Week 31

A-Level Chemistry

Homework bundle for this week

本周作业合集

exercises.lol

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A-Level Chemistry Name: _____ Score: _____

1. Infrared spectroscopy is mainly used to:

   ☐ identify the functional groups in a molecule

   ☐ find the relative molecular mass

   ☐ count the protons

   ☐ measure temperature

2. Chlorine is 75% ^{35}Cl and 25% ^{37}Cl. What is its relative atomic mass? (use (35×75 + 37×25)/100)

   _____

3. A strong dip near a wavenumber of 1700 (per cm) indicates a:

   ☐ C=O bond

   ☐ C–C single bond

   ☐ C=C bond only

   ☐ C–H bond

4. The molecular ion peak (the highest m/e) gives the:

   ☐ relative molecular mass of the whole molecule

   ☐ number of carbons

   ☐ colour of the compound

   ☐ boiling point

5. A broad dip around a wavenumber of 3200–3650 (per cm) indicates an:

   ☐ O–H bond in an alcohol

   ☐ C–H bond

   ☐ C=C bond

   ☐ C–Cl bond

6. A gap of 15 between two peaks means the molecule has lost:

   ☐ a CH_3 group

   ☐ a CHO group

   ☐ a hydrogen atom

   ☐ an OH group

7. Infrared spectroscopy identifies bonds by the _____ they absorb.

_____

8. In mass spectrometry, the peak at the highest m/z (the molecular ion) gives the relative molecular _____.

_____

9. How could IR confirm that an alkene has become an alcohol?

   ☐ the C=C dip disappears and an O–H dip appears

   ☐ a new C=O dip appears

   ☐ all dips vanish

   ☐ the spectrum does not change

10. An [M+2] peak about the same height as M^+ (a 1:1 ratio) shows the molecule contains:

    ☐ one bromine atom

    ☐ one chlorine atom

    ☐ one carbon atom

    ☐ no halogen

22. Analytical techniques

Answers · 答案

A-Level Chemistry

1. **identify the functional groups in a molecule**

   Each bond absorbs IR at its own wavenumber, so the dips reveal the functional groups present.

2. **35.5**

   Ar = (35×75 + 37×25)/100 = (2625 + 925)/100 = 35.5.

3. **C=O bond**

   A dip around a wavenumber of 1700 (per cm) is the C=O bond (aldehyde, ketone, acid or ester).

4. **relative molecular mass of the whole molecule**

   The highest-m/e peak (M^+) is the whole molecule, so it gives the Mr.

5. **O–H bond in an alcohol**

   The broad O–H absorption sits in the 3200–3650 (per cm) wavenumber region.

6. **a CH_3 group**

   A loss of 15 mass units corresponds to a CH_3 fragment; a loss of 29 is CHO or C_2H_5.

7. **frequencies**

   Each bond absorbs a characteristic IR frequency.

8. **mass**

   The M^+ peak equals the Mr.

9. **the C=C dip disappears and an O–H dip appears**

   Losing the C=C and gaining an O–H dip shows the conversion to an alcohol.

10. **one bromine atom**

    One bromine gives a 1:1 [M+2]:M^+ ratio; one chlorine gives about 3:1.

A-LEVEL CHEMISTRY • EXERCISE SHEET

22.1 Infrared spectroscopy

Name: _____ Class: _____ Date: _____ **Total: 8 marks**

KEY WORDS functional group 官能团 • infrared spectroscopy 红外光谱 • wavenumber 波数 • absorption 吸收 • relative atomic mass 相对原子质量

