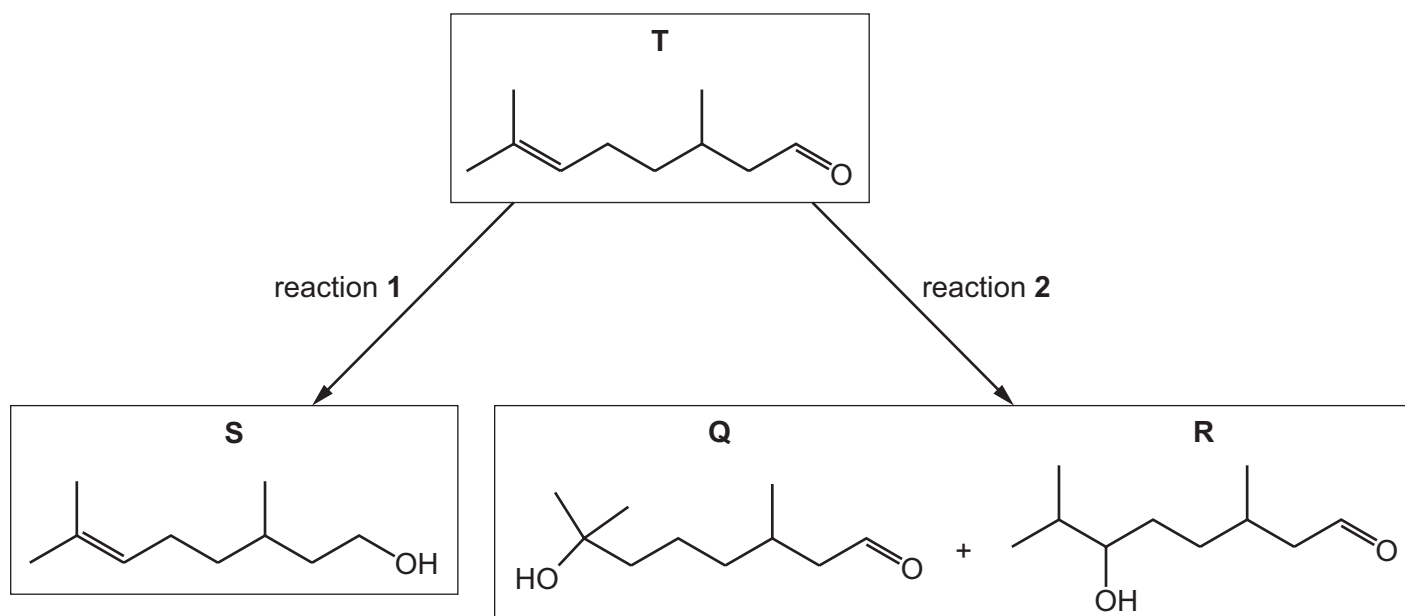


Fig. 3.2

(i) Identify a suitable reagent for reaction 1.

..... [1]

(ii) Identify the reagent and conditions needed for reaction 2.

..... [2]

(iii) Suggest which product formed in reaction 2 has a higher yield. Explain your answer.

..... [3]

- (d) Separate samples of **Q** and **R** are added to separate test-tubes containing acidified $\text{K}_2\text{Cr}_2\text{O}_7(\text{aq})$ and heated.

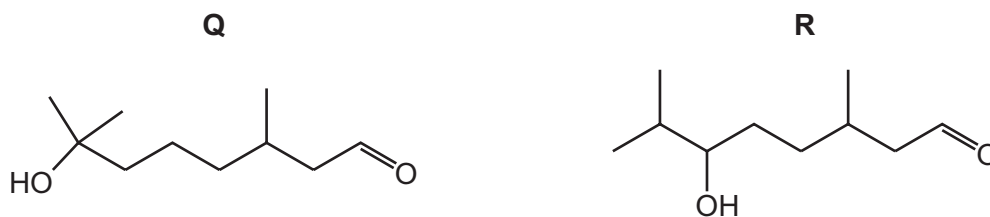


Fig. 3.3

- (i) Predict the observations for each test-tube. Explain your answer in terms of the functional groups present in **Q** and **R**.

.....

 [3]

- (ii) When $\text{PCl}_5(\text{s})$ is added to separate samples of **Q** and **R** at room temperature, both react vigorously.

Complete the equation shown in Fig. 3.4 to describe the reaction that occurs when **R** reacts with $\text{PCl}_5(\text{s})$.

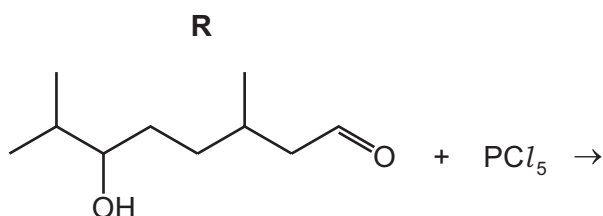


Fig. 3.4

[2]

- (iii) Suggest why samples of **Q** and **R** must be dried before PCl_5 is added. Include a relevant equation to support your answer.

.....

 [2]

[Total: 17]

4 Compound **V** is a liquid.

V contains 77.2% carbon, 11.4% hydrogen and 11.4% oxygen by mass.

V has a relative molecular mass of 280.

(a) Calculate the molecular formula of **V**. Show your working.

molecular formula of **V** = ... [3]

(b) **V** contains two types of functional group: a carboxylic acid and an alkene.

