Miniature Paul–Straubel ion trap with well-defined deep potential well

(rf trap/individual ion/elliptic ring electrode/three-dimensional cooling/minimum micromotion)

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Contributed by Hans Dehmelt, May 8, 1989

ABSTRACT In some recently proposed experiments using ion traps, a Paul trap of conventional size and design is insufficient. We have constructed a miniature Paul–Straubel trap. It has a small elliptic ring (≈ 0.2 mm) and three pairs of planar electrodes (≈ 2 cm part) arranged so that they form a cube. The two conventional end-cap electrodes are replaced by the six planar electrodes. The ring is heatable to a high temperature for improving the uniformity of the dc potential on the ring surface. With this trap, we hope to do such fundamental studies as the true zero-point confinement of a single ion.

Conventional Paul traps for single ion spectroscopy (1–5) are composed of a ring and two end-cap electrodes. When an rf voltage is applied between the ring and end-caps, it forms a three-dimensional harmonic oscillator pseudopotential. Typical size traps are of 1 mm ring diameter. The small size makes controlling orientation in space of the principal axes of the elliptical confining potential very difficult and no previous design has succeeded in doing so. To increase the trapping strength, an even smaller ring size has to be used. Another serious problem with all of the traps used has been the stray offset dc fields existing in the trap. It is well known that such offset potentials introduce a large unwanted micromotion of the trapped ions (5), preventing one from obtaining ultra-high-resolution spectra or achieving real zero-point confinement—an ultimate demonstration of the quantum-mechanical analogue of a particle at rest in free space.

To remedy these problems, we constructed a miniature trap as shown in Fig. 1. In this trap, a Paul–Straubel trap, the usual two end-cap electrodes are replaced by two parallel metal plates perpendicular to the z axis, being 1 cm away from the ring electrode. Any stray dc potentials on the plates would then have a much smaller effect at the center of the ring. The elliptic ring itself, 0.2 mm in diameter and slightly elongated in the y direction, is made of a thin tungsten wire, with two small leads, which attach to two rigid supporting rods (not shown in Fig. 1). By running a large current through the ring, it is possible to heat the ring to a very high temperature at which any surface layer would be cleaned up to the atomic level. This operation should greatly reduce, if not completely remove, the contact potential on the ring surface and accordingly reduce the stray electric fields present at the center of the pseudopotential well. The clean-up process can of course be repeated even in an operating trap. There are also two pairs of auxiliary plates placed on the four sides of the ring perpendicular to the x and y axes, respectively. They are so arranged that the four side plates and the two end plates are on the surfaces of a cube with the ring at its center. Applying some small voltage between the pairs of

FIG. 1. Miniature Paul–Straubel trap. The diameter of the elliptic ring electrode (not drawn to scale) is about 0.2 mm and the separations between pairs of the plates are about 2 cm.

opposite plates should make it possible to null out any residual stray dc fields at the center of the trap.

Straubel (6) showed trapping of macroscopic charged particles using a circular design before. Compared with a conventional Paul trap using end-caps and of the same ring size, the Paul–Straubel trap requires a five times as large rf voltage for the same trapping strength. However, this can be compensated by making the ring twice as small. In fact, the very simple design allows the newly designed trap to be extremely small in size.

With this trap, an attempt can be made to cool a single Ba^+ ion to the very ground state in the trap and to attain a secular frequency comparable to the width of the cooling transition frequency, a necessary condition (1) to cool the ion into the zero-energy state. The ability to eliminate stray dc electrical fields of the trap ensures the minimum micromotion of the ion.

This paper is based on an unpublished 1987 research proposal by H.D. and W.N. Our colleague, M. McDermott, read the paper and offered comments. The research is supported by the National Science Foundation under the Single Atomic Particle at Rest in Free Space Project.

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