Objective

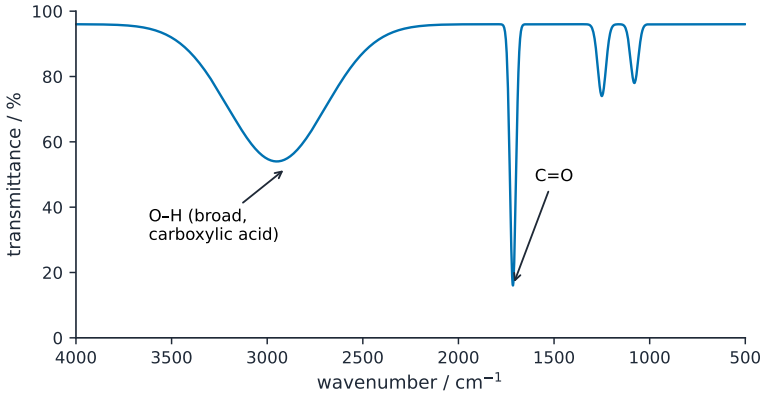
Build the skills to answer exam questions on **infrared spectroscopy** 红外光谱 — using an IR spectrum to identify **functional groups** 官能团.

You must be able to:

- analyse an IR spectrum to identify functional groups (using the given data table)
- use IR to check that a reaction has happened

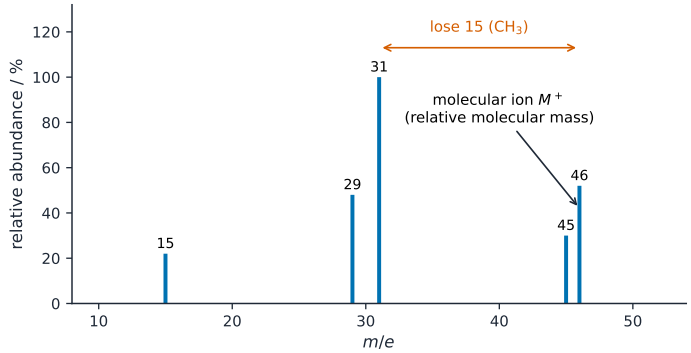
1 Worked examples

Reading an IR spectrum



IR: dips at characteristic wavenumbers identify functional groups (e.g. C=O, O–H)

Each bond absorbs at its own wavenumber, giving a dip. You are given the data table — just match the dips to bonds



M^+ peak $\approx M_r$ · gaps between peaks = mass of fragments lost

IR with mass spectrometry in structure determination

- broad dip ~3200–3650 cm^{-1} → **O–H** of an alcohol.
- dip ~1700 cm^{-1} → **C=O** (aldehyde, ketone, acid, ester).
- broad dip ~2500–3000 cm^{-1} **plus** a C=O dip → a **carboxylic acid**.

Checking a reaction: if propene → propan-2-ol, the C=C dip disappears and an O–H dip appears.

2 Practice

2.1 State the bond responsible for a strong absorption at about 1700 cm^{-1}. [1]

2.2 State which functional group gives a broad absorption around 3200–3650 cm^{-1}. [1]

3 Exam-style questions

3.1 An IR spectrum shows a broad absorption at 2500–3000 cm^{-1} together with a peak at 1710 cm^{-1}. The compound is most likely: [1]

- **A** an alcohol
- **B** an alkane
- **C** a carboxylic acid
- **D** a halogenoalkane

3.2 IR spectroscopy is most useful for identifying: [1]

- **A** the relative atomic mass
- **B** the functional groups present
- **C** the number of carbon atoms
- **D** the boiling point

3.3 Butan-2-ol is oxidised to butanone.

(a) State the change you would see in the IR spectrum (which absorption disappears and which appears). [2]

(b) Explain how IR confirms the oxidation has worked. [2]

Solutions

2.1 a C=O (carbonyl) bond.

2.2 an O–H group (in an alcohol).

3.1 C. The broad 2500–3000 cm^{-1} plus a C=O peak indicates a carboxylic acid.

3.2 B. IR identifies the functional groups present.

3.3 (a) the broad O–H absorption (~3200–3650 cm^{-1}) disappears; a C=O absorption (~1700 cm^{-1}) appears.
(b) losing the O–H and gaining a C=O shows the alcohol has been oxidised to a carbonyl (ketone).

40 The purity of a compound can be determined using infrared spectroscopy.

The table gives the characteristic infrared absorption frequencies for some selected bonds.

