UMP OPEN COURSEWARE

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

CHAPTER 7

MASS SPECTROMETRY

Expected Outcomes

Able to discuss the nature of molecular mass spectra and define some terms used in molecular mass spectrometry.
Able to describe mass spectrometer components
Able to explain various techniques used to form ions from analyte molecules in mass spectrometers
Able to explain the separation of ions based on m/z by mass analyzer
State the applications of mass spectrometry

7.1 Molecular Mass Spectra

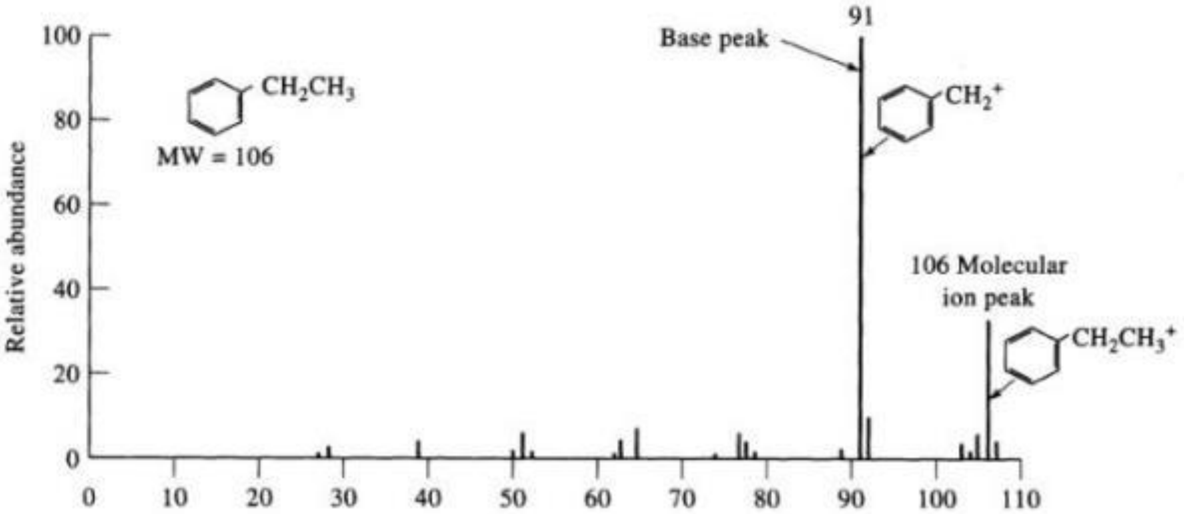
Based on ionization of gas phase molecule followed by analysis of the masses of the ions produced

Mass spectrometry involves ionizing a compound, separating the ions that result on the basis of mass to charge ratio (m/z) and obtaining a plot of number of ions (abundance) versus m/z.

The Mass Spectrum:

Graph of ion intensity versus mass-to-charge ratio (m/z) (units daltons, Da)

Fig 20-1



Picture taken from Fundamentals of Analytical Chemistry by Douglas A. Skoog, Donald M. West and F. James Holler Page 551]

molecular ion peak (M+) m/z corresponds to MW of single charged molecule

fragment peak m/z less than MW of single-charged molecule

base peak most intense m/z

7.2 Mass Spectrometer Components

Instrument Components:

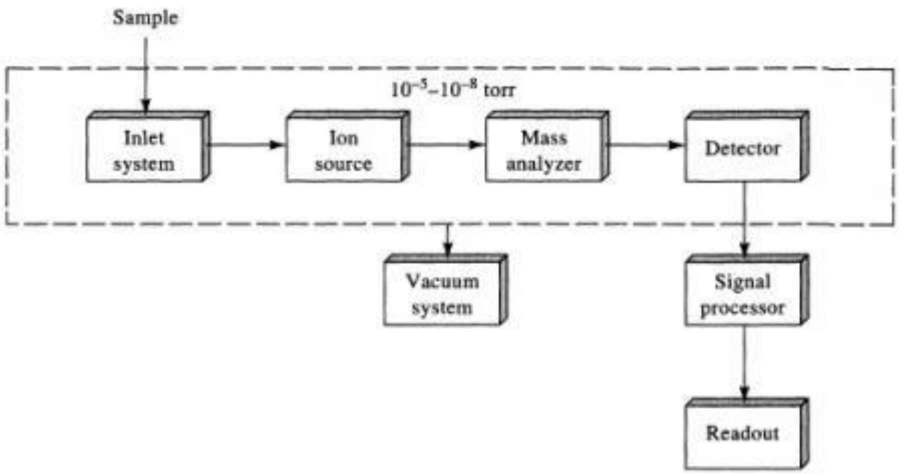


Fig 20-10

- sample introduction system - vaporize sample
- ion source - ionizes analyte gas molecules
- mass analyzer - separates ions according to m/z
- detector - counts ions
- vacuum system - reduces collisions between ions and gas molecules

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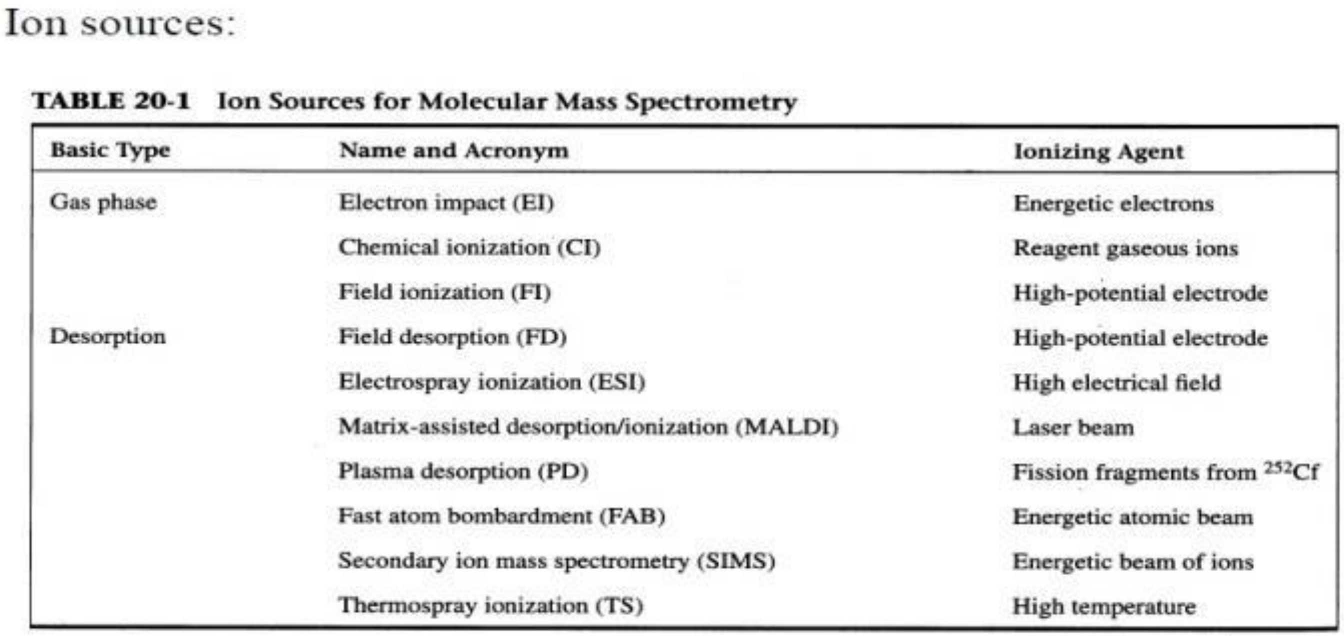
Process in MS

- Ionization- The atom or molecule is ionised by knocking one or more electrons off to give a positive ion
- Acceleration- The ions are accelerated so that they all have the same kinetic energy.
- Dispersion- The ions are then deflected by a magnetic field according to their masses. The lighter they are, the more they are deflected.
- Detection- The beam of ions passing through the machine is detected electrically.

