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Research Article

INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY (ICP-MS)

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ABSTRACT

Inductively coupled plasma mass spectrometry (ICP-MS) is a type of mass spectroscopy that is highly sensitive and capable of the determination of a range of metals and several non-metals at concentrations below one part in 10^{12} (part per trillion). Inductively coupled plasma mass spectrometry is a method used for separating and detecting the ions. In trace elemental analysis, the method has advantages of high speed, precision and sensitivity compared to atomic absorption technique[1]. It is an analytical technique used for elemental determinations. This technique is superior to detection capability of ICP-AES with the same sample throughput and the ability to obtain isotopic information.

Keywords: ICP-MS, ICP-AES, ionization, isotopic

INTRODUCTION

An inductively coupled plasma (ICP) is a type of plasma source in which the energy is supplied by electric currents which are produced by electromagnetic induction, that is, by time-varying magnetic fields[1].There are two types of ICP geometries: planar and cylindrical. In planar geometry, the electrode is a coil of flat metal wound like a spiral. In cylindrical geometry, it is like a helical spring. Inductively Coupled Plasma Mass Spectrometry was commercially introduced in 1983 and has gained general acceptance in many types of laboratories. Inductively Coupled Plasma Mass Spectrometry is an analytical technique used for elemental determinations[1]. The resulting instrument is capable of identifying trace multielement analysis, often at the part per trillion levels. ICP-MS has been used widely over the years, finding applications in a number of different fields including drinking water, wastewater, natural water systems/hydrogeology, geology and soil science, mining/metallurgy, food sciences[1].

The most important things to remember about the argon ICP plasma are[1]

1. The argon discharge with a temperature of around 6000-10000°K is an excellent ion source.
2. The ions formed by the ICP discharge are typically positive ions, M^+ or M^{+2}, therefore, elements that prefer to form negative ions such as Cl, I, F, etc., are very difficult to determine via ICP-MS.
3. The detection capabilities of the technique can vary with the sample introduction technique which allows differing amounts of sample to reach the ICP plasma.
4. Detection capabilities will vary with the sample matrix, which may affect the degree of ionization that will occur in the plasma or allow the formation of species that may interfere with the analyte determination.

PRINCIPLE

Principles of Operation

A number of different ICP-MS designs are commercially available today, each with its own strengths and limitations. They all share similar components such as the nebulizer, spray chamber, plasma torch, interface and detector but can differ significantly in the design of the mass spectrometer and in particular the mass separation device[2]. This chart describes those differences in greater detail. But first, here is an overview of the principles of operation of ICP-MS. Figure 2 shows the basic instrumental components that make up an ICP-MS system. The sample, which must be in a liquid form, is pumped at 1 mL/min (usually with a peristaltic pump) into a nebulizer, where it is converted into a fine aerosol with argon gas at about 1 L/min. The fine droplets of the aerosol, which represent only 1 - 2% of the sample, are separated from larger droplets using a spray chamber [2]. The fine aerosol then emerges from the exit tube of the spray chamber and is transported into the plasma torch via a sample injector.

The plasma torch plays a very different role in ICP-MS. In this technique, the plasma is produced by the interaction of an intense magnetic field (produced by radio frequency [rf] passing through a copper coil) on a tangential flow of gas (normally argon), at about 15 L/min flowing through a concentric quartz tube (torch). This ionizes the gas and when seeded with a source of electrons from a high-voltage spark, forms a very high temperature plasma discharge (~10,000 K) at the open end of the tube. In ICP-MS, the plasma torch is positioned horizontally, and is used to generate positively charged ions rather than photons. In fact, every attempt is made to stop the photons reaching the detector because they have the potential to increase signal noise. It is the production and detection of large quantities of these ions that gives ICP-MS its characteristic ultratrace detection capability - about three to four orders of magnitude better than ICP-OES[2].

