Mass Spectrometry Fundamentals – Theory

BUILDING BETTER SCIENCE

AGILENT AND YOU
Agilent Technologies is committed to the educational community and is willing to provide access to company-owned material.

This slide set was created by Agilent for teaching purposes only.

If you wish to use the pictures, sketches, or drawings for any other purpose, please contact Agilent first.
Mass spectrometry (MS) is an analytical chemistry technique that helps identify the amount and type of chemicals present in a sample by measuring the mass-to-charge ratio and abundance of gas-phase ions.

A mass spectrum (plural spectra) is a plot of the ion signal as a function of the mass-to-charge ratio. From spectra, the mass of the molecular ion and fragments are used to determine the elemental composition or isotopic signature of a compound. This information is used to elucidate the chemical structures of molecules, such as pesticides or peptides.

Mass spectrometry works by ionizing chemical compounds to generate charged molecules or molecule fragments and measuring their mass-to-charge ratios.

Introduction
Nobel Prize Winning Technology

John Fenn and Koichi Tanaka won the Nobel Prize in Chemistry in 2002 for the development of two soft ionization technologies:

- Electrospray technology, Dr. Fenn
- Soft laser desorption, Dr. Tanaka
# Table of Contents (TOC)

## Introduction
- Basic Considerations
- Masses in Mass Spectrometry
- Fundamental Steps

## How It Works
- Ionization
  - Electron Impact
  - Chemical Ionization
  - Sample Considerations (LC-MS)
  - Electrospray
  - Atmospheric Pressure Chemical Ionization
  - Atmospheric Pressure Photo Ionization
  - Multimode Ionization
  - MALDI
  - ICP

## How It Works
- Mass Analyzer
  - Single Quadrupole
  - Triple Quadrupole
  - Ion Trap
  - Time-of-Flight

## Results
- Mass Spectrum
- Single Quad vs. TOF
- Multiply Charged Ions and Deconvolution

## Further Information
- Agilent Academia Webpage
- Publications
Introduction
Basic Considerations

Elements can be uniquely identified by their mass. Mass Spectrometry is an analytical method to measure molecular or atomic weight.

Compounds, consisting of different elements, can be distinguished by their mass:

Glucose $\text{C}_6\text{H}_{12}\text{O}_6$
MW: 180,1559 g/mol

Penicillin $\text{C}_{16}\text{H}_{18}\text{N}_2\text{O}_4\text{S}$
MW: 334,39 g/mol

Source: Periodic table, poster SI-0186
Introduction
Masses in Mass Spectrometry

The **average mass** of a molecule is obtained by summing the average atomic masses of the constituent elements.

**Average mass of water (H\textsubscript{2}O):**

\[
1.00794 + 1.00794 + 15.9994 = 18.01528 \text{ Da}
\]

The **monoisotopic mass** is the sum of the masses of the atoms in a molecule using the unbound, ground-state, rest mass of the principal (most abundant) isotope for each element instead of the isotopic average mass. Monoisotopic mass is typically expressed in unified atomic mass units.

The **accurate mass** (more appropriately, the measured accurate mass) is an experimentally determined mass that allows the elemental composition to be determined. For molecules with mass below 200 u, 5 ppm accuracy is often sufficient to uniquely determine the elemental composition.

Introduction

Fundamental Steps

Typical MS procedure:

- Sample (solid, liquid, gas) is ionized
- Sample’s molecules might break into charged fragments during ionization
- Ions are separated according to their mass-to-charge ratio (m/z)
- Ions are detected by a mechanism capable of detecting charged particles (e.g. electron multiplier)
- Results are displayed as spectra of the relative abundance as a function of m/z ratio
- Identification is done by correlating known masses to the identified masses or through a characteristic fragmentation pattern
How It Works

Ionization

Before the sample can be mass analyzed, it must be ionized in the ion source.

**Gaseous Sample Introduction:**
- Electron Ionization (EI)
- Chemical Ionization (CI)

**Liquid Sample Introduction:**
- Electrospray Ionization (ESI)
- Atmospheric Pressure Chemical Ionization (APCI)
- Atmospheric Pressure Photo Ionization (APPI)
- Multimode Ionization (MMI)
- Matrix Assisted Laser Desorption Ionization (MALDI)
- Inductively Coupled Plasma (ICP)
How It Works

Ionization

Polarity of analytes determines the ionization source.

