

# Organic spectroscopy problem set

## Teacher guide

This document is intended to provide opportunities for students to apply their understanding of the spectroscopic techniques in Module 8 Inquiry Question 2 to a wide range of compounds including those with functional groups from Module 7 Inquiry Question 1. The question stem is adapted from the HSC 2019 Chemistry examination Question 26a with the attached selection of spectra provided to adapt this question to new structures for students. This resource can be used in several ways:

1. Practice HSC style exam question for Module 8 Inquiry Question 2
2. Internal assessment stimulus material
3. Teaching resource for the comparison of each spectrum across the range of techniques covered in Module 8 Inquiry Question 2

Each spectrum provided for use as an unknown is identified in the table below along with a link to the original source (National Institute of Advanced Industrial Science and Technology, Japan, 2018). A complete worked example for each compound is provided as a [video resource](#) to guide students on how to extract data from each spectrum and identify the unknown compound.

Each unknown may be printed on a single double-sided sheet and allocated to students. An answer key is provided on page 5.

This project has been a joint collaboration between the NSW Department of Education, the Royal Australia Chemical Institute NSW Chemistry Education Group and Chemistry Education Division, the University of Sydney, and the University of New South Wales.

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# Syllabus reference

## HSC Chemistry Module 7

Outcomes referenced in this document are from [Chemistry Stage 6 Syllabus](#), © 2017 NSW Education Standards Authority (NESA) for and on behalf of the Crown in right of the State of New South Wales.

### Outcomes

- **CH11/12-5** - analyses and evaluates primary and secondary data and information
- **CH11/12-6** - solves scientific problems using primary and secondary data, critical thinking skills and scientific processes
- **CH11/12-7** - communicates scientific understanding using suitable language and terminology for a specific audience or purpose
- **CH12-14** - analyses the structure of, and predicts reactions involving, carbon compounds

### Content

**Inquiry question** - How do we systematically name organic chemical compounds?

Investigate the nomenclature of organic chemicals, up to C8, using IUPAC conventions, including simple methyl and ethyl branched chains, including: (ACSCH127)

- alkanes
- alkenes
- alkynes
- alcohols (primary, secondary and tertiary)
- aldehydes and ketones
- carboxylic acids
- amines and amides
- halogenated organic compounds

Explore and distinguish the different types of structural isomers, including saturated and unsaturated hydrocarbons, including: (ACSCH035)

- chain isomers
- position isomers
- functional group isomers

# HSC Chemistry Module 8

## Outcomes

- **CH11/12-1** - develops and evaluates questions and hypotheses for scientific investigation
- **CH11/12-2** - designs and evaluates investigations in order to obtain primary and secondary data and information
- **CH11/12-3** - conducts investigations to collect valid and reliable primary and secondary data and information
- **CH11/12-4** - selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media
- **CH11/12-7** - communicates scientific understanding using suitable language and terminology for a specific audience or purpose
- **CH12-15** - describes and evaluates chemical systems used to design and analyse chemical processes

## Content

Inquiry question: How is information about the reactivity and structure of organic compounds obtained?

Conduct qualitative investigations to test for the presence in organic molecules of the following functional groups:

- carbon–carbon double bonds
- hydroxyl groups
- carboxylic acids (AC SCH130)

Investigate the processes used to analyse the structure of simple organic compounds addressed in the course, including but not limited to:

- proton and carbon-13 NMR
- mass spectrometry
- infrared spectroscopy (AC SCH130)

# Answer key

Table 1: Answer key for sample compounds A-Z

Sample spectra	Compound
A	<a href="#">Pentane</a>
B	<a href="#">Hexane</a>
C	<a href="#">Pent-1-ene</a>
D	<a href="#">Hex-1-ene</a>
E	<a href="#">Methanol</a>
F	<a href="#">Ethanol</a>
G	<a href="#">Ethanoic acid</a>
H	<a href="#">Propan-1-ol</a>
I	<a href="#">Propanal</a>
J	<a href="#">Propan-2-ol</a>
K	<a href="#">Propan-2-one</a>
L	<a href="#">Butan-1-ol</a>
M	<a href="#">Butan-2-ol</a>
N	<a href="#">Ethyl acetate</a>
O	<a href="#">2-methylpropan-2-ol</a>
P	<a href="#">Methyl propanoate</a>
Q	<a href="#">Pentanal</a>
R	<a href="#">Pentanoic acid</a>
S	<a href="#">Pantan-2-ol</a>
T	<a href="#">Pantan-2-one</a>
U	<a href="#">Propan-1-amine</a>
V	<a href="#">Butan-1-amine</a>
W	<a href="#">Butanamide</a>
X	<a href="#">Pantanamide</a>
Y	<a href="#">2-chloropropane</a>
Z	<a href="#">1-bromopropane</a>

# Student activity: example

What is the structural formula of this compound? Justify your answer with reference to the information given on its reactivity and to at least three of the provided spectra. (5 marks)

Infrared absorption data

Bond	Wavenumber/cm <sup>-1</sup>
N—H (amines)	3300–3500
O—H (alcohols)	3230–3550 (broad)
C—H	2850–3300
O—H (acids)	2500–3000 (very broad)
C≡N	2220–2260
C=O	1680–1750
C=C	1620–1680
C—O	1000–1300
C—C	750–1100

<sup>13</sup>C NMR chemical shift data

Type of carbon	$\delta$ /ppm
$\begin{array}{c}   &   \\ — C & — C — \\   &   \end{array}$	5–40
$\begin{array}{c}   \\ R — C — Cl \text{ or } Br \\   \end{array}$	10–70
$\begin{array}{c}   \\ R — C — C — \\    \\ O \end{array}$	20–50
$\begin{array}{c}   & / \\ R — C & — N \\   & \backslash \end{array}$	25–60
$\begin{array}{c}   \\ — C — O — \\   \end{array}$	alcohols, ethers or esters
$\begin{array}{c} \backslash & / \\ C = C \\ / & \backslash \end{array}$	90–150
R—C≡N	110–125
	110–160
$\begin{array}{c}   \\ R — C — \\    \\ O \end{array}$	esters or acids
$\begin{array}{c}   \\ R — C — \\    \\ O \end{array}$	aldehydes or ketones
	160–185
	190–220

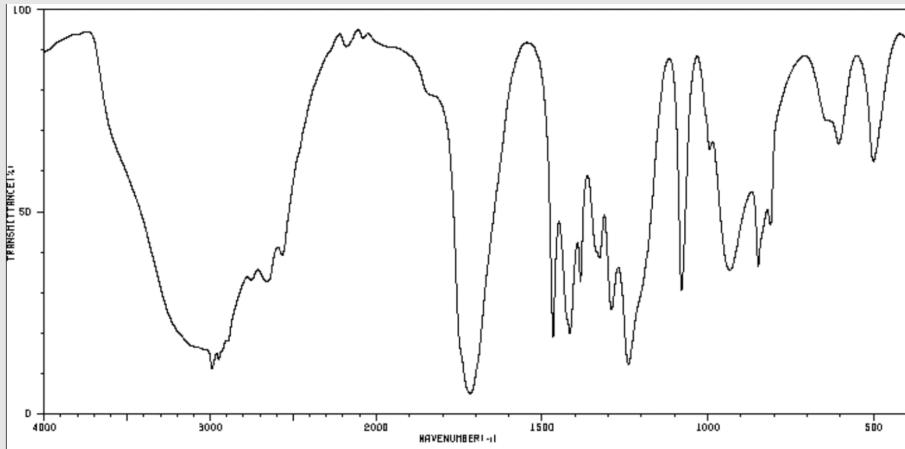
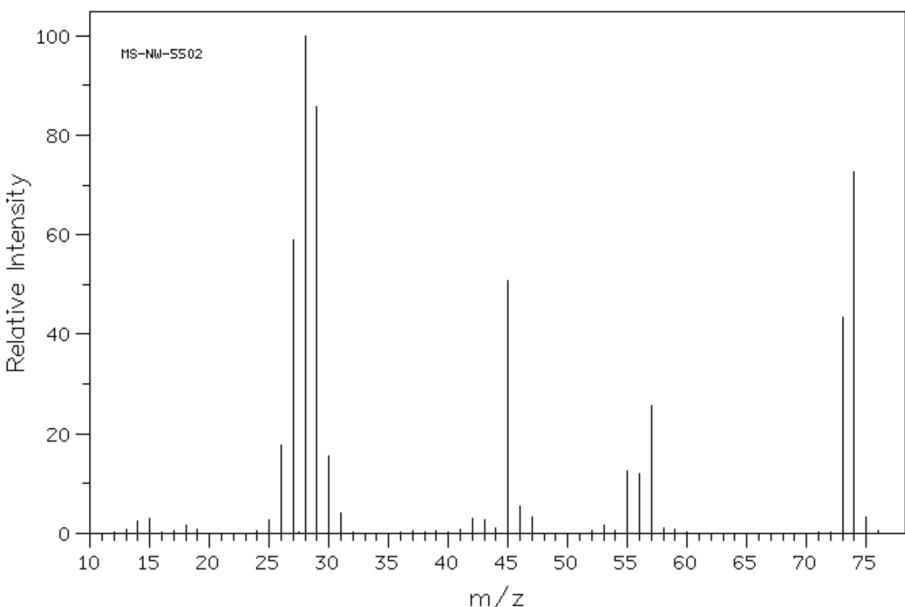
Figure 1: extract from [Chemistry HSC Data Sheet](#) © 2019 NSW Education Standards Authority (NESA) for and behalf of the Crown in right of the State of New South Wales

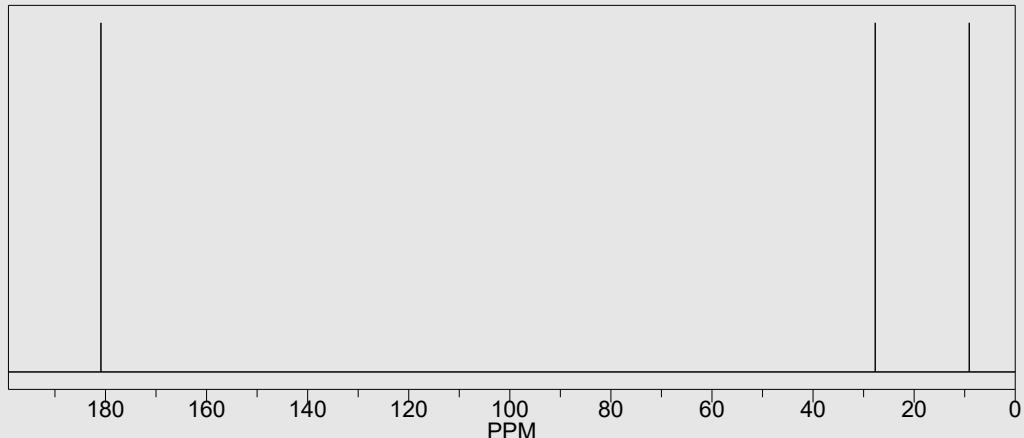
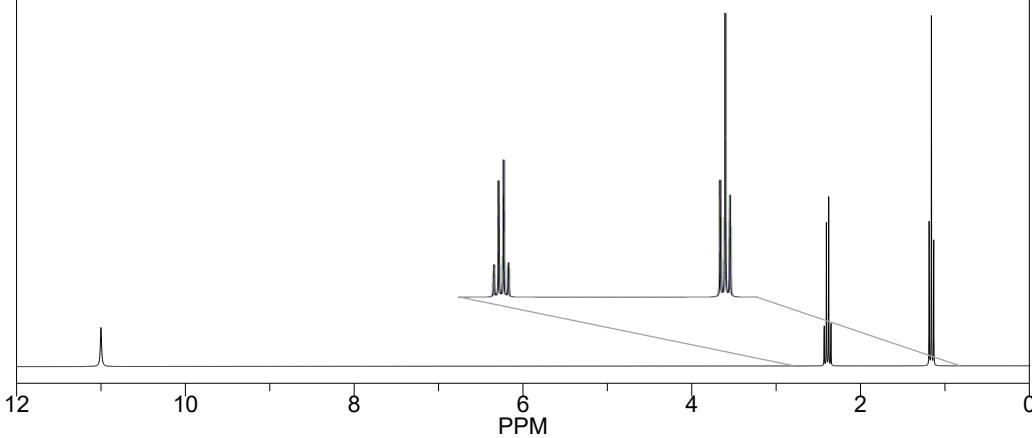
# Marking scheme

**Table 2: Marking scheme from the [2019 HSC Chemistry examination pack](#) Question 26a  
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the State of New South Wales**

Criteria	Marks
<ul style="list-style-type: none"><li>• Gives correct structure and justifies using reactivity and at least three spectra</li></ul>	5
<ul style="list-style-type: none"><li>• Gives substantially correct structure and justifies using reactivity and at least two spectra</li></ul> <p>or</p> <ul style="list-style-type: none"><li>• Gives a correct structure and justifies using at least three spectra</li></ul>	4
<ul style="list-style-type: none"><li>• Gives substantially correct structure and some correct analyses</li></ul> <p>or</p> <ul style="list-style-type: none"><li>• Gives substantially correct analyses with incorrect structure</li></ul>	2-3
<ul style="list-style-type: none"><li>• Provides some relevant information</li></ul>	1

# Example data analysis

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	Bubbles of carbon dioxide
Infrared spectroscopy	
Mass spectrometry Mass of molecular ion: $m/z = 74$	 <p>MS-NW-5502</p> <p>Relative Intensity (%)</p> <p><math>m/z</math></p>

Test	Result
Carbon-13 NMR	 <p>The Carbon-13 NMR spectrum displays two distinct peaks. One peak is located at approximately 175 ppm, and another is at approximately 15 ppm. The x-axis is labeled "PPM" and ranges from 180 to 0.</p>
Proton NMR	 <p>The Proton NMR spectrum shows several peaks. A small peak is visible around 11.5 ppm. In the aromatic region (6-7 ppm), there are two closely spaced peaks. Between 4 and 5 ppm, there is a cluster of peaks. A triplet-like pattern is present between 1 and 2 ppm, with the most intense peak at approximately 1.16 ppm. The x-axis is labeled "PPM" and ranges from 12 to 0.</p>

### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
11.00	1	1
2.38	4	2
1.16	3	3

# Observations and inferences

This question requires the use of a minimum of three (all four are discussed here) of these spectra and the other chemical reactivity information given in the table to propose the identity of this unknown organic compound. It is important to have a structure which agrees with all the information obtained to justify the compound you have proposed. The solution provided here is highly detailed and intended to fully explain the justification above the requirement of the justification needed in the marking scheme.

## Chemical tests

- The orange colour remaining in the unsaturation test is a negative result indicating this compound does not contain a double or triple carbon-carbon bonds.
- The orange colour remaining in the oxidation test is a negative result indicating this compound does not contain a primary/secondary alcohol or aldehyde functional group which are oxidisable.
- The bubbles of carbon dioxide in the sodium carbonate test is a positive result indicating a carboxylic acid functional group is present. This result also eliminates the possibility of any other functional group.

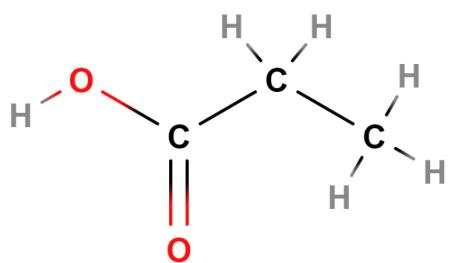
## Infrared spectroscopy

Major observations from the IR spectrum are a broad peak at  $\sim 3000\text{cm}^{-1}$  which indicates the presence of a hydroxyl (OH) group and a narrow peak at  $\sim 1700\text{cm}^{-1}$  which indicates the presence of a carbonyl (C=O) bond. This combination is only possible with a carboxylic acid functional group being present on the structure.

Using the reference table provided, several of the peaks can be identified as the bonds in propanoic acid but does not allow confirmation of the compound's identity. The absence of peaks corresponding to the other functional groups listed in the data sheet also helps to eliminate alternative possible functional groups in this compound. Due to the common nature of C-C and C-H bonds in organic compounds, these peaks are observed in the IR spectrum of all organic compounds and are not particularly useful for determining the unknown structure.

## Mass spectrometry

The mass spectrum gives the molecular ion ( $m^+$ ) peak at  $m/z = 74$  (a very small  $m+1$  peak at  $m/z = 75$  is also present) so it can be determined that the compound has a molecular weight of  $74\text{gmol}^{-1}$ . It is at this point we can first propose a structure, the only carboxylic acid which has a molecular weight of  $74\text{gmol}^{-1}$  is propanoic acid,  $\text{C}_3\text{H}_6\text{O}_2$ :



**Figure 3: A molecular structure for propanoic acid (Bergwerf, 2015)**

Using the proposed structure of propanoic acid the molecular weights of fragments can be more easily matched to the peaks present. When the other spectra (IR/NMR) are available, there is little benefit from analysing the fragmentation pattern in MS. For the completeness of this analysis, other prominent fragment ion peaks are:

Fragment A mass (m/z)	Fragment A	Fragment B	Fragment B mass (m/z)
1	H		73
17			57
45			29

**Table 4: Fragments for spectrometry of propanoic acid**

## Carbon-13 NMR

The carbon-13 NMR contains three peaks, this requires a minimum of three carbons in the compound. This excludes methanoic acid (only 1 carbon) and ethanoic acid (only 2 carbons). Continuing with the hypothesis this compound is propanoic acid allows the use of the reference table provided, these peaks can be identified as specific carbon environments:

- The peak at ~10ppm corresponds to a hydrocarbon chain and is normally a very low shift for a terminal  $\text{CH}_3$  group
- The peak at ~27ppm corresponds to a hydrocarbon chain also and the slightly higher shift gives the indication this carbon is non-terminal as a  $\text{CH}_2$  group
- The peak at ~180ppm corresponds to a carbonyl ( $\text{C}=\text{O}$ ) group as a component of a carboxylic acid.

## Proton NMR

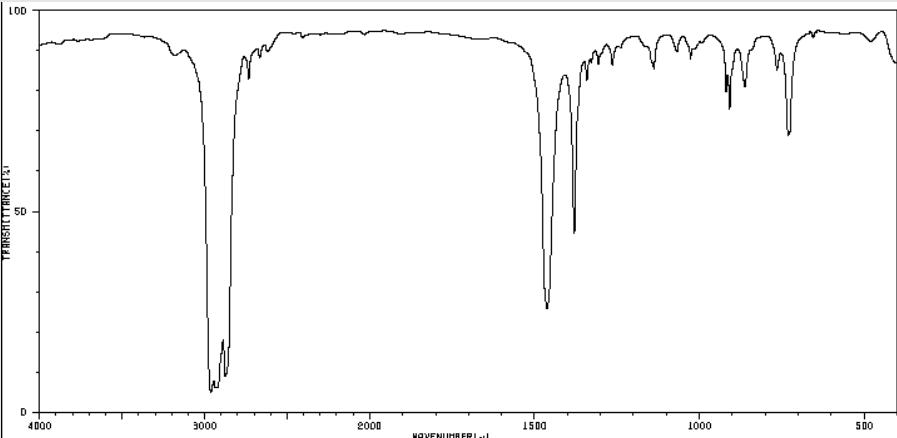
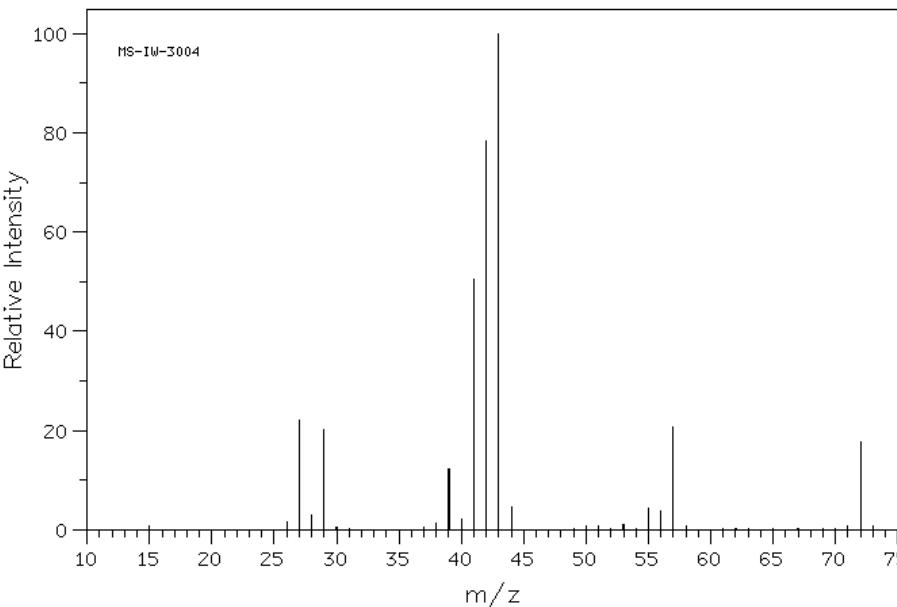
The Proton NMR contains three peaks which indicates the existence of three unique hydrogen environments where each are split according to the arrangement of adjacent hydrogen nuclei. Using the carbon-13 NMR and IR peaks it can be observed the presence of a  $\text{CH}_3$ ,  $\text{CH}_2$  and OH groups which create the hydrogen environments in propanoic acid. Continuing with the hypothesis this compound is propanoic acid allows the peaks to be identified as specific hydrogen environments:

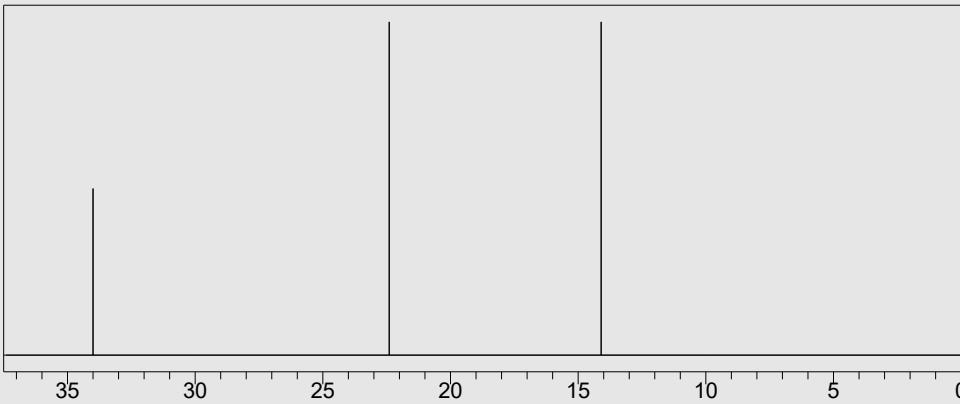
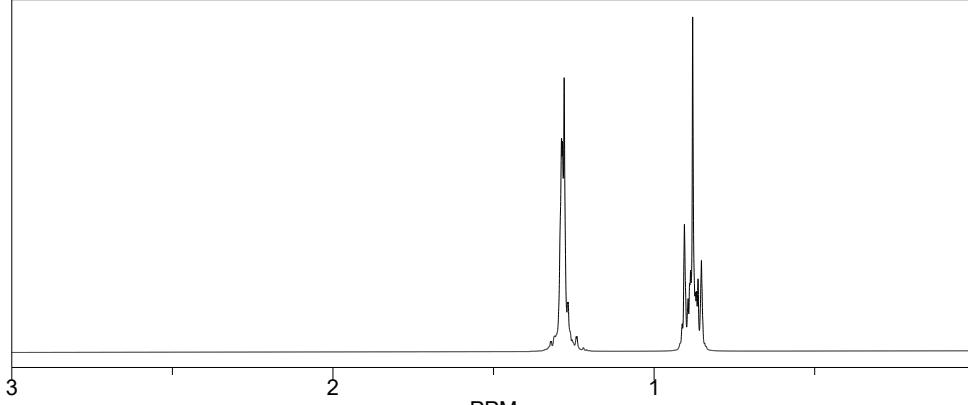
- The peak at ~1ppm is split into a triplet (3 peaks), indicating this hydrogen environment is adjacent to two hydrogens, the terminal  $\text{CH}_3$  group is adjacent to the  $\text{CH}_2$  group capable of this triplet peak and is normally a very low shift for a terminal hydrogen environment
- The peak at ~2.2ppm is split into a quartet (4 peaks), indicating this hydrogen environment is adjacent to three hydrogens, the  $\text{CH}_2$  group is adjacent to the terminal  $\text{CH}_3$  group capable of this quartet peak and the slightly higher shift gives the indication this is a non-terminal hydrogen environment
- The peak at ~11.7ppm is a singlet (not split), indicating this hydrogen environment is not adjacent to any other hydrogens, only the hydroxyl (OH) hydrogen is capable of this peak due to the separation of this hydrogen environment from the others by the oxygen.