Once the ions are produced in the plasma, they are directed into the mass spectrometer via the interface region, which is maintained at a vacuum of 1 - 2 torr with a mechanical roughing pump. This interface region consists of two metallic cones (usually made of nickel)[3], called the sampler and a skimmer cone. Each cone features a small (0.6 - 1.2 mm) orifice to allow the ions through to the ion optics, where they are guided into the mass separation device.

The interface region is one of the most critical areas of an ICP mass spectrometer. Its role is to help the ions to be transported efficiently and with electrical integrity from the plasma, which is at atmospheric pressure (760 torr) to the mass spectrometer analyzer region at approximately 10^{-6} torr. Unfortunately, there is capacitive coupling between the rf coil and the plasma, producing a potential difference of a few hundred volts. If this wasn't eliminated, an electrical discharge (called a secondary discharge or pinch effect) would appear between the plasma and the sampler cone [3]. This discharge increases the formation of interfering species and also dramatically affects the kinetic energy of the ions entering the mass spectrometer, making optimization of the ion optics very erratic and unpredictable. For this reason, the secondary charge must be eliminated by using some kind of rf coil grounding mechanism. A number of approaches have been used over the years to achieve this, including placing a grounding strap between the coil and the interface; balancing the oscillator inside the rf generator circuitry; positioning a grounded shield or plate between the coil and the plasma torch; or using a double-interlaced coil where rf fields go in opposing directions. They all work differently but achieve a similar result - reducing or eliminating the secondary discharge[3].

Once the ions have been successfully extracted from the interface region, they are directed into the main vacuum chamber by a series of electrostatic lenses called ion optics. A turbo molecular pump maintains the operating vacuum in this region at about 10^{-2} torr. There are many different designs of the ion optic region[4], but they serve exactly the same function to electrostatically focus the ion beam towards the mass separation device and to stop photons, particulates, and neutral species from reaching the detector.

The ion beam containing all the analyte and matrix ions exit the ion optics and now pass into the heart of the mass spectrometer - the mass separation device, where a second turbo molecular pump maintains an operating vacuum of approximately 10^{-6} torr. There are many different mass separation devices, all with their own benefits and limitations. Five of the most common types are quadrupole, magnetic sector, time of flight, collision/reaction cells, and dynamic reaction cell technology[4]. They all work differently but all serve the same basic purpose - to allow analyte ions of a particular mass-to-charge ratio (m/z) through to the detector and to filter out all the non-analyte, interfering and matrix ions. Depending on the design of the mass spectrometer, this is either a scanning process

where the ions arrive at the detector sequentially or a simultaneous process where the ions are sampled at the same time.

In the final process, an ion detector converts the ions into an electrical signal. The most common design used today is a discrete dynode detector, which contains a series of metal dynodes along the length of the detector [4]. In this design, when the ions emerge from the mass filter, they impinge on the first dynode and are converted into electrons. As the electrons are attracted to the next dynode, electron multiplication takes place, resulting in a very high stream of electrons emerging from the final dynode. This electronic signal is then processed by the data handling system in the conventional way and converted into analyte concentration using ICP-MS calibration standards. Most detection systems used can handle up to eight orders of dynamic range, which means they can be used to analyze samples from low parts-per-trillion (ppt) levels, up to hundreds of parts-per-million (ppm)[4]. Most commercial ICP mass spectrometers, particularly the quadrupole models, use just one detector. However, specialized magnetic-sector ICP-MS instrumentation with multiple detectors is available for isotopic ratio analysis.

