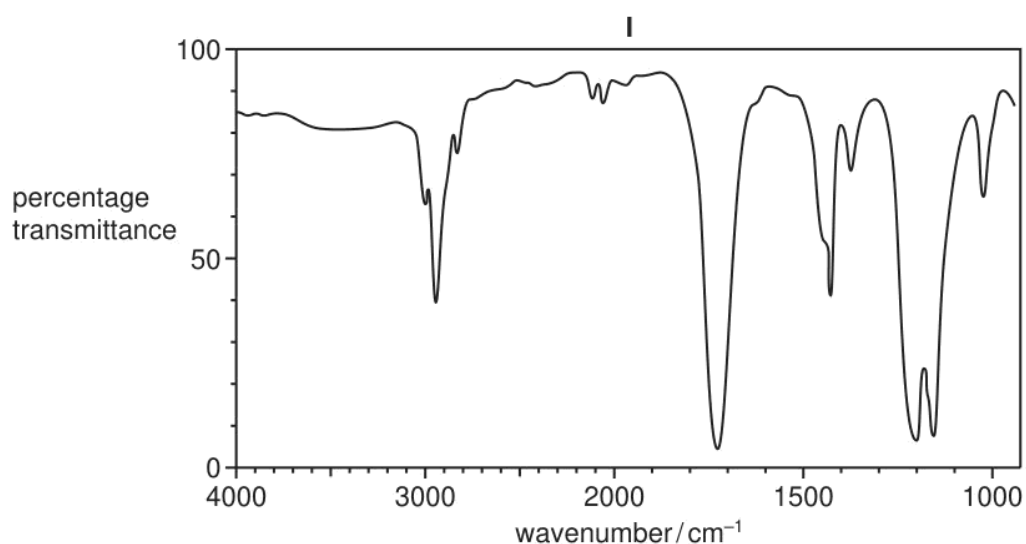
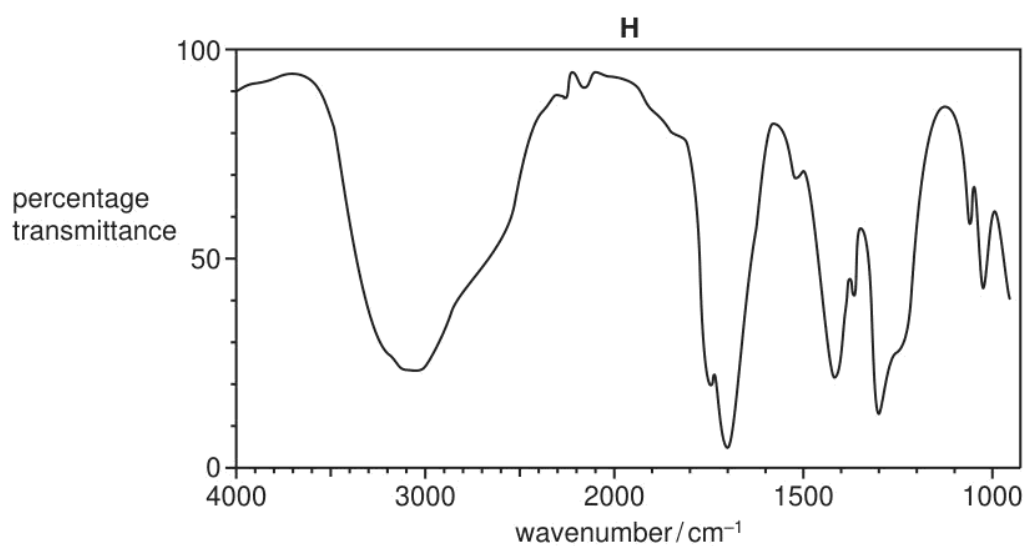


- (d) **H** and **I** are isomers with molecular formula $\text{C}_2\text{H}_4\text{O}_2$. The infra-red spectra of isomers **H** and **I** are shown.



- (i) Identify the bonds responsible for the principal peaks above 1500 cm^{-1} in each spectrum.

spectrum of **H**

.....

spectrum of **I**

.....

[2]

- (ii) Suggest **three** main differences between the infra-red spectra of cyclohexene and adipic acid.

In each case, identify the bond responsible and its characteristic absorption range (in wavenumbers).

1

.....

.....

2

.....

.....

3

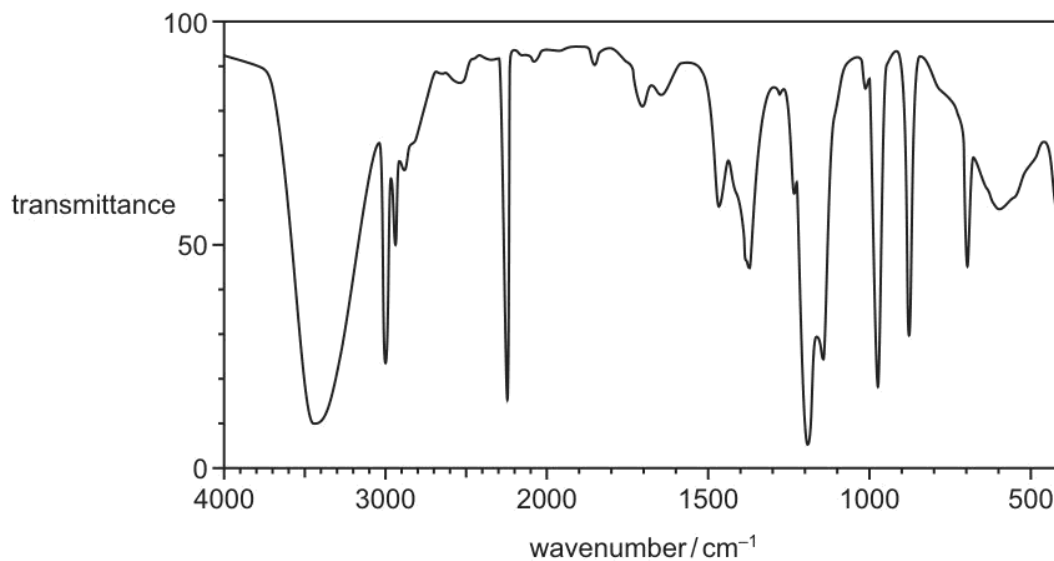
.....

.....

[3]

[Total: 11]

(d) The infra-red spectrum shown corresponds to one of **P**, **Q** or **R**.



Deduce which of the compounds, **P**, **Q** or **R**, produces this spectrum. Explain your reasoning.

In your answer, identify any relevant absorptions in the infra-red spectrum and the bonds that correspond to these absorptions in the region **above** 1500 cm^{-1} .

compound

explanation

.....

.....

[3]

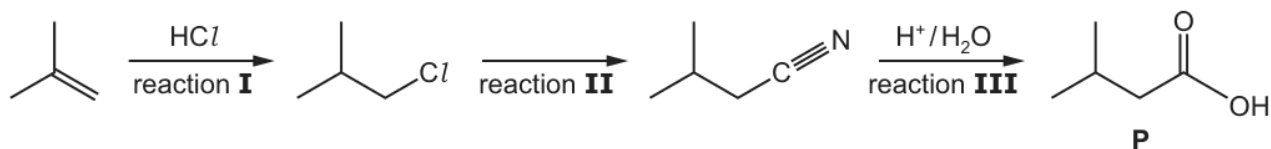
[Total: 9]

(v) Complete the table with the bond responsible for each of the principal absorptions seen in the infra-red spectrum of **Z**.

principal absorptions in infra-red spectrum	bond responsible
$3200\text{--}3600\text{ cm}^{-1}$	
1630 cm^{-1}	
1050 cm^{-1}	

[1]

(e) **P** can be produced as shown.



(i) The progress of reaction **I** can be monitored using infra-red spectroscopy.

One absorption that can be used to monitor the progress of this reaction is that of C–Cl at 730 cm^{-1} .

Identify another absorption that can be used to monitor the progress of this reaction. In your answer, you should refer to the specific bond and its corresponding absorption range in wavenumbers.

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

Oct/Nov 2019 9701/22 · Q4 (e)(i)

- (iii) The C–Br bond has an absorption between 500 cm^{-1} and 600 cm^{-1} in an infrared spectrum.

The infrared spectra for both **T** and **U** have absorptions between 2850 cm^{-1} and 2950 cm^{-1} . These correspond to C–H bonds.

Identify:

- two other absorptions that would be seen in the infrared spectra of both **T** and **U**
- one other absorption that would **only** be seen in the infrared spectrum of **T**.

For each absorption, give the range of the absorption and the bonds that correspond to these absorptions.

absorption 1 present in both spectra

.....

.....

absorption 2 present in both spectra

.....

.....

absorption **only** present in spectrum of **T**

.....

.....

[3]

[Total: 24]

14

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15

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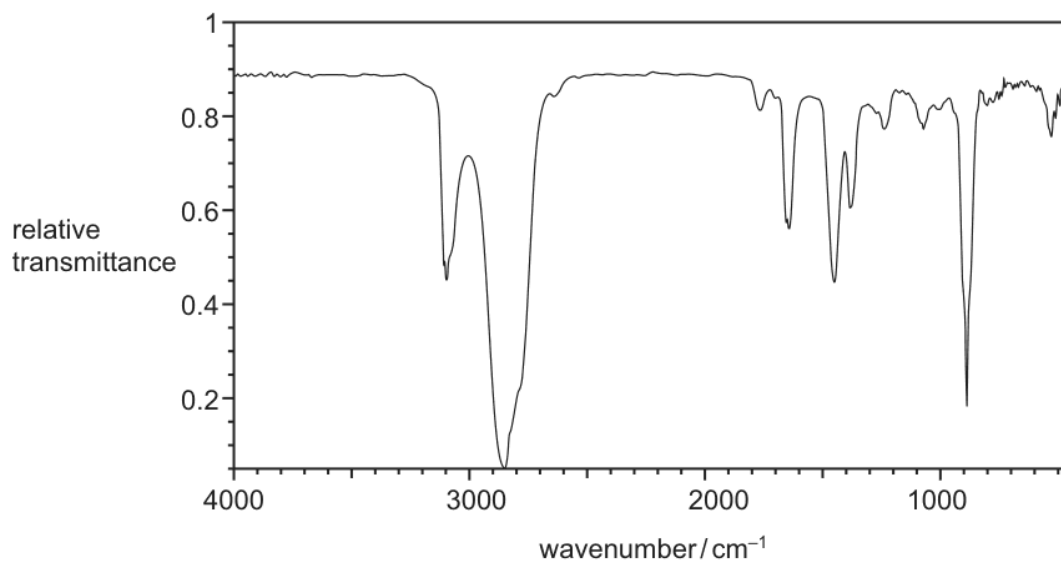
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(e) The infra-red spectrum of 2-methylbut-1-ene is shown.



