



Cambridge International AS & A Level

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CHEMISTRY**9701/21**

Paper 2 AS Level Structured Questions

October/November 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.

1 Chromium, Cr, and its compounds are widely used in many chemical reactions.

(a) Cr exists as four stable isotopes.

(i) The most common isotope of Cr is chromium-52.

Determine the number of protons, neutrons and electrons in an atom of chromium-52.

number of protons neutrons electrons [1]

(ii) Describe how an atom of chromium-54 differs from an atom of chromium-52. Refer to numbers of particles in your answer.

..... [1]

(iii) The relative isotopic masses of the isotopes of Cr can be determined using mass spectrometry.

State what other information is needed to calculate the relative atomic mass, A_r , of Cr.

..... [1]

(iv) Atoms of ^{52}Cr , ^{53}Cr and ^{54}Cr make up more than 95% of naturally occurring chromium atoms. The A_r of naturally occurring Cr is 51.996.

Suggest what these statements imply about the relative isotopic mass of the fourth stable isotope of chromium.

..... [1]

(b) The shorthand electronic configuration of chromium is $[\text{Ar}] 3d^5 4s^1$.

(i) Complete the full electronic configuration of chromium.

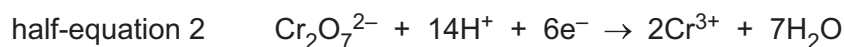
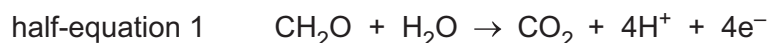
..... $3d^5 4s^1$ [1]

(ii) Deduce the total number of unpaired electrons in an atom of chromium.

..... [1]



- (c) Acidified dichromate(VI) ions will convert methanal, CH_2O , to carbon dioxide. The movement of electrons to or from relevant species is shown in the following half-equations.



- (i) Identify the species that is reduced in half-equation 2. Explain your answer.

..... [1]

- (ii) The oxidation state of the carbon atom in methanal is 0.

Calculate the oxidation state of carbon in carbon dioxide.

..... [1]

- (iii) Construct the ionic equation for the reaction of dichromate(VI) ions with methanal in acidic conditions.

..... [2]

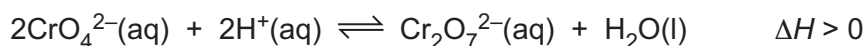
- (iv) Methanal is a liquid at -30°C but carbon dioxide is a gas at this temperature. Explain why.

.....

 [2]



- (d) In acidic conditions, a dynamic equilibrium is established between $\text{CrO}_4^{2-}(\text{aq})$ and $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$.



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

.....
 [1]

- (ii) Identify the condition necessary to establish dynamic equilibrium.

..... [1]

- (iii) $\text{CrO}_4^{2-}(\text{aq})$ ions are yellow and $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$ ions are orange.

State what is observed when the following changes are made to an equilibrium mixture of acidified $\text{CrO}_4^{2-}(\text{aq})$ and $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$ ions.

Explain your answers.

- The equilibrium mixture is warmed gently.

observation

explanation

.....

- Dilute $\text{HCl}(\text{aq})$ is added to the equilibrium mixture.

observation

explanation

.....

[4]

- (e) Chromium(IV) fluoride, CrF_4 , is a covalent molecule that shows similar chemical properties to SiCl_4 .

Suggest the type of reaction that occurs when CrF_4 is placed in water.

Construct a relevant equation for this reaction.

type of reaction

equation

[2]

[Total: 20]





2 The Period 3 elements show trends in physical and chemical properties across the period.

(a) Fig. 2.1 shows the variation in atomic and ionic radii of the Period 3 elements Na to Cl.

The ionic radius of Si is **not** shown.

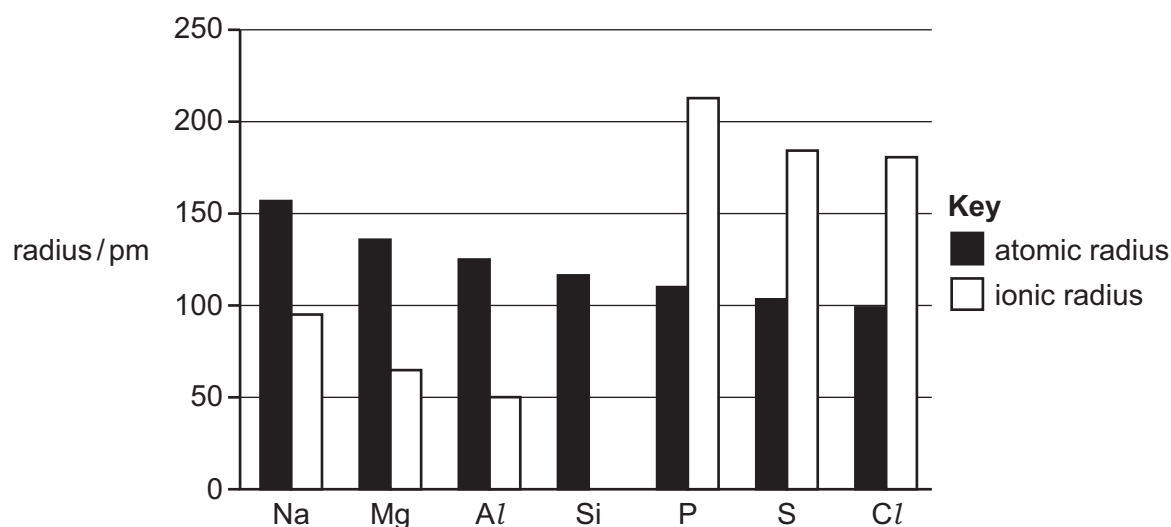


Fig. 2.1

(i) Explain the trend shown in the atomic radii of the Period 3 elements Na to Cl.

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

(ii) Explain why there is a large difference in the ionic radii of Al and P.

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



(b) Table 2.1 gives some information about some of the Period 3 oxides.

Row B gives the pH of the solution that forms when the Period 3 oxide is added to water.

Table 2.1

	formula of Period 3 oxide	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₄ O ₁₀	SO ₃
A	oxidation number of Period 3 element			+3			
B	pH of solution			—	—		

(i) Complete Table 2.1. [2]

(ii) State why there is no data given in row B for Al₂O₃ and SiO₂.

..... [1]

(c) (i) Write an equation for the reaction of Na₂O with dilute hydrochloric acid.

..... [1]

(ii) Construct an equation for the reaction of Al₂O₃ with a base to form NaAlO₂.

..... [1]

(d) Group 2 nitrates decompose on heating to form oxides.

(i) State the trend in thermal stability of the Group 2 nitrates down the group.

..... [1]

(ii) Identify the other products of the thermal decomposition of Group 2 nitrates.

..... [1]

[Total: 11]



- 3 Cycloalkanes show similar chemical properties to alkanes but have the same empirical formula as alkenes.

(a) Define empirical formula.

.....
 [1]

- (b) Cyclopentane, C_5H_{10} , has four cyclic structural isomers. One of these isomers is **C**, shown in Fig. 3.1.

Complete Fig. 3.1 to show two other cyclic structural isomers of C_5H_{10} .

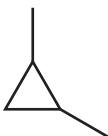
cyclopentane 			C 
--	--	--	---

Fig. 3.1

[2]

- (c) Cyclopentane reacts with Cl_2 in the presence of ultraviolet light to form C_5H_9Cl .

- (i) The reaction is initiated by the bond fission of Cl_2 .

State the type of bond fission shown in the initiation step.

..... [1]

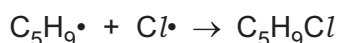
- (ii) Complete the equations to show the two propagation steps that follow the initiation step.

propagation 1 $C_5H_{10} + \dots \rightarrow C_5H_9\cdot + \dots$

propagation 2 $C_5H_9\cdot + \dots \rightarrow \dots$

[2]

- (iii) The final step is shown.



Give the name for this step in the reaction.

..... [1]



(d) Fig. 3.2 shows a reaction cycle involving cyclopentane, cyclopentene and $\text{C}_5\text{H}_9\text{Cl}$.