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

Propan-2-ol is made by hydration of propene. A sample of the product is obtained.

Which feature of the infrared spectrum of the product would show that **no** propene remains in the product?

A absorption in the 2900 cm^{-1} region

B strong absorption below 1000 cm^{-1}

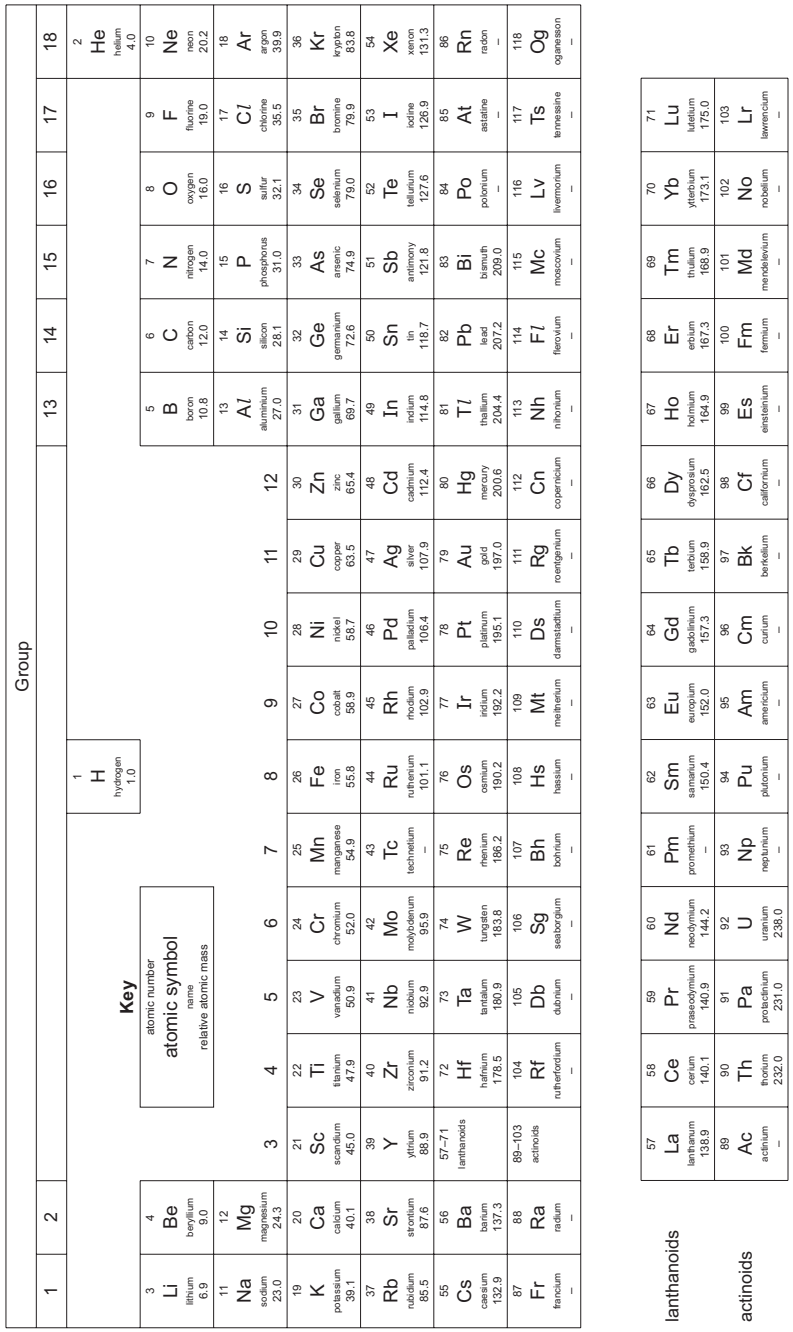
C the lack of absorption at or near 1250 cm^{-1}