(i) Describe a chemical test and observation which confirms the presence of a carboxyl functional group.

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

(ii) A 3.196 g sample of Br_2 reacts completely with 2.800 g of **V**.

Calculate how many alkene functional groups are present in one molecule of **V**. Show your working.

number of alkene functional groups in **V** = ... [1]

(c) **W**, **X** and **Y** have the same molecular formula, $C_5H_{10}O$.

W, **X** and **Y** are added separately to different reagents. Observations for these reactions are described in Table 4.1.

Table 4.1

	+ 2,4-dinitrophenylhydrazine	+ alkaline $I_2(aq)$	+ Fehling's reagent and warm
W	orange precipitate seen	no change	orange-red precipitate seen
X	orange precipitate seen	yellow precipitate seen	no change
Y	orange precipitate seen		

(i) **W**, **X** and **Y** each contain a common functional group.

Name the functional group that is present in all three compounds.

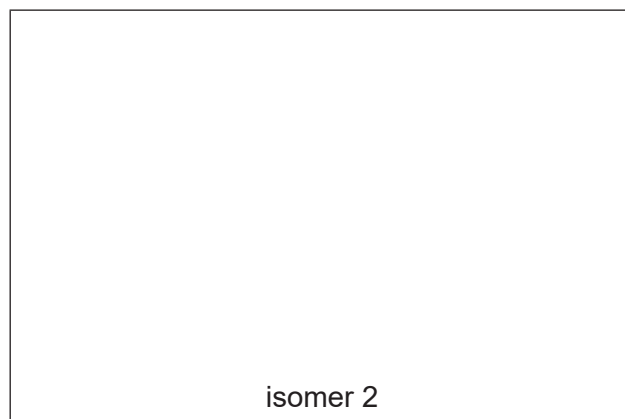
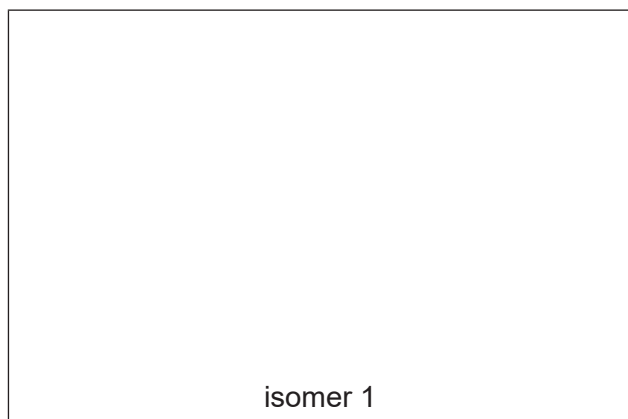
..... [1]

(ii) State the formula of the yellow precipitate produced when **X** is added to alkaline $I_2(aq)$.

..... [1]

(iii) **W** could be one of four structural isomers.

- Draw the skeletal formulae for two possible structural isomers of **W**.
- Describe the type of structural isomerism shown.



type of structural isomerism

..... [3]

(d) Fig. 5.1 shows the mass spectrum of ketone **Z**, $\text{C}_5\text{H}_{10}\text{O}$.

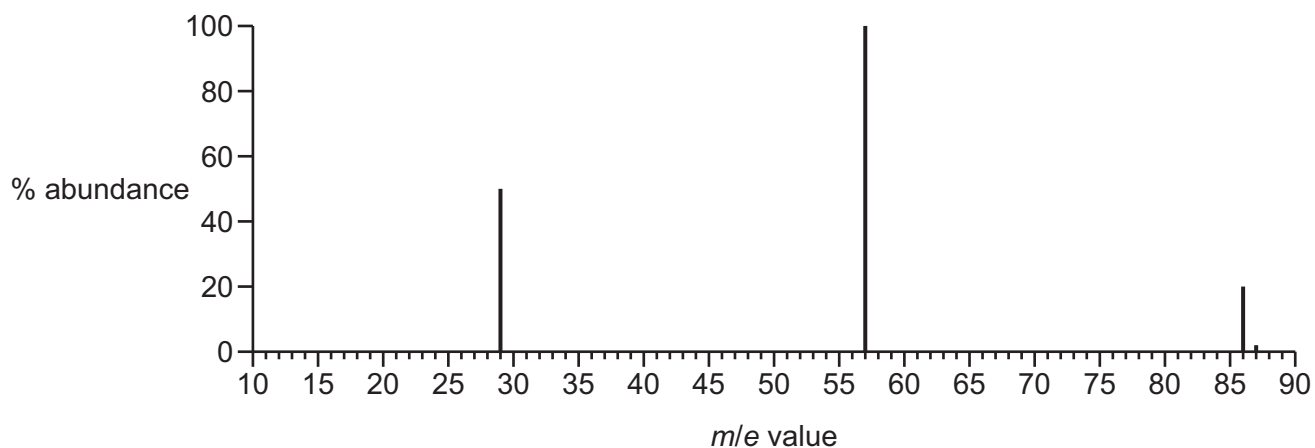


Fig. 5.1

Use the information in Fig. 5.1 to suggest the formulae of the fragments with m/e peaks at 29 and 57. Deduce the identity of **Z**.