Predict two main differences that would be seen between the spectra of **Y**, $\text{CH}_3\text{CH}_2\text{COCH}_3$, and of 2-methylbut-1-ene. Give reasons for your predictions.

Your answer should refer only to the region of each spectrum **above** 1500 cm^{-1} .

.....

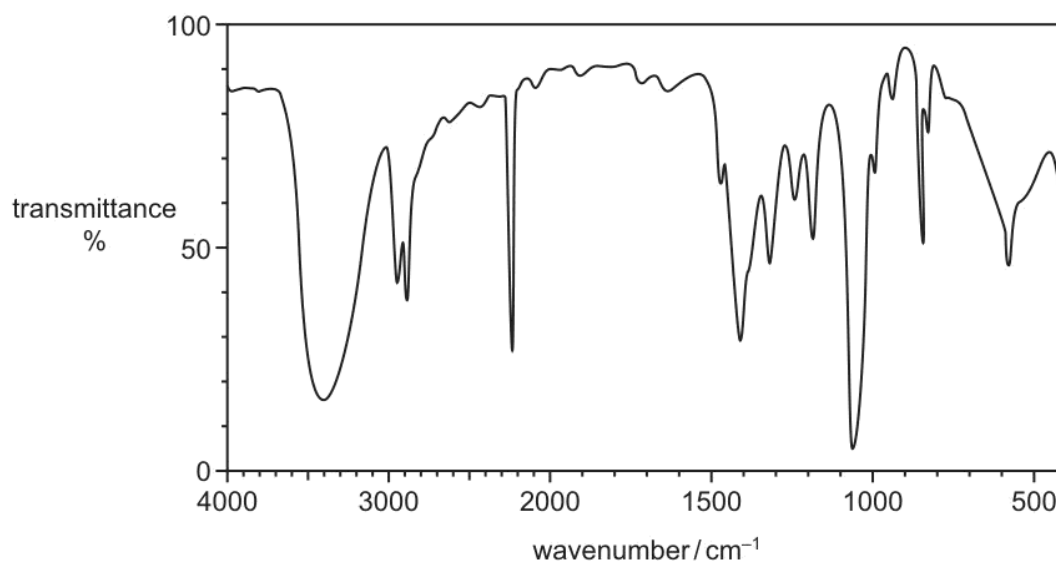
.....

.....

.....

..... [2]

- (v) The infrared spectrum of an organic compound is shown. The organic compound is either **S** or 2-hydroxybutanoic acid.



Deduce the identity of the compound. Give **two** reasons for your answer.

In your answer, identify any relevant absorptions **above 1500 cm⁻¹** in the spectrum and the bonds that correspond to these absorptions.

.....

.....

.....

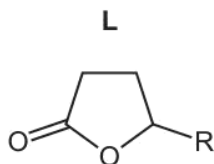
.....

..... [2]

[Total: 17]

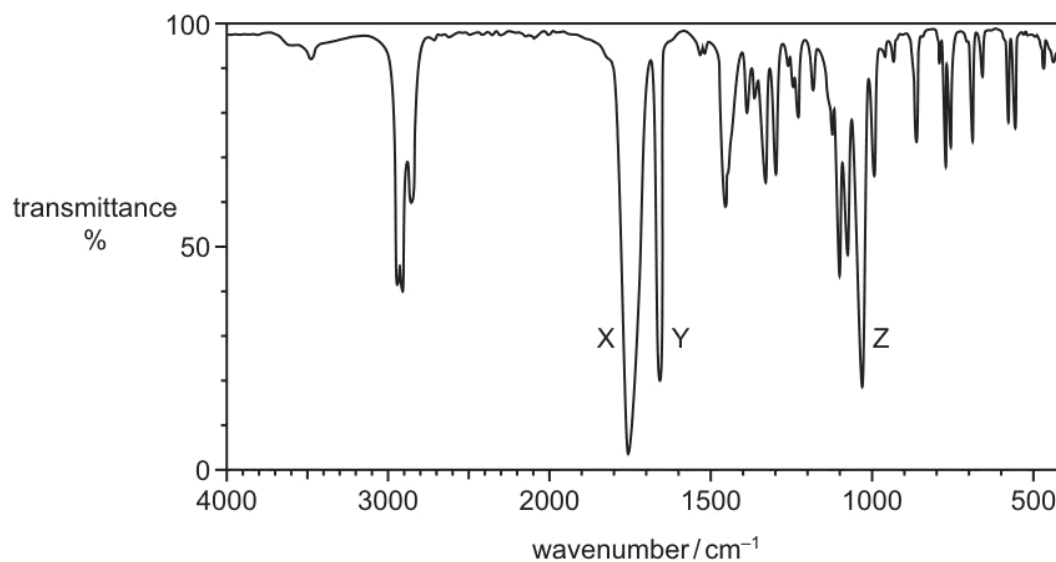
Oct/Nov 2020 9701/21 · Q3 (c)(v)

- (d) The structure of compound **L** is shown. R represents a hydrocarbon chain.



A student was asked to deduce the full structure of **L**.

The student analysed **L** using infrared spectroscopy. The following spectrum was obtained.



- (i) Identify the bonds responsible for the absorptions marked X and Z.

X

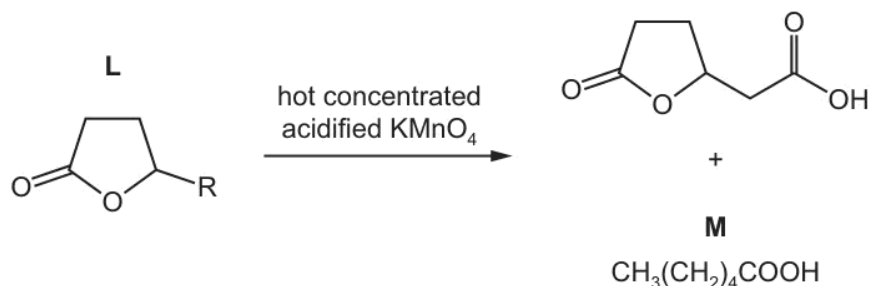
Z

[1]

13

Absorption Y shows that **L** has a C=C bond present in the R group.

The student decided to treat **L** with hot concentrated acidified potassium manganate(VII). The products of the reaction are shown.



Oct/Nov 2020 9701/22 · Q4 (d)(i) (cont.)

(c) **P** and **Q** can be detected in the atmosphere by infrared spectroscopy.

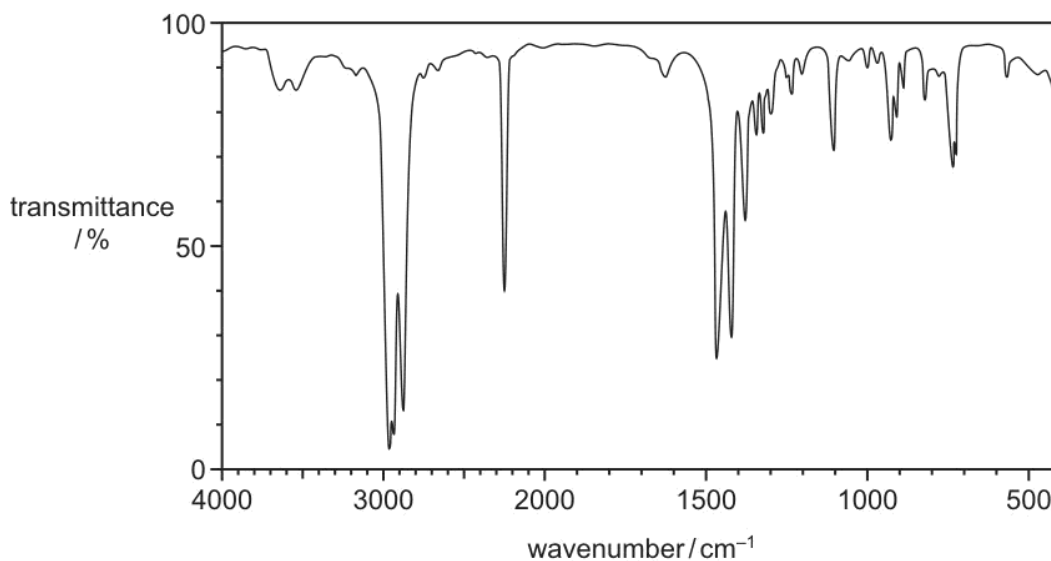
Identify **two** absorptions, and the bonds that correspond to these absorptions, that will appear in the infrared spectra of both **P** and **Q**.

- 1
- 2

[2]

- (v) An unlabelled sample contains either **S**, **T** or **U**.

The sample produces the infrared spectrum shown.



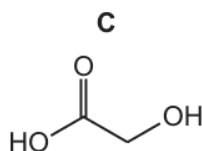
Explain how this spectrum confirms that the unknown sample contains **U**.

In your answer identify **one** relevant absorption in the infrared spectrum and the bond that corresponds to this absorption in the region above 1500 cm⁻¹.

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

[Total: 8]

- (b) Reaction 2 needs to take place in the absence of water to prevent formation of compound **C**.



If **C** is present in the reaction mixture of reaction 3, a different compound, compound **D**, will also form. Compound **D** has two identical functional groups.

The infrared spectrum of **D** shows strong absorptions at 1100cm^{-1} and 1720cm^{-1} , but no absorption due to O–H bonds.

Use the *Data Booklet* to identify the functional group present in **D**.

Explain your answer as fully as you can.

.....

.....

.....

..... [3]

Oct/Nov 2021 9701/21 · Q4 (b)

- (iii) The progress of reaction 2 can be monitored by infrared spectroscopy.

The absorption caused by O–H bonds is always present because water is used as a solvent.

Identify two absorptions, and the bonds responsible for these absorptions, whose appearance will change significantly during the reaction.

1

.....

2

.....

[2]

Oct/Nov 2021 9701/22 · Q3 (d)(iii)

- (iii) Use information from Table 4.2 to suggest how the infrared spectra of
- M**
- and Perspex® would differ. Explain your answer.

.....

