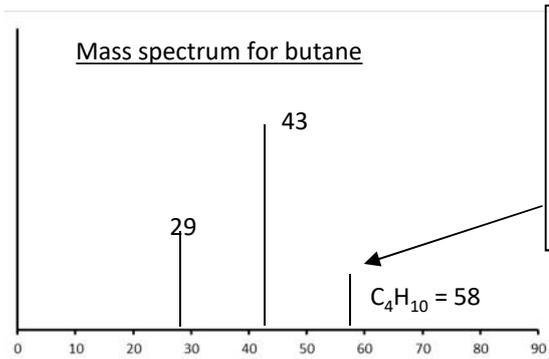


3.6 Organic Analysis

Mass Spectrometry

When organic molecules are passed through a mass spectrometer, it detects both the whole molecule and fragments of the molecule



The peak with the highest mass/charge ratio will be normally due to the original molecule that hasn't fragmented (called the molecular ion). As the charge of the ion is +1 the mass/charge ratio is equal to M_r .

Molecular ion formed: $M \rightarrow [M]^+ + e^-$

Definition: **molecular ion** is the molecule with one electron knocked off (It is both an ion and a free radical)

High resolution mass spectrometry can be used to determine the molecular formula of a compound from the accurate mass of the molecular ion

For example, the following molecular formulas all have a rough M_r of 60, but a more precise M_r can give the molecular formula.

e.g. $M_r = 60.02112$ molecular formula = $C_2H_4O_2$
 $M_r = 60.05751$ molecular formula = C_3H_8O
 $M_r = 60.03235$ molecular formula = CH_4N_2O

High resolution mass spectroscopy can measure the mass to 5 d.p. This can help differentiate between compounds that appear to have similar M_r (to the nearest whole number)

Accurate masses of atoms:

H = 1.0078
C = 12.0000
O = 15.9949
N = 14.0031

Carbon has a value of 12.0000 as it is by definition the standard reference

Example 1

A compound is found to have an accurate relative formula mass of 46.0417. It is thought to be either CH_3CH_2OH or $H_2NCH_2NH_2$. Calculate the M_r of each compound to 4 decimal places to work out which one it is.

$$CH_3CH_2OH = (12.0000 \times 2) + (15.9949 \times 1) + (1.0078 \times 6) = 46.0417$$

$$H_2NCH_2NH_2 = (12.0000 \times 1) + (14.0031 \times 2) + (1.0078 \times 6) = 46.0530$$

M+2 peak

If a compound contains a chlorine or a bromine atom then two molecular ion peaks will occur: a **M** and a **M+2** peak will occur due to the two naturally occurring isotopes of chlorine or bromine.

Chlorine exists as Cl^{35} (75%) and Cl^{37} (25%)
 Bromine exists as Br^{79} (50%) and Br^{81} (50%)

CH_3Cl will have a m/z value of **M** of 50 CH_3Cl^{35} and **M+2** of 52 CH_3Cl^{37}
 The ratio of heights **M:M+2** will be 3:1

CH_3Br will have m/z value of **M** of 94 CH_3Br^{79} and **M+2** of 96 CH_3Br^{81}
 The ratio of heights **M:M+2** will be 1:1

If a compound contains two chlorine or bromine atoms then a **M+2** and a **M+4** peak will occur

$C_2H_4Cl_2$ will have a m/z value of **M** of 98 $C_2H_4Cl^{35}Cl^{35}$, a **M+2** of 100 $C_2H_4Cl^{35}Cl^{37}$ and a **M+4** of 102 $C_2H_4Cl^{37}Cl^{37}$
 The ratio of heights **M:M+2: M+4** will be 9:6:1

$C_2H_4Br_2$ will have a m/z value of **M** of 186 $C_2H_4Br^{79}Br^{79}$, a **M+2** of 188 $C_2H_4Br^{79}Br^{81}$ and a **M+4** of 190 $C_2H_4Br^{81}Br^{81}$
 The ratio of heights **M:M+2: M+4** will be 1:2:1