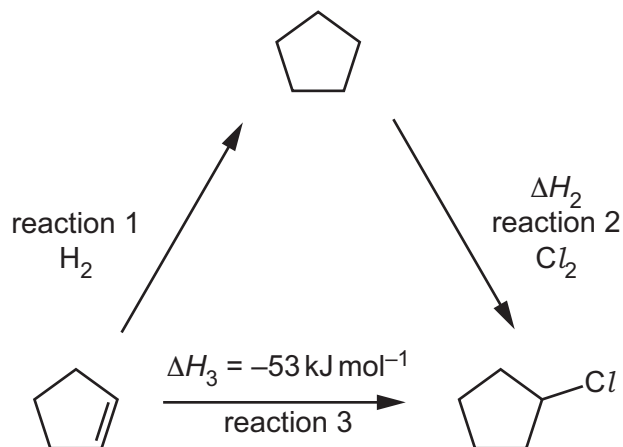


Fig. 3.2

(i) Identify a suitable reagent for reaction 3.

..... [1]

(ii) Use the data in Fig. 3.2 and in Table 3.1 to calculate the enthalpy change of reaction 2, ΔH_2 .

Table 3.1

compound	enthalpy change of combustion, $\Delta H_c / \text{kJ mol}^{-1}$
	-3292
	-3115
H_2	-286

$\Delta H_2 = \dots\dots\dots \text{kJ mol}^{-1}$ [2]



(e) Cyclopentene, C_5H_8 , reacts with hot concentrated acidified $KMnO_4$ to form compound **W**, $C_5H_8O_4$.

(i) Draw the structure of **W**.

[1]

(ii) The infrared spectrum of **W** is shown in Fig. 3.3.

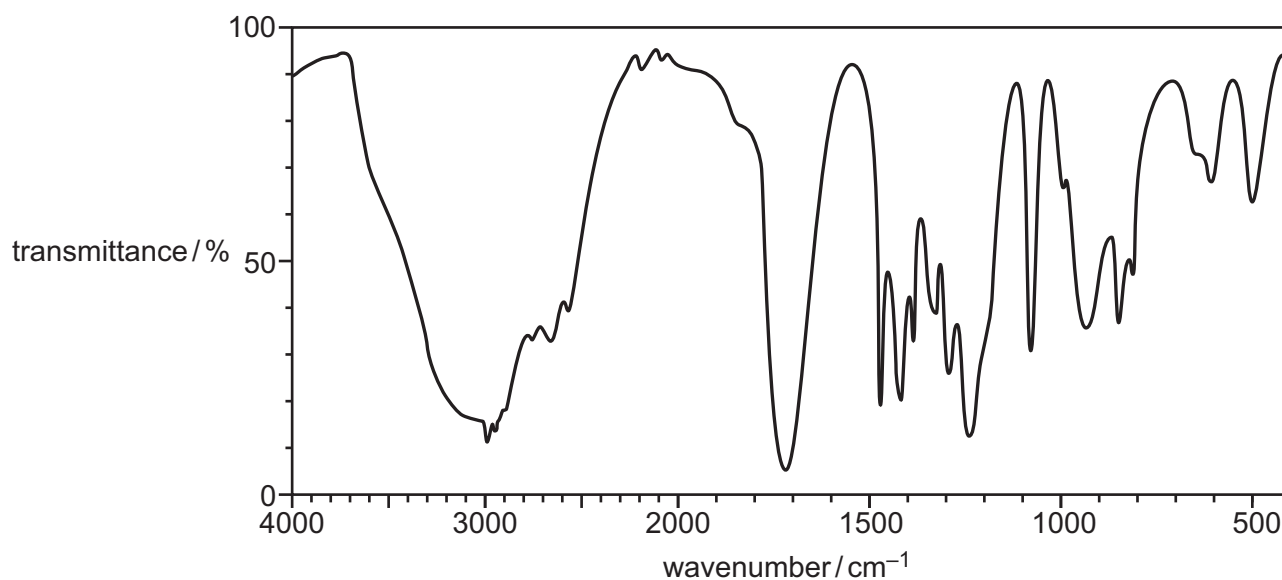


Fig. 3.3

Identify **two** absorptions in the infrared spectrum of **W** that would **not** be present in the infrared spectrum of cyclopentene.

- Write **1** or **2** on Fig. 3.3 against each of these two absorptions.
- Complete Table 3.2 to show which bond is responsible for each absorption that you have identified in Fig. 3.3.

Table 3.2

absorption	1	2
bond responsible		

[2]



Table 3.3

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: 13]



4 Fig. 4.1 shows a possible synthesis of propene, C_3H_6 .

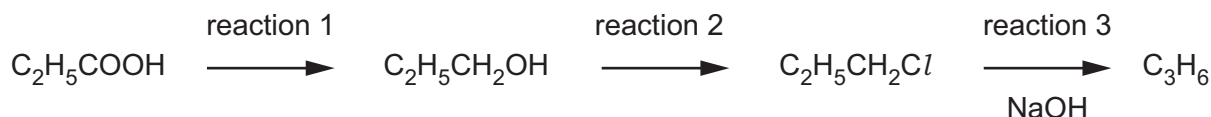


Fig. 4.1

(a) (i) Identify the type of reaction that occurs in reaction 1.

..... [1]

(ii) Suggest a suitable reagent for reaction 2.

..... [1]

(iii) Reaction 3 is an elimination reaction.

Write an equation for this reaction and identify the solvent and conditions used.

equation

solvent and conditions [2]

(iv) $C_2H_5CH_2OH$ can be directly converted to C_3H_6 .

Suggest the reagent and conditions for this conversion.

..... [1]

(b) Under suitable conditions, propene polymerises to form poly(propene).

Poly(propene) exhibits stereoisomerism.

(i) Identify the type of polymerisation that forms poly(propene) from propene.

..... [1]

(ii) Define stereoisomerism.

.....

..... [2]



- (iii) Draw a section of poly(propene), showing **two** repeat units.

Use your diagram to identify the type of stereoisomerism shown by poly(propene).
Explain your answer.

section of poly(propene)

[3]

- (iv) State **two** difficulties associated with the disposal of poly(propene).

1

2 [2]



(c) Under different conditions, two molecules of propene can combine to form compounds **X** and **Y**.



(i) Name **X**.

..... [1]

(ii) Fig. 4.2 shows the mass spectrum of either compound **X** or compound **Y**.

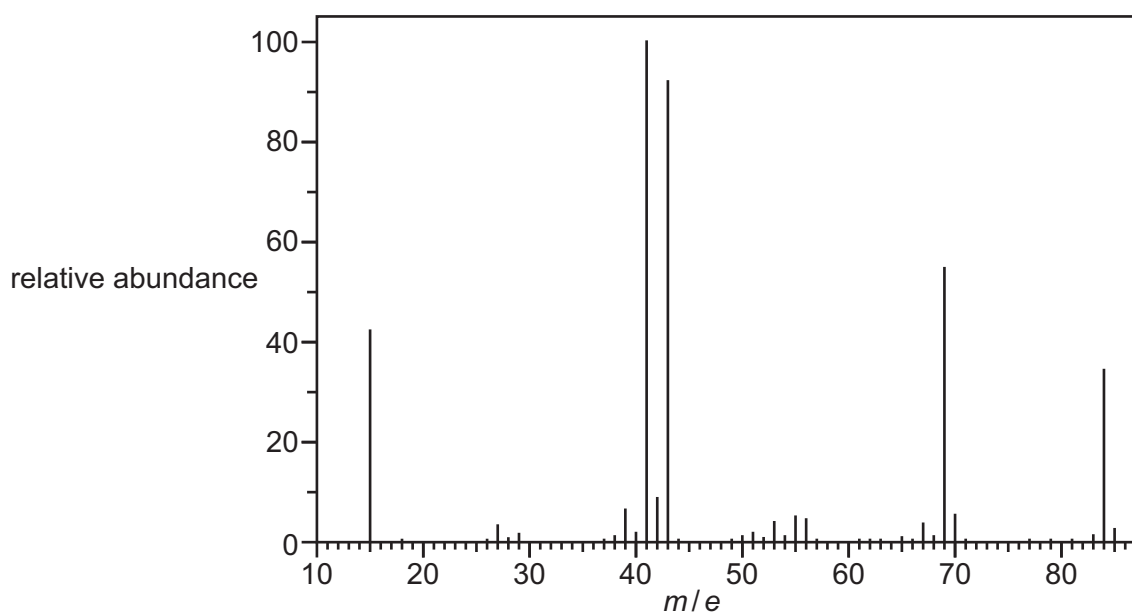


Fig. 4.2

Identify which of **X** and **Y** gives this mass spectrum.

