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14. Abstract/Notes

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ION-ACOUSTIC DOUBLE LAYER IN A MAGNETIC PICKET FENCE CONFIGURATION

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ABSTRACT

A small amplitude double layer formed across the magnetic sheath of a picket fence configuration has been experimentally observed in a multi-magnetic-dipole discharge plasma. The double layer is shown to be associated with the anomalous resistivity caused by an ion-acoustic instability driven by cold electrons diffusing through the confining surface field.

Recently, there has been an increasing interest in the study of double layers associated with the anomalous resistivity generated by an ion-acoustic instability[1-3]. Computer simulations[1] have shown that small amplitude ($\Delta\phi \lesssim kT_e/e$) double layers can be formed over a large length scale ($L \gtrsim 250\lambda_D$) by electrons with drift velocity less than the thermal velocity ($v_d < v_e$). The evolution of such double layers from long wavelength ion-acoustic waves in the presence of drifting electrons has been observed in the laboratory[2]. A series of these small amplitude double layers may be responsible for the acceleration of auroral particles[3].

In this paper we wish to report the formation of a double layer in a magnetic picket fence configuration inserted in a quiescent plasma. The experiment was performed in a multi-magnetic-dipole device, at the Institute for Space Research (Instituto de Pesquisas Espaciais), as shown schematically in Fig. 1. This device contains two independent plasmas separated by a magnetic picket fence. The plasma density at each side can be varied by adjustment of the discharge currents (by manual control of the heating current in the filaments) in the two independent systems of filament cathodes. Discharges are made in argon gas at a pressure $p \cong 5 \times 10^{-4}$mbar. Typical plasma parameters are $n_e \sim 10^{15}m^{-3}$, $T_e \sim 3eV$ and $T_e/T_i \sim 15$. Under these conditions the mean free path for electron-neutral collisions is much longer than the length scales of interest. A plane Langmuir probe is used to measure the electron density and temperature. The plasma potential is measured with an emitting probe and the results checked with the Langmuir probe. The electron drift velocity is estimated from the shift of the electron energy distribution function as detected by back and forward facing disk Langmuir probes (a second harmonic detector circuit is used to obtain the energy distribution function from the probe characteristic curve). The ion temperature is estimated using a grid energy analyzer. Ion-acoustic turbulent density fluctuations are measured by a spectrum analyzer connected to the disk Langmuir probe.

The magnetic picket fence is created by rows of permanent magnets spaced 3cm apart in such a way that the north pole of one row faces the south pole of the adjacent row, as shown in Fig. 2. This figure also shows the profile of the magnetic induction measured along the z axis with a Hall probe. By turning on the filaments in the source chamber only (refer to Fig. 1), a plasma is generated with $n_e \cong 2.4 \times 10^{15} m^{-3}$ and $T_e \cong 2.8eV$. In this situation the plasma diffuses through the confining surface field of the magnetic picket fence into the target chamber, where the plasma density becomes $n_e \cong 1.7 \times 10^{14} m^{-3}$ and the electron temperature $T_e \cong 0.5eV$. The electrons that diffuse across the magnetic field are predominantly of low energy (0.3eV) as a result of a selective collisional process[4] (electron-ion collisions give rise to a diffusion process which is faster for colder electrons). Figure 3 shows the electron temperature profile (the negative part of the z axis corresponds to the source chamber) as obtained from the characteristic curve of the plane Langmuir probe. We verify that the low energy electrons are slighthly heated while diffusing through the surface magnetic field. This is the result of scattering due to ion-acoustic turbulence in the magnetic sheath region. This turbulence extends in space roughly from $z \cong -3cm$ to $z \cong +3cm$ and its effect should be important in the diffusion process of the electrons. It may be pointed out that this ion-acoustic instability can explain the trapping of primary electrons in multipolar discharges by a violation of the invariants of the motion[5]. The accumulation of primary electrons gives rise to an increase of the ionization rate and results in a concentration of density gradients near the walls of the discharge[6]. In addition to the cold electron flow generated by diffusion along the z axis, a net current of reflected hot electrons is detected along the y axis. The peak of the current profile is located in the position $z \cong -2.3cm$, between the peak of the temperature profile in the source chamber, as shown in Fig. 3, and the maximum gradient of the magnetic field. In this region of increasing magnetic field it is possible to identify two electron temperatures. The current along the y axis is mainly due to the grad-B drift of electrons with energies above $\sim 2.8eV$ (with a smaller contribution of the $\vec{E} \times \vec{B}$ drift, which opposes the grad-B drift).