COMPONENTS

Inductively coupled plasma

Inductively coupled plasma is plasma that contains a sufficient concentration of ions and electrons to make the gas electrically conductive. The plasmas used in spectrochemical analysis are essentially electrically neutral, with each positive charge on an ion balanced by a free electron. In these plasmas the positive ions are almost all singly charged and there are few negative ions, so there are nearly equal amounts of ions and electrons in each unit volume of plasma. Inductively coupled plasma (ICP) for spectrometry is sustained in a torch that consists of three concentric tubes, usually made of quartz. The end of this torch is placed inside an induction coil supplied with a radio-frequency electric current [5]. A flow of argon gas (usually 14 to 18 liters per minute) is introduced between the two outermost tubes of the torch and an electric spark is applied for a short time to introduce free electrons into the gas stream. These electrons interact with the radio-frequency magnetic field of the induction coil and are accelerated first in one direction, then the other, as the field changes at high frequency. The accelerated electrons collide with argon atoms, and sometimes a collision causes an argon atom to part with one of its electrons. The released electron is in turn accelerated by the rapidly changing magnetic field. The process continues until the rate of release of new electrons in collisions is balanced by the rate of recombination of electrons with argon ions (atoms that have lost an electron). This produces a 'fireball' that consists mostly of argon atoms with a rather small fraction of free electrons and argon ions. The temperature of the plasma is very high, of the order of 10,000 K[5].

The ICP can be retained in the quartz torch because the flow of gas between the two outermost tubes keeps the plasma away from the walls of the torch. A second flow of argon (around 1 liter per minute) is usually introduced between the central tube and the intermediate tube to keep the plasma away from the end of the central tube. A third flow (again usually around 1 liter per minute) of gas is introduced into the central tube of the torch. This gas flow passes through the center of the plasma, where it forms a channel that is cooler than the surrounding plasma but still much hotter than a chemical flame. Samples to be analyzed are introduced into this central channel, usually as a mist of liquid formed by passing the liquid sample into a nebulizer[6].

As a droplet of nebulized sample enters the central channel of the ICP, it evaporates and any solids that were dissolved in the liquid vaporize and then break down into atoms. At the temperatures prevailing in the plasma a significant proportion of the atoms of many chemical elements are ionized, each atom losing its most loosely bound electron to form a singly charged ion.

Mass spectrometry

For coupling to mass spectrometry, the ions from the plasma are extracted through a series of cones into a mass spectrometer, usually a quadrupole. The ions are separated on the basis of their mass-to-charge ratio and a detector receives an ion signal proportional to the concentration.

The concentration of a sample can be determined through calibration with certified reference material such as single or multi-element reference standards. ICP-MS also lends itself to quantitative determinations through Isotope Dilution, a single point method based on an isotopically enriched standard.

Other mass analyzers coupled to ICP systems include double focusing magnetic-electrostatic sector systems with single and multiple collector, as well as time of flight systems (both axial and orthogonal accelerators have been used[7].

INSTRUMENT DESCRIPTION AND THEORY

ICP technology was built upon the same principles used in atomic emission spectrometry. Samples are decomposed to neutral elements in high temperature argon plasma and analyzed based on their mass to charge ratios (fig 1).

Sample Introduction

The first step in analysis is the introduction of the sample. This has been achieved in ICP-MS through a variety of means. ICP-MS spectrometers can accept solid as well as liquid samples. Solid samples are introduced into the ICP by way of a laser ablation system which can usually be purchased as an accessory. Aqueous samples are introduced by way of a nebulizer which aspirates the sample with high velocity argon, forming a fine mist. The aerosol then passes into a spray chamber where larger droplets are removed via a drain (fig 2).

The most common method is the use of a nebulizer. This is a device which converts liquids into an aerosol, and that aerosol can then be swept into the plasma to create the ions. Nebulizers work best with simple liquid samples (i.e. solutions). However, there have been instances of their use with more complex materials like slurry. Many varieties of nebulizers have been coupled to ICP-MS, which includes pneumatic, cross-flow, Babington, ultrasonic, and desolating types. The aerosol generated is often treated to limit it to only smallest droplets, commonly by means of a double pass or cyclonic spray chamber. Use of auto samplers makes this easier and faster.

Less commonly, the laser ablation has been used as a means of sample introduction. In this method, a laser is focused on the sample and creates a plume of ablated material which can be swept into the plasma. This is particularly useful for solid samples, though can be difficult to create standards for leading the challenges in quantitative analysis.

