



CANDIDATE
NAME

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CENTRE
NUMBER

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NUMBER

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9701/21

May/June 2023

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

- The total mark for this paper is 60.
- The number of marks for each question or part question is shown in brackets [].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

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

- 1 Tellurium is an element in Group 16. The most common isotope of tellurium is ^{130}Te . Its electronic configuration is $[\text{Kr}] 4d^{10} 5s^2 5p^4$.

(a) Complete Table 1.1.

Table 1.1

	nucleon number	number of neutrons	number of electrons
^{130}Te			

[3]

(b) Identify the sub-shell in an atom of Te that contains electrons with the lowest energy.

..... [1]

(c) Construct an equation to represent the first ionisation energy of Te.

..... [1]

(d) (i) The radius of Te ions decreases after each successive ionisation.

State **two** factors that are responsible for the increase in the first six ionisation energies of Te.

.....

 [2]

(ii) Sketch a graph in Fig. 1.1 to show the trend in the first **seven** ionisation energies of Te.

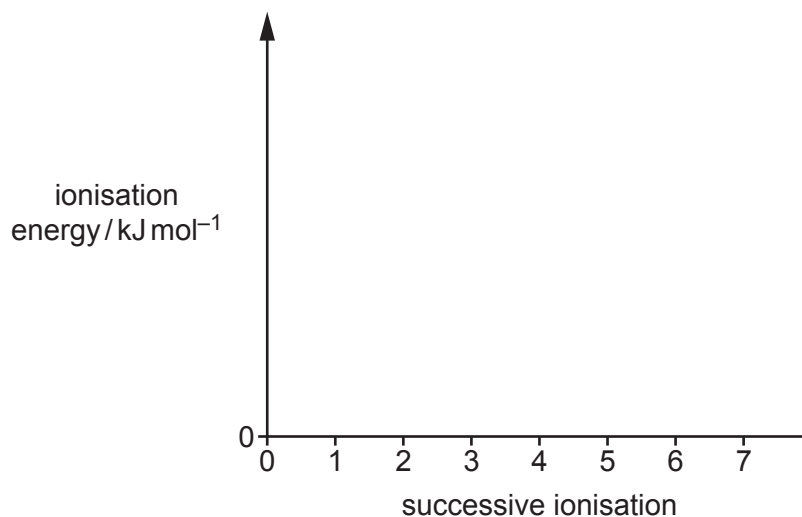


Fig. 1.1

[2]

- (e) Te reacts with F_2 at $150^\circ C$ to form TeF_x . Molecules of TeF_x are octahedral with bond angles of 90° .

Explain why TeF_x is octahedral with bond angles of 90° .

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

- (f) TeF_x reacts with water to form tellurium hydroxide and HF. The oxidation number of tellurium does **not** change during this reaction.

(i) Construct an equation for the reaction of TeF_x with water.

..... [1]

(ii) Name the type of reaction that occurs when TeF_x reacts with water.

..... [1]

[Total: 13]

- 2 A neutralisation reaction occurs when NaOH(aq) is added to H₂SO₄(aq).



- (a) Define enthalpy change of neutralisation, ΔH_{neut} .

.....

 [2]

- (b) An experiment is carried out to calculate ΔH_{neut} for the reaction between NaOH(aq) and H₂SO₄(aq).

100 cm³ of 1.00 mol dm⁻³ NaOH(aq) is added to 75 cm³ of 1.00 mol dm⁻³ H₂SO₄(aq) in a polystyrene cup and stirred. Results from the experiment are shown in Table 2.1.

Table 2.1

initial temperature of NaOH(aq)/°C	20.0
initial temperature of H ₂ SO ₄ (aq)/°C	20.0
maximum temperature of mixture/°C	27.8

- (i) Use equation 1 to calculate the amount, in mol, of H₂SO₄(aq) that is neutralised in the experiment.

amount of H₂SO₄(aq) neutralised = ... mol [1]

- (ii) Calculate ΔH_{neut} using the results in Table 2.1. Include units in your answer.

Assume that:

- the specific heat capacity of the final solution is 4.18 J g⁻¹ K⁻¹
- 1.00 cm³ of the final solution has a mass of 1.00 g
- there is no heat loss to the surroundings
- full dissociation of H₂SO₄(aq) occurs
- the experiment takes place at constant pressure.

Show your working.

$\Delta H_{\text{neut}} = \dots\dots\dots$ units $\dots\dots\dots$

[3]

- (c) (i) Complete the equation for the reaction that occurs when a solution of $\text{Ba}(\text{OH})_2$ is added to aqueous sulfuric acid. Include state symbols.

..... $\text{H}_2\text{SO}_4(\text{aq})$ + ... $\text{Ba}(\text{OH})_2(\text{aq}) \rightarrow$ [2]

- (ii) Suggest why the enthalpy change of neutralisation cannot be determined using the addition of dilute sulfuric acid to aqueous barium hydroxide.

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

[Total: 9]

3 Chlorine is a very reactive element.

- (a)** Chlorine reacts with silicon to form silicon(IV) chloride.
Describe the appearance of silicon(IV) chloride at room temperature and pressure. State its structure and bonding.

appearance

structure and bonding

[2]

- (b)** Samples of magnesium chloride and phosphorus(V) chloride are added to separate beakers of cold water.

Complete Table 3.1. Ignore temperature changes when considering observations for these reactions.

Table 3.1

	magnesium chloride	phosphorus(V) chloride
appearance at room temperature		
one similarity in observation on addition to cold water		
one difference in observation on addition to cold water		
pH of final solution		

[4]

- (c) (i)** State the reagent and conditions required for the formation of sodium chlorate(V) from $Cl_2(g)$.

..... [1]

- (ii)** Explain why the reaction in **(c)(i)** is described as a disproportionation reaction. Your answer should refer to relevant species and their oxidation numbers.

.....

..... [1]

(d) Chlorine reacts with methane in a series of reactions to produce chloroalkanes.

(i) State the conditions required for chlorine to react with methane.

..... [1]

(ii) One of the products of the reaction is CH_2Cl_2 which reacts further to produce CHCl_3 .

Complete Table 3.2 to show details of the mechanism that forms CHCl_3 from CH_2Cl_2 .

Table 3.2

name of step	equation
initiation	
propagation	$\text{CH}_2\text{Cl}_2 + \text{Cl}^\bullet \rightarrow$
termination	 $\rightarrow \text{CHCl}_3$

[3]

(e) CHCl_3 and HF are used to form CHClF_2 in a substitution reaction.

