Ion-ion collision-induced evaporative cooling of atomic and molecular ions by autoresonance in an electrostatic ion beam trap

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Synopsis A new method for cooling beams of any ion is introduced. The method is autoresonance acceleration of ions inside an Electrostatic Ion Beam Trap. Intrabunch collisions of trapped (molecular) ions transfer energy from the "cold" part of the population of the ion distribution to the "hot" part, which, in turn, evaporates from the bunch. As a result, bunches of ions were cooled from about 45 K to well below 1 K.

Translational cooling of bunches of atomic and molecular ions is a requisite in several research areas. An Electrostatic Ion Beam Trap (EIBT), which can trap any ion with any mass or charge using the same tuning conditions, is therefore ideal for ion beam cooling.

A chirped sinusoidal voltage is applied to one of the EIBT mirror electrodes. In this procedure, called autoresonance[1] (AR), a bunch of ions is accelerated out of the rest of the ion beam population. The bunch acceleration efficiency is governed by the strength of the chirped electric field. Depending upon the chirped field intensity and rate, one can control the velocity distribution in the bunch.

A cooling process has been demonstrated in the EIBT that, by using autoresonance, reduced the temperature of ions from an initial value of ~45 K down to about 0.15 K in 80 ms [2]. The EIBT is tuned so that ion density is maximized at the turning point of the trap to achieve thermalization and effective evaporation.

Figure 1 shows the calculated bunch internal temperature as a function of the AR voltage using the measured ion bunch velocity distributions. The AR threshold potential for ion bunch acceleration is about 0.052 V in this data set. The arrow in the figure indicates the initial temperature of the ions in the trap before the AR process.

During AR, it has been shown [2] that the ion-ion collisions transfer kinetic energy from the cold population to the hotter population, which in turn is evaporated from the ion bunch, hence reducing the bunch's temperature and increasing the phase-space density. Further experiments and theoretical models are ongoing to improve the cooling efficiency and to achieve lower temperatures.

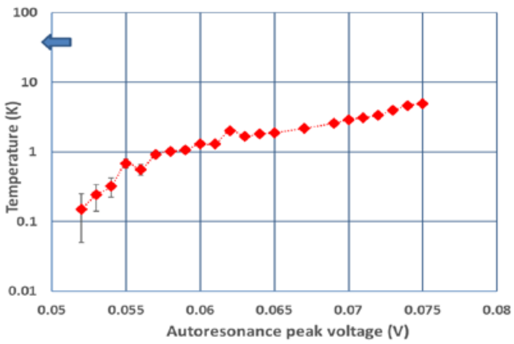

Figure 1. Temperature of the ion bunch after autoresonance acceleration. The arrow indicates the intial temperature of the ions in the EIBT.

Since this process is applicable for any ion and any charge, it has the potential to be useful for reaction studies. Moreover, even without a sufficient number of ions in the trap for intrabeam collisions to produce significant cooling, the AR process by itself is a filtering process for cold population selection.

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References

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