Effect of imperfections on the thermometry of ions stored in a 16-pole radiofrequency ion trap

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Synopsis Multipole radiofrequency ion traps such as 22-pole and 16-pole ion traps are widely used for low-temperature studies relevant to laboratory astrophysics and astrochemstry, where the traps are cooled down to 4–100 K to simulate the interstellar medium (ISM). With the help of buffer-gas cooling, temperatures of the ions can be brought down to close to the buffer gas temperature after sufficient number of collisions. The temperature of the ions has been found to be always higher than the buffer-gas temperature due to a phenomenon called radiofrequency heating. In this study, we demonstrate that even a very small displacement ($\sim 50\,\mu$m) of the electrode position can cause substantial additional RF heating beyond what would occur in an ideal ion trap.

Multipole radiofrequency ion traps such as 22-pole or 16-pole traps are widely used for low-temperature studies such as spectroscopy of molecular ions in the ISM conditions and for measuring ion-molecular reaction rate coefficients as a function of temperatures relevant to astrophysical environments [1]. The ions are cryogenically cooled by lowering the temperature of the traps using a closed-cycle liquid-helium cryostat, and thermalized via collisional energy exchange with a buffer gas, typically helium.

A 22-pole or a 16-pole ion trap provides a relatively large field-free central region in which trapped ions undergo frequent collisions with helium buffer-gas atoms. As ions approach the radiofrequency (RF) electrodes, they experience the rapidly oscillating RF electric field [2]. RF-driven ion motion, coupled with buffer-gas collisions, can lead to RF heating and consequently to an ion translational temperature higher than that of the buffer gas. In this work, we investigate how small geometric imperfections in the fabrication of multipole ion traps influence the ion temperature.

We consider two trap geometries—a 16-pole and a 16-wire ion trap—with the same inscribed radius and hence the same nominal trapping volume. Both traps are operated at identical RF amplitudes and frequencies, and ions with $m/q = 17$ u (corresponding to OH^-) are simulated. Ions are generated within the trap and tracked for 25 ms. Their translational temperature is determined from the ion speed distributions, which are fitted to a Maxwell–Boltzmann distribution. The ions reach thermal equilibrium within approximately 10 ms; the reported temperature is therefore obtained by averaging the fitted temperatures over 10–20 ms.

Figure 1 shows the resulting ion temperature as a function of buffer-gas temperature for ideal 16-pole and 16-wire traps. For comparison, results are also presented for traps in which the alternate set of RF electrodes is displaced by $50\,\mu$m, representing a small geometric fabrication imperfection. The comparison reveals the sensitivity of ion heating to realistic deviations from the ideal trap geometry.

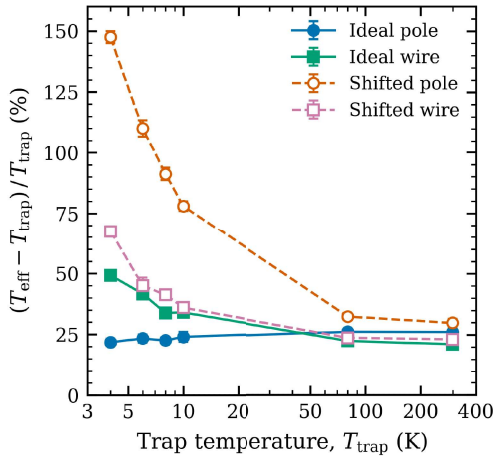

Figure 1. Percentage deviation of ion temperature in ideal and shifted 16-pole and 16-wire ion traps.

References

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