$m/e = 29$

$m/e = 57$

identity of **Z**

[3]

[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	Key										13	14	15	16	17	18	
		atomic number atomic symbol name relative atomic mass																
3	4											5	6	7	8	9		
Li lithium 6.9	Be beryllium 9.0											B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0	F fluorine 19.0		
11	12											13	14	15	16	17		
Na sodium 23.0	Mg magnesium 24.3											Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5		
		3	4	5	6	7	8	9	10	11	12							
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											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 —											Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganeson —	

lanthanoids

actinoids

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	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
72	Hf	hafnium	178.5
73	Ta	tantalum	180.9
74	W	wolframium	183.8
75	Re	rhodium	186.2
76	Os	osmium	190.2
77	Ir	iridium	192.2
78	Pt	platinum	195.1
79	Au	aurum	197.0
80	Hg	hydrargyrum	200.6
81	Tl	thallium	204.4
82	Pb	plumbum	207.2
83	Bi	bismuthum	209.0
84	Po	polonium	—
85	At	astatinum	—
86	Rn	radon	—
87	Fr	francium	—
88	Ra	radium	226.0
89	Ac	actinium	227.0
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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- 1 (a) Magnesium has a melting point of 650 °C and high electrical conductivity.

Explain these properties of magnesium by referring to its structure and bonding.

.....
 [2]

- (b) When magnesium is heated in air, magnesium oxide, MgO, is the major product. Smaller amounts of magnesium nitride, Mg₃N₂, are also made.

- (i) Calculate the oxidation number for magnesium and for the nitrogen species in Mg₃N₂ to complete Table 1.1.

Table 1.1

species	magnesium in Mg ₃ N ₂	nitrogen in Mg ₃ N ₂
oxidation number		

[1]

- (ii) Identify the type of reaction which takes place between magnesium and nitrogen. Explain your answer.

.....
 [1]

- (iii) Define enthalpy change of formation.

.....
 [2]

- (iv) When 3.645 g of Mg(s) burns in excess N₂(g) to form Mg₃N₂(s), 23.05 kJ of energy is released.

Calculate the enthalpy change of formation, ΔH_f , of Mg₃N₂. Show your working.

$$\Delta H_f (\text{Mg}_3\text{N}_2) = \dots\dots\dots [3]$$

[Total: 9]

Question 2 starts on the next page.

- 2** Radium, Ra, is an element found in Group 2 of the Periodic Table. It is a crystalline solid at room temperature and conducts electricity.

Radium chloride, RaCl_2 , has a melting point of 900°C and is soluble in water.

- (a)** Predict the lattice structure of $\text{RaCl}_2(\text{s})$ based on the properties described.

..... [1]

- (b)** Draw a dot-and-cross diagram to show the arrangement of outer electrons in RaCl_2 .

[1]

- (c)** Solid Ra and Ca show similar reactions with H_2O , but the reactions occur at different rates.

Separate samples, each containing a single piece of solid Ra or Ca, are added to equal volumes of cold water.

Each sample contains equal numbers of moles of solid and the H_2O is in excess.

- (i)** Construct an equation for the reaction of Ra with H_2O .

..... [1]

- (ii)** Identify which element, Ra or Ca, reacts with H_2O at a faster rate. Suggest how the observations of each reaction would differ.

.....

..... [1]

- (iii)** Suggest why these reactions occur at different rates.

.....

.....

..... [2]

- (iv) One of the solutions is cloudy when the reaction has finished.

At the end of each reaction, universal indicator is added to each reaction mixture.

Suggest pH values of the solutions made in both reactions. Explain your answer.

.....

 [2]

- (d) A sample of aqueous calcium halide, $\text{CaX}_2(\text{aq})$, contains either chloride, bromide or iodide ions.

Complete Table 2.1 to describe a two-step process that could be used to identify the halide ion present.

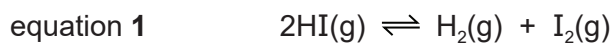
Table 2.1

step	method	observation with CaCl_2	observation with CaBr_2	observation with CaI_2
step 1				
step 2				

[3]

[Total: 11]

- 3 (a) 0.025 mol of HI(g) is added to a closed vessel and left to reach dynamic equilibrium. The total pressure of the vessel is 100 kPa.



- (i) Explain what is meant by dynamic equilibrium.

.....

 [2]

- (ii) Describe **one** difference in the initial appearance of the reaction mixture compared to the mixture at equilibrium.

..... [1]

- (iii) Write an expression for K_p for the reaction described in equation 1.

$K_p =$

[1]

- (iv) At equilibrium the partial pressure of HI(g) is 86.4 kPa.

Calculate the amount of HI(g) present in the mixture at equilibrium. Show your working.

amount of HI(g) = ... mol [2]

- (b) Use equation 1 and the bond energy values in Table 3.1 to calculate the change in enthalpy, ΔH , for the thermal decomposition of 1 mole of HI(g). Show your working.

Table 3.1

bond	bond energy / kJ mol ⁻¹
H–H	436
I–I	151
H–I	299

$\Delta H = \dots\dots\dots$ kJ mol⁻¹ [2]

- (c) Describe the effect of increasing pressure on the value of K_p for the decomposition of HI(g).

$\dots\dots\dots$ [1]

- (d) HCl(g) is prepared by adding NaCl(s) to concentrated H₂SO₄.

HI(g) is **not** prepared by adding NaI(s) to concentrated H₂SO₄ because the HI(g) produced also reacts with concentrated H₂SO₄.

