Chemical Ionisation (C.I.)

In C.I., ionisation of the sample is by ion-molecule reactions in the ion source. A **reagent gas** is present in the source at a high pressure (~ 1 mbar). Electron ionisation is used to produce ions from this gas, which then interact with sample molecules to produce sample ions, with lower energy transfer to the sample molecules than is the case with E.I.

Commonly-used reagent gases are: methane, iso-butane and ammonia.

The most common reaction which occurs between acidic reagent gas ions and sample molecules is proton transfer from the reagent gas ion to the sample molecule.

Other possible reactions which produce positive ions in chemical ionisation are:

Charge exchange, or electron transfer, which occurs with reagent gases which do not contain available hydrogen.

Electrophilic addition, in which cations from reagent gases can be involved in electrophilic addition with sample molecules.

Anion abstraction, which can occur from samples of low proton affinity with a protonating reagent gas.

Negative Ion C.I.

During E.I. and C.I., negative as well as positive ions are formed. Under E.I. conditions, negative ion spectra are weak, and consist mainly of low mass fragment ions. In negative ion C.I., the 'reagent' gas is introduced into the source as for positive ion C.I., but its purpose is to moderate the energy of the electrons to thermal levels. Under these conditions, most organic compounds will capture electrons to form negative molecular ions, which are usually dominant in the spectra.

Negative ion formation mechanisms are:

1) Electron capture
2) Ion-molecule reactions
3) Charge exchange
4) Nucleophilic addition

Nucleophilic attack by anions may occur, forming stable addition ions. For example, chloride anions form $[M+Cl]^-$ ions with a range of compounds.

Fast Atom Bombardment (FAB) or Liquid Secondary Ion Mass Spectrometry (LSIMS)

If a beam of energetic ions or atoms strikes a surface, then particles are ejected from that surface. This process is known as "sputtering". Analysis of the sputtered particles will give information about the composition of the surface.

Dissolving organic compounds in a viscous, involatile material (the "matrix" compound), allows a surface layer to be constantly renewed by diffusion of the sample in the matrix, resulting in long-lived beams of secondary particles.

Primary particle beams most commonly used are Xe (FAB) or Cs^+ (LSIMS).
Typical primary beam energies are 8keV - 35keV.

Typical matrix compounds are glycerol, thioglycerol and 3-nitrobenzyl alcohol.

Ionisation probably occurs by ion-molecule reactions in the region of dense gas above the surface of the matrix, forming predominantly $[M+H]^+$ and $[M-H]^-$ ions. Cationisation also occurs if available cations such as Na^+ or K^+ are present.

Matrix Assisted Laser Desorption Ionisation (MALDI)

In this technique, the analyte is, as with FAB, dissolved in a matrix material. Laser energy is then used to desorb sample molecules from the matrix. The sputtering process and the ionisation mechanisms are thought to be similar to those for FAB.

The main function of the matrix in MALDI is to absorb energy of the wavelength of the laser energy, and thus transform the laser energy into excitation energy leading to sputtering.

Pulsed lasers, usually in the UV wavelength range are used, making the technique incompatible with scanning mass analysers, but ideal for Time-of-Flight (TOF) analysers, which record all the ions produced by each laser pulse.

Typical matrices used are: alpha-cyano 4-hydroxy cinnamic acid and sinapinic (3,5-dimethoxy-4-hydrocinnamic) acid.

Atmospheric Pressure Ionisation (API) techniqes:

1)Electrospray:

In electrospray, a capillary is held at a high voltage relative to a counter electrode, and the analyte in solution passed down it. At the end of the capillary, a cone forms, from which charged droplets are desorbed by the electric field. The capillary inside diameter is ~ 0.1 - 0.15 mm. 3-5kV is applied to the capillary relative to an electrode about 10mm away.
As the solvent evaporates, these droplets reduce in size until single sample molecules contaning one are more charges are left. The ion spray takes place at atmospheric pressure, and a series of 'skimmers' which are differentially pumped, communicate with the vacuum of the spectrometer. Flow rates up to 1ml min^{-1} can be accomodated, making the technique suitable for coupling with liquid chromatography (LC-MS)..

Mechanisms of ion formation are unclear, but usually, especially for large molecules, multiple protonation occurs, leading to the formation of ions in high charge states. The charge states formed are related to the molecular weight, so that m/z values in the 500- 2000Da range are normally observed. Thus compounds of high molecular weight may be analysed using mass analysers with modest m/z range.

Determination of molecular weight from a series of multiply-charged ions peaks:

Taking 2 adjacent peaks, M_i and M_{i+1}, in the spectrum of a compound of molecular weight M_R, and if M_H is the mass of a proton, and i is the number of charges (protons) on the ion M_i,

$$M_i = (M_R + iM_H) / i$$

and

$$M_{i+1} = (M_R + (i+1)M_H) / i+1$$

combining these 2 equations:

$$i = (M_{i+1} - M_H) / (M_i - M_{i+1})$$

or $i = (M_{i+1} - 1) / (M_i - M_{i+1})$

Thus M_R may be determined, since $M_R = i(M_i - M_H)$

2) Atmospheric Pressure Chemical Ionisation (APcI):

In APcI, the sample solution is sprayed at atmospheric pressure through a capillary. A gas is passed concentrically to the capillary to assist in nebulsing the solution. The region at the end of the capillary is heated to assist desolvation. Near the end of the capillary, a pointed electrode is held at a high voltage reletive to a counter electrode. The resulting corona discharge from this electrode causes a plasma consisting mainly of solvent ions to form. Sample ions swept through this plasma undergo ion/molecule reactions, resulting in proton tranfer or abstraction, giving rise to $[M+H]^+$ ions in positive ion mode or $[M-H]^-$ ions in the negative ion mode.

Unlike in electospray, multiple charging does not normally occur, making the technique suitable for a wide range of low molecular weight involatile and labile materials. The source can tolerate liquid flows high enough to allow it to be coupled to LC systems.