CAMBRIDGE INTERNATIONAL AS & A LEVEL CHEMISTRY · 9701

CHEMISTRY



EXAM QUESTION PACK

22 ANALYTICAL TECHNIQUES

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Chapter 21

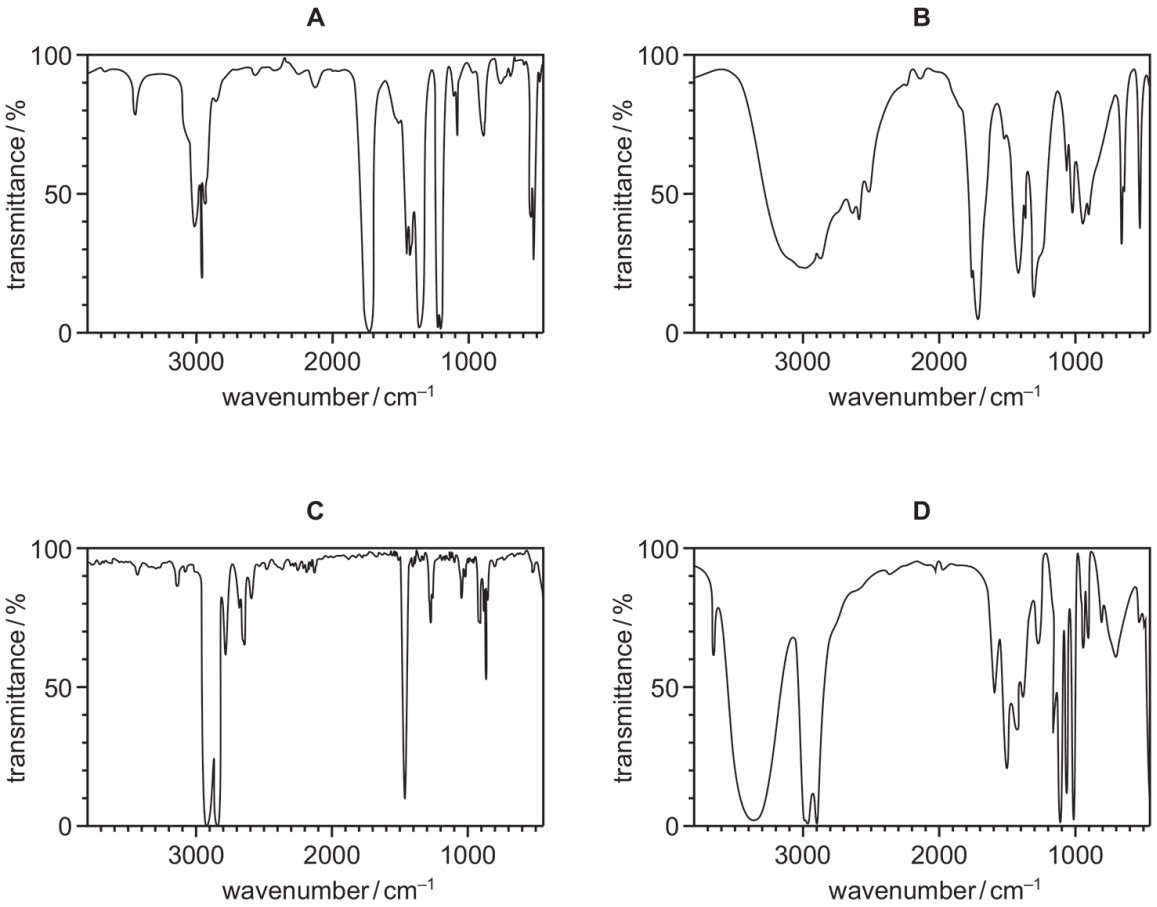
Analytical techniques

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21.1 Infrared spectroscopy

1188. 9701_m22_qp_12 Q: 40

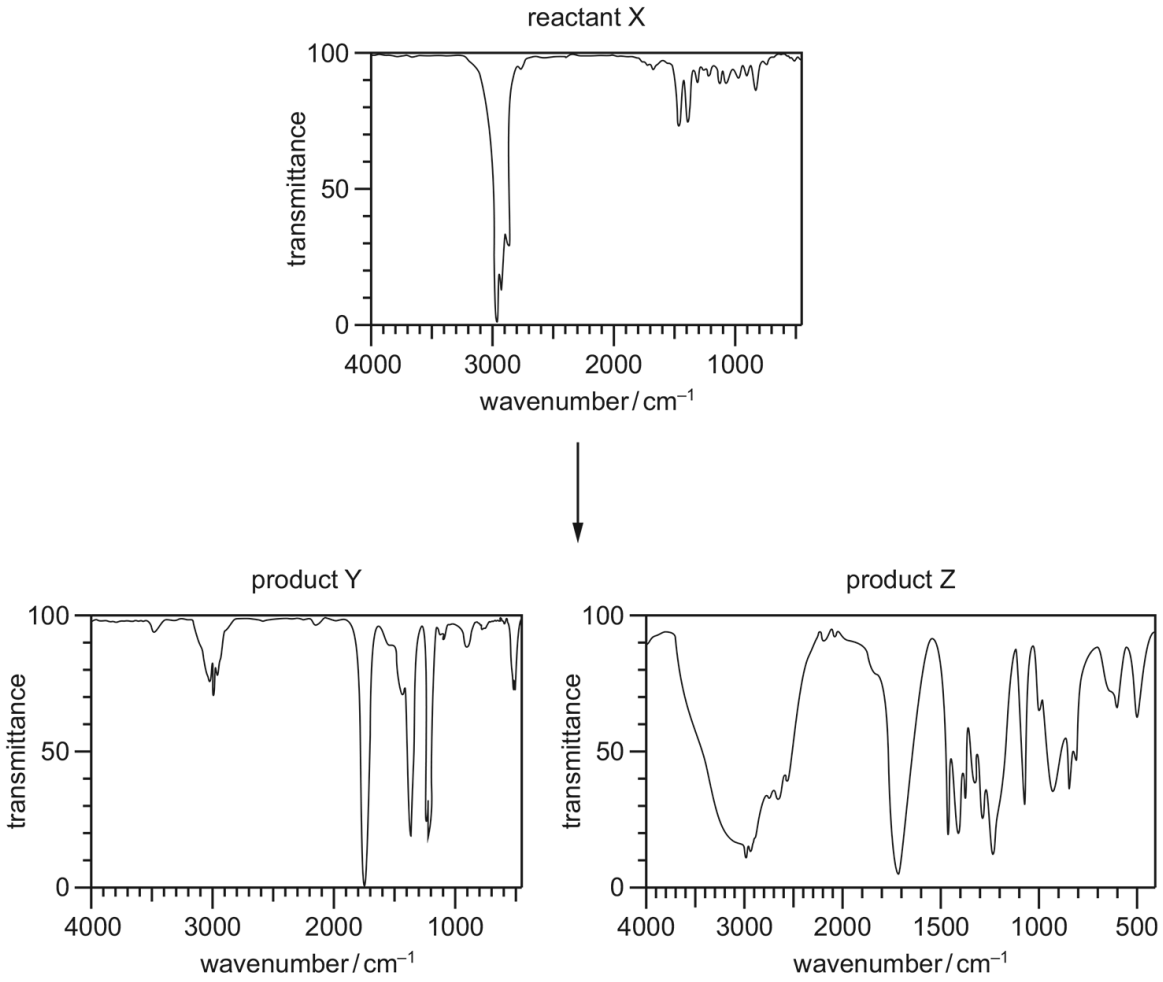
Which diagram shows the infrared spectrum of a compound that contains both a C=O and an O–H group?



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

1189. 9701_m21_qp_12 Q: 30

When reactant X is treated with a suitable reagent, products Y and Z are formed. Infrared spectra of X, Y and Z are shown.

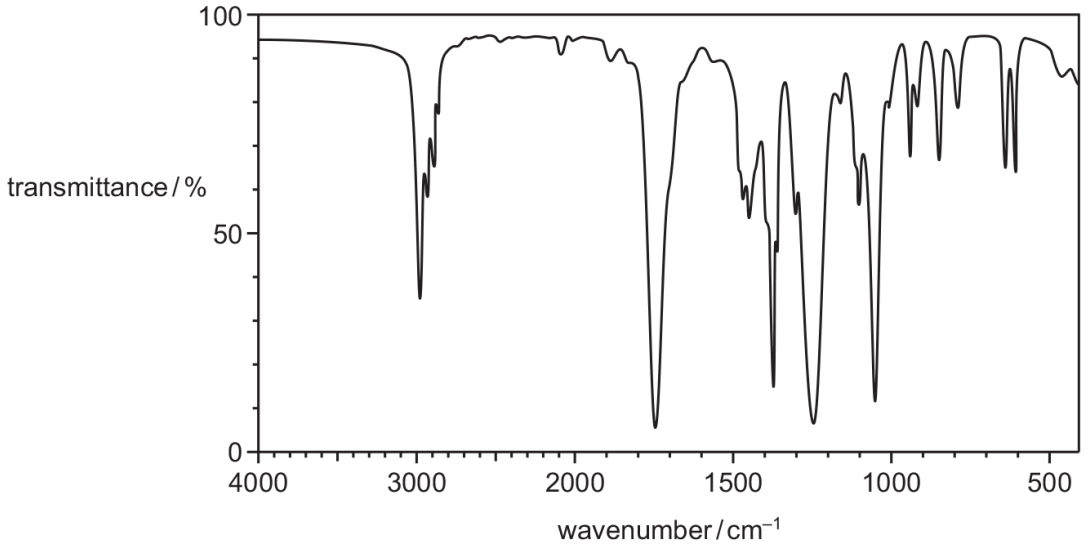


Which row could be correct?

	X	Y	Z
A	2,3-dimethylpent-2-ene	propanone	butanone
B	2-methylpent-2-ene	propanone	propanoic acid
C	pent-2-ene	ethanoic acid	propanoic acid
D	propyl propanoate	propan-1-ol	propanoic acid

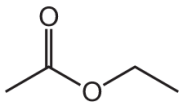
1190. 9701_s21_qp_11 Q: 17

Compound X has the empirical formula C_2H_4O. Its infra-red spectrum is shown.

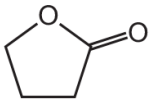


What could be the skeletal formula of compound X?

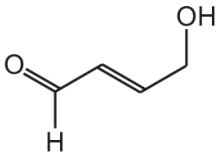
A



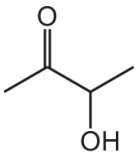
B



C

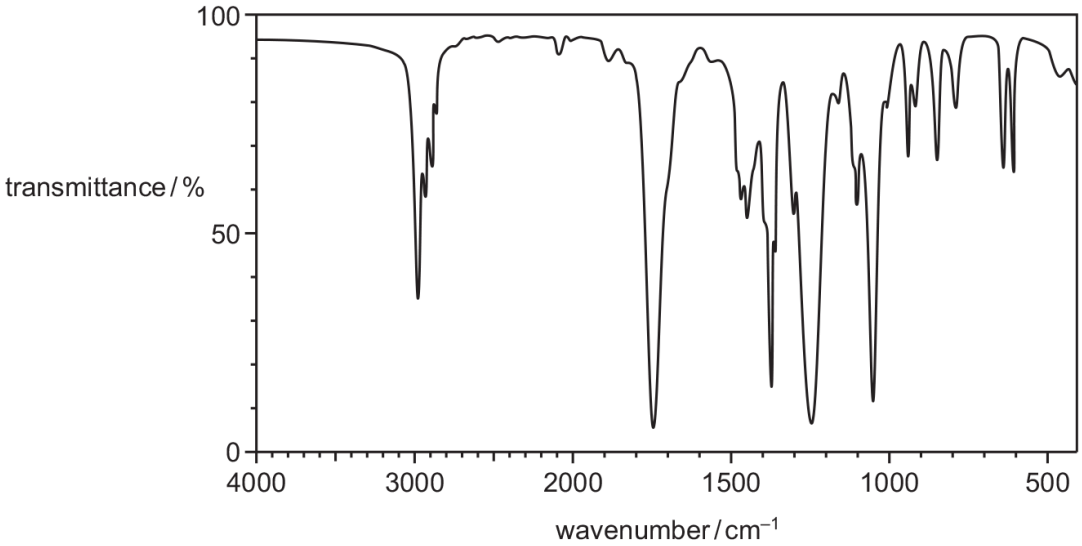


D



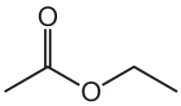
1191. 9701_s21_qp_11 Q: 26

Compound X has the empirical formula C_2H_4O. Its infra-red spectrum is shown.

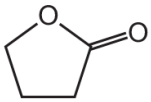


What could be the skeletal formula of compound X?

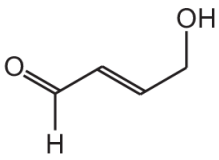
A



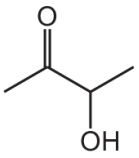
B



C



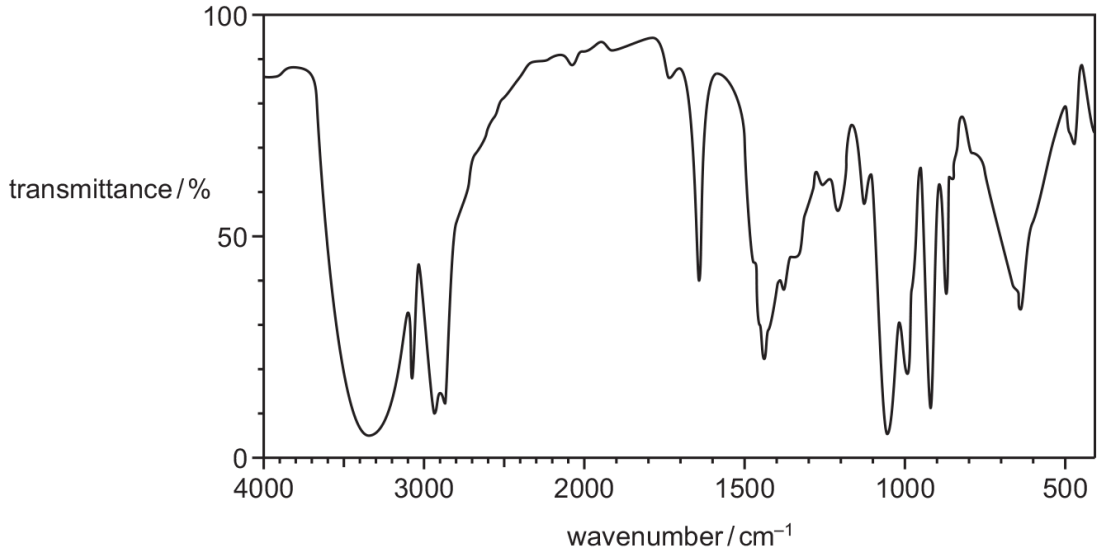
D



1192. 9701_s21_qp_12 Q: 30

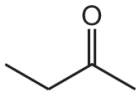
The molecular formula of Z is C_4H_8O.

The infra-red spectrum of Z is shown.

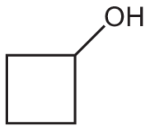


What could be Z?

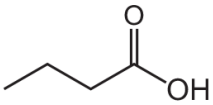
A



B



C

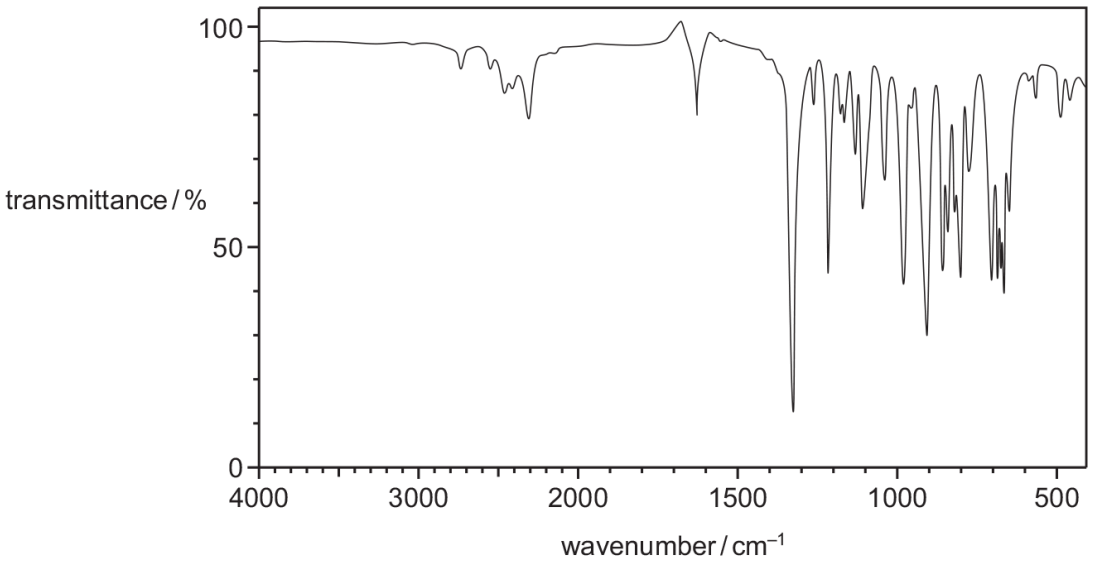


D



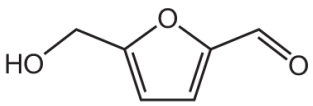
1193. 9701_s21_qp_13 Q: 30

The infra-red spectrum of molecule Z is shown.

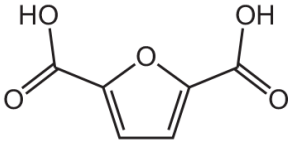


What could be the identity of Z?

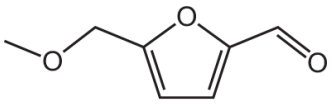
A



B



C



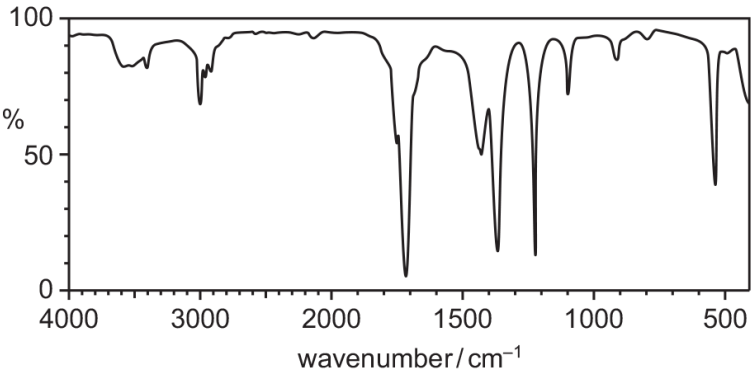
D



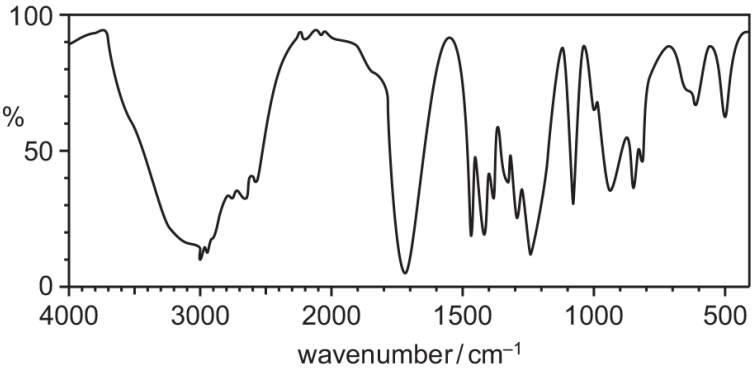
1194. 9701_w21_qp_11 Q: 30

The infra-red spectra of three organic compounds are shown.

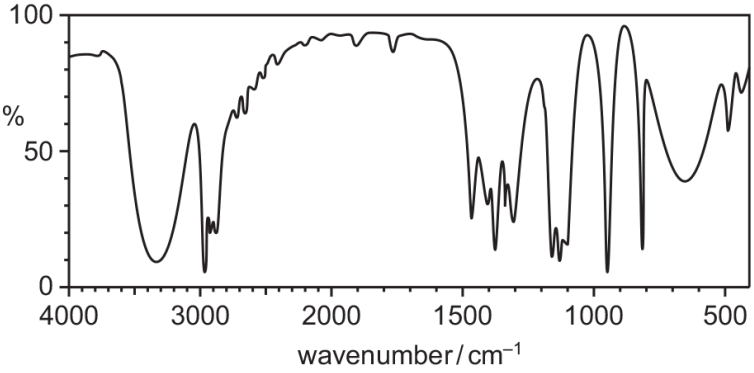
spectrum 1



spectrum 2



spectrum 3

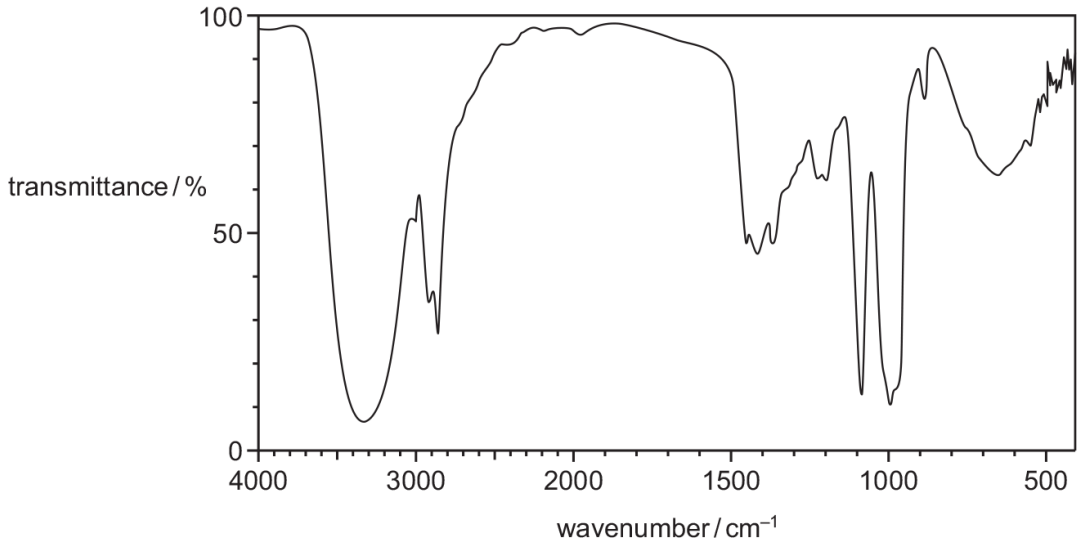


What could the three compounds be?

	spectrum 1	spectrum 2	spectrum 3
A	propanoic acid	propanone	propan-2-ol
B	propanone	propanoic acid	propan-2-ol
C	propanone	propan-2-ol	propanoic acid
D	propan-2-ol	propanoic acid	propanone

1195. 9701_w21_qp_12 Q: 30

The infra-red spectrum of Y is shown.



What could Y be?

A $CH_3CO_2C_2H_5$

B $CH_2(OH)CH=CHCH_2OH$

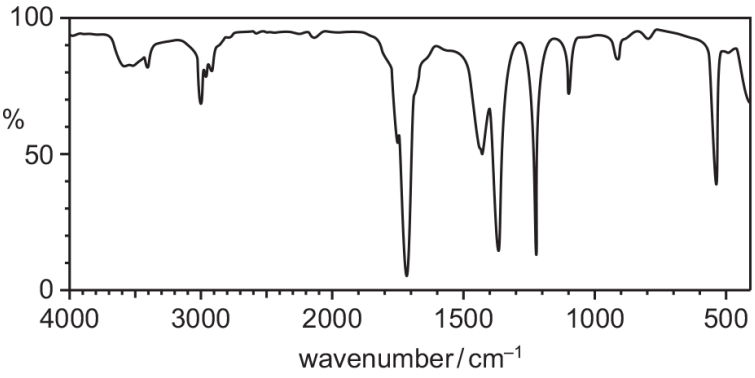
C $CH_3(CH_2)_2CO_2H$

D $CH_2(OH)(CH_2)_2CHO$

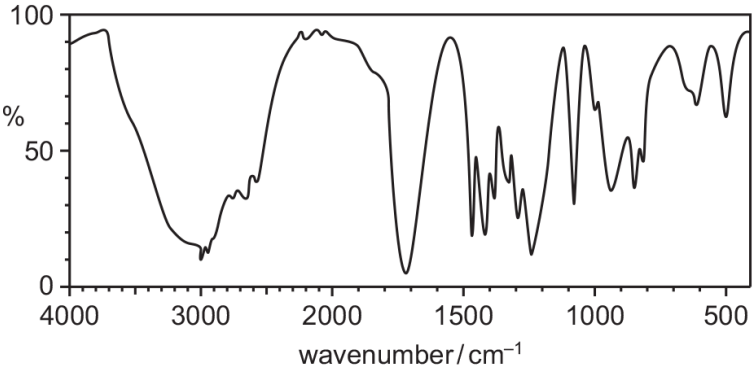
1196. 9701_w21_qp_13 Q: 30

The infra-red spectra of three organic compounds are shown.

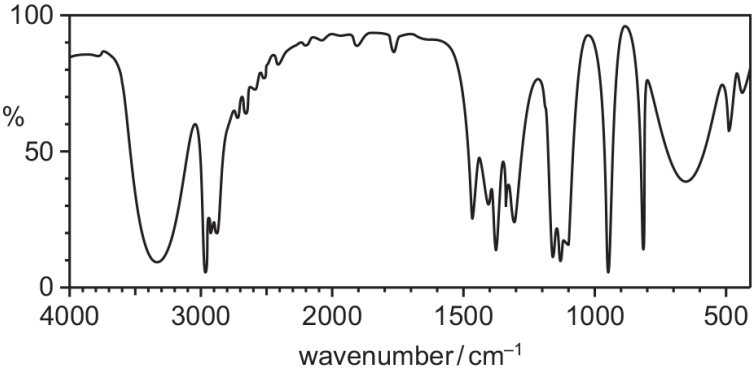
spectrum 1



spectrum 2



spectrum 3

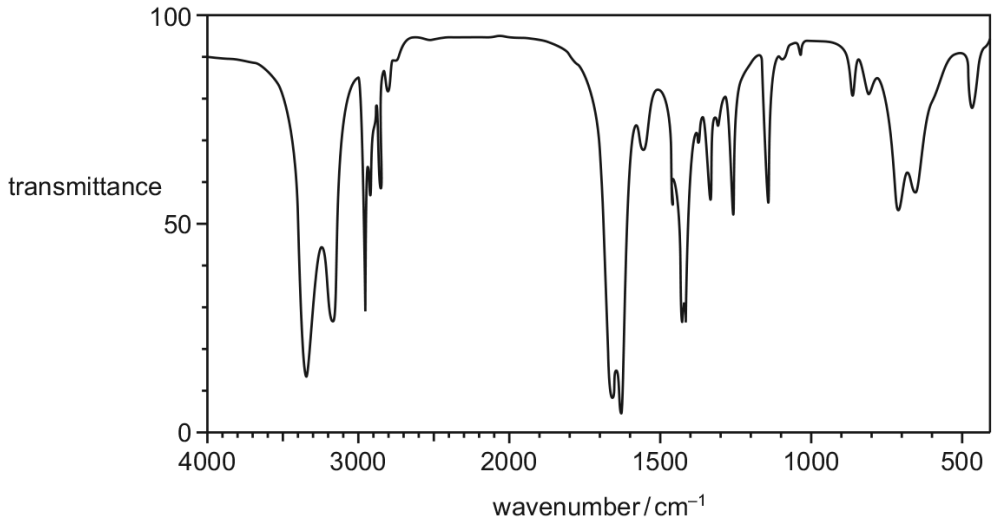


What could the three compounds be?

	spectrum 1	spectrum 2	spectrum 3
A	propanoic acid	propanone	propan-2-ol
B	propanone	propanoic acid	propan-2-ol
C	propanone	propan-2-ol	propanoic acid
D	propan-2-ol	propanoic acid	propanone

1197. 9701_m20_qp_12 Q: 23

The infrared spectrum shown was obtained from a compound J.



Which statement about J is correct?

A Both C=O and C≡N are present.