ESI  Electrospray ionization
APPI  Atmospheric pressure photo ionization
APCI  Atmospheric pressure chemical ionization
GC/MS  Gas chromatography / Mass spectrometry
How It Works

Ionization – Electron Impact (EI)

Electron Impact (EI) is well established, and is the most common method of ionization in Gas Chromatography (GC).

The molecules exiting the gas chromatograph are bombarded by an electron beam (70 eV) which removes an electron from the molecule resulting in a charged ion.

\[
\text{CH}_3\text{OH} + 1 \text{ electron} \rightarrow \text{CH}_3\text{OH}^+ + 2e^- \quad \text{Molecular ion}
\]

EI typically produces single charged molecular ions and fragment ions (smaller parts of the original molecules) which are used for structure elucidation.

\[
\text{CH}_3\text{OH}^+ \rightarrow \text{CH}_2\text{OH}^+ + \text{H}^+ \quad \text{or} \quad \text{CH}_3\text{OH}^+ \rightarrow \text{CH}_3^+ + \text{OH}^+ \quad \text{Fragment ion}
\]

An electron or photomultiplier detects the separated ions. The generated mass spectrum plots the signal intensity at a given m/z ratio.
How It Works
Ionization – Electron Impact (EI)

The GC/MS interface operates at high temperatures.

Column end protrudes 1 to 2 mm into the ionization chamber.

The EI GC/MS Interface. Source: Agilent 7000 Series Triple Quad GC/MS Operation Manual (p 46)
How It Works
Ionization – Chemical Ionization (CI)

EI is a direct energy transfer process with electron kinetic energy deposited directly into an analyte molecule.

CI is an indirect process involving an intermediate chemical agent. This is particularly true in positive chemical ionization (PCI). In PCI, the ion source is filled with a reagent gas which is ionized to create reagent ions which react with the analyte.

Most frequently used reagent gases: methane, iso-butane and ammonia.
The applied reagent gas determines the ionization and fragmentation behavior of the analyte.

The principal methane reactions are:

\[
\begin{align*}
\text{CH}_4 + e^- & \rightarrow \text{CH}_4^+, \text{CH}_3^+, \text{CH}_2^+ \\
\text{CH}_4 + \text{CH}_4^+ & \rightarrow \text{CH}_5^+, \text{CH}_3^* \\
\text{CH}_2^+ + \text{CH}_4 & \rightarrow \text{C}_2\text{H}_4^+ + \text{H}_2 \\
\text{CH}_2^+ + \text{CH}_4 & \rightarrow \text{C}_2\text{H}_3^+ + \text{H}_2^+\text{H}^* \\
\text{CH}_3^+ + \text{CH}_4 & \rightarrow \text{C}_2\text{H}_5^+ + \text{H}_2 \\
\text{C}_2\text{H}_3^+ + \text{CH}_4 & \rightarrow \text{C}_3\text{H}_5^+ + \text{H}_2
\end{align*}
\]

The reagent gas is ionized by electrons entering the ionization source.

See notes for details
# How It Works

## Ionization – Sample Considerations (LC/MS)

<table>
<thead>
<tr>
<th></th>
<th>ESI</th>
<th>APCI</th>
<th>APPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatility not required</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Preferred technique for thermally labile analytes</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Ions formed in solution</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Can form multiply charged ions</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Some volatility required</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Analyte must be thermally stable</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Ions formed in gas phase</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Forms singly charged ions only</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Many compounds will ionize well using all three sources. APCI / APPI can ionize molecules that are too non-polar for ESI to ionize.
# How It Works

## Ionization – Sample Considerations (LC/MS)

<table>
<thead>
<tr>
<th>Method</th>
<th>Sample Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESI</td>
<td>1. <strong>Ions in solution</strong> e.g. catecholamine, sulfate conjugates, quaternary amines</td>
</tr>
<tr>
<td></td>
<td>2. Compounds containing <strong>heteroatoms</strong> e.g. carbamates, benzodiazepines</td>
</tr>
<tr>
<td></td>
<td>3. Compounds that multiply <strong>charge in solution</strong> e.g. proteins, peptides, oligonucleotides</td>
</tr>
<tr>
<td>APCI</td>
<td>1. Compounds of intermediate <strong>MW and polarity</strong> e.g. PAHs, PCBs, fatty acids, phthalates, alcohols</td>
</tr>
<tr>
<td></td>
<td>2. Compounds containing <strong>heteroatoms</strong> e.g. carbamates, benzodiazepines</td>
</tr>
<tr>
<td></td>
<td>3. Compounds that are too <strong>non-polar for ESI response</strong></td>
</tr>
<tr>
<td>APPI</td>
<td>1. Compounds of intermediate <strong>MW and intermediate to low polarity</strong> e.g. PAHs, PCBs, fatty acids, phthalates, alcohols</td>
</tr>
<tr>
<td></td>
<td>2. Compounds containing <strong>heteroatoms</strong> e.g. carbamates, benzodiazepines</td>
</tr>
<tr>
<td></td>
<td>3. Compounds that are too <strong>non-polar for ESI response</strong></td>
</tr>
</tbody>
</table>
How It Works
Ionization – Electrospray (ESI)