..... [1]

Table 4.2

bond	functional group 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	2850–3100
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

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9701/22/F/M/22

[Turn over

March 2022 9701/22 · Q4 (b)(iii)

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

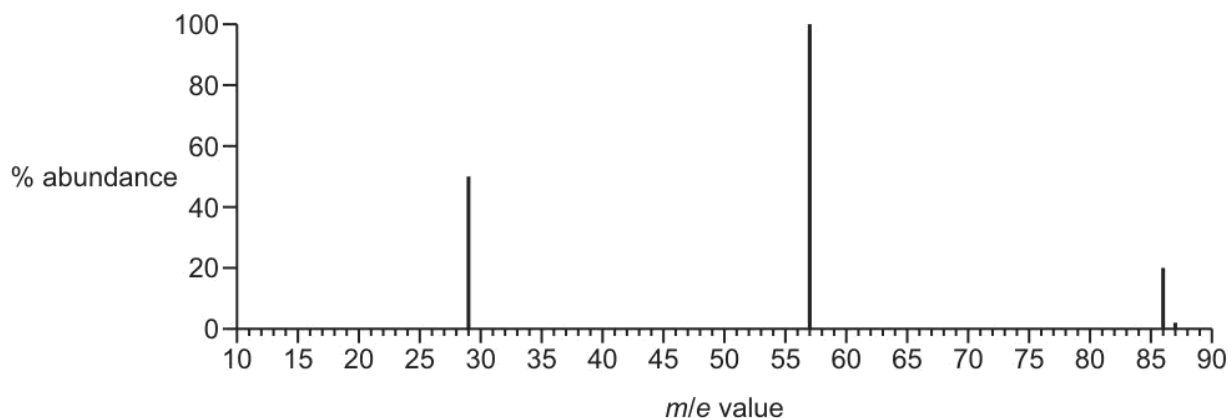


Fig. 5.1

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

$m/e = 29$

$m/e = 57$

identity of **Z**

[3]

[Total: 14]

13

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14

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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)

57	La	lanthanum	138.9
58	Ce	cerium	140.1
59	Pr	praseodymium	140.9
60	Nd	neodymium	144.4
61	Pm	promethium	—
62	Sm	samarium	150.4
63	Eu	europlum	152.0
64	Gd	gadolinium	157.3
65	Tb	terbium	158.9
66	Dy	dysprosium	162.5
67	Ho	holmium	164.9
68	Er	erbium	167.3
69	Tm	thulium	168.9
70	Yb	ytterbium	173.1
71	Lu	lutetium	175.0
72	Hf	hafnium	178.5
73	Ta	tantalum	180.9
74	W	tungsten	183.8
75	Re	rhenium	186.2
76	Os	osmium	190.2
77	Ir	iridium	192.2
78	Pt	platinum	195.1
79	Au	gold	197.0
80	Hg	mercury	200.6
81	Tl	thallium	204.4
82	Pb	lead	207.2
83	Bi	bismuth	209.0
84	Po	polonium	—
85	At	astatine	—
86	Rn	radon	—
87	Fr	francium	—
88	Ra	radium	—
89	Ac	actinium	—
90	Th	thorium	232.0
91	Pa	protactinium	231.0
92	U	uranium	238.0
93	Np	neptunium	—
94	Pu	plutonium	—
95	Am	americium	—
96	Cm	curium	—
97	Bk	berkelium	—
98	Cf	californium	—
99	Es	einsteinium	—
100	Fm	fermium	—
101	Md	mendelevium	—
102	No	nobelium	—
103	Lr	lawrencium	—
104	Rf	rutherfordium	—
105	Db	bohrium	—
106	Sg	seaborgium	—
107	Bh	bohrium	—
108	Hs	hassium	—
109	Mt	meitnerium	—
110	Ds	darmstadtium	—
111	Rg	roentgenium	—
112	Cn	copernicium	—
113	Nh	nihonium	—
114	Fl	flerovium	—
115	Mc	moscovium	—
116	Lv	livermorium	—
117	Ts	tennessine	—
118	Og	oganeson	—

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

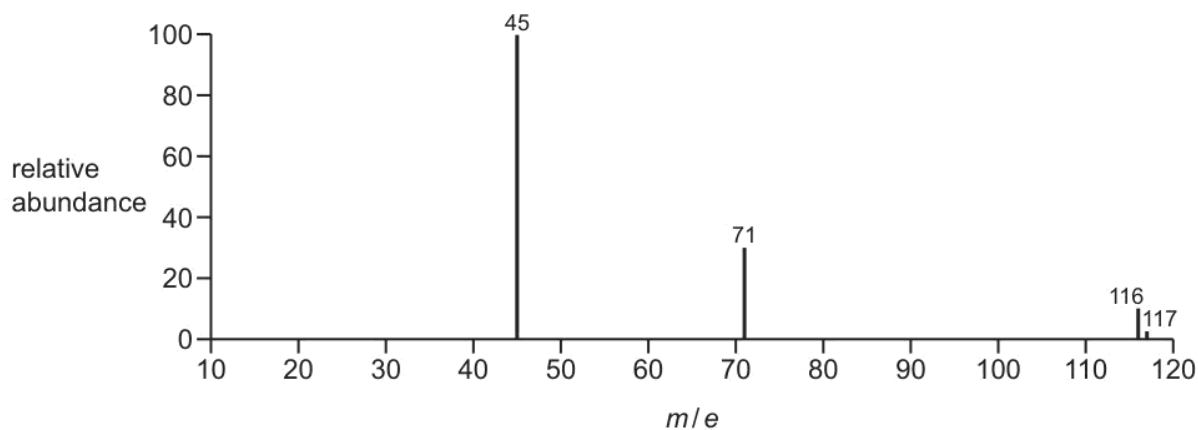


Fig. 6.1

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

[1]

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

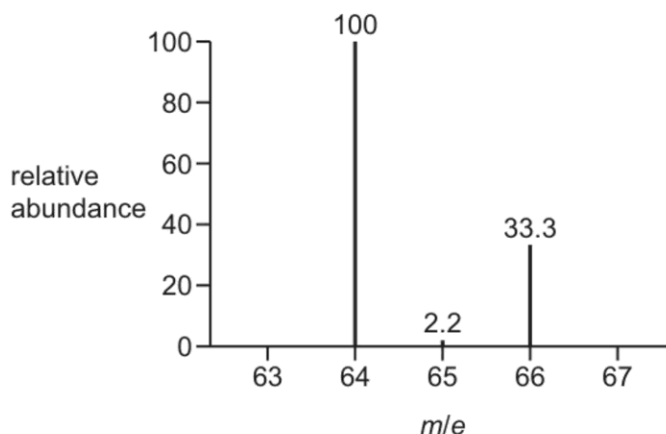


Fig. 5.1

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

..... [1]

(b) A student monitors the progress of reaction 2 using infrared spectroscopy.

Use Table 5.1 to suggest why it is difficult to distinguish between **N** and 5-hydroxyhexanoic acid using infrared spectroscopy.

.....
 [2]

Table 5.1

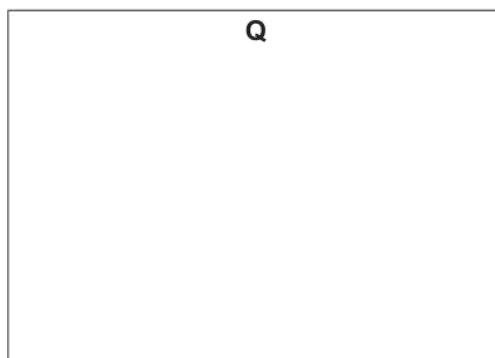
bond	functional group containing the bond	characteristic infrared absorption range (in wavenumbers)/cm ⁻¹
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–3100
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

- (c) Unknown lactone **Q** is analysed using mass spectrometry.
Table 5.2 shows information from the mass spectrum.

Table 5.2

peak	m/e	abundance
M+	72	95.5
M+1	73	3.15

Use these data to deduce the structure of **Q**.
Show your working.



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

[Total: 9]

- (b) Complete Table 1.1 to show the total numbers of protons and electrons in the molecular ions NH_4^+ , CO_3^{2-} and PO_4^{3-} .

Table 1.1

molecular ion	total number of protons	total number of electrons
NH_4^+		
CO_3^{2-}		
PO_4^{3-}		

[3]

Oct/Nov 2022 9701/22 · Q1 (b)

- (c) Organic compound **E** contains three carbon atoms.
E reacts with cold dilute acidified $\text{KMnO}_4(\text{aq})$ to form a single compound **F** with $M_r = 154.9$.
Fig. 3.1 shows the infrared spectrum of **E**.
Fig. 3.2 shows the infrared spectrum of **F**.

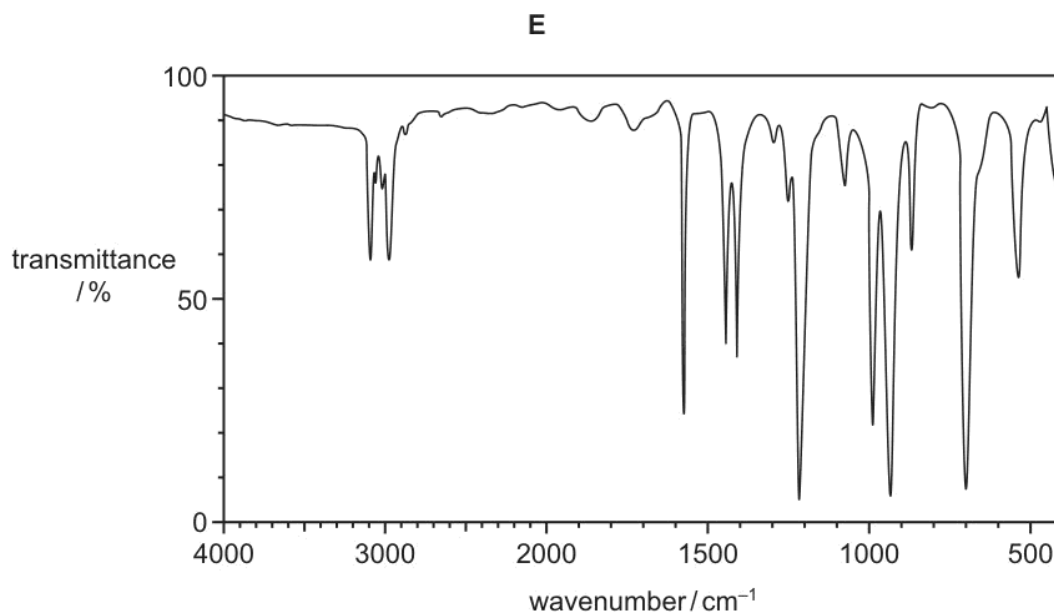


Fig. 3.1

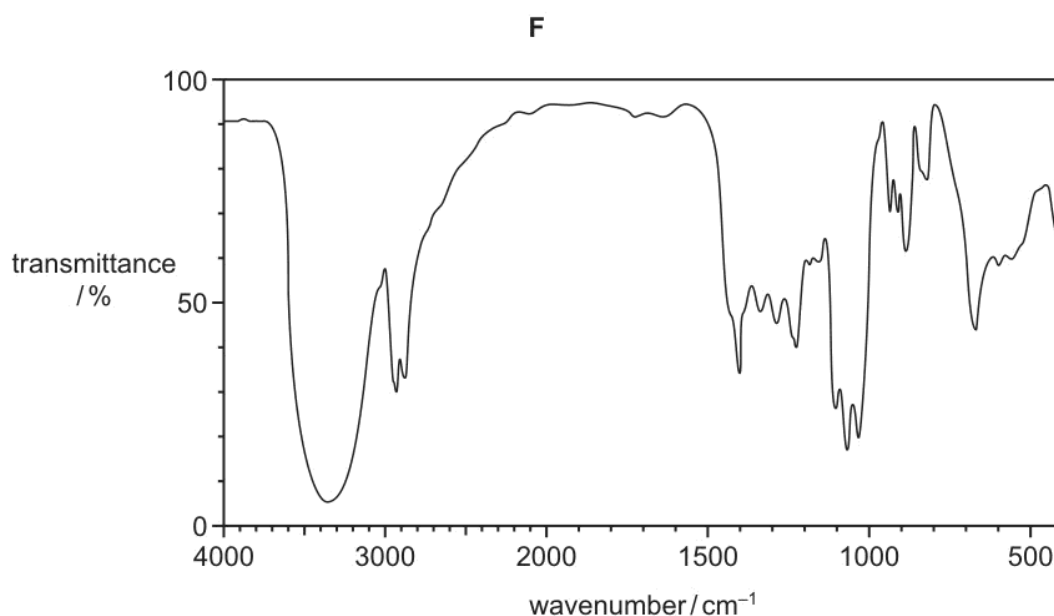


Fig. 3.2

11

Table 3.2

bond	functional group 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	2850–3100
N—H	amine, amide	3300–3500
O—H	carboxyl hydroxy	2500–3000 3200–3650

Both spectra show absorptions between 2850 and 2950 cm⁻¹ owing to C—H bonds in each molecule.

