Past-paper walk-through

Mass spectrometry ▪ 22.2

eXercise

Questions in this set

- 9701/21 N25 Q4 ▪ 15 marks
- 9701/22 N25 Q4 ▪ 16 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 4

9701/21 N25 ▪ Q4 ▪ 15 marks

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

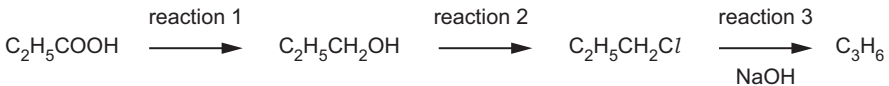


Fig. 4.1

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

Question 4

(ii) Suggest a suitable reagent for reaction 2.

Question 4

(iii) Reaction 3 is an elimination reaction.

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

Question 4

Question 4

[2]

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

Suggest the reagent and conditions for this conversion.

Question 4

(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.

Question 4

(ii) Define stereoisomerism.

Question 4

(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)

Question 4

[3]

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

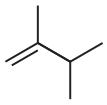
Question 4

Question 4

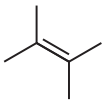
[2]

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

X



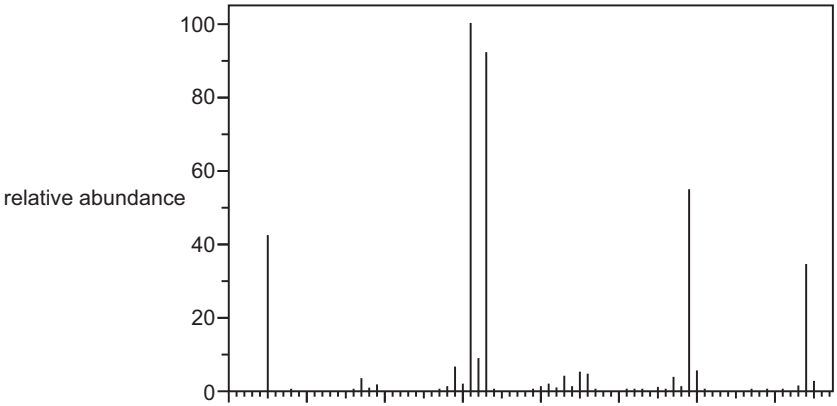
Y



(i) Name **X**.

Question 4

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



Question 4

10 20 30 40 50 60 70 80

Question 4

Fig. 4.2

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

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

Question 4

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

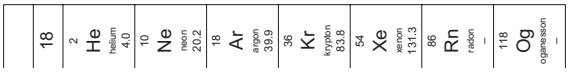
Calculate the relative abundance of the $[M+1]^+$ peak in this spectrum.

Question 4

[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	$c = 4.18\,\text{kJ kg}^{-1}\,\text{K}^{-1}$ ($4.18\,\text{J g}^{-1}\,\text{K}^{-1}$)



nts

		13	14	15	16	17
		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
1	12	13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5
9 u per .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
7 g er 7.9	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
9 u id 7.0	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 –
1 g enium ·	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –

5 b ium 3.9	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
7 k lium ·	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –

The Periodic Table of Elemer

Group

1
H
hydrogen
1.0

Key

atomic number
omic symbol
name
lative atomic mass

5	6	7	8	9	10	1
23	24	25	26	27	28	2
V	Cr	Mn	Fe	Co	Ni	C
vanadium	chromium	manganese	iron	cobalt	nickel	copp
50.9	52.0	54.9	55.8	58.9	58.7	63
41	42	43	44	45	46	4
Nb	Mo	Tc	Ru	Rh	Pd	A
niobium	molybdenum	technetium	ruthenium	rhodium	palladium	silv
92.9	95.9	–	101.1	102.9	106.4	107
73	74	75	76	77	78	7
Ta	W	Re	Os	Ir	Pt	A
tantalum	tungsten	rhenium	osmium	iridium	platinum	gol
180.9	183.8	186.2	190.2	192.2	195.1	197
105	106	107	108	109	110	11
Db	Sg	Bh	Hs	Mt	Ds	R
dubnium	seaborgium	bohrium	hassium	meitnerium	darmstadtium	roentge
–	–	–	–	–	–	–

59	60	61	62	63	64	6
Pr	Nd	Pm	Sm	Eu	Gd	T
praseodymium	neodymium	promethium	samarium	europium	gadolinium	terbi
140.9	144.2	–	150.4	152.0	157.3	15
91	92	93	94	95	96	9
Pa	U	Np	Pu	Am	Cm	B
protactinium	uranium	neptunium	plutonium	americium	curium	berke
231.0	238.0	–	–	–	–	–

1	2		
3 Li lithium 6.9	4 Be beryllium 9.0		at rei
11 Na sodium 23.0	12 Mg magnesium 24.3	3	4
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1
actinoids	89 Ac actinium –	90 Th thorium 232.0

Solution 4

(a)(i)

Mark scheme

- reduction
- 1

Solution 4

(a)(ii)

Mark scheme

- PCl5 / PCl3 / SOCl2
- OR KCl / NaCl AND conc. H2SO4 / conc.H3PO4
- 1 M1
- C2H5CH2Cl + NaOH → C3H6 + H2O + NaCl M2
- ethanol (solvent) AND heat / reflux
- 2

Solution 4

(a)(iv)

Mark scheme

- conc. H2SO4 OR conc. H3PO4 OR Al2O3 AND heat
- 1

Solution 4

(b)(i)

Mark scheme

- addition
- 1

Solution 4

(b)(ii)

Mark scheme

- M1 (molecules that have the) same structural formula (and same molecular formula) **M2**
- but different 3D / spatial arrangement of atoms / groups
- 2