- (i) Identify the type of reaction that occurs when NaI(s) reacts with concentrated H₂SO₄ to form HI(g).

$\dots\dots\dots$ [1]

- (ii) Write an equation for the reaction of HI(g) and concentrated H₂SO₄.

$\dots\dots\dots$ [1]

- (iii) Explain why HI(g) reacts with concentrated H₂SO₄ whereas HCl does not.

$\dots\dots\dots$ [1]

[Total: 12]

- 4 (a) Bromine reacts with butane in the presence of ultraviolet light to form bromobutane.

Two structural isomers with the molecular formula C_4H_9Br are produced during this reaction.

- (i) Draw the two structural isomers and state the systematic name of each isomer.

structural isomer 1

name

structural isomer 2

name

[2]

- (ii) Identify the type of structural isomerism shown in (a)(i).

..... [1]

- (b) Halothane is an anaesthetic.

halothane

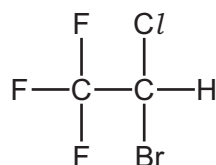


Fig. 4.1

- (i) Identify the chiral centre in halothane and mark it with an asterisk (*). [1]

When halothane reacts in ultraviolet light, homolytic fission occurs and the C–Br bond is broken.

- (ii) Construct an equation to show the homolytic fission of halothane, $CF_3CHBrCl$.

..... [1]

- (iii) Complete Fig. 4.2 to show the arrangement of electrons in a bromine atom using the electrons in boxes notation.

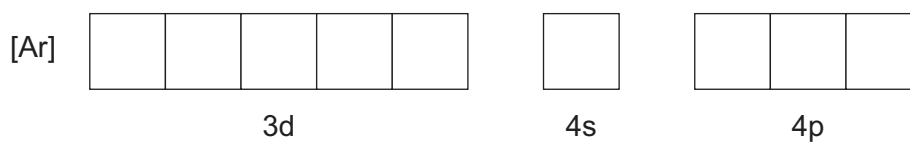


Fig. 4.2

[1]

- (c) **X** is an addition polymer.

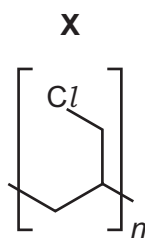


Fig. 4.3

- (i) Draw the monomer of **X**.

[1]

- (ii) Suggest **one** reason why the disposal of items made from **X** is difficult.

..... [1]

[Total: 8]

5 Fig. 5.1 shows three reactions of 2-bromopropane, $\text{CH}_3\text{CH}(\text{Br})\text{CH}_3$.

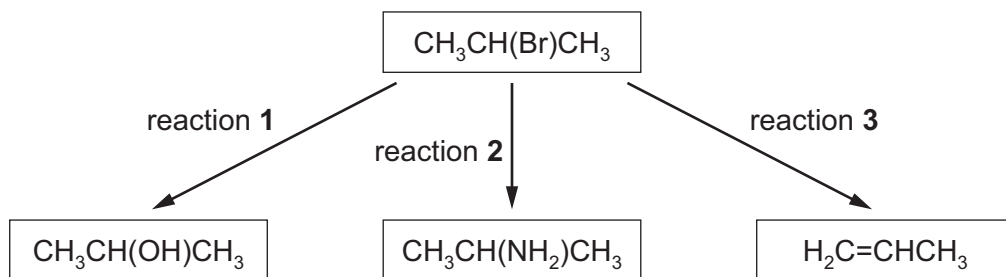


Fig. 5.1

(a) Complete Table 5.1 for each reaction, by:

- stating the reagent and conditions used
- identifying the type of reaction that occurs.

Table 5.1

reaction	reagent and conditions	type of reaction
1		
2		
3		

[6]

(b) A sample of 2-iodopropane, $\text{CH}_3\text{CH}(\text{I})\text{CH}_3$, reacts under the same conditions as reaction 1 to produce $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$.

Explain why 2-iodopropane reacts at a faster rate than 2-bromopropane.

.....

.....

..... [2]

(c) Fig. 5.2 shows how butan-1-ol can be made from 1-bromopropane in three steps.

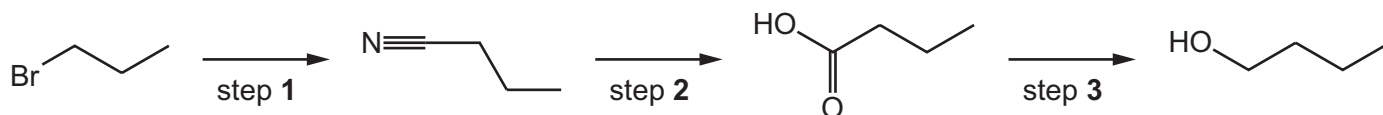


Fig. 5.2

(i) In step 1, 1-bromopropane reacts with CN^- to form butanenitrile.

Complete Fig. 5.3 to show the mechanism for step 1. Include charges, dipoles, lone pairs of electrons and curly arrows as appropriate.