- (i) Use the two infrared spectra and Table 3.2 to identify the functional group present only in **E**.

Explain your answer, referring only to absorptions at frequencies greater than 1500 cm⁻¹.

functional group

explanation

[1]

- (ii) Use the infrared spectrum of **F** to identify the functional group formed when **E** reacts with cold dilute acidified KMnO₄(aq).

Explain your answer, referring only to absorptions at frequencies greater than 1500 cm⁻¹.

functional group

explanation

[1]

- (iii) The mass spectrum of **E** shows a molecular ion peak and an M+2 peak of approximately equal abundance at $m/e = 120$ and 122 .

Deduce the relative molecular mass, M_r , of **E**.

$M_r = \dots\dots\dots$ [1]

12

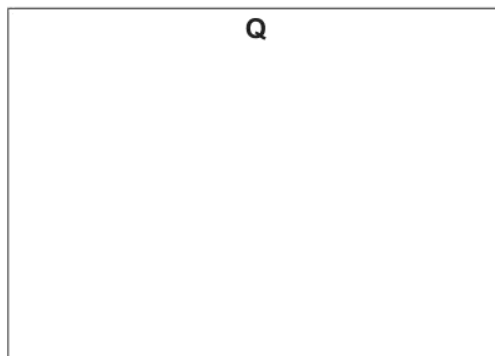
Oct/Nov 2022 9701/22 · Q3 (c)(i), (c)(ii), (c)(iii) (cont.)

- (c) Unknown lactone **Q** is analysed using mass spectrometry.
Table 5.2 shows information from the mass spectrum.

Table 5.2

peak	m/e	abundance
M+	72	95.5
M+1	73	3.15

Use these data to deduce the structure of **Q**.
Show your working.



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

[Total: 9]

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)

57	La	lanthanum	138.9
58	Ce	cerium	140.1
59	Pr	praseodymium	140.9
60	Nd	neodymium	144.4
61	Pm	promethium	—
62	Sm	samarium	150.4
63	Eu	europlum	152.0
64	Gd	gadolinium	157.3
65	Tb	terbium	158.9
66	Dy	dysprosium	162.5
67	Ho	holmium	164.9
68	Er	erbium	167.3
69	Tm	thulium	168.9
70	Yb	ytterbium	173.1
71	Lu	lutetium	175.0
72	Hf	hafnium	178.5
73	Ta	tantalum	180.9
74	W	tungsten	183.8
75	Re	rhenium	186.2
76	Os	osmium	190.2
77	Ir	iridium	192.2
78	Pt	platinum	195.1
79	Au	gold	197.0
80	Hg	mercury	200.6
81	Tl	thallium	204.4
82	Pb	lead	207.2
83	Bi	bismuth	209.0
84	Po	polonium	—
85	At	astatine	—
86	Rn	radon	—
87	Fr	francium	—
88	Ra	radium	—
89	Ac	actinium	—
90	Th	thorium	232.0
91	Pa	protactinium	231.0
92	U	uranium	238.0
93	Np	neptunium	—
94	Pu	plutonium	—
95	Am	americium	—
96	Cm	curium	—
97	Bk	berkelium	—
98	Cf	californium	—
99	Es	einsteinium	—
100	Fm	fermium	—
101	Md	mendelevium	—
102	No	nobelium	—
103	Lr	lawrencium	—
104	Rf	rutherfordium	—
105	Db	bohrium	—
106	Sg	seaborgium	—
107	Bh	bohrium	—
108	Hs	hassium	—
109	Mt	meitnerium	—
110	Ds	darmstadtium	—
111	Rg	roentgenium	—
112	Cn	copernicium	—
113	Nh	nihonium	—
114	Fl	flerovium	—
115	Mc	moscovium	—
116	Lv	livermorium	—
117	Ts	tennessine	—
118	Og	oganeson	—

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- (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]

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

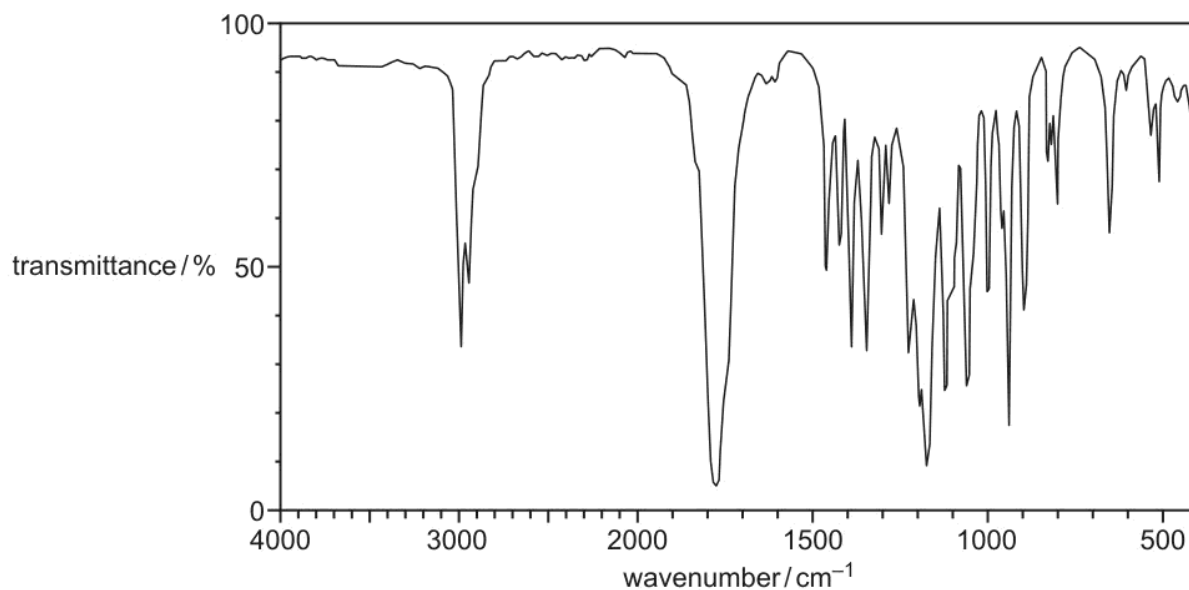


Fig. 5.2

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]

14

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

The Periodic Table of Elements

Group

1	2	Key										1	Group										13	14	15	16	17	18																									
3	4	atomic number atomic symbol name relative atomic mass																				5	6	7	8	9	10	11	12											13	14	15	16	17	18								
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	Ne neon 20.2											13	14	15	16	17	18										
11	12																					Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5	Ar argon 39.9											13	14	15	16	17	18										
Na sodium 23.0	Mg magnesium 24.3																															13	14	15	16	17	18											13	14	15	16	17	18
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36											31	32	33	34	35	36											31	32	33	34	35	36				
K potassium 39.1	Ca calcium 40.1	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8											49	50	51	52	53	54											49	50	51	52	53	54				
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54											81	82	83	84	85	86											81	82	83	84	85	86				
Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3											121	122	123	124	125	126											121	122	123	124	125	126				
55	56	lanthanoids		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86											101	102	103	104	105	106											101	102	103	104	105	106			
Cs caesium 132.9	Ba barium 137.3			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 —	Rn radon —											153	154	155	156	157	158											153	154	155	156	157	158			
87	88	actinoids		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118											165	166	167	168	169	170											165	166	167	168	169	170			
Fr francium —	Ra radium —			Rf rutherfordium —	Db dubnium —	Sg seaborgium —	Bh bohrium —	Hs hassium —	Mt meitnerium —	Ds darmstadtium —	Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganeson —											113	114	115	116	117	118											113	114	115	116	117	118			

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 —

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

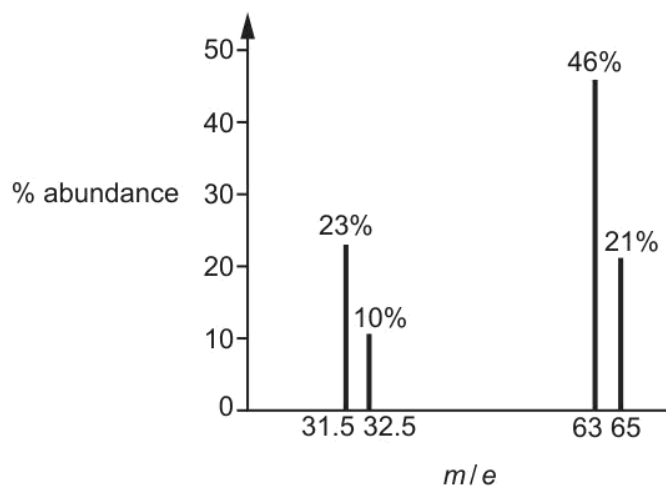


Fig. 1.1

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

..... [1]

- (c) Compounds **S** and **T** react to form organic compound **U**, which has a single functional group.

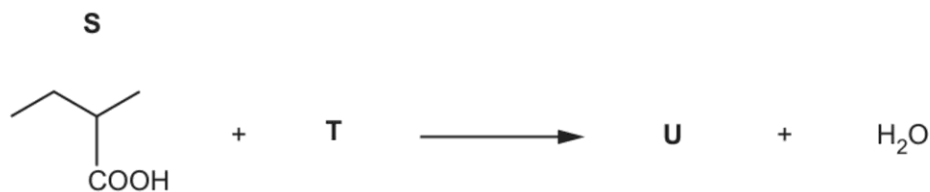


Table 4.2 shows some data from the mass spectrum of **U**.

Table 4.2

peak	relative abundance
M^+	7.2
$[\text{M}+1]^+$	0.55

- (i) Use the data from Table 4.2 to show that **U** contains 7 carbon atoms.

Show your working.