Solution 4

(b)(iii)

Mark scheme

- M2 optical isomerism M3
- the methylated carbon has four different groups attached
- 3

Solution 4

(b)(iv)

Mark scheme

- M1 non-biodegradability M2
- harmful combustion products
- 2

Solution 4

(c)(i)

Mark scheme

- 2,3-dimethylbut-1-ene
- 1
- 9701/21
- October/November 2025

Solution 4

(c)(ii) Mark scheme

- (The spectrum is of) X
- AND
- 41 is [CH2=CCH3]+ / 41 is C3H5+
- OR 43 is [CH3CHCH3]+ / 43 is C3H7+
- OR X would NOT have significant peak at 54 / [(CH3)2C=C+] / C4H6+
- OR X would NOT have significant peak at 42 due to [(CH3)2C+] / C3H6+
- 1

Solution 4

(c)(iii)

Mark scheme

- ([M+1]+ / 34.7 × 100 / 1.1 = 6)

M+1 + = 2.29

- 1

Question 4

9701/22 N25 ▪ Q4 ▪ 16 marks

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

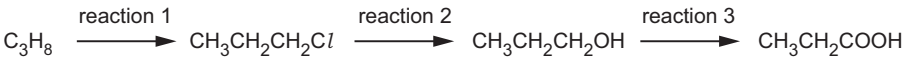


Fig. 4.1

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

$$C_3H_8 + Cl_2 \rightarrow CH_3CH_2CH_2Cl + HCl$$

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

(i) Name the mechanism shown by reaction 1.

Question 4

(ii) Complete the mechanism for reaction 1.

Construct equations to describe the steps of the mechanism.

initiation $Cl_2 \rightarrow 2Cl\bullet$

Question 4

Question 4

Question 4

[3]

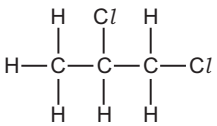
(iii) Reaction 1 is initiated by the bond fission of Cl_2.

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

Question 4

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

Q



Name **Q**.

Question 4

(v) The molecular formula of **Q** is $C_3H_6Cl_2$.

Identify the types of structural isomerism and stereoisomerism that a molecule with molecular formula $C_3H_6Cl_2$ can show.

Question 4

Question 4

[2]

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

Question 4

(c) Reaction 3 takes place when $CH_3CH_2CH_2OH$ is heated under reflux with acidified potassium dichromate(VI) solution.

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

Question 4

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

Question 4

(d) CH_3CH_2COOH reacts with an unsaturated alcohol **R** to form unsaturated ester **S**.

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

Question 4

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

Question 4

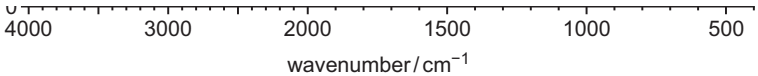


Fig. 4.2

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]

Question 4

[3]

Question 4

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

Question 4

| | | nyaroxy | | 3200–3650 | |

Question 4

(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**.

Question 4

[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))
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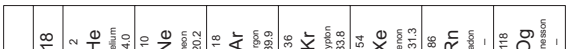

		13	14	15	16	17	
							H hy
		5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	N n 2
	12	13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	A a 3
	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	K kr 8
	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	X xe 1
	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 –	R n
n	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	O oga

	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
	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –

Question 4

The Periodic Table of Elements

Group

1
H hydrogen 1.0

Key

mic number
ic symbol
name
e atomic mass

5	6	7	8	9	10	11
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
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
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
105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgeniun –

59 Pr aseodymium 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
91 Pa rotactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –

1	2			
3 Li lithium 6.9	4 Be beryllium 9.0		ato atom relativ	
11 Na sodium 23.0	12 Mg magnesium 24.3	3	4	
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	pra
actinoids	89 Ac actinium –	90 Th thorium 232.0	p

Solution 4

(a)(i)

Mark scheme

- free-radical substitution
- 1
- 9701/22
- October/November 2025

Solution 4

(a)(ii) Mark scheme

- M1 C3H8 + Cl → CH3CH2CH2 + HCl
- OR C3H8 + Cl → C3H7 + HCl **M2**
- CH3CH2CH2 + Cl2 → CH3CH2CH2Cl + Cl
- OR C3H7 + Cl2 → C3H7Cl + Cl etc **M3**
- CH3CH2CH2 + Cl → CH3CH2CH2Cl
- OR C3H7 + Cl → CH3CH2CH2Cl
- 3

Solution 4

(a)(iii)

Mark scheme

- homolytic
- 1

(a)(iv)

Mark scheme

- 1,2-dichloropropane
- 1

Solution 4

(a)(v)

Mark scheme

- M1 (type of structural isomerism) positional M2
- (type of stereoisomerism) optical
- 2

Solution 4

(b)

Mark scheme

- sodium hydroxide AND water
- 1

Solution 4

(c)(i)

Mark scheme

- orange to green
- 1

(c)(ii)

Mark scheme

- $CH3CH2CH2OH + 2[O] \rightarrow CH3CH2COOH + H2O$
- 1

Solution 4

(d)(i)

Mark scheme

- condensation
- 1

Solution 4

(d)(ii)

Mark scheme

- M1 absorption labelled at approx. 1750 cm–1 identified as C=O M2
- absorption labelled at approx. 1650 cm–1 identified as C=C M3
- absorption labelled at approx. 1170 cm–1 identified as C—O
- 3

Solution 4

(d)(iii)

Mark scheme

- $(0.31 \,/\, 4.7 \times 100 \,/\, 1.1) = 6$ carbon atoms
- 1