D the lack of absorption at or near 1550 cm^{-1}

Important values, constants and standards

molar gas constant	$R = 8.31\,J\,K^{-1}\,mol^{-1}$
Faraday constant	$F = 9.65 \times 10^{4}\,C\,mol^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23}\,mol^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\,C$
molar volume of gas	$V_m = 22.4\,dm^3\,mol^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,dm^3\,mol^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,mol^2\,dm^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,kJ\,kg^{-1}\,K^{-1}$ ($4.18\,J\,g^{-1}\,K^{-1}$)

The Periodic Table of Elements



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

$$C_3H_8 \xrightarrow{\text{reaction 1}} CH_3CH_2CH_2Cl \xrightarrow{\text{reaction 2}} CH_3CH_2CH_2OH \xrightarrow{\text{reaction 3}} CH_3CH_2COOH$$

Fig. 4.1

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

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

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

(i) Name the mechanism shown by reaction 1.

..... [1]

(ii) Complete the mechanism for reaction 1.

Construct equations to describe the steps of the mechanism.

initiation $Cl_2 \rightarrow 2Cl\bullet$

propagation 1 .....

propagation 2 .....

termination ..... $\rightarrow CH_3CH_2CH_2Cl$ [3]

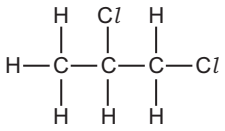
(iii) Reaction 1 is initiated by the bond fission of Cl_2.

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

..... [1]

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

Q



Name **Q**.

..... [1]

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

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

type of structural isomerism .....

type of stereoisomerism ..... [2]

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

..... [1]

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

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

..... [1]

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

..... [1]

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

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

..... [1]

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

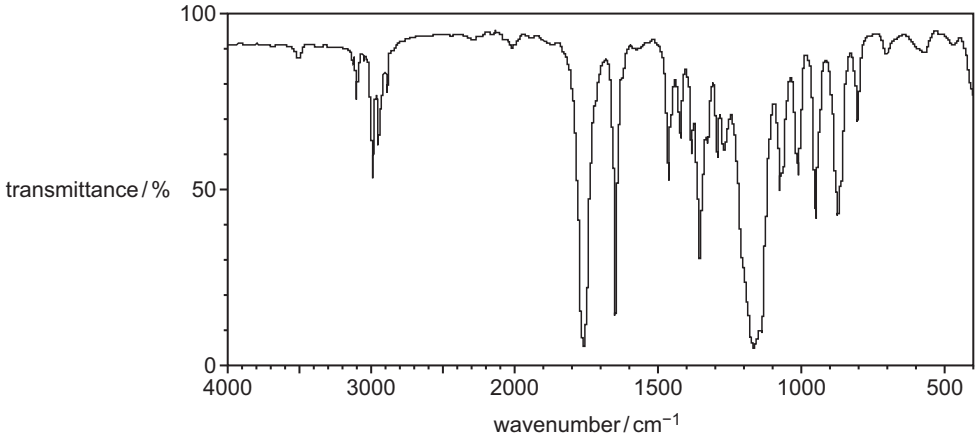


Fig. 4.2

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

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

Table 4.1

absorption	**1**	**2**	**3**
bond responsible			

[3]

Table 4.2

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

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

Table 4.3

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

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

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

[Total: 16]

Important values, constants and standards

molar gas constant	$R = 8.31\,\text{J K}^{-1}\,\text{mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^{4}\,\text{C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23}\,\text{mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\,\text{C}$
molar volume of gas	$V_m = 22.4\,\text{dm}^3\,\text{mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,\text{dm}^3\,\text{mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,\text{mol}^2\,\text{dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,\text{kJ kg}^{-1}\,\text{K}^{-1}$ ($4.18\,\text{J g}^{-1}\,\text{K}^{-1}$)

The Periodic Table of Elements

Group	1	2												13	14	15	16	17	18
								1 H hydrogen 1.0											2 He helium 4.0
	3 Li lithium 6.9	4 Be beryllium 9.0												5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
	11 Na sodium 23.0	12 Mg magnesium 24.3												13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
	19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
	37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
	55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
	87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

