Collisional Cooling of Pure Electron Plasmas Using CO_2

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Abstract.
Inelastic collisions with CO_2 buffer gas cool a pure electron gas in a Penning-Malmberg trap at low magnetic fields. 0.6 eV electrons are cooled by down to 30% of their original temperature.

INTRODUCTION

Pure electron plasmas can be held indefinitely by applying a rotating electric potential. Such "rotating walls" work only if there is some mechanism that cools the plasma to counteract the heating from the rotating wall. Experiments using this technique [1] have relied on electron cyclotron cooling in large B-fields to counter this heating. However, at substantially lower fields, cyclotron cooling is not fast enough to balance the heat-input from the wall drive, therefore requiring another cooling method to achieve confinement.

Inelastic electron collisions with buffer gas can transfer energy from electrons to gas molecules through excitation of molecular vibrational modes, acting to cool electrons, while elastic collisions tend to generate outward radial transport [2]. Good candidate buffer gases should have an inelastic electron scattering cross-section larger than its elastic cross-section for the energy range of interest, in addition to having vibrational modes with energies similar to the electron thermal energy. Motivated by an examination of spectroscopic data, calculations of electron-CO_2 scattering cross-sections [3], work done with gas-cooling in positron experiments [4] and ease of use, CO_2 seemed to be a good candidate for an initial investigation.

EXPERIMENT

Cooling and preliminary compression measurements were carried out in a Penning-Malmberg trap. Typical plasmas used in the experiment measured approximately 30 cm. in length with a radius of 1 cm, and an approximate number density of 10^7 cm^{-3}. The longitudinal B-field was 1500 gauss.

Temperature measurements were performed by gradually lowering the end confinement potential while measuring charge leaving the trap and inferring a $T_{\|}$ from a reconstruction of the tail of the parallel velocity distribution function[5]. Electrons were assumed to be in approximate thermal equilibrium giving $T_{\|} \approx T_{\perp}$. The plasma temperature with no buffer gas (base pressure $5 \cdot 10^{-10}$ torr$to 8 \cdot 10^{-10}$ torr) was approximately

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0.6 eV for these experiments.

The buffer gas was 99.9% dry CO_2 . Gas was introduced into the vacuum chamber via a leak valve and monitored with an ion gauge and residual gas analyzer. For measurements discussed in this paper, the CO_2 was contaminated with water from the gas transport line to a level between 2.5% and 5% partial pressure. Later experimental enhancements eliminated this contamination.

Measurements were made using the standard inject-hold-dump sequence. Hold times were varied and temperature measurements made at the dump cycle. Figure 1 shows cooling curves at several CO_2 pressures.

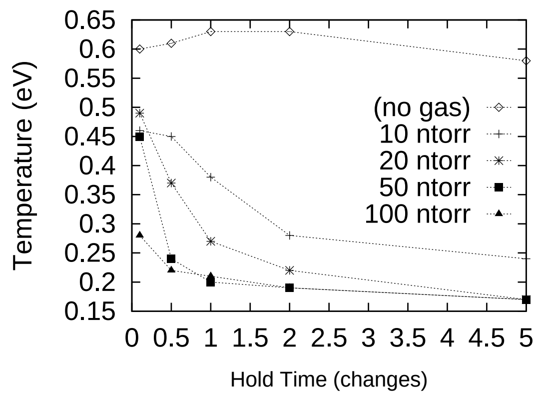

FIGURE 1. Plasma temperature as a function of hold time. Pressures listed are pressure of CO_2 plus base pressure (.8 ntorr).

Preliminary work involving a rotating wall drive was carried out using an annular gate in the center of the plasma column divided into four 90° sectors. A sinusoidal potential was applied to each gate with successive 90° phases with the same rotation sense as E*x*B rotation. The drive frequency was swept linearly for a period of time (chirp time) and held at the end frequency for the remainder of the hold cycle. Measurements of the RMS plasma radius and total number of electrons were made during the dump cycle by dumping the electrons on a phosphor screen and analyzing the image. Figures 2 and 3 show results for one set of parameters.

DISCUSSION

As shown in Fig. 1, the CO_2 buffer gas successfully cools the electron gas. In general, higher CO_2 pressure increased cooling rates, however cooling saturated at temperatures between 0.2 and 0.3 eV. It was uncertain if this effect is due to saturation of the cooling process or is a limitation in the temperature diagnostic.

Higher partial pressures of CO_2 resulted in substantial radial transport and some CO_2 ionization – two effects opposing the goal of infinite plasma confinement. Coupling this system with a rotating wall potential produced some radial compression to counteract this elastic collisional transport.

Figure 2 demonstrates moderate compression using a chirped, rotating wall potential. Maximal compression was achieved with a frequency near the first Trivelpiece-Gould

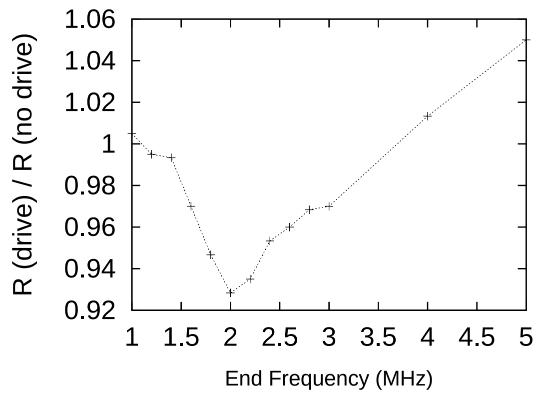

FIGURE 2. Normalized RMS Plasma radius as a function of wall drive end frequency. Wall Drive Voltage: 0.1 V_{pp} Wall Start Frequency: 660 kHz Chirp Time: 20 sec. Total Hold Time: 30 sec. CO_2 Pressure:6 ntorr.

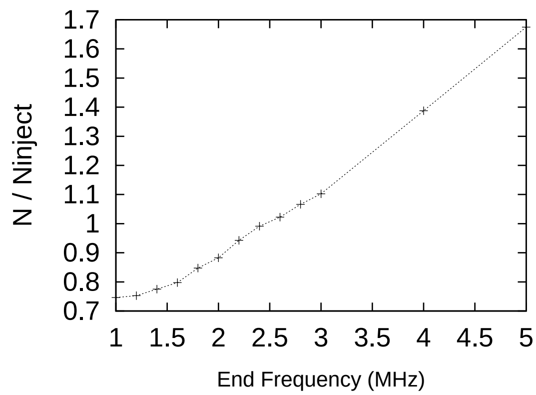

FIGURE 3. Total trapped charge as a function of wall drive and end frequency. Normalized to the amount of charge measured in an inject with no hold time and no buffer gas. System parameters the same as in figure 2.

mode of the system (1.9 MHz), as expected[4]. Unfortunately, this compression was met with much gas ionization, as evident by an increasing amount of total charge in the trap with increasing end frequency (figure 3).

In conclusion, this experiment shows that CO_2 buffer gas cools pure electron plasmas. Thus far, only modest plasma compression was achieved using a rotating wall potential, accompanied with ionization. Whether this is a parameter regime of CO_2 pressure and drive potential in which plasma columns are indefinitely confine remains an open question.

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