

End Losses of a Quiescent Collisionless Plasma in a Magnetic Mirror.

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Collisionless, steady state plasmas showing a remarkably low level of density fluctuation ($\Delta n/n < 5\%$) have been generated in a mirror geometry magnetic field, by applying 50 W, CW, 2.4 Gc/s to a coupling structure of new design.^{1), 2)} The plasma has electron temperatures 5 to 30 eV, ion temperatures around 5 eV, electron densities of 10^{10} to $5 \times 10^{11} \text{ cm}^{-3}$, and can be produced in various gases at pressures as low as 10^{-5} torr. for a wide range of magnetic field strengths ($\Delta B/B < 80\%$). This quiescent plasma, with electron temperatures two orders of magnitude greater than thermal alkali plasma ("Q" machines) is particularly suitable for basic plasma physics studies. Also the long mean free path for ions and electrons makes study of this plasma relevant to problems in space physics and controlled thermonuclear research.

We have investigated experimentally,

- the density fluctuation level
- the temperature and density profiles at different positions along the plasma column
- the variation of density and temperature with magnetic field strength, applied r.f. power and neutral gas pressure.

From these measurements we have studied end losses (the dominant loss mechanism) and have obtained verification of the following simple model for plasma losses in a magnetic mirror. We consider a steady state plasma, volume V , density n and particle energy kT produced by applying r.f. power $P_{R.F.}$ with coupling efficiency η . Then the containment time τ is given by the relation

$$n(VkT/\eta P_{R.F.}) = \tau \quad (1)$$

For constant V , T , and $P_{R.F.}$ we have from (1), $n \propto \tau$. Following Spitzer,³⁾ we employ a particle reflection coefficient R , where $R = 1 - B_{ce}/B_m$, (B_{ce} is the magnetic field strength corresponding to electron cyclotron resonance, and B_m is the maximum field strength in the mirror) and obtain from the consideration of mass conservation

$$-(1/n)(dn/dt) \propto (1-R) \quad (2)$$

From (1) and (2) we have $n \propto \tau \propto (1-R) = B_m/B_{ce}$. Further, we must take account of the fact that in a collisionless plasma, no particle build-up is possible in the absence of mirror confinement; i.e. $n = 0$ for $B_m/B_{ce} = 1$, and $n > 0$ for $B_m/B_{ce} > 1$. Hence we have,

$$n \propto (B_m - B_{ce}) \quad (3)$$

The experimental arrangement is shown in Fig. 1. The r.f. power is fed to an "L" coil^{1), 2)} of 3 cm internal diameter. As the vacuum wavelength of the applied r.f. power ($\lambda = 12.5 \text{ cm}$) is much greater than the cut-off wavelength of the "L" coil, no r.f. power will be radiated out of the coil. Plasma is generated whenever the magnetic field strength equals the value B_{ce} for electron cyclotron resonance (ECR) with the exciting frequency. Because the "L" coil extends over a large region of non uniform magnetic field, plasma is produced for a variation of nearly 80% of the minimum value of B_m (for which plasma generation takes place).

From the measurements a), b), and c) we conclude that for magnetic field strengths in the range $1.2 < B_m < 2 \text{ kG}$, the production of plasma in the ECR region is unaffected by the position of B_{ce} . The neutral gas pressure was 6×10^{-5} torr. for all the reported measurements. With 40 W of applied r.f. power the measured electron temperature was 10 eV and little deviation from this value ($< 10\%$) has been detected on the temperature profiles at various positions along the plasma column. The characterisation of this plasma as collisionless appears well justified from the relevant time and length scales derived from the plasma parameters at the given neutral gas pressure.²⁾

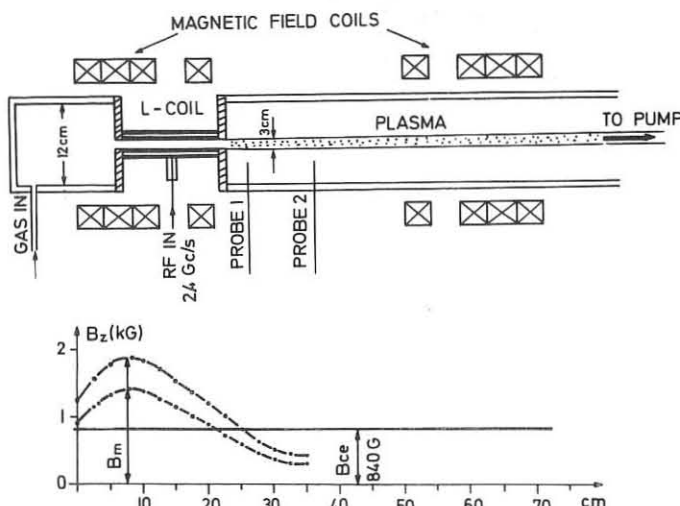


Fig. 1 Experimental arrangement

the mirror. The different sets of data, each for a given r.f. power level, clearly define a common value of magnetic field strength corresponding to the electron cyclotron resonance B_{ce} . With the same neutral gas pressure and the same range of power levels, the zero value of density has been verified with a homogeneous magnetic field $B = B_{ce}$. Clearly the relation (3) is experimentally well verified. Fig. 2b shows plasma density measured at the middle of the mirror plotted against applied power $P_{R.F.}$ for different magnetic field strengths. For const. B_m we have $n \propto P_{R.F.}$ in agreement with (1).

In Fig. 2a the plasma density measured at the centre of the mirror (position of probe 2) is plotted against B_m , the maximum value of the magnetic field strength at the end of

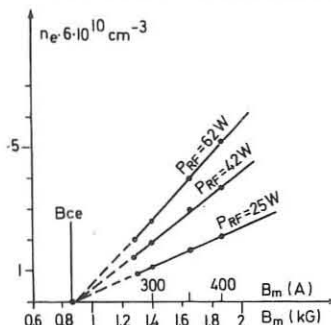


Fig. 2a Plasma density as a function of B_m for different values of applied r.f. power $P_{R.F.}$

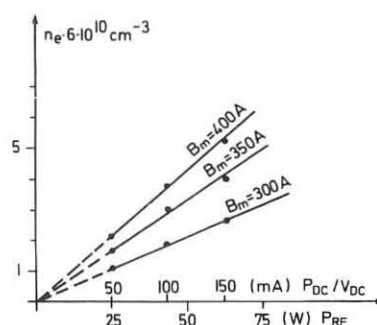


Fig. 2b Plasma density as a function of $P_{R.F.}$ for different values of magnetic field strength B_m .

We have described a particularly versatile plasma source and used it to carry out a study of plasma losses in a magnetic mirror. Experimental results agree well with the description given by a simple model involving the single particle reflection coefficient in a magnetic mirror.

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