Now consider a situation where both systems of filaments are turned on and the value of the plasma density in the target chamber is less than but close to the value of the plasma density in the source chamber (the electron density in the source chamber can be adjusted in the range $10^{14} \sim 2 \times 10^{15} m^{-3}$ and the electron temperature in the range $2.0 \sim 3.0 eV$). In this case there is a net flow of cold electrons directed from the source chamber to the target chamber. Figures 4a-c show the measured profiles of the plasma potential, of the drift velocity of the cold electrons, normalized to the local ion-acoustic speed, and of the electron temperature, respectively. The corresponding plasma density in the source chamber is $n_e \cong 2.4 \times 10^{15} m^{-3}$ and in the target chamber is $n_e \cong 1.6 \times 10^{15} m^{-3}$. The plasma potential shows a wide protuberance associated with the ion rich magnetic sheath. The diffusing electrons are initially accelerated by the rise in plasma potential and afterwards decelerated as the potential in the target chamber returns to approximately the same level as in the source chamber. The drift velocity of the cold electrons inside the magnetic sheath is much larger than the ion-acoustic speed such as to drive an ion-acoustic instability. From the temperature profile we verify that the diffusing cold electrons are heated up to about 1.7eV by the turbulent fields produced by the ion-acoustic instability inside the magnetic sheath. In the target chamber a two electron temperature plasma is formed where the temperature of the hot population is $T_e \cong 3.6 eV$, the density ratio of the cold population to the hot population is about 0.12, and the cold electrons drift with a velocity close to the ion-acoustic speed (but bellow the threshold of the ion-acoustic instability).

Finally, consider a situation where the plasma density in the target chamber is lowered to $n_e \cong 7.1 \times 10^{14} m^{-3}$ (the conditions in the source chamber are kept fixed). Figures 5a-c show the measured profiles of the plasma potential, of the normalized drift velocity of the cold electrons and of the electron temperature. In this case the density of drifting cold electrons relative to the density of plasma electrons is increased (density ratio $\cong$ 0.31) and strong turbulence can be detected well beyond the magnetic sheath. Figures 6a,b show the spectrum of turbulent density fluctuations as detected at the position $z = 5$cm. Figure 6a shows a very low level of fluctuations corresponding to the situation depicted in Figs. 4a-c. Otherwise, Fig. 6b shows the high level of turbulence (notice the change in scale) that is attained in the situation illustrated in Figs. 5a-c. In this case the dc potential buildup associated with the anomalous resistivity accelerates the electrons sufficiently to enhance the original instability (bootstrap action)[1]. In the final stage of the instability a double layer is formed which extends over a long length scale. From Fig. 5a we verify that the double layer extends from the source chamber and across the magnetic sheath to the target chamber, over a distance of the order of $500\lambda_D$. The existence of a negative potential structure in front of the double layer, as predicted by theory[7], can also be observed. In the target chamber the diffusing electrons, after leaving the magnetic sheath region, drift at a velocity about 15 times larger than the ion-acoustic speed and above the threshold for the ion-acoustic instability. The electron temperature profile in Fig. 5c shows that the diffusing electrons are rapidly heated to the plasma temperature $T_e \cong 2.4$eV. This profile shows that the thermal contact between the two plasmas is greatly reduced by the presence of the magnetic field.

From the experimental data it is possible to estimate the average values of the electric field and of the drift velocity in the interval $z = 3 \sim 6$cm (magnetic field free region), when the double layer is formed. We have: $E_z \cong 6$V/m, $v_d \cong 3.4 \times 10^4$m/s. Using Ohm's law, the effective collision frequency is given by $\nu^* = eE_z/(m_e v_d) = 3.1 \times 10^7 s^{-1}$. For a plasma density $n_e \cong 7.1 \times 10^{14} m^{-3}$, we obtain $\nu^*/\omega_e \cong 0.021$. The effective collision frequency can also be calculated according to the spectrum derived from renormalized plasma turbulence theory[8,9]. For an electron temperature $T_e \cong 2.4$eV ($v_d/v_e \cong 0.052$) and a temperature ratio $T_e/T_i \cong 15$ (this gives $T_i \cong 0.16$eV, which roughly agrees with the experimental value $T_i \cong 0.2 \pm 0.1$eV), the theoretical result is $\nu^*/\omega_e \cong 0.017$. This result indicates that the observed anomalous resistivity associated with the formation of the double layer is caused by ion-acoustic turbulence, in reasonable agreement with the value predicted by the renormalized turbulence theory. Lastly, Fig. 7 shows what happens when a conducting grounded mesh is introduced in the target plasma and approaches the magnetic picket fence (the discharge conditions are the same as for the case ilustrated by Figs. 5a-c). The system length has been shortened from $500\lambda_D$ to about $370\lambda_D$ and the potential profile is similar (up to the position where the mesh is located) to the profile shown in Fig. 4a, that is, when no double layer is observed. This indicates that the system length is too short and the acceleration of the diffusing electrons associated with the anomalous resistivity is not sufficient for the formation of a double layer[1].

In conclusion, we observed a small amplitude double layer localized in the region of contact between two plasmas with different densities and temperatures. The double layer extends across the magnetic sheath of the picket fence, which separates the plasmas, and results from an ion-acoustic instability driven by cold electrons diffusing through the confining surface field. The double layer is not formed if the system length is reduced by the placement of a conducting mesh near the picket fence in the target plasma. The results of this experiment are significant for the study of the equilibrium of multipolar discharges (ion and plasma sources), of thermal barriers between different plasmas, of the physics of auroral-particle acceleration and of the mechanism of inhibition of electron thermal transport by ion-acoustic instability.

