EXAM PAPERS PRACTICE

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Practice questions created by actual examiners and assessment experts

Detailed mark scheme

Suitable for all boards

Designed to test your ability and thoroughly prepare you

Level: CIE AS and A Level (9701)
Subject: Chemistry
Topic: CIE Chemistry
Type: Mark Scheme

Chemistry CIE AS & A Level
To be used for all exam preparation for 2025+

CHEMISTRY AS and A

This to be used by all students studying CIE AS and A level Chemistry (9701) But students of other boards may find it useful

Mark Scheme

Answer 1.

a) To calculate the relative atomic mass of boron:

- A_r B = $\frac{(10 \times 20) + (11 \times 80)}{100}$; [1 mark]
- A_r B = 10.8 ; [1 mark]

[Total: 2 marks]

- The relative atomic mass of an element can be calculated by using the relative abundance values using the following equation:
  - $\frac{(\text{relative abundance}_{\text{isotope 1}} \times \text{mass}_{\text{isotope 1}}) + (\text{relative abundance}_{\text{isotope 2}} \times \text{mass}_{\text{isotope 2}}) \text{ etc}}{100}$
- The relative abundance of an isotope is either given or can be read off the mass spectrum

b) To calculate the relative atomic mass of potassium:

- Total abundance = 130.6 + 9.4 = 140; [1 mark]
- A_r K = $\frac{(39 \times 130.6) + (41 \times 9.4)}{140}$ = 39.1 / 39.14; [1 mark]

[Total: 2 marks]

- **Careful:** Abundance can be given as a percentage or the abundance of the atoms
- Since the data can be presented to you in different ways, take your time to make sure you have the correct values in the correct place in the equation
  - In this calculation, you are using information from the mass spectrum which shows the relative abundance
  - Therefore, you need to use 140 as the total abundance, not 100%

c) The equation for the formation of the molecular ion of octane and its *m / e* value are:

- $C_8H_{18} \rightarrow C_8H_{18}^+ + e^-$; [1 mark]
- *m / e* = (8 x 12) + (18 x 1) = 114; [1 mark]

[Total: 2 marks]

- The molecular ion is formed by losing one electron
- Since the mass of an electron is negligible, the molecular ion will have the same mass as the molecule itself

d) There is also a smaller peak at *m / e* = 59.0 on the mass spectrum of butane because of:

- Carbon-13 / ^{13}C isotopes; [1 mark]
- Which adds a mass of 1 onto the molecular ion / causes an M + 1 peak; [1 mark]

[Total: 2 marks]

- Most carbon atoms are carbon-12
- However, approximately 1.1% of all carbon atoms are carbon-13
- This means that there is a chance that one (or potentially more) of the carbon atoms in butane will have a mass of 13 instead of 12

e) The alkane that will have a higher [M+1] peak is:

- Octane
  AND
  (Because,) it contains more carbon atoms; [1 mark]

[Total: 1 mark]

- The M+1 peak appears due to the presence of carbon-13 atoms
- Since octane has more carbon atoms, there is a greater chance of one atom being carbon-13 which results in a larger M+1 peak

e) The difference in the ratio of the M^+ peak to the [M+2] peak in 1-bromobutane and 1-chlorobutane would be:

- In 1-chlorobutane, the ratio of M^+: [M+2] would be 3:1; [1 mark]
- In 1-bromobutane, the ratio of M^+: [M+2] would be 1:1; [1 mark]

[Total: 2 marks]

- Both chlorine and bromine exist as two isotopes:
  - ^{35}Cl and ^{37}Cl
    - ^{35}Cl is 3 times more abundant than ^{37}Cl
  - ^{79}Br and ^{81}Br
    - Their relative abundances are the same
- Compounds containing one Cl atom will have an M^+ peak due to the ^{35}Cl isotope and a [M+2] peak due to ^{37}Cl
  - The M^+ peak is 3 times higher than the [M+2] peak
  - This is because the ^{35}Cl isotope is 3 times more abundant than ^{37}Cl
- Compounds containing one Br atom will have an M^+ peak due to the ^{79}Br isotope and a [M+2] peak due to ^{81}Br
  - The M^+ and the [M+2] peak heights are the same
  - This is because the abundances of the isotopes are the same