Other methods of sample introduction are also utilized. Electro thermal vaporization (ETV) and in torch vaporization (ITV) hot surfaces (graphite or metal, generally) are used to vaporize samples for introduction. These can use very small amounts of liquids, solids, or slurries. Other methods like vapor generation are also known.

Argon Plasma/Sample Ionization

Once the sample passes through the nebulizer and is partially de solvated, the aerosol moves into the torch body and is mixed with more argon gas. A coupling coil is used to transmit radio frequency to the heated argon gas, producing an argon plasma "flame" located at the torch.The hot plasma removes any remaining solvent and causes sample atomization followed by ionization. In addition to being ionized, sample atoms are excited in the hot plasma, a phenomenon which is used in ICP-atomic emission spectroscopy. Shown to the right is an ICP torch. The aerosol moves into the bottom of the torch body. The green ports on the right side of the body are where more argon is introduced to the flow. At the top are two high quality quartz tubes and an inner alumina injector tube (fig 3).

ICP-MS Interface

Because atomization/ionization occurs at atmospheric pressure, the interface between the ICP and MS components becomes crucial in creating a vacuum environment for the MS system. Ions flow through a small orifice, approximately 1 millimeter in diameter, into a pumped vacuum system. Here a supersonic jet forms and the sample ions are passed into the MS system at high speeds, expanding in the vacuum system. The entire mass spectrometer must be kept in a vacuum so that the ions are free to move without collisions with air molecules. Since the ICP is maintained at atmospheric pressure, a pumping system is needed to continuously pull a vacuum inside the spectrometer. In order to most efficiently reduce the pressure several pumps are typically used to gradually reduce pressure to 10^{-5} mbar before the ion stream reaches the quadruple. If only one pump were used, its size would be excessive to reduce the pressure immediately upon entering the mass spectrometer.

Plasma torch

The plasma used in an ICP-MS is made by partially ionizing argon gas ($Ar \rightarrow Ar^{+} + e^{-}$). The energy required for this reaction is obtained by pulsing an electrical current in wires that surround the argon gas.

After the sample is injected, the plasma's extreme temperature causes the sample to separate into individual atoms (atomization). Next, the plasma ionizes these atoms ($M \rightarrow M^{+} + e^{-}$) so that they can be detected by the mass spectrometer (fig 4).

Inductively coupled plasma (ICP) for spectrometry is sustained in a torch that consists of three concentric tubes, usually made of quartz. The end of this torch is placed inside an induction coil supplied with a radio-frequency electric current. A flow of argon gas (usually 14 to 18 liters per minute) is introduced between the two outermost tubes

of the torch and an electrical spark is applied for a short time to introduce free electrons into the gas stream. These electrons interact with the radio-frequency magnetic field of the induction coil and are accelerated first in one direction, then the other, as the field changes at high frequency (usually 27.12 MHz). The accelerated electrons collide with argon atoms, and sometimes a collision causes an argon atom to part fraction of free electrons and argon ions.

An ICP-MS combines a high-temperature ICP (Inductively Coupled Plasma) source with a mass spectrometer. The ICP source converts the atoms of the elements in the sample to ions. These ions are then separated and detected by the mass spectrometer.

Figure 5 shows a schematic representation of an ICP source in an ICP-MS. Argon gas flows inside the concentric channels of the ICP torch. The RF load coil is connected to a radio-frequency (RF) generator. As power is supplied to the load coil from the generator, oscillating electric and magnetic fields are established at the end of the torch (fig 5).

The sample is typically introduced into the ICP plasma as an aerosol, either by aspirating a liquid or dissolved solid sample into a nebulizer or using a laser to directly convert solid samples into an aerosol. Once the sample aerosol is introduced into the ICP torch, it is completely desolvated and the elements in the aerosol are converted first into gaseous atoms and then ionized towards the end of the plasma.