## Student activity: unknowns

What is the structural formula of the allocated compound (A-Z)? Justify your answer with reference to the information given on its reactivity and to at least three of the provided spectra for the allocated unknown (A-Z). (5 marks – using the marking scheme from 2019 Chemistry HSC question 26a)

# Sample A

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays Transmittance (%) on the y-axis (0 to 100) against Wavenumber (<math>\text{cm}^{-1}</math>) on the x-axis (4000 to 500). Key features include a broad absorption band around 3000 <math>\text{cm}^{-1}</math> and multiple sharp peaks in the 1500-1000 <math>\text{cm}^{-1}</math> range.</p>
Mass spectrometry Mass of molecular ion: $m/z = 72$	 <p>The mass spectrum is labeled "MS-IW-3004". The y-axis represents Relative Intensity (0 to 100), and the x-axis represents the mass-to-charge ratio <math>m/z</math> (10 to 75). The most intense peak (base peak) is at <math>m/z = 72</math>. Other labeled peaks include <math>m/z = 42, 44, 46, 56</math>, and <math>m/z = 74</math>.</p>

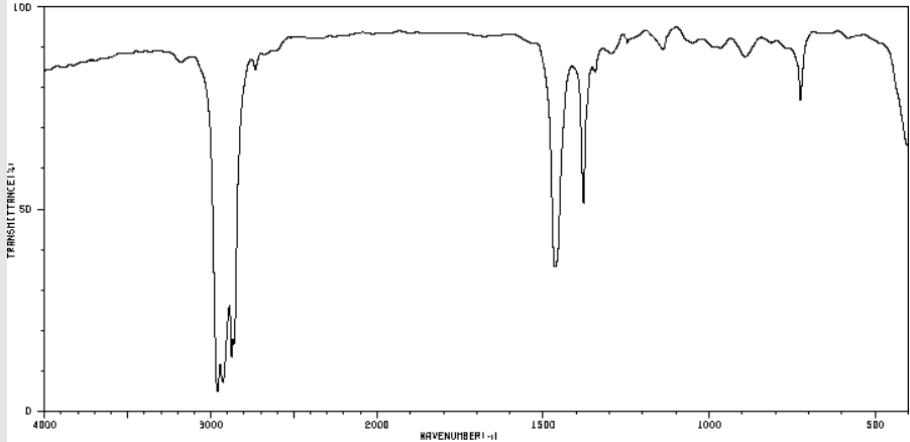
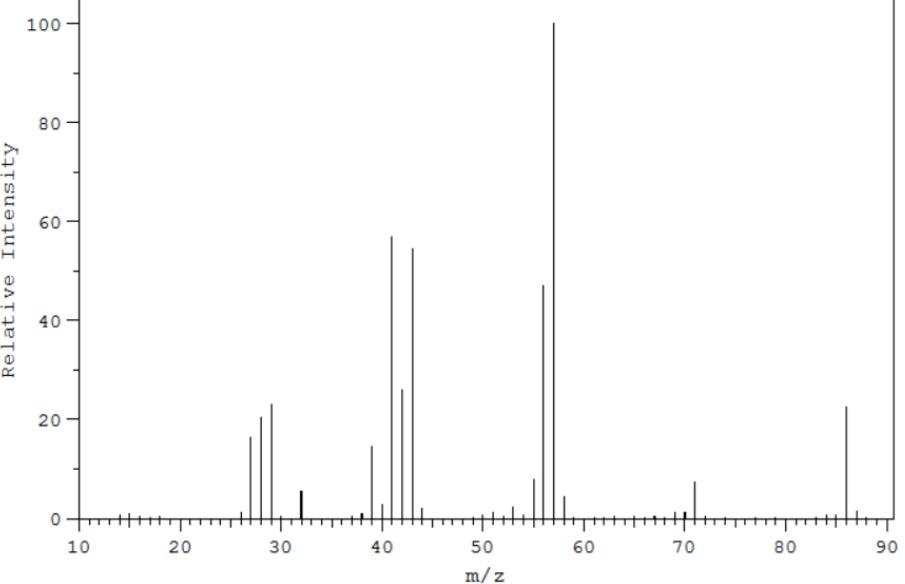
Test	Result
Carbon-13 NMR	 PPM
Proton NMR	 PPM

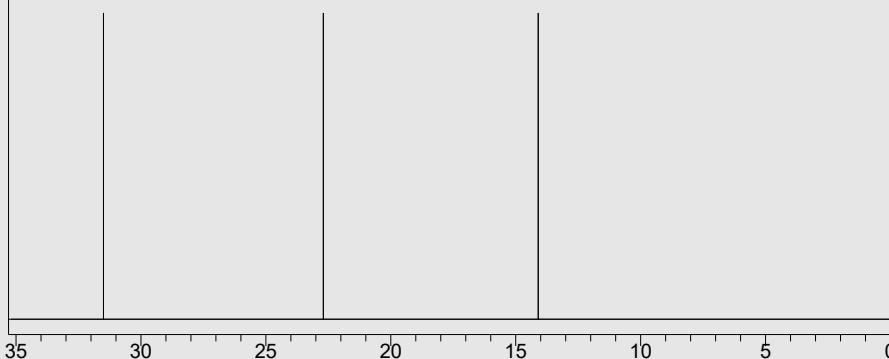
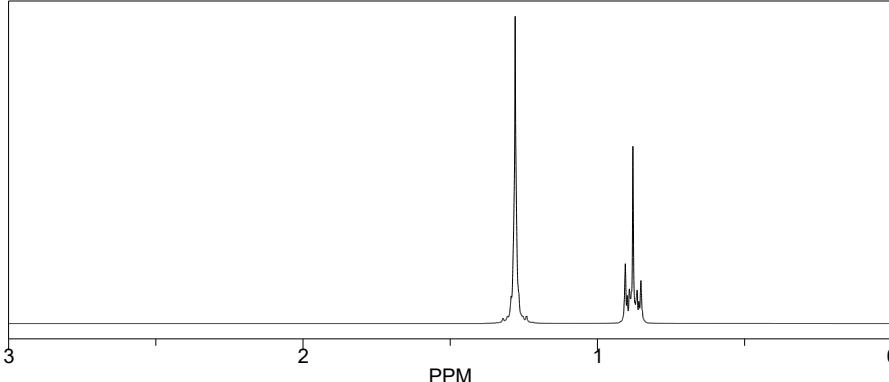
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
1.30	6	4
1.26	5	2
0.884	3	6

Check the solution to Sample A and see a work-through of the problem in [this video on YouTube](#).

## Sample B

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays Transmittance (%) on the y-axis (0 to 100) against Wavenumber (cm⁻¹) on the x-axis (4000 to 500). Key features include a broad absorption band near 3000 cm⁻¹, a sharp peak at approximately 1700 cm⁻¹, and multiple peaks in the 1500-1000 cm⁻¹ range.</p>
Mass spectrometry Mass of molecular ion: $m/z = 86$	 <p>The mass spectrum shows Relative Intensity (%) on the y-axis (0 to 100) versus <math>m/z</math> on the x-axis (10 to 90). The most intense peak (base peak) is at <math>m/z = 86</math>. Other labeled peaks include <math>m/z = 42, 55, 60</math>, and <math>m/z = 70</math>.</p>

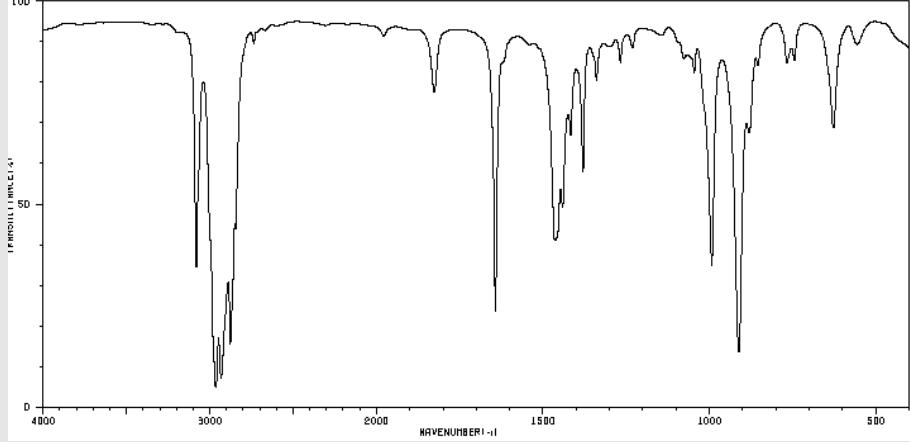
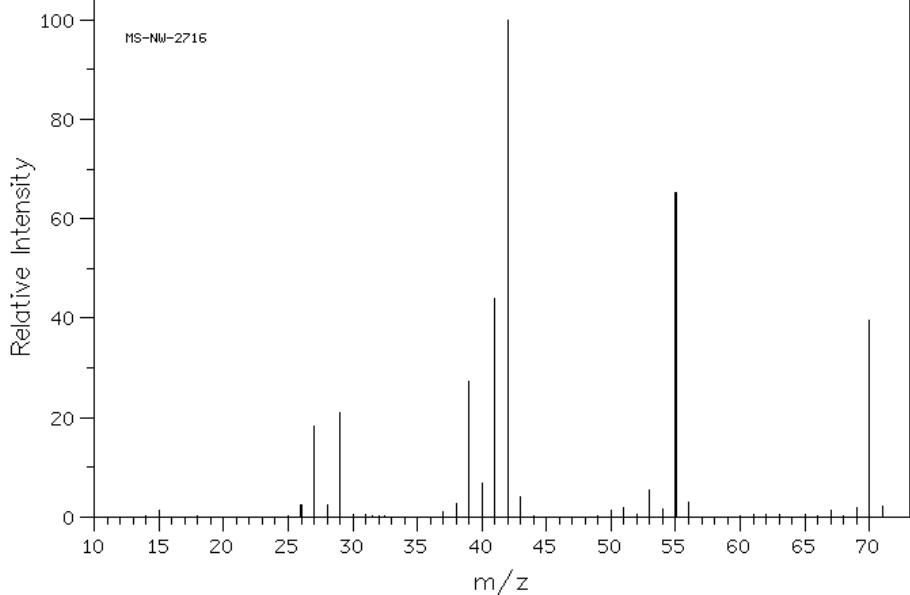
Test	Result
Carbon-13 NMR	 The spectrum shows two distinct peaks. The first peak is at approximately 31 ppm, and the second is at approximately 15 ppm. The x-axis is labeled "PPM" and ranges from 35 to 0.
Proton NMR	 The spectrum shows three distinct peaks. The first peak is at approximately 0.9 ppm, the second at 1.28 ppm, and the third at 1.30 ppm. The x-axis is labeled "PPM" and ranges from 3 to 0.

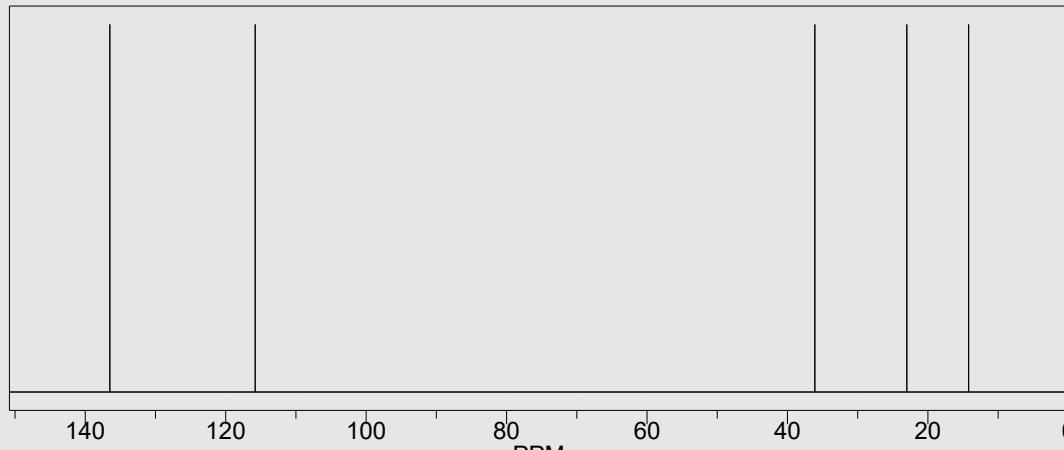
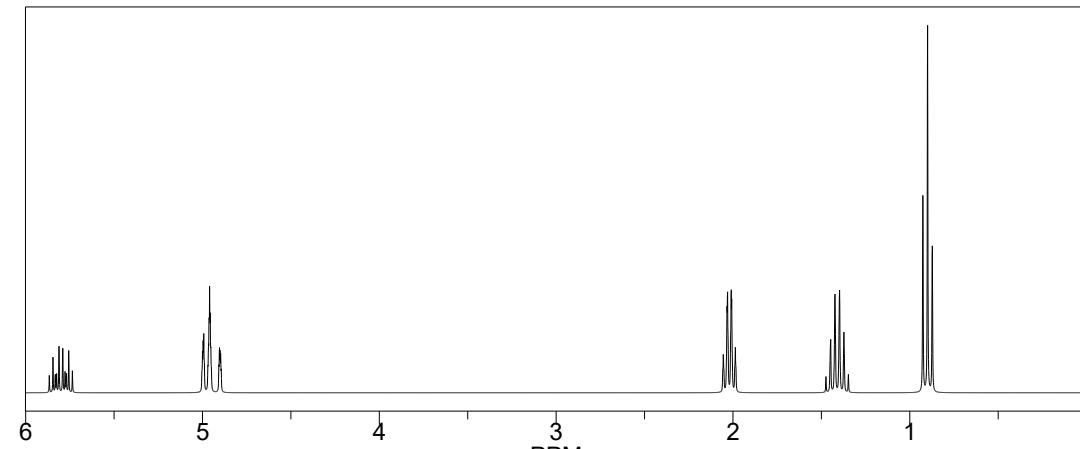
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
1.30	6	4
1.28	5	4
0.90	3	6

Check the solution to Sample B and see a work-through of the problem in [this video on YouTube](#).

## Sample C

Test	Result
Unsaturation test using bromine water	Solution turns colourless
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	
Mass spectrometry Mass of molecular ion: $m/z = 70$	

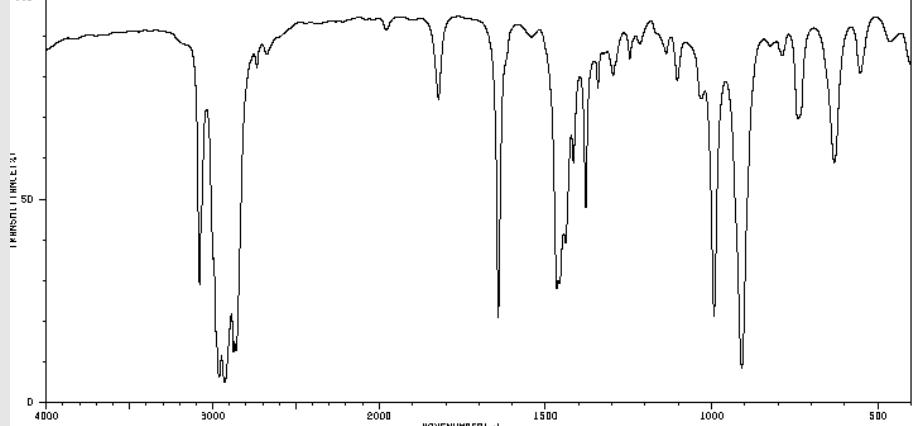
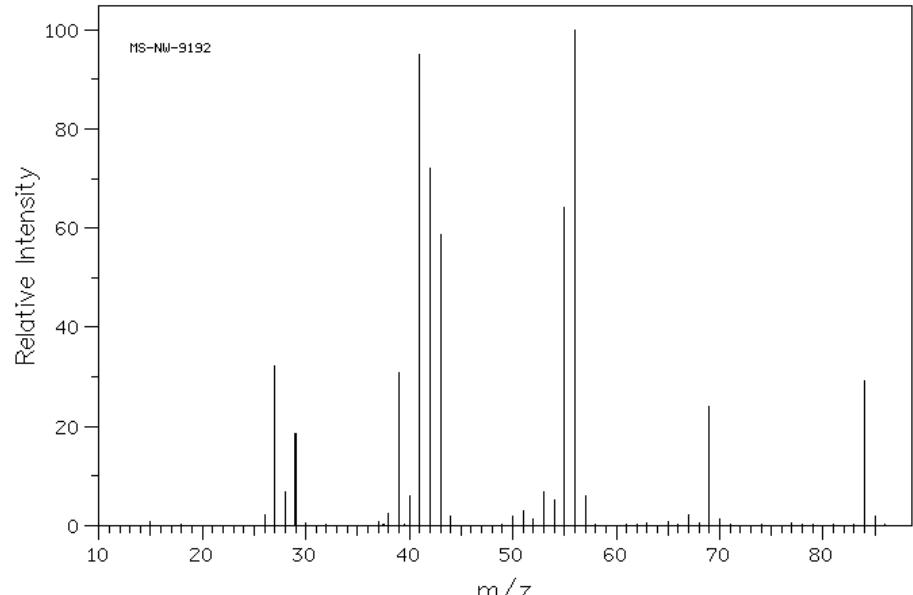
Test	Result
Carbon-13 NMR	
Proton NMR	

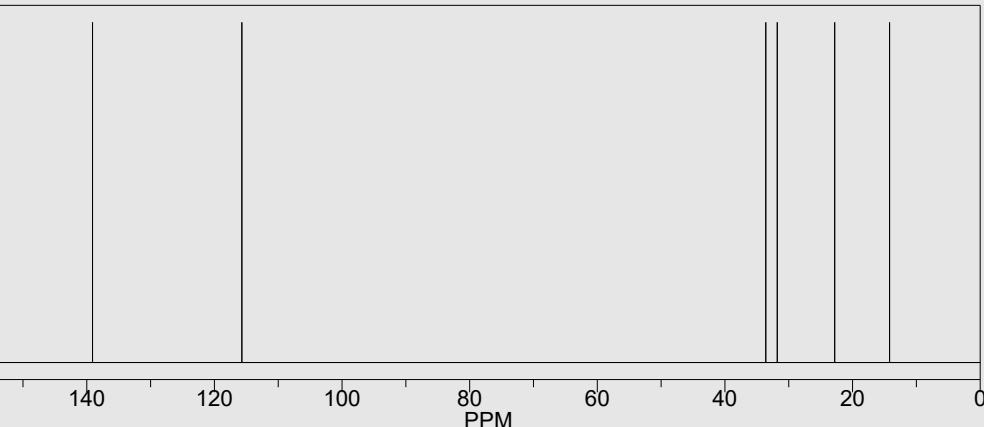
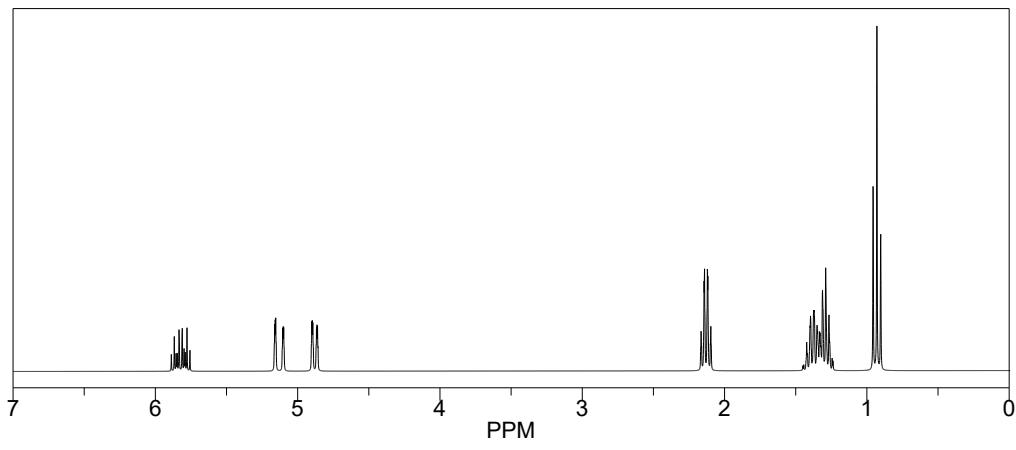
#### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio	Shift (ppm)	Number of peaks	Peak area ratio
5.81	5	1	2.02	4	2
4.97	3	1	1.43	6	2
4.93	3	1	0.91	3	3

Check the solution to Sample C and see a work-through of the problem in [this video on YouTube](#).

## Sample D

Test	Result
Unsaturation test using bromine water	Solution turns colourless
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	
Mass spectrometry Mass of molecular ion: $m/z = 84$	 <p>MS-NW-9192</p>

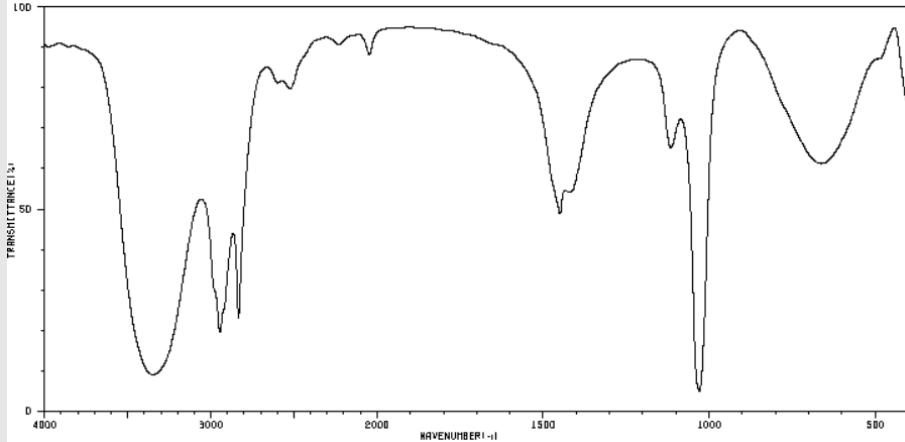
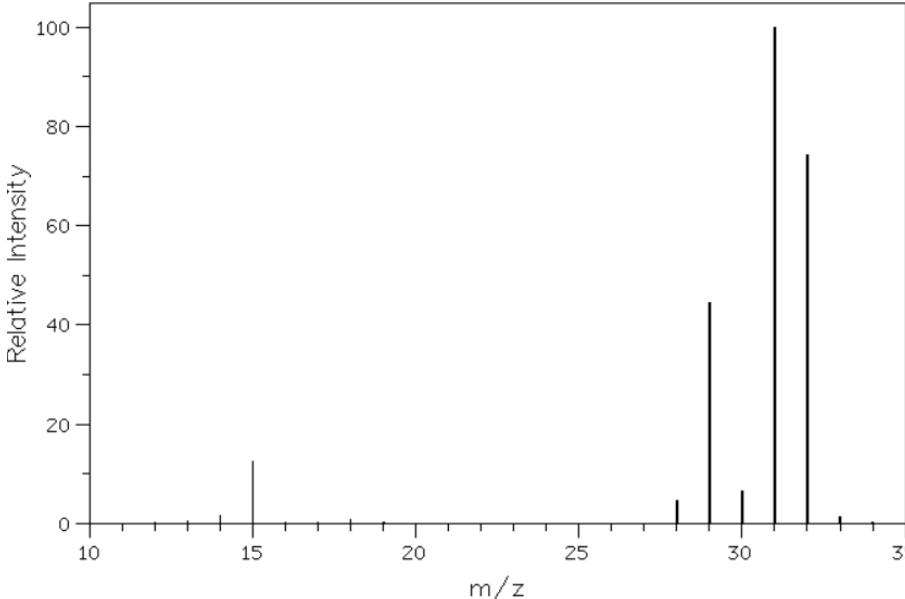
Test	Result
Carbon-13 NMR	
Proton NMR	

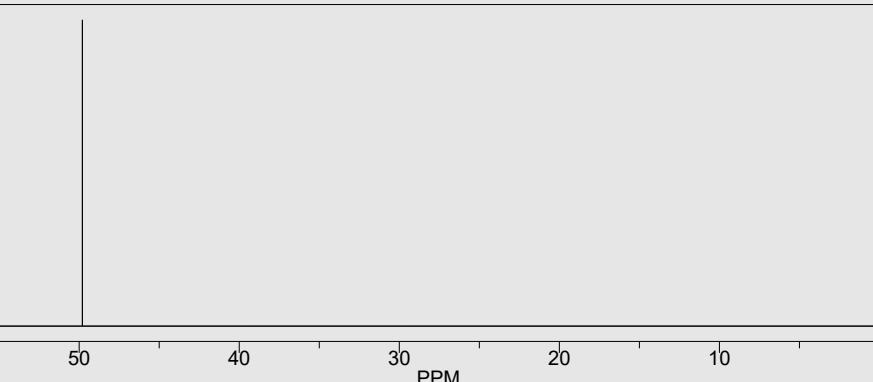
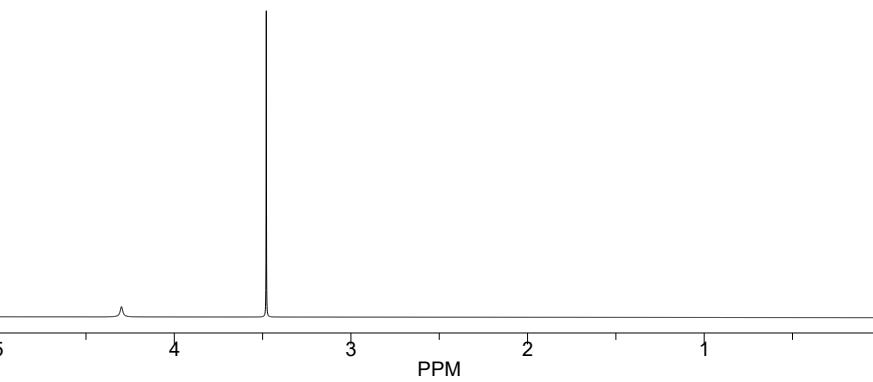
#### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio	Shift (ppm)	Number of peaks	Peak area ratio
5.82	5	1	1.38	6	2
5.13	3	1	1.29	5	2
4.88	3	1	0.90	3	3
2.06	4	2			

Check the solution to Sample D and see a work-through of the problem in [this video on YouTube](#).