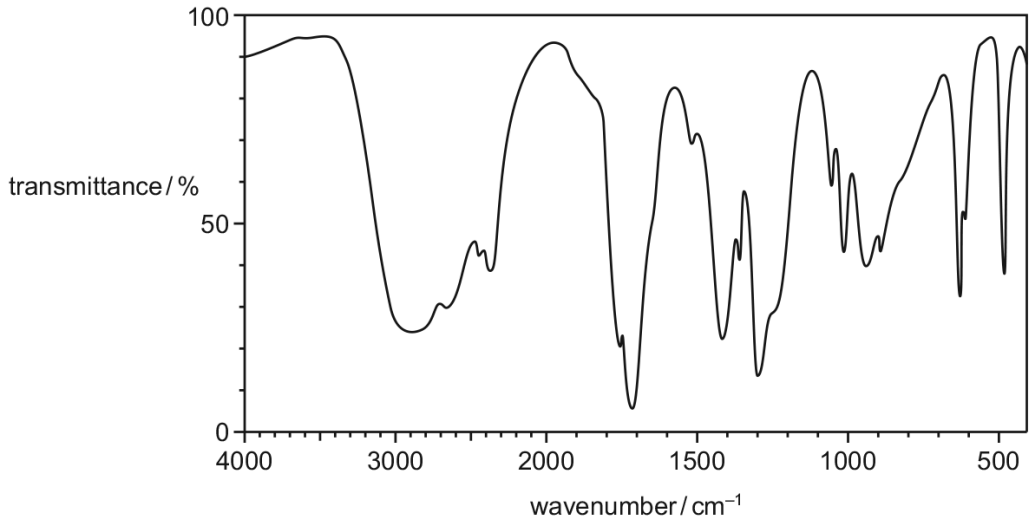
B Neither C=O nor C≡N are present.

C C=O is present but not C≡N.

D C≡N is present but not C=O.

1198. 9701_s20_qp_11 Q: 29

Compound X has the infra-red spectrum shown.



What could be the identity of compound X?

A ethanoic acid

B ethanol

C ethylethanoate

D propanone

1199. 9701_s20_qp_12 Q: 21

The table shows the molecular formulae of three molecules P, Q and R. None of the molecules are cyclic.

molecule	molecular formula
P	CH_4O
Q	CH_2O_2
R	CH_2O

Which molecules show a strong absorption between 1610 cm^{-1} and 1750 cm^{-1} in their infra-red spectra?

A Q only **B** R only **C** Q and R only **D** P, Q and R

1200. 9701_s20_qp_13 Q: 7

The element sulfur produces a mass spectrum with the following peaks.

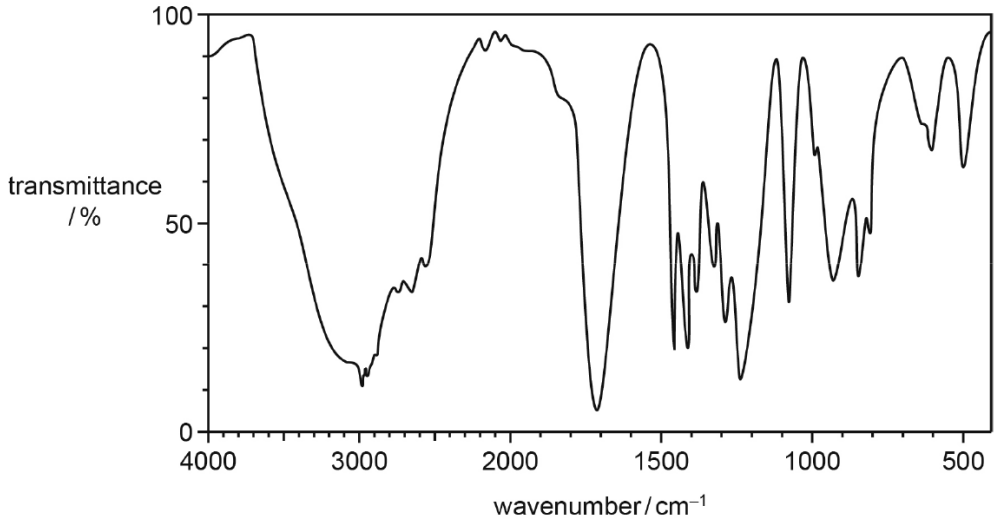
m/*e* value of peak	relative abundance
32	95.02
33	0.76
34	4.20
36	0.02

Which relative atomic mass of sulfur can be calculated from these data, given to four significant figures?

A 32.07 **B** 32.08 **C** 32.09 **D** 32.10

1201. 9701_s20_qp_13 Q: 25

The diagram shows the infrared spectrum of an organic compound.



What could be the identity of this compound?

A propan-1-ol

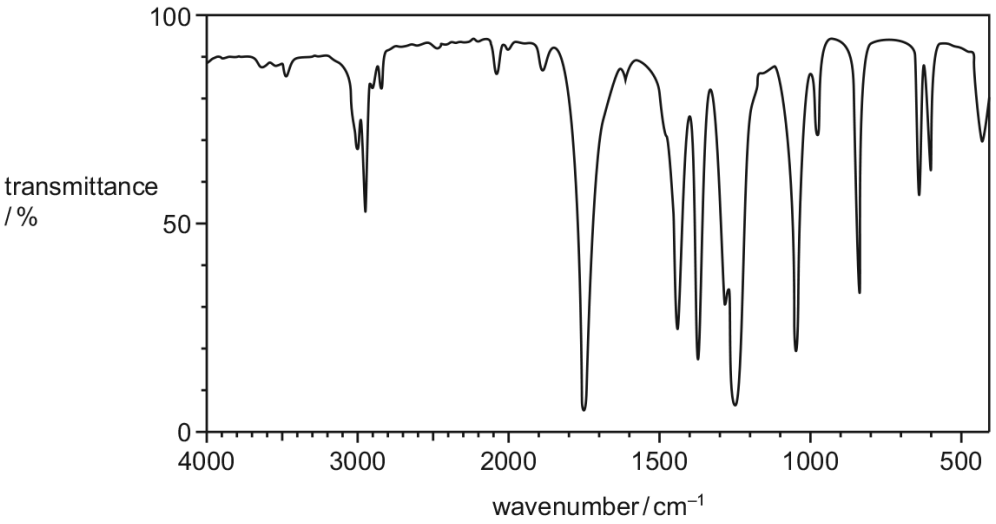
B propanal

C propanoic acid

D propanone

1202. 9701_w20_qp_12 Q: 30

The infra-red spectrum shown was obtained from compound G.



What could be compound G?

A CH_3COCH_2OH

B $CH_3CH_2CO_2H$

C $CH_3CO_2CH_3$

D $CH_3CHCHCH_3$

1203. 9701_m19_qp_12 Q: 30

An infra-red spectrum shows a broad peak at 3000 cm^{-1} and a strong peak at 1710 cm^{-1}.

Which substance could have produced this spectrum?

A methyl propanoate

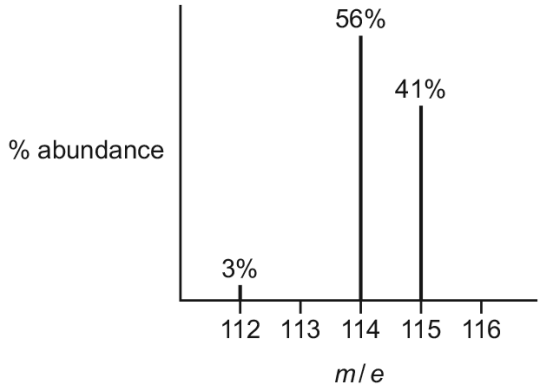
B propan-2-ol

C propanoic acid

D propanone

1204. 9701_s19_qp_11 Q: 2

A sample of element X is analysed using mass spectrometry. The mass spectrum obtained is shown.

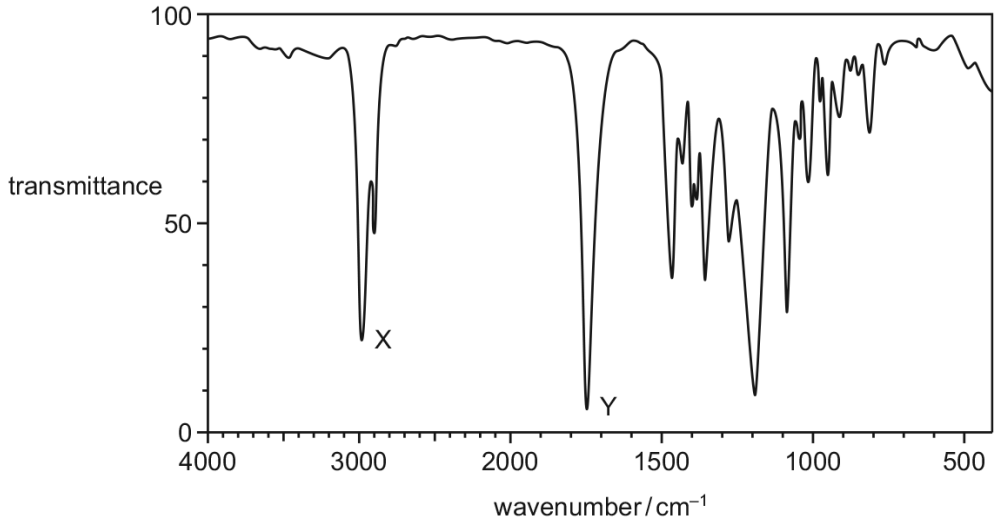


What is the relative atomic mass of this sample of element X?

A 113.7 **B** 114.0 **C** 114.2 **D** 114.4

1205. 9701_s19_qp_11 Q: 24

The infra-red spectrum of a substance with empirical formula C_2H_4O is shown.



Which bonds are responsible for peak X and peak Y?

	peak X	peak Y
A	C–H	C=C
B	C–H	C=O
C	O–H	C=C
D	O–H	C=O

1206. 9701_s19_qp_12 Q: 2

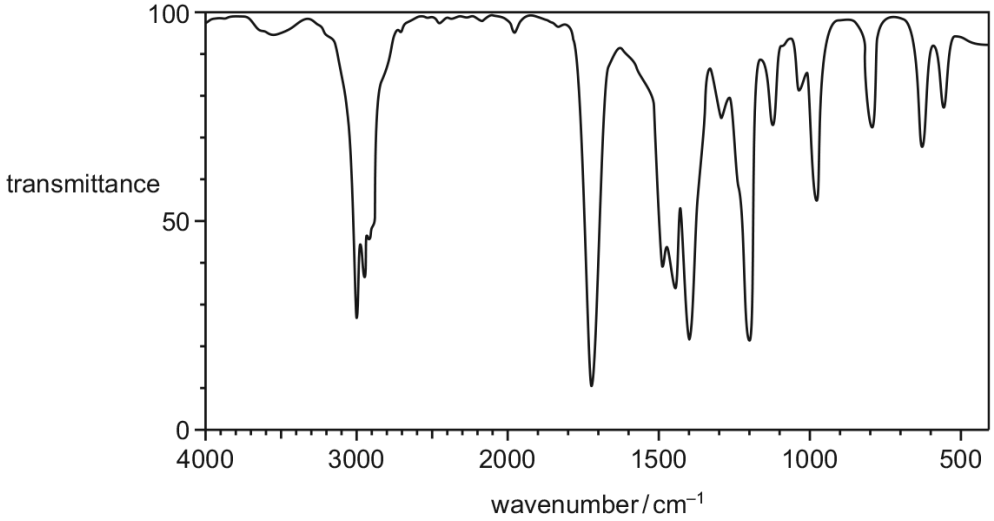
Oxygen has three stable isotopes, ^{16}O, ^{17}O and ^{18}O. All three isotopes are present in a sample of oxygen gas, O_2, which was analysed using a mass spectrometer.

How many peaks associated with the O_2^+ ion would be expected?

A 3 **B** 5 **C** 6 **D** 9

1207. 9701_s19_qp_12 Q: 30

The diagram shows the infra-red spectrum of Q.



What could be Q?

A butan-1-ol

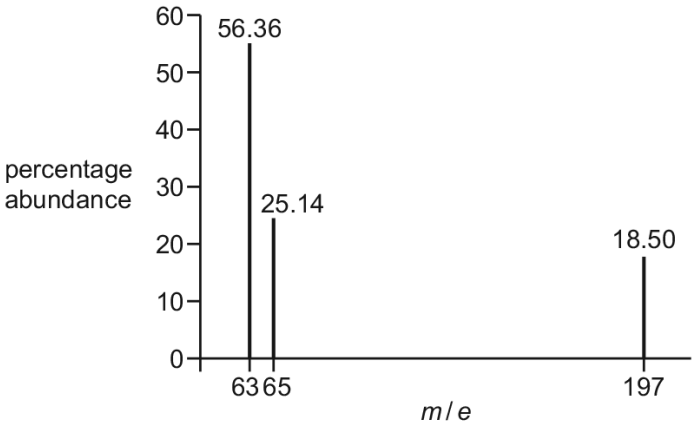
B butanoic acid

C butanone

D 3-hydroxybutanal

1208. 9701_s19_qp_13 Q: 2

The mass spectrum of an alloy of copper and gold is shown.



Which expression can be used to calculate the relative atomic mass, A_r, of copper present in this sample?

A $\dfrac{(56.36 \times 63) + (25.14 \times 65)}{(56.36 + 25.14 + 18.50)}$

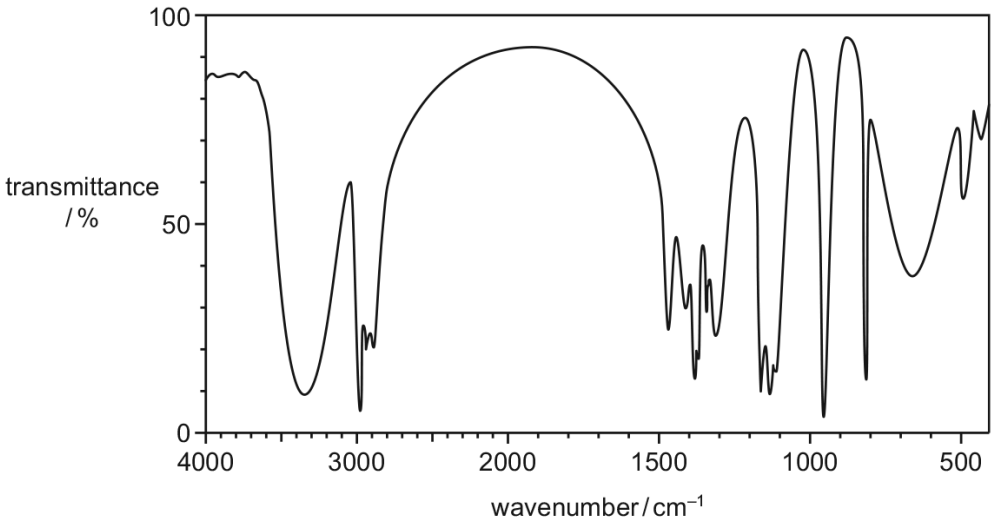
B $\dfrac{(56.36 \times 63) + (25.14 \times 65) + (18.50 \times 197)}{(56.36 + 25.14 + 18.50)}$

C $\dfrac{(56.36 \times 63) + (25.14 \times 65)}{(56.36 + 25.14)}$

D $\dfrac{(56.36 \times 63) + (25.14 \times 65)}{(63 + 65)}$

1209. 9701_w19_qp_11 Q: 30

The infra-red spectrum of compound P is shown.



What could be compound P?

A methyl ethanoate

B propanal

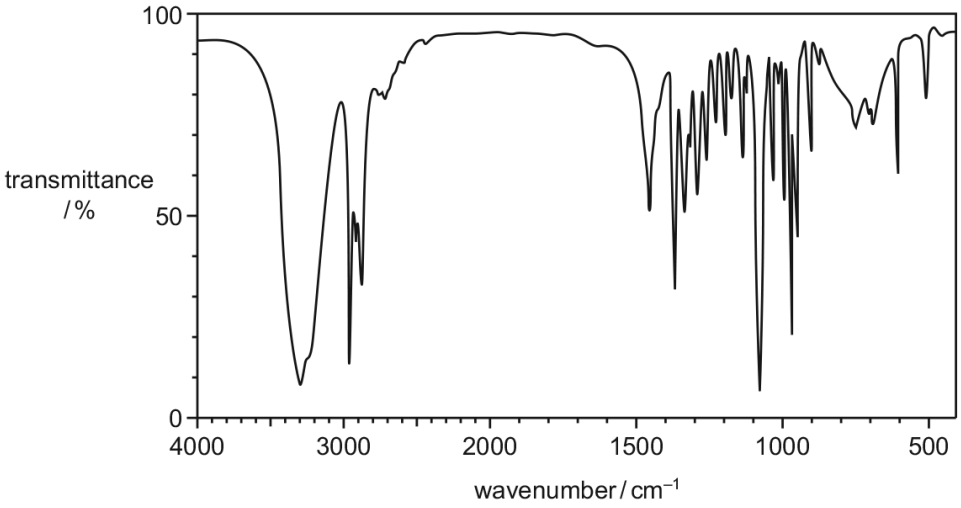
C propanoic acid

D propan-2-ol

1210. 9701_w19_qp_12 Q: 30

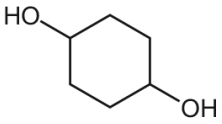
Substance T was analysed and found to contain 62.07% carbon, 10.34% hydrogen and 27.59% oxygen.

The infra-red spectrum of substance T is shown.

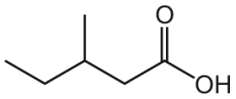


Which substance could be T?

A



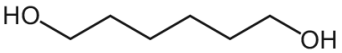
B



C



D



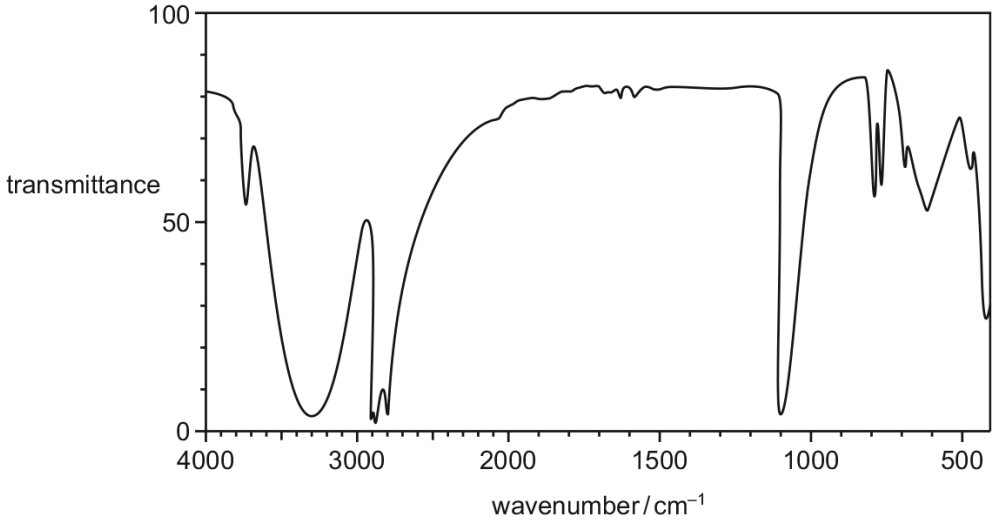
1211. 9701_m18_qp_12 Q: 30

How many **structural** isomers with the molecular formula $C_4H_{10}O$ give infra-red absorptions both at approximately 1200 cm^{-1} and at approximately 3400 cm^{-1}?

A 2 **B** 4 **C** 6 **D** 7

1212. 9701_s18_qp_11 Q: 30

Compound X contains three carbon atoms. Part of a simplified infra-red spectrum of compound X is shown.



Which compound could be X?

A CH_3CH_2CHO

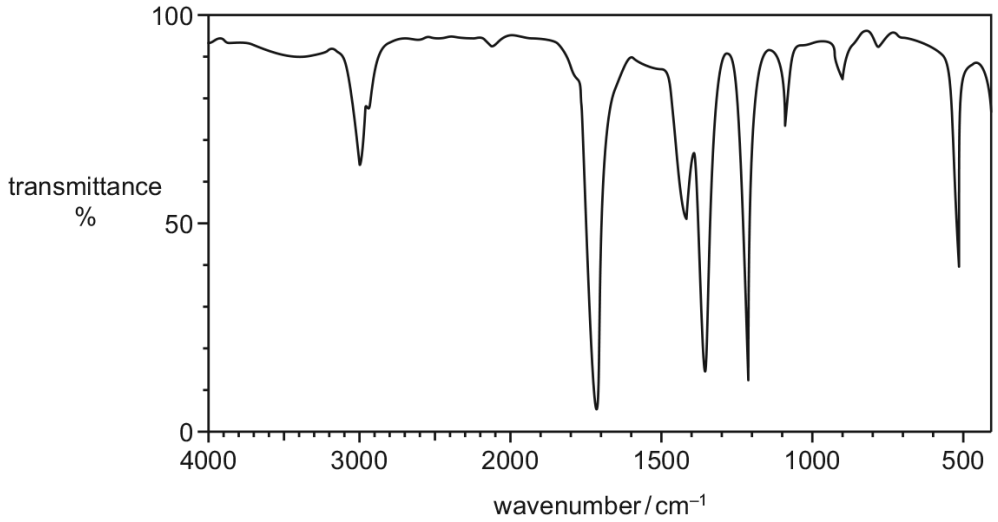
B $CH_3CH_2CO_2H$

C $CH_3CH_2CH_2OH$

D $CH_3CO_2CH_3$

1213. 9701_s18_qp_12 Q: 30

The infra-red spectrum of an organic compound is shown.



Which compound could give this spectrum?

A $CH_3CH_2CO_2H$

B $CH_3CH(OH)CH_3$

C CH_3COCH_3

D CH_3COCH_2OH

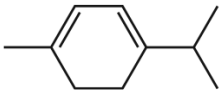
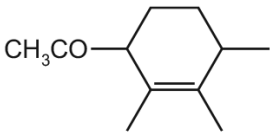
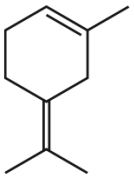
1214. 9701_s18_qp_13 Q: 30

Compound **S** can be extracted from natural compounds. Reacting **S** with hot, concentrated $KMnO_4$ produces the organic product, **T**. Some of the absorptions found in the infra-red spectra of **S** and **T** are described.

S has no strong absorption between 1670 and 1740 cm^{-1}.

T has a strong absorption at 1720 cm^{-1} but has **no** strong, broad absorption between 2500 and 3000 cm^{-1}.

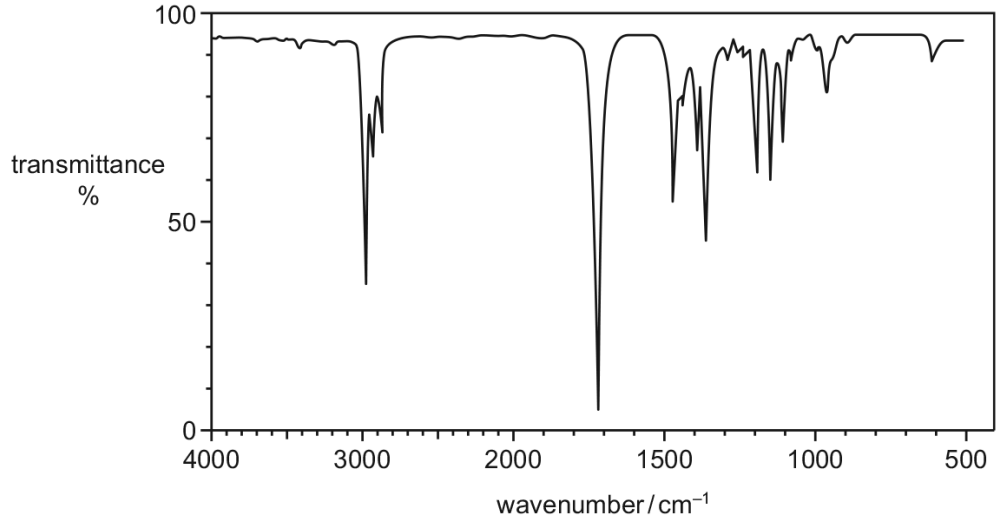
From this information, what could be the formulae of **S** and **T**?

	S	T
A	$CH_3(CH_2)_5CH{=}CH_2$	$CH_3(CH_2)_5CO_2H$
B		$CH_3COCH_2CH_2COCH(CH_3)_2$
C		$CH_3COCH(COCH_3)CH_2CH_2CH(COCH_3)CH_3$
D		$HO_2CCH_2CH_2COCH_2COCH_3$

1215. 9701_w18_qp_11 Q: 30

J is a branched-chain alcohol, $C_5H_{12}O$. **J** is heated under reflux with an excess of $Cr_2O_7^{2-}/H^+$ until no further reaction occurs. An organic compound **K** is formed in good yield.

The infra-red spectrum of **K** is shown.

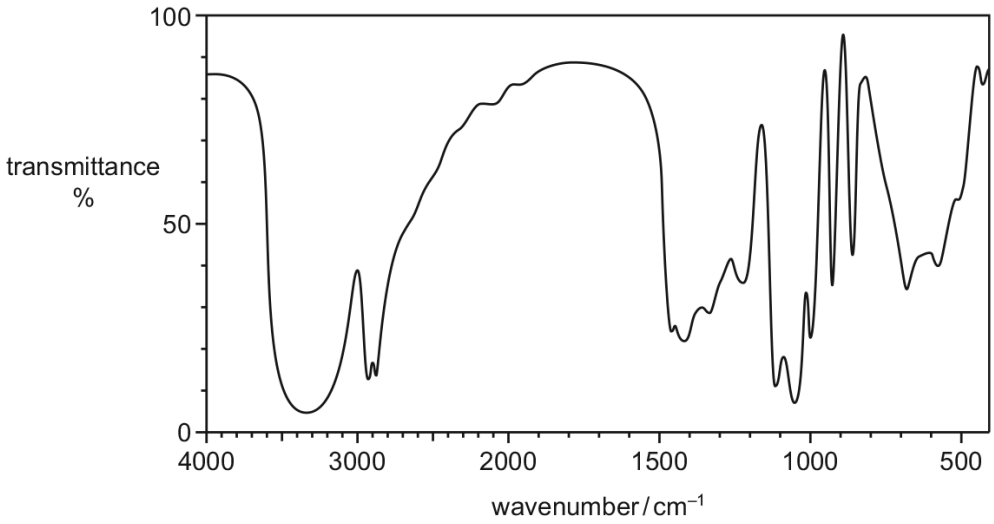


What are the structures of the branched-chain alcohol **J** and compound **K**?

	J	K
A	$CH_3CH(CH_3)CH_2CH_2OH$	$CH_3CH(CH_3)CH_2CHO$
B	$CH_3CH_2CH(OH)CH_2CH_3$	$CH_3CH_2COCH_2CH_3$
C	$CH_3CH(CH_3)CH(OH)CH_3$	$CH_3CH(CH_3)COCH_3$
D	$CH_3CH(CH_3)CH_2CH_2OH$	$CH_3CH(CH_3)CH_2COOH$

1216. 9701_w18_qp_12 Q: 30

The infra-red spectrum of compound **L** is shown.



What could be the structure of **L**?

A $HOCH_2COCH_2OH$

B $HOCH_2CH(OH)CHO$

C $HOCH_2CH(OH)CH_2OH$

D $HOCH_2CH_2COOH$

1217. 9701_s17_qp_11 Q: 2

The mass spectrum of a sample of lithium shows that it contains two isotopes, ^6Li and ^7Li.

The isotopic abundances are shown in the table.

isotope	isotopic abundance
^6Li	7.42%
^7Li	92.58%

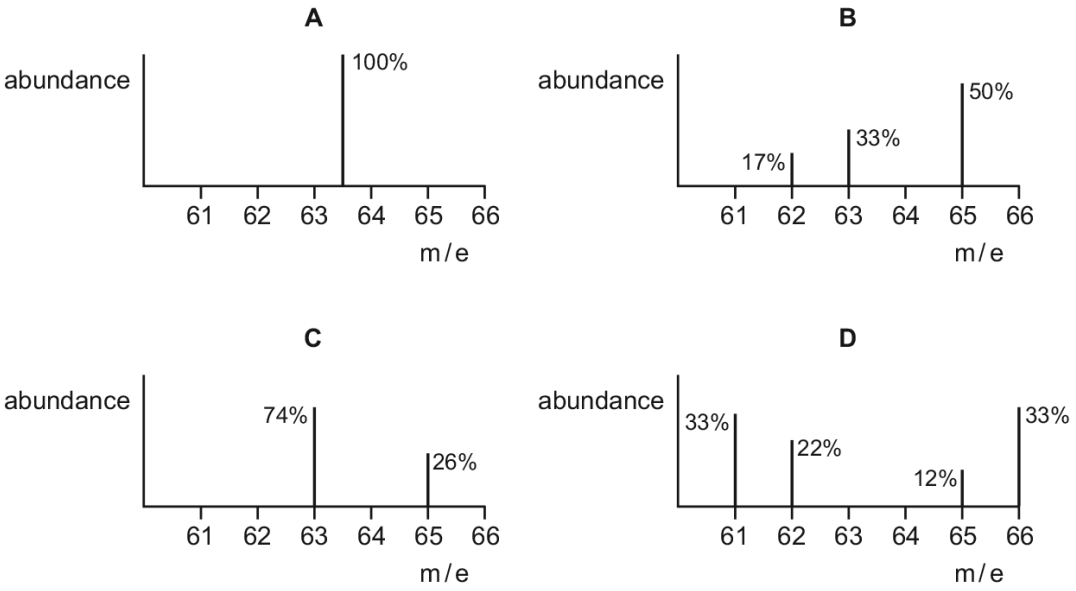
What is the relative atomic mass of this sample of lithium, given to three significant figures?