Answer 2.

a) It can be shown that compound **X** contains 6 carbon atoms by:

- n = (100 / 1.1) × (6.5 / 100); [1 mark]
- So n = 5.91 so there are 6 carbon atoms; [1 mark]

[Total: 2 marks]

- The peaks shown in the diagram are the 2 which are greater than 100, so the peak at m/e = 102 is the molecular ion peak and the peak at m/e = 103 is the [M+1] peak caused by the carbon-13 isotope, which makes up for approximately 1.1% of all carbon atoms
- The number of carbon atoms, *n*, in a compound is deduced from the following formula:

$$n = \frac{100 \times \text{abundance of } [M+1]}{1.1 \times \text{abundance of } M^{+} \text{ ion}}$$

- The abundance of [M+1] = 6.5 and the abundance of M^+ ion = 100, so:

$$n = \frac{100 \times 6.5}{1.1 \times 100} = 5.91$$

- so n = 5.91, rounding this gives 6 carbon atoms

b) The molecular formula of **X** is:

- 102 – (6 × 12) = 30 so $C_6H_{14}O$; [1 mark]

[Total: 1 mark]

- The molecular ion peak occurs at a m/e value that corresponds to the molecular mass of the compound
- So, the molecular mass of compound **X** is 102
- It has 6 carbons which have a mass of 6 x 12 = 72
- The remaining mass must be due to hydrogen and oxygen
  - 102 - 72 = 30
- Oxygen has a mass of 16, so there can only be 1 oxygen atom within the compound (as 2 oxygen atoms would have a combined mass of 32, which is too large)
- The remaining mass must be due to hydrogen atoms:
  - 30 - 16 = 14
- As the mass of a hydrogen atom is 1, there must be 14 carbon atoms

c) The molecular formula of the fragment of **X** at m / e = 31 is:

- $(CH_2OH)^+$; [1 mark]

[Total: 1 mark]

- Think about some common fragments that could be found within a compound containing carbon, hydrogen and oxygen, and their m/e values:
  - CH_3^+ = 15
  - CH_2^+ = 14
  - OH^+ = 17
- Then think about what combination of these fragments would give an m / e value of 31
- CH_2OH^+ would give a value of 14 + 17 = 31

d) The functional group present in **X** is:

- A hydroxy group because of a (broad) peak at 3300
  AND
  One oxygen atom is present in the molecular formula; [1 mark]

[Total: 1 mark]

- The infra-red spectrum shows a broad peak at around 3300 cm^{-1} which corresponds to a hydroxyl group or carboxyl group
- The carboxyl group, -COOH, contains 2 oxygen atoms and the hydroxyl group, -OH, contains 1 oxygen atom
- Compound **X** cannot contain the carboxyl group as it only has 1 oxygen atom, therefore it must contain a hydroxyl group

Answer 3.

a) The relative abundance of the isotopes is:

isotope	relative abundance
^{24}Mg	78-79
^{25}Mg	10
^{26}Mg	11-12

- All three values correct; [1 mark]

[Total: 1 mark]

- A range is given to allow for the readability of the diagram, but the values must add up to 100% to score the mark

b) The relative atomic mass, A_r, of magnesium to two decimal places is:

- (0.78 x 24) + (0.10 x 25) + (0.12 x 26) = 24.34; [1 mark]

[Total: 1 mark]

- To find the relative atomic mass, multiply the abundance by the isotopic mass for each isotope and sum the result
- Don't forget you need to convert the percentage to a decimal or the answer will need to be divided by 100

c) The full electronic configuration of the magnesium ion, $^{26}Mg^{2+}$.