## Sample E

Test	Result
<b>Unsaturation test using bromine water</b>	Orange colour remains
<b>Oxidation test using acidified potassium dichromate</b>	Solution turns green
<b>Carboxylic acid test using sodium carbonate</b>	No bubbles
<b>Infrared spectroscopy</b>	 <p>The infrared spectrum displays Transmittance (%) on the y-axis (0 to 100) and Wavenumber (cm⁻¹) on the x-axis (4000 to 500). Key features include a broad absorption band around 3000 cm⁻¹, a strong peak at approximately 1700 cm⁻¹, and a very strong, sharp peak at approximately 1000 cm⁻¹.</p>
<b>Mass spectrometry</b>  <b>Mass of molecular ion:</b> $m/z = 32$	 <p>The mass spectrum shows Relative Intensity (%) on the y-axis (0 to 100) and <math>m/z</math> on the x-axis (10 to 35). The base peak (100% relative intensity) is at <math>m/z = 32</math>. Other labeled peaks include <math>m/z = 15</math>, <math>m/z = 29</math>, and <math>m/z = 34</math>.</p>

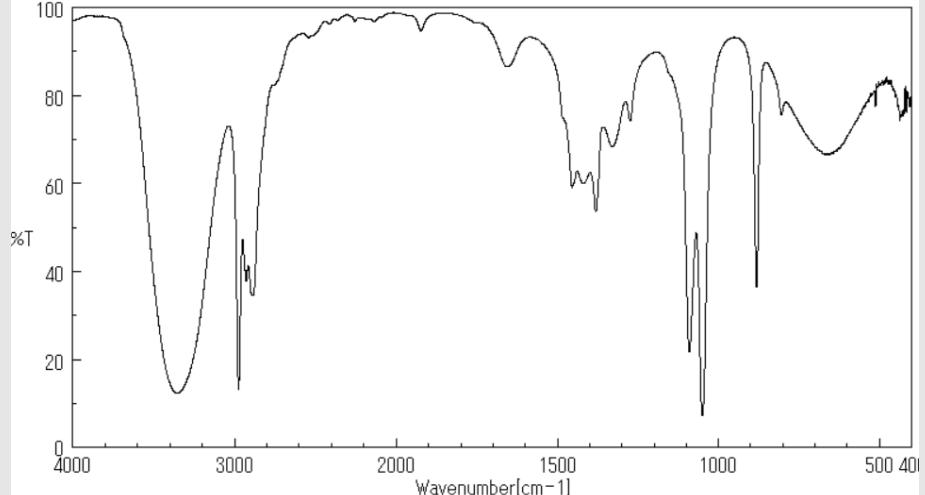
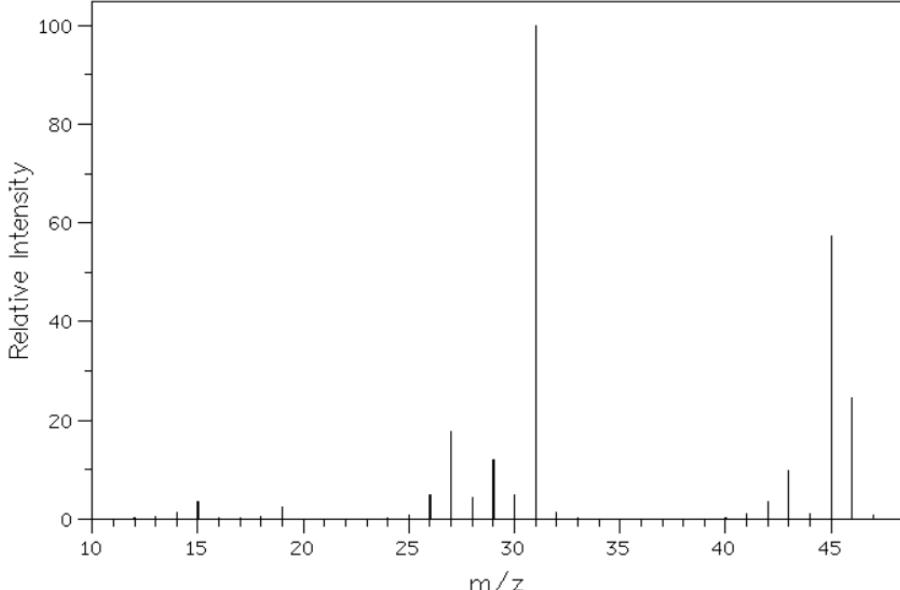
Test	Result
Carbon-13 NMR	 A Carbon-13 NMR spectrum with the x-axis labeled "PPM" ranging from 0 to 50. A single sharp peak is visible at approximately 47 ppm.
Proton NMR	 A Proton NMR spectrum with the x-axis labeled "PPM" ranging from 0 to 5. It shows two peaks: a small peak at approximately 3.48 ppm and a larger peak at approximately 4.30 ppm.

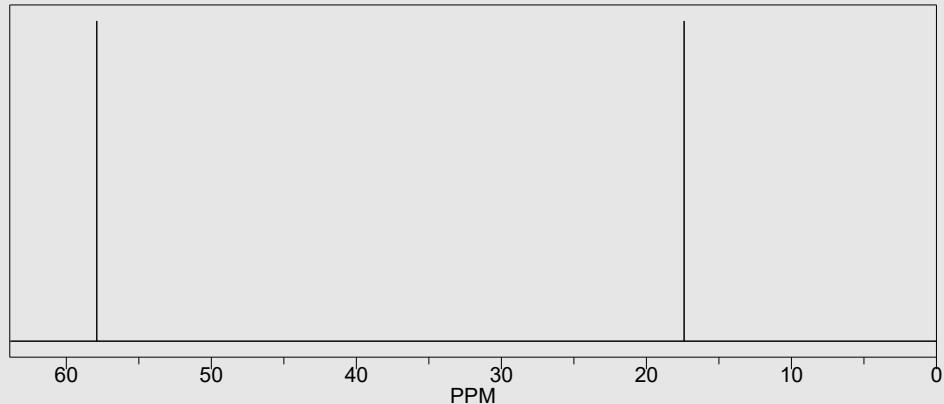
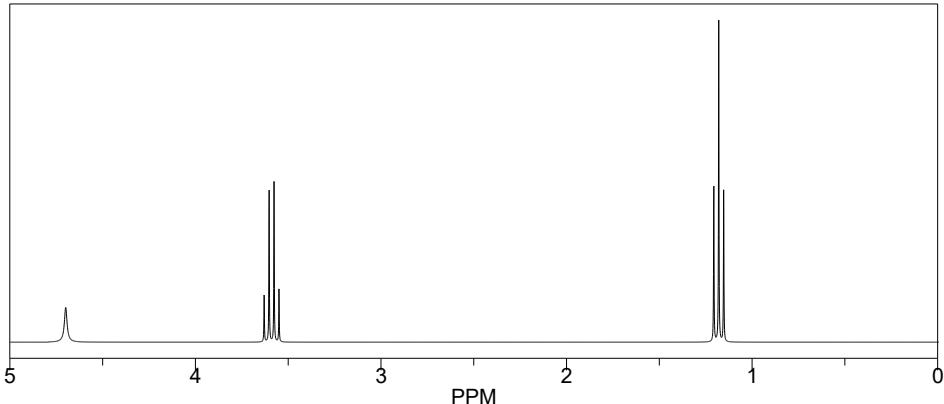
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
4.30	1	1
3.48	1	3

Check the solution to Sample E and see a work-through of the problem in [this video on YouTube](#).

## Sample F

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Solution turns green
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays transmittance (%T) on the y-axis (0 to 100) against wavenumber (<math>\text{cm}^{-1}</math>) on the x-axis (4000 to 400). Key features include a strong absorption at approximately 3000 <math>\text{cm}^{-1}</math>, a sharp peak near 1700 <math>\text{cm}^{-1}</math>, and multiple peaks in the 1000-1500 <math>\text{cm}^{-1}</math> range.</p>
Mass spectrometry Mass of molecular ion: $m/z = 46$	 <p>The mass spectrum plots relative intensity on the y-axis (0 to 100) against the mass-to-charge ratio (<math>m/z</math>) on the x-axis (10 to 45). The most intense peak (base peak) is at <math>m/z = 46</math>. Other labeled peaks include <math>m/z = 31</math>, <math>m/z = 42</math>, and <math>m/z = 45</math>.</p>

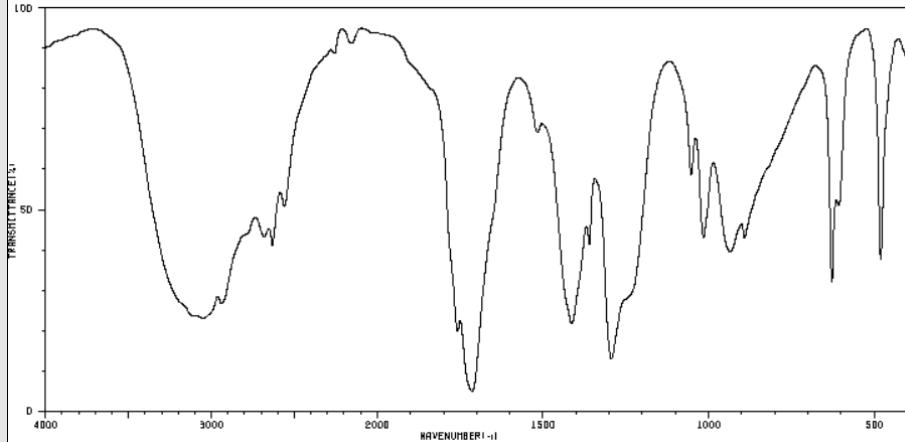
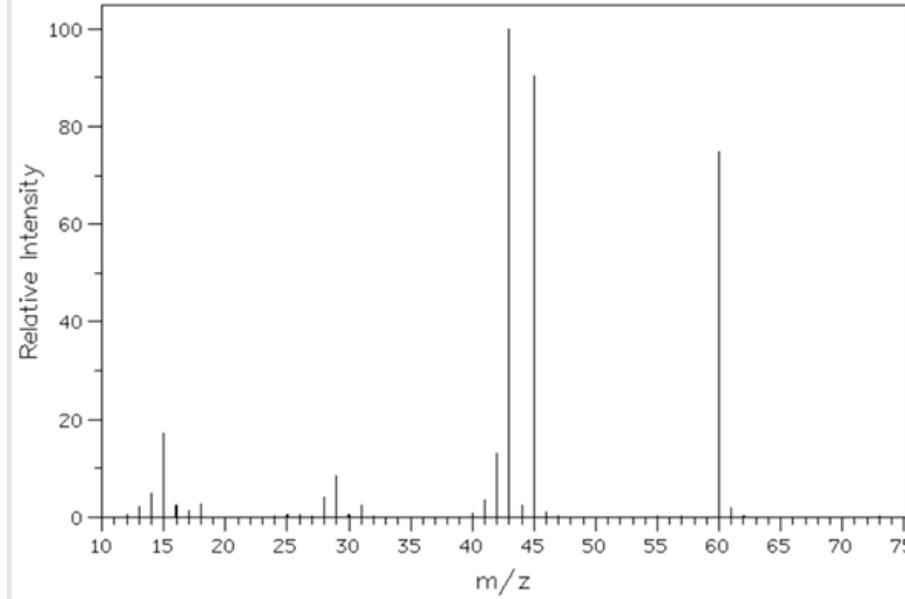
Test	Result
Carbon-13 NMR	
Proton NMR	

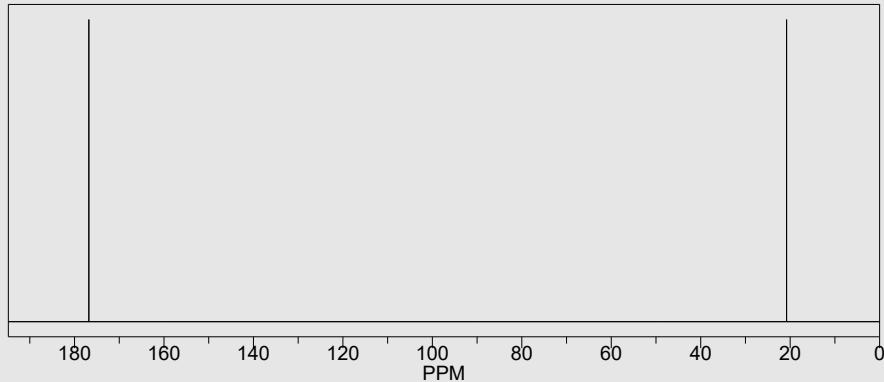
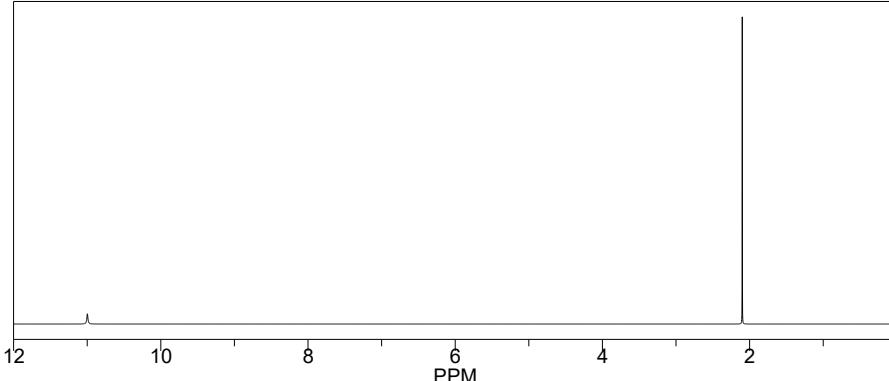
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
4.70	1	1
3.59	4	2
1.18	3	3

Check the solution to Sample F and see a work-through of the problem in [this video on YouTube](#).

# Sample G

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	Bubbles of carbon dioxide
Infrared spectroscopy	
Mass spectrometry  Mass of molecular ion: $m/z = 60$	

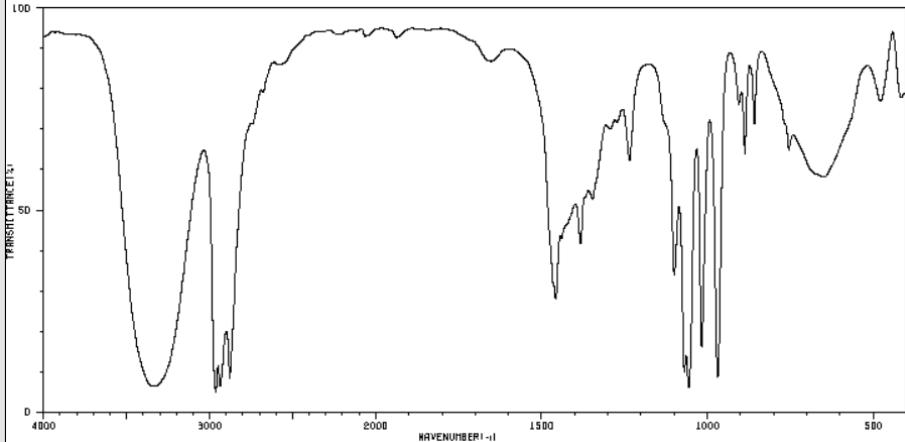
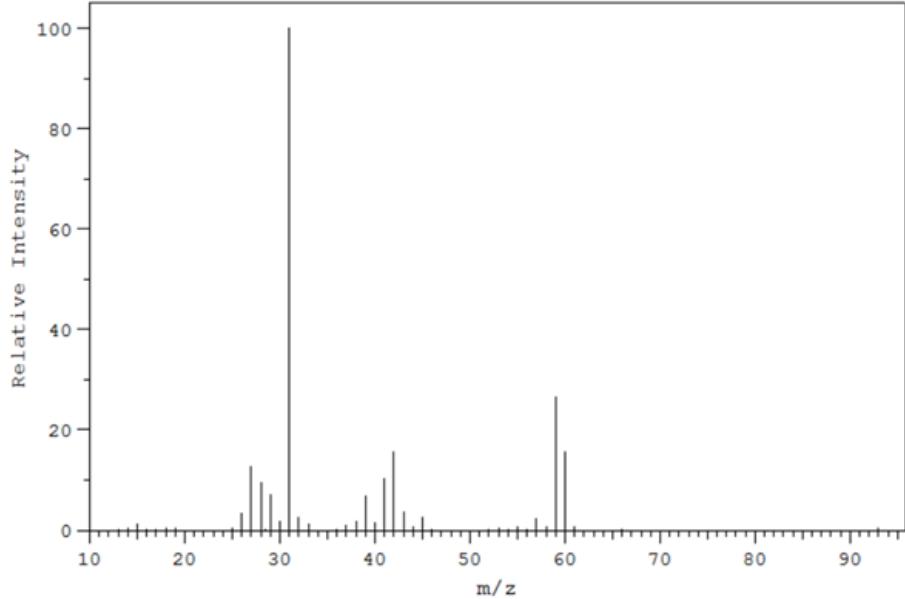
Test	Result
Carbon-13 NMR	 <p>A Carbon-13 NMR spectrum with the x-axis labeled "PPM" ranging from 0 to 180. There are two distinct peaks: one sharp peak at approximately 175 ppm and another sharp peak at approximately 22 ppm.</p>
Proton NMR	 <p>A Proton NMR spectrum with the x-axis labeled "PPM" ranging from 0 to 12. There are two peaks: a very small peak at approximately 11.00 ppm and a much larger, sharp peak at approximately 2.10 ppm.</p>

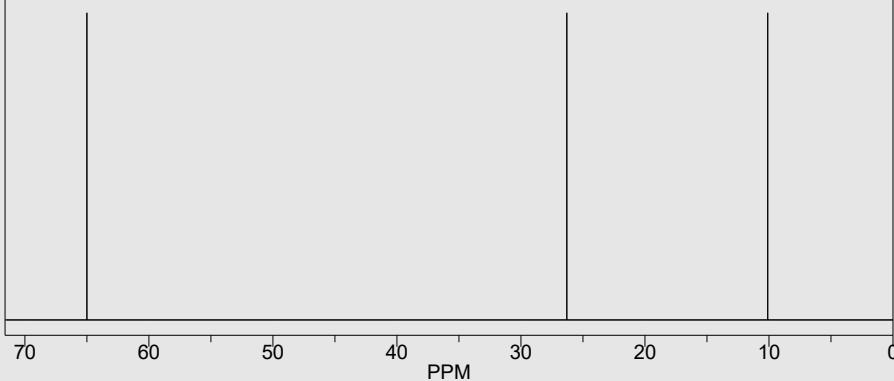
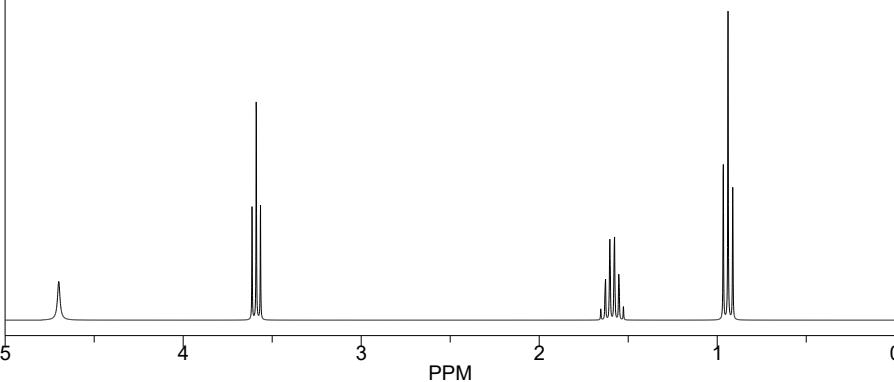
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
11.00	1	1
2.10	1	3

Check the solution to Sample G and see a work-through of the problem in [this video on YouTube](#).