7.3 Ion Sources

- Hard ion sources leave excess energy in molecule – extensive fragmentation
- Soft ion sources little excess energy in molecule – reduced fragmentation



Ion sources:

TABLE 20-1 Ion Sources for Molecular Mass Spectrometry

Basic Type	Name and Acronym	Ionizing Agent
Gas phase	Electron impact (EI)	Energetic electrons
	Chemical ionization (CI)	Reagent gaseous ions
	Field ionization (FI)	High-potential electrode
Desorption	Field desorption (FD)	High-potential electrode
	Electrospray ionization (ESI)	High electrical field
	Matrix-assisted desorption/ionization (MALDI)	Laser beam
	Plasma desorption (PD)	Fission fragments from ^{252}Cf
	Fast atom bombardment (FAB)	Energetic atomic beam
	Secondary ion mass spectrometry (SIMS)	Energetic beam of ions
	Thermospray ionization (TS)	High temperature

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GAS PHASE ION SOURCES

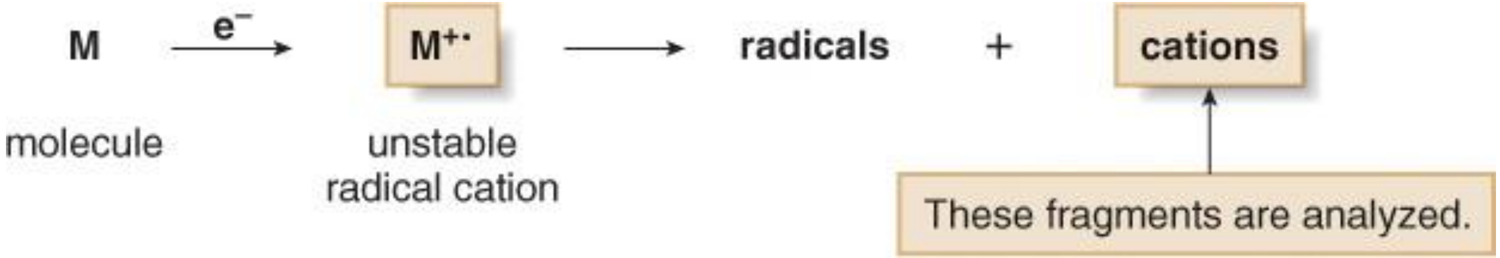
A) ELECTRON IMPACT (IC)

B) CHEMICAL IONIZATION

A) Electron Impact (EI)

Hard inoization- Vapor-phase sample molecules are bombarded with high energy electrons (70 eV). This causes the sample molecules to eject an electron forming a radical cation.

Ionization potential of typical compound < 15 eV. Therefore, extensive bond breaking occurs resulting in smaller cations and radicals.



Benefits

. well-understood
. can be applied to virtually all volatile compounds
. reproducible mass spectra
. fragmentation provides structural information
. libraries of mass spectra can be searched for EI mass spectral "fingerprint“

Limitations

. sample must be thermally volatile and stable
. the molecular ion may be weak or absent for many compounds.

B) Chemical Ionization (CI)

Chemical ionization is a “soft” ionization method. Much less bond breaking occurs than in EI.

Vapor phase sample molecules are mixed with a reagent gas such as CH_4, or NH_3. The reagent gas molecules are ionized by electron impact and then the resulting molecular ions of the reagent gas molecules react with the sample molecules.

$$\mathbf{R + e \rightarrow R^{+\cdot} + 2e}$$
$$\mathbf{R^{+\cdot} + RH \rightarrow RH^{+} + R^{\cdot}}$$
$$\mathbf{RH^{+} + S \rightarrow SH^{+} + R}$$
$$\mathbf{RH+ + S \rightarrow RSH+}$$

(R = reagent, S = sample, e = electron, . = radical electron , H = hydrogen):

SH^{+} is the sample molecule plus one proton m/z = M+1
It is not a radical-cation (it is an even-electron species) and was not produced by excess ionizing voltage. It remains relatively intact – does not fragment.