Electrospray ionization (ESI) is a soft ionization technique.

LC eluent is sprayed (nebulized) into a spray chamber at atmospheric pressure in the presence of a strong electrostatic field and heated drying gas. The electrostatic field occurs between the nebulizer, which is at ground in this design, and the capillary, which is at high voltage.

Suitable molecules:
- Small molecules (glucose) and large biomolecules (proteins, oligonucleotides)

Multiple charging is the phenomena in ESI that allows analysis of larger molecules (→ Deconvolution)

Electrospray ion source
Source: LC/MS concept guides (p 22)
How It Works

Ionization – ESI Process

From charged droplets to analyte ions

The nebulizer produces a uniform droplet size. The charged droplets are attracted toward the dielectric capillary. The heated nitrogen stream surrounding the capillary shrinks the droplets. This process is called desolvation.

The droplets continue to shrink until the repulsive electrostatic (Coulombic) forces exceed the droplet cohesive forces, leading to droplet explosions. This process is repeated until analyte ions are ultimately desorbed into the gas phase, driven by strong electric fields on the surface of the microdroplets. This process is called ion evaporation.
How It Works
Ionization – Atmospheric Pressure Chemical Ionization (APCI)

APCI is a gas-phase chemical ionization process. Therefore, the analyte needs to be in the gas phase for ionization.

LC eluent passes a nebulizing needle, which creates a fine spray.

The droplets are fully vaporized in a heated ceramic tube (~ 400 to 500°C).

Suitable molecules:

- Molecules < 1,500 u
- Less polar and non-polar compounds (typically analyzed by normal-phase chromatography)

Source: LC/MS concept guides (p 27)
How It Works
Ionization – APCI Process

This shows the evaporation and ionization processes of APCI.

Note that the analyte is not ionized until after evaporation and after the reagent gas is ionized.

The reagent gas then transfers a charge to the analyte.

Typically APCI generates just singly charged ions, however, it is possible to get doubly charged ions where the charge sites are held apart (usually by a hydrophobic region).

See notes for details
How It Works
Ionization – Atmospheric Pressure Photo Ionization (APPI)

With the APPI technique, LC eluent passes through a nebulizing needle to create a fine spray.

Droplets are fully vaporized in a heated ceramic tube.

The gas/vapor mixture passes through the ultraviolet light of a krypton lamp to ionize the sample molecules. The sample ions are then introduced into the capillary.

APPI is applicable to many of the same compounds that are typically analyzed by APCI. APPI has proven particularly valuable for analysis of non-polar, aromatic compounds.

Atmospheric pressure photoionization source
Source: LC/MS concept guides (p 29)
How It Works
Ionization – APPI Process

This shows the evaporation and ionization processes of photoionization.

APPI and APCI are similar, with APPI substituting a lamp for the corona needle for ionization. APPI often also uses an additional solvent or mobile phase modifier, called a “dopant” \( (D) \), to assist with the photoionization process.

Direct APPI:

\[
M + h\nu \rightarrow M^{*+} + e^{-}
\]

\[
M^{*+} + SH \rightarrow [M + H]^{+} + S^{*}
\]

Dopant APPI:

\[
D + h\nu \rightarrow D^{*+} + e^{-}
\]

\[
D^{*+} + M \rightarrow [M + H]^{+} + D
\]

\[
D^{*+} + M \rightarrow M^{*+} + D
\]

See notes for details
How It Works

Ionization – Multi Mode Ionization (MMI)

The multimode source is an ion source that can operate in three different modes:

- APCI
- ESI
- Simultaneous APCI/ESI

It incorporates two electrically separated, optimized zones – one for ESI and one for APCI. During simultaneous APCI/ESI, ions from both ionization modes enter the capillary and are analyzed simultaneously by the mass spectrometer.