[2]

- (ii) Fig. 4.2 shows the infrared spectrum of **U**.

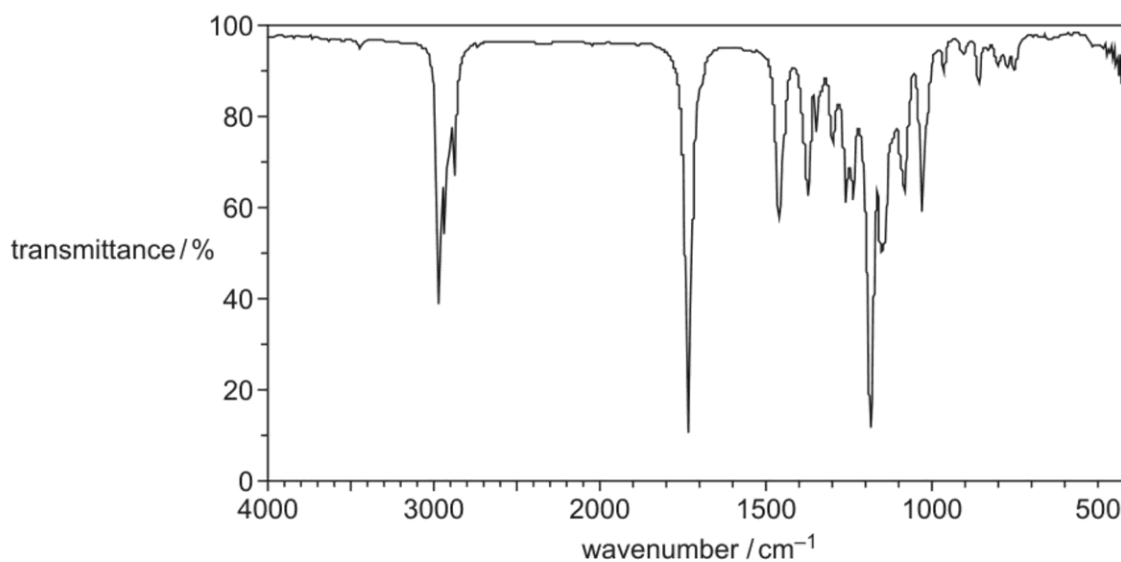


Fig. 4.2

13

Table 4.3

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

Use Fig. 4.2 and Table 4.3 to identify the functional group present in **U**.

Explain your answer fully.

functional group

explanation

.....

[2]

- (c) Both functional groups in one molecule of **Y** react with an inorganic reagent to form one molecule of **Q** and one molecule of methanol, CH_3OH , as shown in Fig. 6.3.

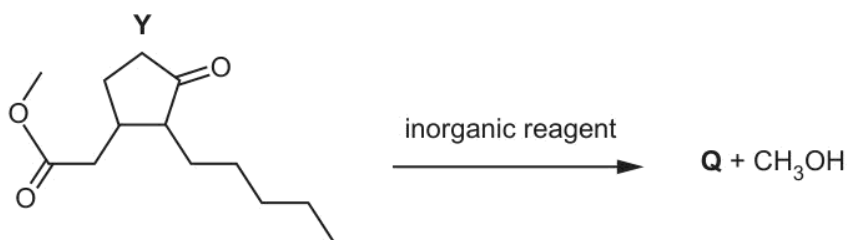


Fig. 6.3

- (i) Part of the mass spectrum for **Q** is shown in Fig. 6.4. Only peaks with m/e greater than 198 are shown.

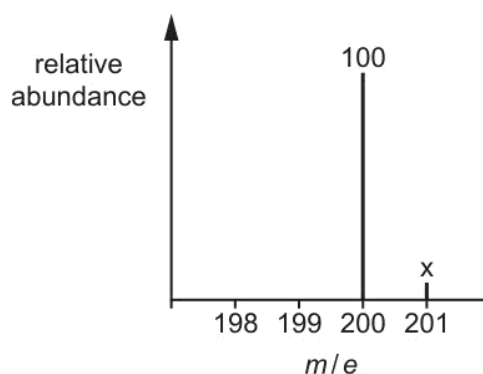


Fig. 6.4

Calculate the relative abundance, x , of the peak at $m/e = 201$.

Show your working.

$x = \dots\dots\dots$ [2]

- (iv) Use Table 6.2 to describe and explain **two** differences between the infrared spectrum of **Y** and **Q** in the region above 1500 cm^{-1} .

.....

.....

..... [2]

Table 6.2

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

[Total: 14]

14

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

The Periodic Table of Elements																															
Group																															
1	2	Key												13	14	15	16	17	18												
		atomic number atomic symbol name relative atomic mass																													
3	4													5	6	7	8	9	10	11	12	13	14	15	16	17	18				
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	Ne neon 20.2							He helium 4.0					
11	12													13	14	15	16	17	18												
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	Ar argon 39.9												
19	20													31	32	33	34	35	36												
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	Kr krypton 83.8												
37	38													49	50	51	52	53	54												
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	Xe xenon 131.3												
55	56	lanthanoids												81	82	83	84	85	86												
Cs caesium 132.9	Ba barium 137.3													Tl thallium 204.4	Pb lead 209.0	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —												
87	88	actinoids												113	114	115	116	117	118												
Fr francium —	Ra radium —													Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganesson —												
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 —

- (a) Table 5.1 shows the two peaks with the greatest m/e values in the mass spectrum of **W**.

Table 5.1

m/e	relative abundance
74	50
75	x

- (i) Calculate the relative abundance, x, of the peak at $m/e = 75$ using the information from Table 5.1.

x = [1]

- (ii) The mass spectrum of **W** also shows peaks at $m/e = 29$ and $m/e = 59$.

Suggest the molecular formulae of these fragments.

$m/e = 29$

$m/e = 59$

[2]

- (b) A sample of **W**, $C_4H_{10}O$, is heated under reflux with an excess of acidified $K_2Cr_2O_7$ until there is no further reaction. Only **one** organic product, **X**, is present in the mixture at the end of the reaction.

Fig. 5.1 shows the infrared spectrum of **W**.

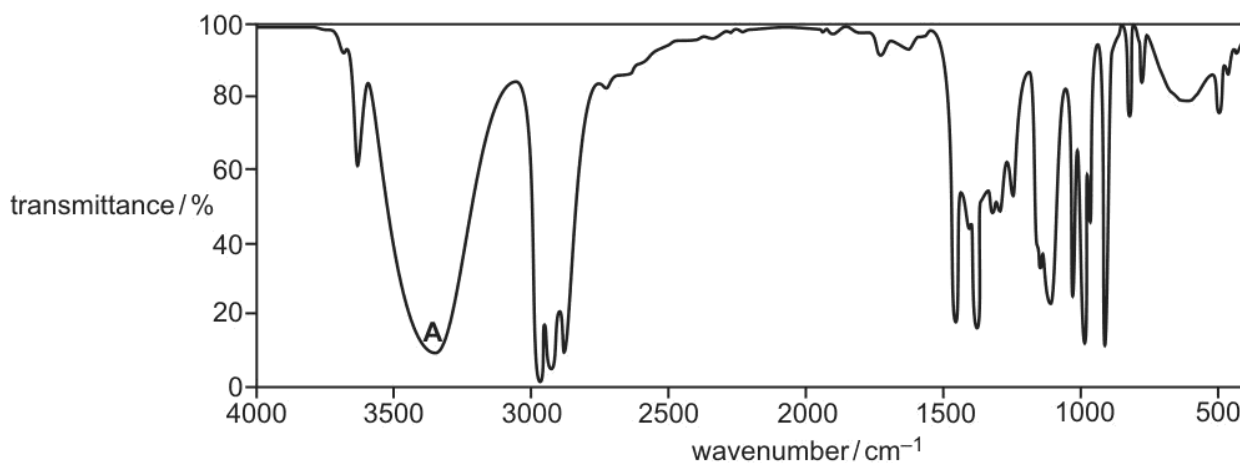


Fig. 5.1



13

Fig. 5.2 shows the infrared spectrum of **X**.

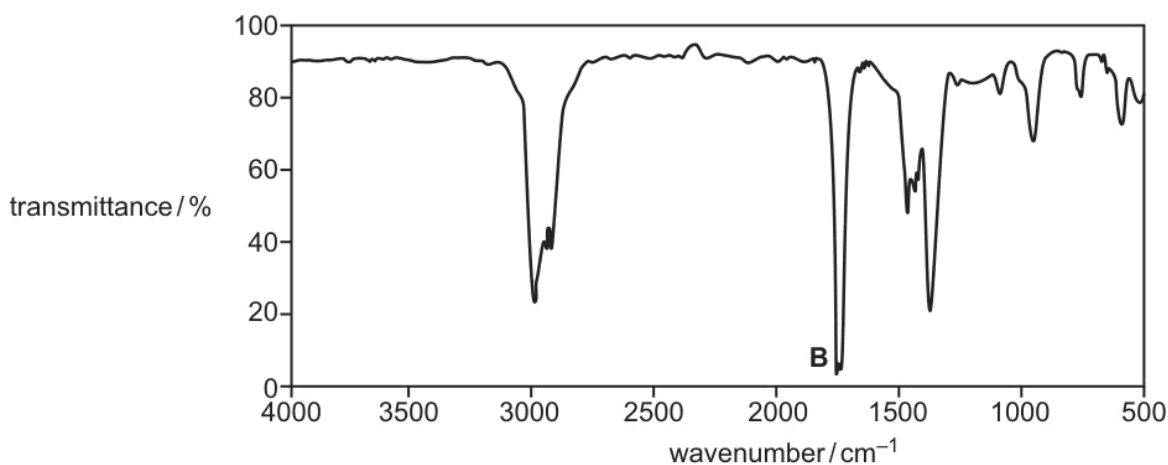


Fig. 5.2

Table 5.2

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

- (i) Absorption **A** is shown in Fig. 5.1.
Absorption **B** is shown in Fig. 5.2.

Complete Table 5.3 using the information given in Fig. 5.1, Fig. 5.2 and Table 5.2.

Table 5.3

absorption	bond	functional group containing the bond
A		
B		

[1]

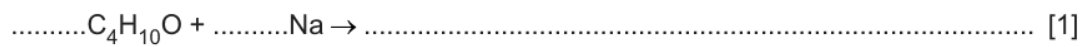




14



(ii) Complete the equation to describe the reaction of **W** or **Y** with sodium.



May/June 2024 9701/22 · Q5 (a)(i), (a)(ii), (b)(i), (c)(ii) (cont.)

(c) The infrared spectrum of **R** is shown in Fig. 5.3.