Benefits

. often gives molecular weight information through molecular-like ions such as $[M+H]^+$, even when EI would not produce a molecular ion.

. simple mass spectra, fragmentation reduced compared to EI

Limitations

. sample must be thermally volatile and stable

. less fragmentation than EI, fragment pattern not informative or reproducible enough for library search

. results depend on reagent gas type, reagent gas pressure or reaction time, and nature of sample.

DESORPTION ION SOURCES

Applicable to non-volatile (>105 Da) or non-stable analytes
Energy applied to analyte causing desorption and ionization
Exact mechanisms still under investigation

A)ESI

B)FAST ATOM BOMBARDMENT (FAB

A) Electrospray (ESI)

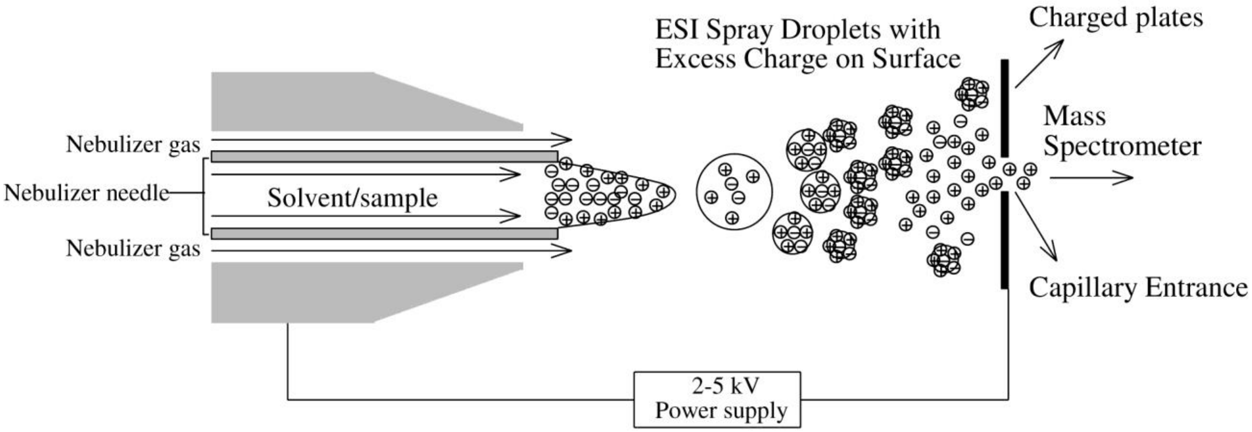
- Explosion of charged droplets containing analytes

- solution analyte pumped through charged (1-5 kV) capillary

- small droplets become charged

- solvent evaporates, drop shrinks, surface charge density Increases

Soft ionization - little fragmentation



Source:http://course1.winona.edu/tnalli/s06/ms1.ppt.

B) Fast Atom Bombardment (FAB)

Hard ionization - fragmentation
Sample in glycerol solution
Bombarded by high energy Ar or Xe atoms (few keV)
Atoms and ions sputtered from surface (ballistic collision)
Both M+ and M- produced
Applicable to small or large (>105 Da) unstable molecule

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

Soft ionization
- analyte dissolved in solution of UV-absorber and solvent
- solid crystals of analyte + absorber grow (matrix)
- pulsed laser fired at crystals in time-of-flight mass spectrometer (TOF-MS)
- molecular ion desorbed from crystal surface