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FIGURE CAPTIONS

Fig. 1 - Schematic of the multi-magnetic-dipole device.

Fig. 2 - Magnetic induction profile across the picket fence.

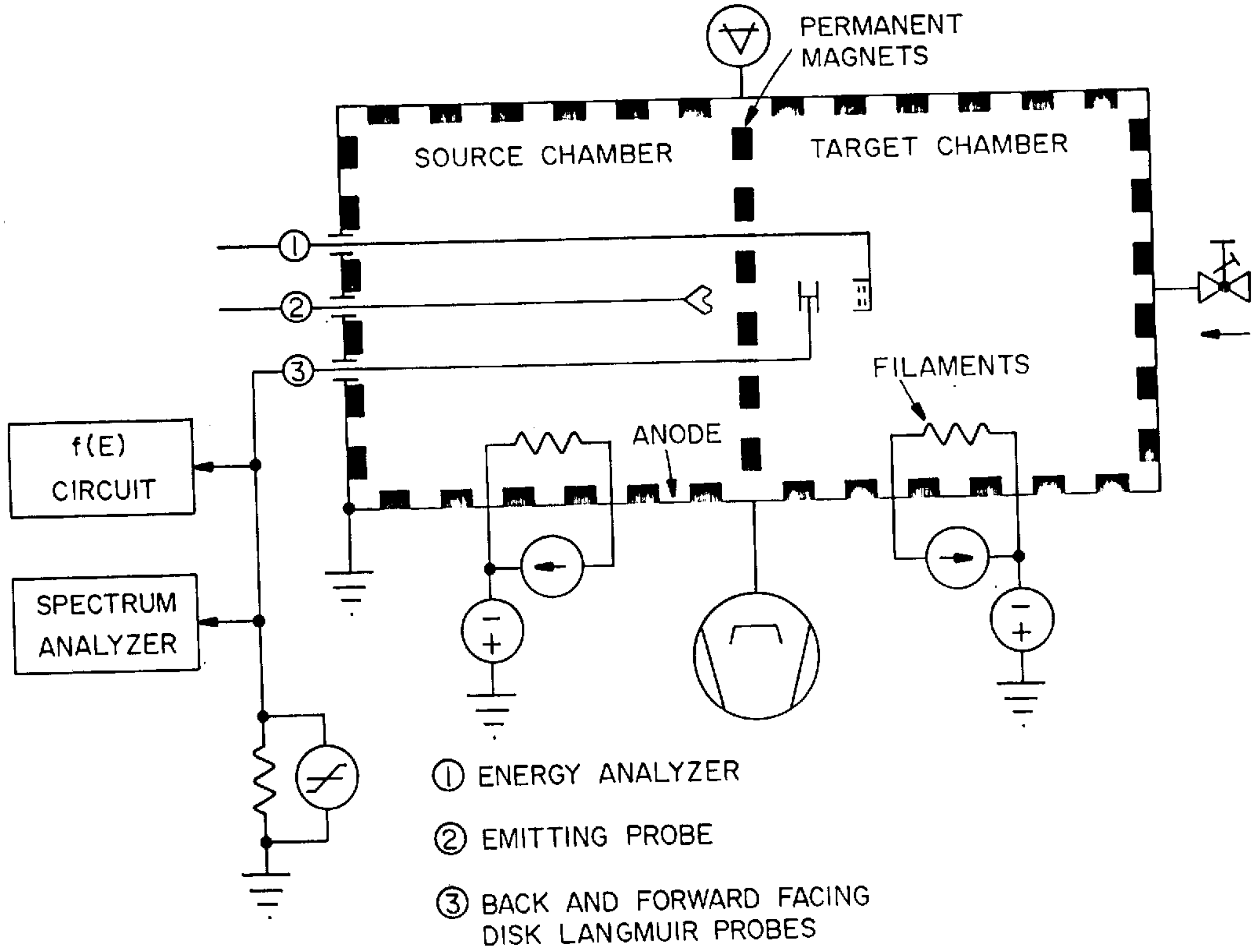
Fig. 3 - Electron temperature profile when the discharge in the target chamber is off.

Figs. 4a-c - Profiles of the plasma potential, of the normalized drift velocity of the diffusing electrons, and of the electron temperature. In this situation the plasma density in the target chamber is 67% of the density in the source chamber.

Figs. 5a-c - Profiles of the plasma potential, of the normalized drift velocity of the diffusing electrons, and of the electron temperature. In this situation the plasma density in the target chamber is 30% of the density in the source chamber.

Figs. 6a-b - Spectrum of turbulent density fluctuations at the position z = 5cm. The low and high levels of turbulence correspond to the situations in Figs. 4a-c and 5a-c, respectively.

Fig. 7 - Plasma potential profile when a conducting grounded mesh is introduced in the target plasma close to the picket fence. In this situation the formation of the double layer is inhibited.