A 6.07 **B** 6.50 **C** 6.90 **D** 6.93

1218. 9701_s16_qp_13 Q: 4

The relative atomic mass of copper is 63.5.

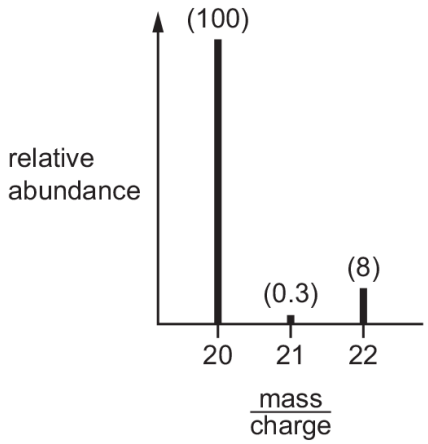
Which chart is a correct mass spectrum that would lead to this value?



21.2 Mass spectrometry

1219. 9701_w21_qp_11 Q: 1

The mass spectrum of a sample of neon is shown. The relative abundance of each peak is written in brackets above it.



What is the relative atomic mass, A_r, of this sample of neon?

A 20.15 **B** 20.20 **C** 21.00 **D** 21.82

1220. 9701_w21_qp_12 Q: 1

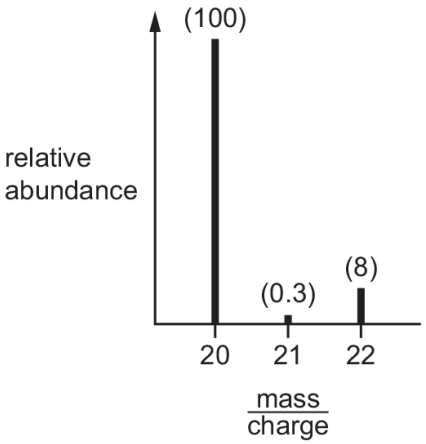
Compound X consists of 40.0% carbon, 6.7% hydrogen and 53.3% oxygen by mass.

What is the empirical formula of compound X?

A CH_2O **B** C_2H_2O **C** C_2H_4O **D** CHO

1221. 9701_w21_qp_13 Q: 1

The mass spectrum of a sample of neon is shown. The relative abundance of each peak is written in brackets above it.



What is the relative atomic mass, A_r, of this sample of neon?

A 20.15 **B** 20.20 **C** 21.00 **D** 21.82

Chapter 19

Analytical techniques

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19.1 Infra-red spectroscopy

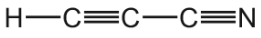
160. 9701_m21_qp_22 Q: 3

Compounds **P**, **Q** and **R** have all been found in the atmosphere of one of Saturn's moons.

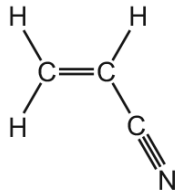
P



Q



R



(a) The equation for the complete combustion of **P**, $C_4N_2(l)$, is shown.

$$C_4N_2(l) + 4O_2(g) \rightarrow 4CO_2(g) + N_2(g) \qquad \Delta H = -2036\,kJ\,mol^{-1}$$

(i) The enthalpy change of formation, ΔH_f, of $CO_2(g)$ is $-384\,kJ\,mol^{-1}$.

Calculate the enthalpy change of formation, ΔH_f, of **P**, in $kJ\,mol^{-1}$.

ΔH_f of **P** = ... $kJ\,mol^{-1}$ [2]

(ii) One of the products of the complete combustion of **P** is nitrogen gas, $N_2(g)$.

Explain the lack of reactivity of nitrogen.

..... [1]

(b) **Q** forms when HCN reacts with ethyne, H—C≡C—H.

(i) Ethyne, HCN and **Q** are all weak Brønsted–Lowry acids.

Explain what is meant by the term *weak Brønsted–Lowry acid*.

.....

.....

..... [2]

(ii) Ethyne, HCN and **Q** all contain triple bonds between two atoms.

A triple bond consists of one sigma (σ) and two pi (π) bonds.

Draw a labelled diagram to show the formation of one pi (π) bond.

[2]

(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 .....

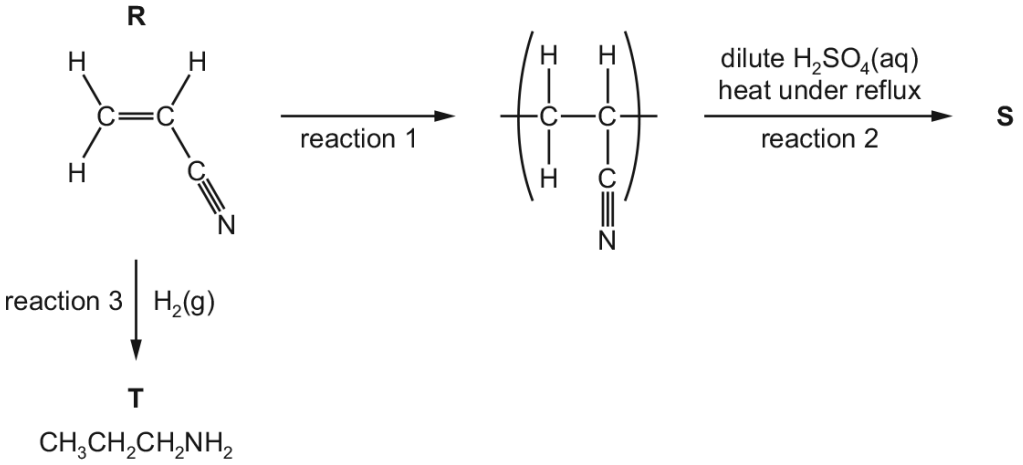
.....

2 .....

.....

[2]

(d) The flow chart shows some reactions of **R**.



(i) Name the type of reaction shown in reaction 1.

..... [1]

(ii) Draw the structure of **S**, the organic product of reaction 2.

[1]

(iii) Name **T**.

..... [1]

(iv) **T** can also be formed by the reaction of $CH_3CH_2CH_2Br$ with ammonia.

State the necessary conditions of this reaction.

..... [1]

[Total: 13]

161. 9701_s21_qp_22 Q: 5

S is a secondary alcohol with molecular formula $C_4H_{10}O$.

(a) Draw the displayed formula of **S**.

[1]

(b) **S** is converted to **V** in a three-step reaction sequence.



In step 1, the secondary alcohol **S** reacts with PBr_3 to produce **T**, which has molecular formula C_4H_9Br.

(i) Give the systematic name of **T**.

..... [1]

(ii) Name the type of reaction that occurs in step 1.

..... [1]

(iii) State the reagent(s) and conditions for step 2.

.....

..... [2]

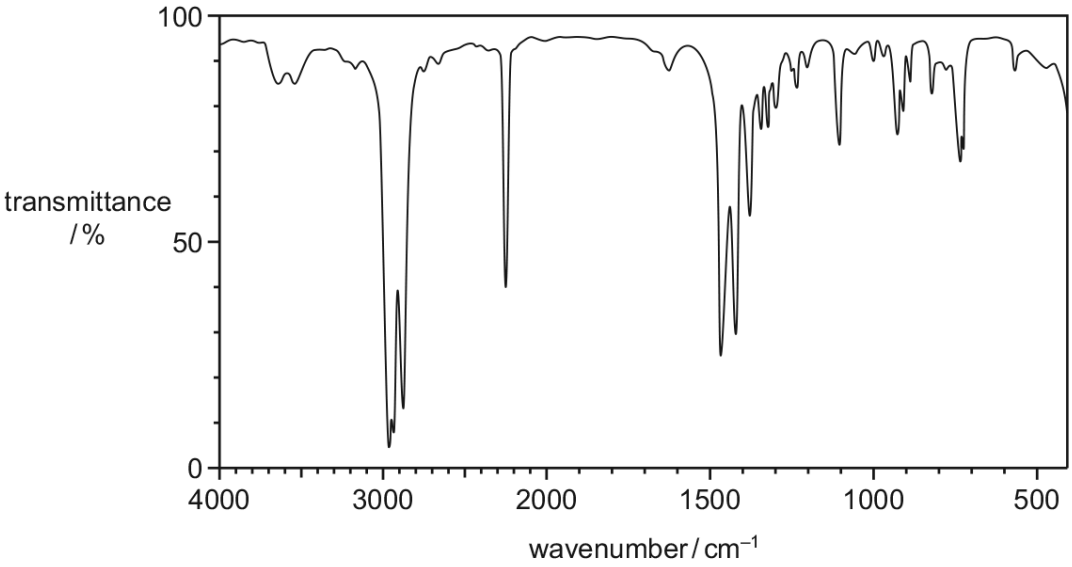
(iv) Step 3 involves heating C_4H_9CN with dilute acid to form **V**.

Complete the equation for this reaction.

$$.....C_4H_9CN + ...H^+ + ...H_2O \rightarrow .....$$ [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}.

.....

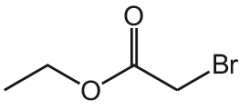
..... [1]

[Total: 8]

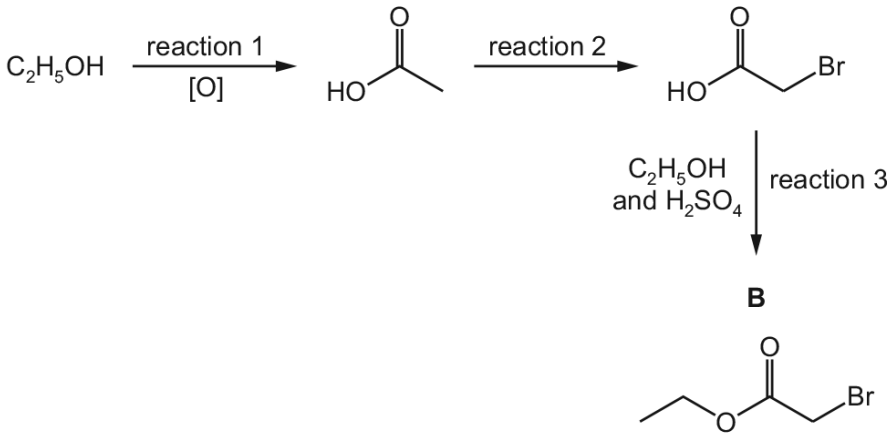
162. 9701_w21_qp_21 Q: 4

Compound **B** is a liquid with a fruity smell.

B



The reaction scheme shows how **B** can be made from ethanol, C_2H_5OH.



(a) (i) Reaction 1 is an oxidation reaction.

Give the reagent(s) and conditions required for reaction 1.

reagent(s) .....

conditions .....

.....

[2]

(ii) Construct an equation to represent reaction 1.

Use [O] to represent an oxygen atom from the oxidising agent in this reaction.

..... [1]

(iii) Suggest the type of reaction that occurs in reaction 2.

..... [1]

(iv) H_2SO_4 acts as a homogeneous catalyst in reaction 3.

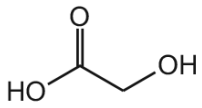
Explain why H_2SO_4 is described as *homogeneous*.

.....

..... [1]

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

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 1100 cm^{-1} and 1720 cm^{-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.

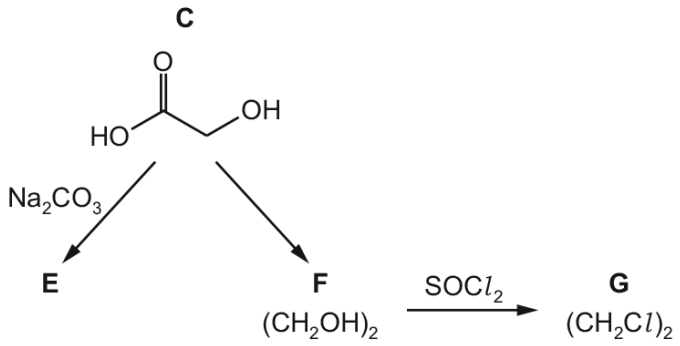
.....

.....

.....

..... [3]

(c) Some other reactions of **C** are shown.



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

[1]

(ii) Suggest why $NaBH_4$ is not a suitable reagent to make **F**, $(CH_2OH)_2$, from **C**.
Explain your answer.

.....

..... [1]

(iii) Construct an equation for the reaction of $(CH_2OH)_2$ with $SOCl_2$ to form **G**, $(CH_2Cl)_2$.

..... [1]

(d) Explain why **C** is very soluble in water.

.....

.....

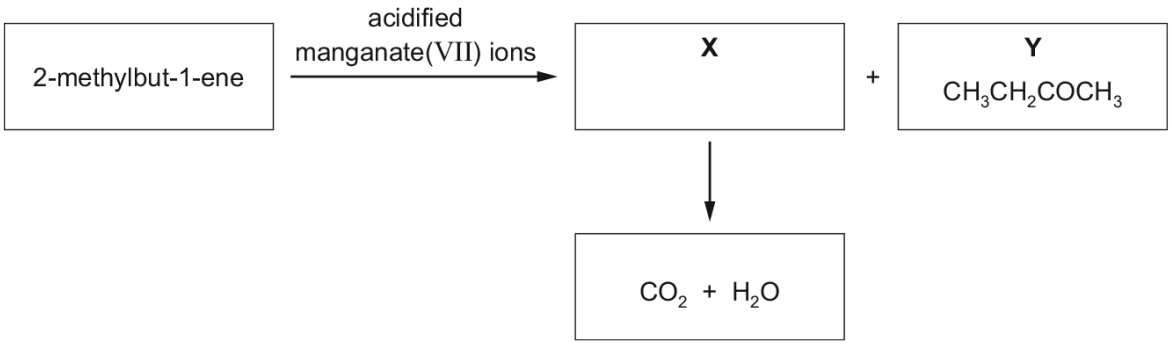
..... [1]

[Total: 12]

163. 9701_s20_qp_21 Q: 6

2-methylbut-1-ene reacts with acidified manganate(VII) ions, under specific conditions, to produce two organic compounds **X** and **Y**.

X immediately reacts with the acidified manganate(VII) ions to form carbon dioxide and water. **Y** has the structural formula $CH_3CH_2COCH_3$.



(a) Draw the skeletal formula of 2-methylbut-1-ene.

[1]

(b) (i) State the specific conditions required for the acidified manganate(VII) ions to react with 2-methylbut-1-ene in this way.

..... [1]

(ii) Name the type of reaction occurring to the functional group in 2-methylbut-1-ene in the reaction in **(b)(i)**.

..... [1]

(c) Draw the structural formula of **X**.

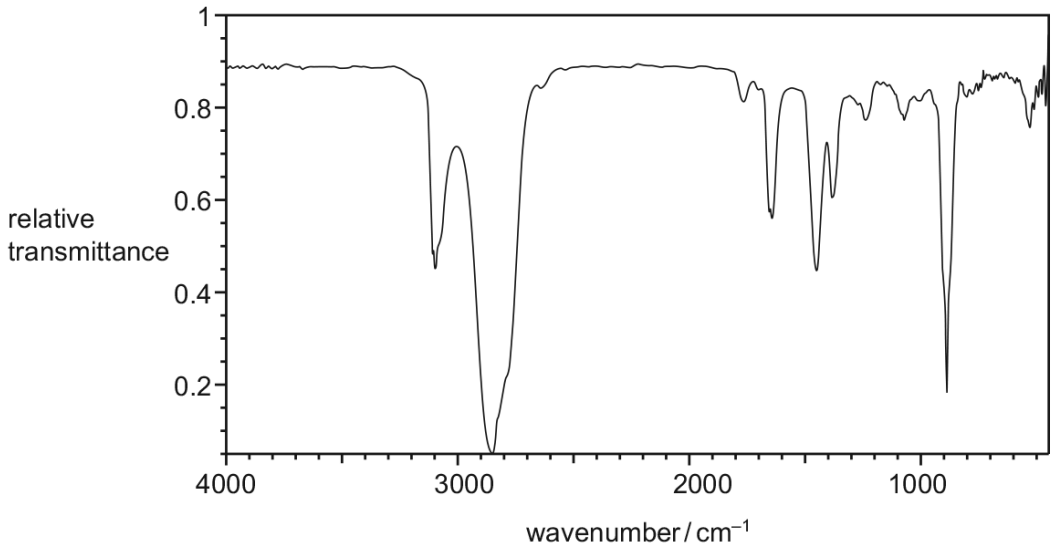
..... [1]

(d) Describe a chemical test and the expected observation(s) to confirm the presence of the carbonyl functional group in **Y**.

.....

..... [2]

(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**, $CH_3CH_2COCH_3$, 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]

(f) Propanoic acid, $CH_3CH_2CO_2H$, is reduced by $LiAlH_4$.

(i) Write an equation to show this reaction. Use [H] to represent an atom of hydrogen from the reducing agent.

..... [1]

(ii) Name the organic product formed in this reaction.

..... [1]

(g) Organic compound **W** is an ester which is a structural isomer of propanoic acid.

(i) State the molecular formula of **W**.

..... [1]

(ii) Draw a possible structure of **W**.

[1]

[Total: 12]

---

164. 9701_w20_qp_21 Q: 3

The reducing agent $LiAlH_4$ can be synthesised by reacting aluminium chloride with lithium hydride, LiH.

(a) (i) At 200 °C, aluminium chloride exists as Al_2Cl_6(g).

Draw the structure of Al_2Cl_6(g), showing fully any coordinate (dative covalent) bonds in the molecule.

[2]

(ii) At 1000 °C, aluminium chloride exists as $AlCl_3$(g).

State the bond angle in $AlCl_3$(g).

..... ° [1]

(iii) Lithium hydride contains the ions Li^+ and H^-.

State the electronic configuration of these two ions.

Li^+ ..... H^- .....
[1]

(iv) $LiAlH_4$ decomposes slowly to form LiAl(s) and H_2(g).

$$LiAlH_4(s) \rightarrow LiAl(s) + 2H_2(g)$$

LiAl(s) shows metallic bonding.

Describe metallic bonding.

.....

.....

..... [1]

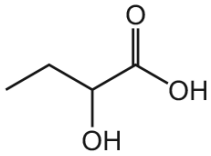
(b) $LiAlH_4$ cannot be used in aqueous solution because it reacts with water to produce LiOH(aq), $H_2(g)$ and a white precipitate which is soluble in excess sodium hydroxide.

Identify the white precipitate.

..... [1]

(c) Two students try to prepare 2-hydroxybutanoic acid in the laboratory.

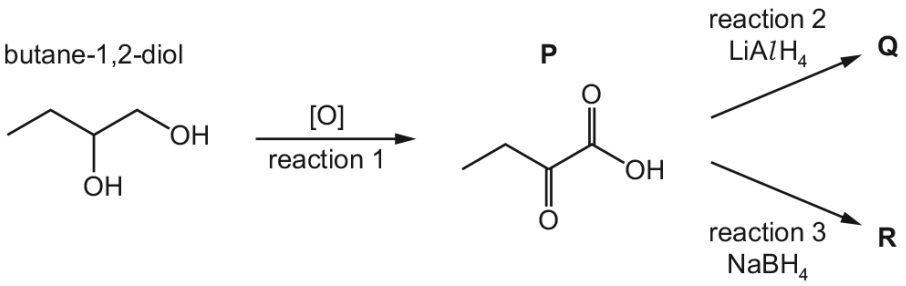
2-hydroxybutanoic acid



Both students oxidise butane-1,2-diol to form **P** in reaction 1.

One student then reduces **P** using $LiAlH_4$. **Q** is formed.

The other student reduces **P** using $NaBH_4$. **R** is formed.



(i) State the reagents and conditions required for reaction 1.

.....

..... [2]

(ii) Only one of the students successfully prepares 2-hydroxybutanoic acid.

Identify which of **Q** or **R** is 2-hydroxybutanoic acid and explain the difference between reactions 2 and 3.

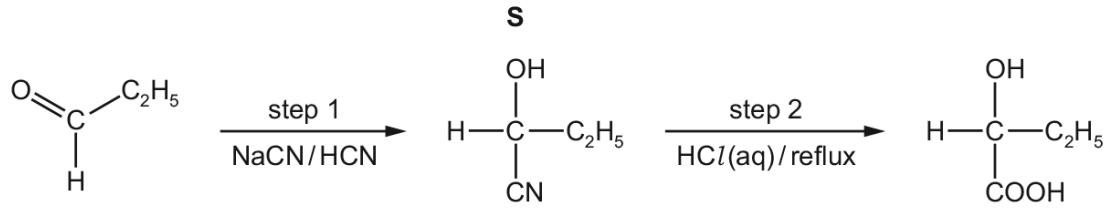
.....

.....

..... [2]

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A third student prepares 2-hydroxybutanoic acid using propanal as the starting material. In step 1 the student reacts propanal with a mixture of NaCN and HCN.



(iii) Draw the mechanism for the reaction of propanal with the mixture of NaCN and HCN to form **S**.

- Identify the ion that reacts with propanal.
- Draw the structure of the intermediate of the reaction.
- Include all charges, partial charges, lone pairs and curly arrows.



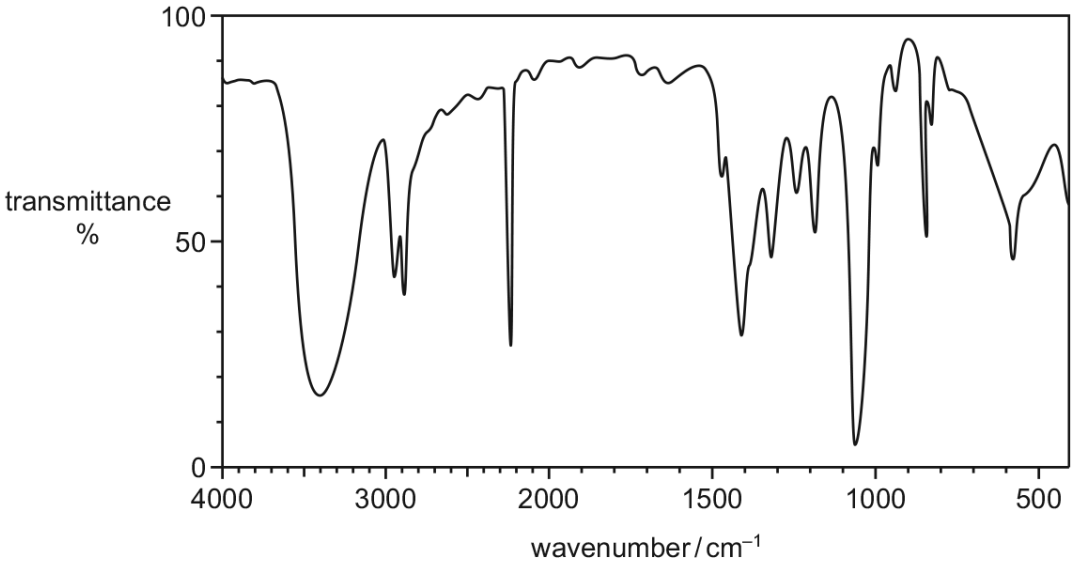
[4]

(iv) Complete the equation for the reaction in step 2, when **S** is heated under reflux with HCl(aq).

$C_2H_5CH(OH)CN$ + ... → $C_2H_5CH(OH)COOH$ + ...

[1]

(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.

.....

.....

.....

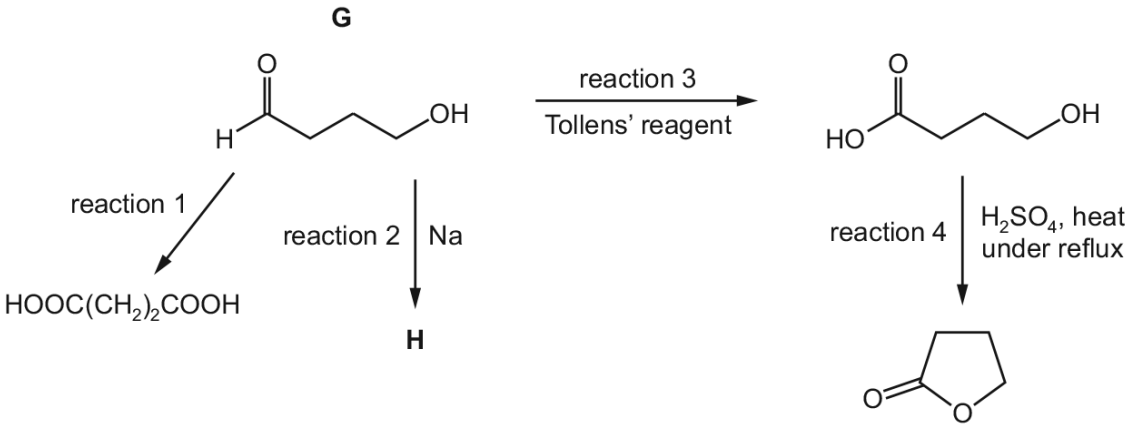
.....

..... [2]

[Total: 17]

165. 9701_w20_qp_22 Q: 4

Some reactions of compound **G** are shown.



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

..... [1]

(ii) Suggest the reagent(s) and conditions required for reaction 1.

.....

..... [2]

(iii) Draw the structure of the organic product, **H**, from reaction 2.

[1]

(iv) State what you would observe in reaction 3.

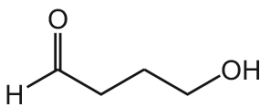
..... [1]

(v) Give the type of reaction shown by reaction 4.

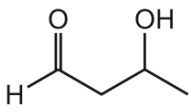
..... [1]

(b) **G** and **J** are structural isomers of each other.

G



J



(i) Name the type of structural isomerism shown by **G** and **J**.

..... [1]

(ii) Suggest **one** chemical test that can distinguish **G** from **J**. Give the result of the test with each compound.

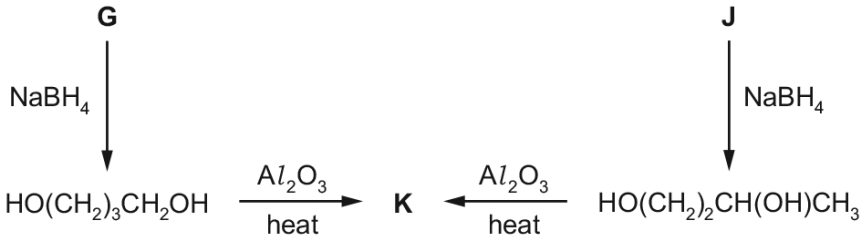
test .....

result with **G** .....

result with **J** .....

[2]

In the reaction schemes below, **G** and **J** are converted into organic compound **K**.



(iii) State the role of $NaBH_4$ in the reactions with **G** and **J**.

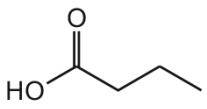
..... [1]

(iv) Identify the organic product **K**.

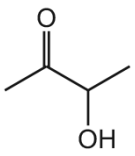
..... [1]

(c) **P** and **Q** have the same molecular formula as **G**.

P



Q



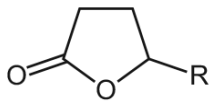
Complete the table with the expected observations for the reactions of **P** and **Q** with the named reagents.

reagent	result with **P**	result with **Q**
Br_2(aq)		
2,4-dinitrophenylhydrazine		
aqueous sodium carbonate		

[3]

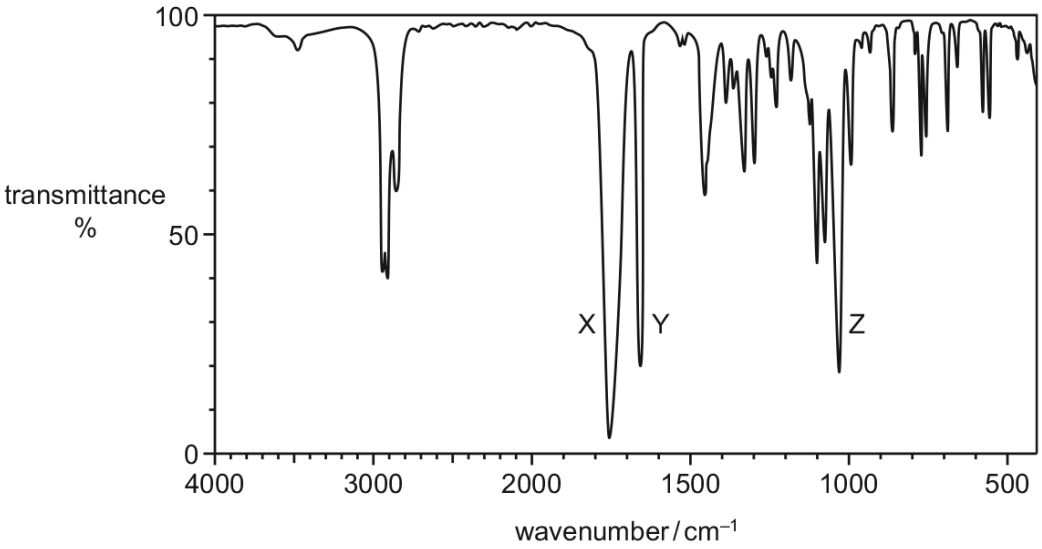
(d) The structure of compound **L** is shown. R represents a hydrocarbon chain.