Relative abundances

$$Cl^{35}Cl^{35} = 0.75 \times 0.75 = 0.5625 \Rightarrow 9$$

$$Cl^{35}Cl^{37} \left. \begin{array}{l} \\ \\ \end{array} \right\} = 0.75 \times 0.25 \times 2 = 0.375 \Rightarrow 6$$

$$Cl^{37}Cl^{37} = 0.25 \times 0.25 = 0.0625 \Rightarrow 1$$

÷ smallest to get whole number ratio

$C_2H_3Cl_3$ will have a m/z value of **M** of 132 $C_2H_4Cl^{35}Cl^{35}Cl^{35}$, a **M+2** of 134 $C_2H_4Cl^{35}Cl^{35}Cl^{37}$, a **M+4** of 136 $C_2H_4Cl^{35}Cl^{37}Cl^{37}$ and a **M+6** of 138 $C_2H_4Cl^{37}Cl^{37}Cl^{37}$
 The ratio of heights **M:M+2:M+4:M+6** will be 27:27:9:1

Relative abundances

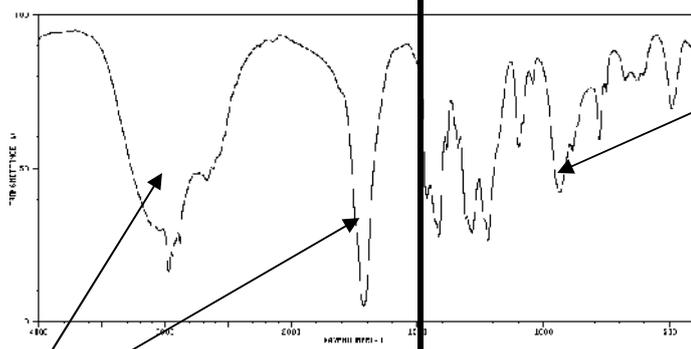
$Cl^{35}Cl^{35}Cl^{35} = 0.75 \times 0.75 \times 0.75 = 0.4219 \Rightarrow 27$
 $Cl^{35}Cl^{35}Cl^{37} = 0.75 \times 0.75 \times 0.25 \times 3 = 0.4219 \Rightarrow 27$
 $Cl^{35}Cl^{37}Cl^{37} = 0.75 \times 0.25 \times 0.25 \times 3 = 0.1406 \Rightarrow 9$
 $Cl^{37}Cl^{37}Cl^{37} = 0.25 \times 0.25 \times 0.25 = 0.0156 \Rightarrow 1$
 \div smallest to get whole number ratio

Infrared spectroscopy

Certain groups in a molecule absorb infra-red radiation at characteristic frequencies

Complicated spectra can be obtained than provide information about the types of bonds present in a molecule

Above 1500 cm^{-1} – “Functional group identification”



Below 1500 cm^{-1} – “Fingerprinting”

Complicated and contains many signals – picking out functional group signals difficult.

This part of the spectrum is unique for every compound, and so can be used as a “fingerprint”.

Use an IR absorption table provided in exam to deduce presence or absence of particular bonds or functional groups

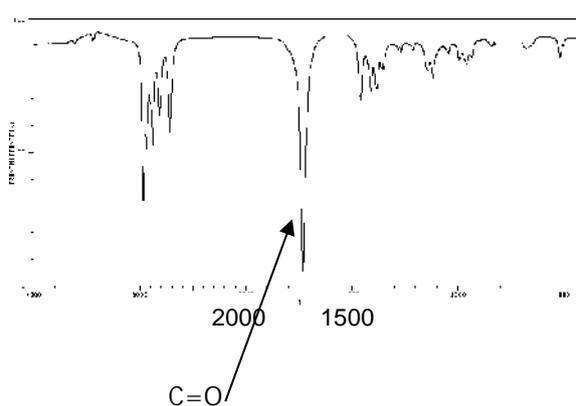
e.g. C=O $1680 - 1750\text{ cm}^{-1}$
 O-H (acid) $2500 - 3000\text{ cm}^{-1}$

A computer will compare the IR spectra against a database of known pure compounds to identify the compound.

