Dipole Field Effects On Ion Ejections From A Paul Ion Trap

J. A. MacAskill* 1, A. Chutjian* 2

* Atomic and Molecular Physics Group, Jet Propulsion Laboratory, Pasadena, California USA

Synopsis
Attempts at improving the quality of mass spectra obtained from a Paul trap mass spectrometer prompted an investigation of the effects of additional fields to supplement the primary rf quadrupole trapping field. Reported here are the results of the first in a series of tests that focuses on the application of a single dipole field to augment the trapping and subsequent ejections of ions stored within a Paul trap. Measurements are presented for a fixed quadrupole frequency with varying dipole frequencies. The presence of the dipole field during the quadrupole trapping phase causes ion ejections of single m/z species at discrete dipole frequencies. During the mass analysis phase, the varying dipole frequency produces a complex set of resonant structures that impact ejection time (mass range), as well as mass spectral peak intensity and width.

A Paul ion trap is a three dimensional ion trap that uses precisely machined hyperbolic electrodes; a central “ring” electrode with two “end cap” electrodes, to form an ideal quadrupolar field for trapping ions of varying mass simultaneously. The small size and versatility of the Paul trap mass spectrometer make it attractive for a variety of field and space flight applications. The Paul trap mass spectrometer’s performance, specifically resolving power, can be improved by placing auxiliary rf waveforms on the end cap electrodes. Providing identical rf waveforms to the end caps with a 180° phase shift between them provides a dipole field in addition to the quadrupole trapping field arising from the rf on the ring electrode.

To better understand and quantify the effects of the dipole field on ion trapping dynamics, during both trapping and analysis phases, one of the JPL high precision Paul traps is configured for dipole application. The quadrupolar trapping rf is supplied by a custom generator built at JPL [1] with the auxiliary dipole field generated from a high purity waveform generator and center tap transformer. The ejected ion signal is multichannel scaled for an entire trapping and analysis period at a fixed dipole frequency. The entire ejection spectrum is then histogrammed as the dipole frequency is increased.

The result of one of these style measurements is shown in Figure 1. Immediately apparent are the frequency-symmetric resonance structures. The effective scan mass range is compressed as dipole frequency varies from the \( n\Omega_0/2 \) resonant points. The intensity and width of individual mass peaks decrease as the mass range is compressed. Over certain dipole frequency ranges, evidence of multiple modes appears as additional resonant structures that exhibit weaker frequency dependence. The presence of multiple modes creates interferences that allows single m/z species to be ejected at multiple times generating spurious peaks in a mass spectrum.

A detailed analysis of dipole field effects including power and frequency dependence of ion ejection time, spectral peak intensity, and spectral resolution is provided.

Figure 1. Intensity plot of ejected ion signal from a Paul trap for a fixed quadrupole frequency (\( \Omega_0 \)) of 1.254 MHz, and dipole frequency (\( \omega_D \)) varying from 0 – 2 \( \Omega_0 \). The trapping phase corresponds to 0-7 ms on the vertical scale while the analysis phase, with the linearly increasing quadrupole amplitude, corresponds to the 13-20 ms time window.

References

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1 E-mail: john.macaskill@jpl.nasa.gov
2 E-mail: ara.chutjian@jpl.nasa.gov