L



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.

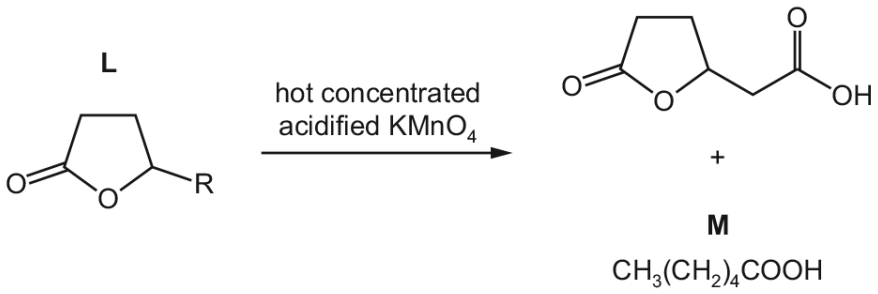
X .....

Z .....

[1]

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.



(ii) Name **M**.

..... [1]

(iii) Use the information in **(d)** to deduce the molecular formula of **L**.

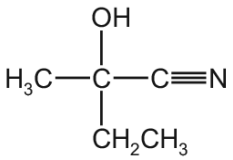
molecular formula of **L** = ... [1]

[Total: 17]

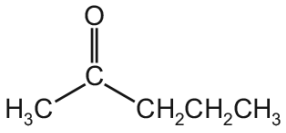
166. 9701_m19_qp_22 Q: 3

P, **Q** and **R** all contain five carbon atoms.

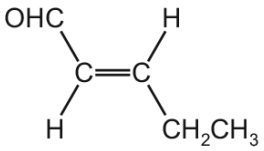
P



Q



R



A student carries out several tests to distinguish between **P**, **Q** and **R**.

(a) Complete the table, identifying any observations for the reaction of each reagent with **P**, **Q** and **R**.

If no reaction occurs, write 'no reaction'.

reagent	observations with		
	P	**Q**	**R**
Na(s)			
2,4-DNPH	no reaction		
acidified $K_2Cr_2O_7$(aq)	no reaction		

[3]

(b) **Q** is reduced by $NaBH_4$.

Write an equation for the reaction of **Q** with $NaBH_4$.

In your answer, use [H] to represent $NaBH_4$.

$C_5H_{10}O$ + ... [1]

(c) **R** exists as a pair of stereoisomers.

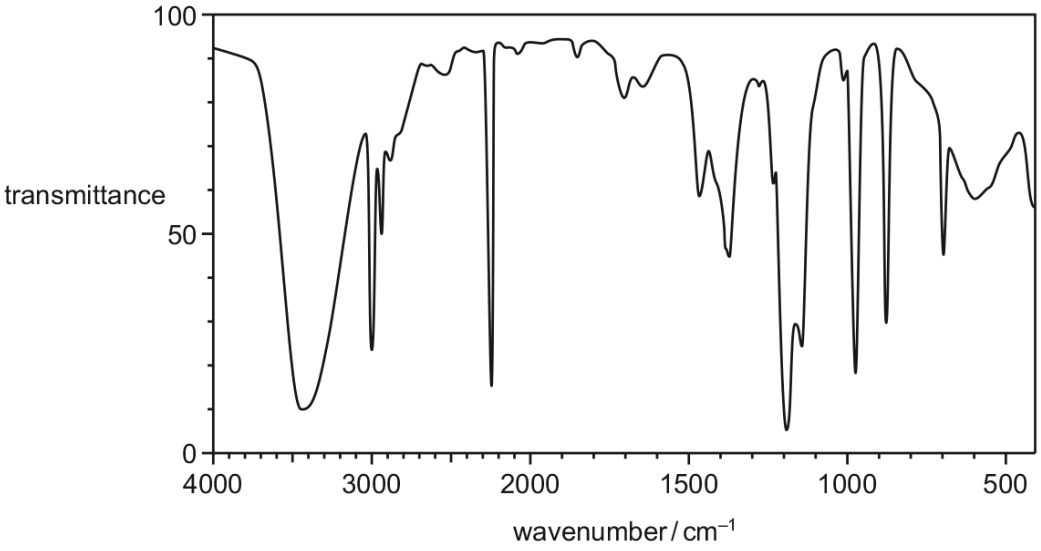
Identify the type of stereoisomerism shown by **R** and draw the structure of the other stereoisomer.

type of stereoisomerism .....

stereoisomer of **R**

[2]

(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 .....

.....

.....

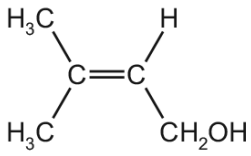
[3]

[Total: 9]

167. 9701_w19_qp_22 Q: 4

Prenol is a naturally occurring organic molecule found in many fruits. It contains both an alkene and an alcohol functional group.

prenol

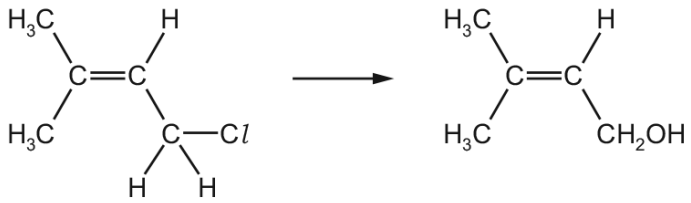


(a) Prenol can be formed by the reaction of **G** with NaOH(aq).

Complete the diagram to show the mechanism of the reaction between **G** and NaOH(aq) to form prenol.

Include all relevant charges, partial charges, lone pairs and curly arrows.

G prenol



[2]

(b) Prenol reacts with steam to form a mixture of three isomers, **J**, **K** and **L**, of molecular formula $C_5H_{12}O_2$.

(i) When **J** is heated with excess acidified potassium dichromate(VI) it forms an organic product which shows no reaction with 2,4-DNPH.

Draw the structure of **J**.

[1]

K and **L** are stereoisomers with molecular formula $C_5H_{12}O_2$.

K and **L** both react when heated with excess acidified potassium dichromate(VI) to form **M**, $C_5H_8O_3$.

M forms an orange precipitate on reaction with 2,4-DNPH.

(ii) Give the structural formula of **K** and **L**.

..... [1]

(iii) Name the type of stereoisomerism shown by **K** and **L**.

..... [1]

(iv) Give the balanced equation to represent the reaction of **K**, $C_5H_{12}O_2$, with acidified potassium dichromate(VI) to form **M**, $C_5H_8O_3$.

Use [O] to represent an atom of oxygen provided by the oxidising agent.

..... [1]

(c) (i) Prenol contains an alkene functional group.

Describe a chemical test to confirm the presence of an alkene functional group. Give the result of the test.

.....

..... [1]

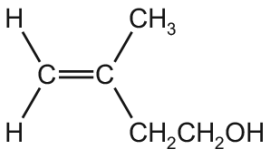
(ii) Prenol can be polymerised to form poly(prenol).

Draw **one** repeat unit of poly(prenol).

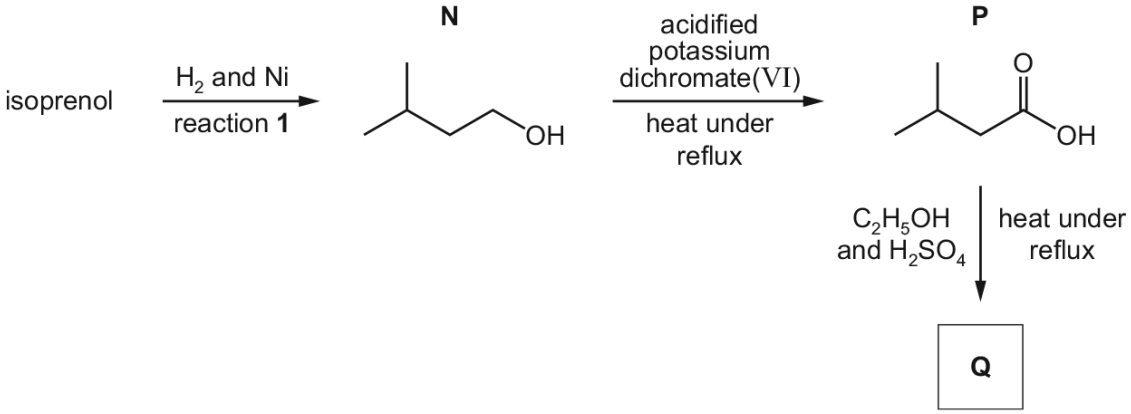
[1]

(d) Isoprenol is a structural isomer of prenol.

isoprenol



The series of reactions shows how isoprenol can be used to form **Q**, a sweet-smelling liquid.



(i) Give the name of **N**.

..... [1]

(ii) Isoprenol is a liquid.

Ni acts as a catalyst for reaction **1**.

Identify the type of catalysis shown by Ni in reaction **1**.

..... [1]

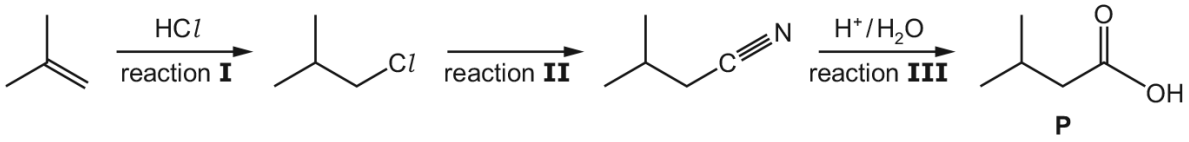
(iii) Draw the **skeletal** formula of **Q** and suggest one commercial use of **Q**.

Q

commercial use .....

[2]

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



P

(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]

(ii) State the reagent(s) needed for reaction **II**.

..... [1]

(iii) Name the type of reaction that occurs in reaction **III**.

..... [1]

(iv) The yield of reaction **I** is very low.

Explain why.

.....

.....

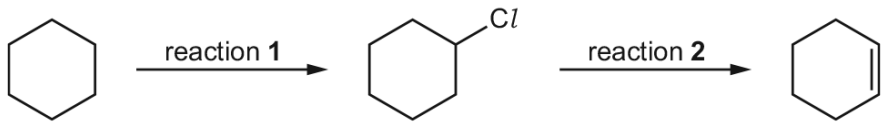
..... [2]

[Total: 17]

168. 9701_m18_qp_22 Q: 4

Cyclohexane is a colourless liquid used in industry to produce synthetic fibres.

A reaction scheme involving cyclohexane is shown.

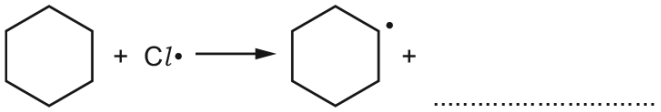
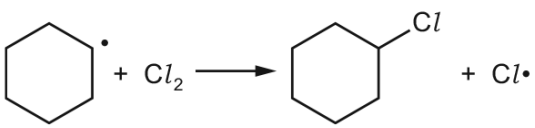


(a) Reaction **1** involves a free radical substitution mechanism.

(i) State the essential condition required for reaction **1** to occur.

..... [1]

(ii) Complete the table to give details of the mechanism in reaction **1**.

name of step	reaction
.....	$Cl_2 \longrightarrow 2Cl\bullet$
propagation	
.....	
termination	

[4]

(b) Name the type of reaction that occurs in reaction **2**.

..... [1]

(c) The product of reaction **2** is cyclohexene.

Cyclohexene can be converted into adipic acid (hexanedioic acid), $HO_2C(CH_2)_4CO_2H$.

(i) Identify the reagents and conditions for the conversion of cyclohexene into adipic acid.

.....

..... [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 .....

.....

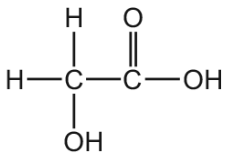
.....

[3]

[Total: 11]

169. 9701_w18_qp_21 Q: 4

The structure of glycolic acid is shown.



glycolic acid

(a) Complete the table to show what you would **observe** when an aqueous solution of glycolic acid is added separately to each of the reagents. If a reaction occurs, state the functional group of glycolic acid that is responsible for the reaction.

reagent	observation with glycolic acid	does a reaction occur? ✓/✗	functional group
$Na_2CO_3(aq)$			
2,4-DNPH			
acidified $Cr_2O_7^{2-}$			

[4]

(b) Two reaction sequences to make glycolic acid are shown.

sequence A $\quad HCHO \xrightarrow[\text{reaction } \mathbf{1}]{\text{HCN and NaCN}} \mathbf{X} \xrightarrow[\text{reaction } \mathbf{2}]{} CH_2(OH)CO_2H$

sequence B $\quad CH_3CO_2H \xrightarrow[\text{reaction } \mathbf{3}]{Br_2} CH_2BrCO_2H \xrightarrow[\text{reaction } \mathbf{4}]{} CH_2(OH)CO_2H$

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

[1]

(ii) Name the reagent for reaction **2**.

..... [1]

(iii) Name the mechanism of reaction **3**.

..... [1]

(iv) Suggest the essential condition for reaction **3**.

..... [1]

(v) Reaction **4** occurs via an S_N2 mechanism.

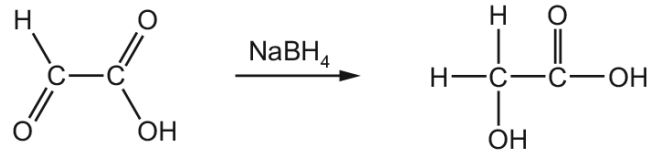
Complete the diagram for the mechanism for reaction **4**.

Include all relevant charges, partial charges, curly arrows and lone pairs.



[2]

(c) Glycolic acid can also be made by reacting glyoxylic acid with $NaBH_4$.



glyoxylic acid glycolic acid

(i) State the role of $NaBH_4$ in this reaction.

..... [1]

(ii) Write an equation for this reaction using molecular formulae.
Use [H] to represent $NaBH_4$.

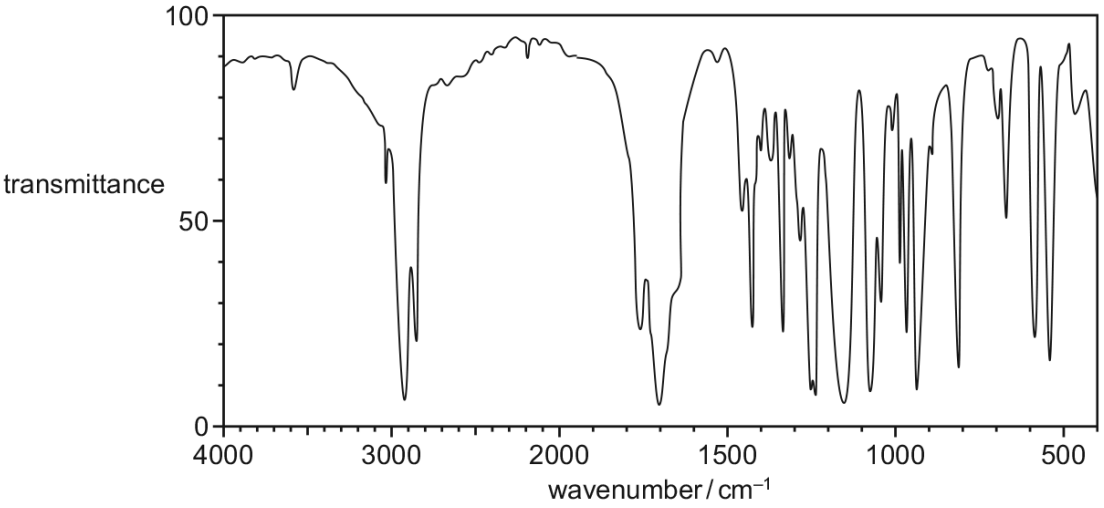
..... [2]

(d) When glycolic acid is heated in the presence of a sulfuric acid catalyst, a new compound, **Y**, $C_4H_4O_4$, is formed.
The equation for the reaction is given.

$$2CH_2(OH)CO_2H \rightarrow C_4H_4O_4 + 2H_2O$$

glycolic acid **Y**

(i) The infra-red spectrum of **Y** is shown.



State how this spectrum differs from an infra-red spectrum of glycolic acid. Explain your answer with particular reference to the peaks within the range 1500 – 4000 cm^{-1}.

.....

.....

..... [2]

(ii) Suggest a structure for **Y**.

[2]

[Total: 17]

170. 9701_w18_qp_22 Q: 3

Trihalomethanes are organic molecules in which three of the hydrogen atoms of methane are replaced by halogen atoms, for example CHF_3.

(a) The equation shows a reaction to produce CHF_3.

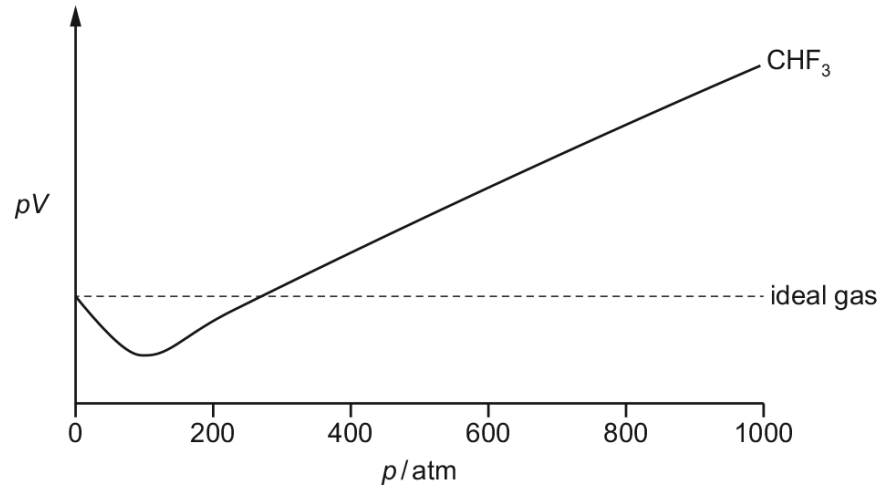
$$CHI_3(s) + 3AgF(s) \rightarrow CHF_3(g) + 3AgI(s)$$

Use the data to calculate the enthalpy change of reaction, ΔH_r, for this formation of CHF_3.

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$CHI_3(s)$	–182.1
$CHF_3(g)$	–692.9
AgF(s)	–204.6
AgI(s)	–61.8

enthalpy change of reaction, ΔH_r = ... kJ mol^{-1} [3]

(b) The graph shows the relationship between pV and p at a given temperature for CHF_3 and an ideal gas.



(i) CHF_3 is not an ideal gas.

State **three** basic assumptions that scientists make about the properties of ideal gases.

1 .....

2 .....

3 .....

[3]

(ii) Explain why CHF_3 deviates from the properties of an ideal gas at pressures greater than 300 atm.

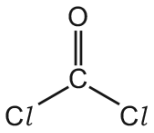
.....

.....

.....

..... [2]

(c) A different trihalomethane, $CHCl_3$, reacts with O_2 to produce carbonyl dichloride. HCl(g) is also released as a product of this reaction.

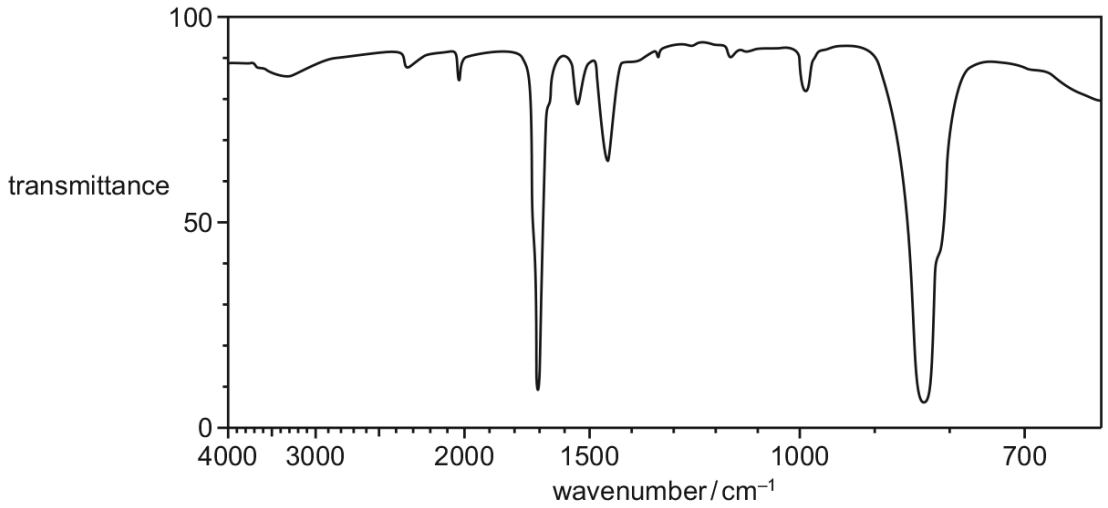


carbonyl dichloride

(i) Write an equation for this reaction of $CHCl_3$ with O_2.

..... [1]

(ii) The conversion of $CHCl_3$ to carbonyl dichloride can be monitored by infra-red spectroscopy. The infra-red spectrum of carbonyl dichloride is shown.



On the infra-red spectrum of carbonyl dichloride identify with an **X** the absorption that would **not** be present in an infra-red spectrum of $CHCl_3$.

Explain your answer.

.....

.....

[2]

(iii) Suggest another difference between the infra-red spectra of $CHCl_3$ and carbonyl dichloride.

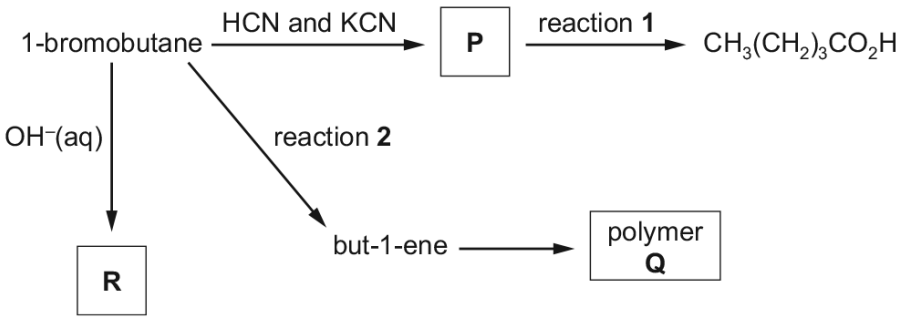
.....

..... [1]

[Total: 12]

171. 9701_m17_qp_22 Q: 3

(a) A series of reactions starting from 1-bromobutane is shown.



(i) Draw the **displayed** formula of compound **P**.

[1]

(ii) Identify the reagent(s) and conditions for reactions **1** and **2**.

reaction **1** .....

reaction **2** .....

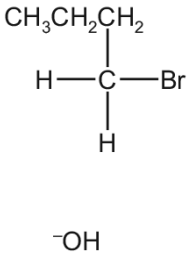
[2]

(iii) Draw the structure of the repeat unit of polymer **Q**.

[2]

(b) Complete the reaction scheme to show the mechanism of the reaction of 1-bromobutane with $OH^-(aq)$ to produce **R**.

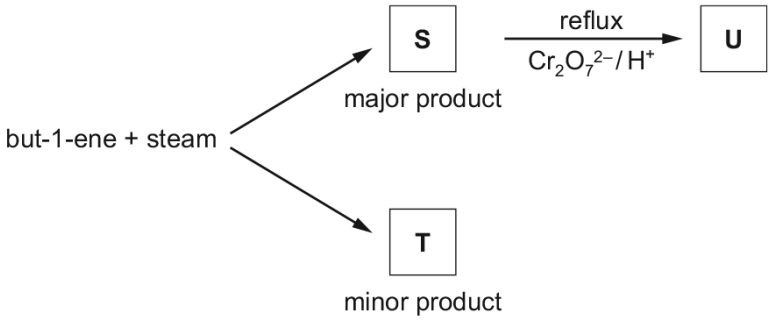
Include all necessary charges, dipoles, lone pairs and curly arrows and the structure of **R**.



^-OH

[3]

(c) But-1-ene reacts with steam as shown to form a mixture of two structural isomers, **S** and **T**.



S can be oxidised with acidified potassium dichromate(VI) to form compound **U**.
S and **U** both react with alkaline aqueous iodine.

(i) Identify the *type of reaction* that occurs when but-1-ene reacts with steam.

..... [1]

(ii) State what can be deduced about the structure of **S** from its reaction with alkaline aqueous iodine.

..... [1]

(iii) Explain why **S** is the major product of the reaction of but-1-ene with steam.

.....

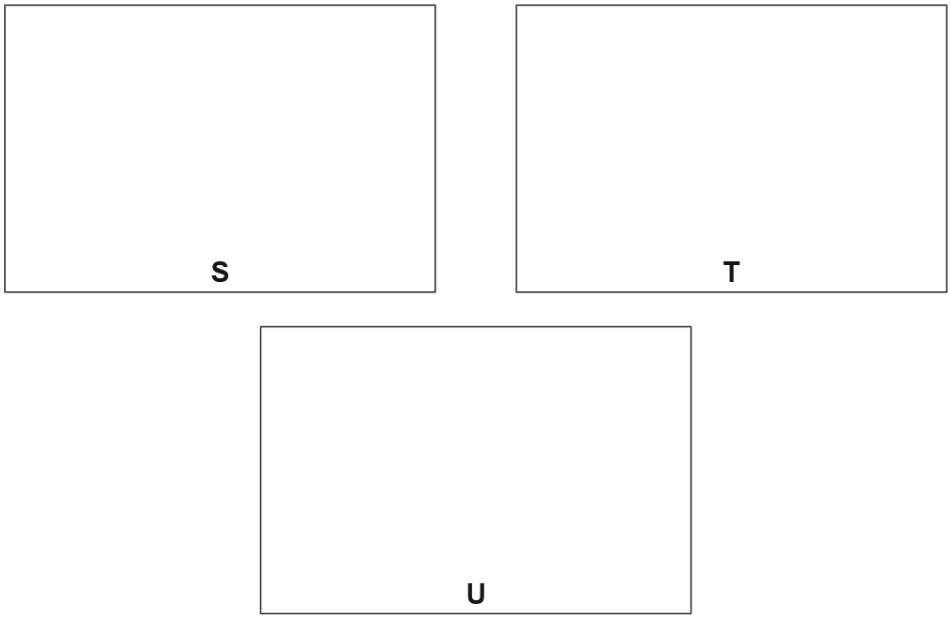
.....

.....

.....

..... [2]

(iv) Draw the **skeletal** formulae of **S**, **T** and **U**.



[3]

(v) Write an equation to represent the oxidation of **S** to **U** by acidified potassium dichromate(VI).

You should use [O] to represent the oxidising agent.

..... [1]

(d) $CH_3(CH_2)_3CO_2H$ is a colourless liquid with an unpleasant odour.

It reacts with methanol in the presence of an acid catalyst to produce an organic product **V**, which has a pleasant fruity smell.

(i) Name **V**.

..... [1]

(ii) A student analysed $CH_3(CH_2)_3CO_2H$, methanol and **V** using infra-red spectroscopy. The spectra were returned to the student without labels.

Identify which of the infra-red spectra, X, Y or Z, corresponds to **V**.

compound	$CH_3(CH_2)_3CO_2H$	methanol	**V**
spectrum			

Explain your answer with reference to relevant features of the **three** spectra in the region above 1500 cm^{-1}.

.....

