Mass spectrometry

- Electron impact Mass spectrometry

Bombard your molecules with high energy electrons

\[ \text{e}^- \quad 70 \text{ eV} \quad \text{M} \quad \rightarrow \quad \text{M}^{++} \quad + \quad 2 \text{e}^- \]

(BANG!)

- 70 eV = 1614 kcal/mol
  - contrast with energy from IR (1-10 kcal/mol) or NMR (0.2 cal/mol)
  - typical C-C bond = 100 kcal/mol
- Point: lots of energy in play here
  - you can eject electrons, break bonds, etc.

- don’t call it spectroscopy (absorption of electromagnetic radiation)

- Electron impact Mass spectrometry

Upon ionization, radical cations (M+) are accelerated toward a negatively charged plate with a slit. Some of the ions pass through the slit to form a beam.

- ions follow a curved path between poles of a magnet.

\[ F = zvB \]

where \( z \) = point charge
\( v \) = velocity
\( B \) = Field strenght

particles follow circular pathway as a function of time
Electron impact Mass spectrometry

- Uniform circular motion in the magnetic field

\[ F = zvB \]
where \( z \) = point charge
\( v \) = velocity
\( B \) = Field strength

Particles follow circular pathway as a function of time.

- Rearranged:
\[ \frac{m}{z} = \frac{RB}{v} \]

Thus, we can observe different masses by holding velocity and radius constant, and varying \( B \).

Usually, \( z = 1 \), so \( m/z = m \).
Molecular Weight vs Exact Mass

**Molecular Mass** refers to the average mass of molecules made from their natural isotopic abundance:

**Exact Mass:** The mass of the most abundant isotopic form of a molecule.

**Example:** \( \text{HOCH}_2\text{CH}_2\text{Cl} \)

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Abundance</th>
<th>Isotope</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^1\text{H})</td>
<td>99.985</td>
<td>(^{17}\text{O})</td>
<td>0.038</td>
</tr>
<tr>
<td>(^2\text{H}) (D)</td>
<td>0.015</td>
<td>(^{18}\text{O})</td>
<td>0.200</td>
</tr>
<tr>
<td>(^{12}\text{C})</td>
<td>98.90</td>
<td>(^{35}\text{Cl})</td>
<td>75.77</td>
</tr>
<tr>
<td>(^{13}\text{C})</td>
<td>1.10</td>
<td>(^{37}\text{Cl})</td>
<td>24.23</td>
</tr>
<tr>
<td>(^{14}\text{N})</td>
<td>99.63</td>
<td>(^{79}\text{Br})</td>
<td>50.69</td>
</tr>
<tr>
<td>(^{15}\text{N})</td>
<td>0.37</td>
<td>(^{81}\text{Br})</td>
<td>49.31</td>
</tr>
<tr>
<td>(^{16}\text{O})</td>
<td>99.762</td>
<td>(^{127}\text{I})</td>
<td>100</td>
</tr>
</tbody>
</table>

**TABLE 15.1 Some Common Isotopes and Their Abundances**

\[
\begin{align*}
\text{Molecular Weight:} & \quad 2 \times \text{C: } 2 \times 12.011 : 24.022 \\
& \quad 1 \times \text{O: } 1 \times 15.999 : 15.999 \\
& \quad 1 \times \text{Cl: } 1 \times 35.453 : 35.453 \\
& \quad 5 \times \text{H: } 5 \times 1.008 : \underline{5.040} \\
& \quad \text{MW: } 80.514 \\
\text{Exact Mass:} & \quad 2 \times \text{C: } 2 \times 12.000 : 24.000 \\
& \quad 1 \times \text{O: } 1 \times 15.9949 : 15.9949 \\
& \quad 1 \times \text{Cl: } 1 \times 34.9689 : 34.9689 \\
& \quad 5 \times \text{H: } 5 \times 1.0078 : \underline{5.0390} \\
& \quad \text{Exact Mass: } 80.003
\end{align*}
\]
High-Resolution MS can determine the exact molecular formula