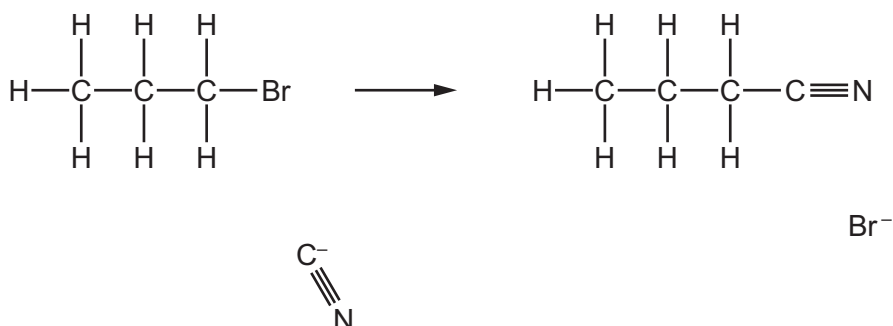


Fig. 5.3

[2]

(ii) In step 2, butanenitrile is heated with HCl(aq) . A hydrolysis reaction occurs.

Construct an equation for the reaction in step 2.

..... [1]

(iii) Step 3 is a reduction reaction.

Construct an equation for the reduction reaction in step 3. Use $[\text{H}]$ to represent one atom of hydrogen from the reducing agent.

..... [1]

(iv) State the identity of a suitable reducing agent in step 3.

..... [1]

[Total: 13]

- 6** **Z** is a molecule which contains the elements carbon, hydrogen and oxygen only.

Z contains only alkene and carboxyl functional groups.

- (a)** Complete Table 6.1 by describing the observations that occur when two different reagents are added to separate samples of **Z**(aq).

Table 6.1

reagent added to Z (aq)	observation
$\text{Br}_2(\text{aq})$	
$\text{Na}_2\text{CO}_3(\text{s})$	

[2]

- (b)** Table 6.2 shows the percentage by mass of each element present in **Z**.

Table 6.2

element	percentage by mass / %
carbon	41.38
hydrogen	3.45
oxygen	55.17

Using the data in Table 6.2, demonstrate that the empirical formula of **Z** is CHO.
Show your working.

[1]

(c) Fig. 6.1 shows the mass spectrum of **Z**.

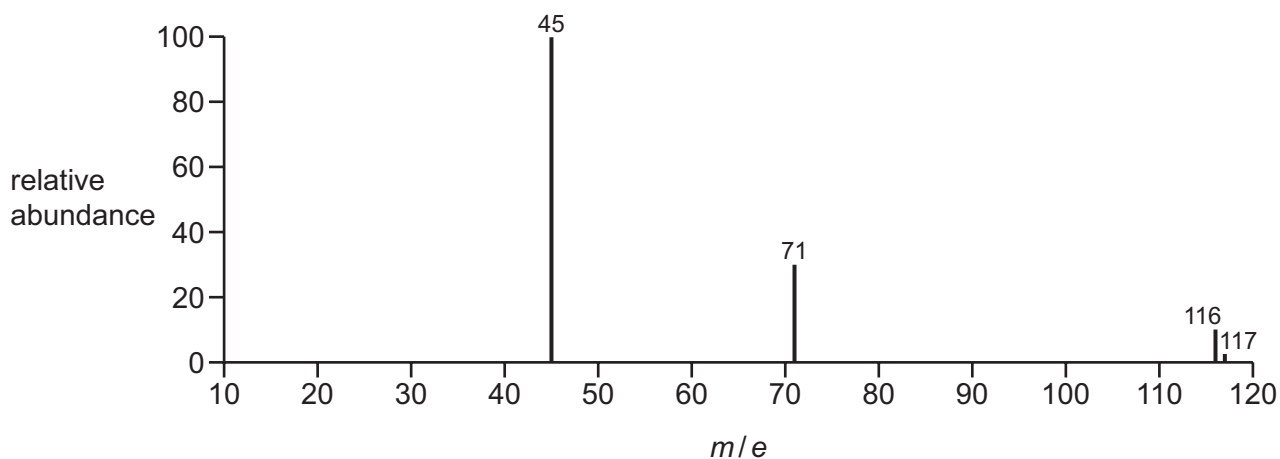


Fig. 6.1

- (i) Deduce the molecular formula of **Z**. Explain your answer by referring to the molecular ion peak in Fig. 6.1 and the empirical formula of **Z**.

[1]

- (ii) Use Fig. 6.1 to suggest the formulae of the fragments with m/e peaks at 45 and at 71.

m/e 45

m/e 71

[2]

- (iii) Suggest the structure of **Z** using relevant information from Table 6.1, (b) and (c).

[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	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
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		13	14	15	16	17	18	
		Key																	2	
3	4	atomic number atomic symbol name relative atomic mass										H hydrogen 1.0							He helium 4.0	
Li lithium 6.9	Be beryllium 9.0																		Ne neon 20.2	
11	12																		18	
Na sodium 23.0	Mg magnesium 24.3																		Ar argon 39.9	
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																		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 —																		Og oganeson —	
																			Ts tennessine —	

lanthanoids

actinoids

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La lanthanum 138.9	Ce cerium 140.1	Pr praseodymium 140.9	Nd neodymium 144.4	Pm promethium —	Sm samarium 150.4	Eu europium 152.0	Gd gadolinium 157.3	Tb terbium 158.9	Dy dysprosium 162.5	Ho holmium 164.9	Er erbium 167.3	Tm thulium 168.9	Yb ytterbium 173.1	Lu lutetium 175.0
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac actinium —	Th thorium 232.0	Pa protactinium 231.0	U uranium 238.0	Np neptunium —	Pu plutonium —	Am americium —	Cm curium —	Bk berkelium —	Cf californium —	Es einsteinium —	Fm fermium —	Md mendelevium —	No nobelium —	Lr lawrencium —

CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/23

May/June 2022

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) Define first ionisation energy.