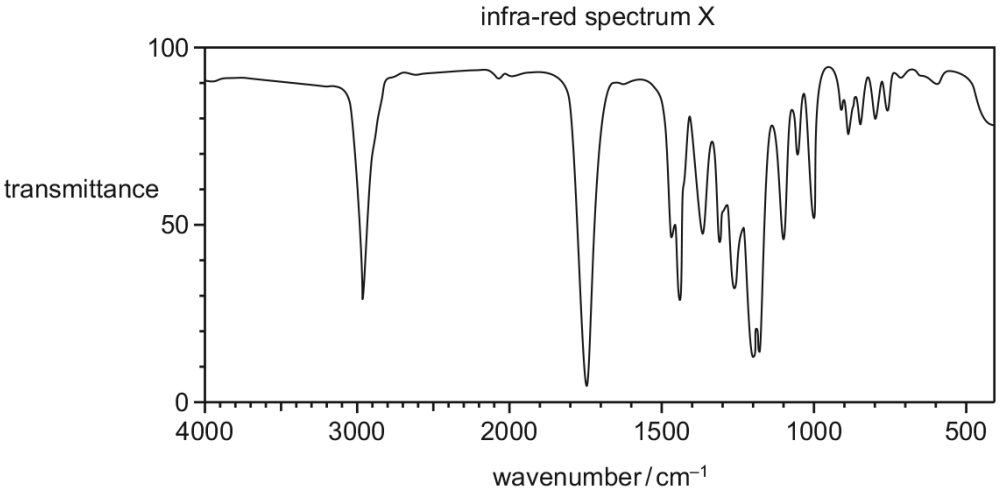
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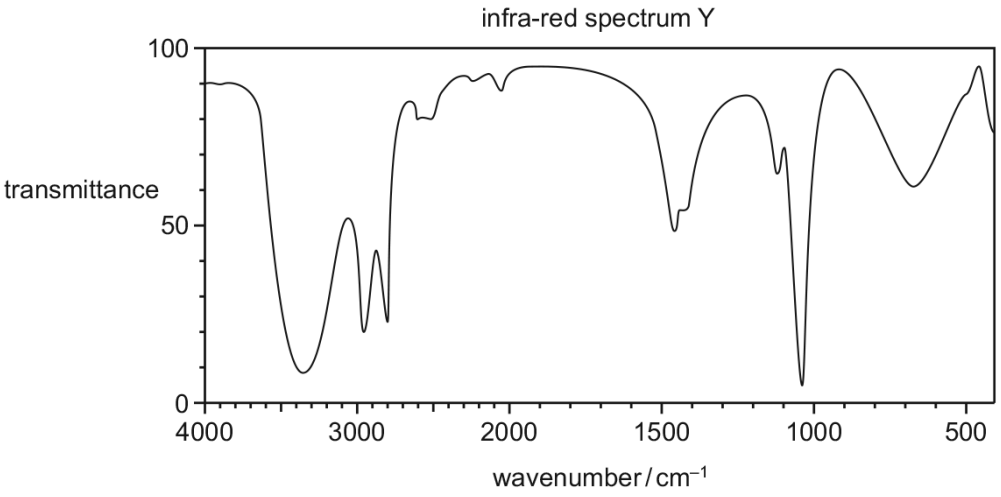
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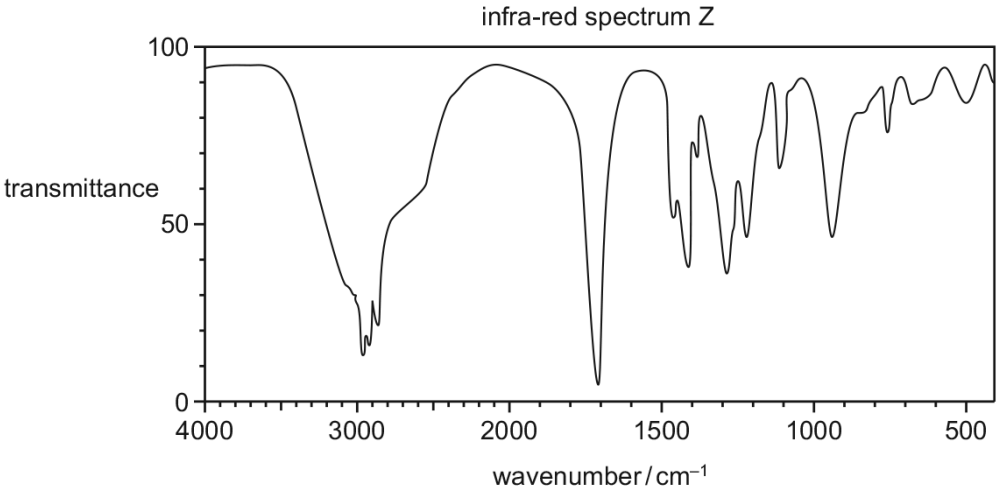
.....

.....

..... [4]


infra-red spectrum X
transmittance
100
50
0
4000
3000
2000
1500
1000
500
wavenumber / cm⁻¹


infra-red spectrum Y
transmittance
100
50
0
4000
3000
2000
1500
1000
500
wavenumber / cm⁻¹


infra-red spectrum Z
transmittance
100
50
0
4000
3000
2000
1500
1000
500
wavenumber / cm⁻¹

[Total: 21]

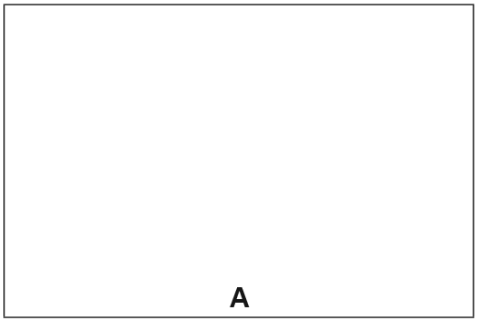
172. 9701_s17_qp_22 Q: 4

(a) The hydrocarbons **A**, C_4H_{10}, and **B**, C_4H_8, are both unbranched.

A does **not** decolourise bromine.

B decolourises bromine and shows geometrical isomerism.

(i) Draw the skeletal formula of **A**.



[1]

(ii) The hydrocarbon **A**, C_4H_{10}, has a branched isomer.

Suggest why unbranched **A** has a higher boiling point than its branched isomer.

.....

.....

.....

.....

..... [2]

(iii) Give the structural formula of **B**.

..... [1]

(iv) Explain why **B** shows geometrical isomerism.

.....

.....

.....

..... [2]

(v) Draw the mechanism of the reaction of **B** with bromine, Br_2.
Include all necessary charges, dipoles, lone pairs and curly arrows.

[4]

(vi) Explain the origin of the dipole on Br_2 in this mechanism.

.....

.....

..... [1]

(b) The alcohols **C** and **D** are isomers of each other with molecular formula $C_4H_{10}O$. Both isomers are branched.

When **C** is heated under reflux with acidified potassium dichromate(VI) no colour change is observed.

When **D** is heated under reflux with acidified potassium dichromate(VI) the colour of the mixture changes from orange to green and **E**, $C_4H_8O_2$, is produced.

E reacts with aqueous sodium carbonate to form carbon dioxide gas.

(i) Identify **C**, **D** and **E**.

C	D	E

[3]

(ii) Write the equation for the reaction between **E** and aqueous sodium carbonate.

..... [1]

(c) The isomers **F** and **G**, $C_5H_{10}O$, both form an orange precipitate when reacted with 2,4-DNPH.

F is unbranched and reacts with alkaline aqueous iodine to produce a yellow precipitate.

G does not react with alkaline aqueous iodine. It contains a chiral centre and produces a silver mirror when warmed with Tollens' reagent.

(i) Name the yellow precipitate produced by the reaction between **F** and alkaline aqueous iodine.

..... [1]

(ii) Give the structural formula of **F** and of **G**.

F .....

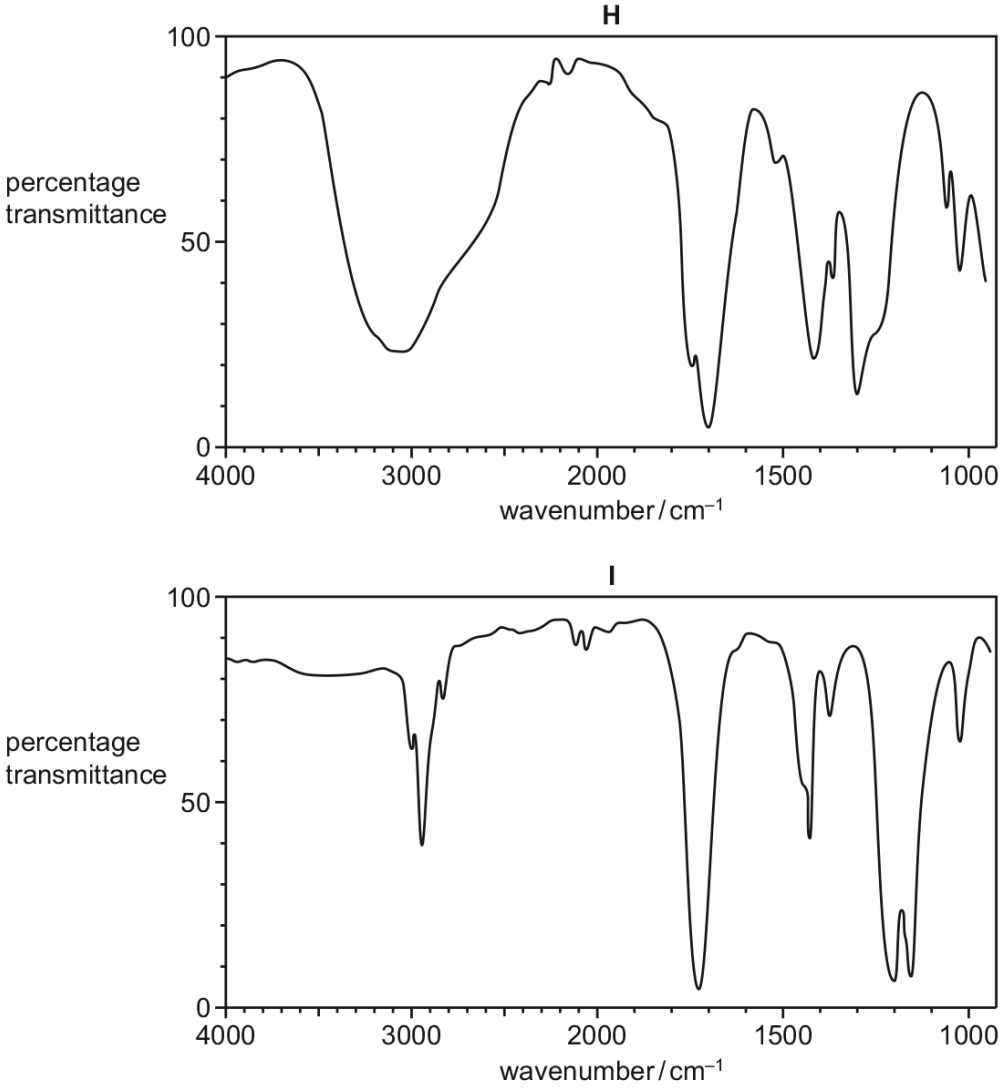
G .....
[2]

(iii) Explain the meaning of the term *chiral centre*.

.....

..... [1]

(d) **H** and **I** are isomers with molecular formula $C_2H_4O_2$. 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) Name **H** and **I**.

H .....

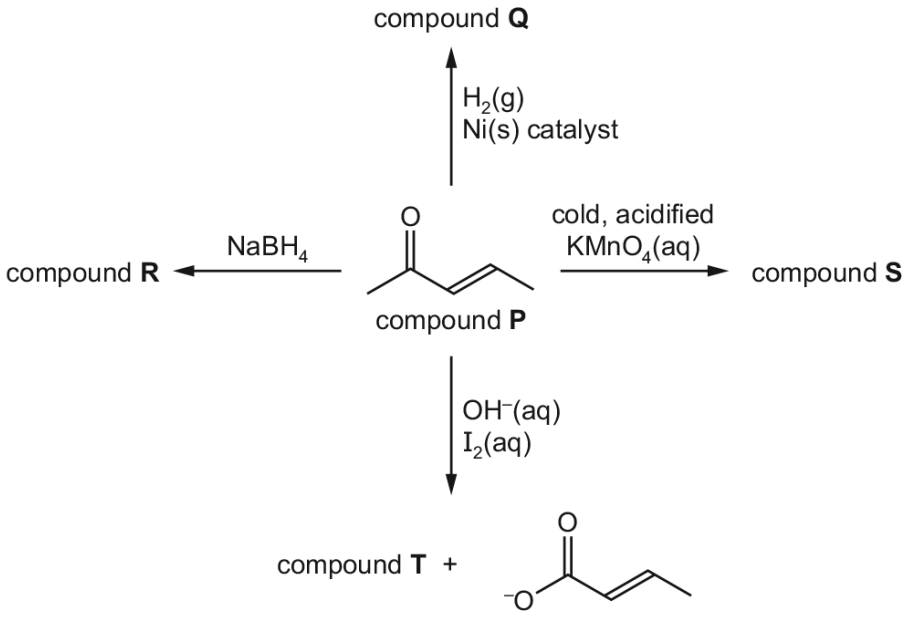
I .....

[2]

[Total: 23]

173. 9701_m16_qp_22 Q: 5

Some reactions of compound **P**, C_5H_8O, are shown.



(a) (i) Give the structures for organic compounds **Q**, **R**, **S** and **T**.

Q

R

S

T

[4]

(ii) Give the systematic name of compound **P**.

..... [1]

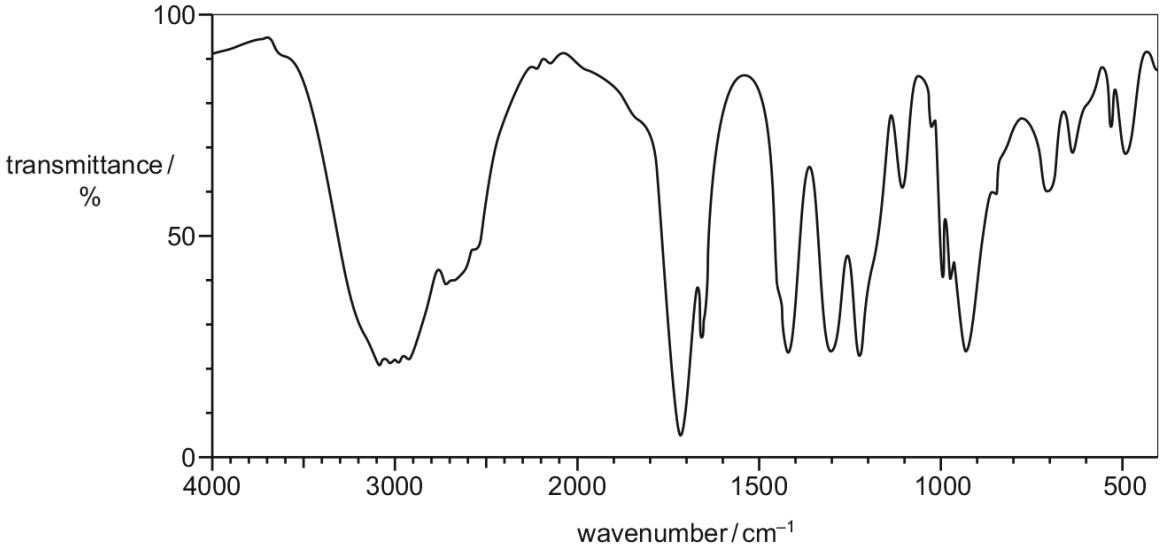
(iii) What would you observe when compound **P** is reacted with 2,4-dinitrophenylhydrazine (2,4-DNPH)?

..... [1]

(b) Compound **U** contains a chiral centre and has the same molecular formula as compound **P**, C_5H_8O.

- Compound **U** readily decolourises a sample of bromine water.
- Compound **U** does not show cis-trans isomerism.
- When compound **U** is heated under reflux in the presence of excess acidified potassium dichromate(VI), the organic product gives the infra-red spectrum shown.

infra-red spectrum of **product**



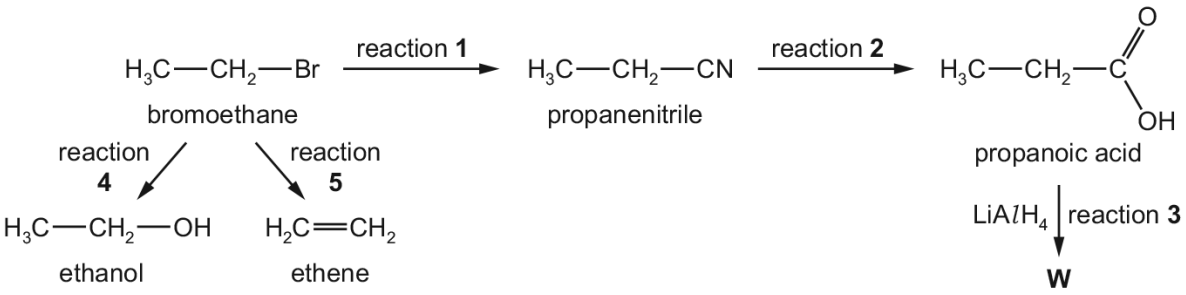
Use the information given to suggest a structure for compound **U**.
Explain your answer.

[4]

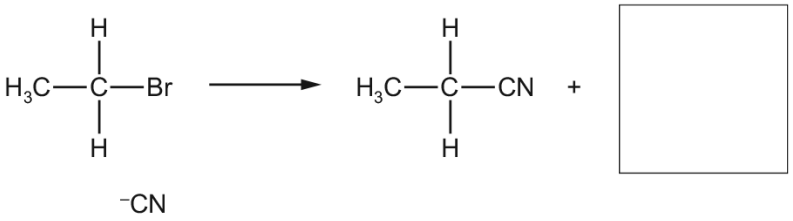
[Total: 10]

174. 9701_s16_qp_21 Q: 5

A reaction sequence is shown.



(a) Complete the diagram to show the mechanism of reaction **1**. Include all necessary charges, partial charges, lone pairs and curly arrows.

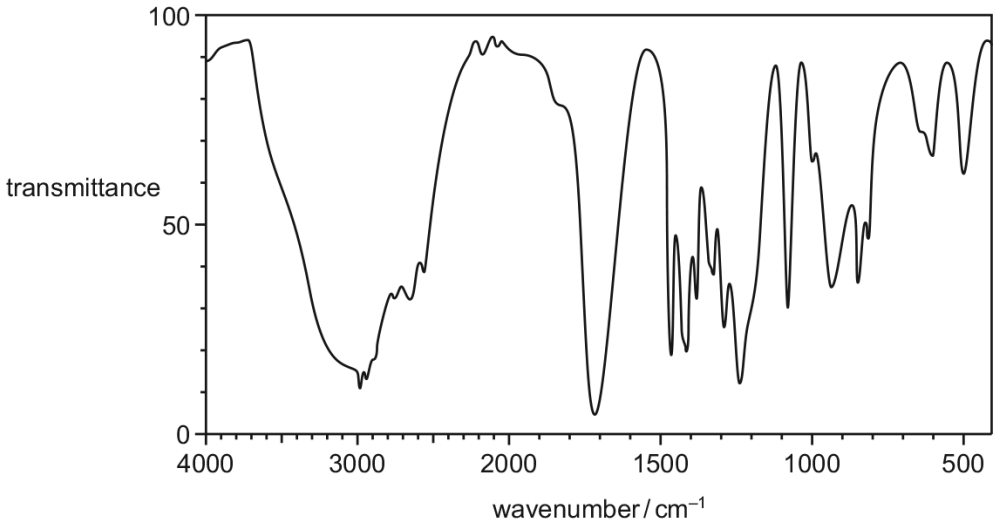


[2]

(b) **(i)** Give the name of the type of reaction involved in reaction **3**.

..... [1]

The infra-red spectrum of the propanoic acid produced by reaction **2** is shown.



(ii) Describe and explain the main difference between the infra-red spectrum of **W** and that of propanoic acid.

.....

..... [2]

(c) **(i)** Reactions **4** and **5** use the same reagent.

Give the reagent and conditions needed for reaction **4**.

reagent .....

conditions ..... [2]

(ii) Give the conditions needed for reaction **5**.

..... [1]

(d) Under appropriate conditions, ethanol and propanoic acid undergo a condensation reaction.

(i) State the condition necessary for the reaction.

..... [1]

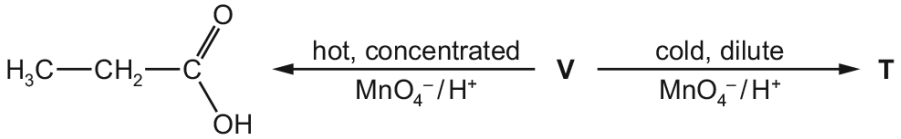
(ii) Draw the skeletal formula of the organic product of this reaction.

[1]

(iii) Name the organic product of this reaction.

..... [1]

(e) **V** reacts with acidified manganate(VII) ions in two different ways depending on the conditions, as shown in the reaction sequence below.



propanoic acid

V decolourises bromine water.

When the acidified manganate(VII) is hot and concentrated, propanoic acid is the only organic product.

When the acidified manganate(VII) is cold and dilute, the organic product is **T** which has two chiral centres.

(i) Give the structural formulae of **V** and **T**.

V ..... **T** .....
[2]

(ii) Identify the types of stereoisomerism shown by **V** and **T**.

V ..... **T** .....
[2]

[Total: 15]

175. 9701_s16_qp_22 Q: 4

This question is about molecules with molecular formula $C_4H_8O_2$.

(a) Give the structural formulae of the pair of **chain** isomers with the formula $C_4H_8O_2$ that are carboxylic acids.

[2]

(b) **(i)** Give the structural formulae of a pair of **positional** isomers with the formula $C_4H_8O_2$ that are esters.

[2]

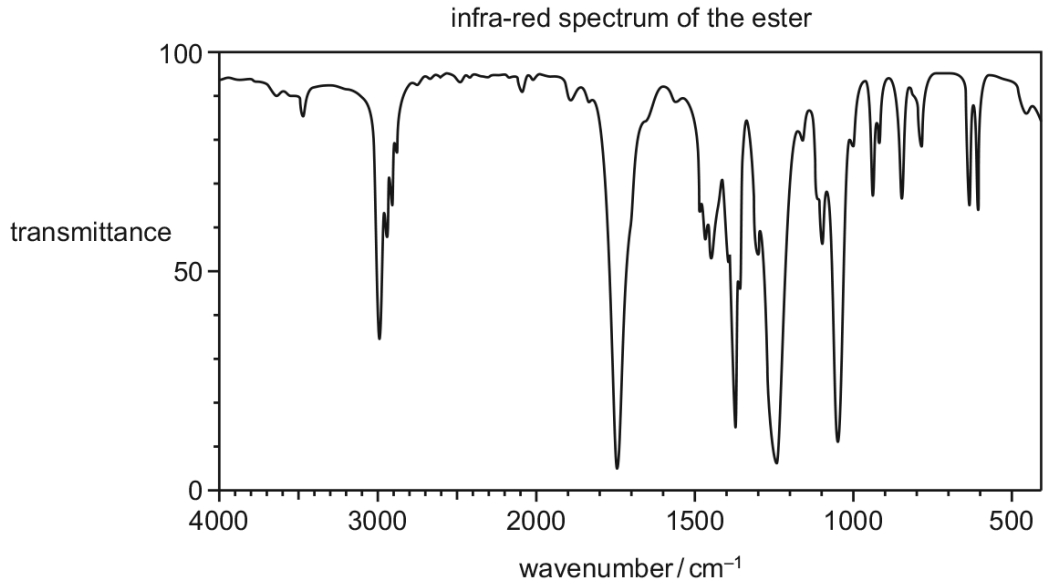
(ii) Give the reagents and conditions needed to produce one of your esters in **(i)**.

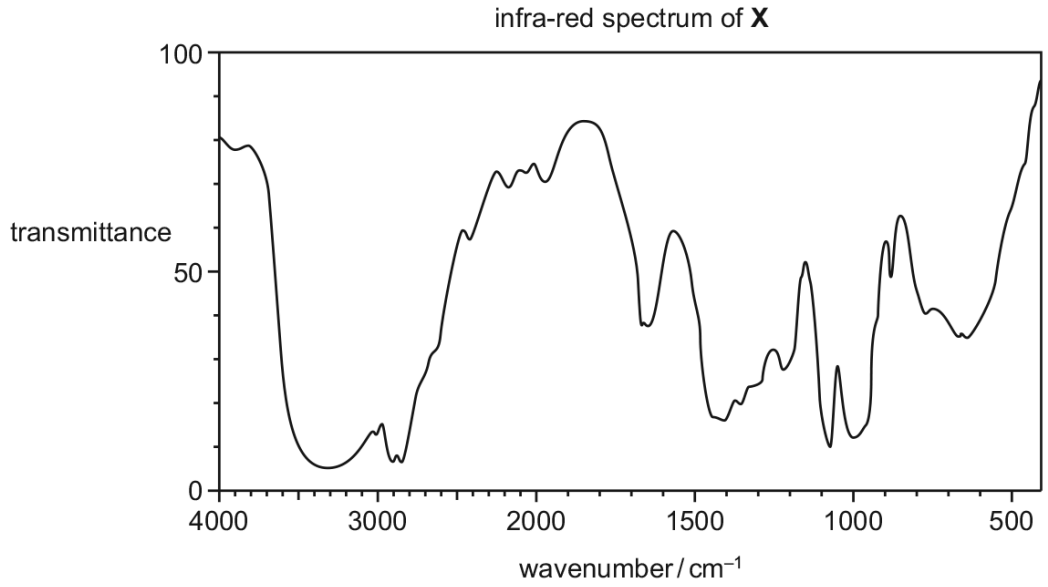
.....

..... [2]

(c) The infra-red spectra of one of the esters and of another isomer, **X**, are shown.

X decolourises bromine water and is not an ester or an acid.





Explain the differences between these two spectra, with particular reference to the peaks with wavenumbers above 1500 cm^{-1}.

.....

.....

.....

..... [3]

[Total: 9]

176. 9701_s16_qp_23 Q: 4

Acetoin, $CH_3COCH(OH)CH_3$, and diacetyl, $CH_3COCOCH_3$, are two of the compounds that give butter its characteristic flavour. Their skeletal formulae are shown.



acetoin diacetyl

(a) Give the systematic name for acetoin.

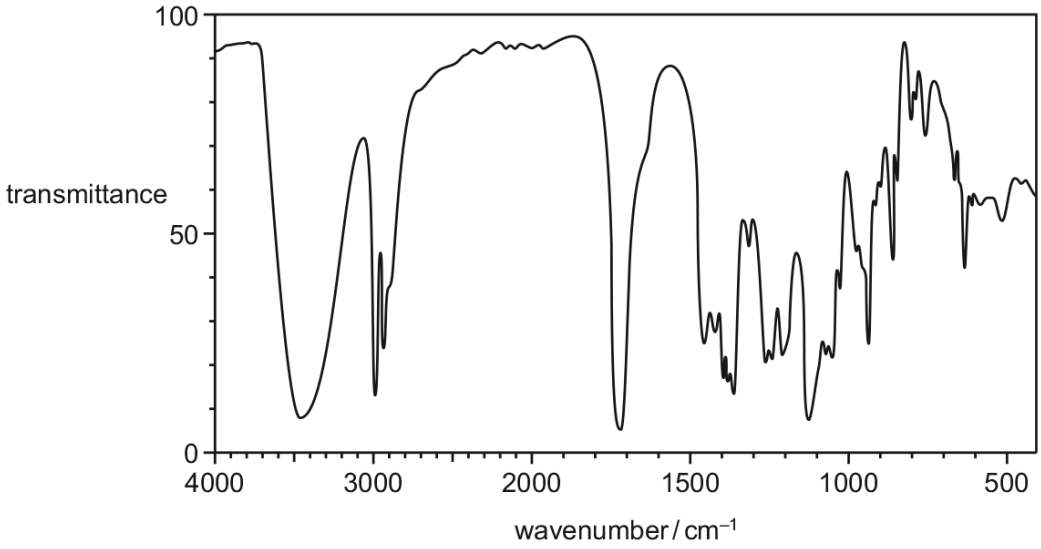
..... [1]

(b) Identify the reagents and conditions necessary for the conversion of acetoin into diacetyl.

.....

..... [2]

(c) The infra-red spectrum for acetoin is shown.



(i) Explain the main features of this spectrum, with reference to the peaks with wavenumbers greater than 1500 cm^{-1}.

.....

.....

.....

.....

..... [3]

(ii) State and explain how the infra-red spectrum for diacetyl would differ from the infra-red spectrum for acetoin.

.....

.....

..... [2]

(d) If a sample of acetoin is reacted with concentrated sulfuric acid, a single product is formed that does **not** exhibit stereoisomerism.

However, if a sample of acetoin is reacted with HBr, a mixture of a pair of stereoisomers is produced.

(i) Give the structural formula of the product of the reaction of acetoin with concentrated sulfuric acid.

..... [1]

(ii) Explain why the product in **(i)** does **not** exhibit stereoisomerism.

.....

.....

..... [2]

(iii) Explain why the product of reaction of acetoin with HBr **does** exhibit stereoisomerism.

.....

.....

..... [1]

(iv) Draw the two stereoisomers from **(iii)** using the conventional representation.

[2]

[Total: 14]

19.2 Mass spectrometry

177. 9701_w18_qp_22 Q: 1

The model of the nuclear atom was first proposed by Ernest Rutherford. He developed this model on the basis of results obtained from an experiment using gold metal foil.

(a) Complete the table with information for two of the particles in an atom of ^{197}Au.

particle	relative mass	relative charge	location within atom	total number in an atom of ^{197}Au
electron	0.0005	–1		79
neutron			nucleus	

[4]

(b) State the type of bonding in gold.

..... [1]

(c) A sample of gold found in the earth consists of only one isotope.

(i) Explain what is meant by the term *isotopes*.

.....

.....