Key

atomic number
atomic symbol
name
relative atomic mass

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –

A-LEVEL CHEMISTRY • EXERCISE SHEET

22.2 Mass spectrometry

Name: _____ Class: _____ Date: _____ **Total: 9 marks**

KEY WORDS molecular ion 分子离子 • molecular ion peak 分子离子峰 • relative atomic mass 相对原子质量 • isotopic abundance 同位素丰度 • mass spectrometry 质谱

Objective

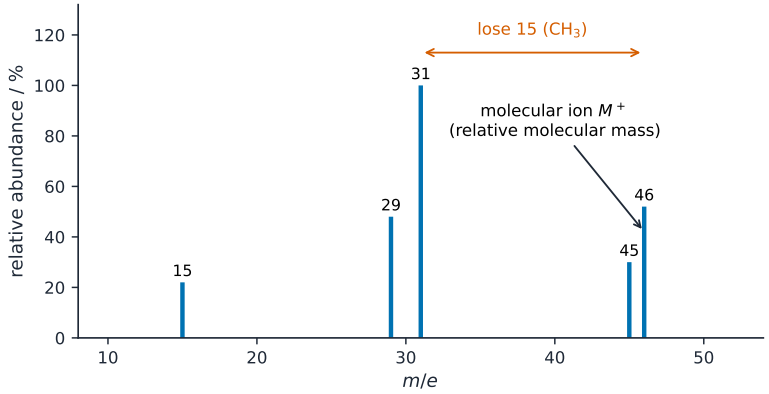
Build the skills to answer exam questions on **mass spectrometry** 质谱 — the **molecular ion** 分子离子, **fragmentation** 碎裂, the **[M+1]** carbon count, and the **[M+2]** halogen test.

You must be able to:

- calculate relative atomic mass from isotopic abundances or a mass spectrum
- deduce molecular mass from the molecular ion peak and identify fragments
- use the [M+1] peak to find the number of carbons, and [M+2] for Cl/Br

1 Worked examples

■ Relative atomic mass and the molecular ion

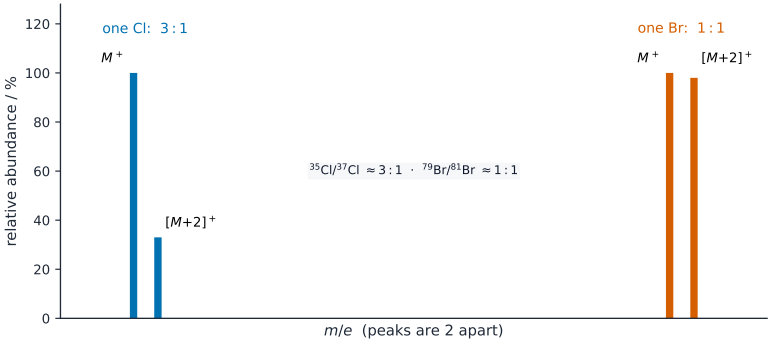


M^+ peak $\approx M_r$ · gaps between peaks = mass of fragments lost

*The peaks are at different m/e values; the **molecular ion** M^+ (highest m/e) gives the M_r*

$$A_r = \frac{\sum(\text{isotope mass} \times \text{abundance})}{\sum \text{abundance}}$$

■ Fragmentation, [M+1] and [M+2]



A small [M+1] peak comes from ^{13}C; an [M+2] peak shows a Cl or Br atom

- **fragments:** the molecule breaks into smaller ions; the mass lost identifies the group (e.g. loss of 15 = CH_3).
- **[M+1] carbon count:** $n = \dfrac{100 \times \text{abundance of } [M+1]}{1.1 \times \text{abundance of } M^+}$.
- **[M+2]:** a peak two higher → Cl (3:1) or Br (1:1).