.....

.....

..... [2]

- (b) Successive ionisation energies for element **A** are shown in Table 1.1.

Table 1.1

ionisation	1st	2nd	3rd	4th	5th	6th	7th	8th
ionisation energy/kJ mol ⁻¹	1310	3390	5320	7450	11 000	13 300	71 000	84 100

Use Table 1.1 to deduce the group of the Periodic Table that **A** belongs to. Explain your answer.

Group

..... [1]

- (c) Across Period 3 there is a general trend for first ionisation energies to increase due to the increase in attraction between the nucleus and the outer electron.

Explain why the first ionisation energy of sulfur is less than the first ionisation energy of phosphorus.

.....

.....

..... [2]

- (d) In an Al^{2+} ion the nuclear attraction for the outer electron is stronger than in an atom of Na.

Compare the electronic structures of Al^{2+} and an atom of Na and explain why the third ionisation energy of aluminium is greater than the first ionisation energy of sodium.

.....

.....

.....

..... [2]

- (e) An isotope of copper has a relative isotopic mass of 65.

Complete Table 1.2 for an atom of copper-65.

Table 1.2

	atomic number	nucleon number	number of neutrons	electronic arrangement
copper-65				

[3]

- (f) (i) The element copper has a relative atomic mass of 63.5.

Calculate how many atoms are present in 1.05 g of copper.

atoms of copper present = ... [1]

- (ii) Copper has a melting point of 1085 °C and a high electrical conductivity.

Explain these properties of copper by referring to its structure and bonding.

.....

 [2]

[Total: 13]

2 (a) Period 3 elements and their compounds show trends in their physical properties.

(i) On Fig. 2.1 sketch a graph to show the melting points of the first five elements in Period 3.

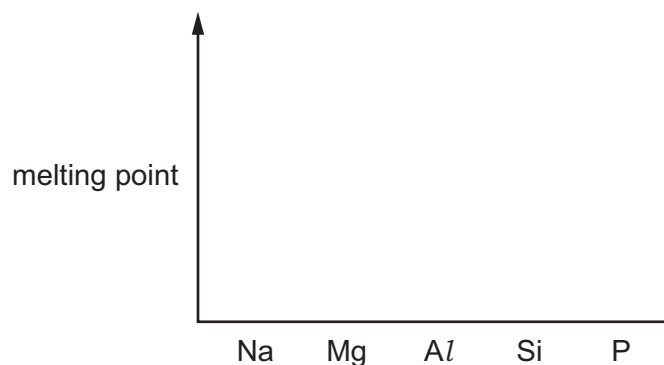


Fig. 2.1

[3]

(ii) Complete Table 2.1 with information for sodium chloride and phosphorus(V) chloride.

Table 2.1

	sodium chloride	phosphorus(V) chloride
state at room temperature		
name of change which occurs on addition of water		
pH of final solution		

[3]

(b) Tennessine, Ts, is an unstable man-made element. It is found below astatine, At, in Group 17. The chemical properties of Ts and its compounds have only been predicted.

(i) Suggest an equation for the reaction of NaTs and Br₂. Assume that Ts follows the same trends as the other elements in Group 17. Explain your answer.

equation

explanation

.....

[2]

- (ii) Some scientists predict that Ts has properties typical of metals like copper.

Complete Table 2.2 with:

- the predicted melting point of tennessine
- the lattice structure of solid chlorine, bromine and tennessine.

Assume that Ts has properties typical of metals like copper.

Table 2.2

element	chlorine	bromine	tennessine
melting point/°C	−101	−7.2	
lattice structure of crystalline solid			

[2]

[Total: 10]

- 3 **G** belongs to a group of compounds called ethers.

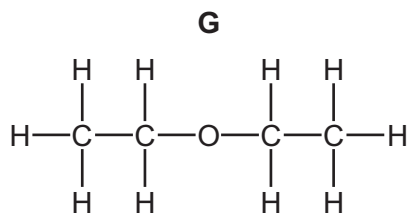
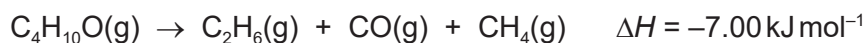


Fig. 3.1

- (a) When **G**, $C_4H_{10}O$, is heated, thermal decomposition occurs.



- (i) The atoms in a molecule of CO are held together by a triple covalent bond. One of these bonds is a coordinate (dative covalent) bond.

Draw a dot-and-cross diagram to show the arrangement of outer electrons in a CO molecule.

Use • to represent electrons from an oxygen atom.
Use × to represent electrons from a carbon atom.

[1]

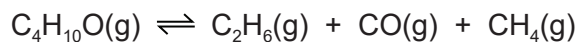
- (ii) Calculate the bond energy of $C \equiv O$ using the bond energy values in Table 3.1 and the enthalpy change, ΔH , for the thermal decomposition of **G**. Show your working.

Table 3.1

bond	bond energy / kJ mol^{-1}
C—C	350
C—O (in G)	360
C—H	410

bond energy ($C \equiv O$) = ... kJ mol^{-1}
[2]

- (iii) When **G**, $\text{C}_4\text{H}_{10}\text{O}$, is heated in a sealed container, an equilibrium mixture is produced.