Construct an equation for this reaction.

..... [1]

(f) **X** is a product of the substitution reaction that occurs when CHClF_2 reacts with Br_2 .

There is only one naturally occurring isotope of fluorine, ^{19}F .

The mass spectrum of **X** shows molecular ion peaks at $m/e = 164, 166$ and 168 .

Complete Table 3.3 to show **all** the molecular ions responsible for each peak.

Table 3.3

m/e	formulae of molecular ions
164	
166	
168	$(\text{CF}_2^{37}\text{Cl}^{81}\text{Br})^+$

[2]

[Total: 15]

4 **V** is a colourless liquid.

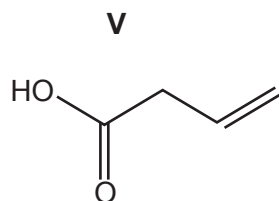
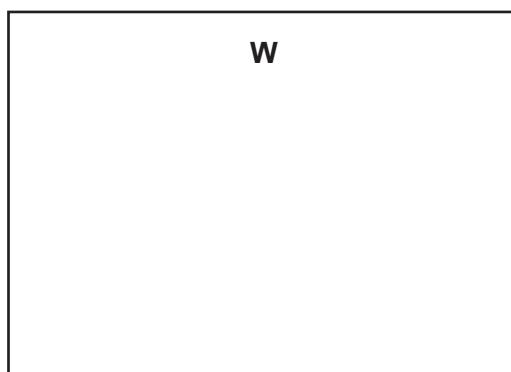


Fig. 4.1

(a) **V** reacts with an excess of LiAlH_4 to form **W**.

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



[1]

(ii) Identify the role of LiAlH_4 in the reaction with **V**.

..... [1]

(b) **V** reacts to form **Z** in a single reaction, as shown in Fig. 4.2.

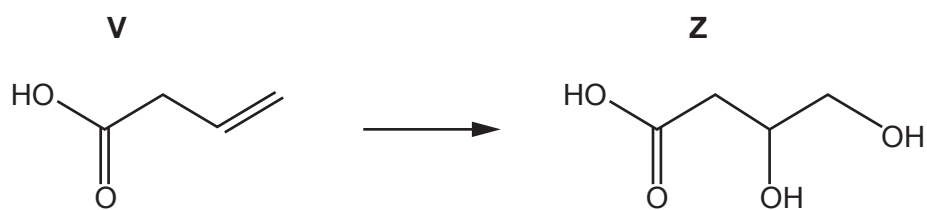


Fig. 4.2

(i) Suggest the reagent and conditions needed to form **Z** from **V**.

..... [1]

(ii) Deduce the empirical formula of **Z**.

..... [1]

- (iii) Complete Table 4.1 to show the number of sp^2 and sp^3 hybridised carbon atoms that are present in a molecule of **V**.

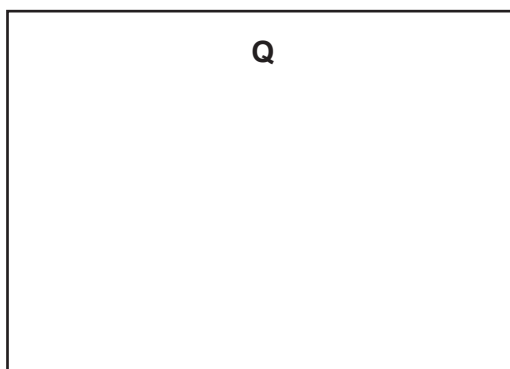
Table 4.1

type of hybridisation	sp^2	sp^3
number of carbon atoms in V		

[2]

- (c) **Q** contains the elements carbon, hydrogen and oxygen only. It is a saturated molecule with no branching in its carbon backbone.
Q contains only one functional group.
 The relative molecular mass of **Q** is 88.
 No effervescence is seen when Na_2CO_3 is added to **Q**.
 Effervescence is seen when sodium is added to **Q**.
Q reacts with alkaline $I_2(aq)$ to form a yellow precipitate.

Draw the structure of **Q** in the box.



[2]

[Total: 8]

- 5 (a) Molecule **M** is present in petrol, a fuel used in cars. **M** is a saturated, non-cyclic hydrocarbon. **M** contains eight carbon atoms.

(i) Construct an equation for the complete combustion of **M**.

..... [2]

(ii) Describe how the composition of products differs when incomplete combustion of **M** occurs.

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

- (b) When petrol is burned in an internal combustion engine, oxides of nitrogen are released into the atmosphere. Oxides of nitrogen are responsible for the formation of acid rain.

(i) Suggest the conditions required for the production of oxides of nitrogen during combustion of **M** in an internal combustion engine. Use an appropriate equation in your answer.

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

(ii) Describe how acid rain is formed in the atmosphere in the presence of oxides of nitrogen and SO_2 . Identify the role of the oxides of nitrogen in this process. Include **all** relevant equations.

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

(iii) State **one** other type of air pollution that is caused by the production of oxides of nitrogen in an internal combustion engine.

..... [1]

- (c) Biodiesel **T** is a fuel made from vegetable oil **R**. Fig. 5.1 shows the production of **T** from **R** in a two-step process.