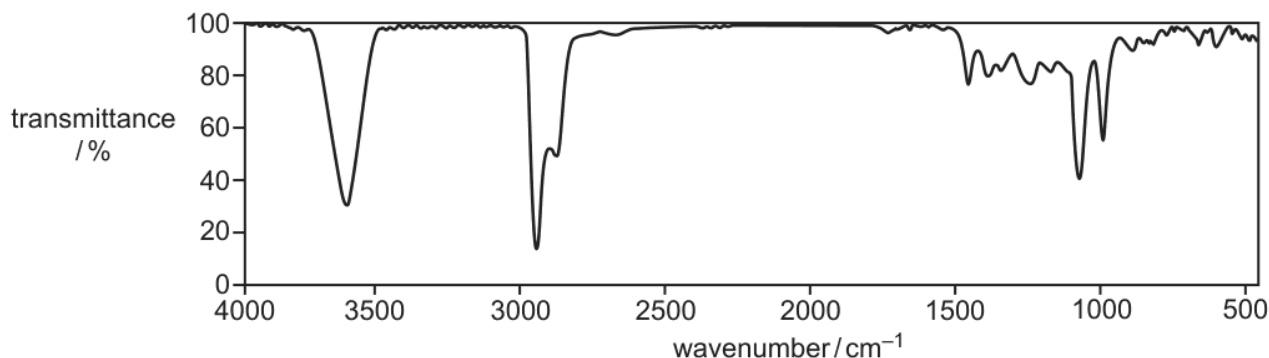


Fig. 5.3

Table 5.1

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 3200–3650

Use the absorptions in the region above 1500 cm⁻¹ in Table 5.1 when answering this question.

- Add **F** to Fig. 5.3 to identify the peak that is present in an infrared spectrum of both **Q** and **R**. Identify the bond that corresponds to the absorption for **F**.

.....

- Add **G** to Fig. 5.3 to identify the peak that is **not** present in an infrared spectrum of **Q**. Identify the bond that corresponds to the absorption for **G**.

.....

[2]

May/June 2024 9701/23 · Q5 (c)

(f) Compounds **A**, **B** and **C** can be distinguished using infrared spectroscopy.

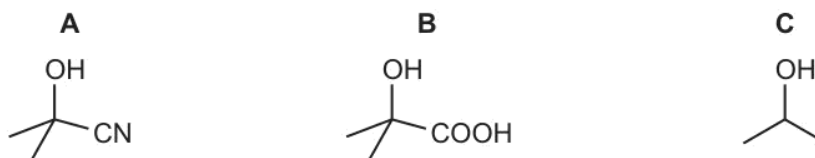


Fig. 4.3 shows the infrared spectrum of one of the compounds.

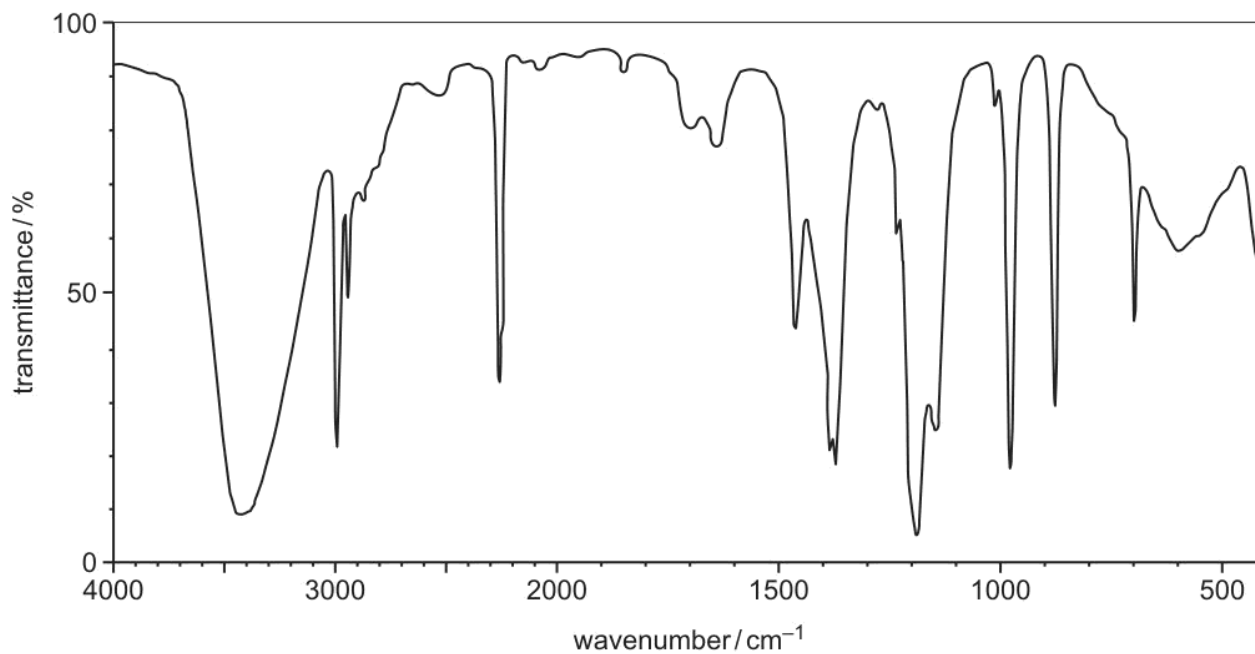


Fig. 4.3

Table 4.1

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





15

- (i) Explain why the absorptions at $2850\text{--}2950\text{ cm}^{-1}$ are **not** useful to help determine which of the compounds **A**, **B** or **C** produces the infrared spectrum in Fig. 4.3.

Use Table 4.1 to answer this question.

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

- (ii) Identify which of compounds **A**, **B** or **C** produces the infrared spectrum in Fig. 4.3. Explain your answer.

compound

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

[Total: 11]





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





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													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																	71 Lu lutetium 175.0		
actinoids																	103 Lr lawrencium —		

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(e) Compound **F** reacts with reagent **G** to form compound **H**.



The infrared spectrum of **H** is shown in Fig. 4.3.

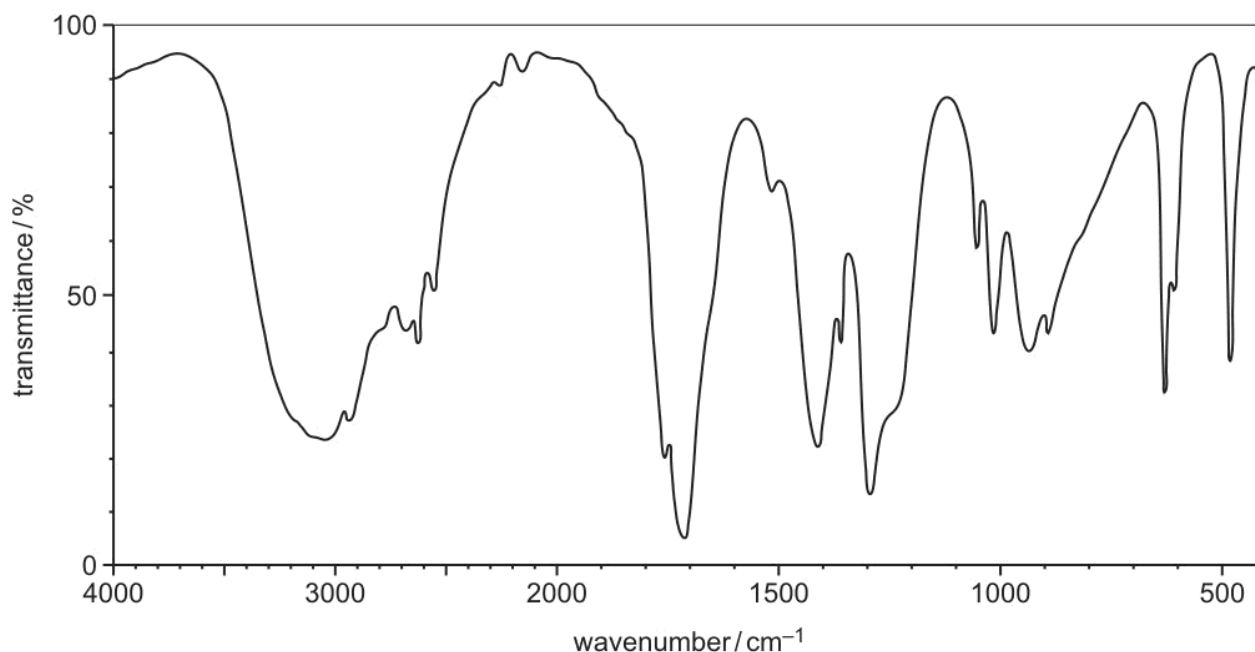


Fig. 4.3

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
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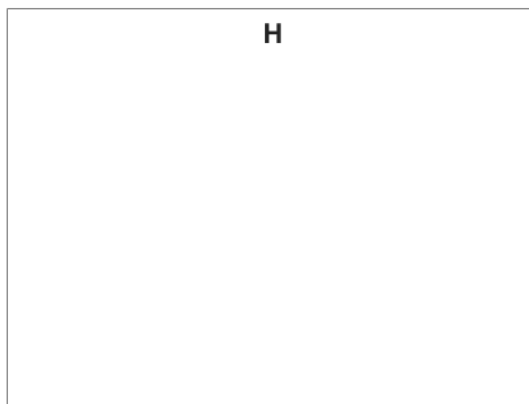




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H also shows a molecular ion peak at $m/e = 60$ in its mass spectrum.

- (i) Use the information in **(e)**, Fig. 4.3 and Table 4.2 to deduce the structure of **H**. Explain your answer fully.



.....

.....

.....

[3]

(f) Compounds **A**, **B** and **C** can be distinguished using infrared spectroscopy.

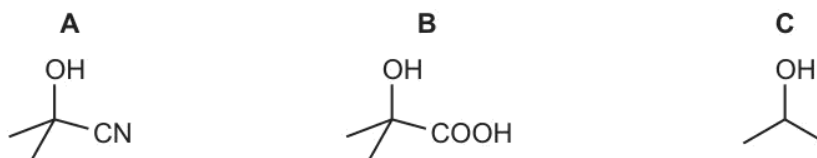


Fig. 4.3 shows the infrared spectrum of one of the compounds.