7.4 Mass Analyser

Mass analyzers: separate ions to measure m/z and intensity

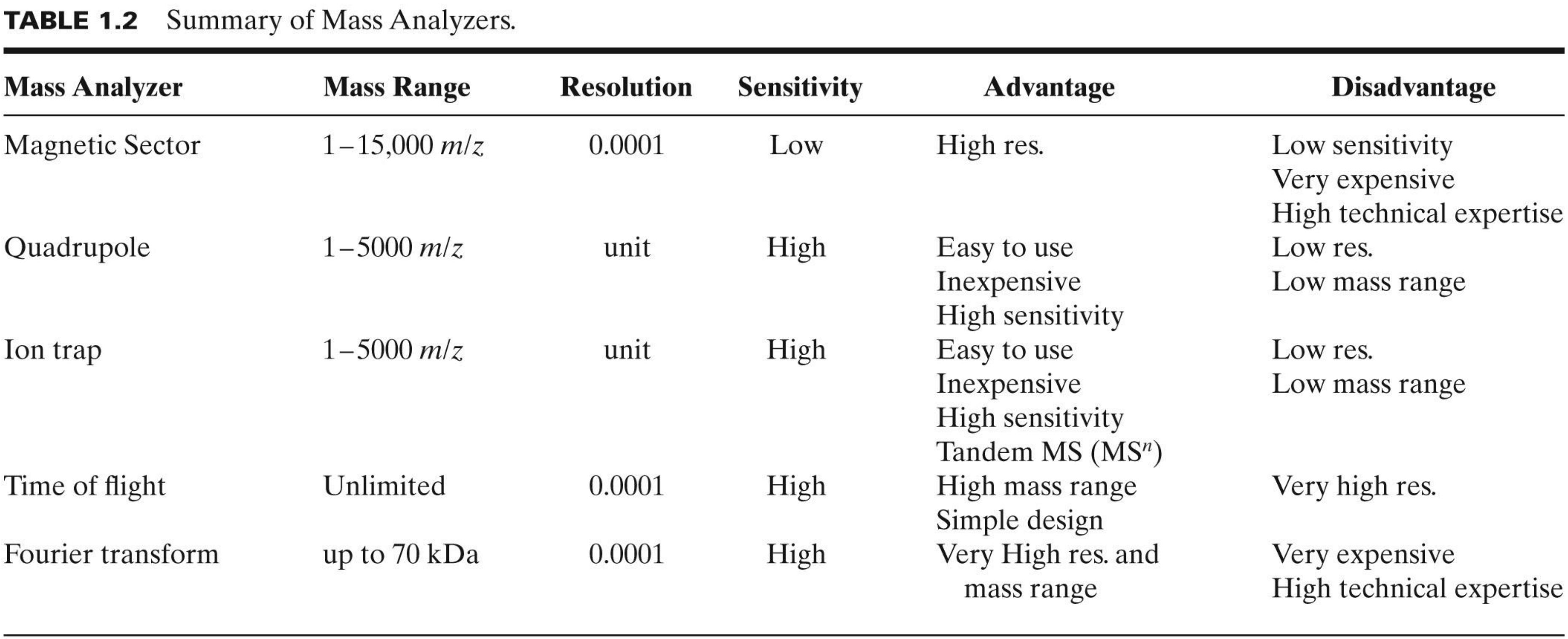
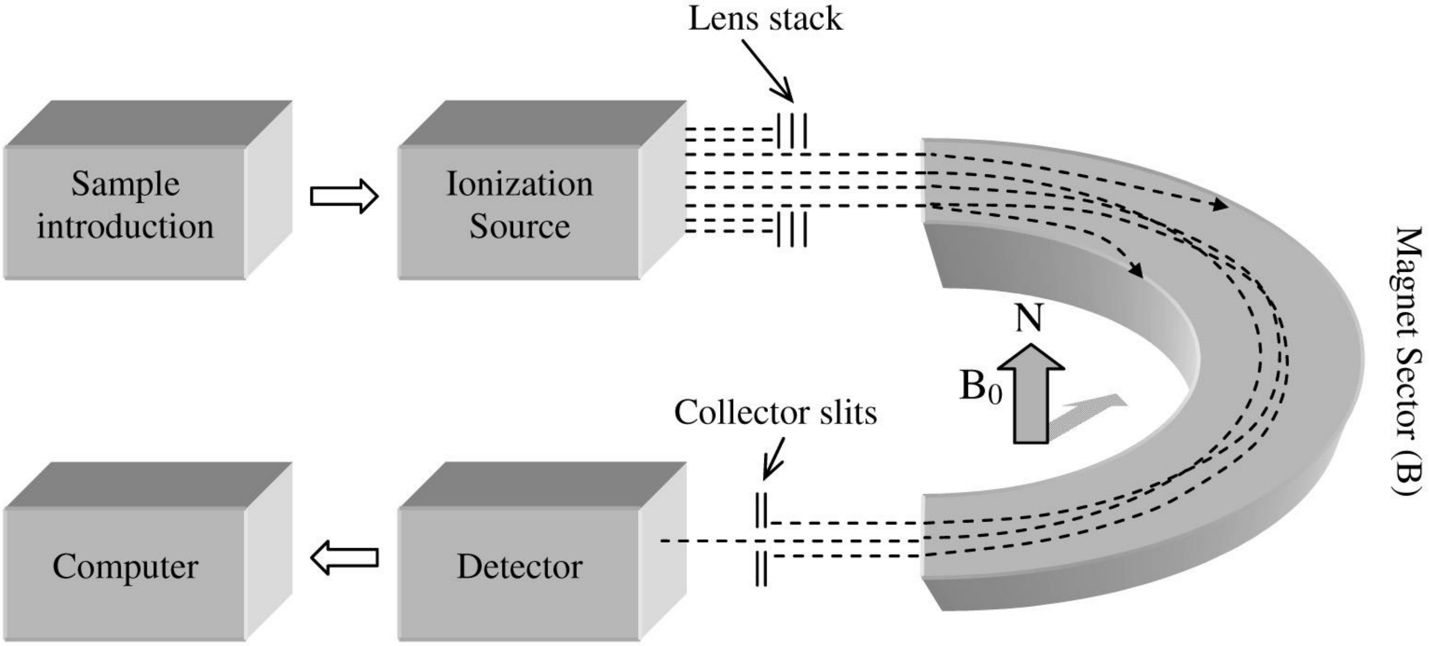