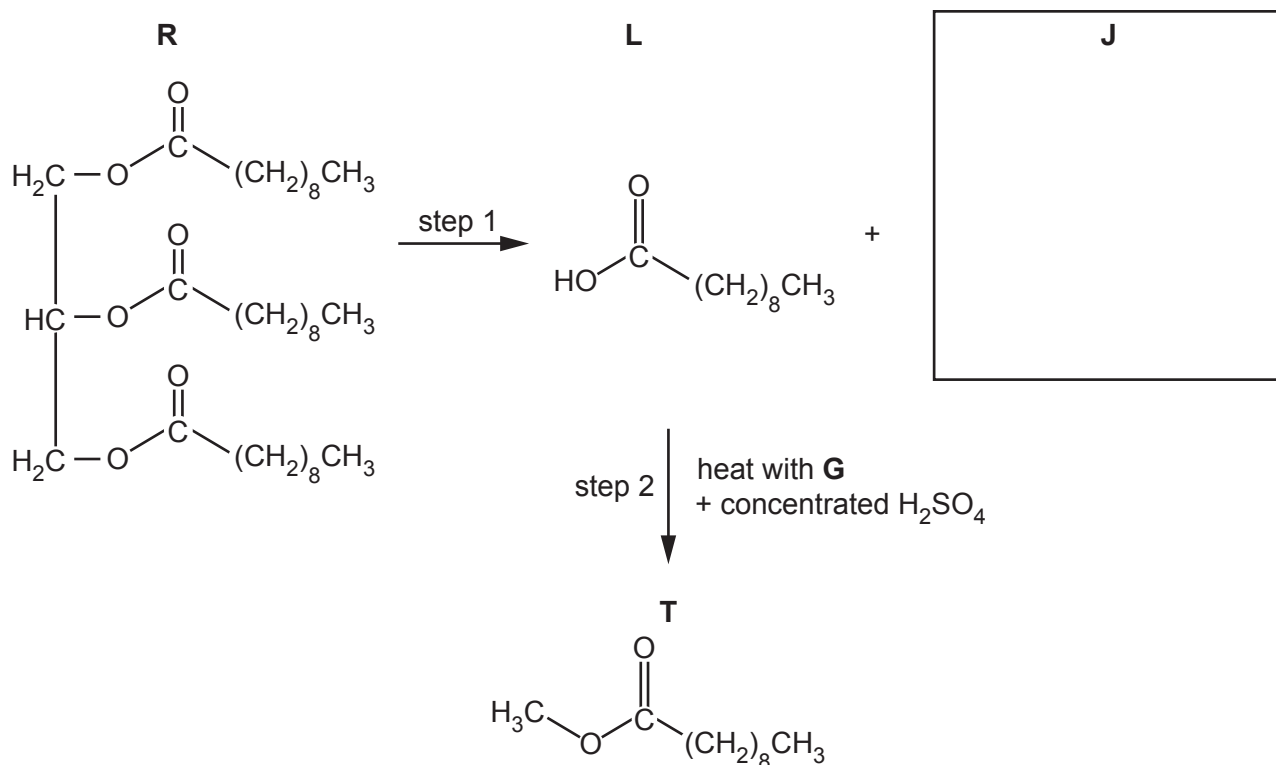


Fig. 5.1

- (i) In step 1 all three ester groups in **R** react. Suggest a suitable reagent and conditions for step 1. [1]
- [1]
- (ii) Draw the structural formula of **J** in the box in Fig. 5.1. [1]
- (iii) Name the type of reaction that occurs in step 2. [1]
- [1]
- (iv) Name organic reagent **G** used in step 2. [1]
- [1]
- (v) **L** is called decanoic acid. Use systematic nomenclature to deduce the name of **T**. [1]
- [1]

[Total: 15]

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													13	14	15	16	17	18			
														1 H hydrogen 1.0								2 He helium 4.0
																				Key		
																				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 oganesson —				

lanthanoids

actinoids

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



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9701/22

May/June 2023

1 hour 15 minutes

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[Turn over

- 1 The melting points of some solids are shown in Table 1.1.

Table 1.1

solid	melting point/K
magnesium	923
phosphorus	317
sodium chloride	1074
sulfur	392

- (a) (i) State the type of bonding present in magnesium and in sodium chloride.

bonding in magnesium

bonding in sodium chloride

[1]

- (ii) Explain the difference in the melting points of magnesium and sodium chloride.

.....

..... [1]

- (iii) Explain the difference in the melting points of phosphorus and sulfur in terms of structure and bonding.

.....

.....

..... [2]

- (b) (i) Define electronegativity.

.....

..... [1]

- (ii) Explain why electronegativity increases across a period.

.....

.....

..... [2]

- (iii) Name the strongest intermolecular force that exists between $\text{NH}_3(\text{l})$ molecules.

..... [1]

- (iv) Draw a diagram to show the formation of the strongest intermolecular force between **two** molecules of $\text{NH}_3(\text{l})$.

Include any relevant lone pairs of electrons and dipoles.

[2]

- (v) The melting points of ice and ammonia are shown in Table 1.2.

Table 1.2

solid	melting point/K
ice	273
ammonia	195

Suggest **two** reasons for the difference in the melting points of ice and ammonia.

.....

 [2]

[Total: 12]

2 Chlorine is a reactive element. It forms many compounds.

- (a) (i) Complete Table 2.1 to show the maximum oxidation number of the elements Na to P in their chlorides.

Table 2.1

element	Na	Mg	Al	Si	P
maximum oxidation number					

[1]

- (ii) State what determines the maximum oxidation number of elements in Period 3.

.....
 [1]

(b) An excess of cold water is added to the chloride of silicon.

- (i) Write an equation for the reaction between an excess of cold water and the chloride of silicon.

..... [1]

- (ii) Suggest the pH of the solution produced in (b)(i).

..... [1]

(c) An excess of cold water is added to the chloride of phosphorus.

- (i) Write an equation for the reaction between an excess of cold water and the chloride of phosphorus.

..... [1]

- (ii) Suggest the pH of the solution produced in (c)(i).

..... [1]

(d) (i) Write an equation for the reaction of chlorine with water.

..... [1]

- (ii) Write an equation for the reaction of chlorine with hot NaOH(aq).

..... [1]

- (e) Bleach is used as a cleaning product to kill bacteria. It is made by adding compounds like sodium chlorate(I), NaClO , to water.

(i) Identify the formula of the ion present in bleach that kills bacteria.

..... [1]

(ii) Sodium chlorate(I), NaClO , reacts with hydrogen peroxide to produce sodium chloride, water and oxygen gas.

Construct an equation for this reaction.

..... [1]

(iii) A sample of bleach **W** contains an unknown concentration of sodium chlorate(I).

10.0cm^3 of **W** is diluted with distilled water to make a total volume of 100cm^3 of bleach solution. 25.0cm^3 of this diluted bleach solution is added to an excess of hydrogen peroxide and the volume of gas produced measured under room conditions. The experiment is repeated and on average 25.0cm^3 of diluted bleach solution produces 42.0cm^3 of gas.

Calculate the concentration, in g dm^{-3} , of sodium chlorate(I) in **W**.

concentration of NaClO in **W** = ... g dm^{-3} [3]

[Total: 13]

- 3 Fig. 3.1 describes a sequence of reactions that can be used to produce a food additive, compound **Y**, from $\text{CH}_3\text{CH}_2\text{Cl}$.