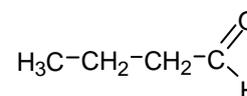
Infrared absorption data

Bond	Wavenumber / cm^{-1}
N-H (amines)	3300–3500
O-H (alcohols)	3230–3550
C-H	2850–3300
O-H (acids)	2500–3000
$C \equiv N$	2220–2260
C=O	1680–1750
C=C	1620–1680
C-O	1000–1300
C-C	750–1100

Use spectra to identify particular functional groups and to identify impurities, limited to data presented in wavenumber form



Spectra for butanal

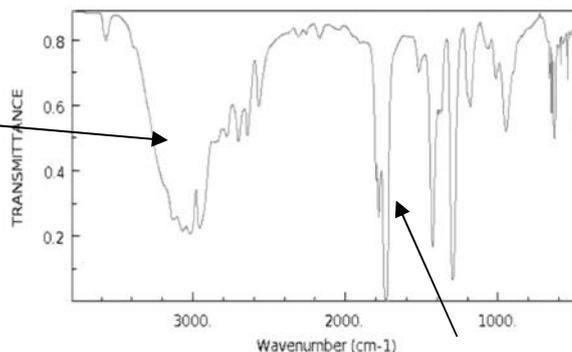


Absorption or trough in between $1680 - 1750\text{ cm}^{-1}$ range indicates presence of C=O bond

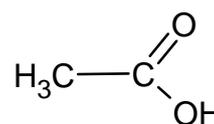
Always quote the wave number range from the data sheet

O-H absorptions tend to be broad

Absorption or trough in between 2500-3000 cm⁻¹ range indicates presence of O-H bond in an acid



Spectra for ethanoic acid



"rogue" absorptions can also occur and are indicators of impurities

C=O
Absorption or trough in between 1680-1750 cm⁻¹ range indicates presence of C=O bond

The absorption of infra-red radiation by bonds in this type of spectroscopy is the same absorption that bonds in CO₂, methane and water vapour in the atmosphere do - that causes the green house effect.

Mechanism of greenhouse effect

UV wavelength radiation passes through the atmosphere to the Earth's surface and heats up Earth's surface. The Earth radiates out infrared long wavelength radiation.

The C=O Bonds in CO₂ absorb infrared radiation so the IR radiation does not escape from the atmosphere.

This energy is transferred to other molecules in the atmosphere by collisions so the atmosphere is warmed.

Identification of functional groups by test-tube reactions

Functional group	Reagent	Result
Alkene	Bromine water	Orange colour decolourises
Aldehyde	Fehling's solution	Blue solution to red precipitate
Aldehyde	Tollens' reagent	Silver mirror formed
Carboxylic acid	Sodium carbonate	Effervescence of CO ₂ evolved
1° 2° alcohol and aldehyde	Sodium dichromate and sulfuric acid	Orange to green colour change
chloroalkane	Warm with silver nitrate	Slow formation of white precipitate of AgCl

Tollens' Reagent

Reagent: Tollens' Reagent formed by mixing aqueous ammonia and silver nitrate. The active substance is the complex ion of [Ag(NH₃)₂]⁺.

Conditions: heat gently

Reaction: aldehydes only are oxidised by Tollens' reagent into a carboxylic acid. The silver(I) ions are reduced to silver atoms

Observation: with aldehydes, a silver mirror forms coating the inside of the test tube. Ketones result in no change.



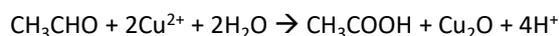
Fehling's solution

Reagent: Fehling's Solution containing blue Cu²⁺ ions.

Conditions: heat gently

Reaction: aldehydes only are oxidised by Fehling's Solution into a carboxylic acid. The copper (II) ions are reduced to copper(I) oxide.

Observation: Aldehydes: Blue Cu²⁺ ions in solution change to a red precipitate of Cu₂O. Ketones do not react



The presence of a carboxylic acid can be tested by addition of **sodium carbonate**. It will fizz and produce carbon dioxide

$$2\text{CH}_3\text{CO}_2\text{H} + \text{Na}_2\text{CO}_3 \rightarrow 2\text{CH}_3\text{CO}_2\text{Na}^+ + \text{H}_2\text{O} + \text{CO}_2$$