Isotopic Abundance

<table>
<thead>
<tr>
<th>Isotope Patterns of Naturally Occurring Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>H  1</td>
</tr>
<tr>
<td>N  14</td>
</tr>
<tr>
<td>Al  27</td>
</tr>
<tr>
<td>K  39</td>
</tr>
<tr>
<td>Mn  55</td>
</tr>
<tr>
<td>Ga  69</td>
</tr>
<tr>
<td>Rb  85</td>
</tr>
</tbody>
</table>
Ionization:

- Lone pair electrons are more easily displaced than bonding electrons.
- Electrons in pi-bonds are more easily displaced than those in single bonds.

Fragmentation: Alkanes

\[
\begin{align*}
\text{Fragmentation: Alkanes} & \\
\text{CH}_2\text{CH}_2\text{CH}_2 & \rightarrow \text{CH}_2\text{CH}_3 + \hat{\text{CH}_3} \\
\text{CH}_3\text{CH}_2\text{CH}_2 & \rightarrow \hat{\text{CH}_3} + \text{CH}_2=\text{CH}_2
\end{align*}
\]
Alkenes/Alkynes

\[
\begin{align*}
\left[\text{alkene}\right]^+ & \rightarrow \text{alkene}^+ \\
\left[\text{alkyne}\right]^+ & \rightarrow \text{alkyne}^+
\end{align*}
\]

Halides:

\[
\begin{align*}
\left[\text{alkene-Br}\right]^+ & \rightarrow \text{alkene-CH}_2^+ + \cdot\text{Br}
\end{align*}
\]

Note: unique isotopic ratio of most halides!
Aromatic:

\[
\begin{align*}
\text{CH}_3 & \quad 70 \text{ ev} \\
\text{m} = 92 & \quad \rightarrow \quad \text{m-1} = 91 \\
\end{align*}
\]

Tropillium ion

\[
\begin{align*}
\text{ROH} & \quad \text{Alcohols} \\
\text{Note: molecular ion is often weak or absent.} \\
\text{alpha cleavage and dehydration are common fragmentations} \\
\end{align*}
\]
**ROR Ethers**
Notes: molecular ion is often weak
alpha cleavage are common fragmentations

\[ \text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3 \] \( \text{**} \) \( \rightarrow \) \[ \text{CH}_2\text{OCH}_2\text{CH}_3 \]
\[ \text{CH}_2\text{OCH}_2\text{CH}_3 \]

Ethers with branched alpha carbons tend to undergo secondary fragmentation

\[ \text{O} \] \( \rightarrow \) \[ \text{H} \]
\[ \text{m} = 102 \]
\[ \text{m-15} = 87 \]
\[ \text{m/z} = 45 \]

**Ketones and Aldehydes:**
Major Fragmentation pattern is alpha cleavage resulting in loss of side-chain and formation of acylium ion
Also McLafferty Rearrangement where possible!

\[ \text{R}_1\text{C}=\text{O} \] \( \text{**} \) \( \rightarrow \) \[ \text{R}_1\text{C}=\text{O} \]
\[ \text{R}_1\text{C}=\text{O} \]

**Esters, Acids, Amides:**
Major Fragmentation pattern is alpha cleavage resulting in loss of side-chain and formation of acylium ion
Also McLafferty Rearrangement where possible!

\[ \text{X} = \text{OH, OR, NH}_2, \text{NHR} \]

**note:**
\[ \text{HO-C}=\text{O} \] \( \text{m/z} = 45 \)
\[ \text{H}_2\text{N-C}=\text{O} \] \( \text{m/z} = 44 \)
The McLafferty Rearrangement:

\[ \text{must have gamma proton} \]