PERMANENT
MAGNETS
SOURCE CHAMBER
TARGET CHAMBER
FILAMENTS
ANODE
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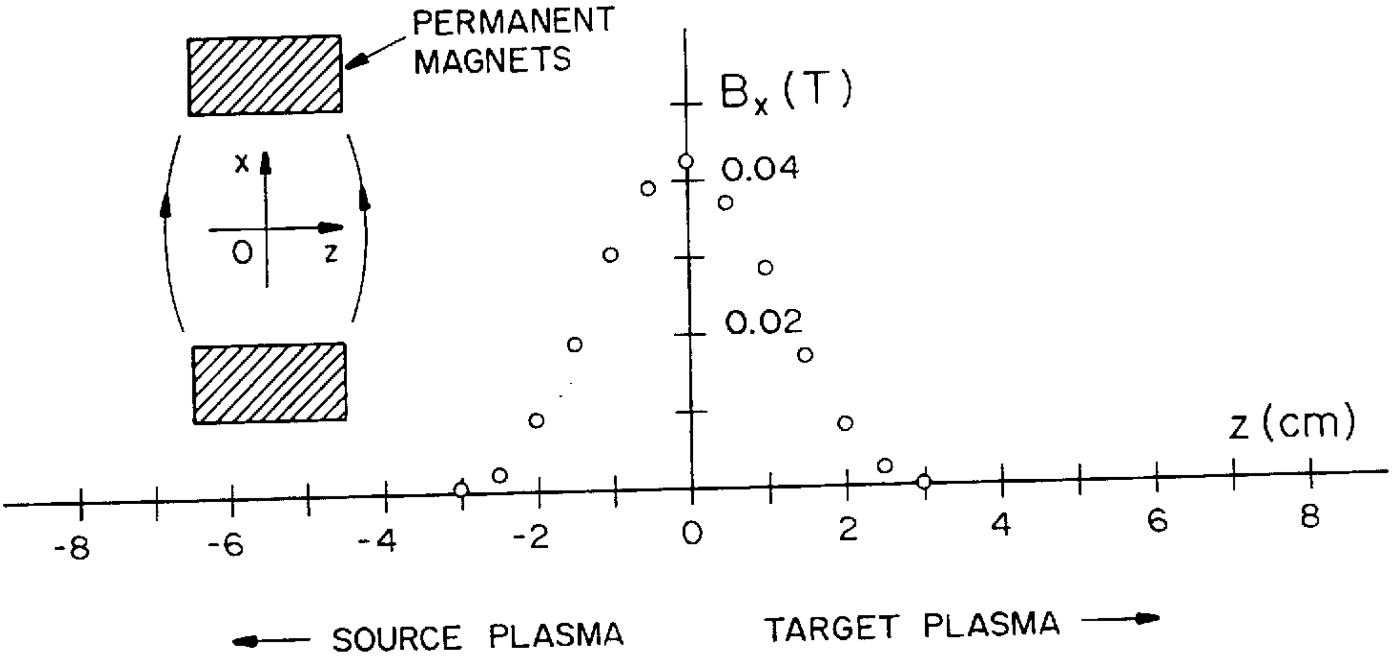
CIRCUIT
SPECTRUM
ANALYZER
① ENERGY ANALYZER
② EMITTING PROBE
③ BACK AND FORWARD FACING
DISK LANGMUIR PROBES

Figure 1



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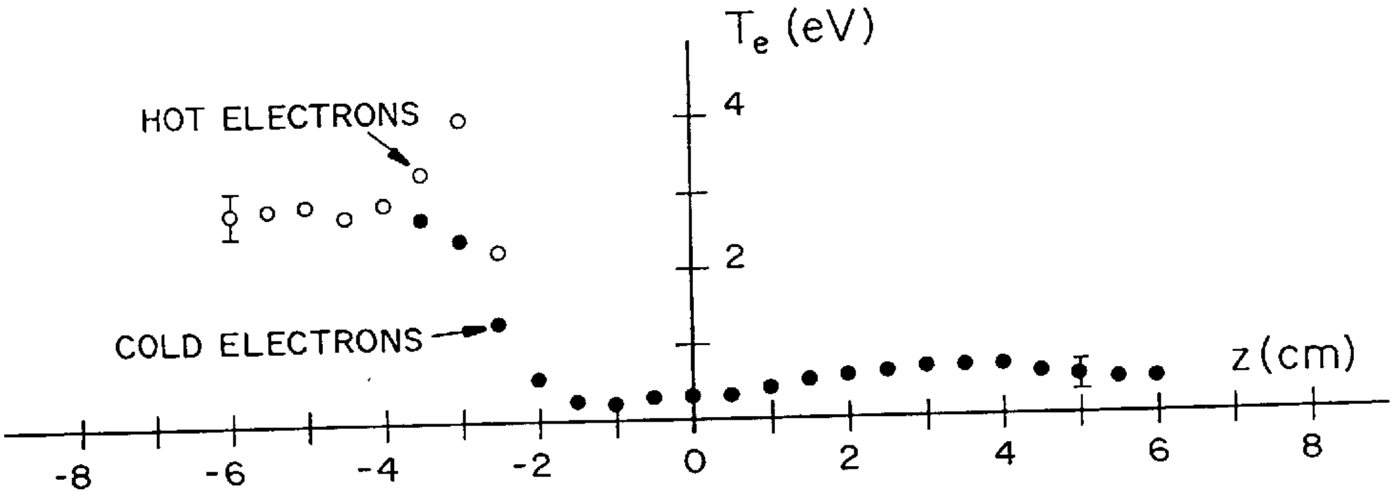

