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CHARGED PARTICLE TRAPPING MEANS EMPLOYING A VOLTAGE DIVIDER AND A PLURALITY OF SIMPLE CONDUCTORS TO PRODUCE COMPLEX TRAPPING FIELDS

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ABSTRACT OF THE DISCLOSURE

Charged particle trapping structures for use in mass spectrometers and the like wherein the ideal potential distribution forming the trapping means is generated using simple geometrical structures in place of the highly precise electrode surfaces previously used for the same purpose. An array of electrodes is arranged and energized in a predetermined manner so as to produce the desired trapping fields.

DISCUSSION OF THE PRIOR ART

Various means employing electric and magnetic fields have been used as traps for charged particles. Those using only electric fields cannot function as traps using electrostatic fields alone, since potentials in charge free regions have their extrema at their boundaries where potentials are defined by conducting electrodes. With electric fields alone, it is possible to generate average effective potential wells for the purpose of trapping charged particles with the proper circumstance of direct and alternating fields. One example of such a trap has been described by W. Paul et al. in U.S. Patent 2,939,952 of June 7, 1960. FIGURE 12 of this patent shows a cross section of Paul's device in which the electric potential is defined at boundaries consisting of conducting electrodes shaped to conform to surfaces which can be defined by the equations

(1) $$\frac{x^2+y^2-2z^2}{r_o^2}=1$$

and

(2) $$\frac{x^2+y^2-2z^2}{r_o^2}=1$$

These surfaces conform to a set of solutions of the Laplace equation, $\nabla^2\phi=0$. If the electrodes are connected to an electric generator, the potential within the electrode structure will conform to one described by:

(3) $$\phi=\phi_o\frac{x^2+y^2-2z^2}{r_o^2}$$

In order to afford a trap or effective average potential well for charged particles of a desired charge-to-mass ratio, the electric generator must provide that $\phi=U+V\cos\omega t$ where U, V, ω, r_o and the charge-to-mass ratio are related in a particular way. Paul and others have shown the conditions under which stable bounded motions (therefore, trapped) can occur for particles of a desired charge-to-mass ratio.

One application of two dimensional traps of this description is the conventional quadrupole mass spectrometer described by Paul and others. In this application, the instability and unbounded motion of charged particles having other than the desired charge-to-mass ratio is used to reject these particles from the direction of transmission through the structure, thereby selecting the particles of desired charge-to-mass ratio for transmission. The instability and unbounded motion in the case of the two dimensional trap takes place in directions transverse to the direction of transmission.

In another application, specifically the one cited above with reference to FIGURE 12 of Paul's patent, the trap is three dimensional, and particles may be retained and confined in all three directions, rather than transmitted as in the case of the conventional quadrupole mass spectrometer.

For devices intended for high resolution of charge-to-mass ratio, whether they be two dimensional or three dimensional traps, the dynamics of motion require that the fields deviate from the ideal fields, defined by the equation above, for example, by as little as possible at all points within the trap. In the familiar two dimensional trap, used in one application as a quadrupole mass spectrometer, the ideal geometry for the electrodes is comprised of four parallel rods whose boundaries in transverse section conform precisely to the sheets of equilateral hyperbolae. The required precision is difficult to achieve with conventional means to form the rods. In order to facilitate manufacture, the desired surfaces are approximated by the use of rods of circular cross section whose radius of curvature approximates that of the vertices of the desired equilateral hyperbolae.

This geometry of electrodes will support fields of approximately the correct conformation near the central axis of the trap. While this arrangement will, in fact, function as a two dimensional trap for charged particles of desired charge-to-mass ratio, its operation is restrained by the fact that the characteristics of the trap favor the trapping of particles of slightly differing charge-to-mass ratio in different parts of the structure. This fact vitiates the purpose of traps having high resolving power. Brubaker (Vacuum Technology conference, 1967), has demonstrated in an improved quadrupole mass spectrometer, having electrode rods of truly hyperbolic section, the efficacy of this preferred geometry.

DISCUSSION OF THE PRESENT INVENTION

The principal object of the present invention is therefore to provide the precise trapping field geometry required for devices of high charge-to-mass resolution without requiring the generation of highly precise physical surfaces having the desired geometrical form.

It is well known that if a region to be bounded by surfaces of electrically conducting materials, which surfaces coincide with solutions of the Laplace equation:

(4) $$\frac{d^2\phi}{dx^2}+\frac{d^2\phi}{dy^2}+\frac{d^2\phi}{dz^2}=0$$

and if these surfaces be excited by an external generator or battery to have potentials ϕ which conform with values of ϕ corresponding to the set of solutions of 4 coinciding with these surfaces, then the potentials within the region will conform to members of the same set of solutions of 4.

As an example, cited above, the case of the two dimensional quadrupole trap illustrates this principle. The hyperbolic surfaces of:

(5) $$x^2-y^2=r_o^2$$

and

(6) $$x^2-y^2=-r_o^2$$

bound the region of interest and if these surfaces are excited to potentials of $+\phi_o$ and $-\phi_o$, respectively, the potential within the area bounded will conform to:

(7) $$\phi=\phi_o\frac{x^2-y^2}{r_o^2}$$

Conventional traps are constructed with boundaries constituting equipotential surfaces as in 5 and 6 or their three dimensional analogs.

The basis of this invention lies in the distribution of a