- $1s^2 2s^2 2p^6$; [1 mark]

[Total: 1 mark]

- Don't be fooled by the question asking you for the electronic configuration of an isotope - the isotopic mass is irrelevant
- You need to subtract two electrons from the atom to achieve the configuration of the +2 ion

EXAM PAPERS PRACTICE

d) Deducing the relative abundance of each isotope of boron:

- $10.8 = \frac{10x + 11(100 - x)}{100}$

OR

$10x + 1100 - 11x = 1080$; [1 mark]

- $\therefore x = 1100 - 1080 = 20$; [1 mark]
- Isotope 1 / 10 relative abundance = 20

AND

Isotope 2 / 11 relative abundance = 80; [1 mark]

[Total: 3 marks]

- If the relative atomic mass is of boron is 10.8 we can take an average of the % abundances and make them equal to the relative atomic mass
- The two isotopes must have respective atomic masses of 10 and 11 as the relative atomic mass is 10.8
- We know that
- $A_r = \frac{(\text{relative abundance} \times \text{mass of isotope}) + (\text{relative abundance} \times \text{mass of isotope})}{100}$
- The relative abundances must add up to 100
- We can then put these numbers into the equation
- $10.8 = \frac{10x + 11(100 - x)}{100}$
- The isotope which has a mass of 10 has an abundance of 20%, as x is equal to 20
- The isotope which has a mass of 11 has an abundance of 80%, as $100-x$ is equal to 80

Answer 4.

a) The evidence to support that compound **X** is a hydrocarbon is:

- Infrared peak at (roughly) 2950 cm^{-1} for C-H bonds; [1 mark]
- No other functional groups present in the infrared spectrum; [1 mark]

[Total: 2 marks]

- Use your exam technique to help answer this question, two marks suggests:
  - Two comments about the infrared spectrum
  - Two comments about the mass spectrum
  - One comment about each spectrum
- This question is two comments about the infrared spectrum:
  - One comment to directly show how the IR spectrum supports the hydrocarbon conclusion
    - The peak at 2950 cm^{-1} is for C-H bonds
  - One comment to indirectly show how the IR spectrum supports the hydrocarbon conclusion
    - No other functional groups present

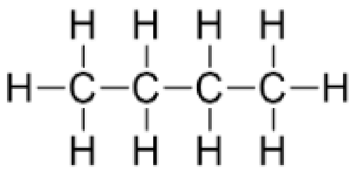
b) The mass spectrum supports that compound **X** has a molecular formula of C_4H_{10} because:

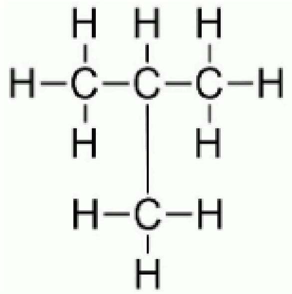
- (There is a) molecular ion / M^+ peak at *m/e* 58
  AND
  C_4H_{10} has a relative molecular mass / M_r of 58; [1 mark]

[Total: 1 mark]

- **Careful**: Be sure to state the supporting piece of evidence **AND** how it supports the conclusion

c) The displayed formulae of **two** possible isomers for compound **X** are:





- Both structures correct; [1 mark]

[Total: 1 mark]

- C_4H_{10} is the molecular formula for butane
- Butane has only one isomer which is methylpropane

d)

i) The fragment ions in the mass spectrum are:

- *m/z* 15 = CH_3^+; [1 mark]
- *m/z* 29 = $C_2H_5^+$; [1 mark]
- *m/z* 43 = $C_3H_7^+$; [1 mark]

ii) Compound **X** is:

- Butane
  AND
  The fragment ions support / prove that compound **X** / the hydrocarbon is a straight chain; [1 mark]

[Total: 4 marks]

- These fragment ions are some of the more basic ones that you can be expected to know
- **Careful:** Don't forget the + charge or you will lose the mark(s)

Answer 5.

a) To calculate the molecular formula of compound **B**:

- Moles of carbon = 5.80
  AND
  Moles of oxygen = 1.16
  AND
  Moles of hydrogen = 11.7; [1 mark]
- Ratio of carbon : oxygen : hydrogen is 5 : 1 : 10
  AND
  Therefore, the empirical formula is $C_5H_{10}O$; [1 mark]
- Molecular formula = $C_5H_{10}O$
  AND
  Because the empirical formula has a mass of 86 which corresponds to the M+1 peak at *m/z* = 87; [1 mark]

[Total: 3 marks]

- This question contains all the little tricks that examiners can do:
  - Not giving you all of the percentages and expecting you to deduce the missing percentage
    - Percentage of hydrogen = 100 - 69.7 - 18.6 = 11.7 %
  - Giving you the elements out of the standard, and almost expected, order
  - Not giving you the specific mass of the unknown compound - although you should be able to determine this from the M+1 peak information
- To calculate the empirical formula:

Element	C	O	H
Value from question	69.7	18.6	11.7
A_r	12.0	16.0	1.0
Moles	$\frac{69.7}{12.0} = 5.80$	$\frac{18.6}{16.0} = 1.16$	$\frac{11.7}{1.0} = 11.7$
Ratio	$\frac{5.80}{1.16} = 5$	$\frac{1.16}{1.16} = 1$	$\frac{11.7}{1.16} = 10.09$

- Therefore, the empirical formula is $C_5H_{10}O$
- $C_5H_{10}O$ has a molar mass of (12.0 x 5) + (1.0 x 10) + 16.0 = 86.0
- This means that $C_5H_{10}O$ would have an M+1 peak at *m* / *e* = 87.0

b) **Two** possible structures for compound **B** are:

- Pentan-2-one
  AND
  Pentan-3-one; [1 mark]

Explanation:

- The (sharp) IR peak at 1705 cm^{-1} corresponds to a carbonyl group / C=O
  AND
  Which suggests / could be an aldehyde or a ketone; [1 mark]
- The fragment ion peak at *m* / *e* = 28 can only come from a C=O fragment
  AND
  Pentanal cannot (easily) form this fragment; [1 mark]

[Total: 3 marks]

- Using a combination of the molecular formula of $C_5H_{10}O$ and the IR peak at 1705 cm^{-1}, you should be able to determine pentanal, pentan-2-one and pentan-3-one as the only possible isomers
- The fragment ion peak at *m* / *e* = 28 removes pentanal as a possibility because it cannot (easily) form that fragment ion

c) The fragment responsible for the mass spectrum peak at *m* / *e* = 29 is:

- $C_2H_5^+$; [1 mark]

How it can be used to distinguish between the two isomers:

- Pentan-2-one can only form one ($C_2H_5^+$) fragment
  AND
  Pentan-3-one can only form two ($C_2H_5^+$) fragments; [1 mark]
- Therefore, pentan-2-one will have a lower relative abundance of the ($C_2H_5^+$) fragment
  OR
  Therefore, pentan-3-one will have a higher relative abundance of the ($C_2H_5^+$) fragment; [1 mark]

[Total: 3 marks]

- **Remember:** A mass spectrum gives *m* / *e* data which can be used to identify potential fragment ions, but the size of the peaks can also give an indication of how much there is of each peak
  - Pentan-2-one can only form one peak at *m* / *e* = 29
  - Due to its symmetry, pentan-3-one can essentially form 2 peaks at *m* / *e* = 29
  - Therefore, you could expect the *m* / *e* = 29 peak to be higher (potentially double) for pentan-3-one

Answer 6.

a) To calculate the molecular formula of alcohol **E**:

- Moles of carbon = 5.68
  AND
  Moles of hydrogen = 13.6
  AND
  Moles of oxygen = 1.14; [1 mark]
- Ratio of carbon : hydrogen : oxygen is 5 : 12 : 1
  AND
  Therefore, the empirical formula is $C_5H_{12}O$; [1 mark]
- M_r of the empirical formula = (5 x 12.0) + (12.0 x 1) + 16.0 = 88.0
  AND
  Therefore, the molecular formula is $C_5H_{12}O$; [1 mark]