MMI is useful for screening of unknowns, or whenever samples contain a mixture of compounds where some respond by ESI and some respond by APCI.

Multimode source
Source: LC/MS concept guides (p 30)
How It Works

Ionization – Matrix-Assisted Laser Desorption/Ionization (MALDI)

Matrix-assisted laser desorption/ionization (MALDI) is a soft ionization technique.

Sample is mixed with matrix and applied to a metal plate.

A pulsed laser irradiates the sample, triggering ablation and desorption.

The analyte molecules are ionized in the hot plume of ablated gases.

Ions are accelerated into the mass spectrometer.

Suitable molecules:

- Biomolecules (DNA, proteins, sugars)
- Large organic molecules (polymers)
How It Works
Ionization – Inductively Coupled Plasma (ICP)

An inductively coupled plasma (ICP) instrument uses a plasma source in which the energy is supplied by electric currents which are produced by electro-magnetic induction, that is, by time varying magnetic fields. The plasma is so energetic it reduces molecules to ionized elements.

There are different types of ICP geometries available that can be coupled to different technologies:

- ICP-AES  Atomic Emission Spectroscopy
- ICP-OES  Optical Emission Spectroscopy
- ICP-MS  Mass Spectrometry
- ICP-RIE  Reactive-Ion Etching


Schematic diagram showing the interrelationships of the various components in a hyphenated ICP-MS system
How It Works
Mass Analyzer

After ionization and ion transport, analytes enter the mass analyzer. The mass spectrometer measures the ion signals resulting in a mass spectra, which can provide valuable information about the molecular weight, structure, identity, and quantity of a compound.

There are different types of mass analyzers:

- Single Quadrupole (SQ)
- Triple Quadrupole (QQQ)
- Time-of-Flight (TOF)
- Ion Trap (IT)
How It Works
Mass Analyzer – Single Quadrupole (SQ)

Charged ions generated in the ion source enter the mass analyzer. The quadrupole mass analyzer is scanned sequentially such that only a single ion m/z may be passed at one time. All other ions are lost.

$m/z$ - mass-to-charge ratio:
Mass of an ion (Daltons or u) divided by the number of charges on the ion

Information received: **MS only**
How It Works

Mass Analyzer – Single Quadrupole (SQ)

Single Ion Monitoring (SIM)

A target ion with specific $m/z$ is monitored. SIM on a single quad permits the best sensitivity for quantitation, however it lacks specificity.

Scan Mode

In Scan MS mode, the quadrupole mass analyzer is scanned sequentially allowing only 1 $m/z$ at a time to pass to the detector.
How It Works
Mass Analyzer – Triple Quadrupole (QQQ)

Charged ions generated in the ion source enter the mass analyzer.

The analyzer consists of three quadrupoles (Q1-Q3) and therefore several modes of operation resulting in different information.

A common set is the following:

• Q1: used as a filter for specific $m/z$ (precursor ion)
• Q2: used as collision cell to fragment the precursor ion and generate product ions
• Q3: set to specific $m/z$ (SRM or MRM) or scan mode (product ion scan)

Information received: **MS and MS/MS**
How It Works
Mass Analyzer – Triple Quadrupole (QQQ)

Multiple Reaction Monitoring (MRM)

Precursor ions with single m/z are passing to collision cell. Fragment ions are generated by collision with nitrogen molecules. Q3 is set to single m/z of specific fragment ion. This is a very sensitive method and used for quantitation.

Full Scan MS/MS Mode

The difference in full scan mode compared to SRM/MRM is the scanning function. Q3 is scanned sequentially allowing only 1 m/z at a time to pass to the detector. A product ion spectrum is generated. This mode of operation is less sensitive compared to SRM/MRM.
How It Works
Mass Analyzer – Ion Trap (IT)

Charged ions generated in the ion source enter the mass analyzer. All ions of the selected polarity over the selected mass range can be stored at once in the trap. The ions can be manipulated in the ion trap mass analyzer – performing multiple isolation and fragmentation stages – until time to detect.

Instead of four parallel rods, the ion trap consists of a circular ring electrode plus two end caps that form a “trap”.

Information received: MS and MS/MS

Conceptual model – Ion Trap
How It Works
Mass Analyzer – Ion Trap (IT)

Step 1: Isolation of Precursor Ion

Once ion injection and accumulation are complete, the ion gate closes and ions are no longer injected into the mass analyzer. Waveforms are applied to eject masses above and below the precursor ion.