Alkene Fragmentation Revisited

McLafferty - like rearrangement of Alkenes.
Commonly Lost Fragments

- m-15 \cdot \text{CH}_3
- m-17 \cdot \text{OH}
- m-26 \cdot \text{CN}
- m-28 \text{H}_2\text{C} = \text{CH}_2
- m-29 \cdot \text{CH}_2\text{CH}_3 \cdot \text{CHO}
- m-31 \cdot \text{OCH}_3
- m-35 \cdot \text{Cl}
- m-43 \text{CH}_3\text{C} = \text{O}
- m-45 \cdot \text{OCH}_2\text{CH}_3
- m-91 \begin{tikzpicture}
  \draw[purple,ultra thick] (0,0) -- (1,0);
  \draw[purple,ultra thick] (0,0) -- (0,1);
  \draw[purple,ultra thick] (1,0) -- (1,1);
  \draw[purple,ultra thick] (0,1) -- (1,1);
\end{tikzpicture}

Common Stable Ions

- m/e = 43 \begin{tikzpicture}
  \draw[blue,ultra thick] (0,0) -- (1,0);
  \draw[blue,ultra thick] (0,0) -- (0,1);
  \draw[blue,ultra thick] (1,0) -- (1,1);
  \draw[blue,ultra thick] (0,1) -- (1,1);
\end{tikzpicture}

- m/e = 91 \begin{tikzpicture}
  \draw[green,ultra thick] (0,0) -- (1,0);
  \draw[green,ultra thick] (0,0) -- (0,1);
  \draw[green,ultra thick] (1,0) -- (1,1);
  \draw[green,ultra thick] (0,1) -- (1,1);
\end{tikzpicture}

- m/e = m-1 \begin{tikzpicture}
  \draw[red,ultra thick] (0,0) -- (1,0);
  \draw[red,ultra thick] (0,0) -- (0,1);
  \draw[red,ultra thick] (1,0) -- (1,1);
  \draw[red,ultra thick] (0,1) -- (1,1);
\end{tikzpicture}

\text{C}_5\text{H}_{12}\text{O} \text{ MW} = 88.15

\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}
Problem: 
$C_7H_7Br$

![Diagram of $C_7H_7Br$ with an m/e range showing peaks at 91, 170, and 172. The diagram also shows structures labeled as $n^+$, $m/e = 91$, and "has bromine!".]

Problem: 
$C_9H_{10}O$  
MW = 134.18

![Diagram of $C_9H_{10}O$ with an m/e range showing peaks at 43, 91, 43, 15, and 134. The diagram also shows structures labeled as $n^+$, $m/e = 91$, and "has an oxide."].
$C_{12}H_{24}O$

13-C NMR

210, s
43.1, t
42.6, t
31.4, t
30.6, t
23.3, t
22.8, t
22.5, t
22.1, t
14.1, t
12.1, q
10, q

1H-NMR

2.45 (broad triplet, J=7.6 Hz, 4H)
1.60 (m, 4H)
1.2-1.4 (m, 10H)
0.96 (broad triplet, J = 6.8 Hz, 6H)

MS:
184.2 (5), 128.1(98), 114.1(100), 99.1(8), 113.1(10),

which is it?
When MS really helps:

Middle of a chain:

Assembly of subunits

Identification of ring substitutions.

What is MS good for?

• The complex fragmentation patterns can be used as a finger print to identify a compound.

• MS is extremely sensitive! fempto-mole quantities can be detected!

• As seen on TV! Used in crime seen investigation to detect trace evidence.

Wanted: Better methods to ionize molecules without the molecule falling apart
Ionization Methods

- Chemical Ionization: A carrier gas (e.g., Methane) is activated by EI. Radical cations protonate the analyte.
- Fast Atom Bombardment: High Energy Atoms (Xe or AR) strike a sample leading to desorption and ionization.
- Electrospray: Formation of charged liquid Droplets which lose solvent to form ionized molecules.

One early major breakthrough, described by M.S.B. Munson and F.H. Field in 1966 [1], was the use of chemical ionisation (CI), which for the first time made it possible to ionise thermo-labile biomolecules. In CI, abundant reagent gas ions are first formed by electric discharge of a reagent gas, and the reagent ions then in turn ionise volatilised molecules of interest.
SIMS Imaging
(Secondary Ionization Mass Spectrometry)