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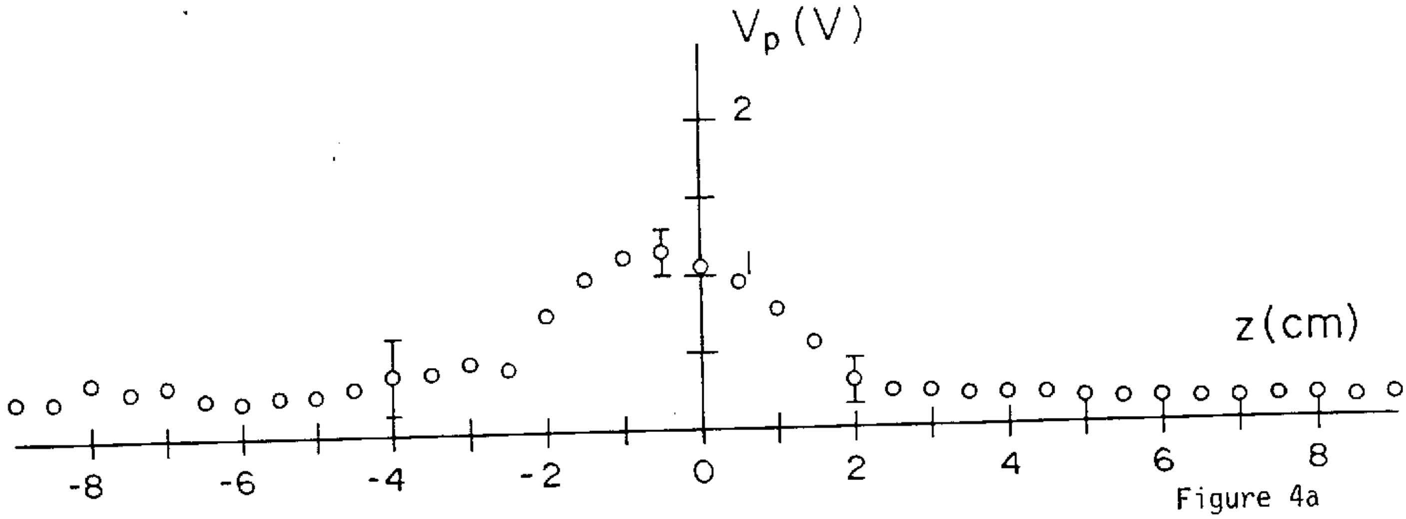