Give **one** reason for your answer, referring to the fragmentation pattern.

..... [1]

(iii) The molecular ion peak in the spectrum in Fig. 4.2 has relative abundance 34.7.

Calculate the relative abundance of the $[M+1]^+$ peak in this spectrum.

relative abundance of $[M+1]^+$ peak = ... [1]



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 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	4																	5	6	7	8	9	10	11	12		
Li	Be																	B	C	N	O	F					
lithium	beryllium																	boron	carbon	nitrogen	oxygen	fluorine					
6.9	9.0																	10.8	12.0	14.0	16.0	19.0					
11	12																	13	14	15	16	17					
Na	Mg																	Al	Si	P	S	Cl					
sodium	magnesium																	aluminium	silicon	phosphorus	sulfur	chlorine					
23.0	24.3																	27.0	28.1	31.0	32.1	35.5					
19	20																	31	32	33	34	35					
K	Ca																	Ga	Ge	As	Se	Br					
potassium	calcium																	gallium	germanium	arsenic	selenium	bromine					
39.1	40.1																	69.7	72.6	74.9	79.0	79.9					
37	38																	49	50	51	52	53					
Rb	Sr																	In	Sn	Sb	Te	I					
rubidium	strontium																	indium	tin	antimony	tellurium	iodine					
85.5	87.6																	114.8	118.7	121.8	127.6	126.9					
55	56																	81	82	83	84	85					
Cs	Ba																	Tl	Pb	Bi	Po	At					
caesium	barium																	thallium	lead	bismuth	polonium	astatine					
132.9	137.3																	204.4	207.2	209.0	—	—					
87	88																	113	114	115	116	117					
Fr	Ra																	Nh	Fl	Mc	Lv	Ts					
francium	radium																	nihonium	flerovium	moscovium	livermorium	tennessine					
—	—																	—	—	—	—	—					

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 —

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CHEMISTRY

9701/22

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1 hour 15 minutes

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1 Manganese, Mn, and its compounds are widely used in many chemical reactions.

(a) Mn is usually found as a single isotope, manganese-55.

(i) Determine the number of protons, neutrons and electrons in an atom of manganese-55.

number of protons neutrons electrons [1]

(ii) Define isotopes.

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

(iii) A sample of manganese from the Moon is found to contain manganese-53 in addition to manganese-55.

State the two pieces of information needed to determine the relative atomic mass, A_r , of manganese in this sample.

1
2 [2]

(b) The shorthand electronic configuration of manganese is $[\text{Ar}] 3d^5 4s^2$.

(i) Complete the full electronic configuration of manganese.

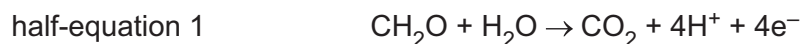
..... $3d^5 4s^2$ [1]

(ii) Deduce the total number of unpaired electrons in an atom of manganese.

..... [1]



- (c) Manganese(IV) oxide reacts with methanal, CH_2O , in acidic conditions to produce carbon dioxide. The movement of electrons to or from relevant species is shown in the following half-equations.



- (i) Identify the species that is reduced in half-equation 2. Explain your answer.

.....
 [1]

- (ii) The oxidation state of carbon in methanal is 0.

Calculate the oxidation state of carbon in carbon dioxide.

..... [1]

- (iii) Construct the ionic equation for the reaction of manganese(IV) oxide with methanal in acidic conditions.

..... [2]

[Total: 10]



2 The Period 3 elements show trends in physical and chemical properties across the period.

(a) (i) Explain why the elements Na to Al are good electrical conductors.

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

(ii) Explain why the elements P, S and Cl do not conduct electricity.

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

(b) Fig. 2.1 shows the variation in melting point of the Period 3 elements Si to Cl.

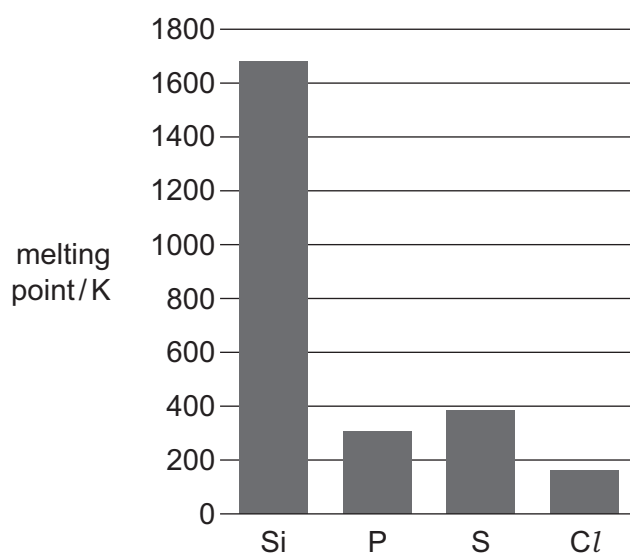


Fig. 2.1

The Period 3 elements Si to Cl are all non-metals.

Explain why there is a large difference between the melting point of Si and the melting points of P, S and Cl.

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



(c) Table 2.1 gives some information about some Period 3 chlorides.

Row B refers to the pH of the solution that forms when the Period 3 chloride is added to water.

Table 2.1

	formula of Period 3 chloride	NaCl	MgCl_2	AlCl_3	SiCl_4	PCl_5
A	oxidation number of element bonded to Cl					
B	pH of solution		6.5			
C	bonding			ionic		
D	structure			giant		

Complete Table 2.1.

You may use the following abbreviations.

I = ionic, C = covalent, M = metallic
G = giant, S = simple

[4]

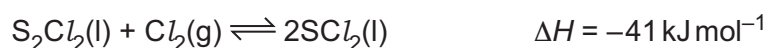
(d) (i) Write an equation for the formation of AlCl_3 from its elements.

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

(ii) Write an equation for the formation of H_3PO_4 from PCl_5 .

..... [1]

(e) $\text{S}_2\text{Cl}_2(\text{l})$ reacts with $\text{Cl}_2(\text{g})$ in a reversible reaction to form $\text{SCl}_2(\text{l})$. Under certain conditions, a dynamic equilibrium is established.



(i) State what is meant by dynamic equilibrium.

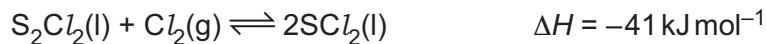
.....
..... [1]

(ii) Identify the condition necessary to establish dynamic equilibrium.

..... [1]



(iii) $S_2Cl_2(l)$ is yellow and $SCl_2(l)$ is red.



State what is observed when the following changes are made to an equilibrium mixture of $S_2Cl_2(l)$ and $SCl_2(l)$.

Explain your answers.

- The equilibrium mixture is warmed gently.

observation

explanation

.....

.....

- The overall pressure of the equilibrium mixture is increased.

observation

explanation

.....

.....

[4]

(f) Aqueous $MgCl_2$ reacts with aqueous Na_2CO_3 to form a white precipitate. Upon heating, the white precipitate undergoes thermal decomposition.

- (i) Construct an equation to show the reaction of aqueous $MgCl_2$ with aqueous Na_2CO_3 . Use state symbols in your equation.

..... [2]

- (ii) Identify the products of the thermal decomposition of the white precipitate.

..... [1]

- (iii) State the trend in thermal stability of the Group 2 carbonates down the group.

..... [1]

[Total: 20]





- 3 The alkanes are a homologous series of organic molecules. Alkanes are generally unreactive and are commonly used as fuels.

(a) Define homologous series.

.....
 [2]

(b) Give two reasons to explain the general unreactivity of alkanes.

1
 2 [2]

(c) Alkanes with low relative molecular mass, M_r , are more useful than those found in heavier crude oil fractions.

Name the process that is used to obtain alkanes with low M_r from heavier crude oil fractions.