[Total: 3 marks]

- Part (i) is a standard empirical formula calculation
-

Element	C	H	O
Value from question	68.2	13.6	18.2
A_r	12.0	1.0	16.0
Moles	$\frac{68.2}{12.0}$ = 5.68	$\frac{13.6}{1.0}$ = 13.6	$\frac{18.2}{16.0}$ = 1.14
Ratio	$\frac{5.68}{1.14}$ = 4.98	$\frac{13.6}{1.14}$ = 11.93	$\frac{1.14}{1.14}$ = 1

- Therefore, the empirical formula is $C_5H_{12}O$
- **Careful:** Don't assume that the empirical formula is the molecular formula
  - Use the molecular ion *m* / *e* value of 88 to determine if the empirical formula is the molecular formula
  - In this instance, the molecular and empirical formulae are the same
  - Without this check, you will lose a mark

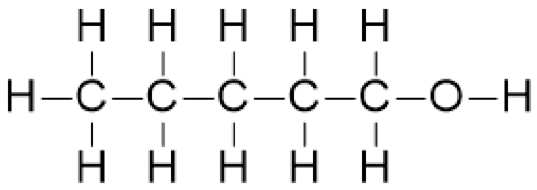
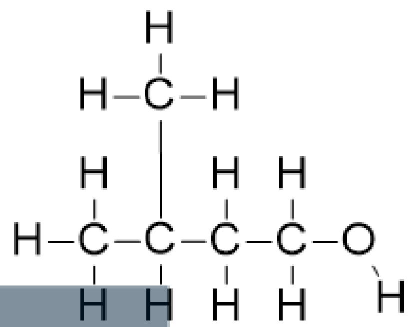
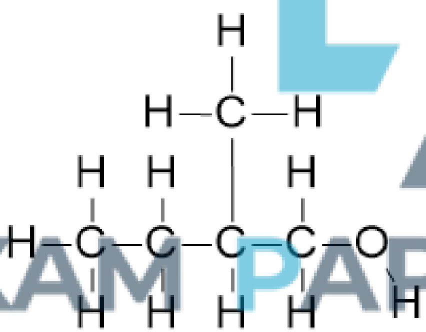
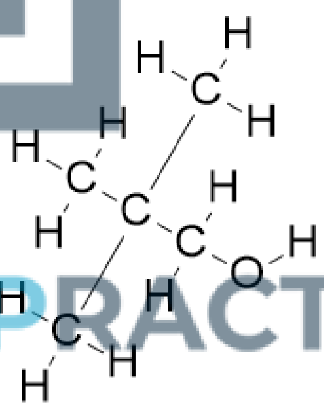
b) The information this tells us about the structure of alcohol **E** is:

- It is a primary / 1° alcohol; [1 mark]

[Total: 1 mark]

- **Remember**:
    - Primary alcohols are oxidised to aldehydes and then carboxylic acids
    - Secondary alcohols are oxidised to ketones
    - Tertiary alcohols can't be further oxidised

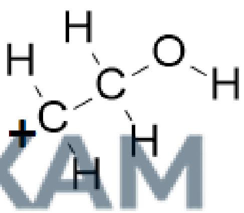
c) The fully displayed formulae and names of the **four** possible structural isomers that could be alcohol **E** are:

 **AND** Name = Pentan-1-ol; [1 mark]	 **AND** Name = 3-methylbutan-1-ol; [1 mark]
 **AND** Name = 2-methylbutan-1-ol; [1 mark]	 **AND** Name = 2,2-dimethylpropan-1-ol; [1 mark]

[Total: 4 marks]

- Take your time drawing the four structural isomers and naming them correctly:
  - From part **(c)**, you are drawing structural isomers of primary alcohols so don't be tempted to draw secondary or tertiary structures
  - Always double check they are in fact isomers and not the same molecule
  - Take care with the naming rules as without a name you will not be awarded the full marks
- Apart from pentan-1-ol, you can also score the mark by giving a name that does not include the -1-, e.g. 3-methylbutanol
  - This is because the alcohol group is fixed at carbon 1
  - This means that the molecule is numbered from carbon-1, which is the carbon with the alcohol group

d) The structure of the species that could give a major peak at *m* / *e* = 45.