Figure 4a

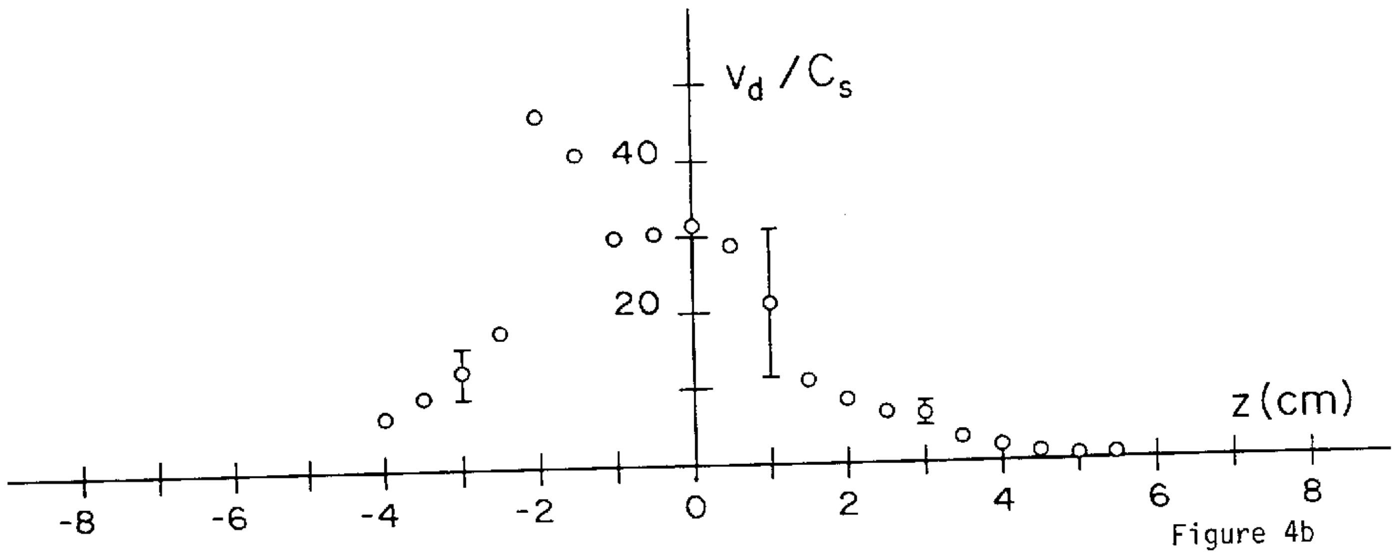

Figure 4b

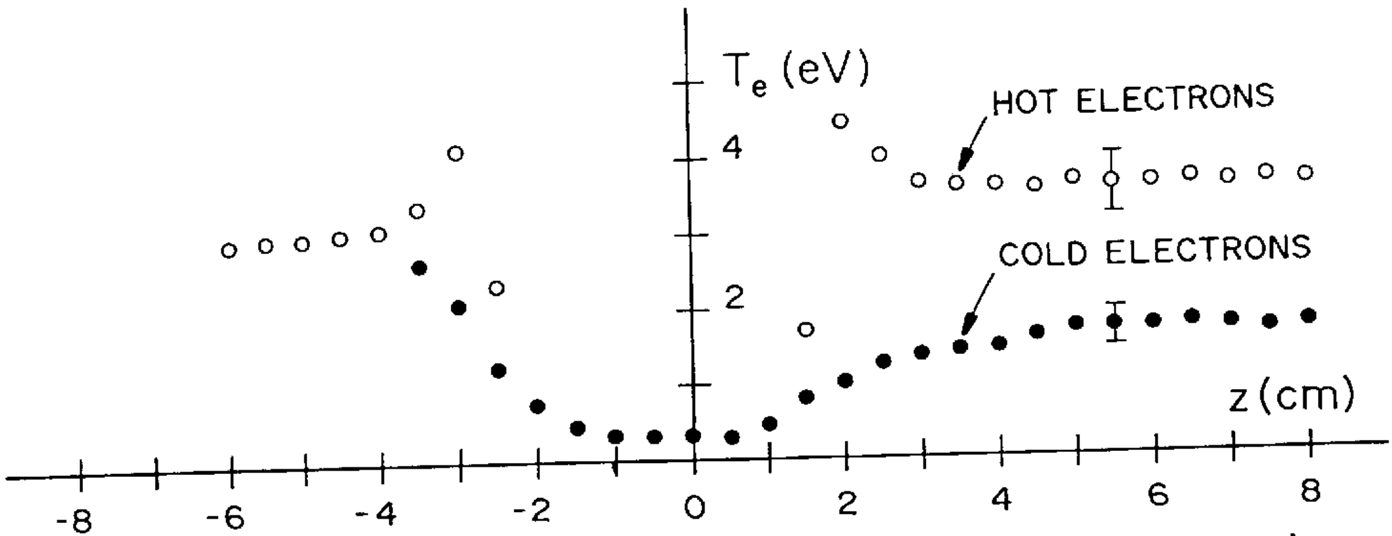

Figure 4c