..... [1]

(d) Hexane, C_6H_{14} , has four structural isomers.

Fig. 3.1 shows hexane and two of its structural isomers.

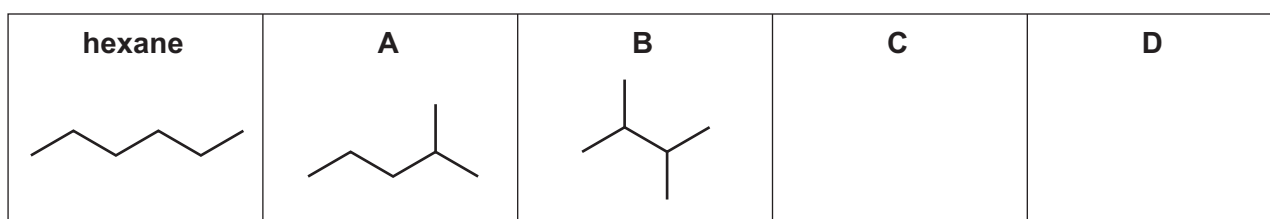


Fig. 3.1

(i) Complete Fig. 3.1 by drawing structures for **C** and **D**, the other two structural isomers of hexane. [2]

(ii) **A**, **B** and hexane have different boiling points.

Arrange **A**, **B** and hexane in order of increasing boiling point.

Explain your answer.

lowest < < highest

.....

 [3]



- (e) Hexane can be converted into compounds **E** and **F** at high temperature and pressure. Fig. 3.2 shows the reaction scheme involving hexane, **E** and **F**.

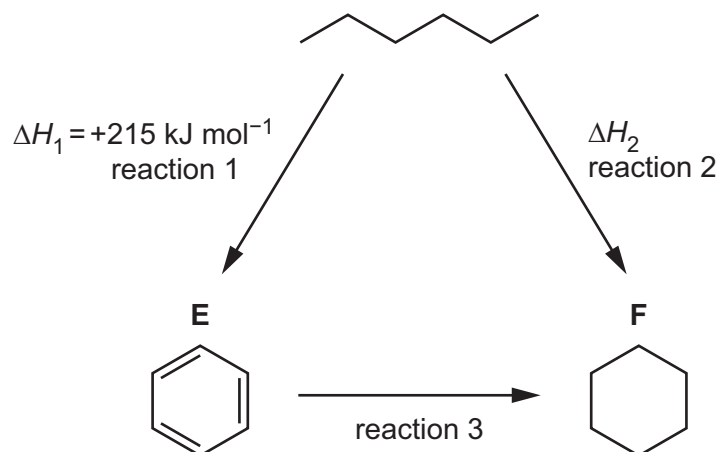


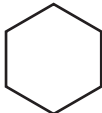
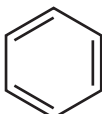
Fig. 3.2

- (i) Identify a suitable reagent for reaction 3.

..... [1]

- (ii) Use the data in Fig. 3.2 and in Table 3.1 to calculate the enthalpy change of reaction 2, ΔH_2 .

Table 3.1

compound	enthalpy change of formation, $\Delta H_f / \text{kJ mol}^{-1}$
	-156
	+48

$\Delta H_2 = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

- (iii) Write an equation for the complete combustion of hexane.

..... [1]



- 4 Fig. 4.1 shows how propane, C_3H_8 , can be converted to propanoic acid, CH_3CH_2COOH .

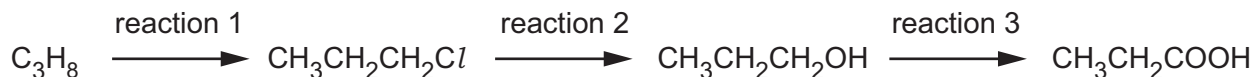
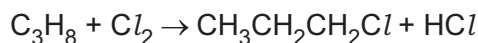


Fig. 4.1

- (a) Reaction 1 in Fig. 4.1 takes place in the presence of sunlight.



The reaction takes place via initiation, propagation and termination steps.

- (i) Name the mechanism shown by reaction 1.

..... [1]

- (ii) Complete the mechanism for reaction 1.

Construct equations to describe the steps of the mechanism.



propagation 1

propagation 2

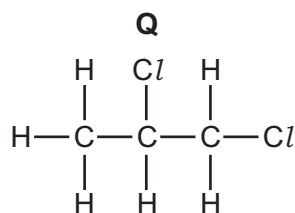
termination $\rightarrow CH_3CH_2CH_2Cl$ [3]

- (iii) Reaction 1 is initiated by the bond fission of Cl_2 .

State the type of bond fission shown in the initiation step.

..... [1]

- (iv) Compound **Q** is a by-product of reaction 1.



Name **Q**.

..... [1]



- (v) The molecular formula of **Q** is $\text{C}_3\text{H}_6\text{Cl}_2$.

Identify the types of structural isomerism and stereoisomerism that a molecule with molecular formula $\text{C}_3\text{H}_6\text{Cl}_2$ can show.

type of structural isomerism

type of stereoisomerism

[2]

- (b) State the reagent and solvent required for reaction 2.

..... [1]

- (c) Reaction 3 takes place when $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ is heated under reflux with acidified potassium dichromate(VI) solution.

- (i) State the colour change that takes place in the reaction mixture.

..... [1]

- (ii) Construct an equation to represent reaction 3. Use [O] to represent an atom of oxygen from the oxidising agent.

..... [1]



(d) $\text{CH}_3\text{CH}_2\text{COOH}$ reacts with an unsaturated alcohol **R** to form unsaturated ester **S**.

(i) State the **type** of reaction that forms **S**.

..... [1]

(ii) The infrared spectrum of **S** is shown in Fig. 4.2.

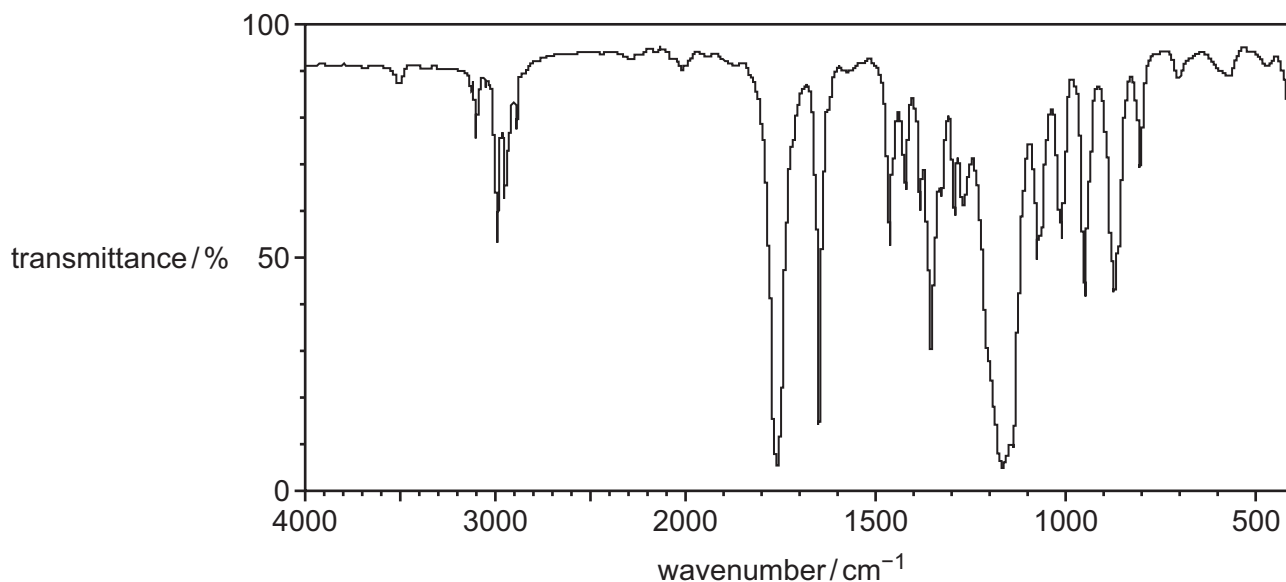


Fig. 4.2

Three absorptions in the infrared spectrum in Fig. 4.2 confirm that **S** is an ester and is unsaturated.