TABLE 1.2 Summary of Mass Analyzers.

Mass Analyzer	Mass Range	Resolution	Sensitivity	Advantage	Disadvantage
Magnetic Sector	1–15,000 *m/z*	0.0001	Low	High res.	Low sensitivity Very expensive High technical expertise
Quadrupole	1–5000 *m/z*	unit	High	Easy to use Inexpensive High sensitivity	Low res. Low mass range
Ion trap	1–5000 *m/z*	unit	High	Easy to use Inexpensive High sensitivity Tandem MS (MS^n)	Low res. Low mass range
Time of flight	Unlimited	0.0001	High	High mass range Simple design	Very high res.
Fourier transform	up to 70 kDa	0.0001	High	Very High res. and mass range	Very expensive High technical expertise

Source:http://course1.winona.edu/tnalli/s06/ms1.ppt.

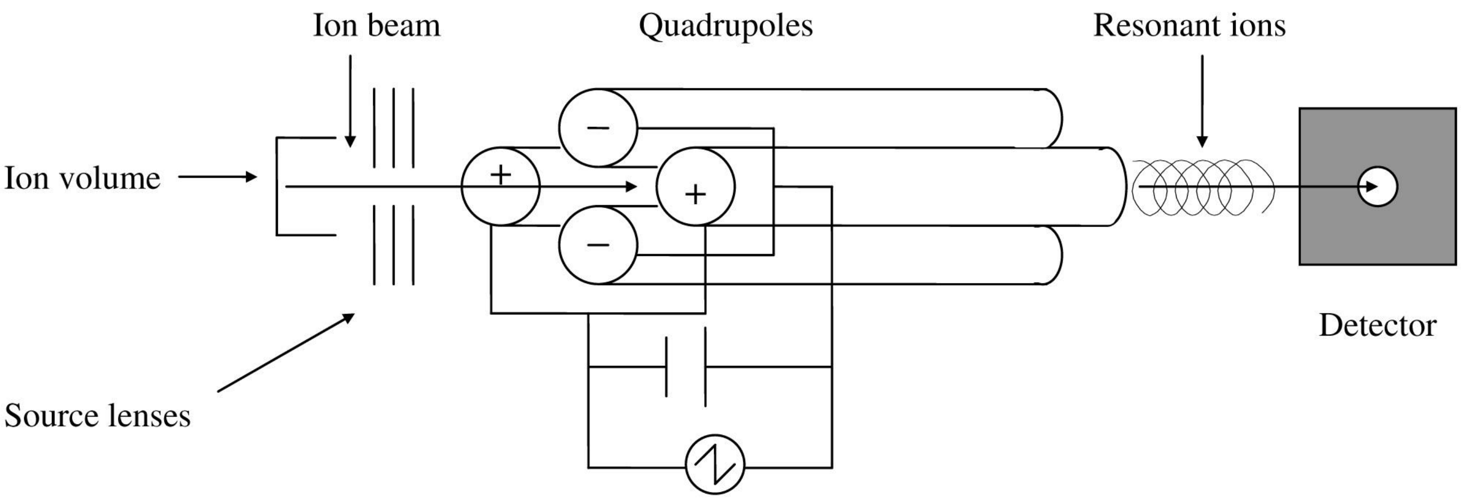
Magnetic Sector

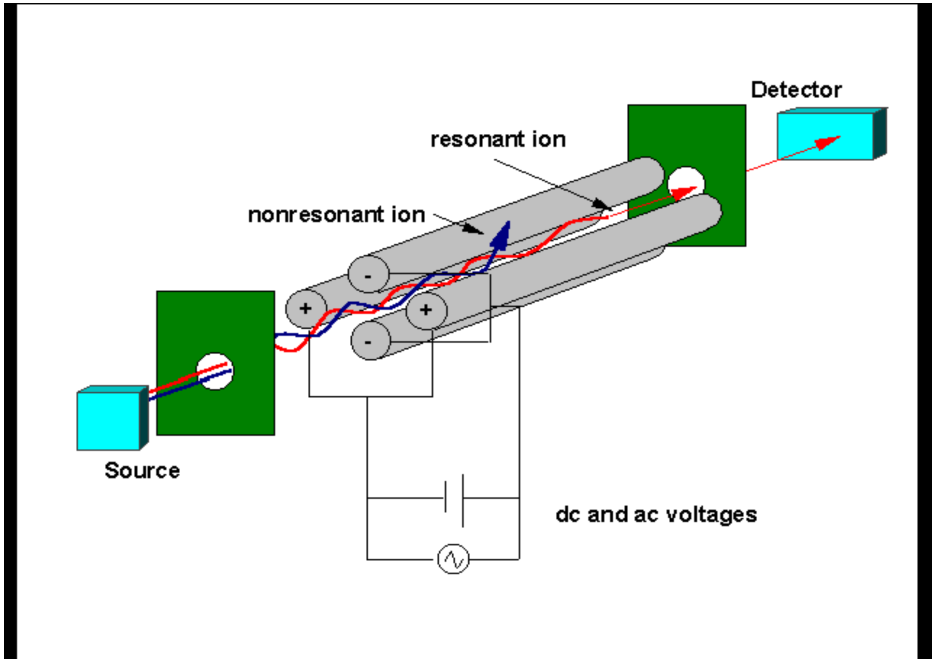


Source:http://course1.winona.edu/tnalli/s06/ms1.ppt.

- Magnetic field is used to separate the ions.
- As moving charges enter a magnetic field, the charge is deflected to a circular motion of a unique radius in a direction perpendicular to the applied magnetic field.
- Ions in the magnetic field experience two equal forces; force due to the magnetic field and centripetal force

Quadrupole





Source:http://www.chemicool.com/definition/quadrupole_mass_spectrometry.html

- Uses an electric field to separate ions.Ions are ejected into a vacuum chamber that contains 4 parallel metal rods.