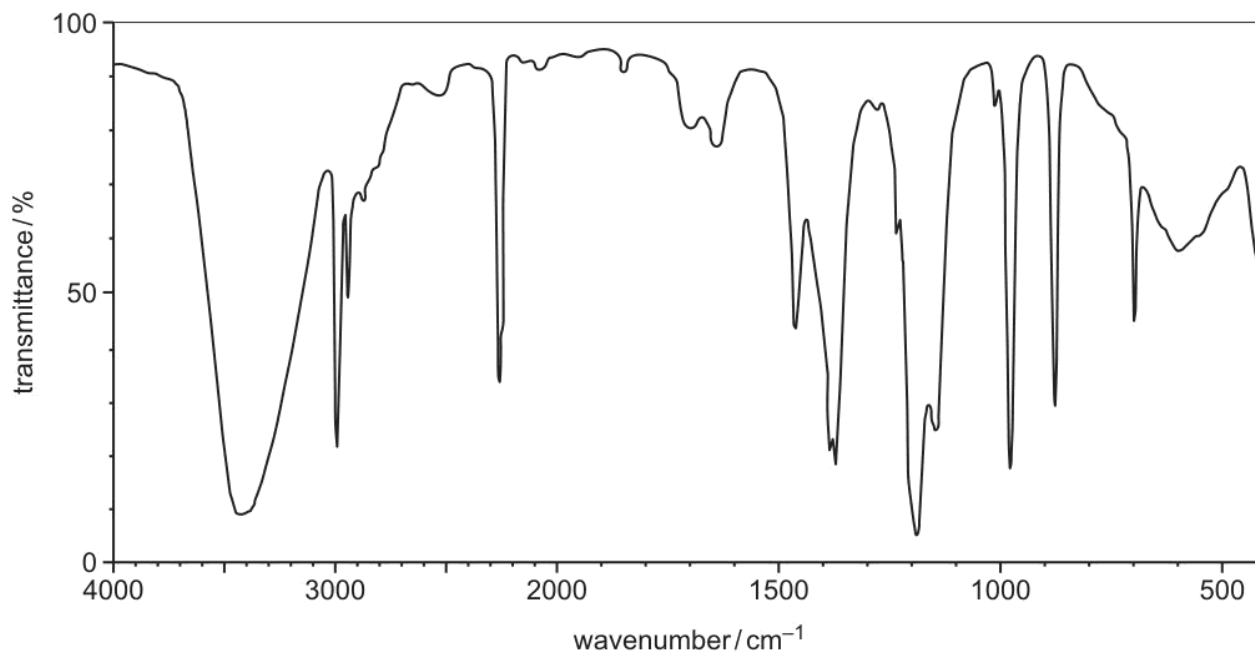


Fig. 4.3

Table 4.1

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N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3600





15

- (i) Explain why the absorptions at $2850\text{--}2950\text{ cm}^{-1}$ are **not** useful to help determine which of the compounds **A**, **B** or **C** produces the infrared spectrum in Fig. 4.3.

Use Table 4.1 to answer this question.

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

- (ii) Identify which of compounds **A**, **B** or **C** produces the infrared spectrum in Fig. 4.3. Explain your answer.

compound

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

[Total: 11]





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Important values, constants and standards

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11	12																					
Na sodium 23.0	Mg magnesium 24.3																					
19	20	21	22	23	24	25	26	27	28	29	30	31						32	33	34	35	36
K potassium 39.1	Ca calcium 40.1	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7						Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8
37	38	39	40	41	42	43	44	45	46	47	48	49						50	51	52	53	54
Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8						Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3
55	56	57–71 lanthanoids	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 —	Rn radon —
87	88	89–103 actinoids	Rf rutherfordium —	Db dubnium —	Sg seaborgium —	Bh bohrium —	Hs hassium —	Mt meitnerium —	Ds darmstadtium —	Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganeson —					
Fr francium —	Ra radium —																					
lanthanoids																						
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 144.2	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 —								
actinoids																						

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- (d) Compound **D** contains carbon, hydrogen and chlorine **only**.

Fig. 1.2 shows the mass spectrum of **D**.

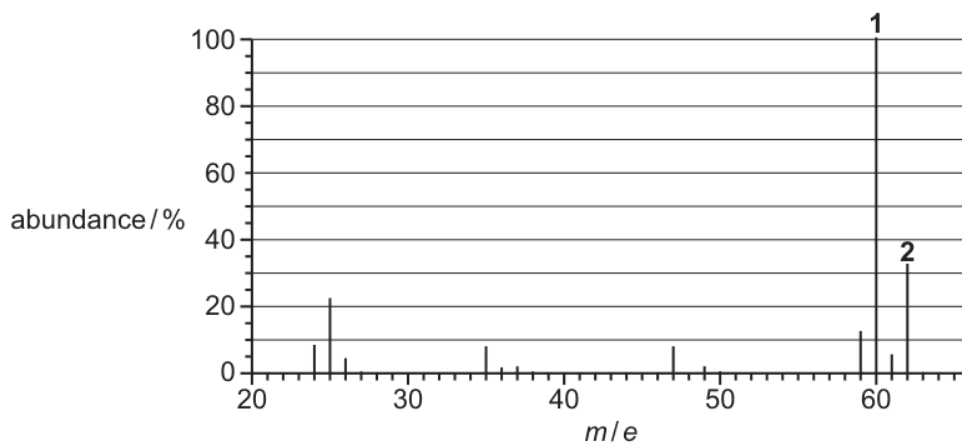


Fig. 1.2

- (i) Explain the relative abundance of peaks 1 and 2 in the mass spectrum in Fig. 1.2.

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

- (c) Predict **two** absorptions that will be seen in the infrared spectra of both vitamin C and **Q**. Describe the relevant bond and the specific functional group that is responsible for each absorption identified.

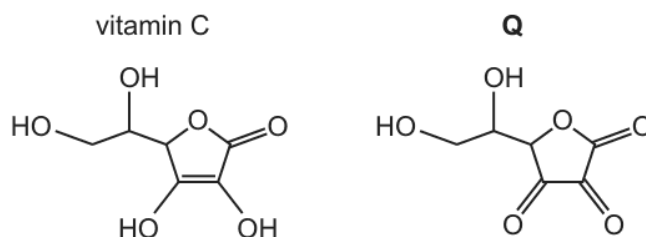


Fig. 4.3

.....

.....

..... [2]

[Total: 9]

Table 4.1

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers)/cm ⁻¹
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650





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May/June 2025 9701/21 · Q4 (c) (cont.)

- (iii) The progress of the reaction of vitamin C with $I_2(aq)$ to produce **M** is monitored using infrared spectroscopy.

Table 5.1 indicates the presence of some absorptions in the infrared spectrum of vitamin C. Complete Table 5.1 to predict which of these absorptions, if any, are present in the infrared spectrum of **M**.

Table 5.1

absorption / cm^{-1}	present in spectrum of vitamin C	present in spectrum of M
1500–1680	✓	
2850–2950	✓	
3200–3650	✓	

[1]

Table 5.2

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

[Total: 5]





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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	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
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	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ ($4.18 \text{ J g}^{-1} \text{ K}^{-1}$)





1		2		Group										13		14		15		16		17		18																																															
3 Li lithium 6.9		4 Be beryllium 9.0		Key atomic number atomic symbol name relative atomic mass										1 H hydrogen 1.0																																																									
11 Na sodium 23.0	12 Mg magnesium 24.3	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8	37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium —	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3	55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium —	85 At astatine —	86 Rn radon —	87 Fr francium —	88 Ra radium —	89–103 actinoids	104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —	113 Nh nihonium —	114 Fl flerovium —	115 Mc moscovium —	116 Lv livermorium —	117 Ts tennessine —	118 Og oganeson —

actinoids

57	La	58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu
lanthanum	138.9	cerium	140.1	praseodymium	140.9	neodymium	144.2	—	promethium	150.4	samarium	152.0	europium	157.3	gadolinium	158.9	terbium	162.5	dysprosium	164.9	holmium	167.3	erbium	thulium	168.9	ytterbium	173.1	lutetium	
Ac	89	Th	90	Pa	91	U	92	Np	93	Pu	94	Am	95	Cm	96	Bk	97	Cf	98	Es	99	Fm	100	Md	101	No	102	Lr	103
actinium	227	thorium	232	protactinium	231	uranium	238	neptunium	237	plutonium	244	americium	243	curium	247	berkelium	247	californium	251	einsteinium	252	fermium	257	mendelevium	258	nobelium	259	lawrencium	



May/June 2025 9701/22 · Q5 (b)(iii) (cont.)

- (v) Fig. 5.3 shows the structure of **Z**.
Fig. 5.4 is the infrared spectrum of **Z**.

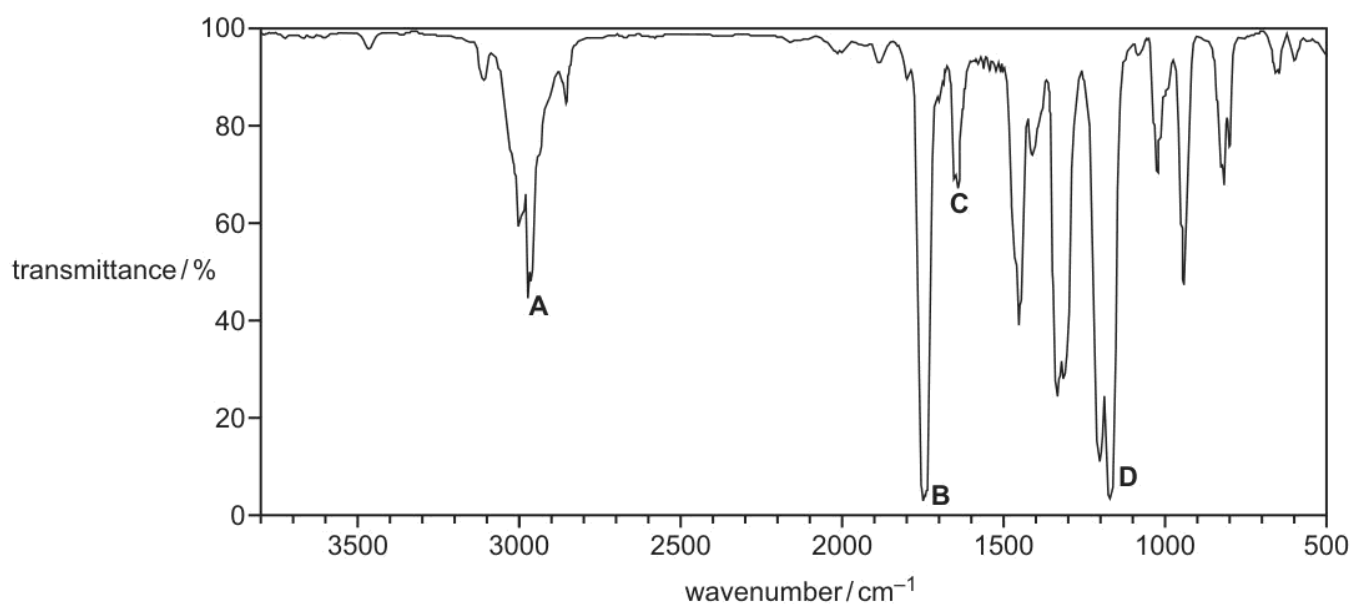


Fig. 5.4

Identify the bond and functional group responsible for each of the absorptions labelled **A**, **B**, **C** and **D** in Fig. 5.4.

A

B

C

D

[2]





Table 5.2

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

May/June 2025 9701/23 · Q5 (b)(v) (cont.)

- (c) The mass spectrum of hydrocarbon **R** is recorded.
Information about the two peaks with m/e greater than 135 is shown in Fig. 6.1.