- Write **1**, **2** or **3** on Fig. 4.2 against each of these three absorptions.
- Complete Table 4.1 to show which bond is responsible for each absorption that you have identified in Fig. 4.2.

Table 4.1

absorption	1	2	3
bond responsible			

[3]



Table 4.2

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

(iii) The mass spectrum of **S** shows the following peaks.

Table 4.3

peak	relative abundance
M ⁺	4.7
[M+1] ⁺	0.31

Use Table 4.3 to calculate the number of carbon atoms in **S**.

number of carbon atoms in **S** = ... [1]

[Total: 16]





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 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 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 oganeson —
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 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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Cambridge International AS & A Level

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CHEMISTRY

9701/23

Paper 2 AS Level Structured Questions

October/November 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.

1 Chromium, Cr, and its compounds are widely used in many chemical reactions.

(a) Cr exists as four stable isotopes.

(i) The most common isotope of Cr is chromium-52.

Determine the number of protons, neutrons and electrons in an atom of chromium-52.

number of protons neutrons electrons [1]

(ii) Describe how an atom of chromium-54 differs from an atom of chromium-52. Refer to numbers of particles in your answer.

..... [1]

(iii) The relative isotopic masses of the isotopes of Cr can be determined using mass spectrometry.

State what other information is needed to calculate the relative atomic mass, A_r , of Cr.

..... [1]

(iv) Atoms of ^{52}Cr , ^{53}Cr and ^{54}Cr make up more than 95% of naturally occurring chromium atoms. The A_r of naturally occurring Cr is 51.996.

Suggest what these statements imply about the relative isotopic mass of the fourth stable isotope of chromium.

..... [1]

(b) The shorthand electronic configuration of chromium is $[\text{Ar}] 3d^5 4s^1$.

(i) Complete the full electronic configuration of chromium.

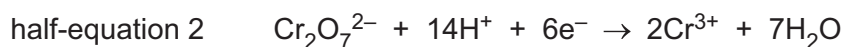
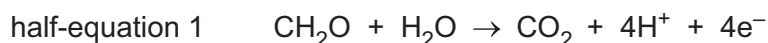
..... $3d^5 4s^1$ [1]

(ii) Deduce the total number of unpaired electrons in an atom of chromium.

..... [1]



- (c) Acidified dichromate(VI) ions will convert methanal, CH_2O , to carbon dioxide. The movement of electrons to or from relevant species is shown in the following half-equations.



- (i) Identify the species that is reduced in half-equation 2. Explain your answer.

..... [1]

- (ii) The oxidation state of the carbon atom in methanal is 0.

Calculate the oxidation state of carbon in carbon dioxide.

..... [1]

- (iii) Construct the ionic equation for the reaction of dichromate(VI) ions with methanal in acidic conditions.

..... [2]

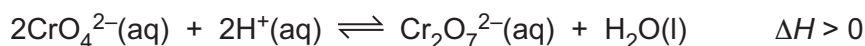
- (iv) Methanal is a liquid at -30°C but carbon dioxide is a gas at this temperature. Explain why.

.....

 [2]



- (d) In acidic conditions, a dynamic equilibrium is established between $\text{CrO}_4^{2-}(\text{aq})$ and $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$.



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

.....
 [1]

- (ii) Identify the condition necessary to establish dynamic equilibrium.

..... [1]

- (iii) $\text{CrO}_4^{2-}(\text{aq})$ ions are yellow and $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$ ions are orange.

State what is observed when the following changes are made to an equilibrium mixture of acidified $\text{CrO}_4^{2-}(\text{aq})$ and $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$ ions.

Explain your answers.

- The equilibrium mixture is warmed gently.

observation

explanation

.....

- Dilute $\text{HCl}(\text{aq})$ is added to the equilibrium mixture.

observation

explanation

.....

[4]

- (e) Chromium(IV) fluoride, CrF_4 , is a covalent molecule that shows similar chemical properties to SiCl_4 .

Suggest the type of reaction that occurs when CrF_4 is placed in water.

Construct a relevant equation for this reaction.

type of reaction

equation

[2]

[Total: 20]





2 The Period 3 elements show trends in physical and chemical properties across the period.

(a) Fig. 2.1 shows the variation in atomic and ionic radii of the Period 3 elements Na to Cl.

The ionic radius of Si is **not** shown.

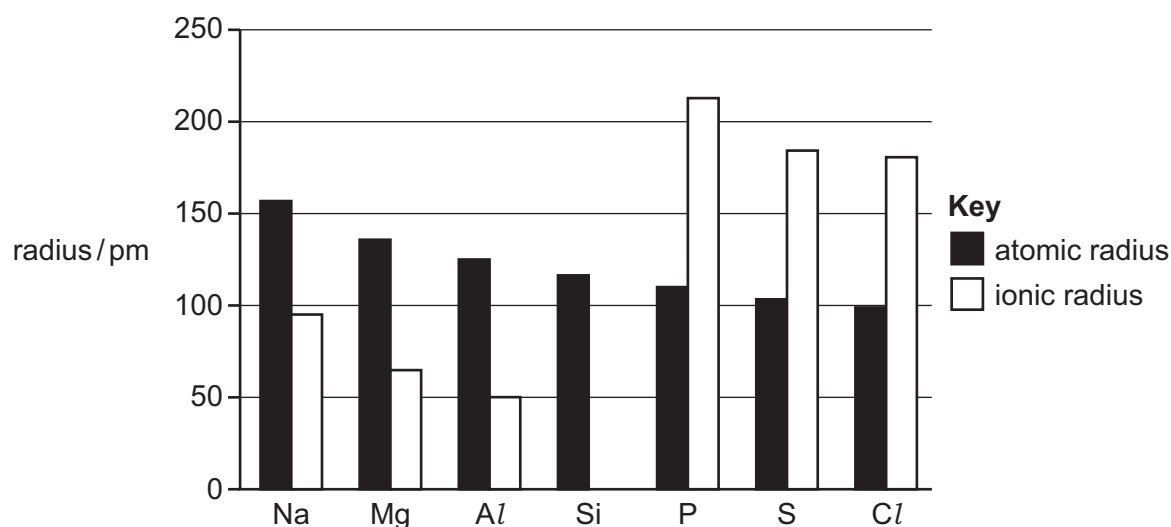


Fig. 2.1

(i) Explain the trend shown in the atomic radii of the Period 3 elements Na to Cl.

.....

.....

.....

..... [2]

(ii) Explain why there is a large difference in the ionic radii of Al and P.

.....

.....

.....

..... [2]



(b) Table 2.1 gives some information about some of the Period 3 oxides.

Row B gives the pH of the solution that forms when the Period 3 oxide is added to water.

Table 2.1

	formula of Period 3 oxide	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₄ O ₁₀	SO ₃
A	oxidation number of Period 3 element			+3			
B	pH of solution			—	—		

(i) Complete Table 2.1. [2]

(ii) State why there is no data given in row B for Al₂O₃ and SiO₂.

..... [1]

(c) (i) Write an equation for the reaction of Na₂O with dilute hydrochloric acid.

..... [1]

(ii) Construct an equation for the reaction of Al₂O₃ with a base to form NaAlO₂.

..... [1]

(d) Group 2 nitrates decompose on heating to form oxides.

(i) State the trend in thermal stability of the Group 2 nitrates down the group.

..... [1]

(ii) Identify the other products of the thermal decomposition of Group 2 nitrates.

..... [1]

[Total: 11]



- 3 Cycloalkanes show similar chemical properties to alkanes but have the same empirical formula as alkenes.

(a) Define empirical formula.

.....
 [1]

- (b) Cyclopentane, C_5H_{10} , has four cyclic structural isomers. One of these isomers is **C**, shown in Fig. 3.1.

Complete Fig. 3.1 to show two other cyclic structural isomers of C_5H_{10} .

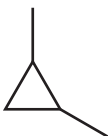
cyclopentane 			C 
--	--	--	---

Fig. 3.1

[2]

- (c) Cyclopentane reacts with Cl_2 in the presence of ultraviolet light to form C_5H_9Cl .

- (i) The reaction is initiated by the bond fission of Cl_2 .