# Sample H

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Solution turns green
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	
Mass spectrometry  Mass of molecular ion: $m/z = 60$	

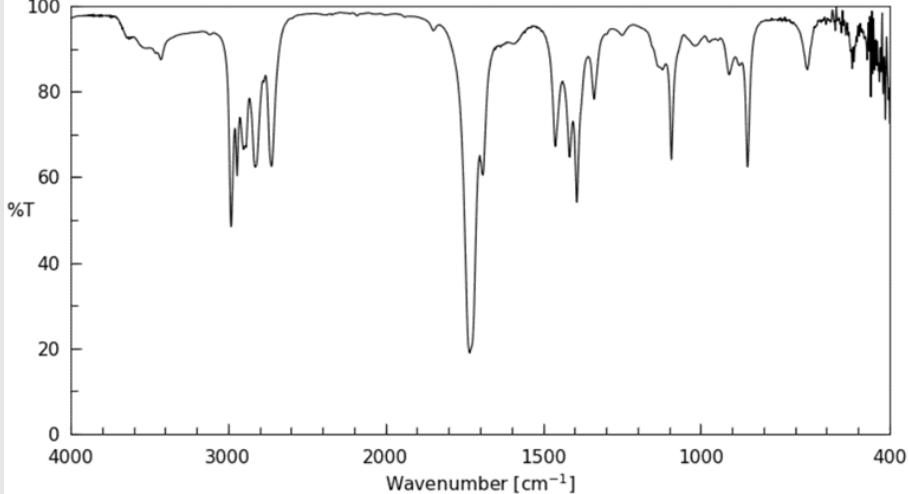
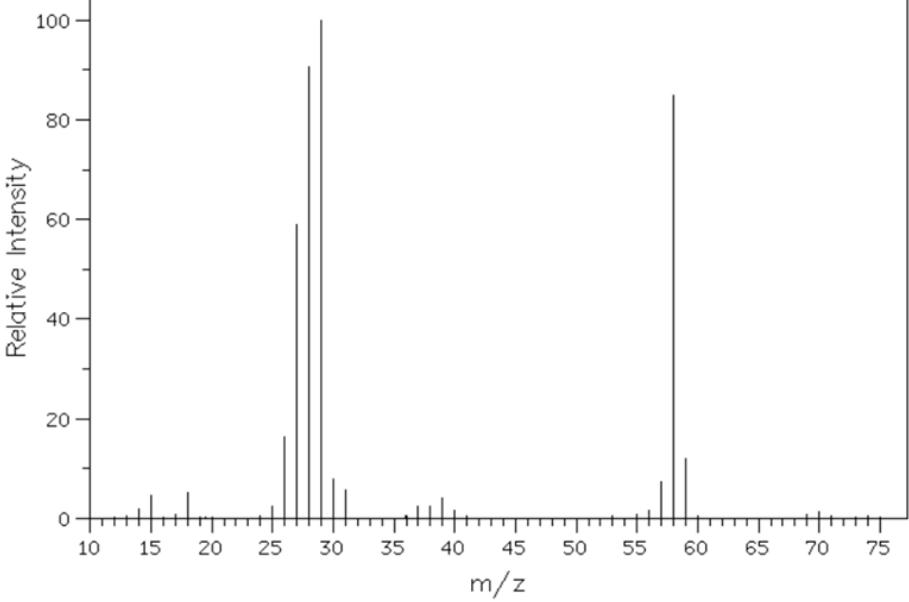
Test	Result
Carbon-13 NMR	
Proton NMR	

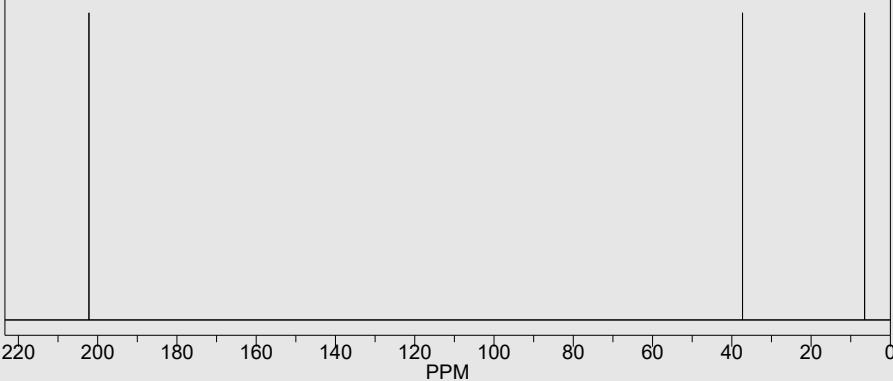
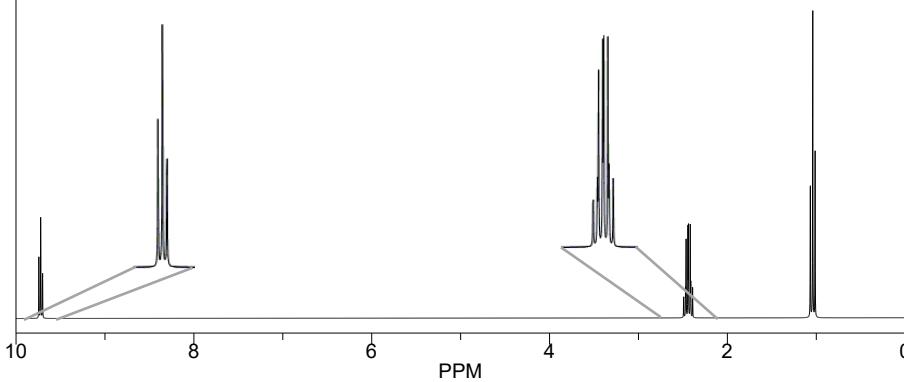
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
4.70	1	1
3.59	3	2
1.59	6	2
0.94	3	3

Check the solution to Sample H and see a work-through of the problem in [this video on YouTube](#).

# Sample I

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Solution turns green
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays transmittance (%T) on the y-axis (0 to 100) against wavenumber (<math>\text{cm}^{-1}</math>) on the x-axis (4000 to 400). Key features include a strong absorption band near 3000 <math>\text{cm}^{-1}</math>, a sharp peak at approximately 1700 <math>\text{cm}^{-1}</math>, and multiple peaks in the 1000-1500 <math>\text{cm}^{-1}</math> range.</p>
Mass spectrometry Mass of molecular ion: $m/z = 58$	 <p>The mass spectrum plots relative intensity on the y-axis (0 to 100) against the mass-to-charge ratio (<math>m/z</math>) on the x-axis (10 to 75). The most intense peak (base peak) is at <math>m/z = 58</math>. Other labeled peaks include <math>m/z = 28</math>, <math>m/z = 30</math>, and <math>m/z = 60</math>.</p>

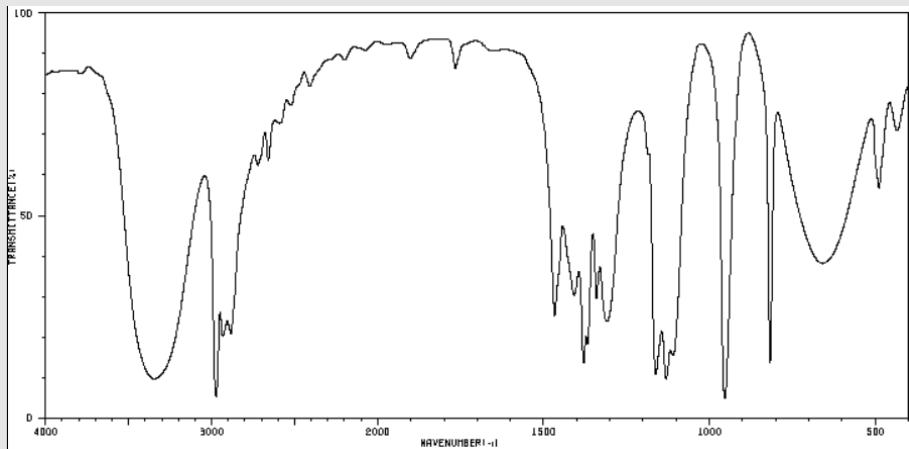
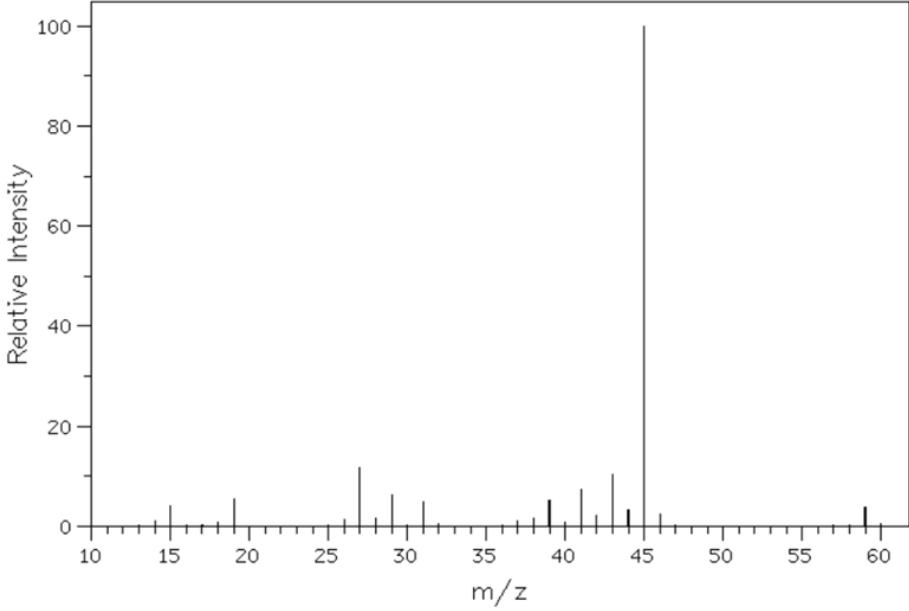
Test	Result
Carbon-13 NMR	 <p>A Carbon-13 NMR spectrum with the x-axis labeled "PPM" ranging from 220 to 0. There are two distinct vertical lines (peaks) at approximately 178 ppm and 14 ppm.</p>
Proton NMR	 <p>A Proton NMR spectrum with the x-axis labeled "PPM" ranging from 10 to 0. Five peaks are visible: one at ~9.80 ppm, a multiplet between ~7.20 and ~7.30 ppm, a complex multiplet between ~4.20 and ~4.80 ppm, one at ~1.11 ppm, and one at ~0.91 ppm.</p>

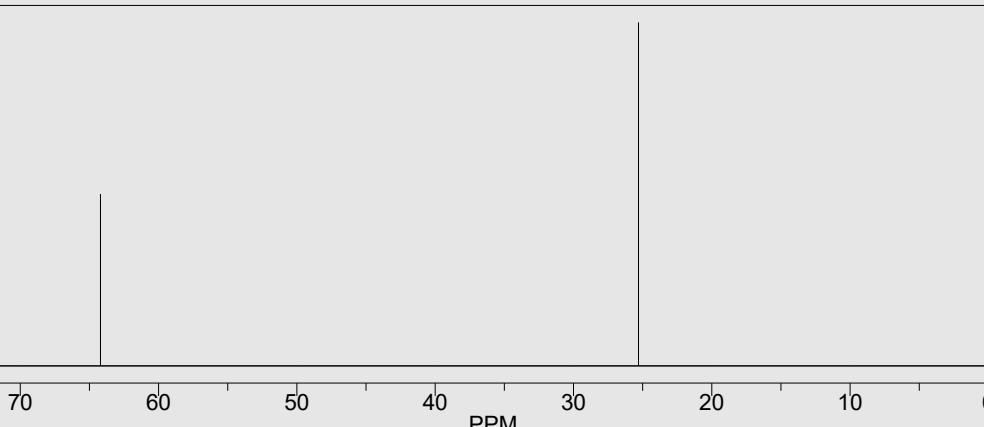
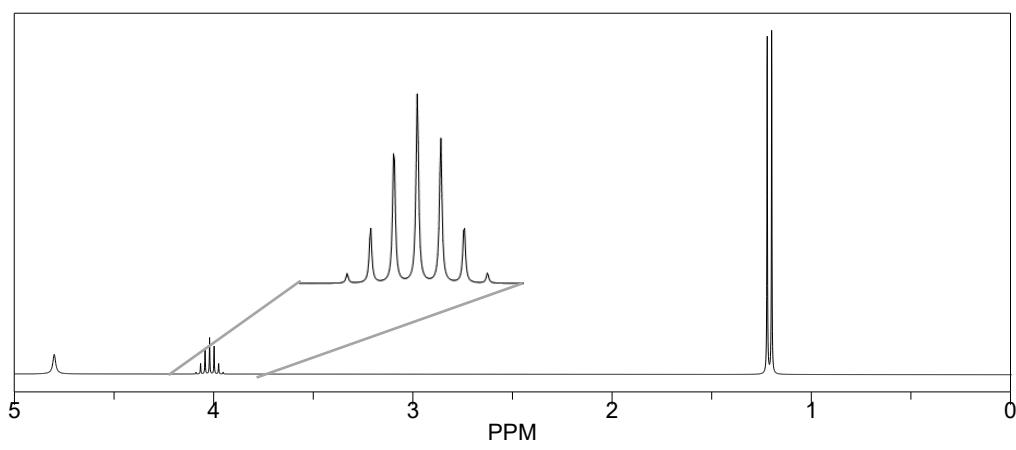
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
9.80	3	1
2.44	5	2
1.11	3	3

Check the solution to Sample I and see a work-through of the problem in [this video on YouTube](#).

# Sample J

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Solution turns green
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	
Mass spectrometry Mass of molecular ion: $m/z = 60$	

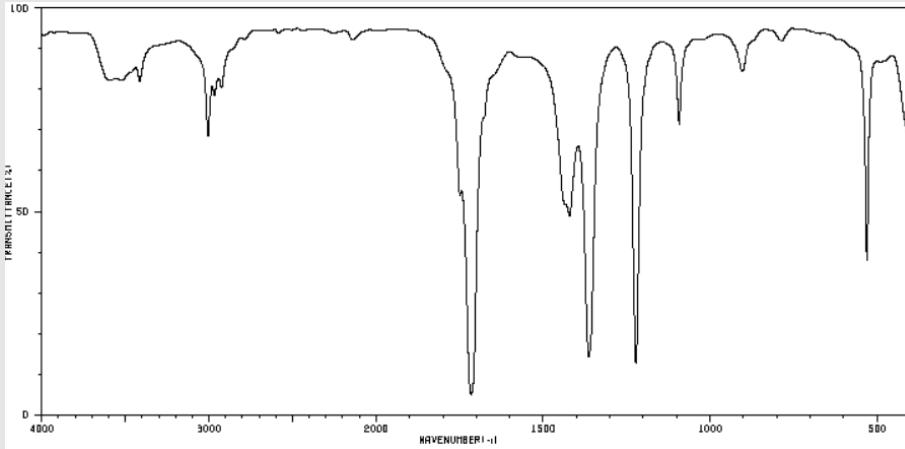
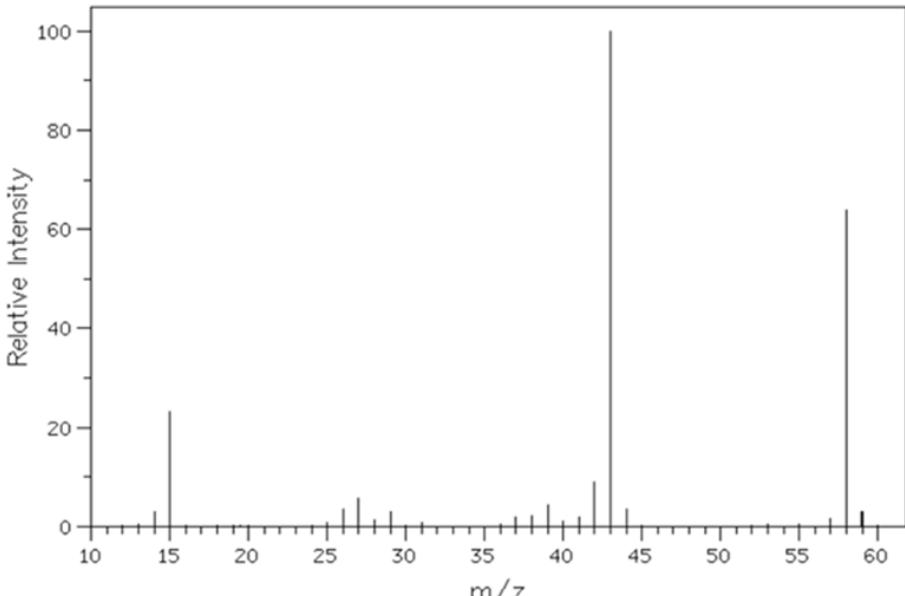
Test	Result
Carbon-13 NMR	
Proton NMR	

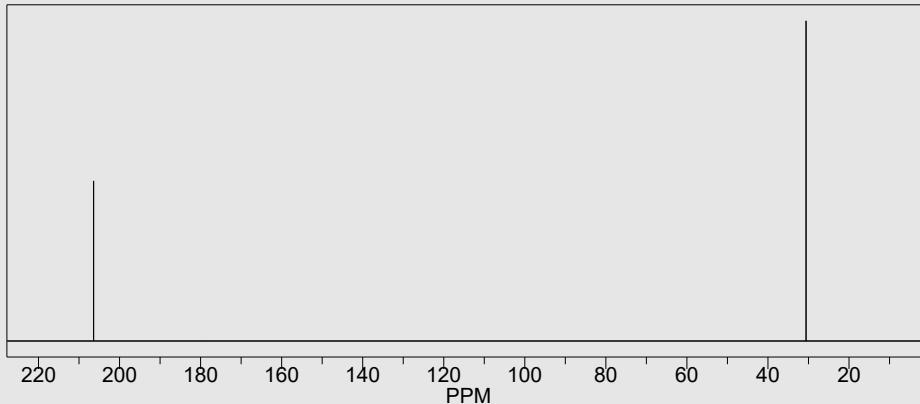
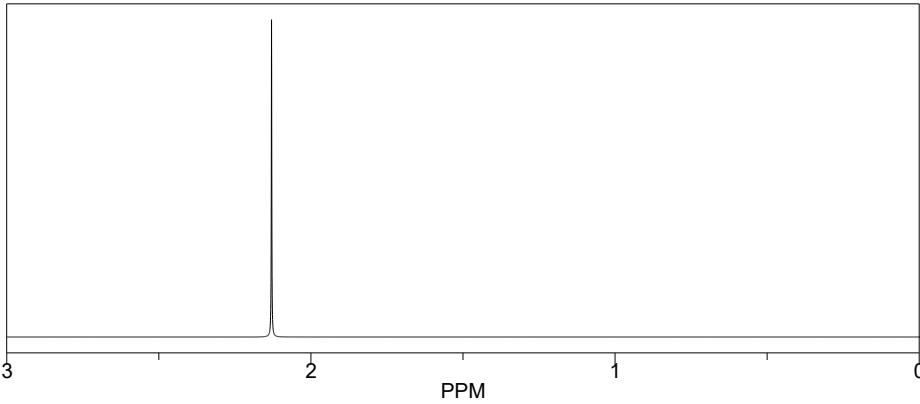
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
4.80	1	1
4.02	7	1
1.21	2	6

Check the solution to Sample J and see a work-through of the problem in [this video on YouTube](#).

# Sample K

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	
Mass spectrometry Mass of molecular ion: $m/z = 58$	

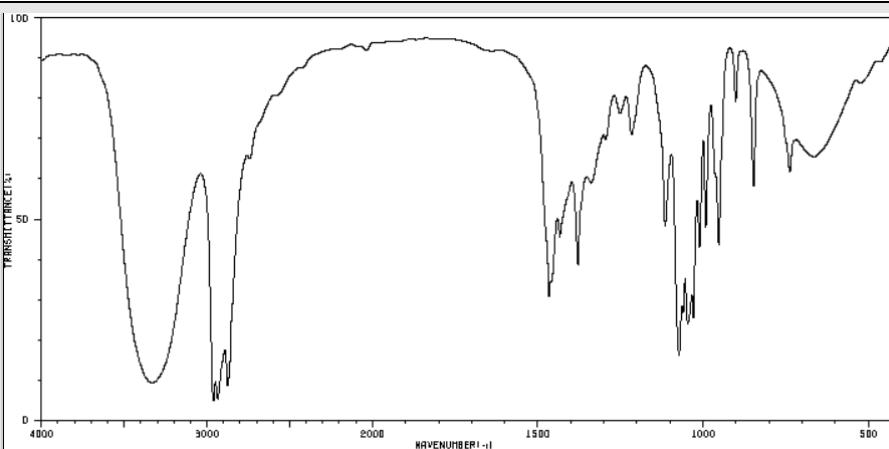
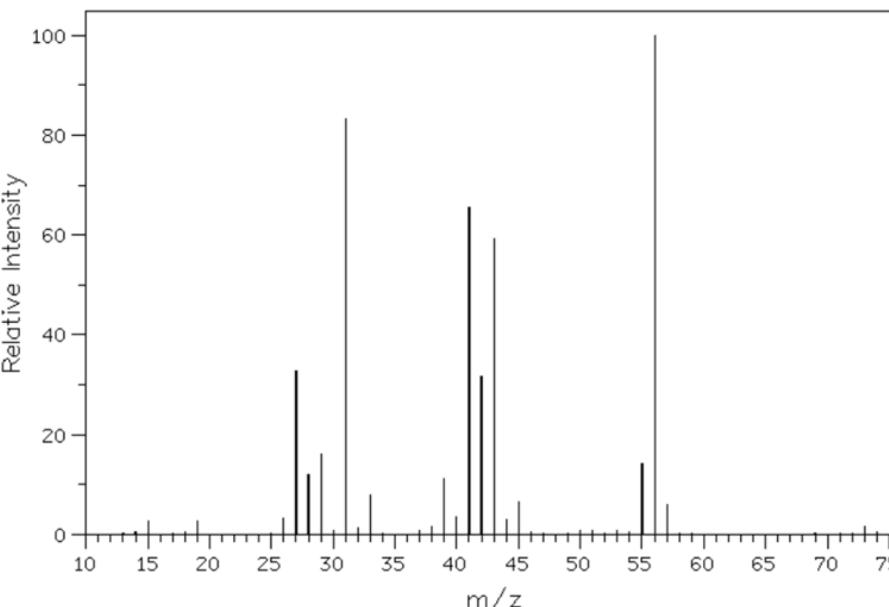
Test	Result
Carbon-13 NMR	 PPM
Proton NMR	 PPM

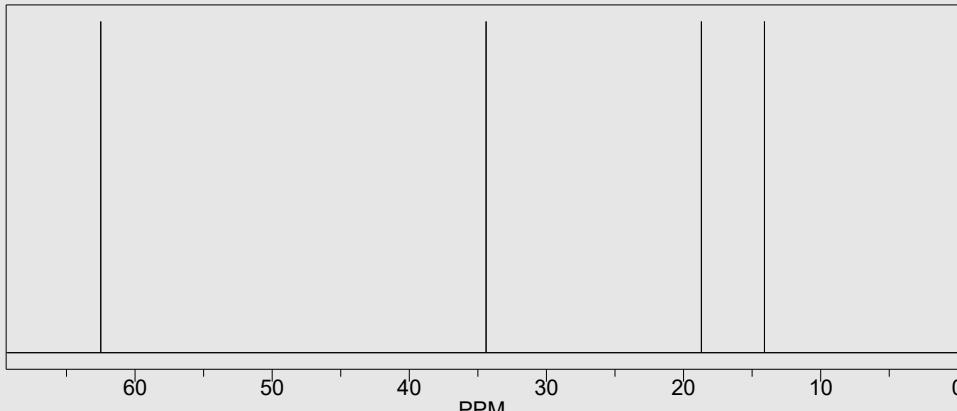
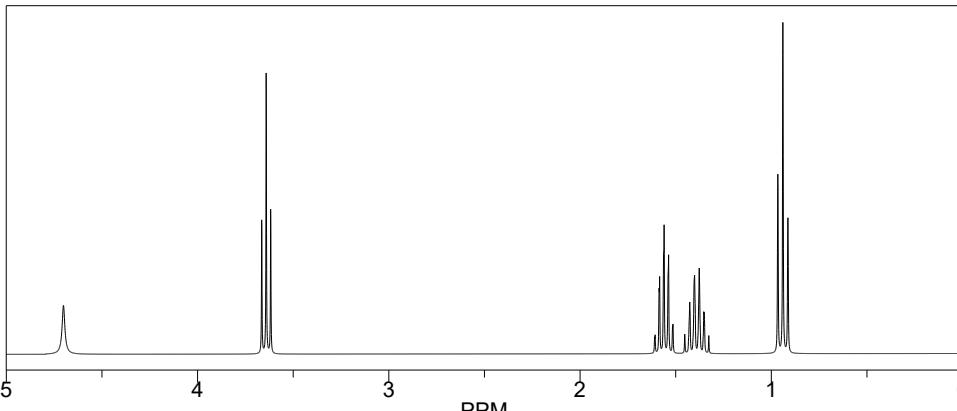
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
2.16	1	6

Check the solution to Sample K and see a work-through of the problem in [this video on YouTube](#).

