Adiabatic cooling of nonneutral antiproton plasmas

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Nonneutral plasmas have received much attention in the last few decades, particularly because very accurate table-top experiments can be devised to study their properties. In particular, the creation and confinement of nonneutral plasmas consisting of antiprotons is a major issue for the production of significant amounts of neutral antimatter in the form of antihydrogen atoms.

The antihydrogen atoms are usually trapped in a magnetic well (Penning-Malmberg trap), where the effective confining potential should have a depth of about 1K in temperature units. As the antiprotons are created with much higher energies, their cooling constitutes a major challenge to achieve an effective confinement.

Recently, using an adiabatic cooling technique, Gabrielse et al. [1] managed to cool down several million antiprotons to about 3.5 K with almost no losses observed. Adiabatic cooling is achieved by slowly decreasing the trapping frequency and letting the plasma occupy a larger volume.

The experimental measurements of Ref. [1] determined the final temperature (after adiabatic cooling) as a function of the initial trapping frequency. The most salient features of these results were that: (i) the final temperature is proportional to the initial frequency raised to the power -1.2 and (ii) the temperature levels off at around 3.5 K for initial frequencies above a certain threshold, thus making the cooling procedure inefficient.

In the present contribution, we develop a fully kinetic time-dependent theory of adiabatic cooling for plasmas trapped in a one-dimensional well [2]. The antiproton dynamics is described by a Vlasov equation coupled to Poisson's equation for the self-consistent electric potential. Collisions are modeled via a relaxation term that couples the longitudianl and transverse temperatures of the antiproton plasma. The self-similar plasma expansion is treated by means of a scaling technique. The theory contains no fitting parameters: all quantities are either taken from the experiments, or (in the case of the collision rate) computed from a first-principles model.

Numerical simulations based on our model [2] are compared to the recent experimental results of Ref. [1] with excellent quantitative agreement between the two. We recover the correct slope of the temperature curve against the initial frequency, as well as the leveling off of the temperature for initial trapping frequencies above 500 kHz. Finally, we suggest some ways to improve the efficiency of the adiabatic cooling by reducing the effect of the temperature saturation at high trapping frequencies.

References

[1] G. Gabrielse et al., *Phys. Rev. Lett.* **106**, 073002 (2011).

[2] G. Manfredi and P.-A. Hervieux, *Phys. Rev. Lett.* **109**, 255005 (2012).