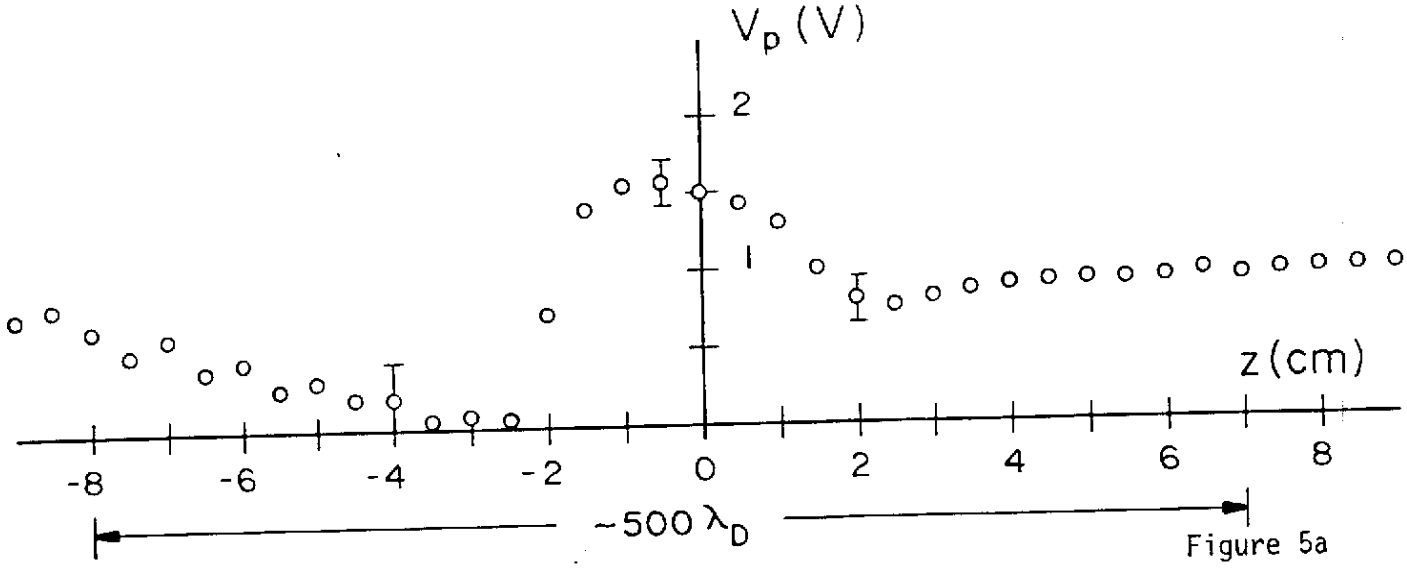

Figure 5a

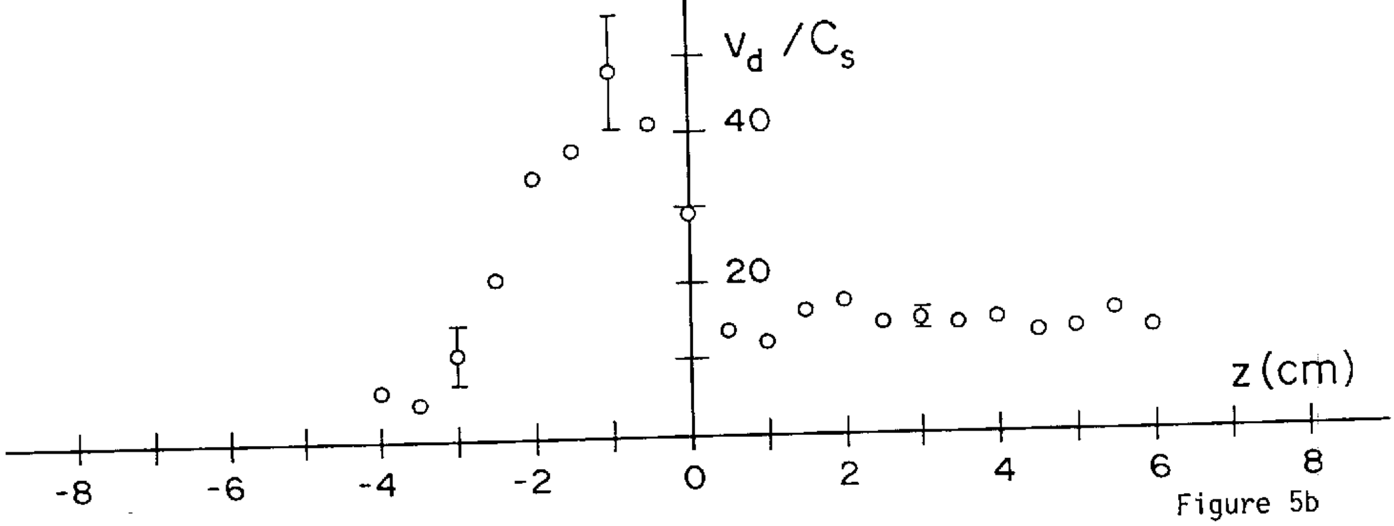

Figure 5b

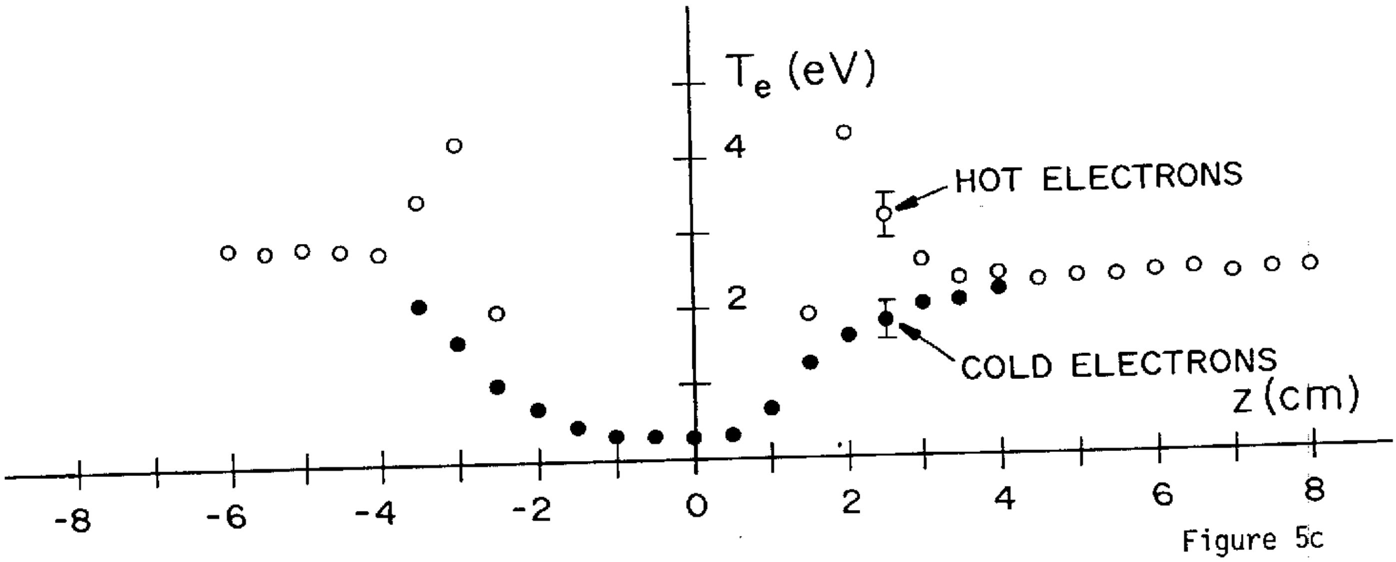