Mass Spectrometer

In the first stage of the mass spectrometer ions are removed from the plasma by a pumped extraction system. An ion beam is produced and focused further into the actual unit. There are several different types of mass analyzers which can be employed to separate isotopes based on their mass to charge ratio. Quadrupole analyzers are compact and easy to use but offer lower resolution when dealing with ions of the same mass to charge (m/z) ratio. Double focusing sector analyzers offer better resolution but are larger and have higher capital cost.

The quadrupole mass filter is made up of four metal rods aligned in a parallel diamond pattern. A combined DC and AC electrical potential is applied to the rods with opposite rods having a net negative or positive potential. Ions enter into the path between all of the rods. When the DC and AC voltages are set to certain values only one particular ion is able to continue on a path between the rods and the others are forced out of this path. This ion will have a specific m/z ratio. Many combinations of voltages are chosen which allows an array of different m/z ratio ions to be detected.

Shown below is animation of this process. Three mass fragments enter into the quadrupole vacuum chamber. The voltage of the rods is set so that only the pink mass fragment passes completely through the quadrupole rod array and into the detector. The green and blue fragments are unstable at this voltage combination and their path eventually brings them into contact with the rods so that they never reach the detector (fig 6).

Quadrupole rods require periodic maintenance and cleaning due to the buildup of ions which are removed during the mass discrimination process. These ions form a film which eventually builds up and dulls the metallic surface. To remove this film the vacuum chamber must be repressurized and disassembled. This process can be time consuming and very delicate but is essential to keep a mass spectrometer performing well (fig 7).

Once the ions enter the mass spectrometer, they are separated by their mass-to-charge ratio. The most commonly used type of mass spectrometer is the quadrupole mass filter. In this type, 4 rods (approximately 1 cm in diameter and 15-20 cm long) are arranged as in (Fig 8).

In a quadrupole mass filter, alternating AC and DC voltages are applied to opposite pairs of the rods. These voltages are then rapidly switched along with an RF-field. The result is that an electrostatic filter is established that only allows ions of a single mass-to-charge ratio (m/e) pass through the rods to the detector at a given instant in time. So, the quadrupole mass filter is really a sequential filter, with the settings being change for each specific m/e at a time. However, the voltages on the rods can be switched at a very rapid rate. The result is that the quadrupole mass filter can separate up to 2400 amu (atomic mass units) per second.

Detector

The most common type of ion detector found in an ICP-MS system is the channeltron electron multiplier. This cone or horn shaped tube has a high voltage applied to it opposite in charge to that of the ions being detected. Ions leaving the quadrupole are attracted to the interior cone surface. When they strike the surface additional secondary electrons are emitted which move farther into the tube emitting additional secondary electrons (fig 9).

As the process continues even more electrons are formed, resulting in as many as 10^8 electrons at the other end of the tube after one ion strikes at the entrance of the cone. The drawing below is an illustration of electron multiplying and the photograph is an actual electron multiplier removed from a mass spectrometer for cleaning. Importance of cleaning is similar to that of the quadrupole rods (fig 10).

A few things to remember about the ICP-MS detector

1. It is a consumable item. As ions hit the surface of the detector and are converted to electrons, the active film coating will be consumed. Depending on usage, a typical discrete dynode detector will last 6-18 months in a quadrupole ICP-MS.
2. It should be protected from high signal count rates. Most manufacturers' design the detector circuitry to protect it from potentially fatal ion count rates. However, the users can further this by diluting samples with known high concentration values or choosing a less abundant isotope for their analysis.
3. They are expensive. A new detector will cost on the order of $1500-2500 depending on the specific type. Care should be taken to protect it.
4. They are light sensitive. Most detectors are as sensitive to photons as they are to ions. Care should be taken to store spare detectors in the dark and never expose a detector to the light while the high voltage power supply to it is on.

Detection Limits

One of the great advantages to ICP-MS is extremely low detection limits for a wide variety of elements. Some elements can be measured down to part per quadrillion range while most can be detected at part per trillion levels. The table below shows some common detection limits by element.