2 Practice

2.1 State what the molecular ion peak (highest m/e) tells you about a compound. [1]

2.2 A mass spectrum shows a peak at M and another of nearly equal height at M+2. What element is present? [1]

3 Exam-style questions

3.1 Chlorine has isotopes ^{35}Cl (75%) and ^{37}Cl (25%). Its relative atomic mass is: [1]

- **A** 35.0
- **B** 35.5
- **C** 36.0
- **D** 37.0

3.2 Loss of a fragment of mass 15 from a molecular ion suggests the loss of: [1]

- **A** OH
- **B** CH_3
- **C** C_2H_5
- **D** Cl

3.3 A compound has a molecular ion peak M^+ at m/e = 88 (abundance 100) and an [M+1] peak (abundance 4.4).

(a) Use $n = \dfrac{100 \times \text{abundance of } [M+1]}{1.1 \times \text{abundance of } M^+}$ to find the number of carbon atoms. [2]

(b) The compound is a carboxylic acid of M_r 88. Suggest its molecular formula. [1]

3.4 A mass spectrum has peaks at m/e = 78 and 80 in a 1:1 ratio. State, with a reason, which halogen is present. [2]

Solutions

2.1 its molecular mass / M_r (the mass of the whole molecule).

2.2 bromine (Br) — the $^{79}Br/^{81}Br$ ratio is about 1:1.

3.1 B. $A_r = \dfrac{(35 \times 75) + (37 \times 25)}{100} = 35.5$.

3.2 B. A loss of 15 is a CH_3 group.

3.3 (a) $n = \dfrac{100 \times 4.4}{1.1 \times 100} = 4$.
(b) $C_4H_8O_2$ (e.g. butanoic acid).

3.4 bromine; the two peaks two apart in a ~1:1 ratio match the ^{79}Br and ^{81}Br isotopes.

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

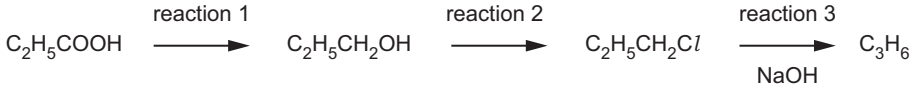


Fig. 4.1

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

..... [1]

(ii) Suggest a suitable reagent for reaction 2.

..... [1]

(iii) Reaction 3 is an elimination reaction.

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

equation .....

solvent and conditions .....
[2]

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

Suggest the reagent and conditions for this conversion.

..... [1]

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

Poly(propene) exhibits stereoisomerism.

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

..... [1]

(ii) Define stereoisomerism.

.....

..... [2]

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

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

section of poly(propene)

.....

.....

.....

.....

[3]

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

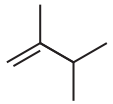
1 .....

2 .....

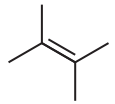
[2]

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

X



Y



(i) Name **X**.

..... [1]

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

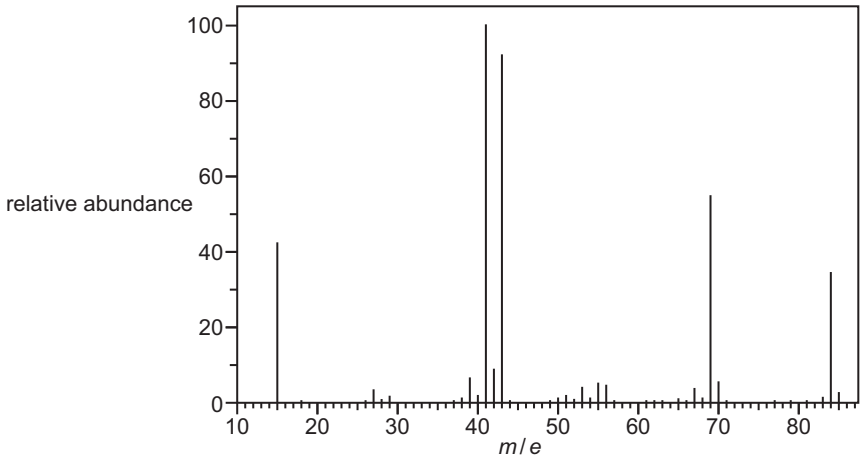


Fig. 4.2

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

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

.....