Step 2: Fragmentation of Precursor Ion

Resonance excitation of the precursor ion causes collision induced dissociation (CID) and product ions are generated (a). The full scan product ions are ejected to the detector (b).
How It Works
Mass Analyzer – Time-of-Flight (TOF)

Charged ions generated in the ion source enter the mass analyzer.

Analyzer components:
• Mass filter (Q1), optional
• Flight tube
• Collision cell (Q-TOF)

After ions have passed the quadrupole or collision cell they arrive at the ion pulser. A high voltage pulse is applied which accelerates the ions into the flight tube. An ion mirror at the end of the tube reflects the ions and sends them to the detector that records their time of arrival.

Information received:

TOF: **MS only**
Q-TOF: **MS and MS/MS**

Schematic of Time-of-Flight mass spectrometer.
Source: Time-of-Flight Mass Spectrometry
Graphic shows a Q-TOF
How It Works
Mass Analyzer – Time-of-Flight (TOF)

The flight time ($t$) for each mass is unique and is determined by the energy ($E$) to which an ion is accelerated, the distance ($d$) it has to travel, and $m/z$.

$$E = \frac{1}{2}mv^2$$

which is solved for $m$ looks like:

$$m = \frac{2E}{v^2}$$

and solved for $v$ looks like:

$$v = \sqrt{\frac{2E}{m}}$$

equation 1

The equation says that for a given kinetic energy, $E$, smaller masses will have greater velocities than larger masses. Ions with lower masses arrive at the detector earlier. Velocity is determined (and consequently the mass) by measuring the time it takes an ion to reach the detector.
How It Works
Mass Analyzer – Time-of-Flight (TOF)

The second equation is the familiar velocity (v) equals distance (d) divided by time (t):  
\[ v = \frac{d}{t} \]

Combing equation 1 and 2 yields:  
\[ m = \frac{2E}{d^2} t^2 \]

For a given energy (E) and distance, the mass is proportional to the square of the flight time of the ion. E and d are kept constant and summarized in variable A which leads to a simplified equation:  
\[ m = A \cdot t^2 \]

To be really precise, a time delay for applying the high voltage needs to be considered as well:  
\[ t = t_m - t_0 \]

This results in the final equation:  
\[ m = A(t_m - t_0)^2 \]
Results

Example 1

Mass spectrum of sulfmethazine analyzed with a single quadrupole mass analyzer

Molecular Formula: \( \text{C}_{12}\text{H}_{14}\text{N}_{4}\text{O}_{2}\text{S} \)

\([M+H]^+ : \) 279.33

Mass spectrum of sulfmethazine.
Source: Agilent 6100 Series Quadrupole LC/MS Systems (p 17)
Results

Example 2

Mass spectrum of cocaethylene with a Q-TOF mass analyzer

Molecular Formula: $\text{C}_{18}\text{H}_{23}\text{NO}_4$  
$[\text{M}+\text{H}]^+$: 318.387

Mass spectrum of Cocaethylene.  
Source: A comparison of several LC/MS techniques for use in toxicology (Fig 36, p 37)
Results

Single Quad vs. High Resolution TOF

The analysis with a Single (Triple) quadrupole delivers nominal mass information (low resolving power), Time-of-Flight instruments can deliver accurate mass information (high resolving power).

Continuous calibration of a TOF system is needed for time-of-flight analysis to ensure best possible mass accuracy. Measurements typically deviate by only a few parts per million (ppm).

With sufficient mass resolution and mass accuracy, a TOF mass spectrometer can positively confirm elemental composition.

Resolving power of Single quadrupole (a) versus Time-of-Flight (b) Source: 5989-2549EN (p 14)
Results

Single Quad vs. TOF

Typical Single Quadrupole mass spectrum

Mass spectrum of sulfamethazine. Source: G1960-90083 (p 17)

Typical TOF mass spectrum

Mass spectrum of sulfachloropyridazine with adduct and fragment ions. Source: 5989-2549EN (p 25)
Results

Multiply Charged Ions and Deconvolution

Depending on the analyzed molecule and the ionization technique, multiple charged ions can be generated.

Small molecules and APCI delivers single charged molecules:

The measured $m/z$ corresponds to the molecular weight after subtracting (positive ion) or adding (negative ion) the charge carrier.