Element	Detection Limit (ppt)
U, Cs, Bi	less than 10
Ag, Be, Cd, Rb, Sn, Sb, Au	10-50
Ba, Pb, Se, Sr, Co, W, Mo, Mg	50-100
Cr, Cu, Mn	100-200
Zn, As, Ti	400-500
Li, P	1-3 ppb
Ca	less than 20 ppb

MAINTENANCE OF INSTRUMENT

There are many aspects of maintenance that need to be encompassed by daily, weekly and annual procedures. The frequency of maintenance is typically determined by the sample volume and cumulative run time that the instrument is subjected to.

One of the most frequent forms of routine maintenance is replacing sample and waste tubing on the peristaltic pump, as these tubes can get worn fairly quickly resulting in holes and clogs in the sample line, resulting in skewed results. Other parts that will need regular cleaning and/or replacing are sample tips, nebulizer tips, sample cones, skimmer cones, injector tubes, torches and lenses. It may also be necessary to change the oil in the interface roughing pump as well as the vacuum backing pump, depending on the workload put on the instrument.

SAMPLE PREPARATION

For most clinical methods using ICP-MS, there is a relatively simple and quick sample prep process. The main component to the sample is an internal standard, which also serves as the diluent. This internal standard consists primarily of deionized water with nitric or hydrochloric acid, and Indium and/or Gallium. Depending on the sample type, usually 5 ml of the internal standard is added to a test tube along with 10–500 micro liters of sample. This mixture is then vortexed for several seconds or until mixed well and then loaded onto the auto sampler tray. For other applications that may involve very viscous samples or samples that have particulate matter, a process known as sample digestion may have to be carried out, before it can be pipetted and analyzed. This adds an extra first step to the above process, and therefore makes the sample prep more length.

ELEMENTAL ANALYSIS

The ICP-MS allows determination of elements with atomic mass ranges 7 to 250. This encompasses Li to U. Some masses are prohibited such as 40 due to the abundance of

argon in the sample. Other blocked regions may include mass 80 (due to the argon dimer), and mass 56 (due to ArO), the latter of which greatly hinders Fe analysis unless the instrumentation is fitted with a reaction chamber.

A typical ICP-MS will be able to detect in the region of Nano grams per liter to 10 or 100 milligrams per liter or around 8 orders of magnitude of concentration units.

PHARMACEUTICAL APPLICATIONS

1. One of the largest volume uses for ICP-MS is in the medical and forensic field, specifically, toxicology. A physician may order a metal assay for a number of reasons, such as suspicion of heavy metal poisoning, metabolic concerns, and even hepatological issues. Depending on the specific parameters unique to each patient's diagnostic plan, samples collected for analysis can range from whole blood, urine, plasma, serum, to even packed red blood cells.
2. Another primary use for this instrument lies in the environmental field. Such applications include water testing for municipalities or private individuals all the way to soil, water and other material analysis for industrial purposes.
3. This technique is also widely used the field of radiometric dating, in which it is used to analyze relative abundance of different isotopes. ICP-MS is more suitable for this application than the previously used Thermal Ionization Mass Spectrometry, as species with high ionization energy such as Osmium (Os) and Tungsten (Hf-W) can be easily ionized.
4. In the field of flow cytometry, a new technique uses ICP-MS to replace the traditional fluorochromes. Briefly, instead of labeling antibodies (or other biological probes) with fluorochromes, each antibody is labeled with a distinct combination of lanthanides.
5. Regardless of the sample type, blood, water, etc., it is important that it be free of clots or other particulate matter, as even the smallest clot can disrupt sample flow and block or clog the sample tips within the spray chamber. Very high concentrations of salts, e.g. sodium chloride in sea water, can eventually lead to blockages as some of the ions reunite after leaving the torch and build up around the orifice of the skimmer cone. This can be avoided by diluting samples whenever high salt concentrations are suspected, though at a cost to detection limits.
6. Quantification of proteins and bio molecules by icp-ms: There is an increasing trend of using ICP-MS as a tool in speciation analysis normally involves a front end chromatograph separation and an elemental selective detector such as AAS and ICP-MS. For example, ICP-MS may be combined with size exclusion chromatography and quantitative preparative native continuous polyacrylamide gel electrophoresis for identifying and quantifying native metal in bio fluids. Also the phosphorylation status of proteins can be analyzed.
7. A new type of protein tagging reagents called metal coded affinity tags (Me CAT) were introduced to label proteins quantitatively with metals, especially lanthanides. The Me CAT labeling allows relative and absolute quantification of all kind of proteins or other biomolecules like peptides. Me CAT comprises a site-specific biomolecule tagging group with at least a strong chelate group which binds metals.
8. The Me CAT labeled proteins can be accurately quantified by ICP-MS down to low attomol amount of analyte which is at least 2–3 orders of magnitude more sensitive than other mass spectrometry based quantification methods.
9. By introducing several Me CAT labels to a biomolecule and further optimization of LC-ICP-MS detection limits in the zeptomol range are within the realms of possibility. By using different lanthanides Me CAT multiplexing can be used for pharmacokinetics of proteins and peptides or the analysis of the differential expression of proteins e.g. in biological fluids.