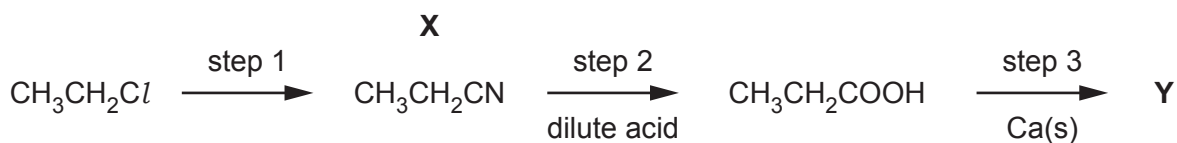


Fig. 3.1

- (a) (i) State the reagent and conditions for step 1 in Fig. 3.1.

..... [1]

- (ii) Give the systematic name of **X**.

..... [1]

- (iii) Identify the type of reaction that occurs when dilute acid is added to **X** in step 2.

..... [1]

- (iv) In step 3, **Y** and a gas are produced.
Construct an equation for step 3.

..... [2]

- (b) $\text{CH}_3\text{CH}_2\text{COOH}$ can also be formed from propan-1-ol and potassium dichromate(VI).
State the conditions required.

..... [1]

- (c) Complete Table 3.1 to show the number of sigma bonds (σ) and pi bonds (π) present in a molecule of **X**.

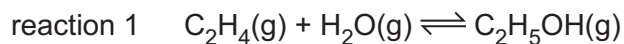
Table 3.1

type of bond	number of bonds in X
sigma (σ)	
pi (π)	

[2]

[Total: 8]

- 4 In industry, ethanol is made by reacting ethene with steam in the presence of H_3PO_4 .



- (a) Use the bond energy values in Table 4.1 to calculate the enthalpy change, ΔH_r , for reaction 1.

Table 4.1

bond	bond energy / kJ mol^{-1}
C–C	350
C=C	610
C≡C	840
C–H	410
C–O	360
C=O	740
O–H	460

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

- (b) Reaction 1 reaches equilibrium at constant temperature and pressure.

Deduce what effect increasing the pressure will have on the amount of ethanol in the new equilibrium mixture. Use Le Chatelier's principle to explain your answer.

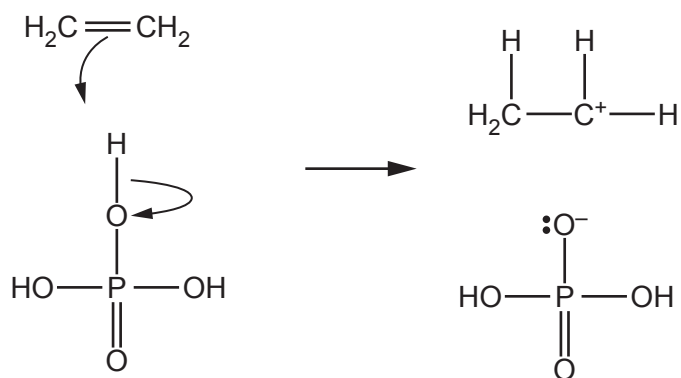
effect of increasing pressure

explanation

..... [2]

- (c) The mechanism for reaction 1 can be described in three steps. Steps 1 and 2 for reaction 1 are shown in Fig. 4.1.

step 1



step 2

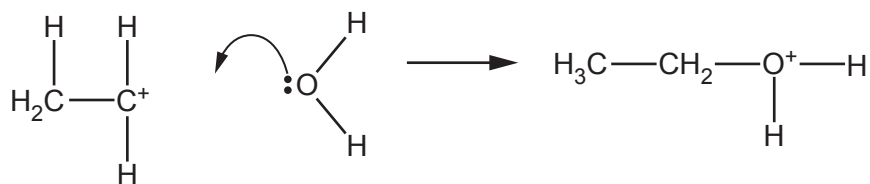


Fig. 4.1

- (i) Describe the behaviour of H_3PO_4 in step 1 in Fig. 4.1. Explain your answer.

.....
 [1]

- (ii) Identify the species that behaves as an electrophile in step 2 in Fig. 4.1. Explain your answer.

.....
 [1]

- (iii) Complete Fig. 4.2 to show the mechanism for step 3 of reaction 1. Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

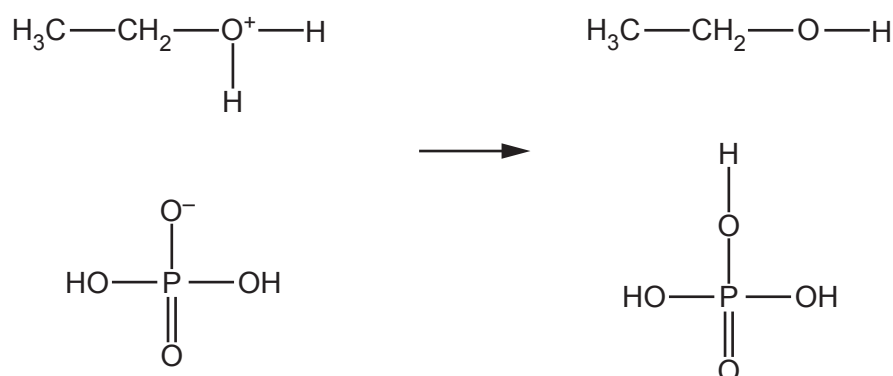


Fig. 4.2

[2]

- (iv) Describe how a catalyst affects a reaction. Explain your answer.

.....
 [2]

- (v) Use Fig. 4.1 and Fig. 4.2 to justify why H_3PO_4 is described as a catalyst in reaction 1.

.....
 [1]

- (vi) Propene also reacts with steam. A mixture of organic products is produced.

Explain why propan-2-ol is produced in the higher yield.

.....

 [2]

- (d) Describe the covalent bonds present between the carbon atoms in an ethene molecule by completing Table 4.2.

Table 4.2

	sigma (σ)	pi (π)
type of orbitals involved in bond		
how the orbitals overlap		

[2]

[Total: 15]

5 (a) Describe structural isomerism.

.....
 [1]

(b) **A** and **B** are structural isomers with molecular formula $C_5H_{10}O$.

They are both straight-chained molecules with only one functional group.

Table 5.1 describes observations when separate samples of **A** and **B** are added to different reagents.

