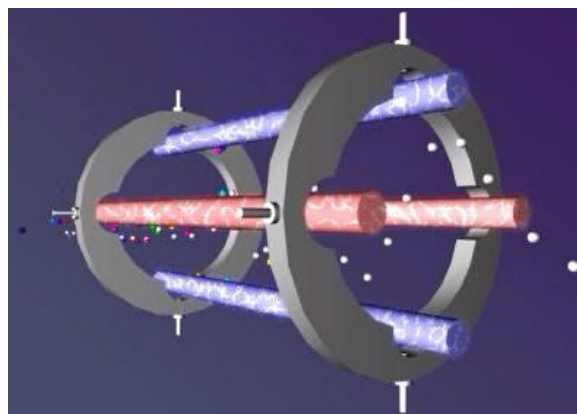
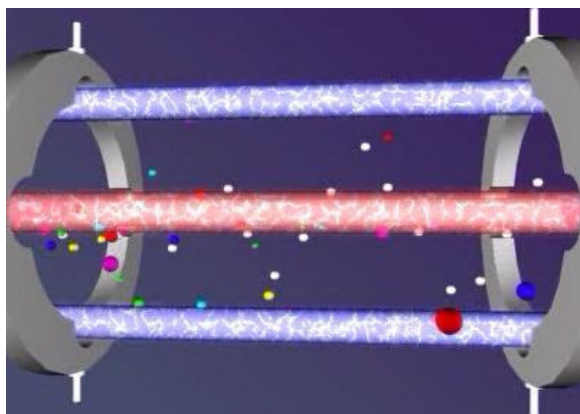


## 7. The Mass Filter

### Quadrupole Mass Analysers

In quadrupole mass analysing devices electric fields are used to separate ions according to their mass-to-charge ratio ( $m/z$ ) as they pass along the central axis of four parallel equidistant rods (or poles) that have fixed DC and alternating RF voltages applied to them

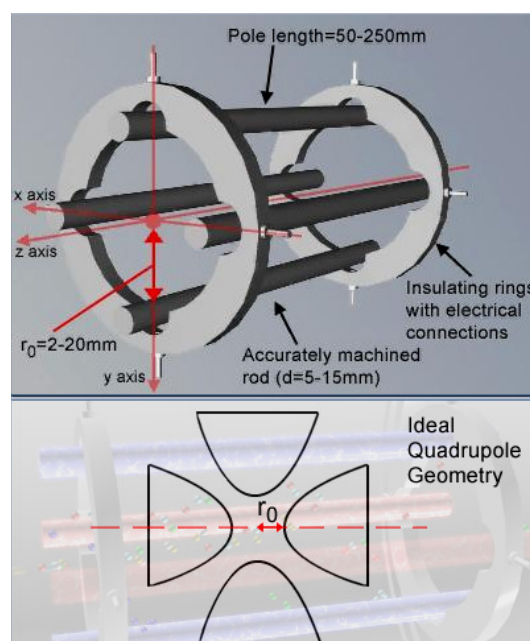


*Quadrupole mass analysing devices*

Depending upon the magnitude of these voltages it can be arranged that ions of only certain mass are allowed to pass the whole length of the quadrupole to be detected, the other ions being deflected onto trajectories causing them to collide with the rods and pass out of the analysing device.

## Quadrupole Rods

The four rods with circular cross-section used to construct the quadrupole mass analyser are shown below, along with the theoretically desired cross-section which is actually hyperbolic. Rods are used for engineering convenience in most systems, however, the machining of the rods and their spatial positioning is critical for mass accuracy and resolution.



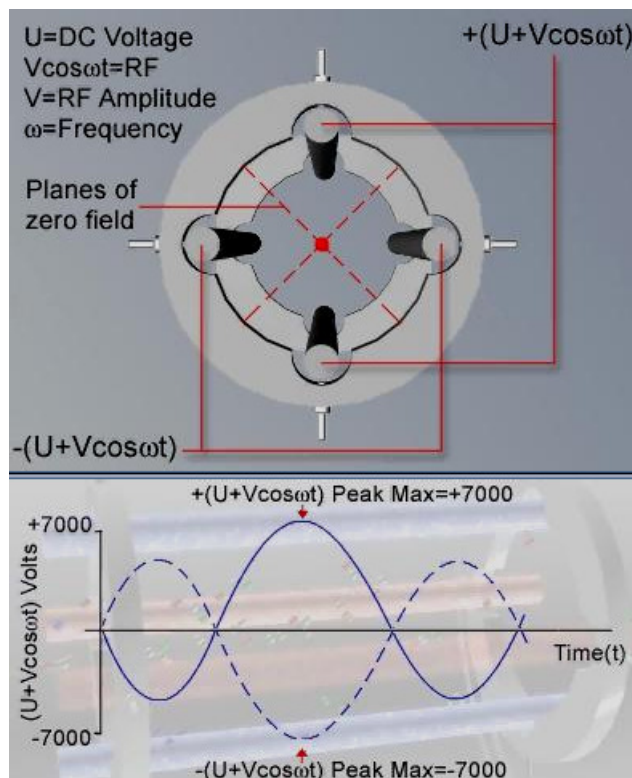
*Construction of a quadrupole mass analyser*