.....

..... [1]

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

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

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

Important values, constants and standards

molar gas constant	$R = 8.31\,\text{J K}^{-1}\,\text{mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^{4}\,\text{C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23}\,\text{mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\,\text{C}$
molar volume of gas	$V_m = 22.4\,\text{dm}^3\,\text{mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,\text{dm}^3\,\text{mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,\text{mol}^2\,\text{dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,\text{kJ kg}^{-1}\,\text{K}^{-1}$ ($4.18\,\text{J g}^{-1}\,\text{K}^{-1}$)

The Periodic Table of Elements

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								1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0												5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3												13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

Key

atomic number
atomic symbol
name
relative atomic mass

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –

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

$$C_3H_8 \xrightarrow{\text{reaction 1}} CH_3CH_2CH_2Cl \xrightarrow{\text{reaction 2}} CH_3CH_2CH_2OH \xrightarrow{\text{reaction 3}} CH_3CH_2COOH$$

Fig. 4.1

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

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

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

(i) Name the mechanism shown by reaction 1.

..... [1]

(ii) Complete the mechanism for reaction 1.

Construct equations to describe the steps of the mechanism.

initiation $Cl_2 \rightarrow 2Cl\bullet$

propagation 1 .....

propagation 2 .....

termination ..... $\rightarrow CH_3CH_2CH_2Cl$ [3]

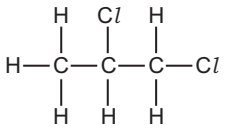
(iii) Reaction 1 is initiated by the bond fission of Cl_2.

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

..... [1]

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

Q



Name **Q**.

..... [1]

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

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

type of structural isomerism .....

type of stereoisomerism ..... [2]

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

..... [1]

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

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

..... [1]

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

..... [1]

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

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

..... [1]

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

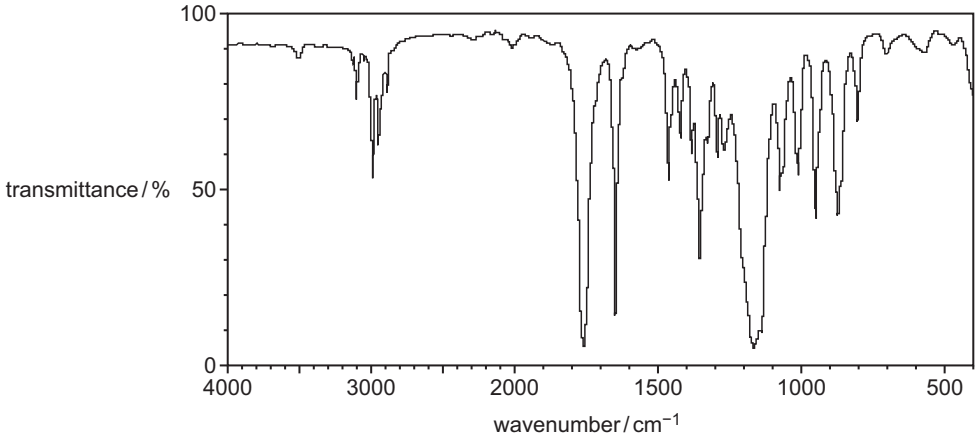


Fig. 4.2

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

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

Table 4.1

absorption	**1**	**2**	**3**
bond responsible			

[3]

Table 4.2

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

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

Table 4.3

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

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

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

[Total: 16]

Important values, constants and standards

molar gas constant	$R = 8.31\,J\,K^{-1}\,mol^{-1}$
Faraday constant	$F = 9.65 \times 10^4\,C\,mol^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23}\,mol^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\,C$
molar volume of gas	$V_m = 22.4\,dm^3\,mol^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,dm^3\,mol^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,mol^2\,dm^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,kJ\,kg^{-1}\,K^{-1}$ ($4.18\,J\,g^{-1}\,K^{-1}$)

The Periodic Table of Elements

Group																	
1	2											13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
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