- 

AND

Positive charge included in the diagram; [1 mark]

[Total: 1 mark]

- Take your time deducing the fragment ion
  - It will be linked to one of the isomers that you have just drawn so you are best starting with the CH_2OH which is common to all of the isomers
  - This has a mass of 31
  - This leaves a mass of 14, which is a CH_2 group
  - Therefore, the fragment is CH_2CH_2OH
  - **Remember:** The question asks for the fragment ion which is $CH_2CH_2OH^+$

e) The identity of alcohol **E** is:

- 3-methyl-butan-1-ol
  AND
  This is the only alcohol with a branched chain that forms $CH_2OHCH_2^+$ / $C_2H_4OH^+$ / peak at 45.0;
  [1 mark]

[Total: 1 mark]

- There are three branched structural isomers:
  - 3-methylbutan-1-ol
  - 2-methylbutan-1-ol
  - 2,2-dimethylpropan-1-ol
- Only 3-methylbutan-1-ol can form a fragment ion with an *m* / *e* value of 45.0

Answer 7.

a)

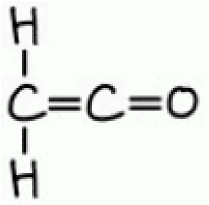
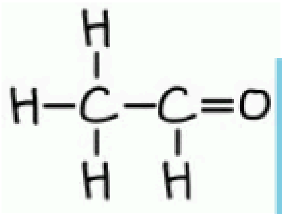
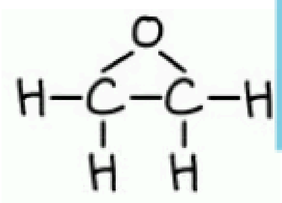
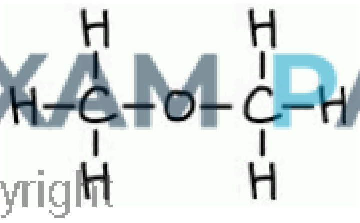
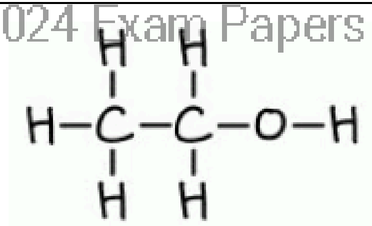
i) To determine whether compound **F** is a carbohydrate according to the previous chemistry definition:

- Percentage of carbon = 55.81 (%)
  AND
  Moles of carbon = 4.65; [1 mark]
- Moles of hydrogen = 6.98
  AND
  Moles of oxygen = 2.34; [1 mark]
- Ratio of carbon : hydrogen: oxygen is 2 : 3 : 1
  AND
  Therefore, the empirical formula is C_2H_3O; [1 mark]
- Compound **F** is not a carbohydrate according to the previous chemistry definition
  AND
  Because the number of hydrogen and oxygen atoms does not match the H_2O / $(H_2O)_n$ in the general formula; [1 mark]

ii) The answer to part **(i)** cannot be the molecular formula of compound **F** because:

- The number of hydrogens is not possible for a complete / fully bonded molecule
  OR
  The molecules possible with two carbon atoms and one oxygen atom have an incorrect number of hydrogen atoms; [1 mark]

Plus any **three** of the following:

Displayed formula	Justification, in terms of hydrogen atoms	
	Not enough hydrogen atoms	; [1 mark]
	Too many hydrogen atoms	; [1 mark]
	Too many hydrogen atoms	; [1 mark]
	Too many hydrogen atoms	; [1 mark]
	Too many hydrogen atoms	; [1 mark]