Complete the expression for the equilibrium constant, K_c , for this reaction.
State the units of K_c .

$K_c =$

units = ...

[2]

- (iv) Thermal decomposition of **G** in the presence of I_2 affects the activation energy, E_a , for the reaction. Table 3.2 shows E_a for the thermal decomposition of **G** with and without I_2 .

Table 3.2

reaction	E_a (with I_2)/ kJ mol^{-1}	E_a / kJ mol^{-1}
$\text{C}_4\text{H}_{10}\text{O}(\text{g}) \rightarrow \text{C}_2\text{H}_6(\text{g}) + \text{CO}(\text{g}) + \text{CH}_4(\text{g})$	143	224

State what effect adding I_2 to the reaction mixture has on the value of K_c .
Explain your answer.

.....

 [2]

- (v) Fig. 3.2 shows the Boltzmann distribution of energies for molecules of **G** at constant temperature, $T^\circ\text{C}$.

Sketch, on Fig. 3.2, the Boltzmann distribution of energies for molecules of **G** at a higher temperature, $(T+100)^\circ\text{C}$.

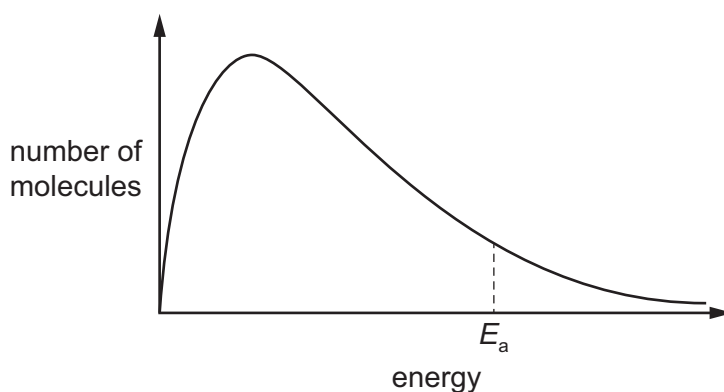


Fig. 3.2

[2]

- (b) The functional group in **G** is an oxygen atom bonded to two carbon atoms.

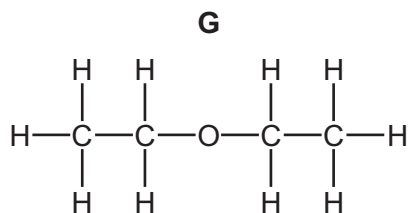


Fig. 3.3

G, **H** and **J** are structural isomers with molecular formula $C_4H_{10}O$.

H and **J** are straight chain molecules.

Table 3.3 shows the boiling points and reactions of **G**, **H** and **J** when heated under reflux with excess acidified $K_2Cr_2O_7$.

Table 3.3

	G	H	J
boiling point/ $^{\circ}C$	35	117	98
heat under reflux with excess acidified $K_2Cr_2O_7$	remains orange	orange to green	orange to green

- (i) Identify the type of structural isomerism shown between **G** and **H** using the information in Table 3.3.

..... [1]

- (ii) Identify the type of structural isomerism shown between **H** and **J** using the information in Table 3.3.

..... [1]

- (iii) Draw a possible structure for **H** and for **J**. State the systematic name for each structure.

H

name

J

name

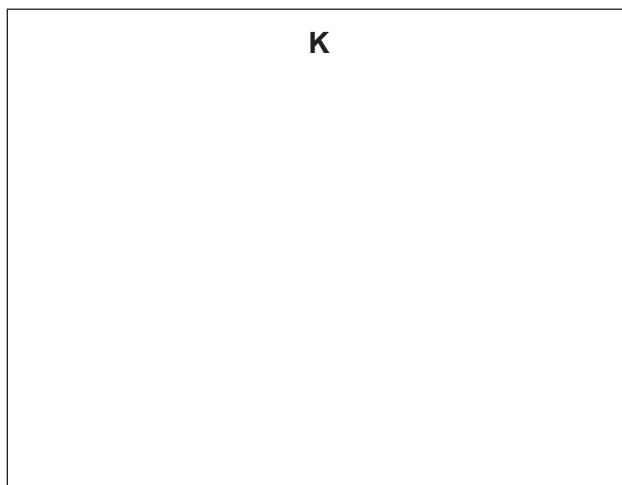
[3]

(c) **K** has molecular formula $\text{C}_3\text{H}_6\text{O}$.

When **K** is added to 2,4-dinitrophenylhydrazine, an orange precipitate forms.

When **K** is warmed with Tollens' reagent, a silver mirror forms.

Draw the displayed formula of **K**.



[2]

[Total: 16]

- 4 (a) 2-methylpropene reacts with HCl(g) at room temperature. The major organic product is 2-chloro-2-methylpropane.

- (i) Complete Fig. 4.1 to show the structure of the intermediate and mechanism for this reaction. Include charges, dipoles, lone pairs of electrons and curly arrows as appropriate.



Fig. 4.1

[3]

- (ii) Explain why, in this reaction, 2-chloro-2-methylpropane is produced at a higher yield than 1-chloro-2-methylpropane.

.....

.....

