Experimental Plasma Flow into a Vacuum Magnetic Cusp Field*

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A directed dense plasma has been observed to penetrate and be detained by a vacuum cusp magnetic field. A gross measurement of the directed velocity of the deuterium plasma was $(8.5\pm0.5)\times10^6$ cm/sec. Ion density in the central region of the cusp was measured to be 8.5×10^{15} at 16 μsec after injection and had a decay constant of 13.5 μsec. Magnetic probe measurements are shown which indicate the gross reaction of the magnetic field to the injected plasma. Observation of impurity emission indicates that the plasma electrons cool rapidly and that the collision-dominated plasma is in contact with the container walls at the cusp ring.

RECENTLY considerable interest has been shown in acceleration and trapping of dense plasma in a cusp magnetic field.[1,2] The present note is a report of experimental observations of "trapping" of a collision dominated plasma. A schematic of the system is shown in Fig. 1. The plasma accelerator is a modified conical pinch tube[3] previously used for strong shock experiments. The addition of a fast gas valve which introduces only a puff of gas allows the injection, heating and acceleration of the puff into an evacuated cylinder.[4] The valve is similar to one reported by Per Gloersen.[5] The cusp field into which the plasma flows is formed by four concentric coils connected in series. The current in the front pair is directed in the opposite sense to the current in the downstream pair forming a null field in the center.

The directed axial velocity of the ejected diffuse plasma was measured indirectly. By placing a solid normal surface at several positions along the cylinder, all plasma flow is stopped and a buildup of ion density occurs at the surface position. By observing the time of appearance of ion pressure-broadened emission light (10 A away from D_β) at each of the surface positions, a gross value of the axial plasma flow velocity was found to be $(8.5\pm0.5)\times10^6$ cm/sec. This corresponds to a directed energy of 60 ev for deuterium. Optical observations of the radial spreading through a 1-inch aperture indicated that the internal temperature is of the order of 5 electron volts.

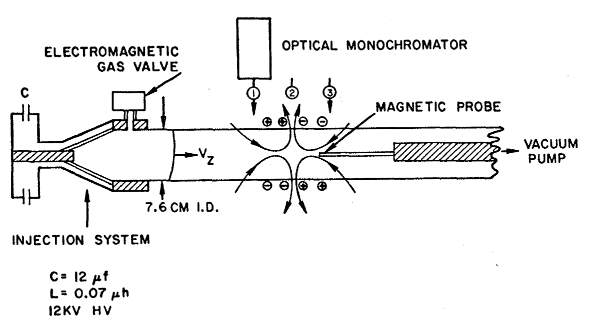

FIG. 1. A schematic diagram of the equipment.

In order to determine the gross response of the cusp field to the injection of the plasma, the axial component of the cusp field was measured at several positions with a small magnetic probe.[6] The results are shown in Fig.2. The general features to be noted are first the drastic decrease of the field on the upstream side indicating a conducting fluid has penetrated the field, second only a slight change in the downstream peak field indicating no transmission of plasma. There is also a general deformation of the field in the downstream direction and finally the relaxation in 10 μsec to a configuration close

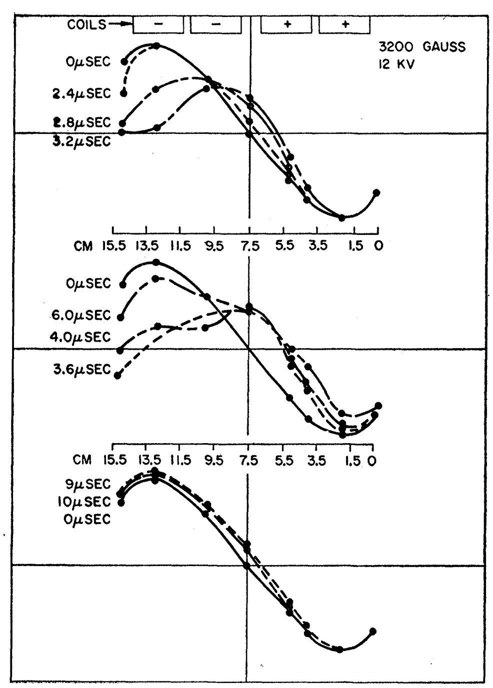

FIG. 2. The cusp field as a function of position and time.

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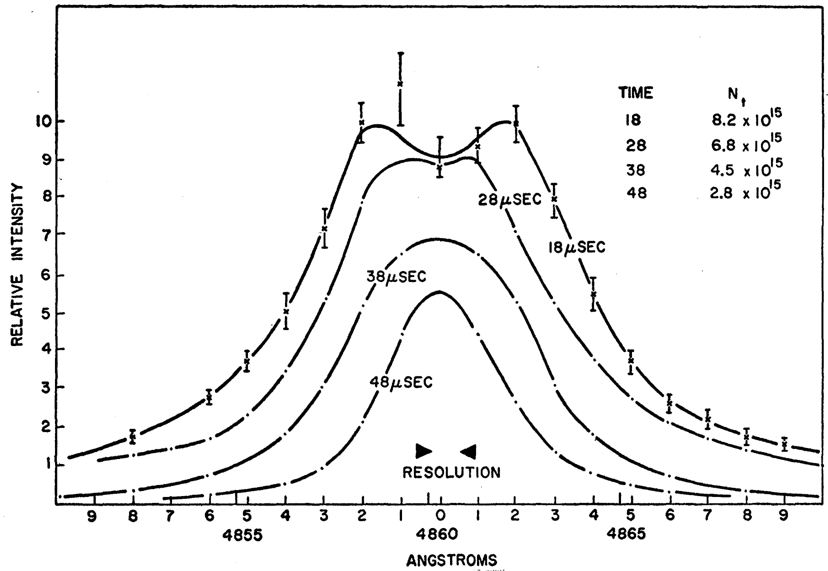

FIG. 3. The shape of the Balmer emission line as a function of time.

to the initial field distribution. The gross description is compatable with the notion that the field has absorbed a large axial momentum from the plasma.

To determine the ion density of the "trapped" plasma the spectral shape of the D_β emission line was measured in three positions as indicated in Fig. 1. Figure 3 shows the results from measurements taken at position 2 under the same operating conditions as in Fig. 2 excluding the probe. The shape of the emission line fits the recent theory of Griem, Kolb, and Shen[7] for the broadest line for an ion density of 8×10^{15}. The temperature dependence is insensitive in this region. The shape of the line at later times was affected by the equipment resolution, but an estimate of the ion density could be made for at least 50 μsec showing an e folding decay time of 13 μsec. Observations at position 1 indicates a peak ion density of 5×10^{15} at 28 μsec and at position 3 a peak density of 2×10^{15} at 18 μsec. Observation of Si^{IV}, Si^{III}, Si^{II} emission lines as a function of time showed successive peaking of each species with Si^{II} being the last. By plotting the logarithm of the ratio of these line intensities as a function of time a cooling rate of the electrons in the plasma was found to be 6 μsec indicating that the plasma was in contact with and cooled by the glass wall at the cusp. Similar data was obtained from He^{II}, He^{I} emission lines when He was used as the plasma.

The data here presented indicate that a directed plasma can indeed be detained in a vacuum cusp field. The rapid cooling of the electrons and the rapid decay of the ion density indicate that the "trapped" plasma is in direct contact with the glass walls at the cusp and is a collision dominated plasma. In order to examine the possibilities of cusp containment indicated by Tuck[1] and Grad[2] much higher directed energies and better isolation of the field must be found.

ACKNOWLEDGMENT

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