..... [2]

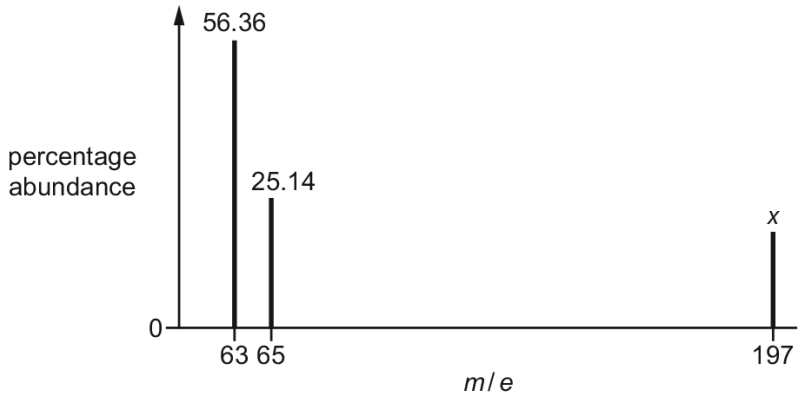
(ii) A different sample of gold contains more than one isotope.

Suggest why this different sample of gold has the same **chemical** properties as the sample found in the earth.

.....

..... [1]

(d) *Tumbaga* is an alloy of copper and gold. A sample of tumbaga was analysed. The mass spectrum of the sample is shown.



(i) Calculate the percentage abundance of gold, *x*, in the sample of tumbaga.

x = ... % [1]

(ii) Calculate the relative atomic mass, A_r, of the copper present in this sample.
Give your answer to **two** decimal places.

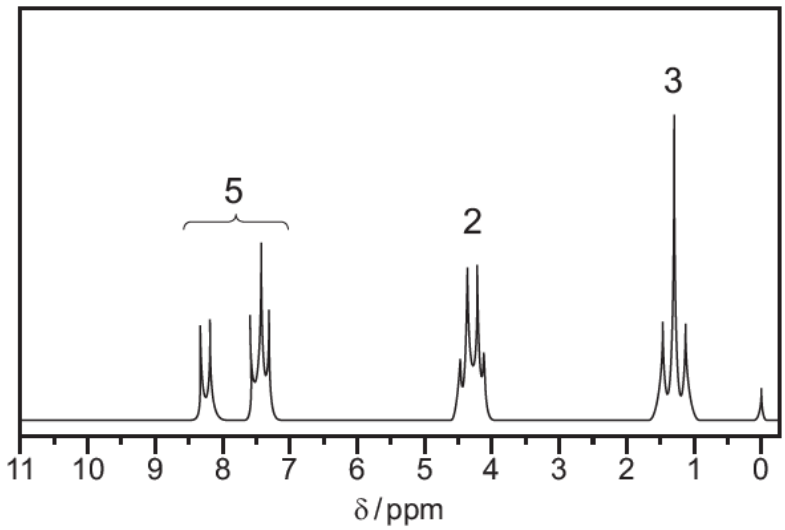
A_r (Cu) = ... [2]

[Total: 11]

Analytical chemistry - 2021

1. Nov/2020/Paper_41/No.9

The proton NMR spectrum of compound **E** in the solvent $CDCl_3$ is shown. The molecular formula of compound **E** is $C_9H_{10}O_2$.



(a) Explain why $CDCl_3$ is used as a solvent instead of $CHCl_3$.

..... [1]

(b) Explain why TMS is added to give the small peak at chemical shift $\delta = 0$.

..... [1]

(c) Compound **E** is hydrolysed by hot NaOH(aq), giving two organic products only. One of these products is ethanol.

Name the functional group in compound **E** that is hydrolysed by hot NaOH(aq).

..... [1]

(d) **(i)** Describe and explain the splitting patterns of the peaks at $\delta = 1.4$ and $\delta = 4.3$.

splitting pattern at $\delta = 1.4$ .....

reason for splitting pattern at $\delta = 1.4$ .....

splitting pattern at $\delta = 4.3$ .....

reason for splitting pattern at $\delta = 4.3$ .....

[2]

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(ii) Each molecule of compound **E** contains five protons which give rise to the peaks between $\delta = 7.0$ and $\delta = 8.5$.

Identify the functional group in compound **E** which contains these protons.

..... [1]

(iii) Give the structural formula of compound **E**.

[1]

(e) The mass spectrum of compound **E** includes fragment ions with *m*/*e* values of 29 and 77.

Give the formulae of these fragment ions.

fragment ion with *m*/*e* = 29 .....

fragment ion with *m*/*e* = 77 .....

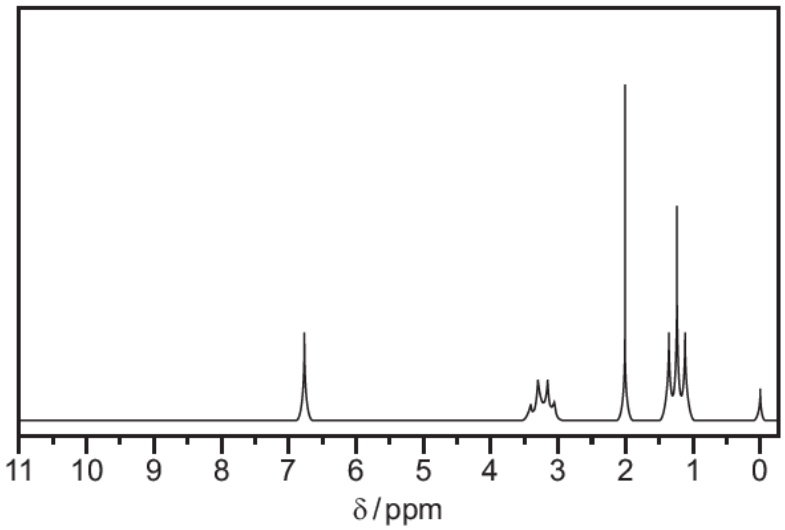
[2]

[Total: 9]

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(d) Compound **A** can also be used to make the amide $CH_3CONHC_2H_5$.

The proton NMR spectrum of the amide $CH_3CONHC_2H_5$ in the solvent $CDCl_3$ is shown.

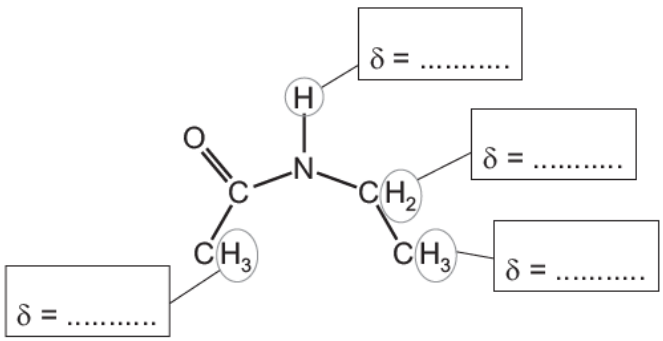


(i) Explain why $CDCl_3$ is used as a solvent instead of $CHCl_3$.

.....

[1]

(ii) Complete the diagram with the chemical shifts, δ, of the protons labelled in the $CH_3CONHC_2H_5$ molecule.



[2]

(iii) State and explain how the proton NMR spectrum of the amide $CH_3CONHC_2H_5$ differs when dissolved in D_2O rather than $CDCl_3$.

.....

.....

.....

[2]

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(e) The mass spectrum of the amide $CH_3CONHC_2H_5$ includes a fragment ion with *m*/*e* value of 58.

Give the molecular formula of this fragment ion.

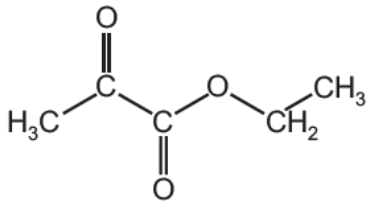
fragment ion with *m*/*e* value of 58 is ..... [1]

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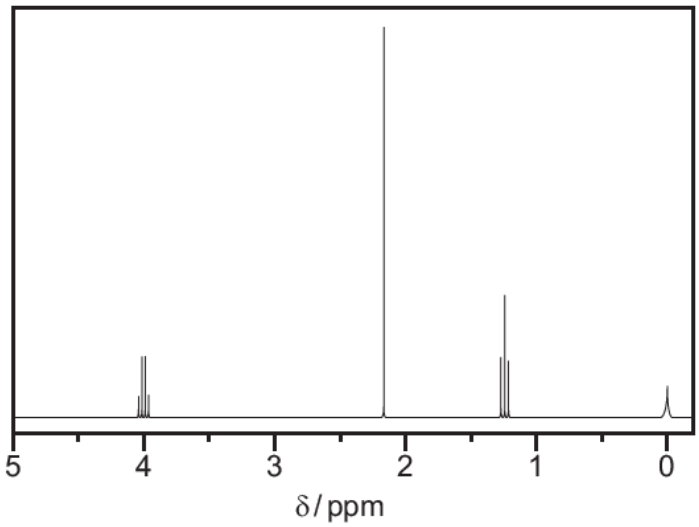
3. June/2020/Paper_41/No.6e,6f

(e) An ester of pyruvic acid, **F**, is dissolved in $CDCl_3$ and analysed by proton NMR spectroscopy.

F



The proton NMR spectrum of **F** is shown.



Use the proton NMR spectrum of **F** to complete the table.

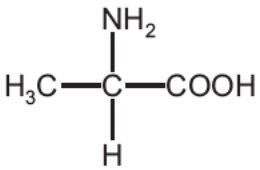
chemical shift (δ)	group responsible for the peak	splitting pattern	number of ^1H atoms responsible for the peak
1.3			
2.2			
4.0			

[3]

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(f) Deuterium oxide, D_2O, where D is ^2H, can be used as a solvent in proton NMR spectroscopy.
The proton NMR spectrum of alanine in $CDCl_3$ has 4 peaks.
The proton NMR spectrum of alanine in D_2O has 2 peaks.

alanine



On the diagram of alanine, circle the protons that show peaks in **both** NMR spectra.
Explain your answer.

.....

.....

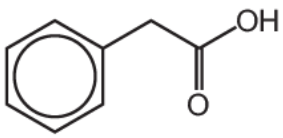
..... [2]

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Analytical chemistry - 2021

1. Nov/2021/Paper_41/No.7a

The structure of phenylethanoic acid is shown.



(a) Give the number of different peaks in the carbon-13 (^{13}C) NMR spectrum of phenylethanoic acid.

number of peaks = ... [1]

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(d) The relative abundance of the molecular ion peak in the mass spectrum of ethylamine is 62.

(i) Calculate the relative abundance of the M+1 peak in the mass spectrum of ethylamine.

relative abundance = ... [1]

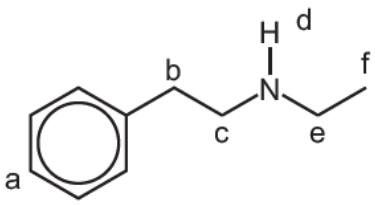
(ii) The mass spectrum of compound **T** contains several fragments. The *m/e* values of two of these fragments are 29 and 91.

Draw the structures of the ions responsible for these peaks.

m/e	structure of ion
29	
91	

[2]

(e) The proton (^{1}H) NMR spectrum of compound **T** shows hydrogen atoms in different environments. Six of these environments are shown on the structure using letters a, b, c, d, e and f.



Use the letters a, b, c, d, e and f to answer the questions that follow. The questions relate to the proton (^{1}H) NMR spectrum of **T**.

Proton d does not cause splitting of the peaks for protons c or e under the conditions used.

Each answer may be one, or more than one, of the letters a, b, c, d, e and f.

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(i) Identify the proton or protons with a chemical shift (δ) in the range 6.0 to 9.0.

..... [1]

(ii) Identify the proton or protons whose peak will disappear if D_2O is added.

..... [1]

(iii) Identify the proton or protons whose peak is a triplet.

..... [1]

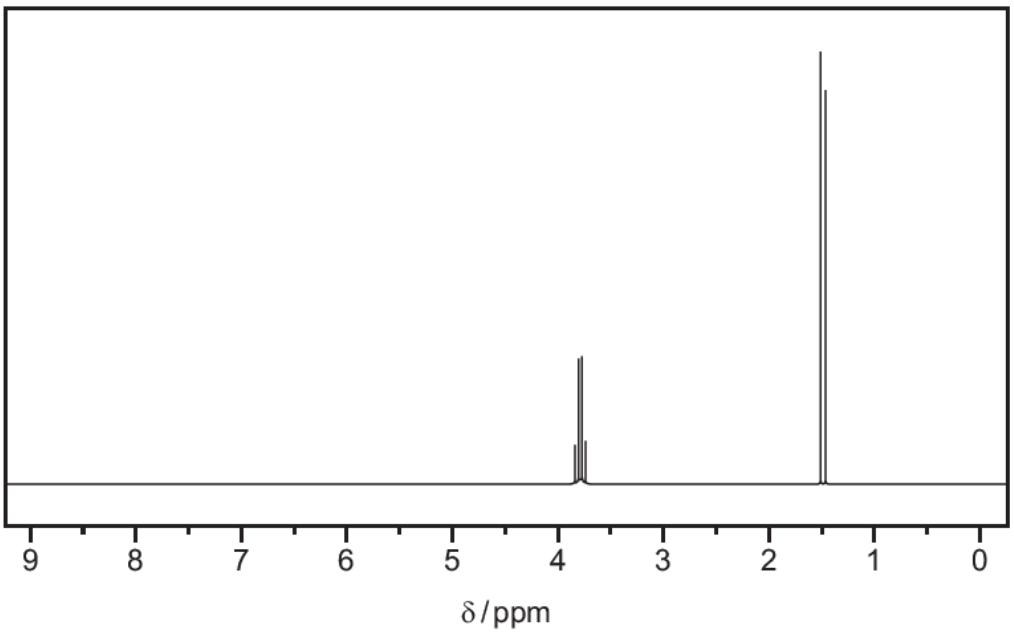
(iv) Identify the proton or protons with the lowest chemical shift (δ).

..... [1]

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3. Nov/2021/Paper_42/No.8b,8c

(b) The proton (^{1}H) NMR spectrum of **either** alanine in D_2O or glutamic acid in D_2O is shown.



State whether this is the spectrum of alanine in D_2O or the spectrum of glutamic acid in D_2O. Explain your answer by reference to the number of peaks and splitting patterns.

.....

.....

.....

..... [3]

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(c) The mass spectrum of glutamic acid, $H_2NCH(CH_2CH_2CO_2H)CO_2H$, is obtained.

(i) State the *m*/*e* value of the molecular ion peak in this spectrum.

..... [1]

(ii) The spectrum has peaks with *m*/*e* values of 88 and 131.

Draw the structures of the ions responsible for these peaks.

m/*e*	structure of ion
88	
131	

[2]

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1. June/2022/Paper_41/No.6(b, f, g)

(b) Asparagine is an amino acid that contains a chiral carbon atom and displays stereoisomerism.

Separate samples of asparagine are dissolved in $CDCl_3$ and analysed using carbon-13 and proton (^1H) NMR spectroscopy.

asparagine

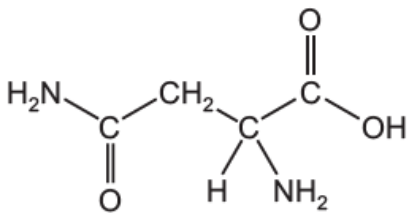


Fig. 6.1

Predict the number of peaks seen in the carbon-13 and proton (^1H) NMR spectra of asparagine.

	carbon-13 NMR	proton (^1H) NMR
number of peaks		

[1]

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(f) Thin-layer and gas-liquid chromatography can be used to analyse mixtures of substances.

Each type of chromatography makes use of a stationary phase and a mobile phase.

(i) Complete Table 6.1 with an example of each of these.

Table 6.1

	stationary phase	mobile phase
thin-layer chromatography		
gas-liquid chromatography		

[1]

(ii) An unknown amino acid is analysed using thin-layer chromatography. Two chromatographs of the unknown amino acid and four reference amino acids, **P**, **Q**, **R** and **S**, are obtained using two different solvents.

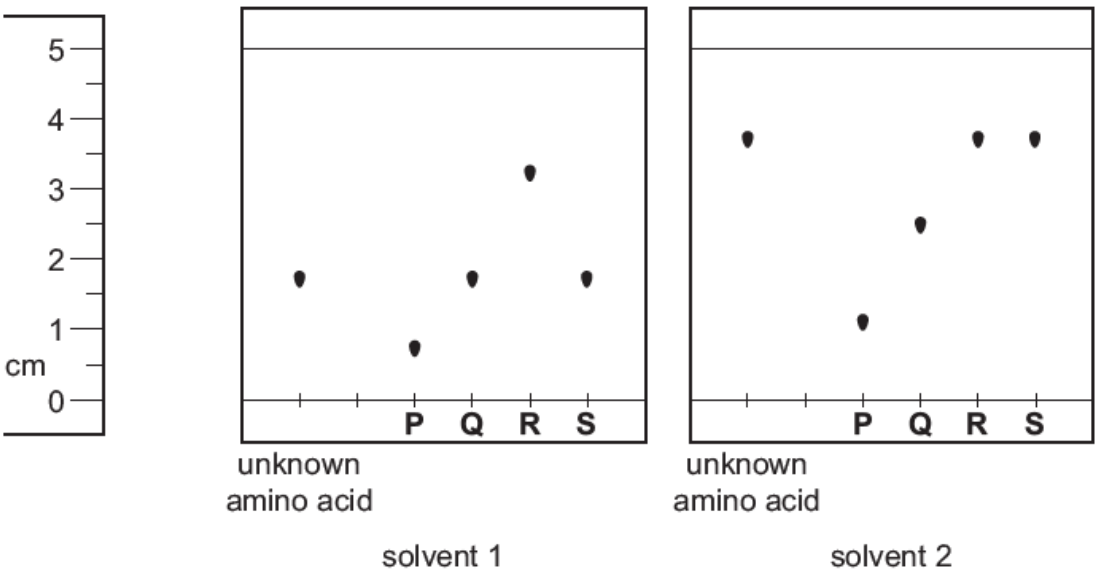


Fig. 6.4

Identify the unknown amino acid. Justify your answer.

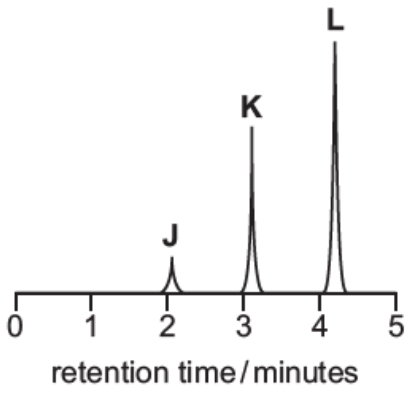
.....

.....

..... [1]

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(g) A mixture containing three organic compounds is analysed by gas chromatography and mass spectrometry. The gas chromatogram is shown.



peak	J	K	L
area / mm^2	8	44	58

Fig. 6.5

The area underneath each peak is proportional to the mass of the respective compound in the mixture.

The concentration of **K** in the mixture is 5.52×10^{-2} g dm^{-3}.

Calculate the concentration, in mol dm^{-3}, of compound **L** in the mixture.
[M_r: **L**, 116]

concentration of **L** = ... mol dm^{-3} [1]

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2. June/2022/Paper_42/No.7

(a) State the uses of TMS and D_2O in NMR spectroscopy.

TMS .....

D_2O .....

[1]

(b) The three isomeric ketones with molecular formula $C_5H_{10}O$ are:

- pentan-2-one
- pentan-3-one
- 3-methylbutanone.

(i) Complete Table 7.1 to show the number of peaks observed in the proton (^1H) NMR spectrum and in the carbon-13 NMR spectrum for each compound listed.

Table 7.1

ketone	number of peaks observed in the proton (^1H) NMR spectrum	number of peaks observed in the carbon-13 NMR spectrum
pentan-2-one		
pentan-3-one		
3-methylbutanone		

[2]

(ii) State **all** the ketones with molecular formula $C_5H_{10}O$ that have:

a doublet in their proton (^1H) NMR spectrum

.....

a singlet in their proton (^1H) NMR spectrum.

.....

[2]

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(c) Cortisone, $C_{21}H_{28}O_5$, is a naturally occurring chemical that contains chiral carbon atoms.

cortisone

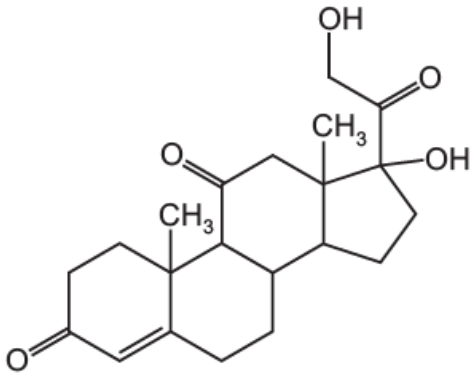


Fig. 7.1

(i) Deduce the number of chiral carbon atoms in one molecule of cortisone.

..... [1]

(ii) Cortisone is reacted with an excess of $NaBH_4$.

State the molecular formula of the organic compound formed.

..... [1]

(iii) Cortisone is an optically active molecule.

Explain what is meant by optically active.

.....

.....

..... [1]

[Total: 8]

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1. Nov/2022/Paper_41/No.9

(a) Gas-liquid chromatography involves a stationary phase and a mobile phase.

(i) Name, or describe in detail, a suitable substance that could be used for each phase.

stationary .....

mobile .....

[1]

A mixture of three organic compounds is separated by gas-liquid chromatography. The chromatogram obtained is shown in Fig. 9.1. The amount of each substance is proportional to the area under its peak.

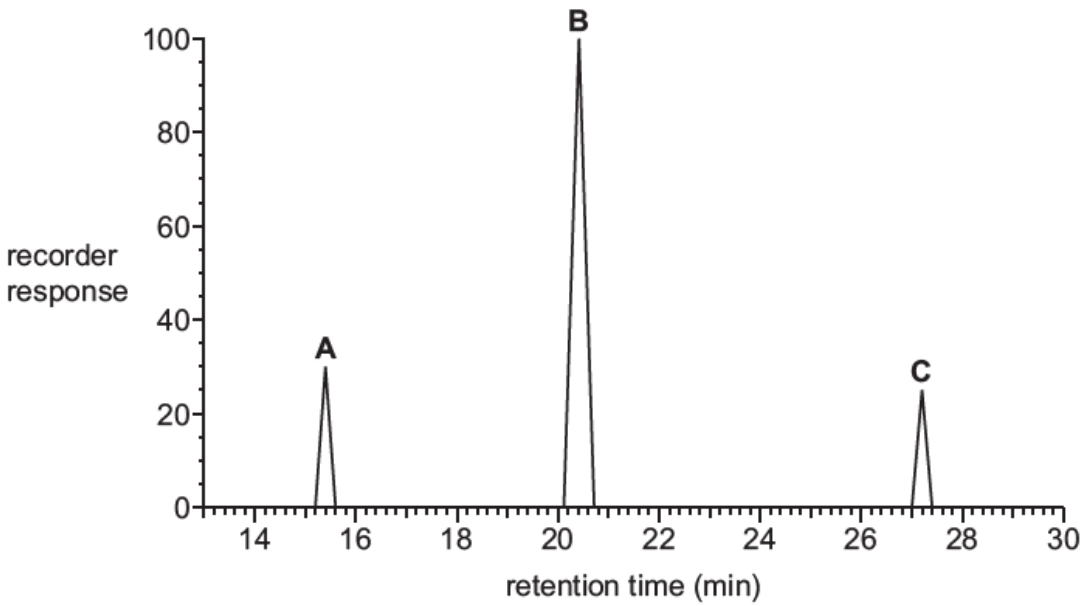


Fig. 9.1

(ii) Explain the meaning of retention time.

.....

..... [1]

(iii) Calculate the percentage of **B** in the mixture. Show your working.

percentage of **B** = ... % [2]

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(b) Complete Table 9.1 to give the number of peaks in the carbon-13 NMR spectrum of each of the five isomers of $C_5H_{10}O_2$ that has an ester group.

Table 9.1

structural formula	number of peaks
$CH_3CH_2CH_2CO_2CH_3$	
$CH_3CH_2CO_2CH_2CH_3$	
$CH_3CO_2CH_2CH_2CH_3$	
$(CH_3)_2CHCO_2CH_3$	
$CH_3CO_2CH(CH_3)_2$	

[2]

(c) State the number of peaks that would be seen in the proton (^1H) NMR spectrum of methyl butanoate, $CH_3CH_2CH_2CO_2CH_3$. Name all the splitting patterns seen in this spectrum.

number of peaks .....

splitting patterns .....

[2]

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(d) **D** and **E** are both esters with the molecular formula $C_5H_{10}O_2$. Their proton (^1H) NMR spectra are shown in Fig. 9.2 and Fig. 9.3.

D

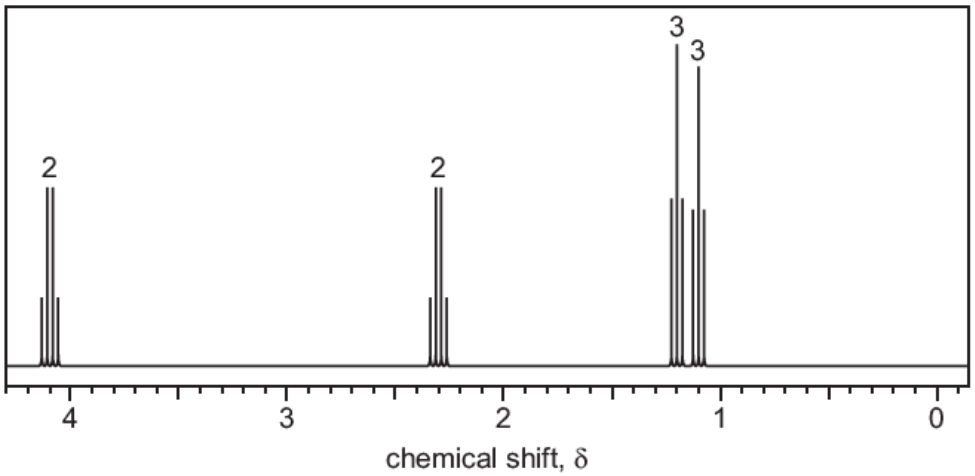


Fig. 9.2

E

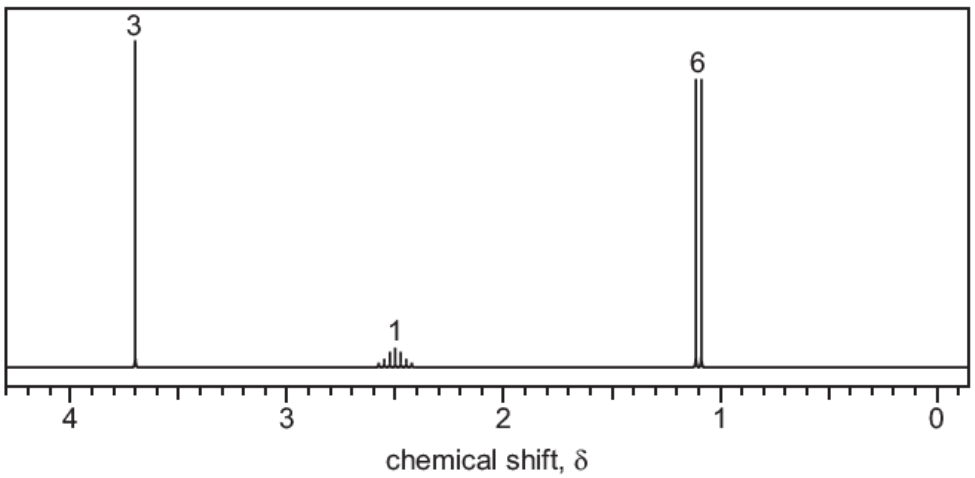


Fig. 9.3

Table 9.2

environment of proton	example	typical chemical shift range, δ/ppm
alkane	$-CH_3$, $-CH_2-$, $>CH-$	0.9–1.7
alkyl next to C=O	$CH_3-C=O$, $-CH_2-C=O$, $>CH-C=O$	2.2–3.0
alkyl next to aromatic ring	CH_3-Ar, $-CH_2-Ar$, $>CH-Ar$	2.3–3.0
alkyl next to electronegative atom	CH_3-O, $-CH_2-O$, $-CH_2-Cl$	3.2–4.0
attached to alkene	=CHR	4.5–6.0

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(i) Deduce the structures of the two esters **D** and **E** and draw their displayed formulae in the boxes below.

D $C_5H_{10}O_2$	**E** $C_5H_{10}O_2$

[2]

(ii) The spectrum of **D** includes a quartet at δ 4.1.

Identify the protons responsible for this quartet on your structure in **(i)** by labelling these protons with the letter **F**.

Explain why this peak is split into a quartet.

.....

.....

[1]

(iii) The spectrum of **E** has a doublet at δ 1.1.

Identify the protons responsible for this doublet on your structure in **(i)** by labelling these protons with the letter **G**.

Explain why this peak has a chemical shift of 1.1.

.....

.....