# Sample L

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Solution turns green
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays Transmittance (%) on the y-axis (0 to 100) against Wavenumber (cm⁻¹) on the x-axis (4000 to 500). Key features include a broad absorption band between 3000 and 3500 cm⁻¹, a sharp peak near 2950 cm⁻¹, and several distinct peaks in the fingerprint region below 1500 cm⁻¹.</p>
Mass spectrometry Mass of molecular ion: $m/z = 74$	 <p>The mass spectrum shows Relative Intensity on the y-axis (0 to 100) versus <math>m/z</math> on the x-axis (10 to 75). The base peak (100% relative intensity) is at <math>m/z = 74</math>. Other labeled peaks include <math>m/z = 42</math>, <math>m/z = 55</math>, and <math>m/z = 31</math>.</p>

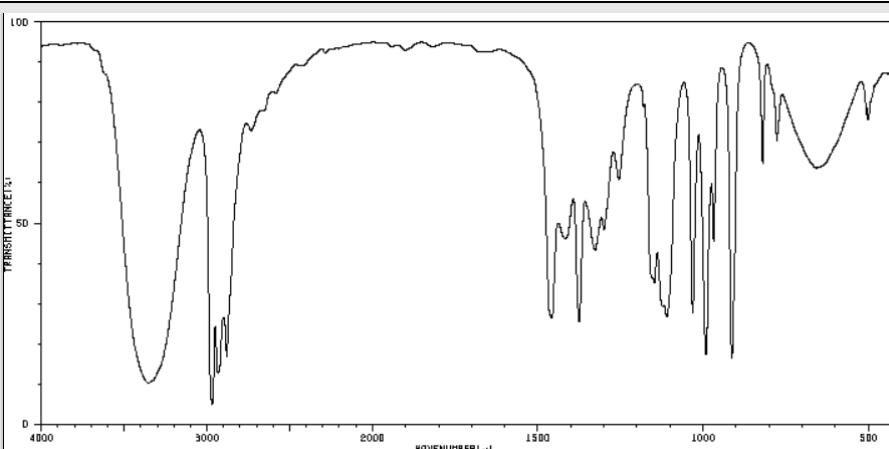
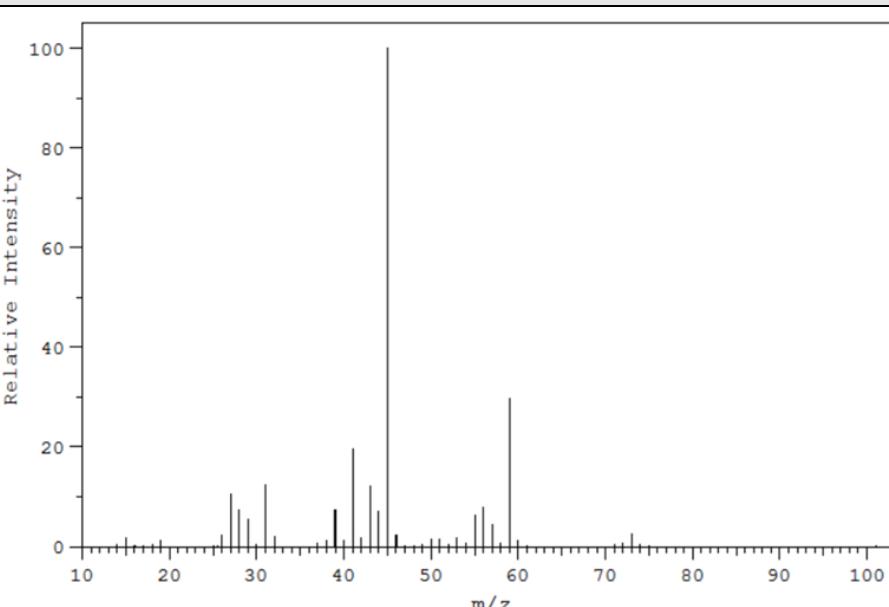
Test	Result
Carbon-13 NMR	 PPM
Proton NMR	 PPM

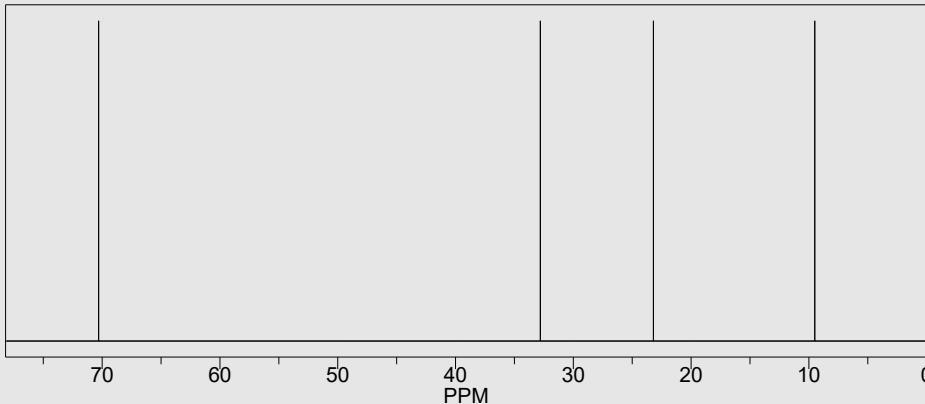
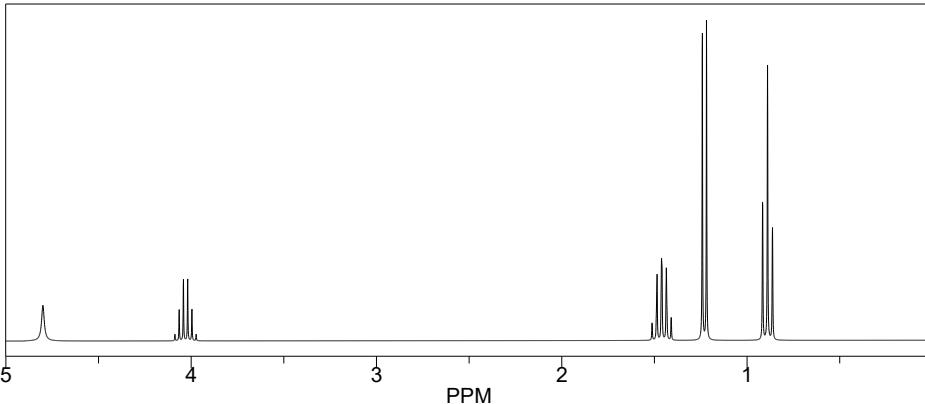
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio	Shift (ppm)	Number of peaks	Peak area ratio
4.70	1	1	1.39	6	2
3.63	3	2	0.94	3	3
1.53	5	2			

Check the solution to Sample L and see a work-through of the problem in [this video on YouTube](#).

# Sample M

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Solution turns green
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays Transmittance (%) on the y-axis (0 to 100) against Wavenumber (<math>\text{cm}^{-1}</math>) on the x-axis (4000 to 500). Key features include a broad absorption band centered around 3000 <math>\text{cm}^{-1}</math> and multiple sharp peaks in the fingerprint region between 1500 and 500 <math>\text{cm}^{-1}</math>.</p>
Mass spectrometry Mass of molecular ion: $m/z = 74$	 <p>The mass spectrum shows Relative Intensity on the y-axis (0 to 100) versus <math>m/z</math> on the x-axis (10 to 100). The base peak (100% relative intensity) is observed at <math>m/z = 74</math>. Other labeled peaks include <math>m/z = 42</math>, <math>m/z = 56</math>, and <math>m/z = 60</math>.</p>

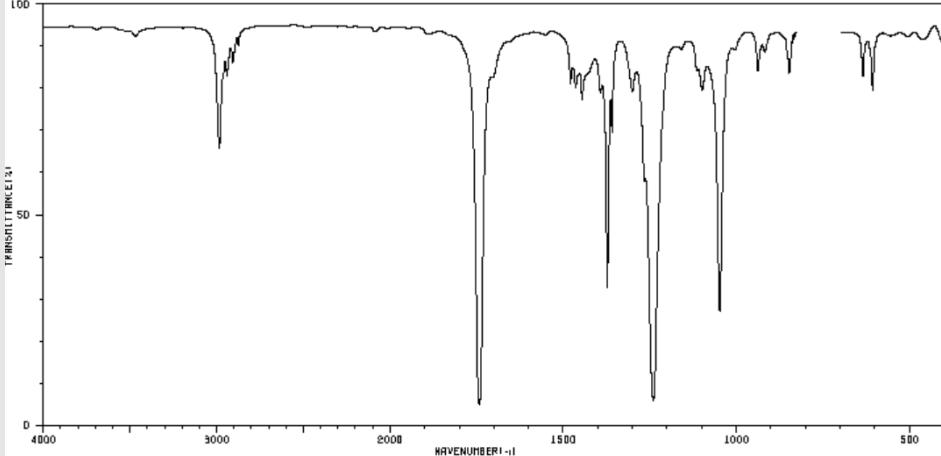
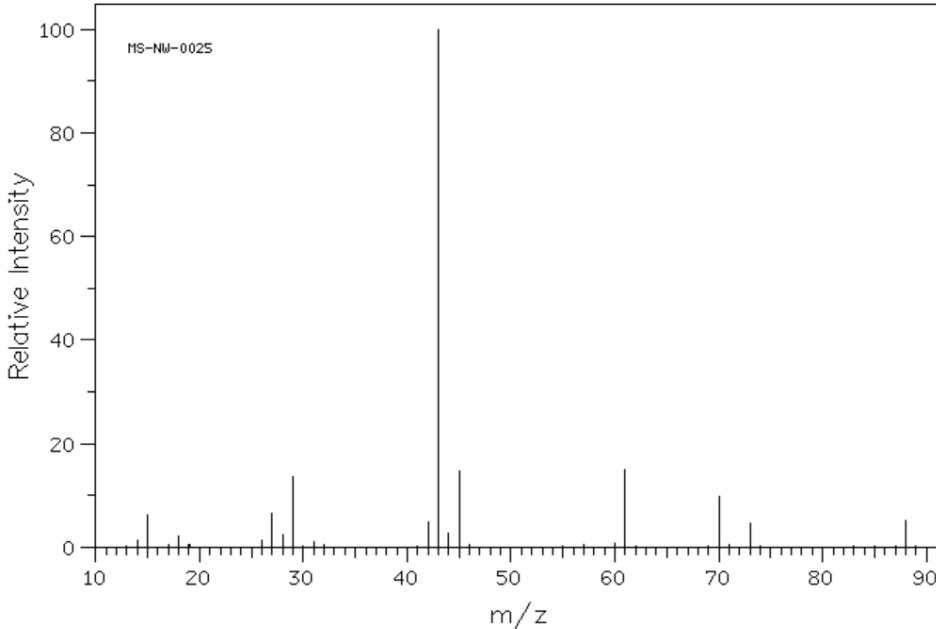
Test	Result
Carbon-13 NMR	 70    60    50    40    30    20    10    0 PPM
Proton NMR	 5    4    3    2    1    0 PPM

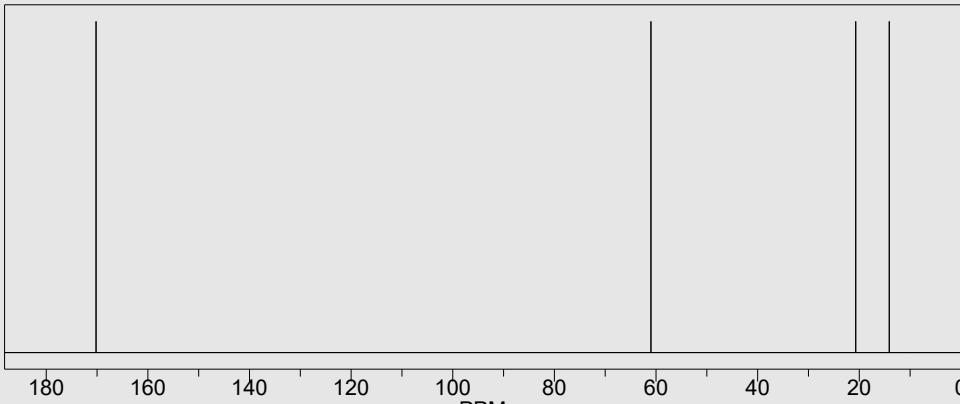
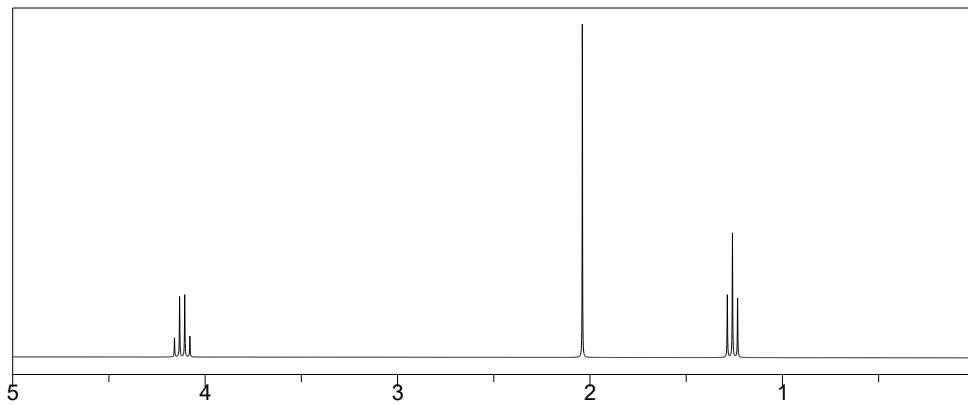
#### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio	Shift (ppm)	Number of peaks	Peak area ratio
4.80	1	1	1.23	2	3
4.03	6	1	0.89	3	3
1.46	5	2			

Check the solution to Sample M and see a work-through of the problem in [this video on YouTube](#).

# Sample N

Test	Result																																						
Unsaturation test using bromine water	Orange colour remains																																						
Oxidation test using acidified potassium dichromate	Orange colour remains																																						
Carboxylic acid test using sodium carbonate	No bubbles																																						
Infrared spectroscopy																																							
Mass spectrometry Mass of molecular ion: $m/z = 74$	<p>MS-NW-0025</p>  <table border="1"> <caption>Approximate peak data for Sample N mass spectrum</caption> <thead> <tr> <th>m/z</th> <th>Relative Intensity (approx.)</th> </tr> </thead> <tbody> <tr><td>10</td><td>5</td></tr> <tr><td>15</td><td>10</td></tr> <tr><td>20</td><td>5</td></tr> <tr><td>25</td><td>10</td></tr> <tr><td>30</td><td>15</td></tr> <tr><td>35</td><td>10</td></tr> <tr><td>43</td><td>100</td></tr> <tr><td>45</td><td>5</td></tr> <tr><td>57</td><td>80</td></tr> <tr><td>59</td><td>10</td></tr> <tr><td>61</td><td>15</td></tr> <tr><td>65</td><td>10</td></tr> <tr><td>70</td><td>10</td></tr> <tr><td>74</td><td>100</td></tr> <tr><td>77</td><td>5</td></tr> <tr><td>85</td><td>5</td></tr> <tr><td>91</td><td>10</td></tr> <tr><td>95</td><td>5</td></tr> </tbody> </table>	m/z	Relative Intensity (approx.)	10	5	15	10	20	5	25	10	30	15	35	10	43	100	45	5	57	80	59	10	61	15	65	10	70	10	74	100	77	5	85	5	91	10	95	5
m/z	Relative Intensity (approx.)																																						
10	5																																						
15	10																																						
20	5																																						
25	10																																						
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45	5																																						
57	80																																						
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61	15																																						
65	10																																						
70	10																																						
74	100																																						
77	5																																						
85	5																																						
91	10																																						
95	5																																						

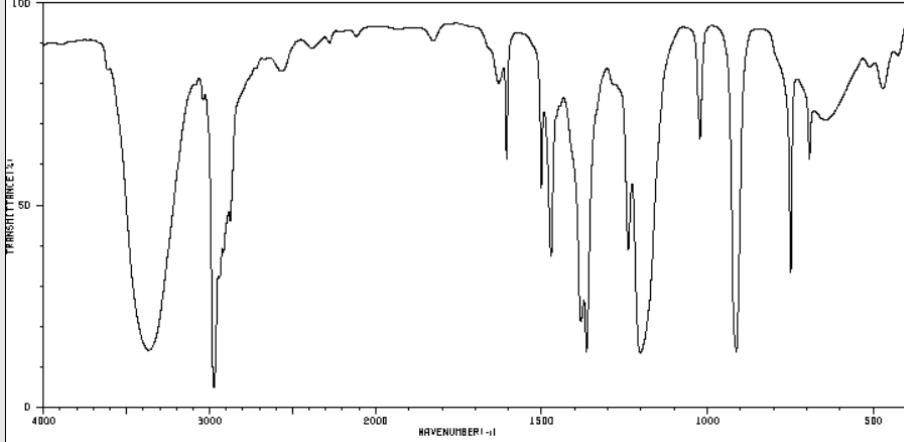
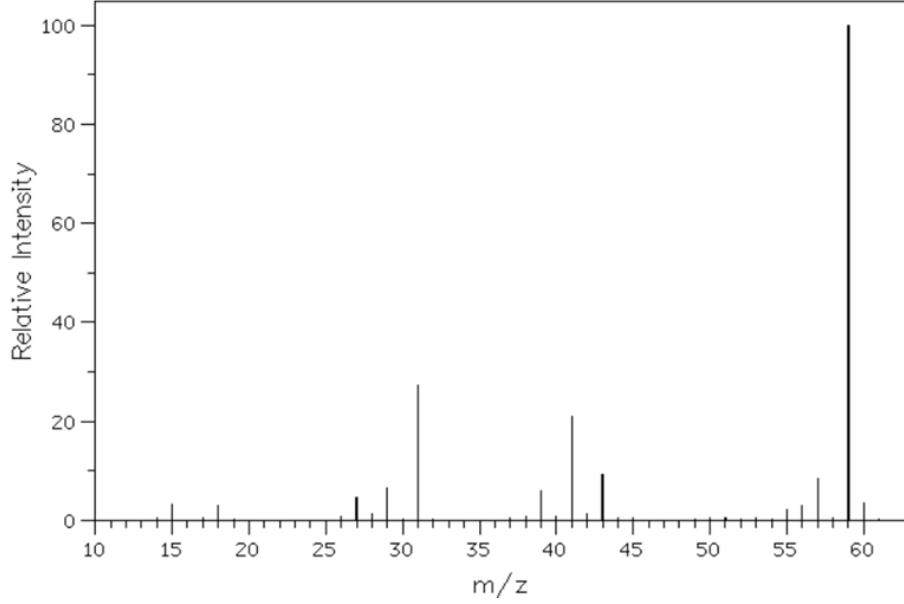
Test	Result
Carbon-13 NMR	
Proton NMR	

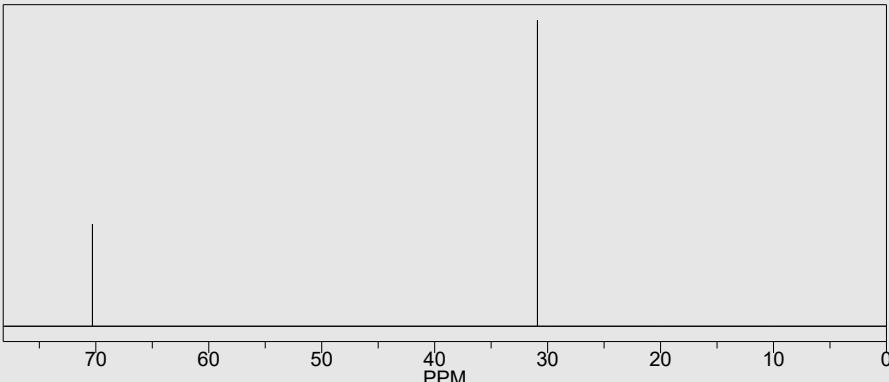
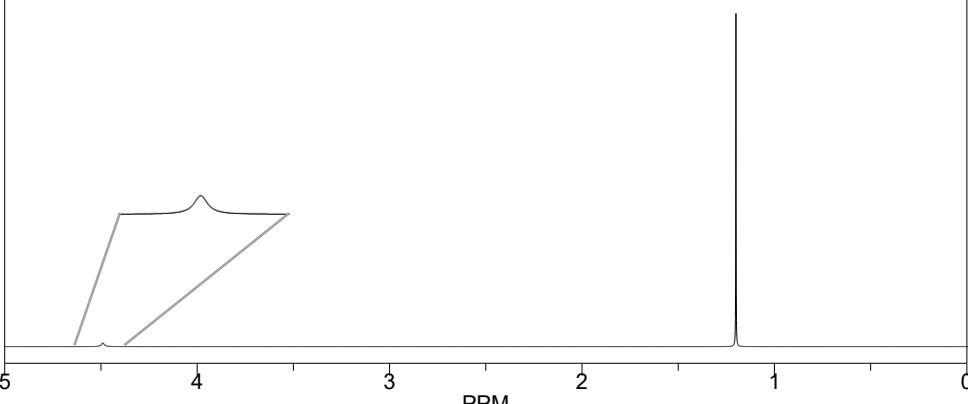
#### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
4.12	4	2
2.04	1	3
1.26	3	3

Check the solution to Sample N and see a work-through of the problem in [this video on YouTube](#).

# Sample O

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays transmittance (%) on the y-axis (0 to 100) against wavenumber (<math>\text{cm}^{-1}</math>) on the x-axis (4000 to 500). Key features include a strong absorption band around 3000 <math>\text{cm}^{-1}</math>, a sharp peak near 1700 <math>\text{cm}^{-1}</math>, and multiple peaks in the fingerprint region between 1500 and 500 <math>\text{cm}^{-1}</math>.</p>
Mass spectrometry Mass of molecular ion: $m/z = 74$	 <p>The mass spectrum shows relative intensity (%) on the y-axis (0 to 100) versus the mass-to-charge ratio (<math>m/z</math>) on the x-axis (10 to 60). The base peak is at <math>m/z = 74</math>. Other labeled peaks include <math>m/z = 32</math>, <math>m/z = 40</math>, <math>m/z = 44</math>, and <math>m/z = 60</math>.</p>

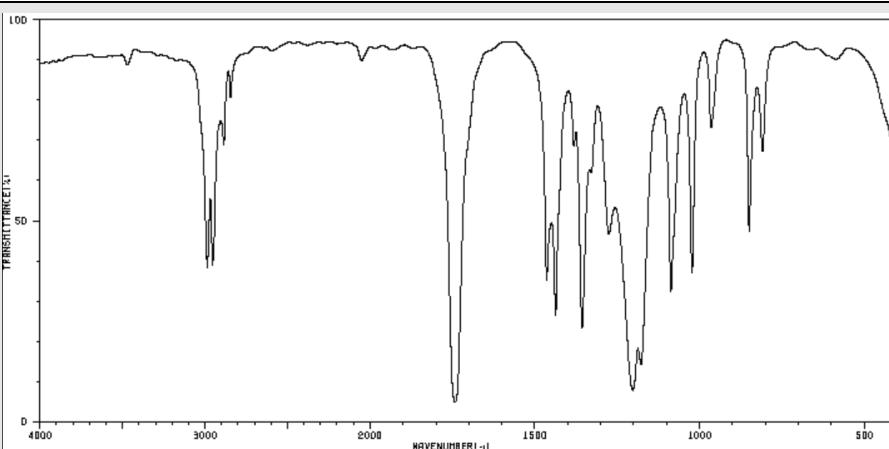
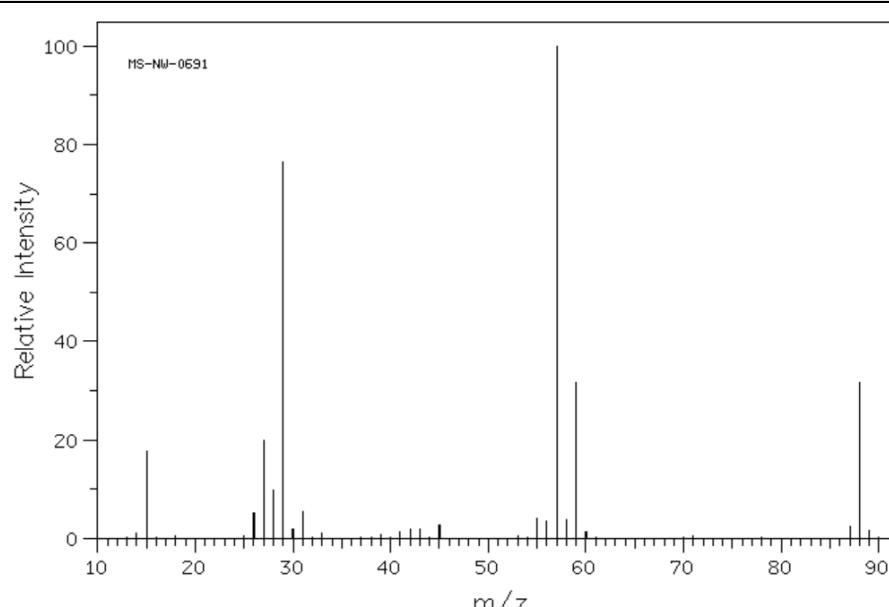
Test	Result
Carbon-13 NMR	 <p>A Carbon-13 NMR spectrum with the x-axis labeled "PPM" ranging from 70 to 0. There are two distinct peaks: one sharp peak at approximately 70 ppm and another sharp peak at approximately 30 ppm.</p>
Proton NMR	 <p>A Proton NMR spectrum with the x-axis labeled "PPM" ranging from 5 to 0. It features a complex multiplet between 3.5 and 4.5 ppm and a very sharp singlet at 1.26 ppm.</p>

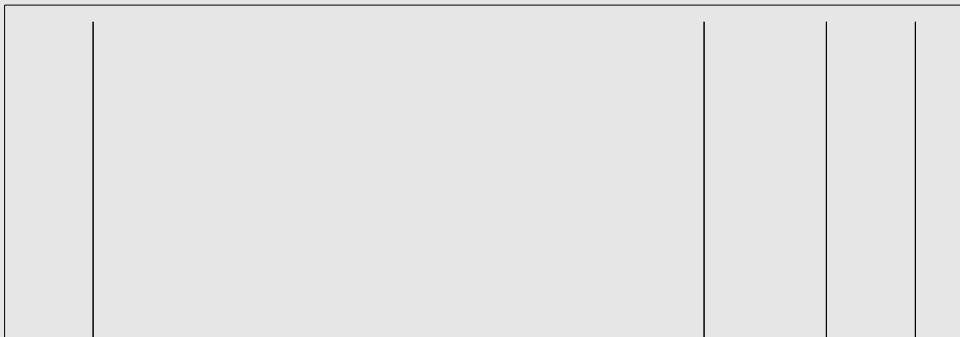
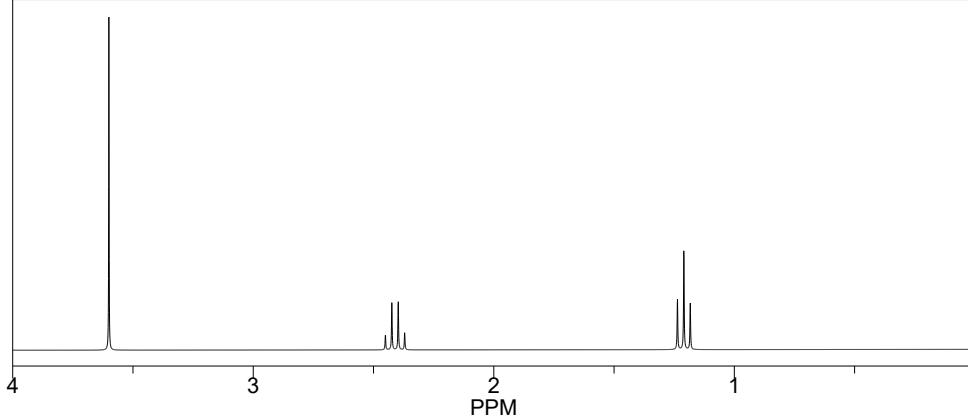
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
4.49	1	1
1.26	1	9

Check the solution to Sample O and see a work-through of the problem in [this video on YouTube](#).

