Abstract

Single particle dynamics in radio frequency traps has been extensively researched for several decades and many interesting properties and applications have been brought to the fore. However, collective dynamics of the single species charged particles inside a Paul trap is not very well understood. The understanding of the phenomena of plasma heating on account of the applied radio frequency electric field is still in its infancy. This thesis theoretically investigates the dynamics of a non-neutral plasma inside a Paul trap and provides a mathematical framework to understand the plasma temperature variations, which will hopefully aid researchers in better understanding the phenomena of radio frequency heating.

Firstly, we analyze a single species plasma in a Paul trap wherein space charge effects have been neglected and the plasma is considered to be collisionless. These are reasonable conditions to impose in the analysis of a dilute single species plasma. We begin by constructing an analytical time-dependent plasma distribution function which, for a carefully chosen initial form of $q$-Gaussian type Tsallis distribution and scale length, becomes time-periodic with the same frequency as that of the applied radio frequency electric field. Experimental observation of the existence of power law tails in the particle distribution is one of the primary motivation behind choosing a Tsallis distribution. The time averaged distribution function shows a double hump beyond a certain spatial threshold and the double hump moves away from the bulk as the Tsallis parameter $q$ increases, thereby indicating that the $q$-Gaussian distribution is perhaps more stable as compared to the Maxwellian distribution which is obtained from Tsallis distribution when $q = 1$. Also, the plasma temperature increases with an increase in the distance from the central axis of the device, which is indicative of the increase in radio frequency heating of the plasma inside a Paul trap.

Secondly, we investigate the dynamics of a single species plasma in a recently proposed dual frequency Paul trap. Such a device is a viable option to trap charged particles of varied charge to mass ratio and offers a flexible confinement of charged particle by keeping the primary voltage and frequency fixed, while varying the secondary voltage and frequency. This changes the form of the pseudo potential well and allows for different spatial regions of confinement. We compare this device with a conventional single frequency Paul trap. The double hump in the time averaged distribution function has a global maxima at $v = 0$ and it seems that a plasma is likely to be more stable in a dual frequency trap than in a conventional single frequency trap. Though the temperature in a dual frequency Paul trap also increases with distance from the central axis of the device, its temporal variation shows an interesting property for periodic solutions of the plasma distribution. If the applied frequencies are rationally related, the temperature oscillates with a time-period given by the LCM of the two time-periods of the applied voltages and their linear combinations. Hence, if the ratio of frequencies is an integer, the plasma temperature oscillations occur.
at the lower one among these two frequencies. Notably, the systematic shifts in frequency standards on account of second order Doppler and Stark effects are of the same order as that observed for a single frequency Paul trap.

Thirdly, we analyze plasma dynamics in presence of excess micro motion due to stray electric fields and phase mismatch between the electrodes. Since the particles are likely to experience a drift with respect to both position as well as velocity, it becomes important to accommodate such drifts in the initial form of distribution function. The stroboscopic plot reveals a closed curve indicating the existence of a time periodic distribution function in the Paul trap. The instantaneous temperature exhibits an asymmetrical profile quite different from the one obtained in a conventional Paul trap without excess micro motion.