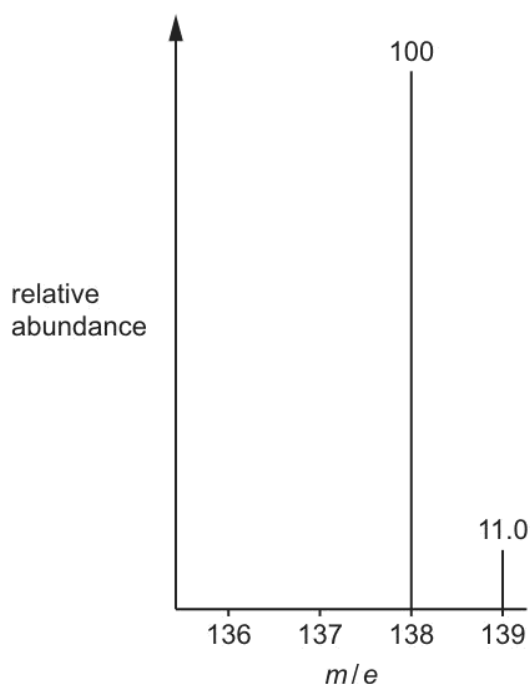


Fig. 6.1

- (i) Use Fig. 6.1 to deduce the number of carbon atoms in a molecule of **R**.

Show your working.

number of carbon atoms = [2]

May/June 2025 9701/24 · Q6 (c)(i)

- (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]

Oct/Nov 2025 9701/21 · Q1 (a)(iii)

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

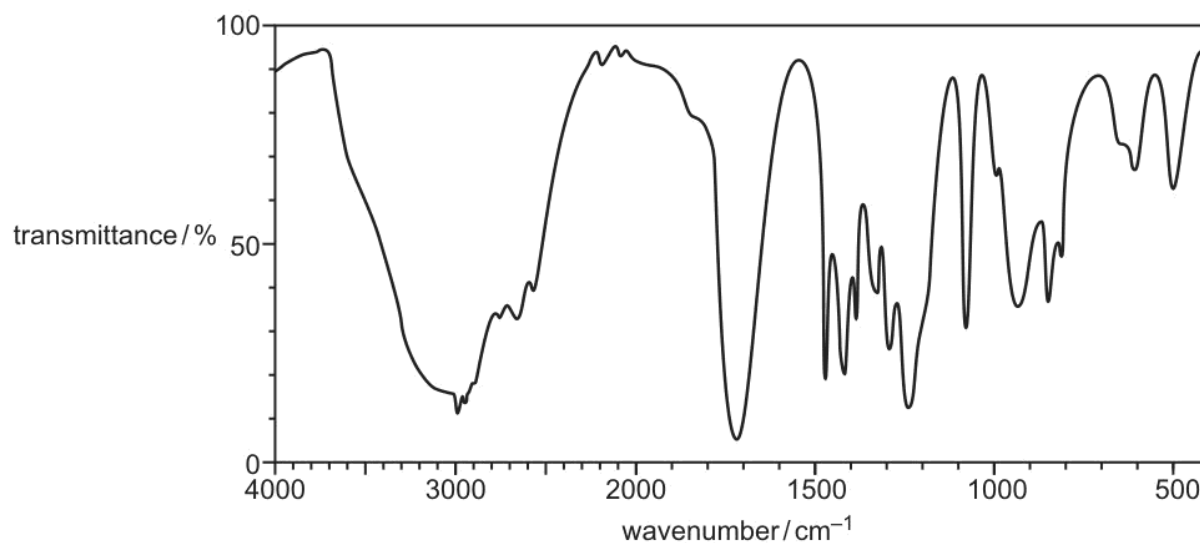


Fig. 3.3

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]





11

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]





Oct/Nov 2025 9701/21 · Q3 (e)(ii) (cont.)

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

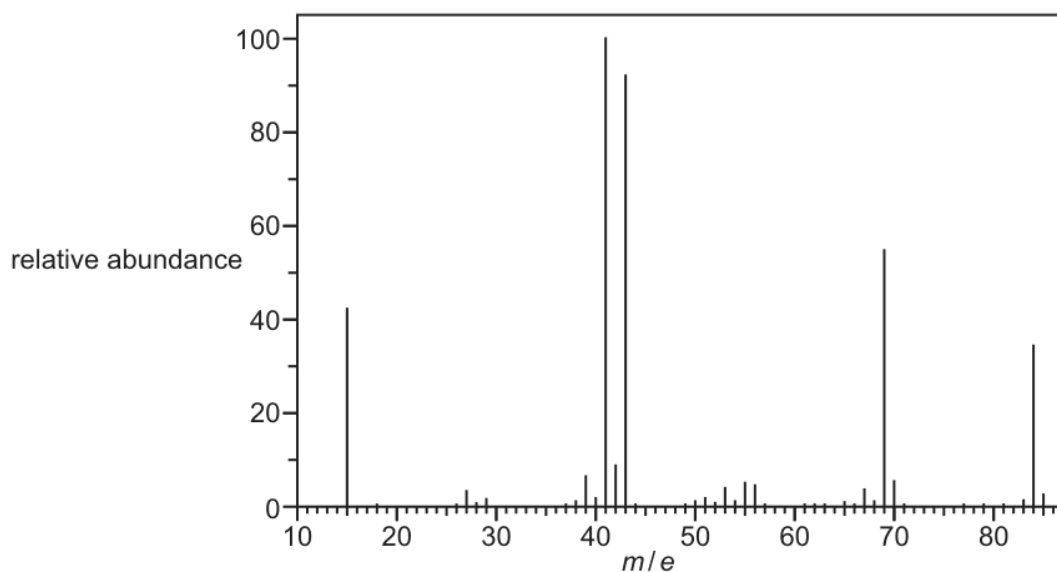


Fig. 4.2

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

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

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

Oct/Nov 2025 9701/21 · Q4 (c)(ii)

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

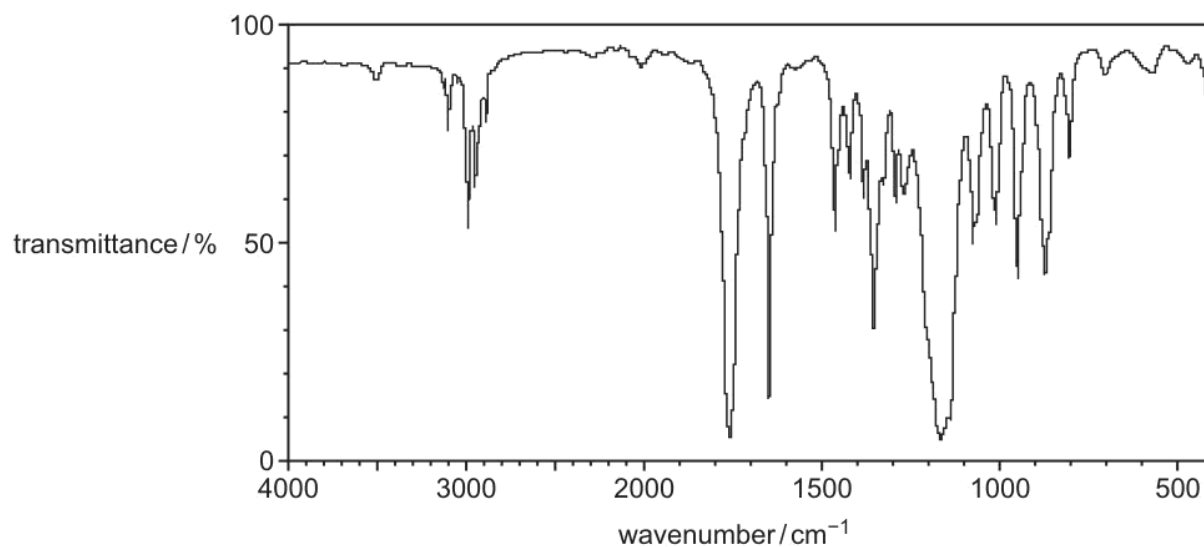


Fig. 4.2

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]





13

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]





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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	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
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)





16

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	euroium	152.0	64	Gd	gadolinium	157.3	65	Tb	terbium	158.9	66	Dy	dyprosium	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	237.0	94	Pu	plutonium	244.0	95	Am	americium	243.0	96	Cm	curium	247.0	97	Bk	berkelium	247.0	98	Cf	californium	251.0	99	Es	einsteinium	252.0	100	Fm	fermium	257.0	101	Md	mendelevium	258.0	102	No	nobelium	259.0	103	Lr	lawrencium	262.0

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

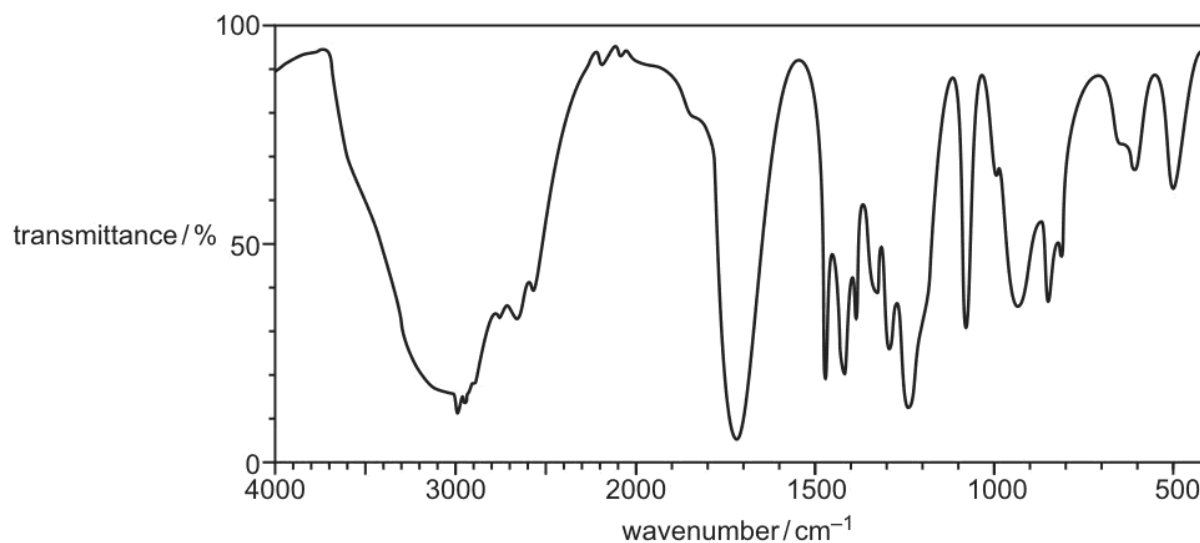


Fig. 3.3

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]





11

Table 3.3

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers)/cm ⁻¹
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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]





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Oct/Nov 2025 9701/23 · Q3 (e)(ii) (cont.)

(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.

peak at $m/e = 150$

peak at $m/e = 152$

[2]

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9701/24/O/N/25

[Turn over]



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