State the type of bond fission shown in the initiation step.

..... [1]

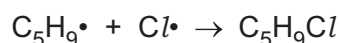
- (ii) Complete the equations to show the two propagation steps that follow the initiation step.

propagation 1 $C_5H_{10} + \dots \rightarrow C_5H_9\cdot + \dots$

propagation 2 $C_5H_9\cdot + \dots \rightarrow \dots$

[2]

- (iii) The final step is shown.



Give the name for this step in the reaction.

..... [1]



(d) Fig. 3.2 shows a reaction cycle involving cyclopentane, cyclopentene and $\text{C}_5\text{H}_9\text{Cl}$.

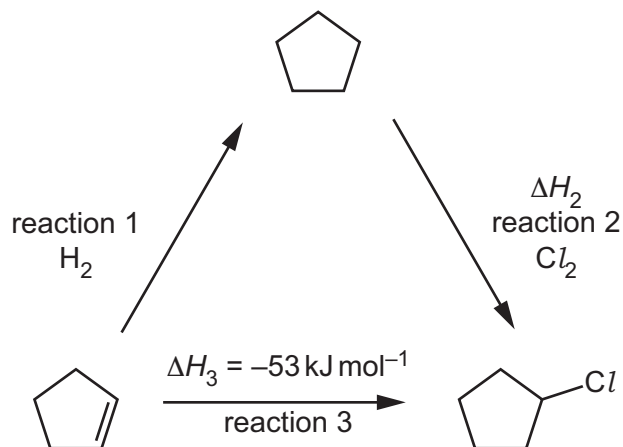


Fig. 3.2

(i) Identify a suitable reagent for reaction 3.

..... [1]

(ii) Use the data in Fig. 3.2 and in Table 3.1 to calculate the enthalpy change of reaction 2, ΔH_2 .

Table 3.1

compound	enthalpy change of combustion, $\Delta H_c / \text{kJ mol}^{-1}$
	-3292
	-3115
H_2	-286

$\Delta H_2 = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]



(e) Cyclopentene, C_5H_8 , reacts with hot concentrated acidified $KMnO_4$ to form compound **W**, $C_5H_8O_4$.

(i) Draw the structure of **W**.

[1]

(ii) The infrared spectrum of **W** is shown in Fig. 3.3.

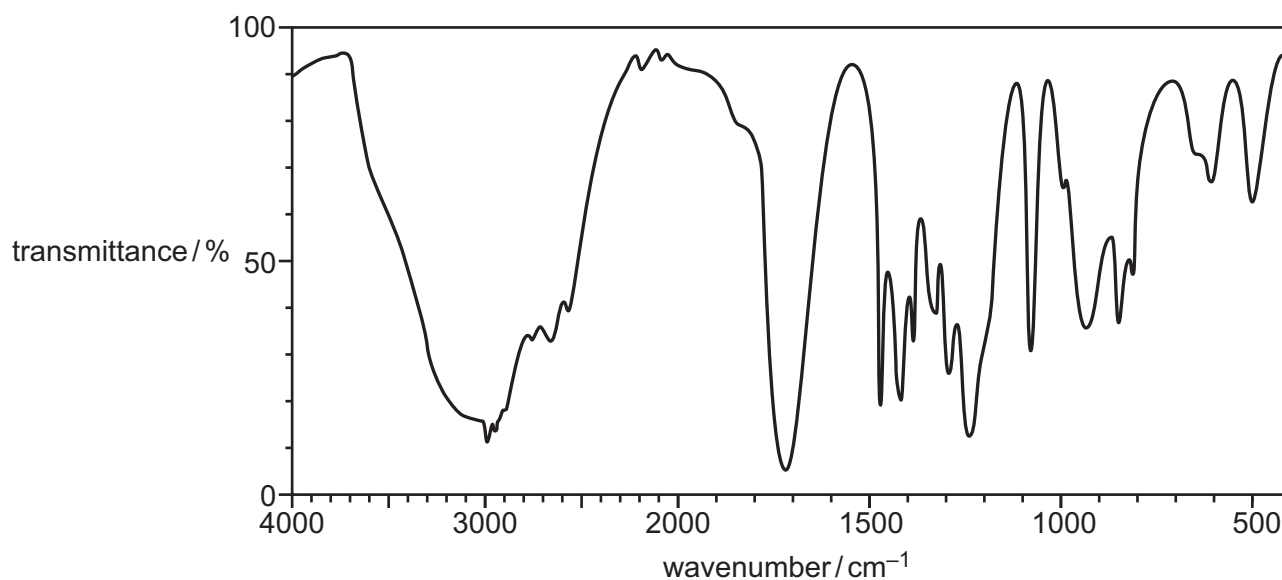


Fig. 3.3

Identify **two** absorptions in the infrared spectrum of **W** that would **not** be present in the infrared spectrum of cyclopentene.

- Write **1** or **2** on Fig. 3.3 against each of these two absorptions.
- Complete Table 3.2 to show which bond is responsible for each absorption that you have identified in Fig. 3.3.

Table 3.2

absorption	1	2
bond responsible		

[2]



Table 3.3

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: 13]



4 Fig. 4.1 shows a possible synthesis of propene, C_3H_6 .

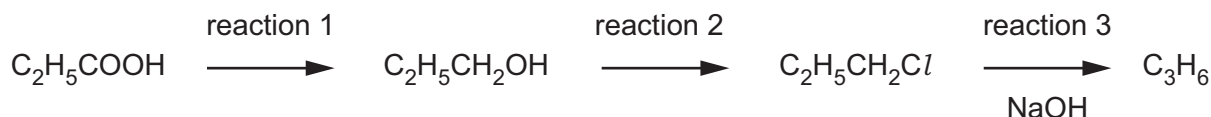


Fig. 4.1

(a) (i) Identify the type of reaction that occurs in reaction 1.

..... [1]

(ii) Suggest a suitable reagent for reaction 2.

..... [1]

(iii) Reaction 3 is an elimination reaction.

Write an equation for this reaction and identify the solvent and conditions used.

equation

solvent and conditions [2]

(iv) $C_2H_5CH_2OH$ can be directly converted to C_3H_6 .

Suggest the reagent and conditions for this conversion.

..... [1]

(b) Under suitable conditions, propene polymerises to form poly(propene).

Poly(propene) exhibits stereoisomerism.

(i) Identify the type of polymerisation that forms poly(propene) from propene.

..... [1]

(ii) Define stereoisomerism.

.....

..... [2]



- (iii) Draw a section of poly(propene), showing **two** repeat units.

Use your diagram to identify the type of stereoisomerism shown by poly(propene).
Explain your answer.

section of poly(propene)

[3]

- (iv) State **two** difficulties associated with the disposal of poly(propene).

1

2 [2]



(c) Under different conditions, two molecules of propene can combine to form compounds **X** and **Y**.



(i) Name **X**.

..... [1]

(ii) Fig. 4.2 shows the mass spectrum of either compound **X** or compound **Y**.

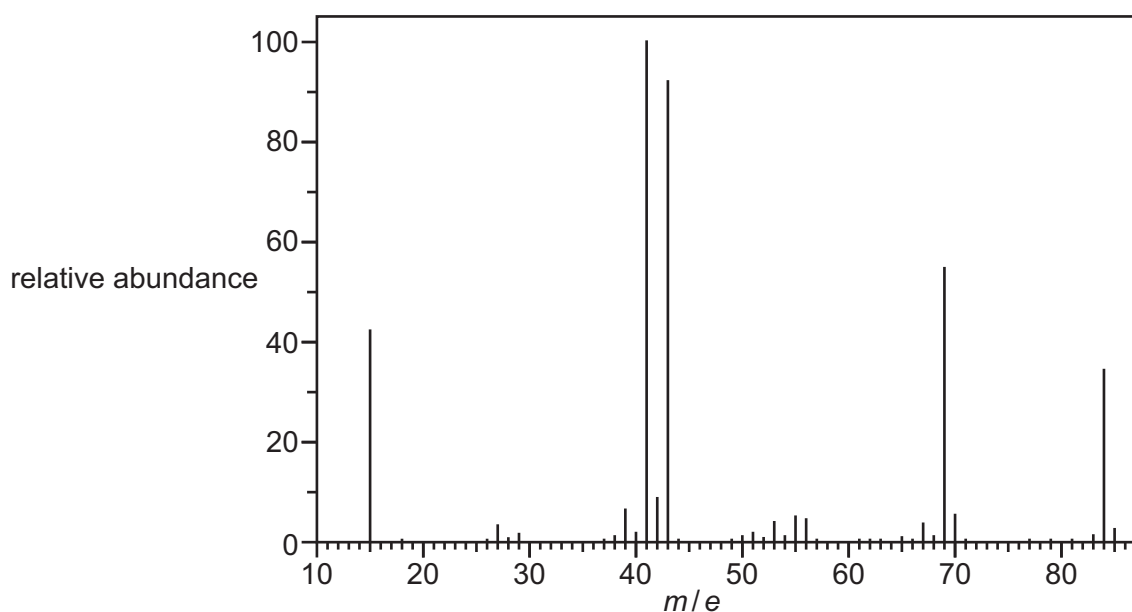


Fig. 4.2

Identify which of **X** and **Y** gives this mass spectrum.