# Sample P

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays transmittance percentage on the y-axis (0 to 100) against wavenumber in cm⁻¹ on the x-axis (4000 to 500). Key features include a broad absorption band near 3000 cm⁻¹ and a series of sharp peaks in the 1000-1500 cm⁻¹ range.</p>
Mass spectrometry Mass of molecular ion: $m/z = 88$	 <p>The mass spectrum is labeled "MS-NW-0691". The x-axis represents the mass-to-charge ratio (<math>m/z</math>) from 10 to 90, and the y-axis represents relative intensity from 0 to 100. The most intense peak (base peak) is at <math>m/z = 88</math>. Other labeled peaks include <math>m/z = 16</math>, <math>m/z = 28</math>, <math>m/z = 57</math>, and <math>m/z = 60</math>.</p>

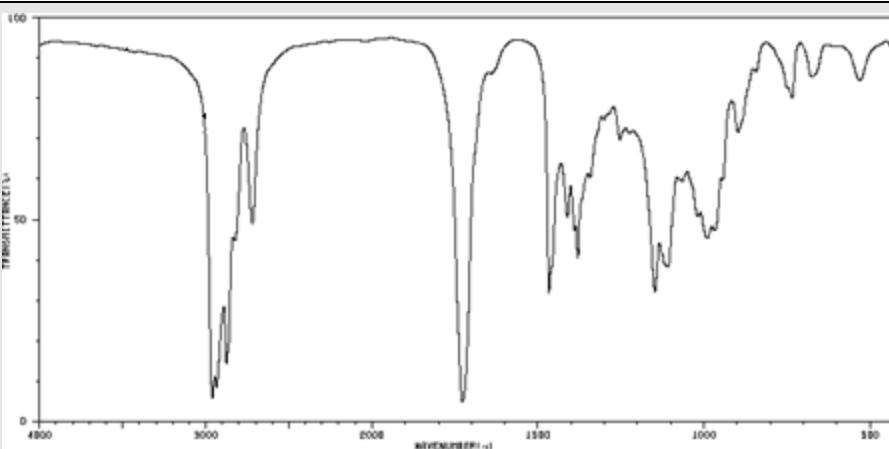
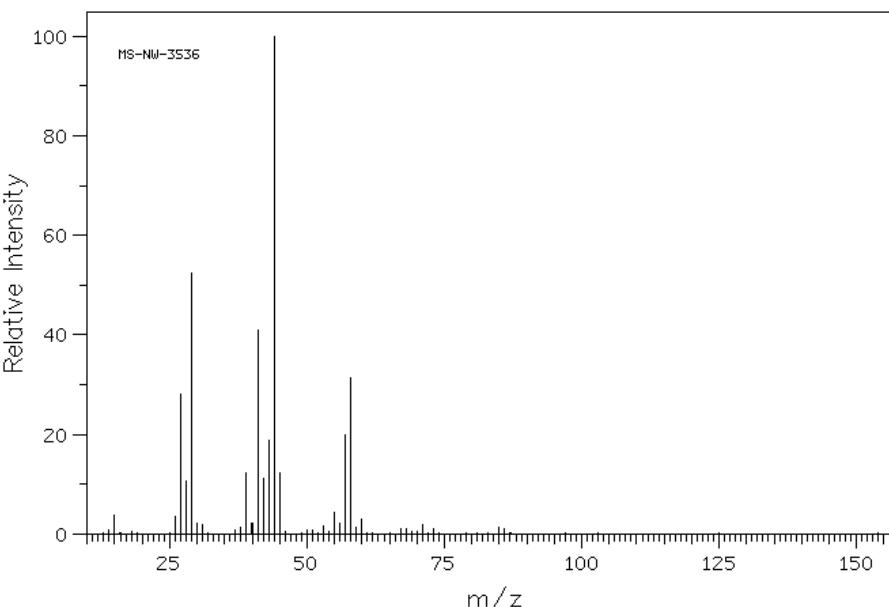
Test	Result
Carbon-13 NMR	 The spectrum shows a single sharp peak at approximately 175 ppm, indicating a carbonyl group.
Proton NMR	 The spectrum shows three distinct signals: a triplet at 3.60 ppm, a quartet at 2.41 ppm, and a triplet at 1.21 ppm.

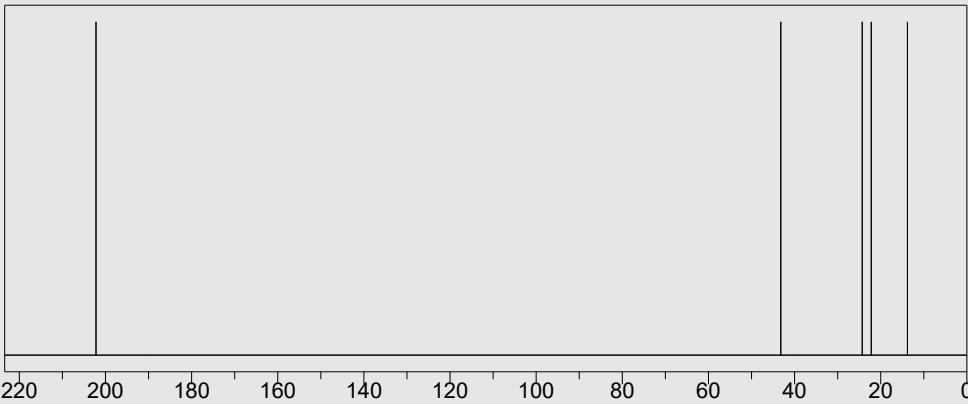
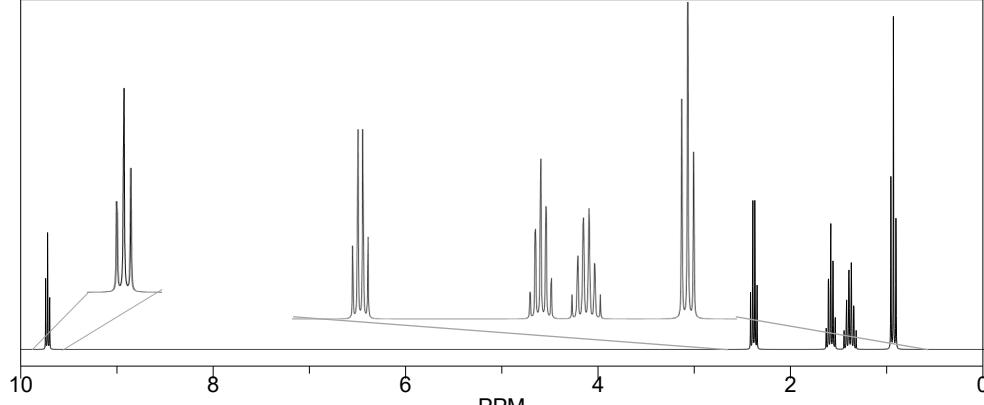
#### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
3.60	1	3
2.41	4	2
1.21	3	3

Check the solution to Sample P and see a work-through of the problem in [this video on YouTube](#).

# Sample Q

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Solution turns green
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum shows transmittance (%) on the y-axis ranging from 0 to 100, and wavenumber (cm⁻¹) on the x-axis ranging from 4000 to 800. Key absorption bands are visible around 3000 cm⁻¹, 1700 cm⁻¹, and 1100 cm⁻¹.</p>
Mass spectrometry Mass of molecular ion: $m/z = 86$	 <p>The mass spectrum shows relative intensity (%) on the y-axis ranging from 0 to 100, and <math>m/z</math> on the x-axis ranging from 25 to 150. The base peak (100% relative intensity) is at <math>m/z = 86</math>. Other significant peaks are observed at <math>m/z = 28, 42, 50, 74, 98, 110, 128, 146, 164, 182</math>, and <math>190</math>.</p>

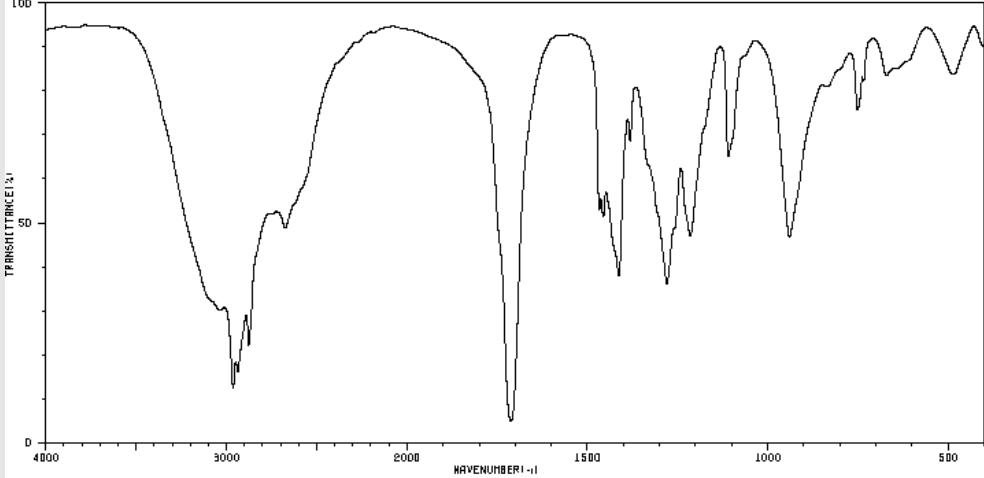
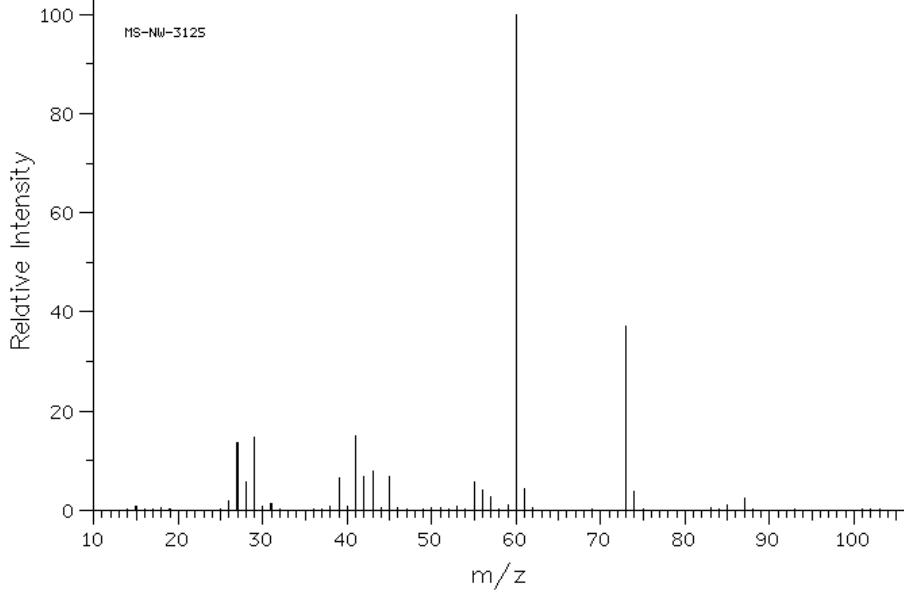
Test	Result
Carbon-13 NMR	 <p>The Carbon-13 NMR spectrum displays peaks in the aromatic region (~198 ppm), aliphatic region (~45 ppm), and aldehyde carbonyl region (~22 ppm). There is also a small peak near 18 ppm.</p>
Proton NMR	 <p>The Proton NMR spectrum shows a complex pattern of peaks across the chemical shift range from 0 to 10 ppm. Key features include a sharp peak at ~9.76 ppm, a multiplet between 2.4 and 2.6 ppm, and a large multiplet centered around 1.59 ppm.</p>

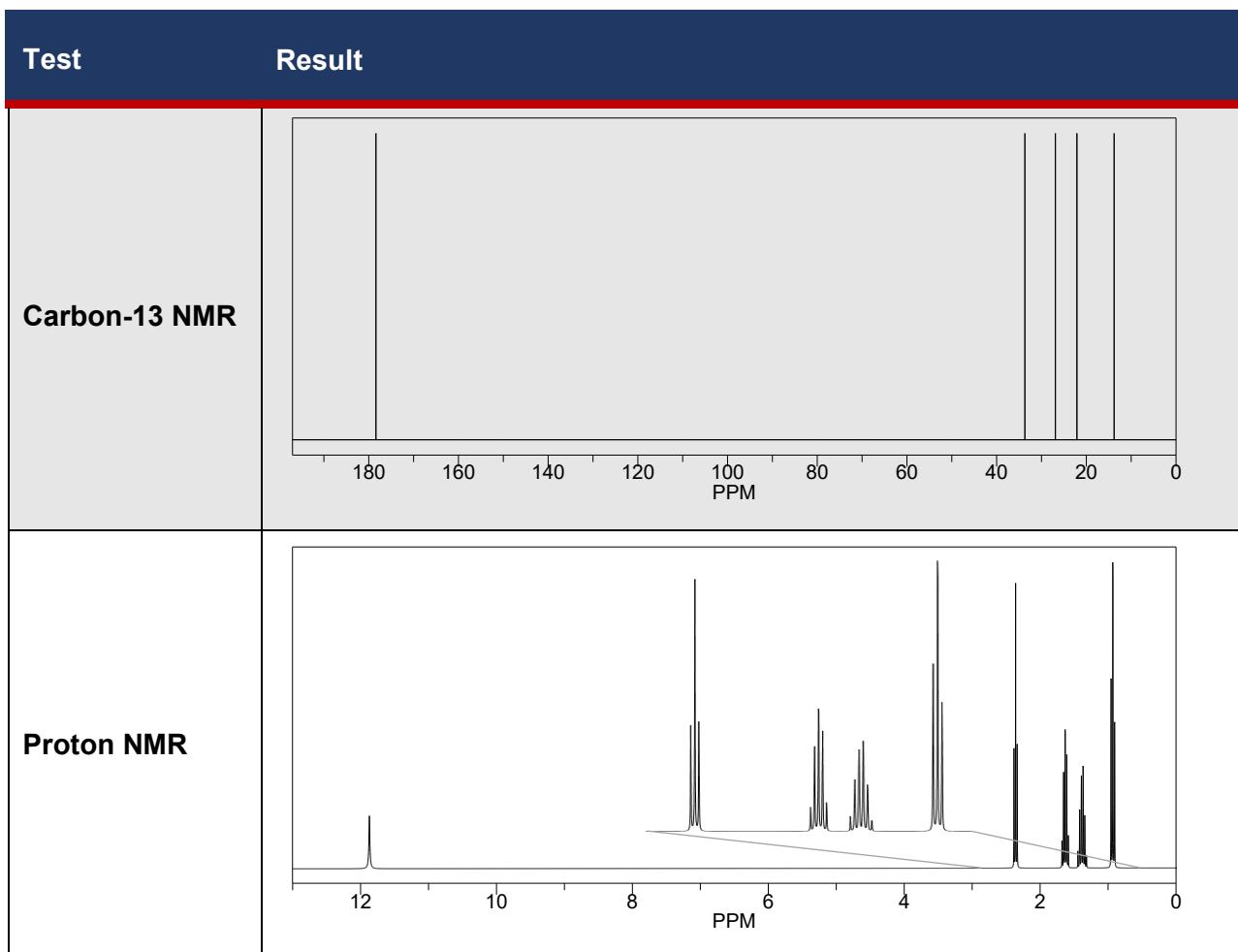
#### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio	Shift (ppm)	Number of peaks	Peak area ratio
9.76	3	1	1.35	6	2
2.42	4	2	0.93	3	3
1.59	5	2			

Check the solution to Sample Q and see a work-through of the problem in [this video on YouTube](#).

# Sample R

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	Bubbles of carbon dioxide
Infrared spectroscopy	 <p>The infrared spectrum displays transmittance percentage on the y-axis (0 to 100) against wavenumber in cm⁻¹ on the x-axis (4000 to 500). Key features include a strong absorption band near 3000 cm⁻¹, a broad peak around 1700 cm⁻¹, and multiple sharp peaks in the fingerprint region below 1500 cm⁻¹.</p>
Mass spectrometry Mass of molecular ion: $m/z = 102$	 <p>The mass spectrum shows relative intensity on the y-axis (0 to 100) versus the mass-to-charge ratio (<math>m/z</math>) on the x-axis (10 to 100). The base peak is at <math>m/z = 102</math>. Other labeled peaks include <math>m/z = 28</math>, <math>m/z = 42</math>, <math>m/z = 62</math>, <math>m/z = 74</math>, and <math>m/z = 86</math>.</p>

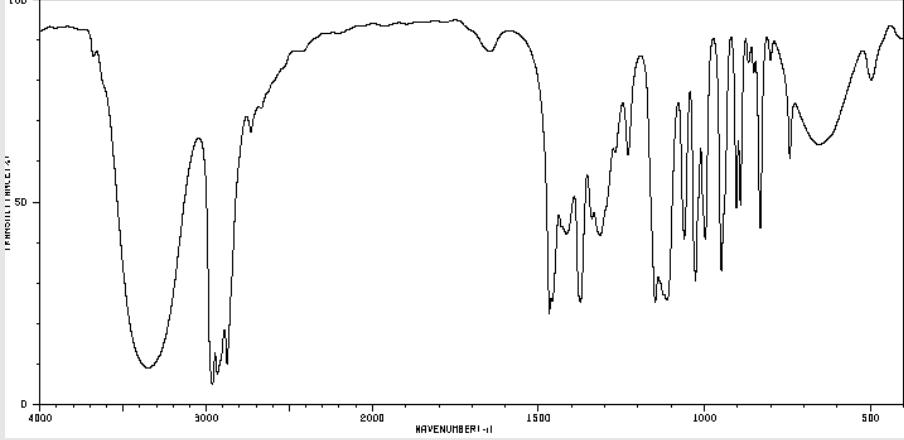
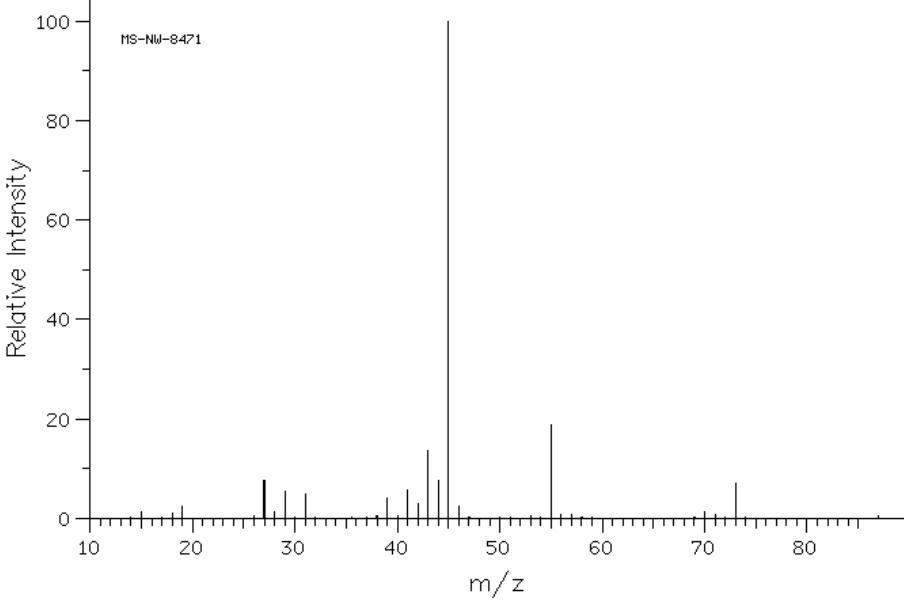


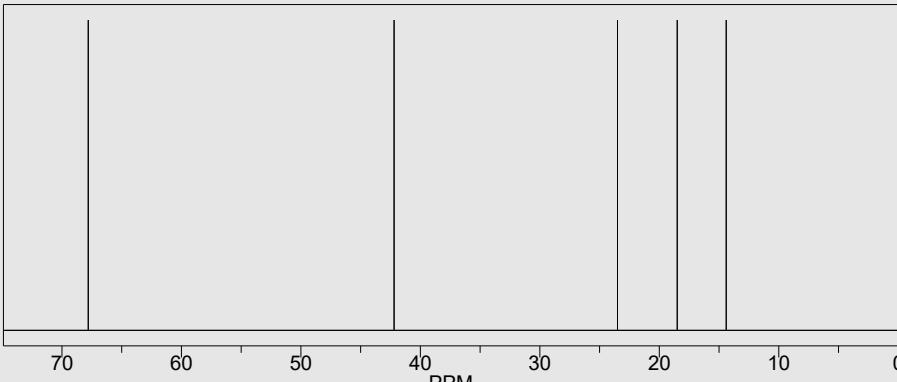
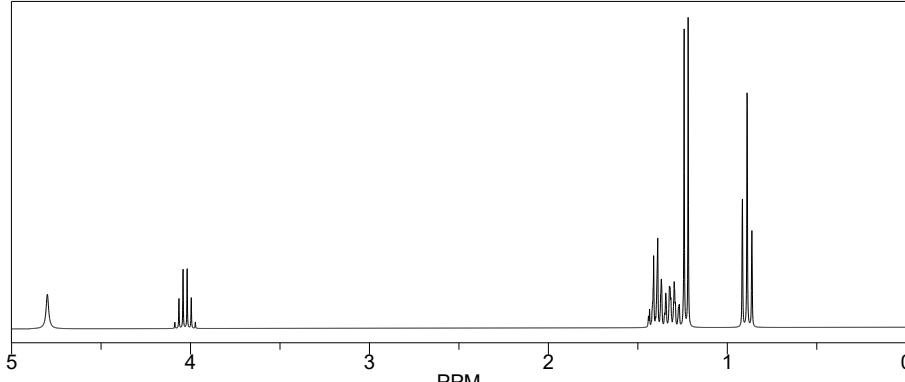
#### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio	Shift (ppm)	Number of peaks	Peak area ratio
11.96	1	1	1.39	6	2
2.35	3	2	0.93	3	3
1.62	5	2			

Check the solution to Sample R and see a work-through of the problem in [this video on YouTube](#).