..... [2]

- (b) Two bottles labelled **Q** and **M** each contain a straight-chain halogenoalkane with molecular formula $\text{C}_4\text{H}_9\text{X}$, where **X** represents Cl, Br or I. A sample from each bottle is added to separate samples of equal amounts of aqueous silver nitrate in ethanol. In each reaction, the same organic product, **T**, and a precipitate are made, as shown in Fig. 4.2.



Fig. 4.2

Table 4.1 describes the colour of each of the precipitates made.

Table 4.1

halogenoalkane added to $\text{AgNO}_3(\text{aq})$ in ethanol	colour of precipitate
Q	white
M	yellow

- (i) Identify the functional group present in **T** and name the type of reaction that occurs using the information in Fig. 4.2 and Table 4.1.

functional group in **T**

type of reaction

[2]

- (ii) Construct an ionic equation to describe the formation of the yellow precipitate produced when **M** reacts with $\text{AgNO}_3(\text{aq})$ in ethanol.

..... [1]

- (iii) Describe which reagent, **Q** or **M**, will produce a precipitate more quickly when each is added to $\text{AgNO}_3(\text{aq})$ in ethanol. Explain your answer.

reagent

.....

.....

[1]

- (iv) When pure **T** is added to alkaline $\text{I}_2(\text{aq})$, a yellow precipitate and an anion, **L**, are made.

Identify the anion **L**.

..... [1]

- (v) Deduce the structure of the straight-chain halogenoalkane **M**.

[2]

[Total: 12]

- 5 (a) But-2-ene reacts with KMnO_4 to form organic product, **Y**.
Y does not react with Na_2CO_3 .
 A gas is produced when an excess of Na is added to **Y**.

(i) Describe the conditions for the KMnO_4 used in the reaction to form **Y** from but-2-ene.

..... [1]

- (ii) 24.0cm^3 of gas is produced when an excess of Na is added to 0.001mol of **Y**, when measured under room conditions.
 Assume that 1mol of gas occupies 24.0dm^3 under room conditions.

Deduce a possible structure of **Y**. Explain your answer.

.....

 [3]

- (b) **Z** contains three types of atom: carbon, hydrogen and a halogen. The mass spectrum of **Z** is recorded. Fig. 5.1 shows a section of the mass spectrum at m/e greater than 63.
 The fragment at $m/e = 64$ is the molecular ion peak.

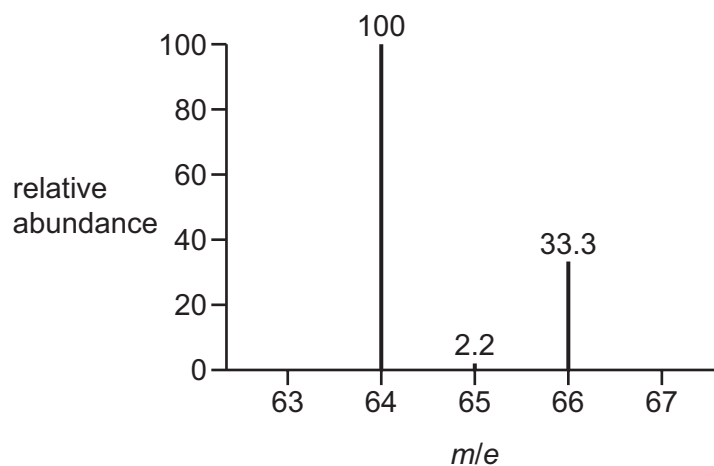


Fig. 5.1

- (i) Deduce the number of carbon atoms present in a molecule of **Z** using Fig. 5.1.
 Show your working.

..... [1]

- (ii) Deduce which halogen is present in **Z** using Fig. 5.1. Explain your answer.

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

- (iii) There are also peaks at $m/e = 29$ and $m/e = 49$.

Suggest the formulae of these fragments.
Deduce the name of **Z**.

$m/e = 29$

$m/e = 49$

name of **Z** [3]

[Total: 9]

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
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The Periodic Table of Elements

Group																																																																							
1	2																17	18																																																					
3 Li lithium 6.9	4 Be beryllium 9.0	Key																	2 He helium 4.0																																																				
		atomic number atomic symbol name relative atomic mass															1 H hydrogen 1.0																																																						
		3 Sc scandium 45.0	4 Ti titanium 47.9	5 V vanadium 50.9	6 Cr chromium 52.0	7 Mn manganese 54.9	8 Fe iron 55.8	9 Co cobalt 58.9	10 Ni nickel 58.7	11 Cu copper 63.5	12 Zn zinc 65.4	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																																																							
11 Na sodium 23.0	12 Mg magnesium 24.3	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	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La lanthanum 138.9	Ce cerium 140.1	Pr praseodymium 140.9	Nd neodymium 144.4	Pm promethium —	Sm samarium 150.4	Eu europium 152.0	Gd gadolinium 157.3	Tb terbium 158.9	Dy dysprosium 162.5	Ho holmium 164.9	Er erbium 167.3	Tm thulium 168.9	Yb ytterbium 173.1	Lu lutetium 175.0
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac actinium —	Th thorium 232.0	Pa protactinium 231.0	U uranium 238.0	Np neptunium —	Pu plutonium —	Am americium —	Cm curium —	Bk berkelium —	Cf californium —	Es einsteinium —	Fm fermium —	Md mendelevium —	No nobelium —	Lr lawrencium —