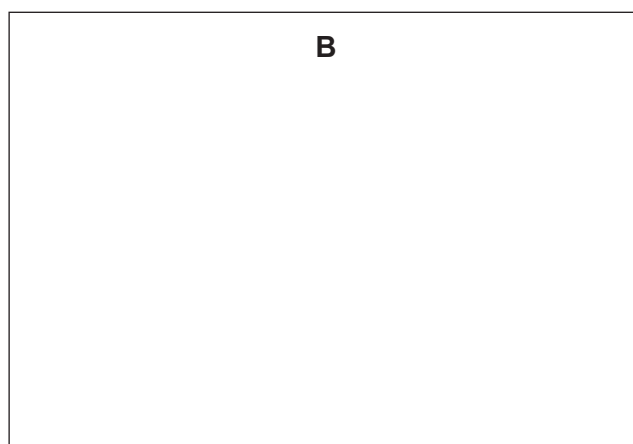
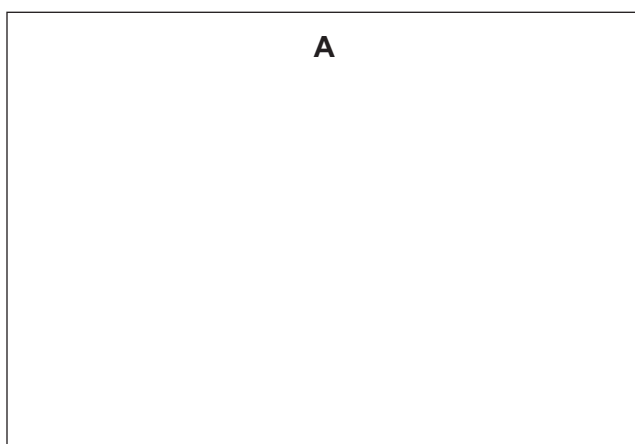
Table 5.1

reagent	A	B
2,4-dinitrophenylhydrazine (2,4-DNPH reagent)	orange precipitate appears	orange precipitate appears
Tollens' reagent	silver mirror appears	no reaction
alkaline $I_2(aq)$	no reaction	no reaction

(i) Name the functional group present in both **A** and **B**.

..... [1]

(ii) Draw the structures of **A** and **B** in the boxes.



[2]

(c) **C** is a structural isomer of **A** and **B**.

C is straight chained and has two functional groups.

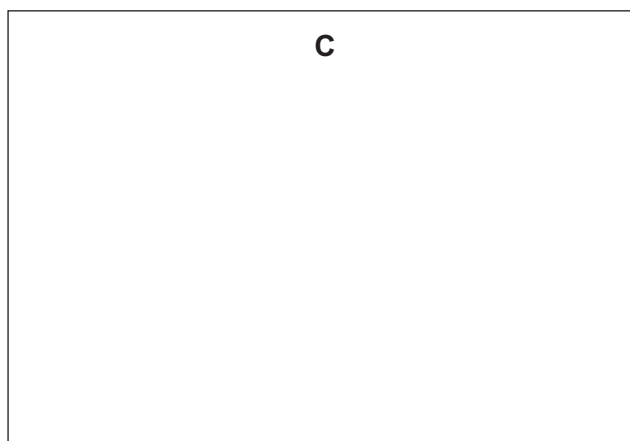
C shows only one type of stereoisomerism.

Table 5.2 describes observations when separate samples of **C** are added to different reagents.

Table 5.2

reagent	C
2,4-dinitrophenylhydrazine (2,4-DNPH reagent)	no reaction
$\text{Br}_2(\text{aq})$	orange to colourless
alkaline $\text{I}_2(\text{aq})$	yellow precipitate appears

(i) Draw the structure of **C** in the box.



[2]

(ii) Name the type of stereoisomerism shown by molecules of **C**.

..... [1]

(d) **D** reacts in the presence of a sulfuric acid catalyst to form **E** and water.

The structure of **E** is shown in Fig. 5.1.

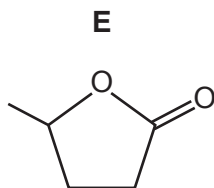


Fig. 5.1

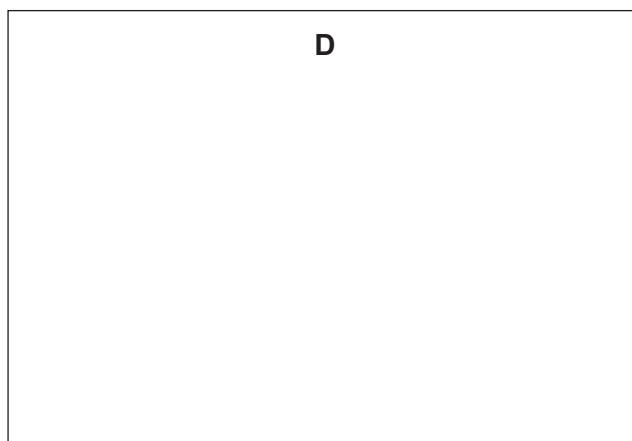
(i) Name the functional group present in **E**.

..... [1]

(ii) Identify the type of reaction that occurs when **D** reacts to form **E**.

..... [1]

(iii) Draw the structure of **D** in the box.



[1]

(iv) The infrared spectrum of **E** is shown in Fig. 5.2.