# Sample S

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Solution turns green
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum shows a broad absorption band around 3400 cm⁻¹, a sharp peak at approximately 2950 cm⁻¹, and several fingerprint region peaks between 1500 and 500 cm⁻¹.</p>
Mass spectrometry Mass of molecular ion: $m/z = 88$	 <p>The mass spectrum displays a base peak at <math>m/z = 88</math>. Other significant peaks are observed at <math>m/z = 43</math>, <math>m/z = 57</math>, and <math>m/z = 69</math>.</p>

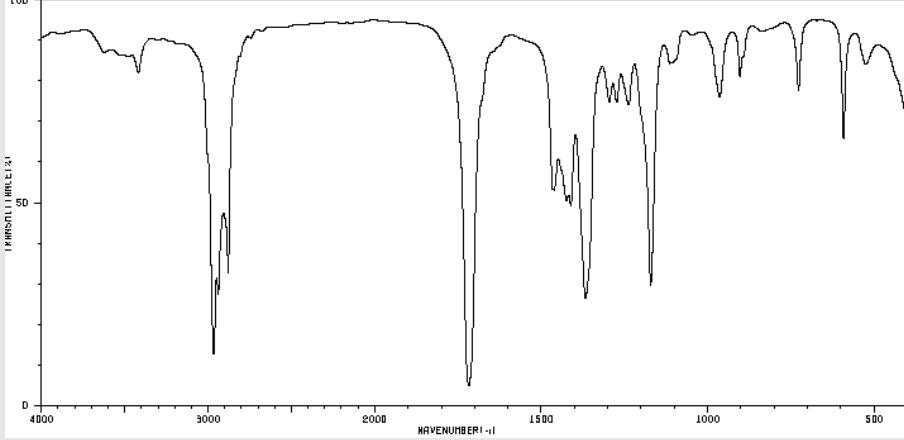
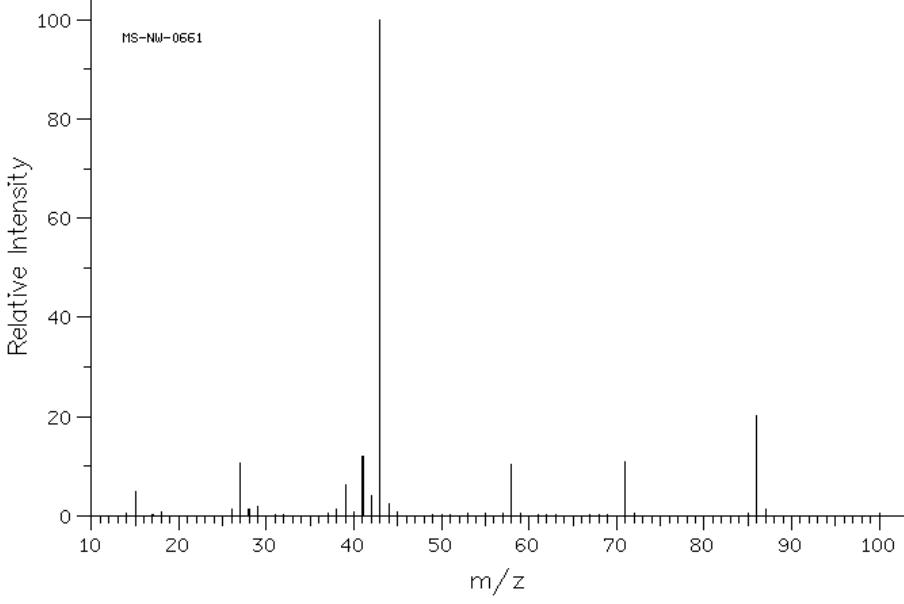
Test	Result
Carbon-13 NMR	 <p>A Carbon-13 NMR spectrum with the x-axis labeled "PPM" ranging from 0 to 70. There are four distinct peaks: a sharp peak at ~70 ppm, a broad peak at ~60 ppm, a triplet-like peak at ~20 ppm, and a triplet-like peak at ~10 ppm.</p>
Proton NMR	 <p>A Proton NMR spectrum with the x-axis labeled "PPM" ranging from 0 to 5. It shows several peaks: a singlet at ~5.3 ppm, a multiplet at ~4.0 ppm, a triplet at ~1.4 ppm, a sextet at ~1.3 ppm, a doublet at ~1.1 ppm, and a triplet at ~0.9 ppm.</p>

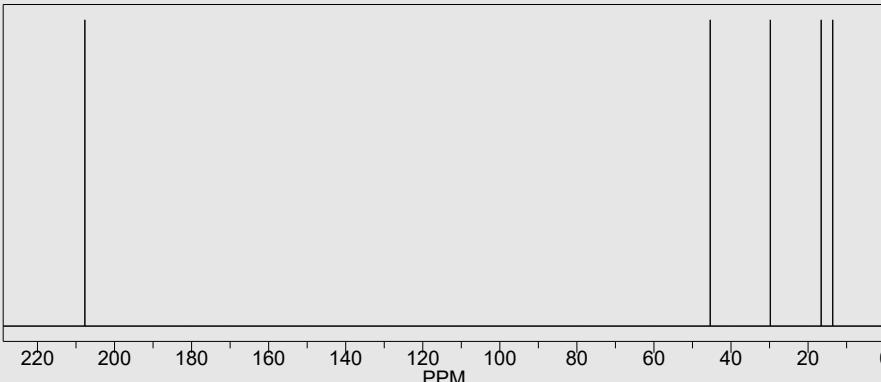
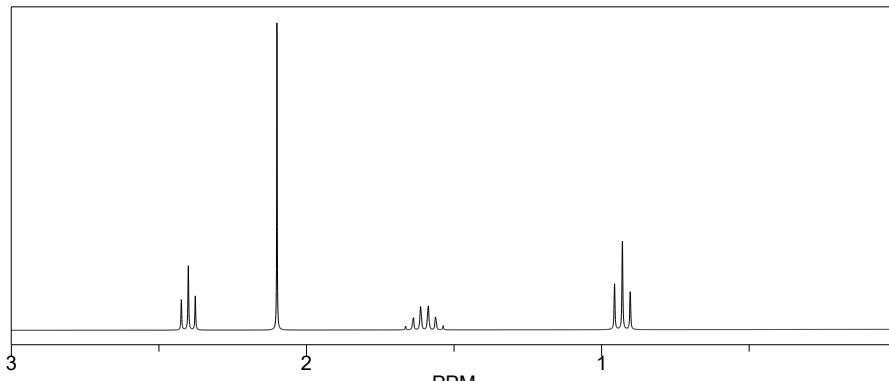
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio	Shift (ppm)	Number of peaks	Peak area ratio
2.66	1	1	1.36	6	2
3.79	6	1	1.17	2	3
1.44	4	2	0.92	3	3

Check the solution to Sample S and see a work-through of the problem in [this video on YouTube](#).

# Sample T

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays absorbance (A) on the y-axis and wavenumber (cm⁻¹) on the x-axis, ranging from 4000 to 500. Key features include a sharp peak at approximately 3000 cm⁻¹, a strong absorption band between 1500 and 1800 cm⁻¹, and multiple peaks in the fingerprint region below 1500 cm⁻¹.</p>
<b>Mass spectrometry</b> <b>Mass of molecular ion:</b> <b><math>m/z = 86</math></b>	 <p>The mass spectrum shows relative intensity on the y-axis (0 to 100) and <math>m/z</math> on the x-axis (10 to 100). The base peak is at <math>m/z = 86</math>. Other significant peaks are observed at <math>m/z = 42</math>, <math>m/z = 60</math>, and <math>m/z = 70</math>.</p>

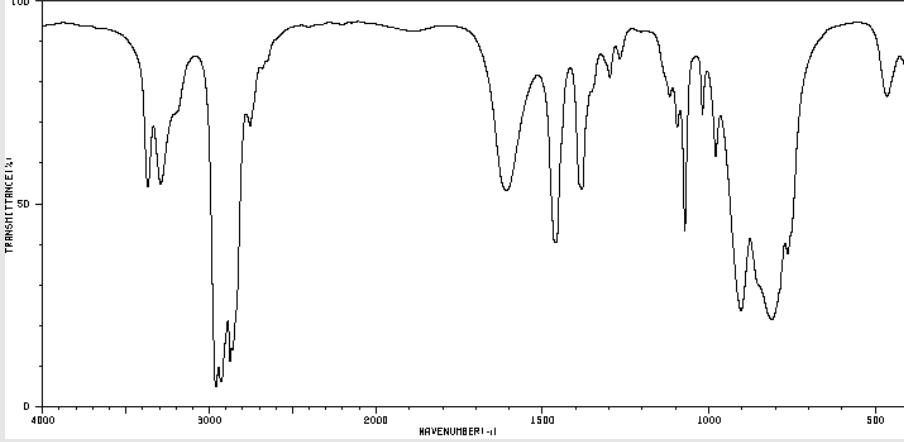
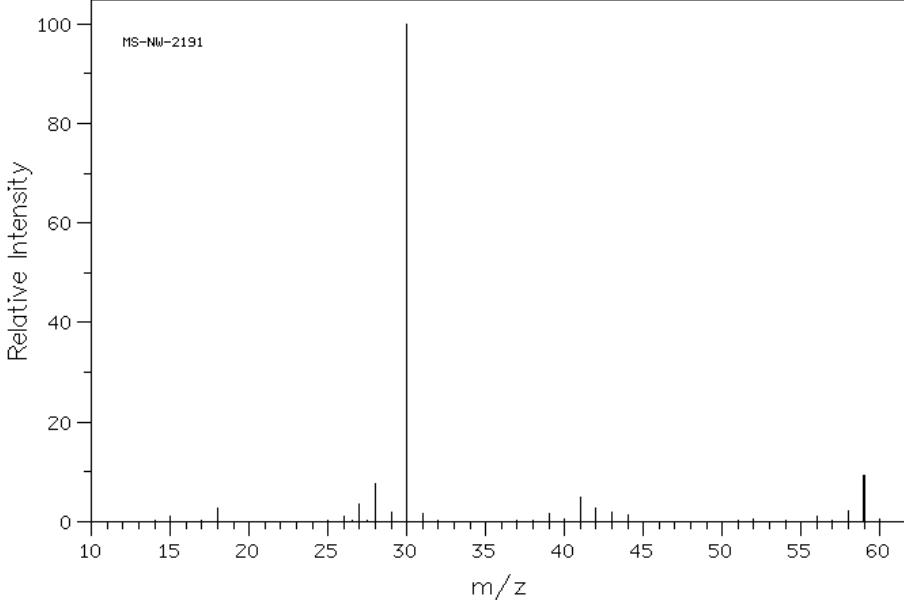
Test	Result
Carbon-13 NMR	 PPM
Proton NMR	 PPM

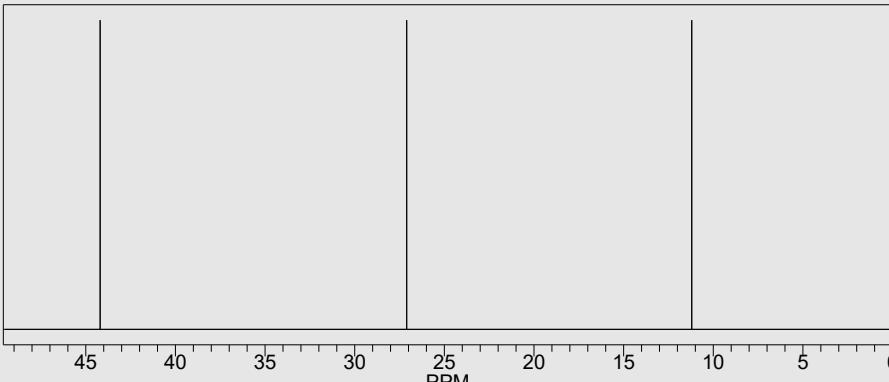
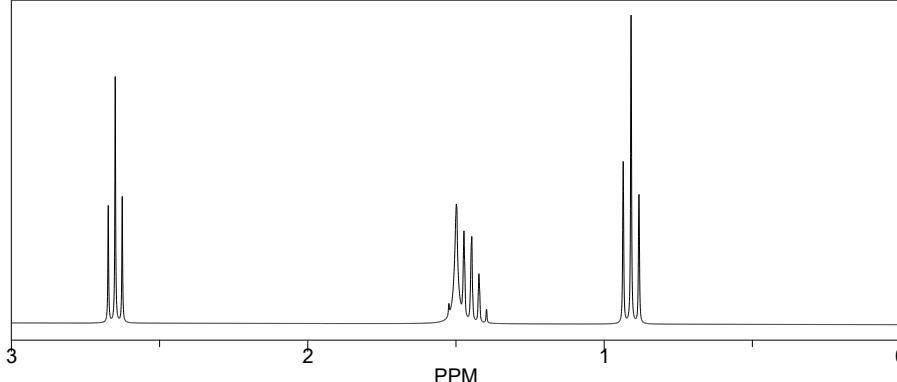
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
2.40	3	2
2.13	1	3
1.60	6	2
0.93	3	3

Check the solution to Sample T and see a work-through of the problem in [this video on YouTube](#).

# Sample U

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays Transmittance (%) on the y-axis (0 to 100) and Wavenumber (<math>\text{cm}^{-1}</math>) on the x-axis (4000 to 500). Key features include a strong absorption band around 3000 <math>\text{cm}^{-1}</math>, a sharp peak near 1700 <math>\text{cm}^{-1}</math>, and a complex pattern of peaks in the 1000-1500 <math>\text{cm}^{-1}</math> range.</p>
Mass spectrometry Mass of molecular ion: $m/z = 59$	 <p>The mass spectrum is labeled "MS-NW-2191". The y-axis represents Relative Intensity (%) from 0 to 100, and the x-axis represents the mass-to-charge ratio <math>m/z</math> from 10 to 60. The base peak is at <math>m/z = 59</math>. Other labeled peaks include <math>m/z = 15, 29, 31, 41, 57, 61</math>.</p>

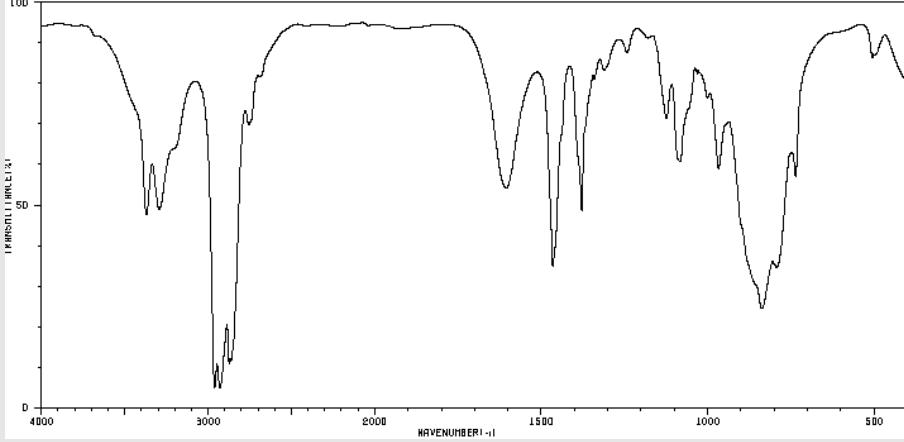
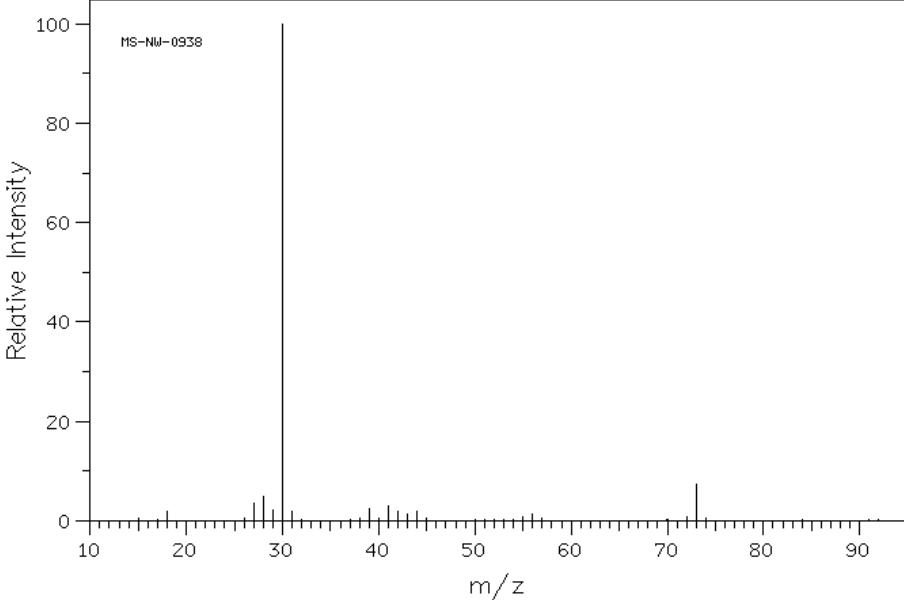
Test	Result
Carbon-13 NMR	 The spectrum shows a single sharp peak at approximately 45 ppm, indicating a quaternary carbon atom.
Proton NMR	 The spectrum shows four distinct signals: a triplet at 0.92 ppm, a multiplet at 1.46 ppm, a singlet at 1.50 ppm, and a triplet at 2.65 ppm.

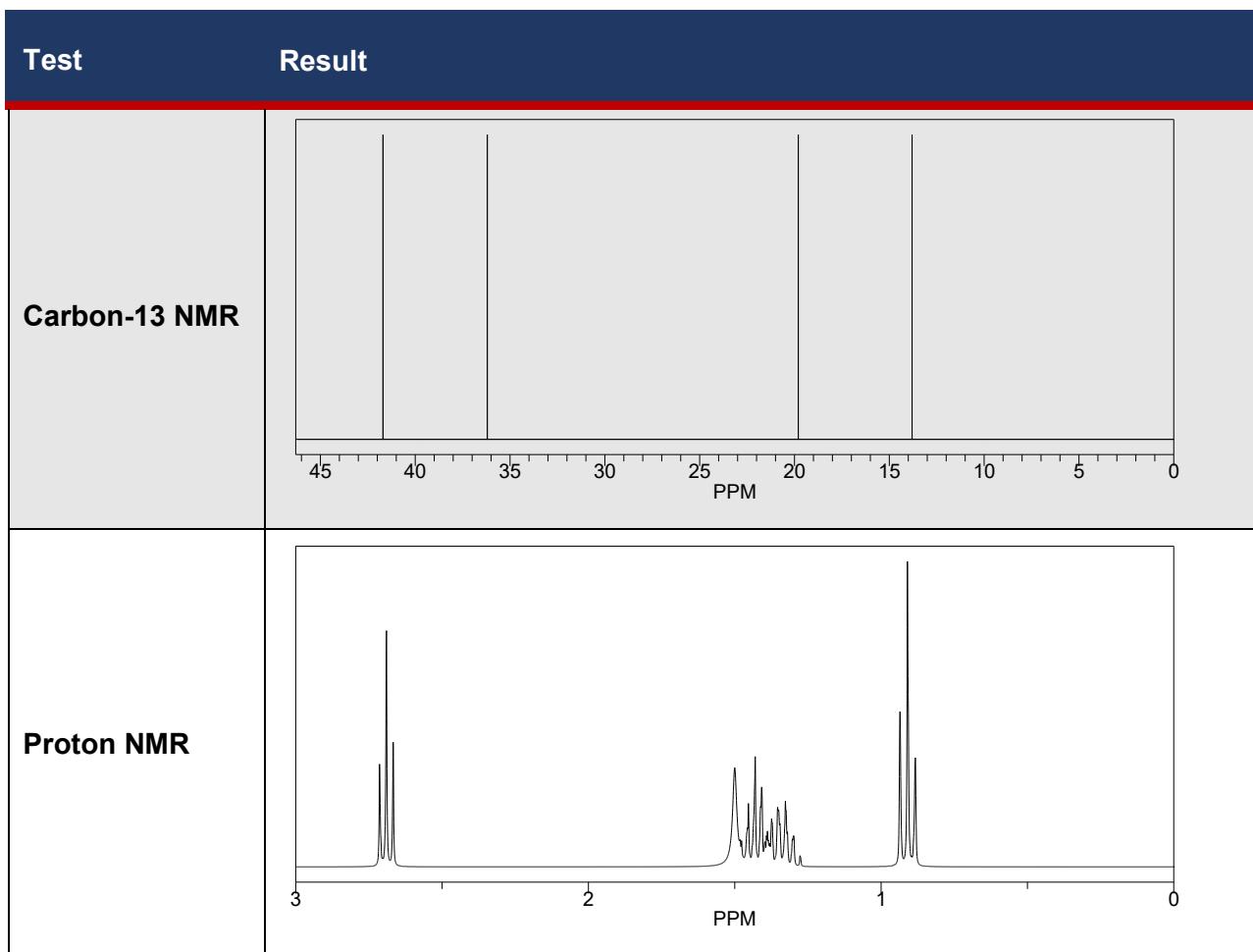
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
2.65	3	2
1.50	1	2
1.46	6	2
0.92	3	3

Check the solution to Sample U and see a work-through of the problem in [this video on YouTube](#).