Give **one** reason for your answer, referring to the fragmentation pattern.

.....

 [1]

(iii) The molecular ion peak in the spectrum in Fig. 4.2 has relative abundance 34.7.

Calculate the relative abundance of the $[M+1]^+$ peak in this spectrum.

relative abundance of $[M+1]^+$ peak = ... [1]



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	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
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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	4																		
Li	Be																		
lithium	beryllium																		
6.9	9.0																		
11	12																		
Na	Mg																		
sodium	magnesium																		
23.0	24.3																		
		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	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
potassium	calcium	scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	gallium	germanium	arsenic	selenium	bromine	krypton		
39.1	40.1	44.0	47.9	50.9	52.0	54.9	55.8	58.9	58.7	63.5	65.4	69.7	72.6	74.9	79.0	79.9	83.8		
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54		
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
rubidium	strontium	yttrium	zirconium	niobium	molybdenum	technetium	ruthenium	rhodium	palladium	silver	cadmium	indium	tin	antimony	tellurium	iodine	xenon		
85.5	87.6	88.9	91.2	92.9	95.9	—	101.1	102.9	106.4	107.9	112.4	114.8	118.7	121.8	127.6	126.9	131.3		
55	56	57–71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86		
Cs	Ba	lanthanoids	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
caesium	barium		hafnium	tantalum	tungsten	rhenium	osmium	iridium	platinum	gold	mercury	thallium	lead	bismuth	polonium	astatine	radon		
132.9	137.3		178.5	180.9	183.8	186.2	190.2	192.2	195.1	197.0	200.6	204.4	207.2	209.0	—	—	—		
87	88	89–103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118		
Fr	Ra	actinoids	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og		
francium	radium		rutherfordium	dubnium	seaborgium	bohrium	hassium	meitnerium	darmstadtium	roentgenium	copernicium	nihonium	flerovium	moscovium	livermorium	tennessine	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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Cambridge International AS & A Level

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CHEMISTRY

9701/24

Paper 2 AS Level Structured Questions

October/November 2025

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

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- Important values, constants and standards are printed in the question paper.

This document has **16** pages. Any blank pages are indicated.

1 The Group 17 elements are oxidising agents.

(a) (i) Explain how the Group 17 elements act as oxidising agents.

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

(ii) Write an equation to show the reaction in which Cl_2 oxidises aluminium metal.

..... [1]

(iii) A student heats equal amounts of $I_2(g)$ and $H_2(g)$ in a sealed flask. The student leaves the contents to cool.

State what you would observe during the reaction.

..... [1]

(b) Cl_2 and Br_2 can each react with NH_3 to give N_2 and a hydrogen halide, HX .



The relative bond strengths of $X-X$ and $H-X$ determine the difference in enthalpy change of the two reactions.

(i) Describe and explain the difference in the $X-X$ bond strengths of Cl_2 and Br_2 .

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

(ii) Describe the relative thermal stabilities of HCl and HBr .

..... [1]



(iii) Define enthalpy change of formation, ΔH_f .

.....

.....

..... [2]

(iv) Table 1.1 gives data relevant to the reaction of $\text{Cl}_2(\text{g})$ with $\text{NH}_3(\text{g})$.

Table 1.1

compound	enthalpy change of formation, $\Delta H_f / \text{kJ mol}^{-1}$
$\text{NH}_3(\text{g})$	−46
$\text{HCl}(\text{g})$	−92

Use the data in Table 1.1 to calculate the enthalpy change of the reaction of $\text{Cl}_2(\text{g})$ with $\text{NH}_3(\text{g})$.

enthalpy change of reaction = ... kJ mol^{-1} [2]

(v) I_2 reacts with NH_3 to form NI_3 .

Predict the shape of a molecule of NI_3 . Explain your answer.

shape

explanation

..... [2]



(c) Table 1.2 shows some information about reactions of NaCl , NaBr and NaI .

Table 1.2

	NaCl	NaBr	NaI
observation with $\text{Ag}^+(\text{aq})$	white precipitate		
type of reaction with concentrated H_2SO_4	acid–base	acid–base, then redox	acid–base, then redox
observations with concentrated H_2SO_4			- black solid - yellow solid - effervescence

(i) Complete Table 1.2. [4]

(ii) Suggest an identity for the species that produces each observation in the reaction of NaI with concentrated H_2SO_4 .

black solid

yellow solid

effervescence

[2]

(d) Table 1.3 gives some information about MgCl_2 and SiCl_4 .

Table 1.3

	MgCl_2	SiCl_4
electrical conductivity when liquid	conducts	does not conduct
observation when added to water	dissolves	vigorous reaction

(i) Explain the difference between the electrical conductivity of liquid MgCl_2 and of liquid SiCl_4 . Refer to bonding and relevant particles in your answer.

.....

 [2]

(ii) Suggest the pH of the solutions that form when each chloride is added to water.

MgCl_2 SiCl_4 [2]

[Total: 22]





- 2 Aluminium oxide, Al_2O_3 , and phosphorus(V) oxide, P_4O_{10} , are both used as reagents and catalysts.

- (a) The melting point of Al_2O_3 is $2072^\circ C$. The melting point of P_4O_{10} is $340^\circ C$.

Explain the difference in the melting points of these two compounds.

.....

.....

.....

..... [3]

- (b) A 5.00 dm^3 sealed flask contains 0.400 mol of $CO(g)$ and 0.800 mol of $H_2(g)$ and an Al_2O_3 catalyst. The flask is heated to a temperature of $290^\circ C$ and allowed to reach equilibrium. Equation 1 shows the reaction.



The equilibrium constant, K_c , of equation 1 is given.

$$K_c = \frac{[CH_3OH]}{[CO][H_2]^2}$$

- (i) State the units of K_c .

..... [1]

- (ii) The equilibrium mixture contains 0.280 mol of $CH_3OH(g)$.

Calculate the value of K_c .

Give your answer to **three** significant figures.

value of $K_c =$ [3]

- (iii) State and explain the effect, if any, on the value of K_c when the overall pressure in the sealed flask is increased.

.....

..... [1]



(c) P_4O_{10} catalyses the reversible reaction of CO with H_2 to form CH_3OH .



P_4O_{10} then acts as a dehydrating agent, causing CH_3OH to form CH_3OCH_3 .

(i) Explain how the presence of a catalyst affects a chemical reaction.

.....

 [1]

(ii) Construct an equation for the dehydration reaction of CH_3OH to form CH_3OCH_3 .

..... [1]

(iii) Write an equation to show the reaction of P_4O_{10} with an excess of water.

..... [1]

[Total: 11]



- 3 Propan-2-ol, $(\text{CH}_3)_2\text{CHOH}$, is sometimes added to fuel to help it burn.

Fig. 3.1 shows some reactions of propan-2-ol.