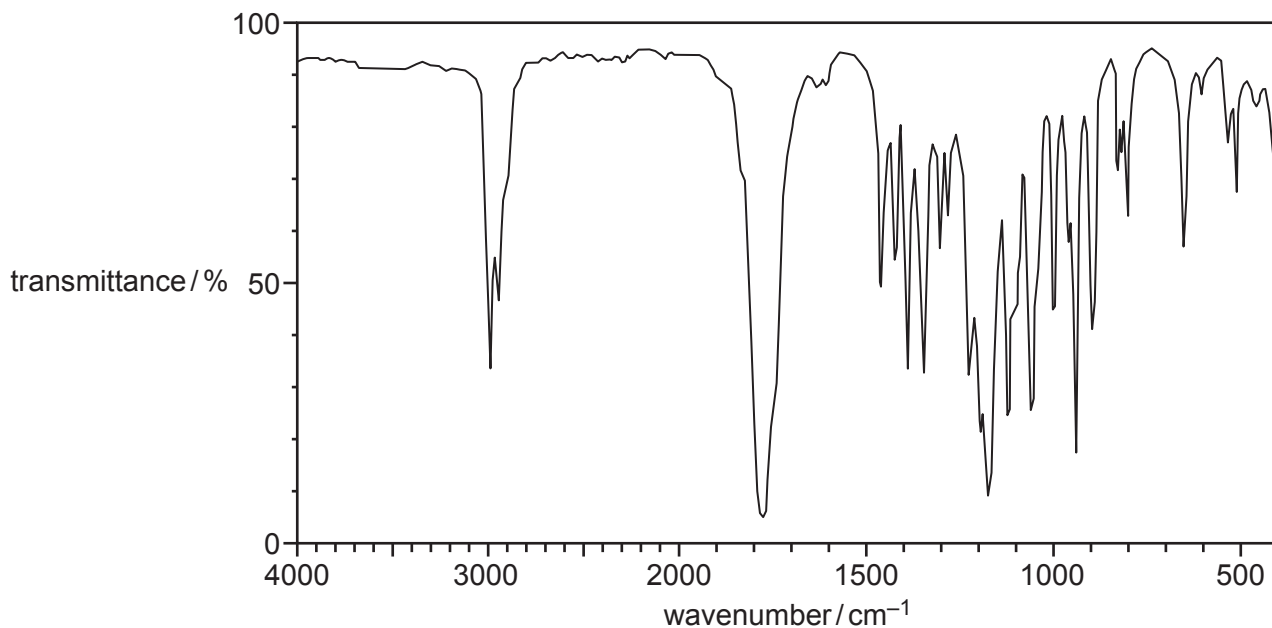


Fig. 5.2

Table 5.3

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 3200–3600

Use Fig. 5.2 and Table 5.3 to predict **two** differences in the absorptions above 1500 cm^{-1} of the infrared spectrum of **D** compared to **E**. Explain your answer.

.....

.....

..... [2]

[Total: 12]

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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 atomic number atomic symbol name relative atomic mass											1 H hydrogen 1.0															
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												
19	20											31	32	33	34	35												
K potassium 39.1	Ca calcium 40.1											Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9												
37	38											49	50	51	52	53												
Rb rubidium 85.5	Sr strontium 87.6											In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9												
55	56											81	82	83	84	85												
Cs caesium 132.9	Ba barium 137.3											Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —												
87	88											113	114	115	116	117												
Fr francium —	Ra radium —											Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —												
												112	113	114	115	116	117											
												Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —											
												111	112	113	114	115	116	117										
												Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —										
												109	110	111	112	113	114	115	116	117								
												Mt meitnerium —	Ds darmstadtium —	Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —								
												108	109	110	111	112	113	114	115	116	117							
												Hs hassium —	Mt meitnerium —	Ds darmstadtium —	Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —							
												76	77	78	79	80	81	82	83	84	85							
												Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —							
												75	76	77	78	79	80	81	82	83	84	85						
												Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —						
												74	75	76	77	78	79	80	81	82	83	84	85					
												W tungsten 183.8	Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —					
												73	74	75	76	77	78	79	80	81	82	83	84	85				
												Ta tantalum 180.9	W tungsten 183.8	Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —				
												72	73	74	75	76	77	78	79	80	81	82	83	84	85			
												Hf hafnium 178.5	Ta tantalum 180.9	W tungsten 183.8	Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —			
												41	42	43	44	45	46	47	48	49	50	51	52	53				
												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			
												39	40	41	42	43	44	45	46	47	48	49	50	51	52	53		
												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		
												21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
												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		
												3	4	5	6	7	8	9	10	11	12							
												3	4	5	6	7	8	9	10	11	12							

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	168.9	69	Tm	thulium	168.9	70	Yb	yterbium	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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CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/23

May/June 2023

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

- The total mark for this paper is 60.
- The number of marks for each question or part question is shown in brackets [].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **20** pages. Any blank pages are indicated.

1 Copper is used in electrical equipment. It has a melting point of 1085 °C.

(a) (i) Identify the lattice structure of copper.

..... [1]

(ii) Draw a labelled diagram to show the bonding present in copper.

[1]

(b) The relative isotopic masses and natural abundances of the two isotopes in a sample of copper are shown in Table 1.1.

Table 1.1

isotope	relative isotopic mass	% abundance
^{63}Cu	62.930	69.15
^{65}Cu	64.928	30.85

(i) Define the unified atomic mass unit.

.....
 [1]

(ii) Define relative atomic mass, A_r , in terms of the unified atomic mass unit.

.....
 [1]

(iii) Calculate the relative atomic mass, A_r , of copper in this sample using the data in Table 1.1.

Show your working.

$A_r =$ [1]

(c) The mass spectrum of a sample of pure copper is shown in Fig. 1.1.

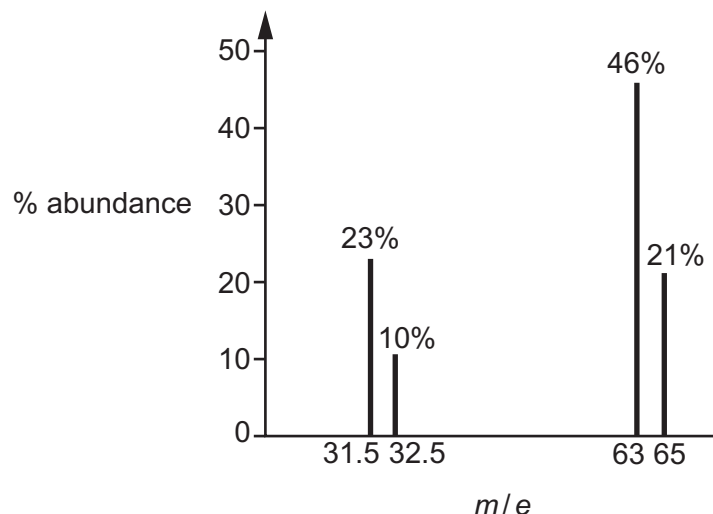


Fig. 1.1

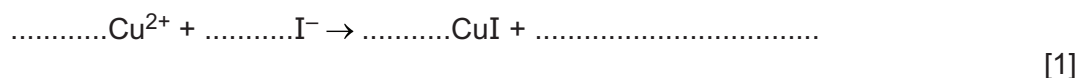
Identify the ion with an abundance of 23% in the sample.

..... [1]

(d) When KI(aq) is added to $\text{CuSO}_4\text{(aq)}$ the blue-coloured solution turns brown and a white precipitate of CuI(s) is seen.

The reaction between copper ions and iodide forms only two products.

(i) Complete the equation for this reaction.



(ii) Identify the oxidising agent in this reaction. Explain your answer in terms of electron transfer.

.....
 [1]

(iii) State the full electronic configuration of Cu^{2+} .