[Total: 8 marks]

- For part **(i)**
  - This question gives you the elements out of the standard, and almost expected, order
  - You also have to calculate the missing percentage:
    - Percentage of hydrogen = 100 - 6.98 - 37.21 = 55.81 %
  - To calculate the empirical formula:
    -

Element	C	H	O
Value from question	55.81	6.98	37.21
A_r	12.0	1.0	16.0
Moles	$\frac{55.81}{12.0}$ = 4.65	$\frac{6.98}{1.0}$ = 6.98	$\frac{37.21}{16.0}$ = 2.34
Ratio	$\frac{4.65}{2.34}$ = 1.99	$\frac{6.98}{2.34}$ = 2.98	$\frac{2.34}{2.34}$ = 1

    - Therefore, the empirical formula is C_2H_3O
  - It is the H_2O portion of the general formula $C_m(H_2O)_n$ that is important
    - The number of carbon atoms, m, is independent of the hydrogen and oxygen atoms
    - The $(H_2O)_n$ portion shows that there must always be a ratio of 2 hydrogen atoms : 1 oxygen atom
    - The H_3O portion of the empirical formula cannot satisfy this ratio
    - Therefore, compound **F** cannot be a carbohydrate according to the previous chemistry definition

- For part **(ii)**
  - This is a challenging variation of determining isomer structures

  - The extra guidance of this question provides a very big clue but is hard to spot
    - By asking you to justify your answer in terms of hydrogen atoms, you are able to place the carbon and oxygen atoms in any position that you wish and then add hydrogen atoms
    - Therefore, you should be drawing **three** different and complete displayed formulae that contain two carbon atoms, one oxygen atom and enough hydrogen atoms to satisfy all the bonds within the molecule
      - However you try this, it is not possible to have two carbon atoms, one oxygen

b) To deduce the molecular formula of compound **F**:

- M_r of the empirical formula of compound **F** = 43.0
  AND
  M_r of compound **F** = 86.0; [1 mark]
- $\frac{86.0}{43.0} = 2$
  AND
  The molecular formula of compound **F** is $C_4H_6O_2$; [1 mark]

[Total: 2 marks]

- The spectrum shows a large peak at *m* / *e* = 86.0 which corresponds to the molecular ion of compound **F**
  - Therefore, the M_r of compound **F** is 86.0
- The empirical formula of compound **F** is C_2H_3O
  - The M_r of the empirical formula = (12.0 x 2) + (1.0 x 3) + 16.0 = 43.0
- Dividing the M_r of compound **F** by the M_r of the empirical formula tells you how many empirical formula pieces are required to get the molecular formula
  - $\frac{86.0}{43.0}$ = 2, which means that there are 2 empirical formula pieces in the molecular formula
  - 2 x C_2H_3O = $C_4H_6O_2$

c) The completed table is:

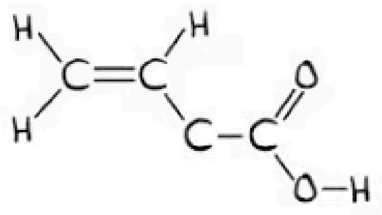
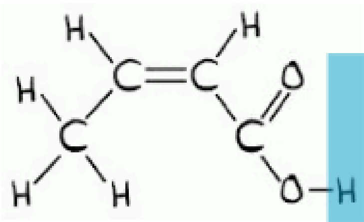
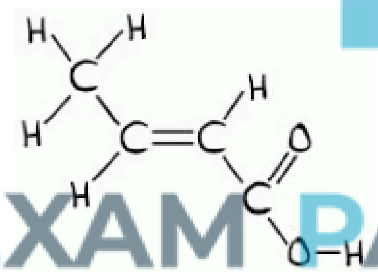
principal absorptions in infra-red spectrum	**bond responsible**
2500 - 3000 cm^{-1}	Carboxyl OH **OR** Carboxylic acid
1710 cm^{-1}	Carboxyl CO / C=O **OR** Carboxylic acid
1620 cm^{-1}	C=C **OR** Alkene