- One pair of rods, located opposite each other are positively charged, while the other pair is negatively charged.

- On top of the static positive and negative charges of the sets of rod, an additional +/- oscillation is also imposed on the rods.

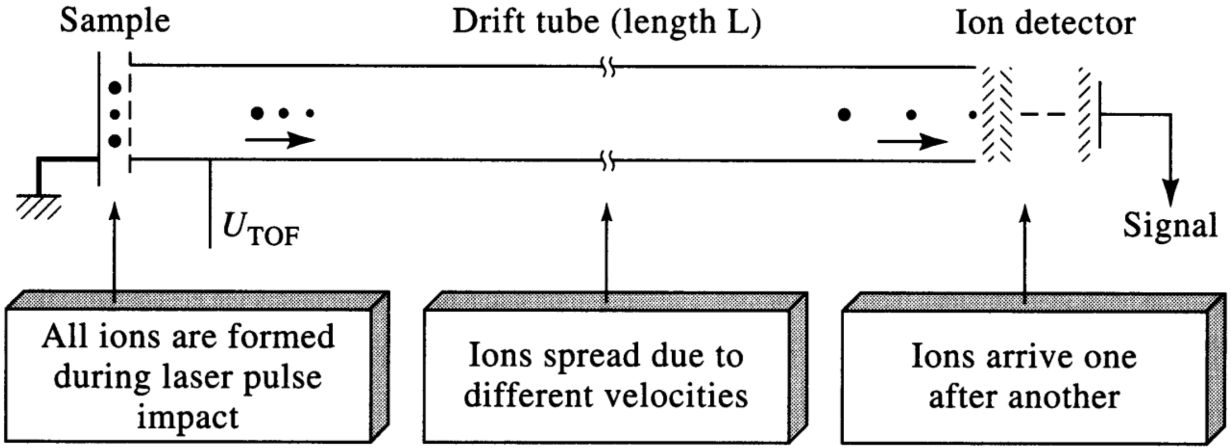
- The combination of oscillating positive and negative fields makes the ions in the vacuum chamber move in a spiral pattern.

- At a given oscillation frequency, ions of either very large or very small mass spiral from the centre and collide with the rods rather than reaching the mass detector at the end of the chamber.

- Thus only ions of a particular mass can be observed at a given oscillation frequency. By changing the oscillation frequency other ions of other masses are allowed to hit the detector. Thus a scan of all frequencies gives a scan of all ions in the sample

Time of Flight (TOF)

- separation is based on the kinetic energy and velocity of the ions
- Ions travel down field-free tube separate according to mass
- light ions arrive first, heavy ions arrive later
- Unlimited mass range m/z max > 100 kDa
- Poor resolution R max < 1000
- Poor sensitivity



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7.5 Applications Of Molecular Mass Spectrometry

Identification of Pure Compounds:

(a) Nominal M^+ peak (one m/z resolution) (or $(M+1)^+$ or $(M-1)^+$ gives MW

(b) Exact m/z (fractional m/z resolution) can give stoichiometry but not structure (double-focusing instrument)

(c) Fragment peaks give evidence for functional groups

- $(M-15)^+$ peak for methyl
- $(M-18)^+$ OH or water
- $(M-45)^+$ for CO_2H
- series (M-14)+, (M-28)+, (M-42)+ for sequential CH_2

(d) Isotopic peaks can indicate presence of certain atoms

- Cl, Br, S, Si

(e) Isotopic ratios can suggest plausible molecules from M+,

(f) Comparison with library spectra

Summary of MS

One of most powerful analytical tools:

- sensitive (10-6 to <10-13 g)
- range of ion sources for different situations
- elemental composition for small and large MW
- biomolecules
- limited structural information
- qualitative and quantitative analysis of mixtures
- composition of solid surfaces
- isotopic information in compounds

But:

- complex instrumentation
- expensive
- high resolution
- structure obtained indirectly
- complex spectra/fragmentation for hard ionization sources
- simple spectra for soft ionization sources