For large molecules (peptides, proteins) ionized with ESI, more than one potential charge site (for protonation or deprotonation) is available which can result in multiply charged ions:

This makes large molecules like antibodies (> 1 Mio Da) accessible to mass spectrometry since the measured ions are shifted to a more readily measure $m/z$ range.

A mathematic algorithm is needed to determine the real molecular weight from the measured $m/z$. This process is known as deconvolution.
Results
Multiply Charged Ions and Deconvolution – Example

Mass spectrum of expressed glutamine synthetase.

Deconvoluted mass spectrum of expressed glutamine synthetase.

Source: Accurate-Mass LC/TOF-MS for Molecular Weight Confirmation of Intact Proteins (Fig 1, p 4)
# Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>APCI</td>
<td>Atmospheric Pressure Chemical Ionization</td>
</tr>
<tr>
<td>APPI</td>
<td>Atmospheric Pressure Photo Ionization</td>
</tr>
<tr>
<td>CI</td>
<td>Chemical Ionization</td>
</tr>
<tr>
<td>CID</td>
<td>Collision Induced Dissociation</td>
</tr>
<tr>
<td>D</td>
<td>Dopant (APPI)</td>
</tr>
<tr>
<td>Da</td>
<td>Dalton</td>
</tr>
<tr>
<td>EI</td>
<td>Electron Impact</td>
</tr>
<tr>
<td>ESI</td>
<td>Electrospray Ionization</td>
</tr>
<tr>
<td>GC</td>
<td>Gas Chromatography</td>
</tr>
<tr>
<td>GC/MS</td>
<td>Gas Chromatography Mass Spectrometry</td>
</tr>
<tr>
<td>ICP</td>
<td>Inductively Coupled Plasma</td>
</tr>
<tr>
<td>IT</td>
<td>Ion Trap</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC/MS</td>
<td>Liquid Chromatography Mass Spectrometry</td>
</tr>
<tr>
<td>M</td>
<td>Molecule Ion</td>
</tr>
<tr>
<td>MALDI</td>
<td>Matrix Assisted Laser Desorption Ionization</td>
</tr>
<tr>
<td>MMI</td>
<td>Multimode Ionization</td>
</tr>
<tr>
<td>MS</td>
<td>Mass Spectrometry</td>
</tr>
<tr>
<td>m/z</td>
<td>Mass to Charge Ratio</td>
</tr>
<tr>
<td>QQQ</td>
<td>Triple Quadrupole</td>
</tr>
<tr>
<td>SIM</td>
<td>Single Ion Monitoring</td>
</tr>
<tr>
<td>SH</td>
<td>Solvent Molecules</td>
</tr>
<tr>
<td>SQ</td>
<td>Single Quadrupole</td>
</tr>
<tr>
<td>MRM</td>
<td>Multiple Reaction Monitoring</td>
</tr>
<tr>
<td>(Q) - TOF</td>
<td>Time-of-Flight</td>
</tr>
</tbody>
</table>
Further Information

For more information on products from Agilent, visit [www.agilent.com](http://www.agilent.com) or [www.agilent.com/chem/academia](http://www.agilent.com/chem/academia)

For questions or suggestions about this presentation, contact [academia.team@agilent.com](mailto:academia.team@agilent.com)

<table>
<thead>
<tr>
<th>Publication</th>
<th>Title</th>
<th>Pub. No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>Agilent 7000 Series Triple Quad GC/MS Operation Manual</td>
<td>G7000-90044</td>
</tr>
<tr>
<td>Application compendium</td>
<td>Time-of-Flight Solutions in Pharmaceutical Development – the Power of</td>
<td>5989-2549EN</td>
</tr>
<tr>
<td></td>
<td>Accurate Mass</td>
<td></td>
</tr>
<tr>
<td>Technical Overview</td>
<td>Time-of-Flight Mass Spectrometry</td>
<td>5990-9207EN</td>
</tr>
<tr>
<td>Application</td>
<td>Accurate-Mass LC/TOF-MS for Molecular Weight Confirmation of Intact</td>
<td>5989-7406EN</td>
</tr>
<tr>
<td></td>
<td>Proteins</td>
<td></td>
</tr>
<tr>
<td>Application</td>
<td>A Comparison of Several LC/MS Techniques for Use in Toxicology</td>
<td>5990-3450EN</td>
</tr>
<tr>
<td>Images</td>
<td><a href="http://www.agilent.com/chem/teachingresources">www.agilent.com/chem/teachingresources</a></td>
<td></td>
</tr>
</tbody>
</table>
THANK YOU