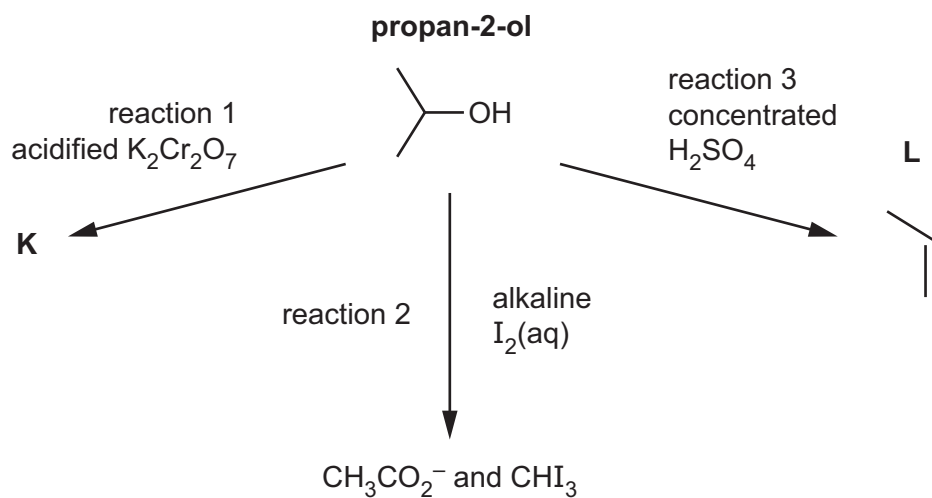


Fig. 3.1

- (a) (i) Draw the structure of organic compound **K**.

[1]

- (ii) State an observation you would make in reaction 2.

[1]

- (iii) State the type of reaction that is shown in reaction 3.

[1]

- (iv) Complete Fig. 3.2 to show the pi (π) bond in **L** that is formed from orbital overlap.

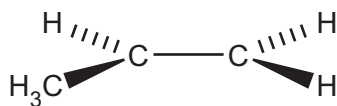


Fig. 3.2

[1]



- (b) Propan-2-ol reacts with sodium to produce $(\text{CH}_3)_2\text{CH}-\text{O}^-$ anions.

These anions react with 2-bromopropane to form compound **N**, as shown in Fig. 3.3.

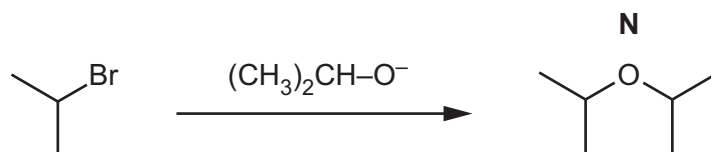


Fig. 3.3

- (i) Write an equation for the reaction of propan-2-ol with sodium.

..... [1]

- (ii) The reaction of 2-bromopropane with $(\text{CH}_3)_2\text{CH}-\text{O}^-$ anions follows an $\text{S}_{\text{N}}1$ mechanism.

Complete Fig. 3.4 to show this mechanism. Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.



Fig. 3.4

[3]

- (iii) Suggest how the rate of the $\text{S}_{\text{N}}1$ reaction would change, if at all, if 2-chloropropane were used instead of 2-bromopropane.

Explain your answer.

..... [2]

- (iv) **N** is also added to petrol to make it burn more smoothly.

Construct an equation for the complete combustion of **N**, $\text{C}_6\text{H}_{14}\text{O}$.

$\text{C}_6\text{H}_{14}\text{O}$ [1]

[Total: 11]



4 Compounds **P** and **Q** are structural isomers.



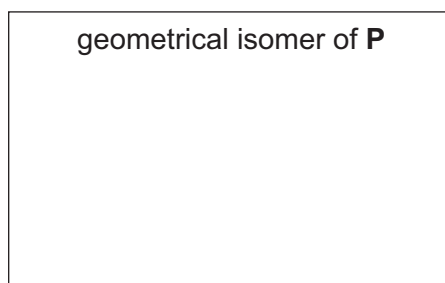
Fig. 4.1

(a) (i) Define structural isomerism.

.....
 [2]

(ii) **P** shows geometrical isomerism.

Draw the geometrical isomer of **P**. Explain why the two isomers are **not** identical.



explanation

 [2]

(iii) Both **P** and **Q** react with aqueous bromine.

Name the mechanism of this reaction.

..... [1]

(iv) **Q** is oxidised by hot concentrated acidified $\text{KMnO}_4(\text{aq})$, forming two different organic products.

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

$(\text{CH}_3)_2\text{C}=\text{CHCH}_3$ [2]



(v) **Q** reacts with HBr(g) to produce two structural isomers, **R** and **S**, as shown in Fig. 4.2.

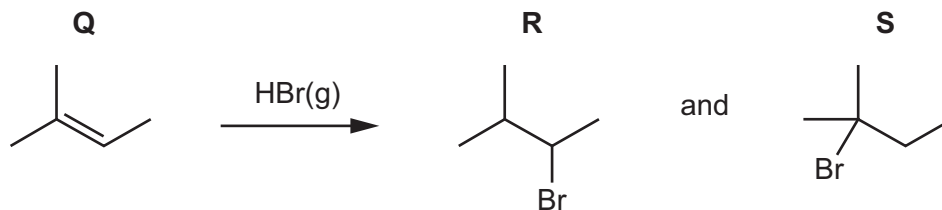


Fig. 4.2

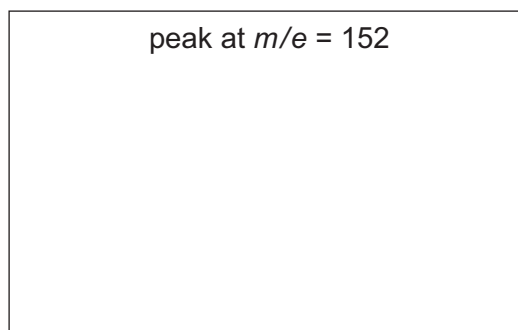
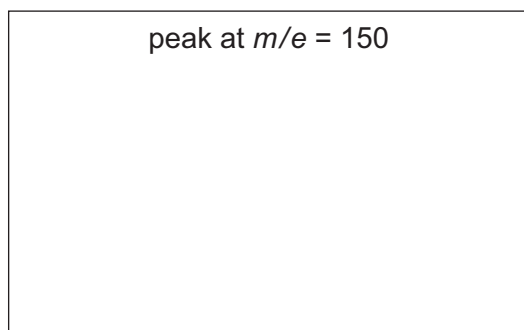
State and explain why isomer **S** is the major product of the reaction.

.....

 [2]

(vi) The mass spectrum of **R** shows peaks at $m/e = 150$ and $m/e = 152$.

Suggest structures for the ions responsible for these peaks.



[2]



(b) Fig. 4.3 shows a synthesis starting from **T**, a different isomer of **R** and **S**.

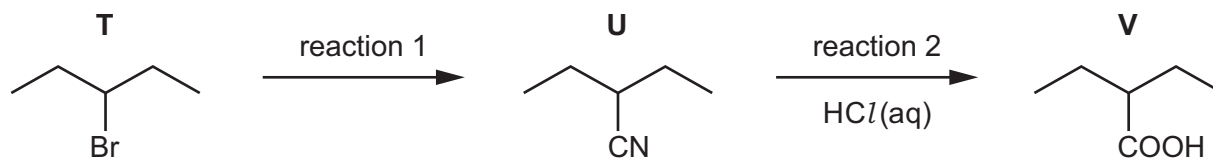


Fig. 4.3

(i) Identify the reagent and conditions for reaction 1.

..... [1]

(ii) Reaction 2 is a hydrolysis reaction.

Construct an equation for reaction 2.

$(\text{C}_2\text{H}_5)_2\text{CHCN}$ [1]

(iii) **V** reacts with propan-2-ol in the presence of a catalytic amount of H_2SO_4 to form organic compound **W**.

Complete Table 4.1 to give details of this reaction.

Table 4.1

	reaction of V with propan-2-ol
type of reaction	
functional group formed	
molecular formula of organic product W	

[3]

[Total: 16]







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 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										1 H hydrogen 1.0						
3 Li lithium 6.9	4 Be beryllium 9.0																	
11 Na sodium 23.0	12 Mg magnesium 24.3	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	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	
19 K potassium 39.1	20 Ca calcium 40.1	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 —	
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 —	
—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	

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	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	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	mendelivium	—	102	No	nobelium	—	103	Lr	lawrencium	—

actinoids

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