- All bonds responsible correct; [1 mark]

[Total: 1 mark]

- This question just requires you to look the values up in the table
- **Careful:** Some of the peaks require specific answers
  - For the peak at 2500 - 3000 cm^{-1}, you must specify if it is an alcohol OH bond or a carboxylic acid / carboxyl OH bond
  - For the peak at 1710 cm^{-1}, you must specify if it is a carbonyl CO bond or a carboxylic acid / carboxyl CO bond

d) The displayed formulae and names of the **three** possible isomers that could be compound **F** are:

-  **AND** correct name of but-3-enoic acid; [1 mark]
-  **AND** correct name of cis-but-2-enoic acid / Z-but-2-enoic acid; [1 mark]
-  **AND** correct name of trans-but-2-enoic acid / E-but-2-enoic acid; [1 mark]

[Total: 3 marks]

- From parts **(b)** and **(c)**, you should have determined that compound **F**:
  - Has a molecular formula of $C_4H_6O_2$
  - Contains a carbon=carbon double bond / C=C
  - Contains a carboxylic acid group / –COOH
- **Tip:** When building / deducing organic structures, leave the hydrogen atoms to last as they essentially finish off the molecule
- If you start with the carboxylic acid group / –COOH
  - –COOH
  - This leaves you with three carbons
- Attach a second carbon to the carboxylic acid group / –COOH
  - Due to the bonds that form the carboxylic acid group, this new bond must be a carbon-carbon single bond
  - –C–COOH
  - This leaves you with two carbons
- The question tells you that compound **F** is a straight-chain molecule
  - This means that the remaining carbons must attach consecutively to the second carbon
  - C–C–C–COOH
- You know that there is a carbon=carbon double bond / C=C somewhere in the chain
  - As previously discussed, it cannot go between carbon-1 and carbon-2
  - It could go between carbon-2 and carbon-3
    - C–C=C–COOH
    - This forms but-2-enoic acid which exhibits geometrical isomerism
    - Therefore, this structure has two possible isomers, cis-but-2-enoic acid and trans-but-2-enoic acid
  - It could, alternatively, go between carbon-3 and carbon-4
    - C=C–C–COOH
    - This structure is called but-3-enoic acid and does not exhibit geometrical isomerism

- **Remember:** When you draw your final answers, make sure that you have all the appropriate hydrogen atoms in place or you will lose a mark
  - **Careful:** Make sure that all of the carbons, especially the alkene carbons, have the correct number of bonds
  - It is very common to accidentally add an extra hydrogen atom making 5 bonds around the alkene carbon atoms

e) Compound **F** is:

- cis-but-2-enoic acid
  AND
  The arrangement of functional groups around the carbon=carbon double bond / C=C reduces the intermolecular / van der Waals forces (meaning less energy is required to overcome the forces); [1 mark]

[Total: 1 mark]

- The three isomers identified in part **(d)** are:
  - But-3-enoic acid
  - cis-but-2-enoic acid
  - trans-but-2-enoic acid
- There are two types of stereoisomers:
  - Geometrical (cis-trans) isomerism
  - Optical isomerism
- Compound **F** cannot be but-3-enoic acid as this does not show stereoisomerism
  - The carbon=carbon double bond / C=C has two hydrogen atoms attached to one of the carbons so it cannot show geometrical isomerism
  - There are no chiral centres so it cannot show optical isomerism
- This means that compound **F** is either cis-but-2-enoic acid or trans-but-2-enoic acid
  - They both have hydrogen bonding and van der Waals forces
  - The shapes of the molecules will affect the van der Waals forces
  - The shape of the cis-isomer means that it has a smaller surface area
    - This reduces the strength of the van der Waals forces
    - Weaker van der Waals forces mean that less energy is required to overcome the forces, resulting in a lower boiling point