[1]

[Total: 12]

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2. Nov/2022/Paper_42/No.8

When answering this question it should be assumed that together all the hydrogen atoms in a benzene ring result in a single unsplit peak at δ = 7.2 in a proton (^{1}H) NMR spectrum.
The structures of five isomeric ketones, **P**, **Q**, **R**, **S** and **T** are given.

P $C_6H_5COCH(CH_3)_2$

Q $C_6H_5COCH_2CH_2CH_3$

R $C_6H_5CH_2COCH_2CH_3$

S $C_6H_5CH_2CH_2COCH_3$

T $C_6H_5CH(CH_3)COCH_3$

(a) Identify all the chiral carbon atoms on the structures above. Label each chiral carbon atom with an asterisk (*). [1]

(b) The proton (^{1}H) NMR spectrum of one of the five isomers, **P**, **Q**, **R**, **S** or **T**, is shown in Fig. 8.1.

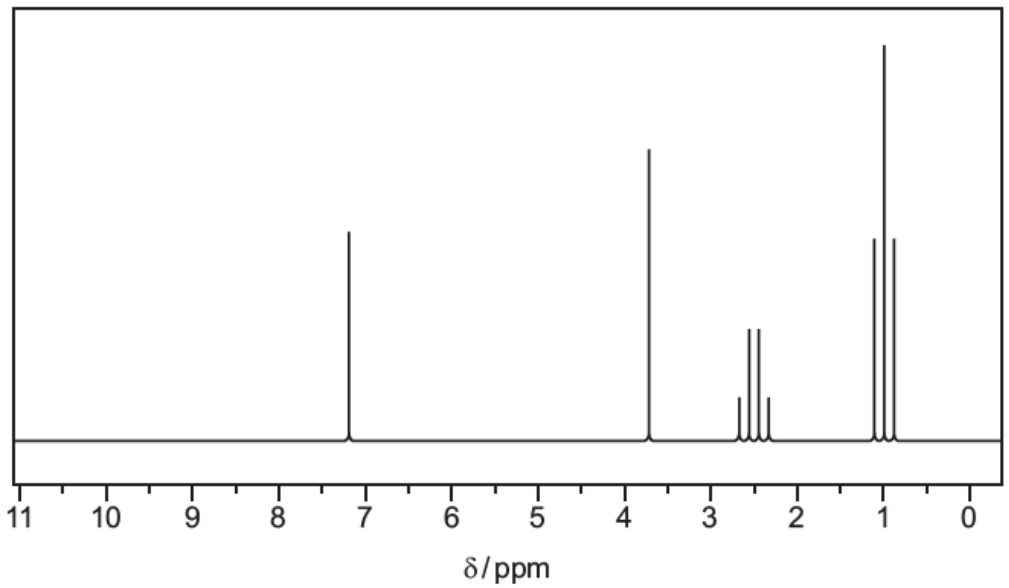


Fig. 8.1

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(i) Identify which of the compounds **P**, **Q**, **R**, **S** or **T** gives this spectrum.
Draw the displayed formula of the compound you have identified. Identify the protons responsible for the peaks at δ = 3.7, δ = 2.5 and δ = 1.0 on the structure you have drawn.

[2]

(ii) Name the splitting pattern of the peak at δ = 3.7. Explain why it has this splitting pattern.

.....

..... [1]

(c) Choose from the letters **P**, **Q**, **R**, **S** and **T** to identify:

(i) the **two** compounds that each have a doublet peak in the proton (^{1}H) NMR spectrum

..... [1]

(ii) the compound with only three peaks in its proton (^{1}H) NMR spectrum.

..... [1]

(d) Suggest a suitable solvent that should be used for obtaining the spectrum shown in Fig. 8.1.

..... [1]

(e) The proton (^{1}H) NMR spectrum of compound **T** is compared in the presence of D_2O and in the absence of D_2O.

Describe any difference between the two spectra. Explain your answer.

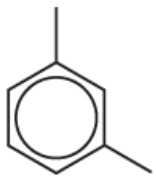
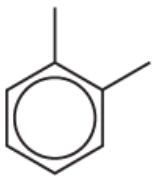
.....

..... [1]

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(f) Complete Table 8.1 below to give the number of peaks in the carbon-13 NMR spectrum of each compound.

Table 8.1

compound	number of peaks	compound	number of peaks
			
			

[2]

[Total: 10]

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1. Nov/2023/Paper_9701/41/No.7(d)

Sunset Yellow is an additive used for colouring foods.

A synthetic route for making Sunset Yellow is shown.

Molecules **E** and **G** each contain one $-SO_3^-$ group. These groups are unchanged in the formation of Sunset Yellow.

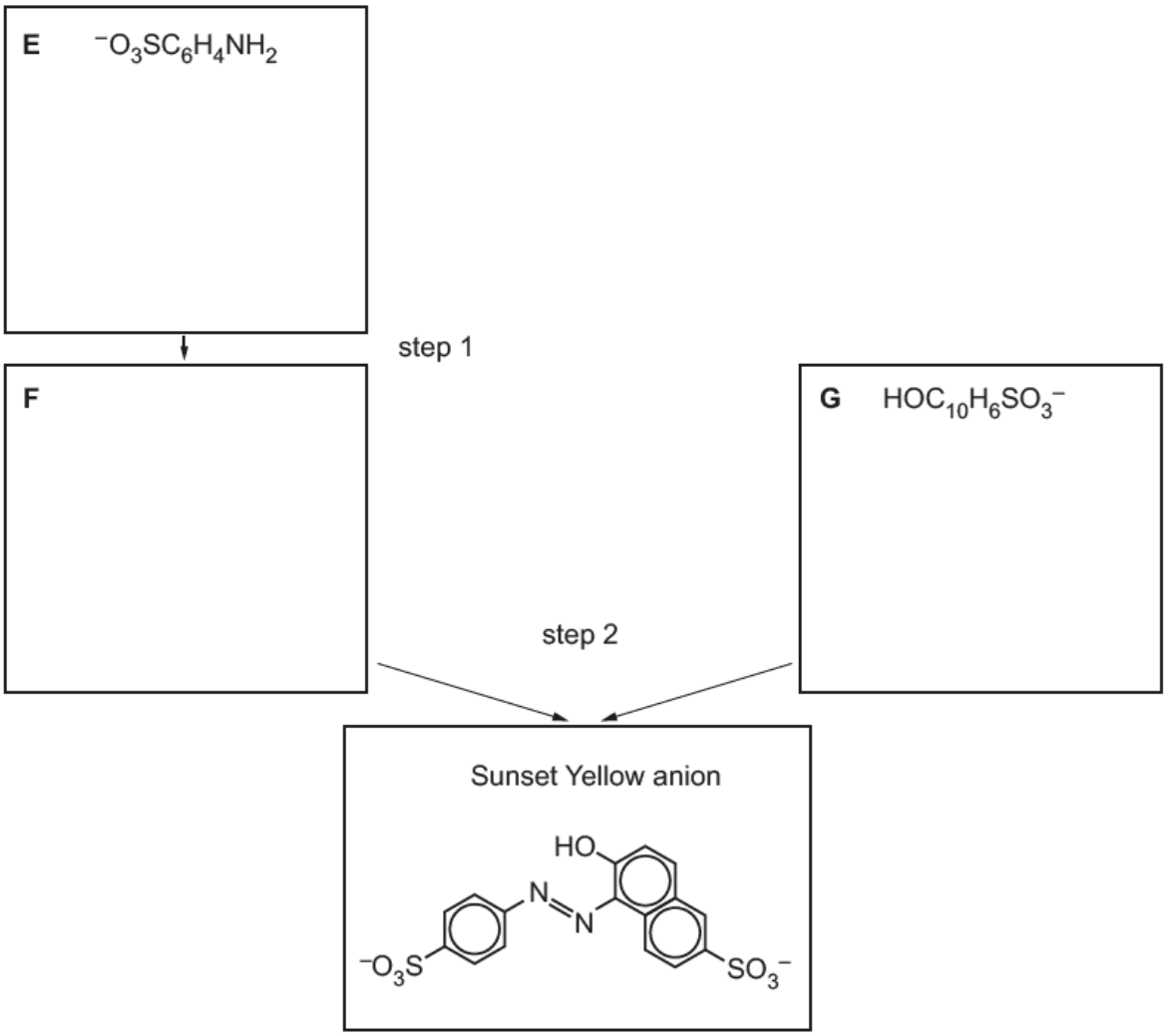


Fig. 7.1

(d) Predict the number of peaks in the carbon-13 NMR spectrum of the Sunset Yellow anion.

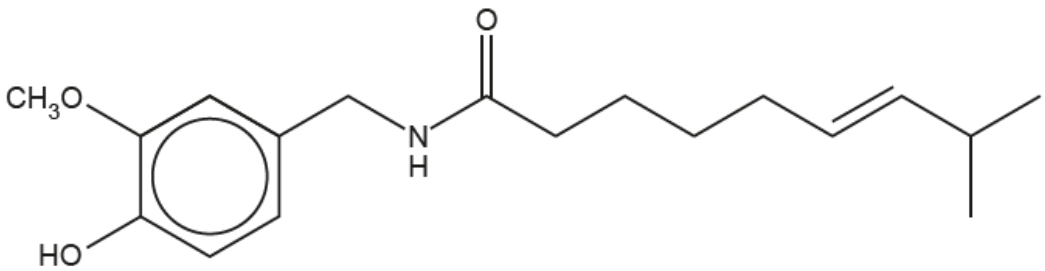
..... [1]

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2. Nov/2023/Paper_9701/41/No.8(d)

Capsaicin is found in chilli peppers.

capsaicin



You should assume the CH_3O group is unreactive in the reactions involved in this question.

(d) When capsaicin is treated with reagent **J** under suitable conditions one of the products is methylpropanoic acid, $CH_3CH(CH_3)COOH$.

(i) Identify reagent **J** and any necessary conditions.

..... [1]

(ii) There are three different peaks in the proton (^1H) NMR spectrum of $CH_3CH(CH_3)COOH$ in $CDCl_3$.

Table 8.1

environment of proton	example	chemical shift range δ/ppm
alkane	$-C\mathbf{H}_3$, $-C\mathbf{H}_2-$, $>C\mathbf{H}-$	0.9–1.7
alkyl next to C=O	$C\mathbf{H}_3-C=O$, $-C\mathbf{H}_2-C=O$, $>C\mathbf{H}-C=O$	2.2–3.0
alkyl next to aromatic ring	$C\mathbf{H}_3$–Ar, $-C\mathbf{H}_2$–Ar, $>C\mathbf{H}$–Ar	2.3–3.0
alkyl next to electronegative atom	$C\mathbf{H}_3-O$, $-C\mathbf{H}_2-O$, $-C\mathbf{H}_2-Cl$	3.2–4.0
attached to alkene	=C**H**R	4.5–6.0
attached to aromatic ring	**H**–Ar	6.0–9.0
aldehyde	**H**COR	9.3–10.5
alcohol	RO**H**	0.5–6.0
phenol	Ar–O**H**	4.5–7.0
carboxylic acid	RCOO**H**	9.0–13.0

Use Table 8.1 to complete Table 8.2 and state:

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- the typical proton (^1H) chemical shift values (δ) for the protons
- the splitting pattern (singlet, doublet, triplet, quartet or multiplet) shown by each peak
- the explanation for the splitting patterns of the CH_3 protons and the CH proton.

Table 8.2

environment	δ/ppm	splitting pattern	explanation for splitting pattern
CH_3			
CH			
COOH			

[3]

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3. Nov/2023/Paper_9701/42/No.7

Benzene can be used to make benzoic acid in the two-step process shown in Fig. 7.1.

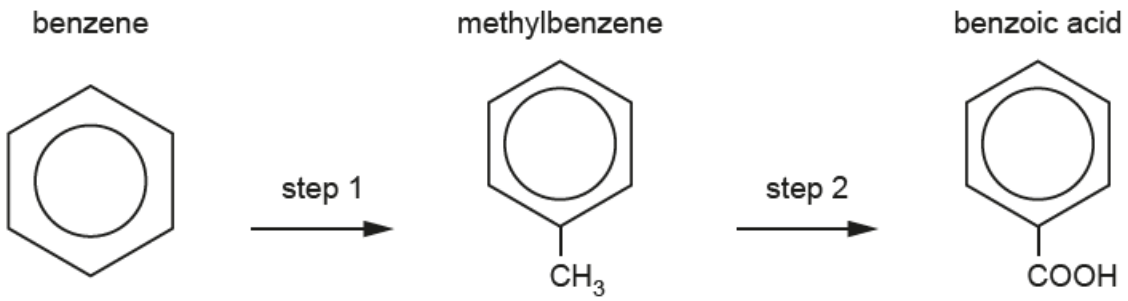


Fig. 7.1

(a) Give the reagents and conditions for step 1 and step 2.

step 1 .....

step 2 .....

[2]

(b) Methylbenzene and benzoic acid each have five different peaks in the carbon (^{13}C) NMR spectrum.

Table 7.1

hybridisation of the carbon atom	environment of carbon atom	example	chemical shift range /ppm
sp^3	alkyl	$\mathbf{C}H_3$–, –$\mathbf{C}H_2$–, –$\mathbf{C}$H<, >$\mathbf{C}$<	0–50
sp^3	next to alkene/arene	–$\mathbf{C}$–C=C, –$\mathbf{C}$–Ar	25–50
sp^3	next to carbonyl/carboxyl	$\mathbf{C}$–COR, $\mathbf{C}$–O_2R	30–65
sp^3	next to halogen	$\mathbf{C}$–X	30–60
sp^3	next to oxygen	$\mathbf{C}$–O	50–70
sp^2	alkene or arene	>$\mathbf{C}$=$\mathbf{C}$<, 	110–160
sp^2	carboxyl	R–$\mathbf{C}$OOH, R–$\mathbf{C}$OOR	160–185
sp^2	carbonyl	R–$\mathbf{C}$HO, R–$\mathbf{C}$O–R	190–220
sp	nitrile	R–$\mathbf{C}$≡N	100–125

Use Table 7.1 to complete the two sentences to suggest descriptions of these two spectra.

The carbon (^{13}C) NMR spectrum of methylbenzene:

- has ..... peak(s) in the chemical shift range of ..... and
- has ..... peak(s) in the chemical shift range of ..... .

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The carbon (^{13}C) NMR spectrum of benzoic acid:

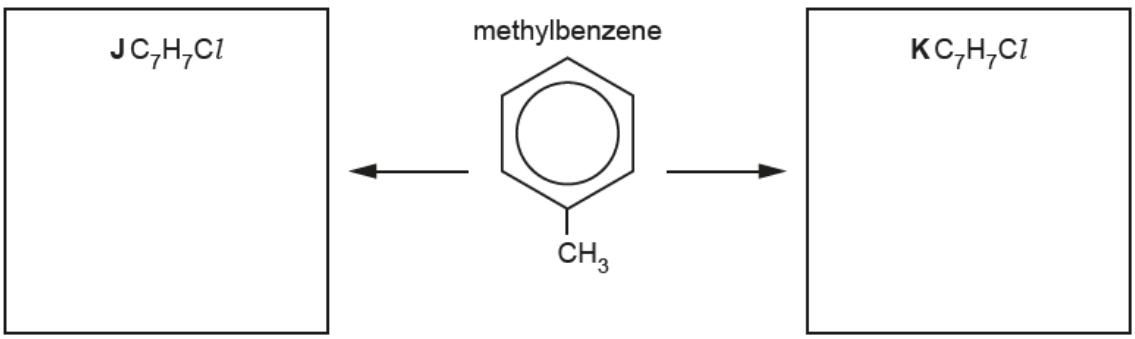
- has ..... peak(s) in the chemical shift range of ..... and
- has ..... peak(s) in the chemical shift range of ..... .

[2]

(c) (i) When treated with Cl_2 under suitable conditions, methylbenzene forms compound **J**.

When treated with Cl_2 under **different** conditions with **different** reagents, methylbenzene forms compound **K**.

Suggest and draw structures of compounds **J** and **K** in the boxes. The molecular formula of each compound is given.



State the reagents and conditions required to form each product.

to form compound **J** .....

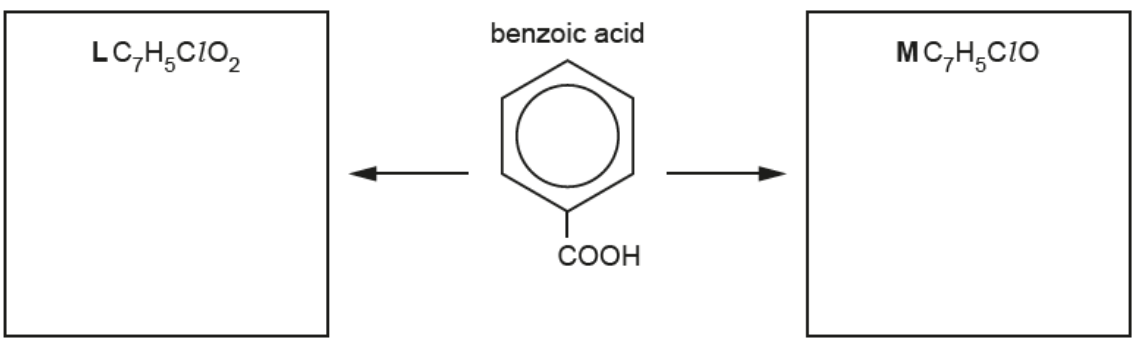
to form compound **K** .....

[4]

(ii) When treated with a chlorine-containing reagent under suitable conditions, benzoic acid forms compound **L**.

When treated with a **different** chlorine-containing reagent under **different** conditions, benzoic acid forms compound **M**.

Suggest and draw structures of compounds **L** and **M** in the boxes. The molecular formula of each product is given.



State the reagents and conditions to form compound **M** from benzoic acid.

..... [3]

[Total: 11]

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4. Nov/2023/Paper_9701/42/No.8(b, c)

Lactic acid, $CH_3CH(OH)COOH$, is the only monomer needed to form the polymer polylactic acid, PLA.

(b) The proton (^1H) NMR spectrum of $CH_3CH(OH)COOH$ in $CDCl_3$ is shown in Fig. 8.1. The proton NMR chemical shift ranges are shown in Table 8.1.

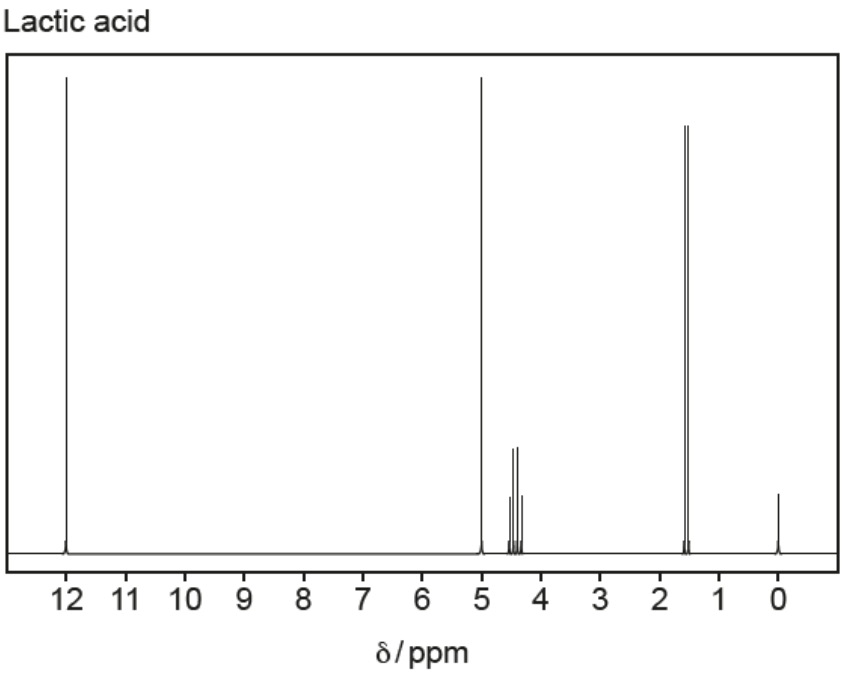


Fig. 8.1

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Table 8.1

environment of proton	example	chemical shift range δ / ppm
alkane	–C**H**$_3$, –C**H**$_2$–, >C**H**–	0.9–1.7
alkyl next to C=O	C**H**$_3$–C=O, –C**H**$_2$–C=O, >C**H**–C=O	2.2–3.0
alkyl next to aromatic ring	C**H**$_3$–Ar, –C**H**$_2$–Ar, >C**H**–Ar	2.3–3.0
alkyl next to electronegative atom	C**H**$_3$–O, –C**H**$_2$–O, –C**H**$_2$–Cl	3.2–4.0
attached to alkene	=C**H**R	4.5–6.0
attached to aromatic ring	**H**–Ar	6.0–9.0
aldehyde	**H**COR	9.3–10.5
alcohol	RO**H**	0.5–6.0
phenol	Ar–O**H**	4.5–7.0
carboxylic acid	RCOO**H**	9.0–13.0

(i) Use Fig. 8.1 and Table 8.1 to complete Table 8.2.

Table 8.2

proton environment	chemical shift (δ)	name of splitting pattern
–COOH		
⩾CH		
–OH		
–CH$_3$		

[3]

(ii) Name the substance responsible for the peak at δ = 0.0.

..... [1]

(iii) Explain why CDCl_3 is a better solvent than CHCl_3 for use in proton NMR.

.....

..... [1]

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(c) An impure sample of $CH_3CH(OH)COOH$ contains pentan-3-one as the only contaminant. The mixture is analysed using gas/liquid chromatography. The pentan-3-one is found to have a longer retention time than the lactic acid.

(i) Explain what is meant by retention time.

.....

..... [1]

(ii) Suggest suitable substances, or types of substances, that could be used as the mobile and stationary phases.

mobile phase .....

stationary phase .....
[1]

(iii) Describe how the percentage composition of the mixture can be determined from the gas / liquid chromatogram.

.....

..... [1]

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W

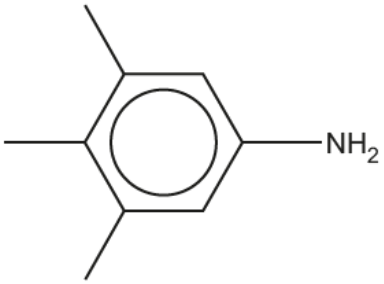


Fig. 4.2

Give the systematic name of **W**.

..... [1]

(d) Complete Table 4.1 to show the number of peaks observed in the carbon-13 NMR spectrum for **W** and **Z**.

Table 4.1

compound	number of peaks observed
W	
Z	

[1]

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6. June/2023/Paper_9701/41/No.7(e)

(e) Alanine, $H_2NCH(CH_3)COOH$, reacts with methanol to form the ester **G** under certain conditions.

The proton (^1H) NMR spectrum of **G** dissolved in D_2O is shown in Fig. 7.3.

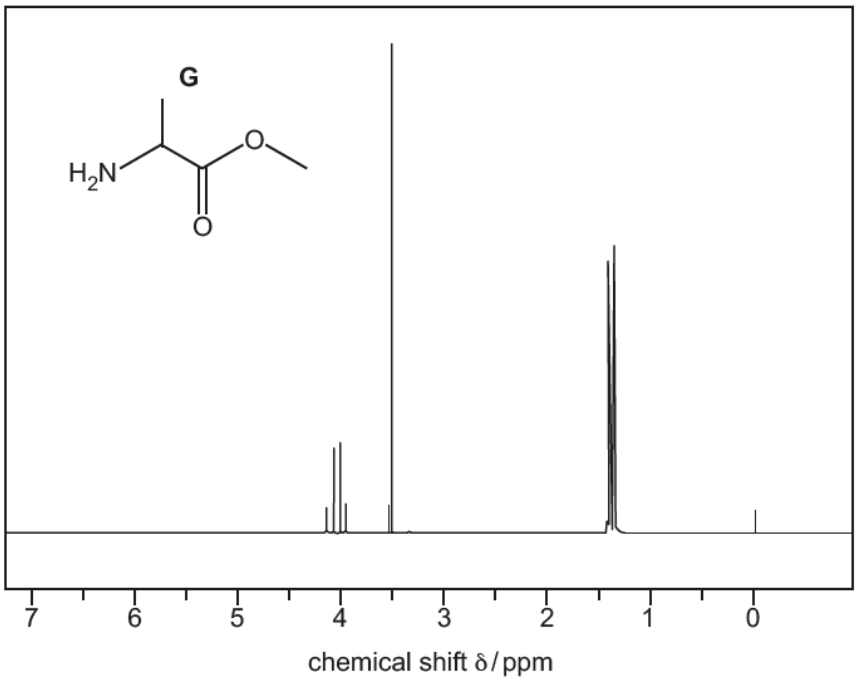


Fig. 7.3

Table 7.1

environment of proton	example	chemical shift range, δ / ppm
alkane	–C**H**$_3$, –C**H**$_2$–, >C**H**–	0.9–1.7
alkyl next to C=O	C**H**$_3$–C=O, –C**H**$_2$–C=O, >C**H**–C=O	2.2–3.0
alkyl next to aromatic ring	C**H**$_3$–Ar, –C**H**$_2$–Ar, >C**H**–Ar	2.3–3.0
alkyl next to electronegative atom	C**H**$_3$–O, –C**H**$_2$–O, –C**H**$_2$–C*l*	3.2–4.0
attached to alkene	=C**H**R	4.5–6.0
attached to aromatic ring	**H**–Ar	6.0–9.0
aldehyde	**H**COR	9.3–10.5
alcohol	RO**H**	0.5–6.0
phenol	Ar–O**H**	4.5–7.0
carboxylic acid	RCOO**H**	9.0–13.0
alkyl amine	R–N**H**–	1.0–5.0
aryl amine	Ar–N**H**$_2$	3.0–6.0
amide	RCON**H**R	5.0–12.0

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(i) Complete Table 7.2 for the proton (^{1}H) NMR spectrum of **G**.

Table 7.2

chemical shift (δ)	splitting pattern	number of ^{1}H atoms responsible for the peak	number of protons on adjacent carbon atoms
1.4			
3.5			
4.0			

[3]

(ii) The proton (^{1}H) NMR spectrum of **G** dissolved in $CDCl_3$ is obtained.

Describe the difference observed between this spectrum and the proton NMR spectrum in D_2O shown in Fig 7.3.

Explain your answer.

.....

.....

..... [1]

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(c) The proton (^{1}H) NMR spectrum of compound **T**, $C_5H_9O_2Cl$, in $CDCl_3$ is shown in Fig. 8.2.

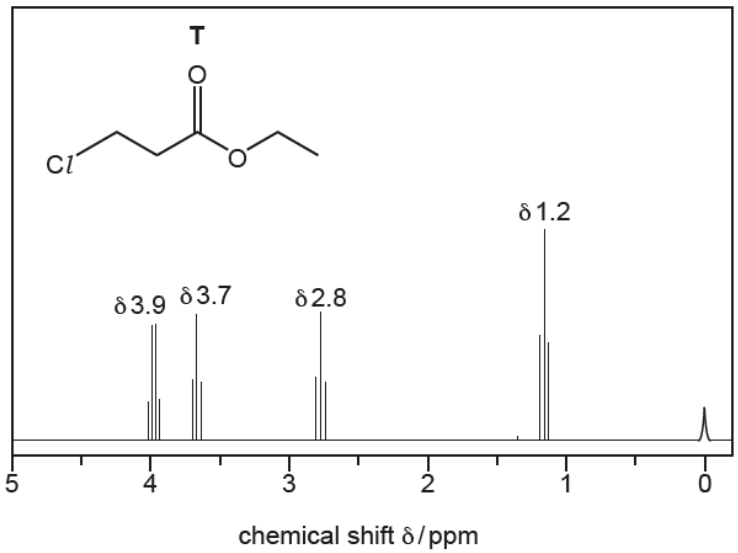


Fig. 8.2

Table 8.1

environment of proton	example	chemical shift range δ/ppm
alkane	–C**H**$_3$, –C**H**$_2$–, >C**H**–	0.9–1.7
alkyl next to C=O	C**H**$_3$–C=O, –C**H**$_2$–C=O, >C**H**–C=O	2.2–3.0
alkyl next to aromatic ring	C**H**$_3$–Ar, –C**H**$_2$–Ar, >C**H**–Ar	2.3–3.0
alkyl next to electronegative atom	C**H**$_3$–O, –C**H**$_2$–O, –C**H**$_2$–C*l*	3.2–4.0
attached to alkene	=C**H**R	4.5–6.0
attached to aromatic ring	**H**–Ar	6.0–9.0
aldehyde	**H**COR	9.3–10.5
alcohol	RO**H**	0.5–6.0
phenol	Ar–O**H**	4.5–7.0
carboxylic acid	RCOO**H**	9.0–13.0
alkyl amine	R–N**H**–	1.0–5.0
aryl amine	Ar–N**H**$_2$	3.0–6.0
amide	RCONHR	5.0–12.0

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(i) Suggest why $CDCl_3$ is used as a solvent instead of $CHCl_3$ for the proton (^1H) NMR spectrum.