The pole assemblies range in length from about 50 - 250 mm, depending upon the nature of the application and the pole diameters lie in the range 5-15 mm, typical quadrupole tunnel radii ( $r_0$ ) being 5mm. Insulating rings that are drilled to allow the passage of the connections to the DC and RF supplies normally hold the poles. Very high mechanical accuracy is needed (in the micron region), in both the machining of the rods and their spatial positioning in order to achieve maximum performance.

For example, a quadrupole with a tunnel radius accurate to  $10^{-3} r_0$  would have a maximum resolution of 500 u ( $0.5r_0/10^{-3}r_0$ ).

Unlike simple deflection or acceleration of ions in magnetic and electric fields, the trajectory of ions in the quadrupolar field is complex.

Each rod is paired with its diametric opposite and has a potential of  $+(U+V\cos(\omega t))$  or  $-(U+V\cos(\omega t))$  as shown where  $U$  is the DC voltage and  $V\cos(\omega t)$  is the radio frequency (RF) with amplitude  $V$  (from 0 to  $\pm V$ ) and frequency  $\omega$ . As  $\cos(\omega t)$  cycles with time ( $t$ ), the applied voltages on opposed pairs of rods change in the manner shown below:



*Voltages applied to quadrupole rods*

Note that each rod pair is successively positive and negative, allowing ions to be both attracted and repelled away from the rods or the central axis of the mass analyser. Along the central axis of the quadrupole assembly and the planes shown, the resultant electric field is zero. Also note that for each pair of rods the peak maximum current in the positive or negative direction will be different. This can be explained by considering the permanent bias of each pair of rods.

If a DC of 1000V is applied with RF amplitude of 6000V;

For the positive rod pair the total current experienced by these rods will be

$+(U \pm V \cos \omega t) = +1000(U) \pm 6000(V) = +7000$  to  $-5000$  (peak max. in positive cycle)

For the negative rod pair the total current experienced will range from:

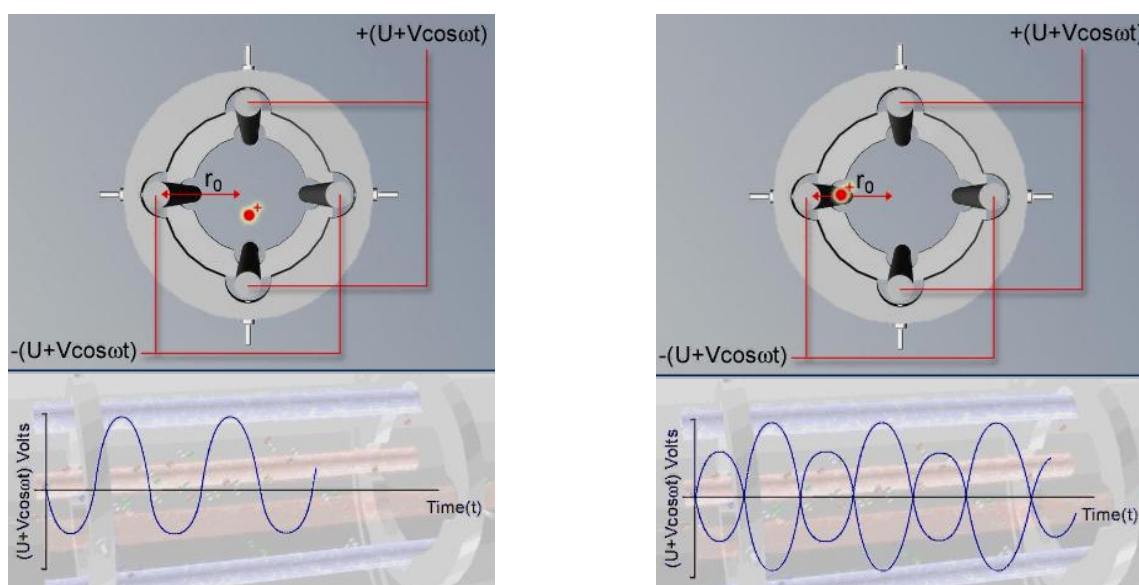
$-(U \pm V \cos \omega t) = -1000U \pm 6000V = -7000V$  to  $+5000V$  (peak max. in negative cycle)