..... [1]

[Total: 9]

- 2 (a) The reaction of pure aluminium is only observed if the aluminium oxide layer is removed first. When pure aluminium is added to cold water, bubbles of gas are seen.

(i) State **one** property of aluminium oxide that explains why an aluminium object does **not** react with cold water until the aluminium oxide layer is removed.

..... [1]

(ii) Write an equation, with state symbols, for the reaction of aluminium oxide with an excess of NaOH(aq).

..... [2]

(iii) Name **one** other Period 3 element that also produces bubbles of gas when added to cold water.

..... [1]

- (b) Aluminium nitrate is a white soluble salt. On heating aluminium nitrate, thermal decomposition occurs and a brown gas is seen.

State the formula of the salt of another element in Period 3 which also decomposes on heating to produce a brown gas.

..... [1]

- (c) Aluminium chloride and phosphorus chloride are both white solids.

(i) State the maximum oxidation number of aluminium and of phosphorus in these solid chloride salts.

maximum oxidation number of aluminium

maximum oxidation number of phosphorus

[1]

(ii) State why the maximum oxidation number of aluminium is different from that of phosphorus.

.....

..... [1]

(iii) Write an equation for the reaction of solid phosphorus chloride and excess water.

..... [1]

- (iv) Name the type of reaction that occurs when aluminium chloride is added to water.

..... [1]

- (v) Explain why the solution produced after aluminium chloride is added to water has a pH of 1–2.

.....

..... [1]

[Total: 10]

- 3 A neutralisation reaction occurs when NaOH(aq) is added to H₂SO₄(aq).



- (a) Define enthalpy change of neutralisation, ΔH_{neut} .

.....

 [2]

- (b) In an experiment, 50.0 cm³ of 2.00 mol dm⁻³ NaOH(aq) is added to 60.0 cm³ of 1.00 mol dm⁻³ H₂SO₄(aq) in a polystyrene cup and stirred. Both solutions have a temperature of 21.4 °C before mixing. The maximum temperature of the mixture is measured.

- (i) Use equation 1 to calculate the amount, in mol, of H₂SO₄(aq) that is neutralised in the experiment.

amount of H₂SO₄ neutralised = ... mol [1]

- (ii) Calculate the theoretical maximum temperature of the mixture in this experiment.

Assume that:

- enthalpy change of neutralisation, ΔH_{neut} , of NaOH(aq) and H₂SO₄(aq) is -57.1 kJ mol⁻¹
- full dissociation of H₂SO₄(aq) occurs
- the specific heat capacity of the final solution is 4.18 J g⁻¹ K⁻¹
- 1.00 cm³ of the final solution has a mass of 1.00 g
- there is no heat loss to the surroundings
- the experiment takes place at constant pressure.

Show your working.

theoretical maximum temperature = ... °C [3]

(c) The enthalpy change of neutralisation of $\text{CH}_3\text{COOH}(\text{aq})$ and $\text{NaOH}(\text{aq})$ is $-55.2 \text{ kJ mol}^{-1}$.

(i) Complete the equation for the reaction.



(ii) Values for the enthalpy change of neutralisation, ΔH_{neut} , are shown in Table 3.1.

Table 3.1

reagents	$\Delta H_{\text{neut}}/\text{kJ mol}^{-1}$
$\text{NaOH} + \text{HCl}$	-57.1
$\text{NaOH} + \text{CH}_3\text{COOH}$	-55.2

Suggest why the value for ΔH_{neut} of the weak acid, CH_3COOH , reacting with NaOH is different to the value obtained using the strong acid, HCl . Assume that the values are determined under the same conditions.

.....
 [1]

[Total: 8]

- 4 (a) Hydrogen chloride gas is made in the laboratory by adding concentrated sulfuric acid to potassium chloride.

(i) Construct an equation for this reaction.

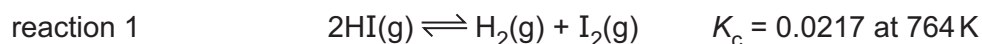
..... [1]

(ii) Explain why hydrogen iodide is **not** prepared by adding concentrated sulfuric acid to sodium iodide.

.....

..... [2]

- (b) A sample of HI(g) is added to a 2.00 dm³ sealed vessel at 764 K and allowed to reach equilibrium.



At equilibrium the mixture contains 1.70 mol of HI(g).

(i) State **one** difference in the appearance of the initial reaction mixture compared to the mixture at equilibrium.

.....

..... [1]

(ii) Deduce the expression for equilibrium constant K_c for reaction 1.

$K_c =$

[1]

(iii) Calculate the concentration of I₂ present in the reaction mixture at equilibrium. Show your working.

concentration of I₂ = ... mol dm⁻³ [3]

(c) The experiment is repeated at 500 K. The value of K_c under these conditions is 0.00625.

- (i) Describe the difference in the composition of the equilibrium mixture at 500 K compared to 764 K.

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

- (ii) Use Le Chatelier's principle to deduce whether the decomposition of HI(g) is endothermic or exothermic. Explain your answer.

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

[Total: 10]

5 **Y** is formed from **X** in a single-step reaction, as shown in Fig. 5.1.



Fig. 5.1

(a) Deduce the empirical formula of **Y**.

..... [1]

(b) The formation of **Y** from **X** requires the addition of a suitable reducing agent.

(i) Construct an equation using molecular formulae and [H] for the reaction in Fig. 5.1. Use [H] to represent one atom of hydrogen from the reducing agent.

..... [1]

(ii) Identify a suitable non-gaseous reducing agent for the formation of **Y** from **X**.

..... [1]

(c) Complete Table 5.1 to show the number of sp^2 and sp^3 hybridised carbon atoms in a molecule of **X**.

Table 5.1

type of hybridisation	sp^2	sp^3
number of carbon atoms in X		

[2]

- (d) Complete Table 5.2 with the expected observations that occur when the reagents shown are added to separate solutions of **X** and **Y**. Do **not** refer to temperature changes in your answer.

Table 5.2

reagent	observation on addition to X	observation on addition to Y
aqueous sodium carbonate		
2,4-dinitrophenylhydrazine (2,4-DNPH reagent)		
alkaline aqueous iodine		

[3]

[Total: 8]

6 Compound **W**, $\text{CH}_2=\text{CHCN}$, is used to make an addition polymer which is present in carbon fibres.

(a) Draw **one** repeat unit of the addition polymer of **W**.

[1]

(b) CH_3CHO is used in a two-step synthetic route to form **W**, as shown in Fig. 6.1.
In step 1, CH_3CHO is heated with HCN in the presence of KCN .