## Sample V

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	
Mass spectrometry Mass of molecular ion: $m/z = 73$	 <p>MS-NI-0938</p>

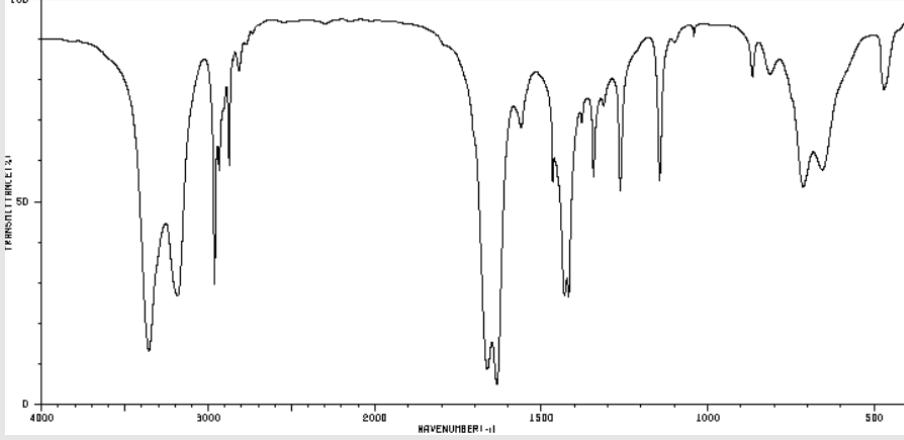
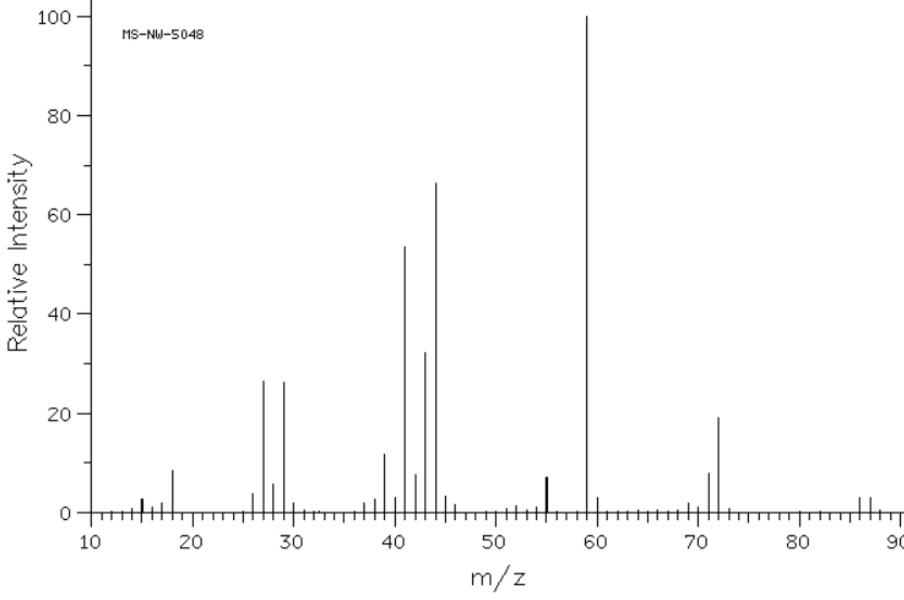


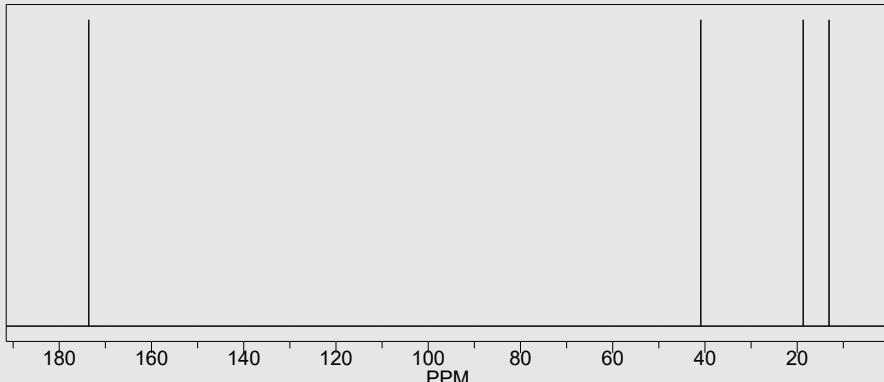
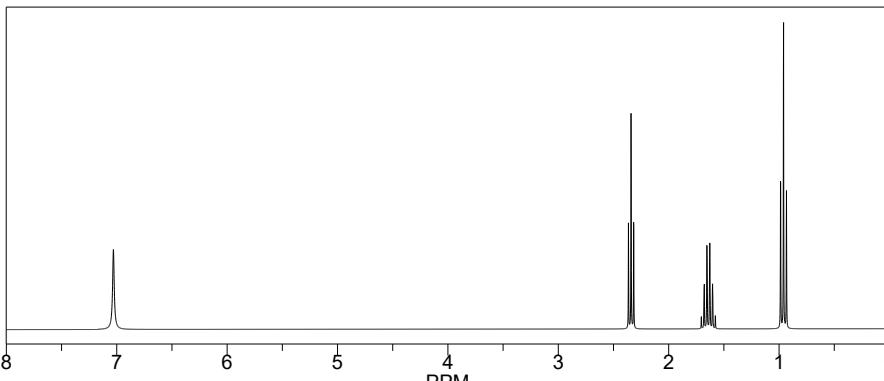
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio	Shift (ppm)	Number of peaks	Peak area ratio
2.68	3	2	1.33	6	2
1.50	1	2	0.92	3	3
1.43	5	2			

Check the solution to Sample V and see a work-through of the problem in [this video on YouTube](#).

# Sample W

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	
Mass spectrometry Mass of molecular ion: $m/z = 87$	<p>MS-NW-5048</p> 

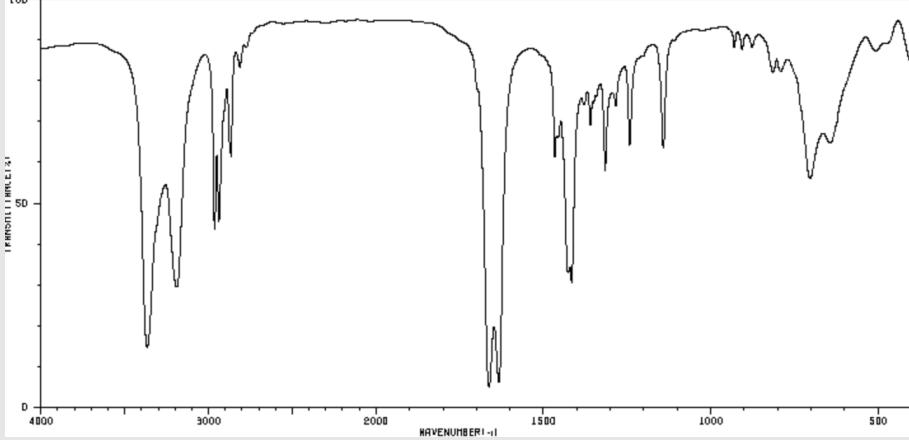
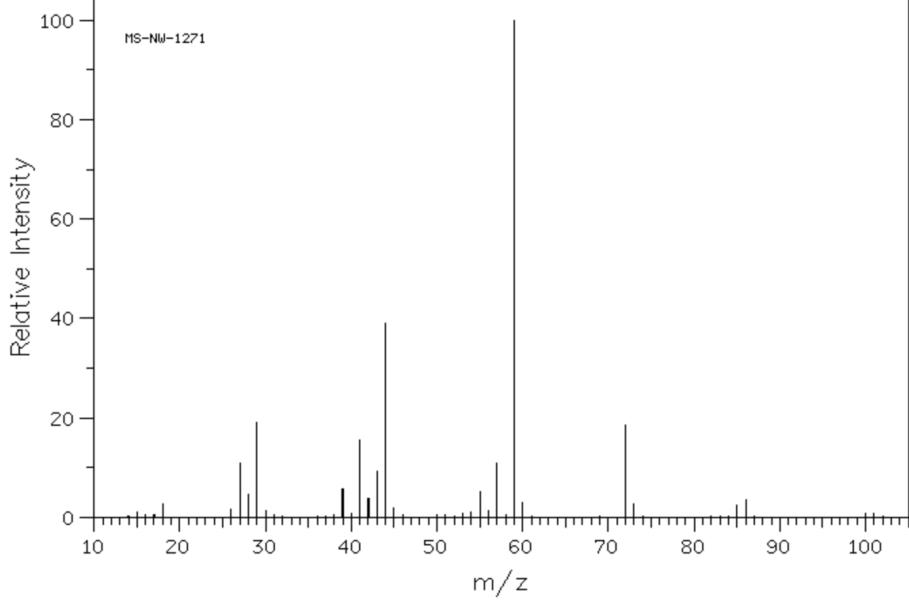
Test	Result
Carbon-13 NMR	 <p>The Carbon-13 NMR spectrum shows a sharp peak at approximately 170 ppm, a triplet-like peak at approximately 40 ppm, a doublet at approximately 20 ppm, and a triplet at approximately 10 ppm.</p>
Proton NMR	 <p>The Proton NMR spectrum shows an aromatic peak at 7.03 ppm, a triplet at 2.02 ppm, and several aliphatic peaks at 1.64 ppm, 0.96 ppm, and a small peak near 1.4 ppm.</p>

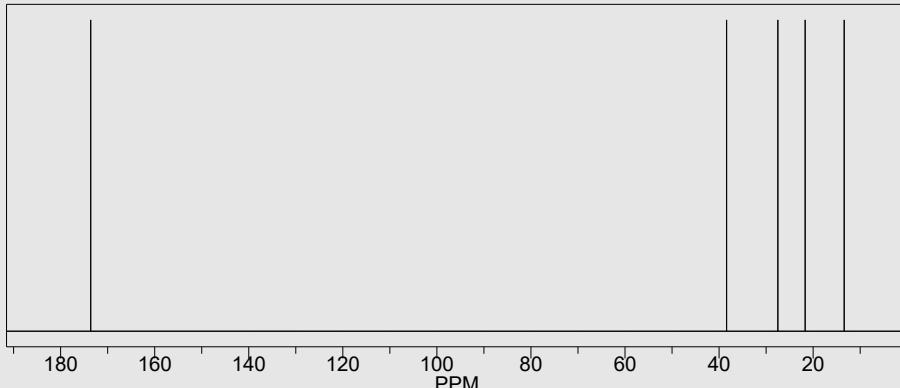
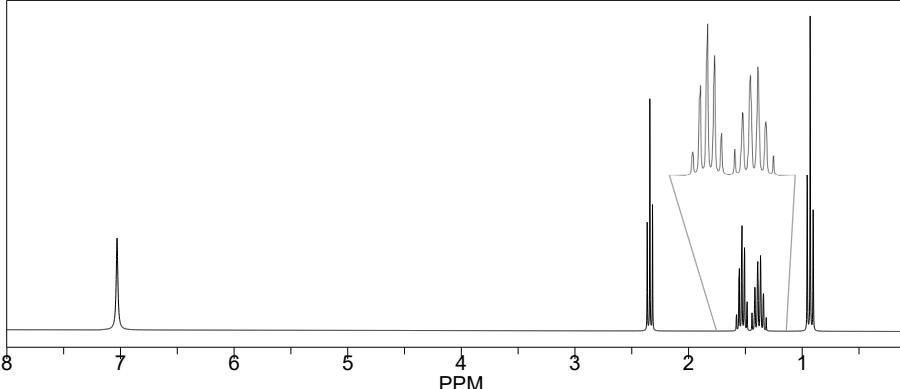
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio	Shift (ppm)	Number of peaks	Peak area ratio
7.03	1	2	1.64	6	2
2.02	3	2	0.96	3	3

Check the solution to Sample W and see a work-through of the problem in [this video on YouTube](#).

# Sample X

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays transmittance absorbance in <math>\text{cm}^{-1}</math> on the y-axis (0 to 100) against wavenumber in <math>\text{cm}^{-1}</math> on the x-axis (4000 to 500). Key features include a broad peak near 3000 <math>\text{cm}^{-1}</math>, a sharp peak at approximately 1700 <math>\text{cm}^{-1}</math>, and multiple peaks in the 1500-1000 <math>\text{cm}^{-1}</math> range.</p>
Mass spectrometry Mass of molecular ion: $m/z = 101$	 <p>The mass spectrum is labeled MS-Nu-1271. The x-axis represents the mass-to-charge ratio (<math>m/z</math>) from 10 to 100, and the y-axis represents relative intensity from 0 to 100. The base peak is at <math>m/z = 101</math>. Other labeled peaks include <math>m/z = 113, 43, 31, 61, 73, 41</math>.</p>

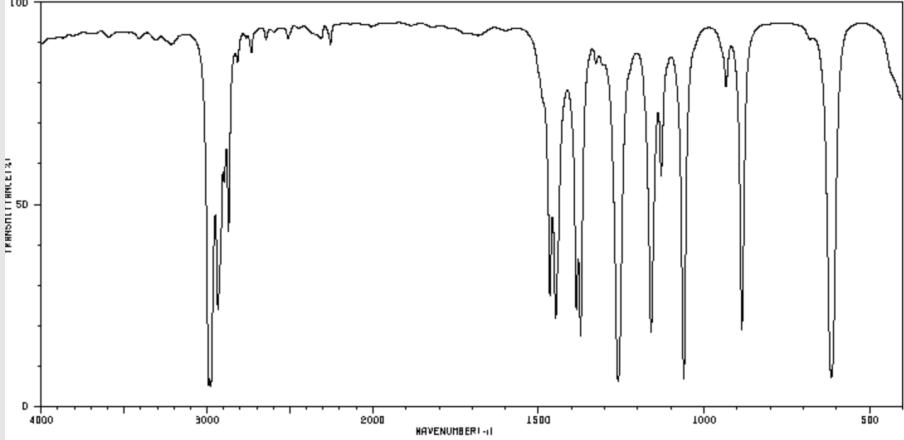
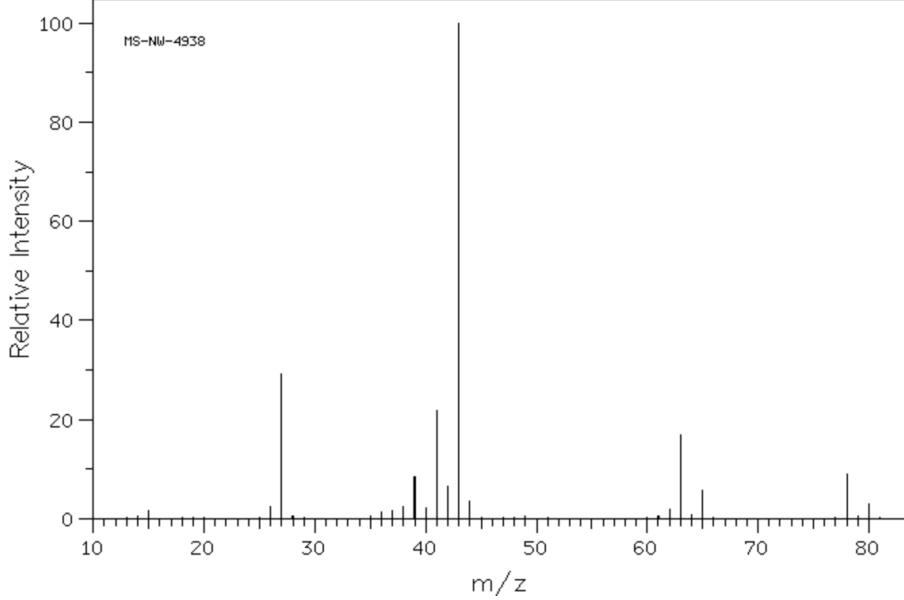
Test	Result
Carbon-13 NMR	
Proton NMR	

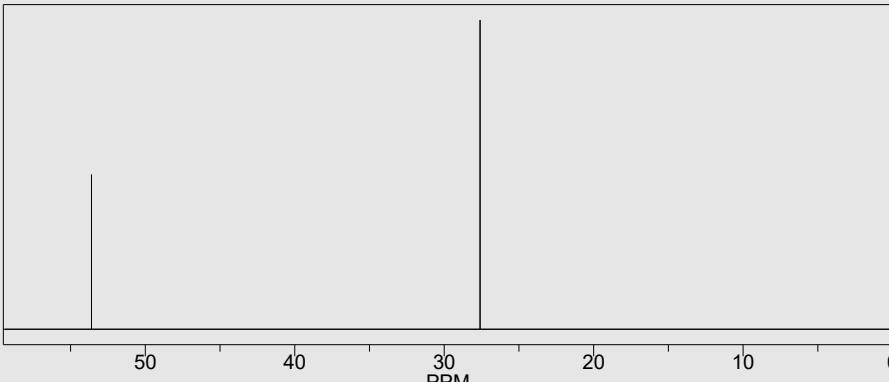
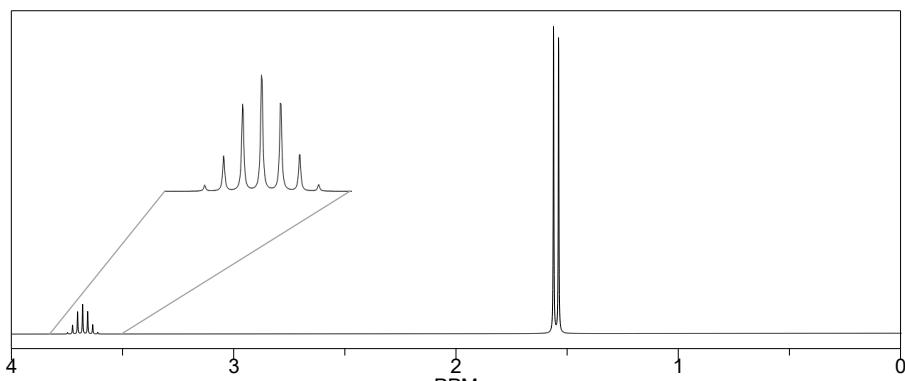
#### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio	Shift (ppm)	Number of peaks	Peak area ratio
7.03	1	1	1.53	5	2
2.34	3	2	1.37	6	2
			0.93	3	3

Check the solution to Sample X and see a work-through of the problem in [this video on YouTube](#).

# Sample Y

Test	Result												
Unsaturation test using bromine water	Orange colour remains												
Oxidation test using acidified potassium dichromate	Orange colour remains												
Carboxylic acid test using sodium carbonate	No bubbles												
Infrared spectroscopy													
Mass spectrometry Mass of molecular ion: $m/z = 78$	<p>MS-Nu-4938</p>  <table border="1"> <caption>Approximate peak data for Sample Y mass spectrum</caption> <thead> <tr> <th>m/z</th> <th>Relative Intensity (approx.)</th> </tr> </thead> <tbody> <tr><td>27</td><td>30</td></tr> <tr><td>41</td><td>10</td></tr> <tr><td>63</td><td>20</td></tr> <tr><td>78</td><td>100</td></tr> <tr><td>81</td><td>10</td></tr> </tbody> </table>	m/z	Relative Intensity (approx.)	27	30	41	10	63	20	78	100	81	10
m/z	Relative Intensity (approx.)												
27	30												
41	10												
63	20												
78	100												
81	10												

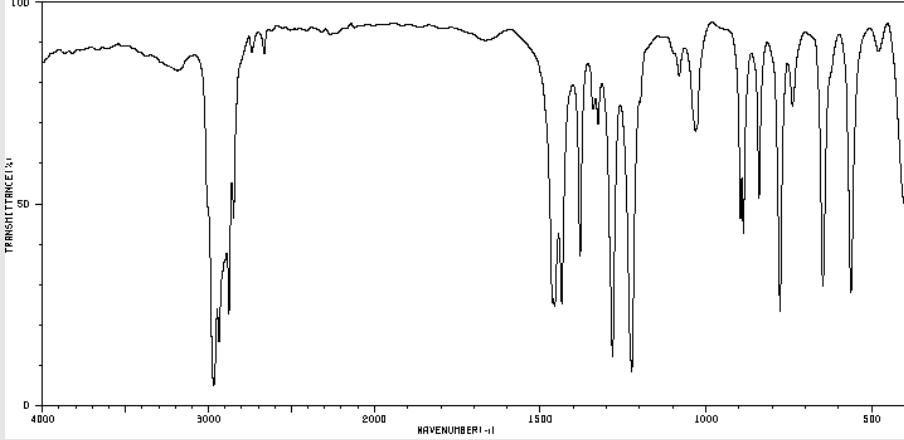
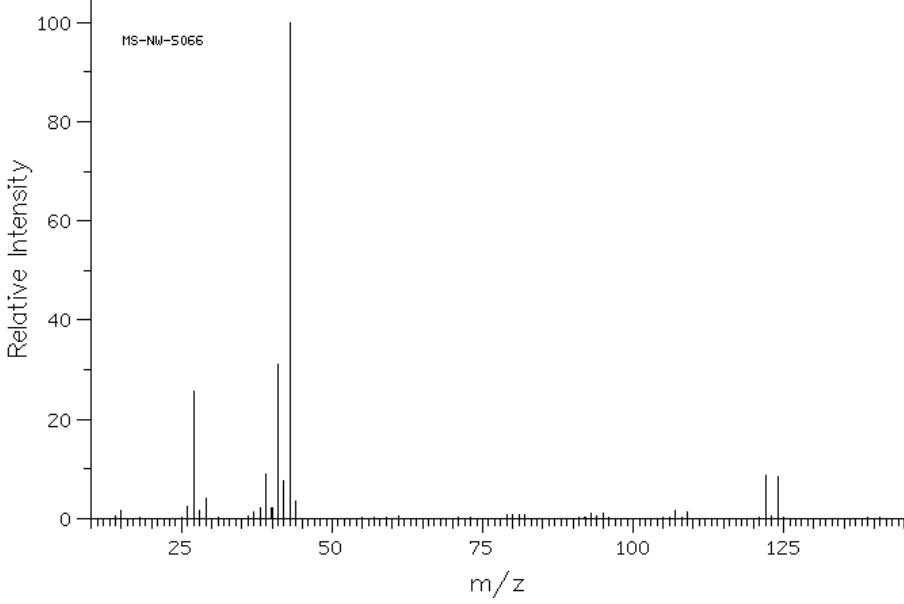
Test	Result
Carbon-13 NMR	 <p>A Carbon-13 NMR spectrum with the x-axis labeled "PPM" ranging from 0 to 50. There are two distinct peaks: one sharp peak at approximately 45 ppm and another sharp peak at approximately 17 ppm.</p>
Proton NMR	 <p>A Proton NMR spectrum with the x-axis labeled "PPM" ranging from 0 to 4. On the left side, there is a complex multiplet of peaks between 1 and 4 ppm. On the right side, there is a very sharp singlet at 1.55 ppm.</p>

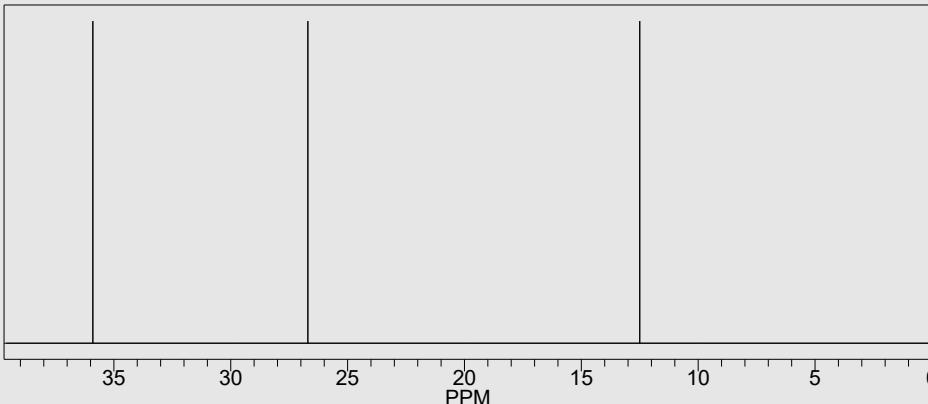
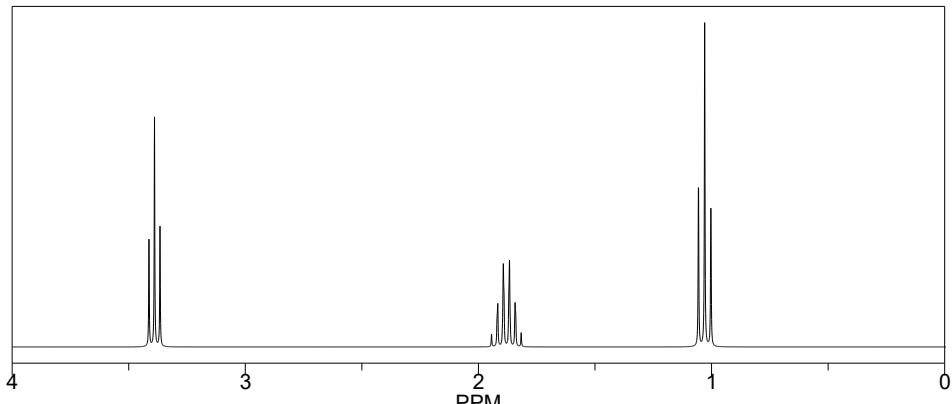
### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
3.68	7	1
1.55	2	6

Check the solution to Sample Y and see a work-through of the problem in [this video on YouTube](#).

# Sample Z

Test	Result
Unsaturation test using bromine water	Orange colour remains
Oxidation test using acidified potassium dichromate	Orange colour remains
Carboxylic acid test using sodium carbonate	No bubbles
Infrared spectroscopy	 <p>The infrared spectrum displays transmittance percentage on the y-axis (0 to 100) against wavenumber in cm⁻¹ on the x-axis (4000 to 500). Key features include a broad absorption band centered around 3000 cm⁻¹, several sharp peaks between 1500 and 1000 cm⁻¹, and a complex pattern of peaks in the fingerprint region below 1500 cm⁻¹.</p>
Mass spectrometry Mass of molecular ion: $m/z = 122$	 <p>The mass spectrum shows relative intensity on the y-axis (0 to 100) versus the mass-to-charge ratio (<math>m/z</math>) on the x-axis (25 to 125). The base peak is at <math>m/z = 122</math>. Other labeled peaks include <math>m/z = 27</math>, <math>m/z = 35</math>, and <math>m/z = 43</math>.</p>

Test	Result
Carbon-13 NMR	 PPM
Proton NMR	 PPM

### Proton NMR peak data

Shift (ppm)	Number of peaks	Peak area ratio
3.39	3	2
1.87	6	2
1.03	3	3

Check the solution to Sample Z and see a work-through of the problem in [this video on YouTube](#).

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