.....

..... [1]

(ii) Complete Table 8.2 for the proton (^1H) NMR spectrum of **T**.

Table 8.2

chemical shift δ / ppm	environment of proton	splitting pattern	number of ^1H atoms responsible for the peak
1.2			
2.8			
3.7			
3.9			

[4]

(iii) Explain the splitting pattern of the peak at δ 3.9 ppm.

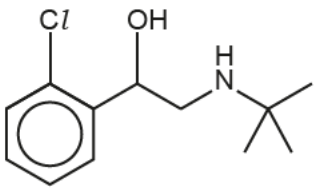
.....

..... [1]

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8. March/2023/Paper_9701/42/No.5(f)

tulobuterol



(f) **(i)** Predict the number of peaks that would be seen in the carbon-13 NMR spectrum of tulobuterol.

..... [1]

(ii) The proton (^{1}H) NMR spectrum of tulobuterol dissolved in D_2O shows peaks in four different types of proton environment.

The peak for the —CH_2N— environment is a doublet in the chemical shift range δ = 2.0–3.0 ppm.

Give details for each of the other **three** peaks in the proton NMR spectrum of tulobuterol, to include:

- chemical shift
- environment of the proton
- splitting pattern
- number of ^{1}H atoms responsible.

Table 5.1 gives information about typical chemical shift values.

.....

.....

.....

.....

.....

.....

..... [3]

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Table 5.1

environment of proton	example	chemical shift range δ / ppm
alkane	–C**H**$_3$, –C**H**$_2$–, >C**H**–	0.9–1.7
alkyl next to C=O	C**H**$_3$–C=O, –C**H**$_2$–C=O, >C**H**–C=O	2.2–3.0
alkyl next to aromatic ring	C**H**$_3$–Ar, –C**H**$_2$–Ar, >C**H**–Ar	2.3–3.0
alkyl next to electronegative atom	C**H**$_3$–O, –C**H**$_2$–O, –C**H**$_2$–C*l*	3.2–4.0
attached to alkene	=C**H**R	4.5–6.0
attached to aromatic ring	**H**–Ar	6.0–9.0
aldehyde	**H**COR	9.3–10.5
alcohol	RO**H**	0.5–6.0
phenol	Ar–O**H**	4.5–7.0
carboxylic acid	RCOO**H**	9.0–13.0
alkyl amine	R–N**H**–	1.0–5.0
aryl amine	Ar–N**H**$_2$	3.0–6.0
amide	RCON**H**R	5.0–12.0

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9. March/2023/Paper_9701/42/No.6(a _ c)

A student uses thin-layer chromatography (TLC) to analyse a mixture containing different metal cations. The student repeats the experiment using different solvents.

Fig. 6.1 shows the chromatogram obtained by the student using water as a solvent.

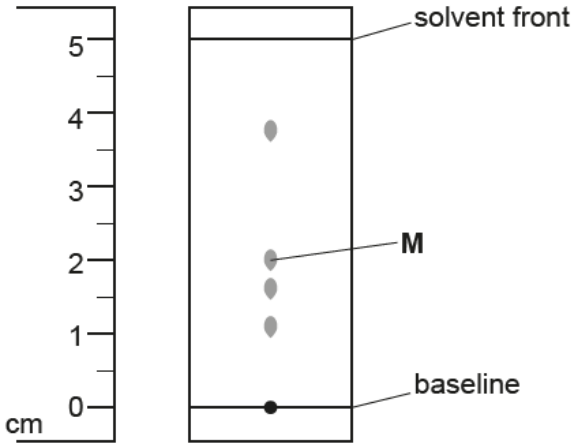


Fig. 6.1

(a) (i) Suggest a compound that could be used as the stationary phase in this experiment.

..... [1]

(ii) Table 6.1 shows the R_f values for different metal cations when separated by TLC using water as a solvent.

Table 6.1

cation	R_f value (water)
$Cd^{2+}(aq)$	0.40
$Co^{2+}(aq)$	0.77
$Cu^{2+}(aq)$	0.32
$Fe^{3+}(aq)$	0.12
$Hg^{2+}(aq)$	0.23
$Ni^{2+}(aq)$	0.75

Suggest the identity of the cation that causes the spot at **M** in Fig. 6.1.

Explain your answer.

.....

..... [1]

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(b) The student repeats the experiment using butan-1-ol as a solvent.

The metal cations do **not** travel as far up the TLC plate in this experiment.

Suggest why the metal cations do not move as far up the TLC plate with butan-1-ol as a solvent.

.....

..... [1]

(c) The student sprays the TLC plate in Fig. 6.1 with KSCN(aq).

The colour of some of the spots changes, as some of the metal cations undergo a ligand exchange reaction.

Identify the ligands involved in the ligand exchange reaction.

..... exchanges with .....
[1]

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Analytical techniques – 2022 June AS Chemistry 9701

1. June/2022/Paper_11/No.40

A scientist chooses either infrared spectroscopy or mass spectrometry to find a particular piece of information.

In which row has the **best** choice been made?

	target information	analytic method used
A	identities of functional groups in an organic compound	infrared spectroscopy
B	identities of functional groups in an organic compound	mass spectrometry
C	values of successive ionisation energies of Na	infrared spectroscopy
D	values of successive ionisation energies of Na	mass spectrometry

2. June/2022/Paper_12/No.40

Three organic compounds are listed.

1 ethanal

2 propan-1-ol

3 propan-2-ol

Which compounds will have a mass spectrum that contains a fragment peak at $m/e = 43$?

A 1 only **B** 1 and 2 only **C** 2 and 3 only **D** 1, 2 and 3

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3. June/2022/Paper_21/No.4(d)

(d) Fig. 5.1 shows the mass spectrum of ketone **Z**, $C_5H_{10}O$.

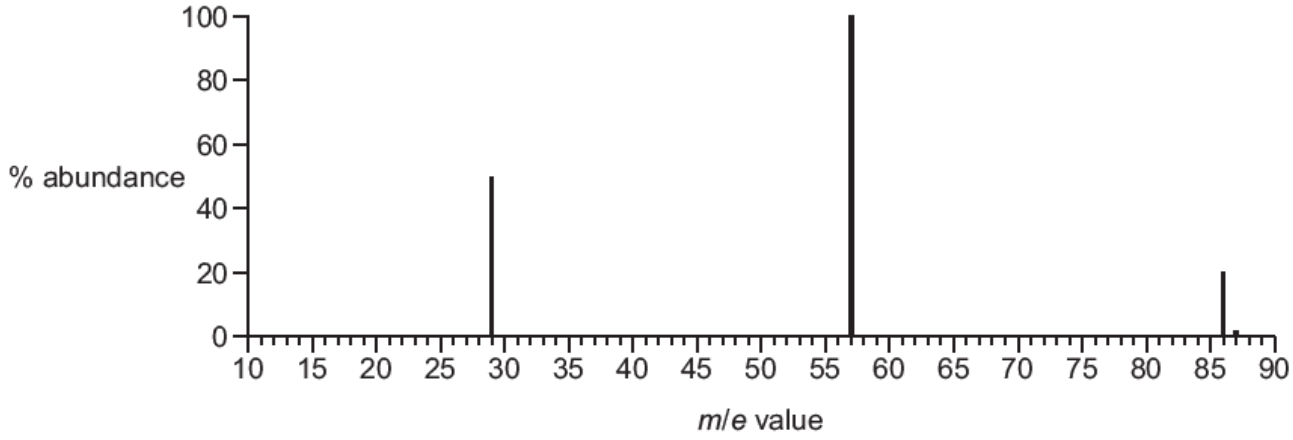


Fig. 5.1

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]

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4. June/2022/Paper_22/No.4(c)

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

X

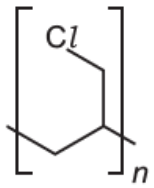


Fig. 4.3

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

[1]

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

..... [1]

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5. June/2022/Paper_23/No.5(b)

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

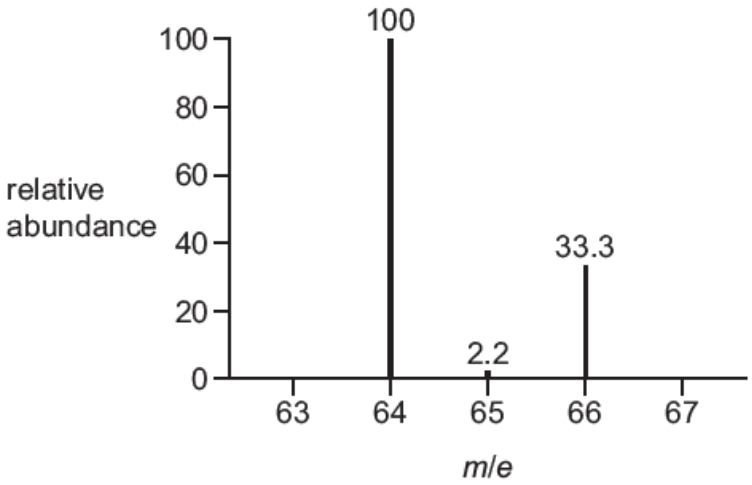


Fig. 5.1

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

..... [1]

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

.....

..... [1]

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

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

m/*e* = 29 .....

m/*e* = 49 .....

name of **Z** .....
[3]

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Analytical techniques – 2022 Nov AS Chemistry 9701

1. Nov/2022/Paper_11/No.40

In the mass spectrum of a compound, Z, the relative abundances of the M and M+1 peaks are in the ratio 13 : 1.

What is compound Z?

A butyl butanoate

B hexan-3-one

C 2,2,3-trimethylhexane

D 3,3-dimethylpentan-1-ol

2. Nov/2022/Paper_12/No.40

A molecule of an organic compound, P, contains three carbon atoms and shows a strong absorption at 1720 cm^{-1} in its infrared spectrum.

P is reacted with an excess of hot acidified potassium dichromate(VI) forming organic product Q.

Q shows a strong absorption at 1700 cm^{-1} and a strong, broad absorption centred at 2800 cm^{-1} in its infrared spectrum.

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	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3600

What is P?

A propanal

B propanone

C propan-1-ol

D propan-2-ol

3. Nov/2022/Paper_21/No.5(b, c)

(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

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(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.

Q

.....

.....

[2]

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4. Nov/2022/Paper_22/No.3(c)

(c) Organic compound **E** contains three carbon atoms.
E reacts with cold dilute acidified $KMnO_4(aq)$ 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**.

E

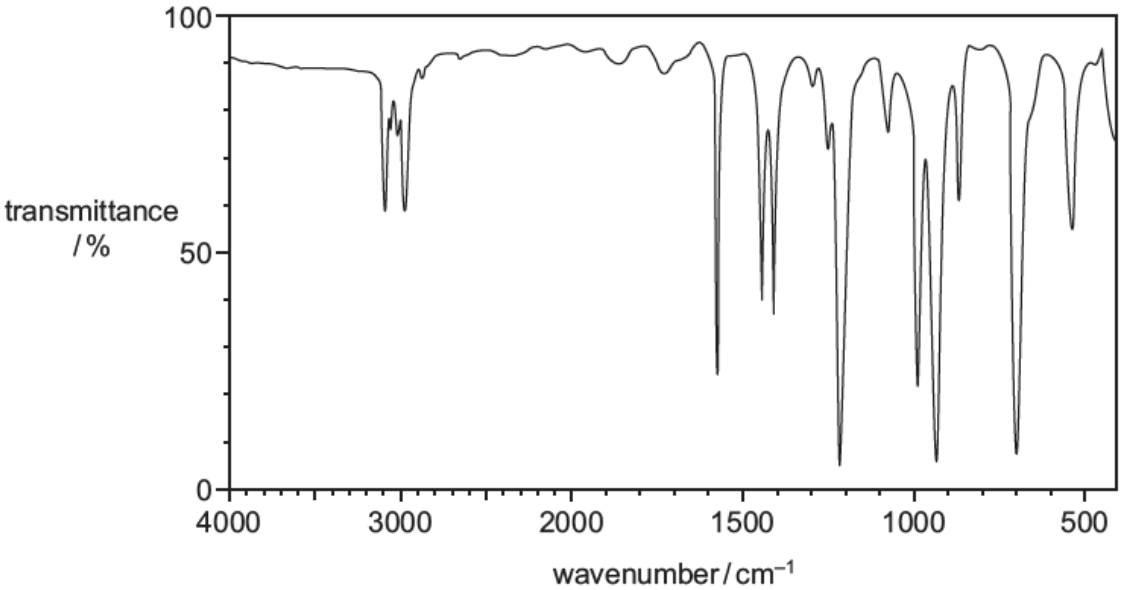


Fig. 3.1

F

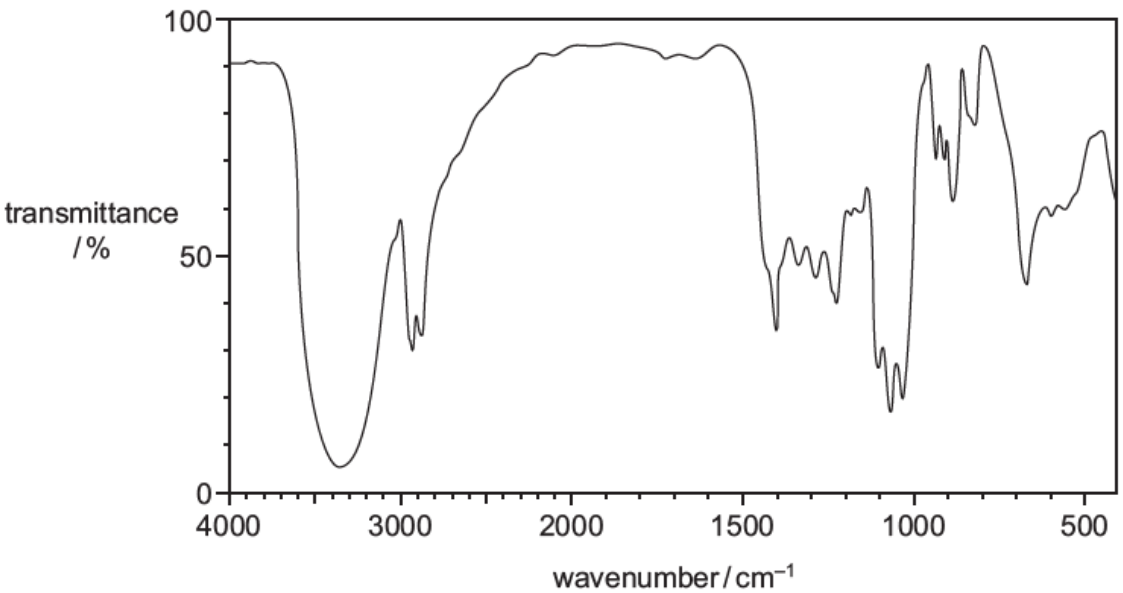


Fig. 3.2

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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 $KMnO_4(aq)$.
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 = ... [1]

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(iv) Use the information in **3(c)** to suggest a structure for **E**.

[1]

(v) Complete the equation for the reaction of **E** with cold dilute acidified $KMnO_4(aq)$ to form **F**. In the equation, [O] represents cold dilute acidified $KMnO_4(aq)$.

H_2O + [O] + ... → .....

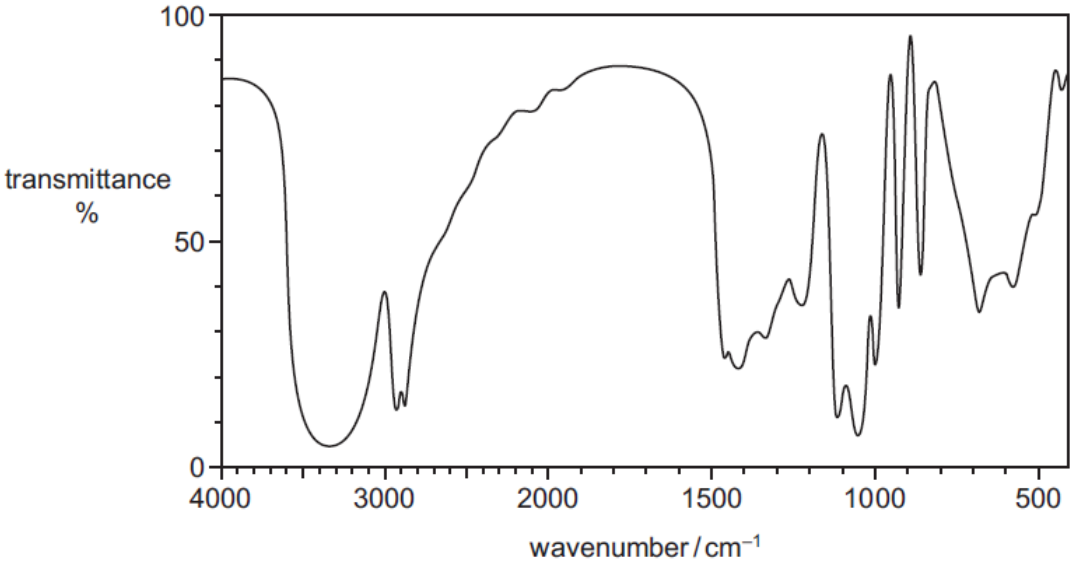
[1]

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Analytical techniques – 2023 AS Chemistry 9701

1. Nov/2023/Paper_ 9701/11/No.39

The infrared spectrum of compound L is shown.



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

What is the structure of L?

A $HOCH_2COCH_2OH$

B $HOCH_2CH(OH)CHO$

C $HOCH_2CH(OH)CH_2OH$

D $HOCH_2CH_2COOH$

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2. Nov/2023/Paper_ 9701/11/No.40

In the mass spectrum of compound J, the ratio of the height of the M +1 ion peak to the height of the M + ion peak is 4 : 91.

Compound J forms a carboxylic acid when heated with acidified $K_2Cr_2O_7$.

What is compound J?

A butanal

B butanone

C propan-1-ol

D propanenitrile

3. Nov/2023/Paper_ 9701/12/No.40

Oxygen has three stable isotopes, ^{16}O, ^{17}O and ^{18}O. All three isotopes are present in a sample of oxygen gas, O_2, which was analysed using a mass spectrometer.

How many peaks associated with the O_2^+ ion would be expected?

A 3 **B** 5 **C** 6 **D** 9

4. Nov/2023/Paper_ 9701/21/No.4(b)

(b) The mass spectrum of **C** shows a molecular ion peak at *m/e* = 70. This peak has a relative intensity of 48.7.

The relative intensity of the [M+1] peak is 2.7.

Show that this information is consistent with the molecular formula of **C**.

[2]

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5. Nov/2023/Paper_ 9701/22/No.3c(iv)

(iv) Reaction 3 is monitored using infrared spectroscopy. It is not possible to use the O—H absorption frequency to monitor the reaction.

Use Table 3.2 to identify a suitable bond whose absorption frequency can be used to monitor the progress of reaction 3.

State the change you would see in the infrared spectrum during reaction 3.

bond .....

change in infrared spectrum .....

.....

[2]

Table 3.2

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–H	alkane	2850–2950

6. June/2023/Paper_9701/11/No.40

There are two naturally occuring isotopes of bromine. One isotope has 44 neutrons. The other isotope has 46 neutrons.

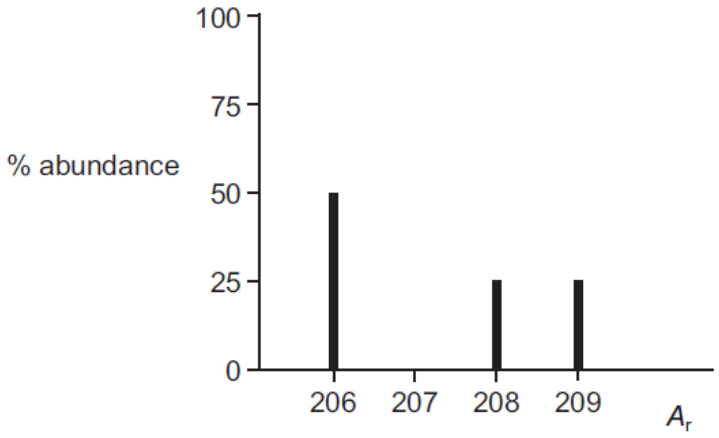
Ignoring fragments, how many peaks are there in the mass spectrum of tribromomethane, $^{12}C^{1}HBr_3$?

A 2 **B** 3 **C** 4 **D** 6

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7. June/2023/Paper_9701/12/No.40

The diagram shows the relative abundance of different isotopes of lead in a sample of lead ore. The abundance of 208 is half that of 206. The abundances of 208 and 209 are equal.



What is the relative atomic mass of the lead in the sample?

A 207.00 **B** 207.25 **C** 207.50 **D** 207.67

8. June/2023/Paper_9701/13/No.40

The mass spectrum of compound X has M, M+1 and M+2 peaks. Other peaks are also present.

Peak M is the molecular ion peak, M^+. Peak M has a relative abundance fifteen times that of peak M+1.

Peaks M and M+2 are of equal height.

What could be compound X?

A 1-chloro-2,2-dimethylpentane

B 2-chloro-3-methylpentane

C 2-bromo-2-methylhexane

D 3-bromo-2,2-dimethylbutane

9. June/2023/Paper_9701/22/No.5(d)

(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.

E



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.

D

[1]

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

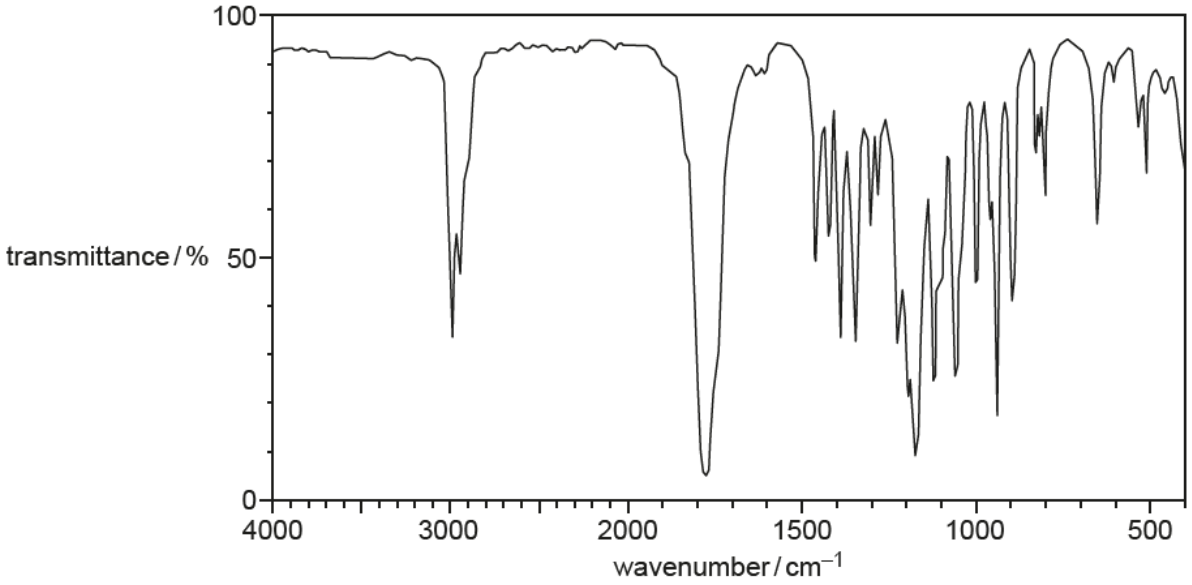


Fig. 5.2

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]

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10. June/2023/Paper_9701/23/No.5b(I _ ii)

(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]

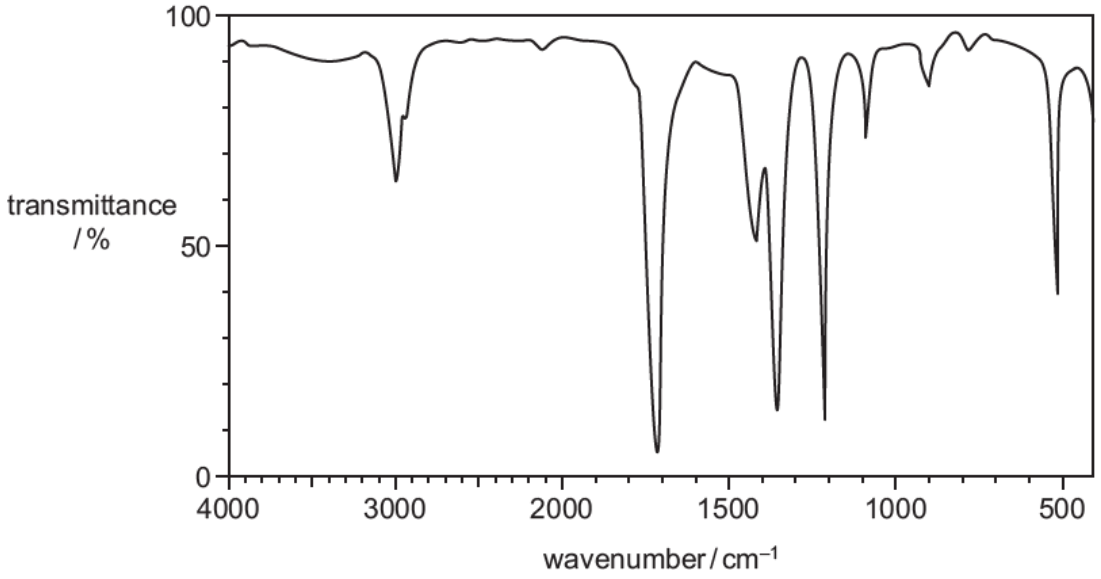
(ii) Identify a suitable non-gaseous reducing agent for the formation of **Y** from **X**.

..... [1]

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11. March/2023/Paper_9701/12/No.38

The infrared spectrum of an organic compound is shown.



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

Which compound could give this spectrum?

A $CH_3CH_2CO_2H$

B $CH_3CH(OH)CH_3$

C CH_3COCH_3

D CH_3COCH_2OH

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(d) (i) Fig. 4.2 shows the infrared spectrum of one of the compounds **D**, **E**, **F**, **G** or **H**.

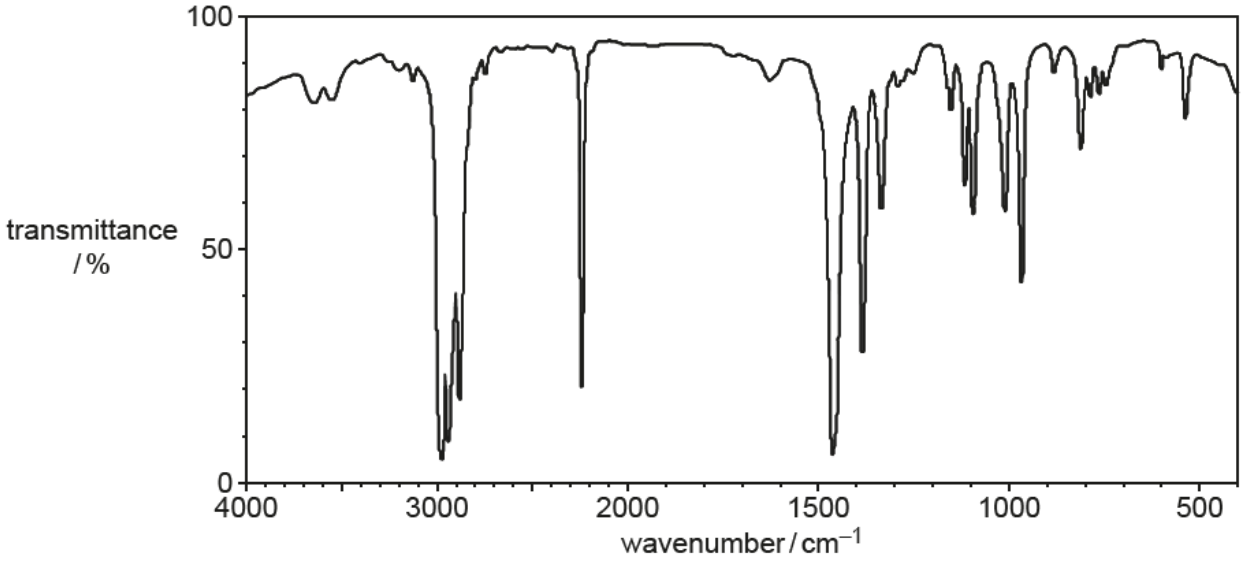


Fig. 4.2

Use information from Table 4.1 (on page 14) to identify which of the compounds **D**, **E**, **F**, **G** or **H** produces the infrared spectrum in Fig. 4.2.

Explain your answer.

.....

.....

..... [2]

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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

(ii) In the mass spectrum of **D**, the relative abundance of the molecular ion peak is 3.4.

Predict the relative abundance of the M+2 peak for **D**.

Explain your answer.

.....

.....

..... [1]

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