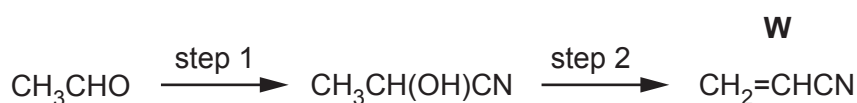


Fig. 6.1

(i) Name the mechanism for the reaction in step 1 in Fig. 6.1.

..... [1]

(ii) Complete Fig. 6.2 to show the mechanism for the reaction in step 1.
Include all products, charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

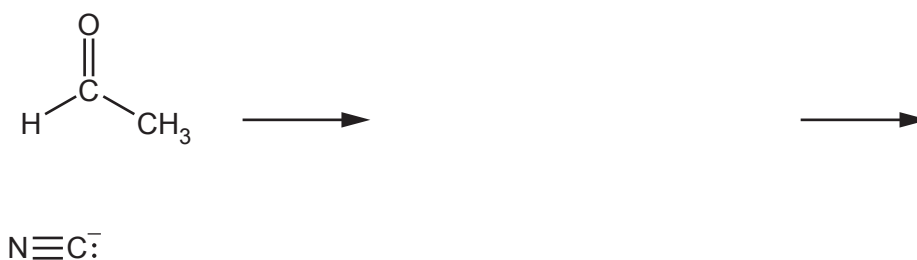


Fig. 6.2

[3]

(iii) Suggest a suitable reagent and conditions for step 2 in Fig. 6.1.

..... [1]

(iv) Fig. 6.3 shows the infrared spectrum of **W**, $\text{CH}_2=\text{CHCN}$.

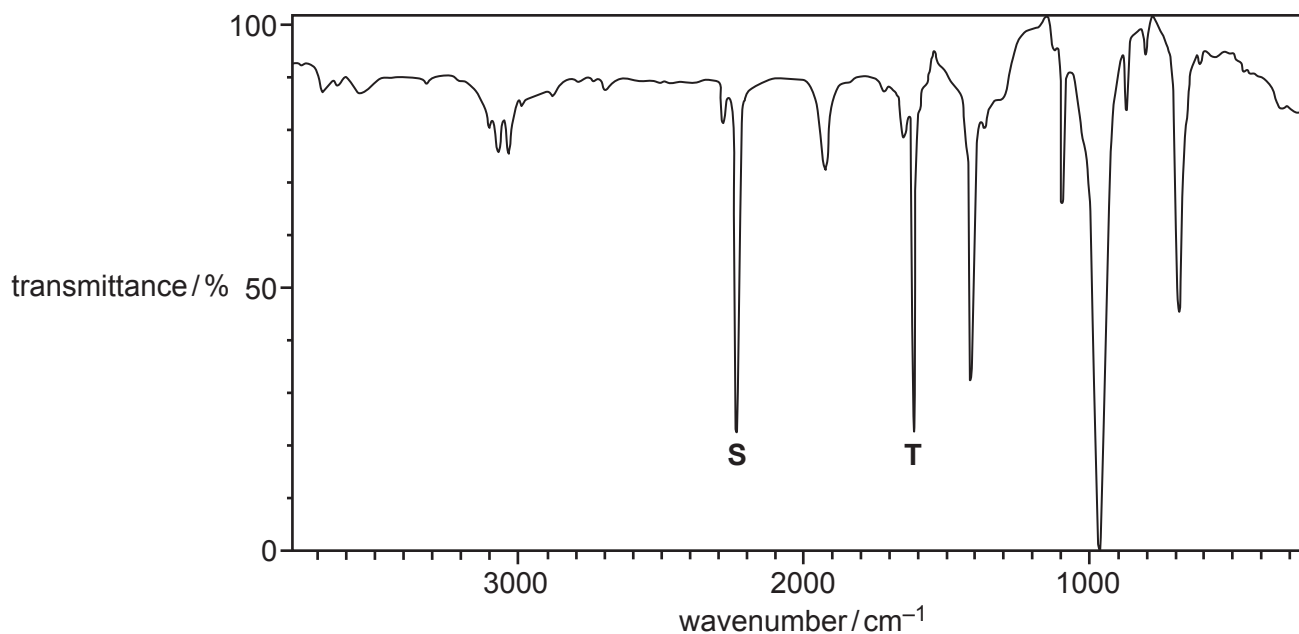


Fig. 6.3

Table 6.1

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers)/ cm^{-1}
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3600

Use Table 6.1 to identify the bonds responsible for the absorptions marked **S** and **T** on Fig. 6.3.

S

T

[1]

(c) Molecules of **W**, $\text{CH}_2=\text{CHCN}$, do **not** show stereoisomerism.

(i) Describe stereoisomerism.

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

(ii) Describe the **two** essential features of an alkene molecule that cause it to show geometrical stereoisomerism.

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

(d) Molecules of $\text{CH}_3\text{CH}(\text{OH})\text{CN}$ exist as a pair of optical isomers.

Draw three-dimensional diagrams in the boxes to show the optical isomers of $\text{CH}_3\text{CH}(\text{OH})\text{CN}$.

isomer 1	isomer 2

[1]

(e) Propanenitrile is heated with hydrogen gas and a platinum catalyst. The only product is propylamine.

Construct an equation for this reaction.

..... [1]

- (f) Propylamine can also be formed in a two-step synthesis from propan-1-ol, as shown in Fig. 6.4.

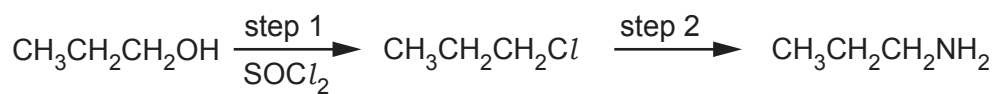


Fig. 6.4

- (i) Name the type of reaction in step 1 in Fig. 6.4.

..... [1]

- (ii) Identify the reagent and conditions for step 2 in Fig. 6.4.

.....

..... [2]

[Total: 15]

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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													13	14	15	16	17	18		
		1 Hhydrogen1.0																		2 Hehelium4.0	
		Key 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	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 —	actinoids		104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —	113 Nh nihonium —	114 Fl flerovium —	115 Mc moscovium —	116 Lv livermorium —	117 Ts tennessine —	118 Og oganesson —			
lanthanoids		57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.4	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 —					

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 —