CONCULSION

It is here by concluded that this technique is superior to other technique giving the result's up to a level of one part in trillion by using same sample.

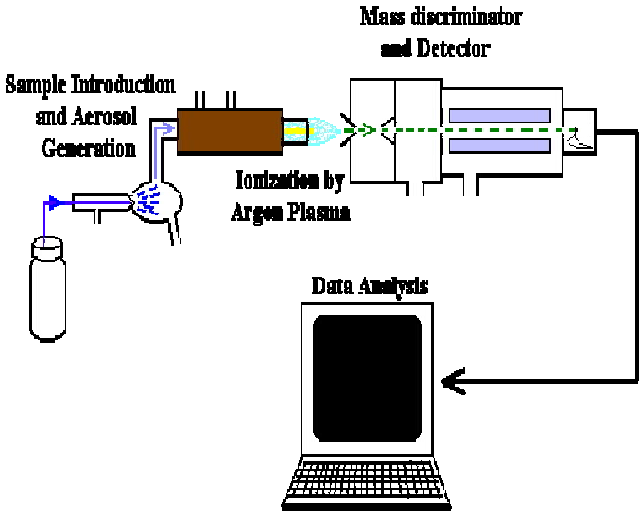

Fig. 1: Schematic of ICP-MS main processes

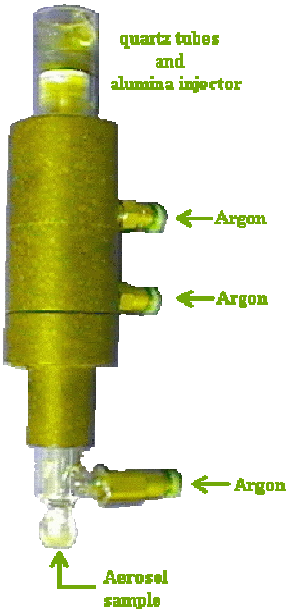

Fig. 4: ICP torch body

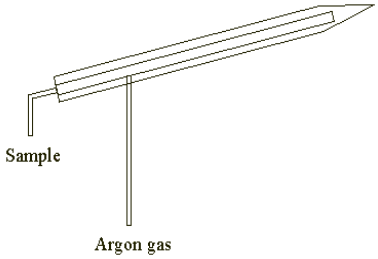

Fig. 2: Generation of aerosol by nebulizer

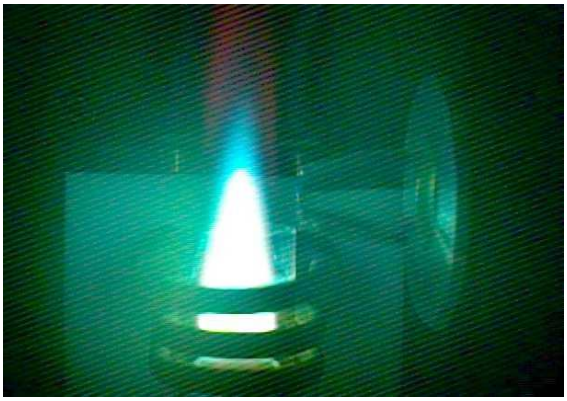

Fig. 3: Photo of argon plasma in operation

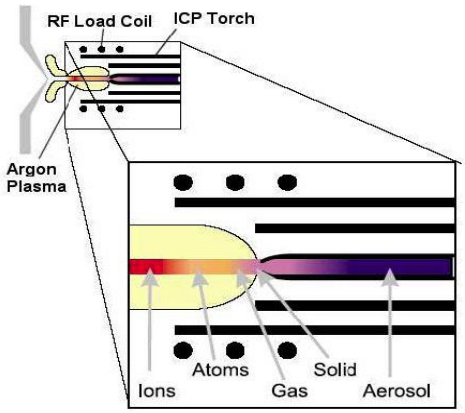

Fig. 5: ICP Torch showing the fate of the sample

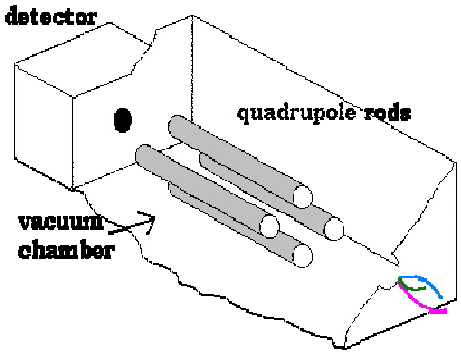

Fig. 6: Animation of quadrupole mass filter separating ions