## Equations of Ion Motion

In order to explain the motion of ions within the mass analyser, the equation for the field strength (electric potential -  $F$ ) at differing positions in the  $x$  and  $y$  plane (transverse direction) within the quadrupole;

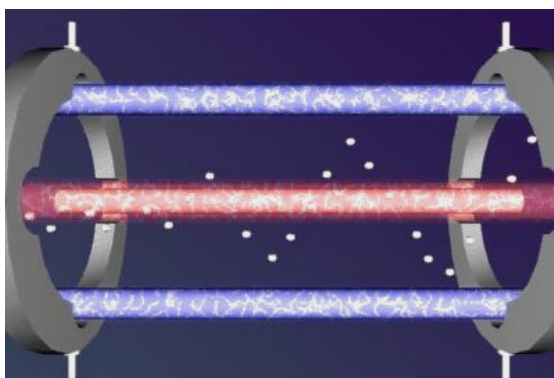
$$F = \frac{x^2 - y^2}{r^2} (U + V \cos \omega t) \quad (1)$$

Where  $x$  and  $y$  are the distances along the co-ordinate axes,  $r_0$  is the distance from the  $z$ -axis to either of the quadrupole surfaces,  $\omega$  is the angular frequency ( $2\pi f$ ) of the alternating current,  $V$  is the amplitude of the applied Rf signal and  $U$  is the magnitude of the DC potential applied to the poles.



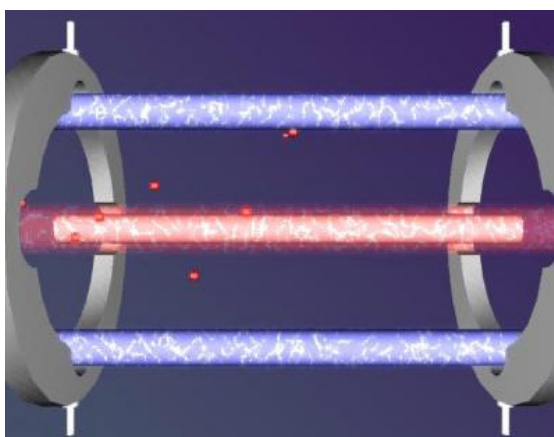
*Oscillating potentials applied to opposite rods creating the quadrupolar field*

As can be seen when  $x = y$ ,  $F=0$ , giving rise to planes of zero field strength within the quadrupole. At all other positions between the poles, the oscillating electric field ( $F$ ) causes ions to be alternately attracted to and repelled by the pairs of rods. Note that the equation above shows that the field ( $F$ ) has no effect along the direction of the central ( $z$ ) axis within the quadrupole and so to facilitate the passage of ions through this region an accelerating voltage is applied prior to the mass analyser which is usually in the region of 5 V.



As long as  $x$  and  $y$ , which determine the position of an ion from the centre of the rods, remains less than  $r_0$ , the ion will be able to pass through the quadrupole without touching the rods. This is known as a non-collisional, resonant or stable trajectory.

*Ions on a stable trajectory within the quadrupole*



Where the ion is caused to oscillate with a trajectory whose amplitude exceeds  $r_0$  it will collide with a rod, discharge itself and not be detected. This is known as an unstable or collisional trajectory. This for any particular  $m/z$  value the passage of the ion through the quadrupole is critically dependant upon the DC voltage ( $U$ ), the RF amplitude ( $V$ ), the RF frequency ( $\omega$ ) and the distance apart of the poles ( $2r_0$ ).

*Ions on a non-stable trajectory within the quadrupole*

From mathematical solution to equation (1) proposed by Mathieu, two factors  $a$  and  $q$  emerge as being important in defining regions of stable ion trajectory:

$$a = \frac{8zU}{mr^2\omega^2}$$

$$q = \frac{4zV}{mr^2\omega^2}$$

$$\frac{a}{q} = \frac{2U}{V}$$