Fig. 7: Photo of quadrupole rods from mass spectrometer

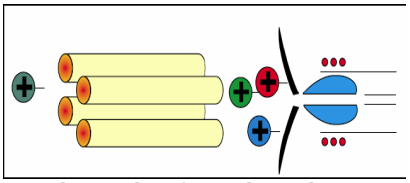

Fig. 8: Schematic of quadrupole mass filter

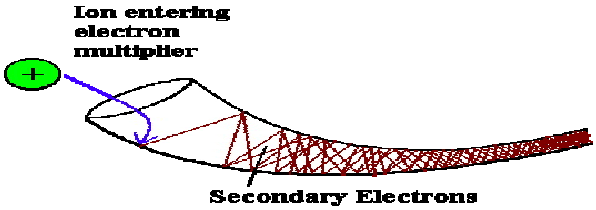

Fig. 9: Electron Multiplier Schematic

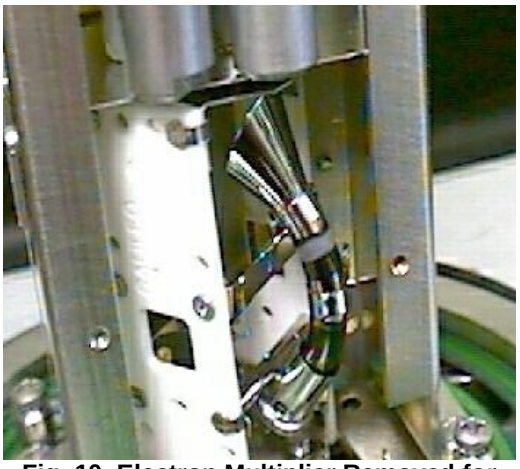

Fig. 10: Electron Multiplier Removed for Cleaning

ABBREVATIONS

ICP-MS: - Inductively coupled plasma mass spectrometry.
LA ICP-MS: - Laser Ablation Inductively Coupled Plasma Mass Spectrometry.
AC: - Alternating Current.
DC: -Direct Current.
ETV:-Electro thermal Vaporization
ITV: - In Torch Vaporization.
AMU:-Atomic Mass Unit
RF:-Radio Frequency.
M/z: - Mass to charge ratio.
Me CAT:-Metal coded affinity tags.

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