Figure 5c

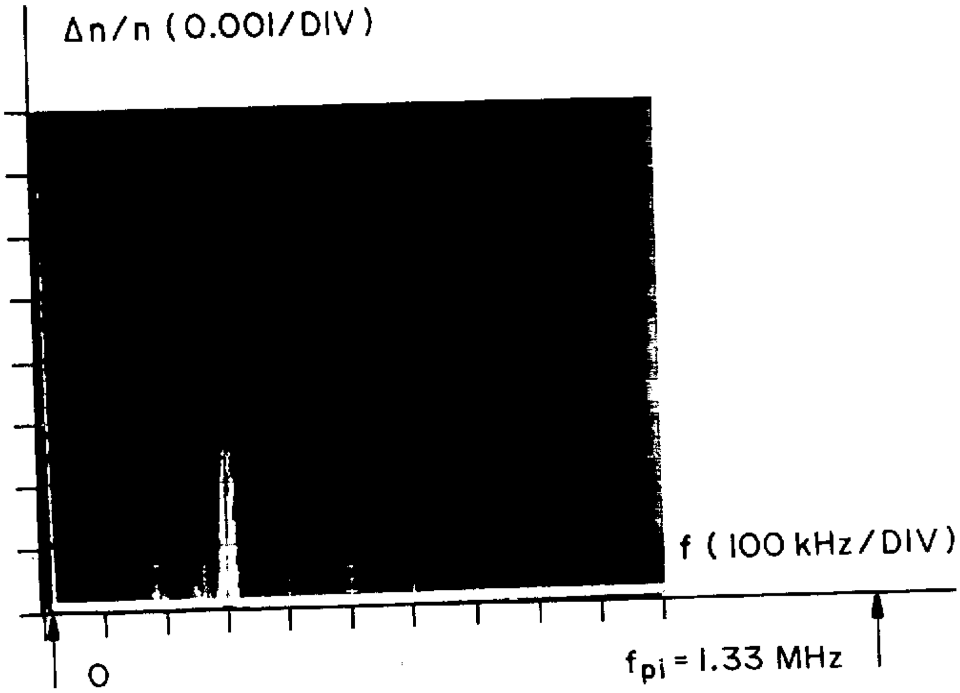

Figure 6a

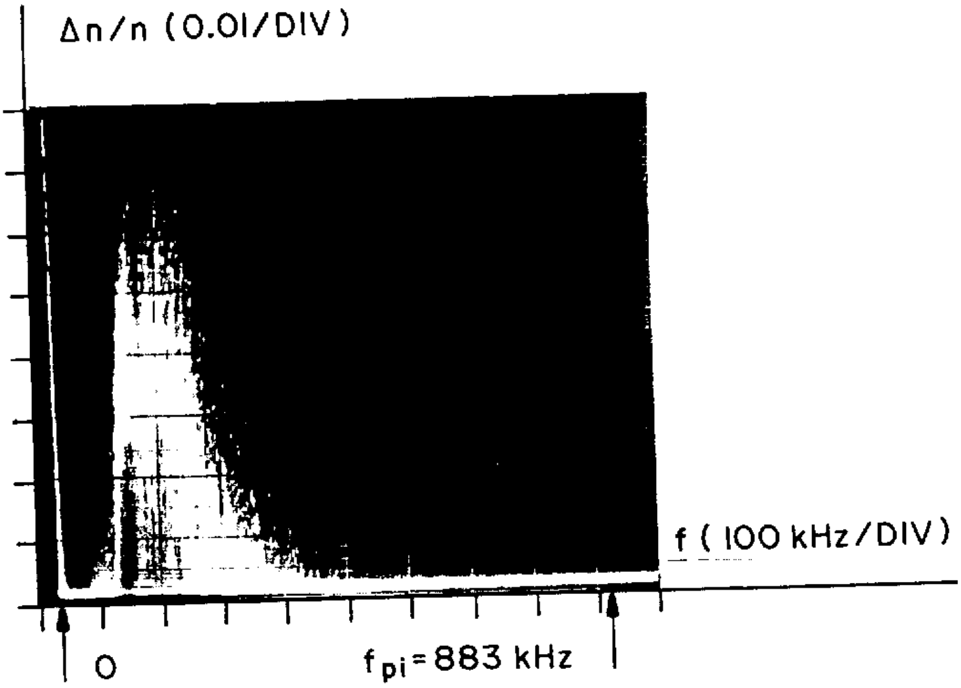

Figure 6b

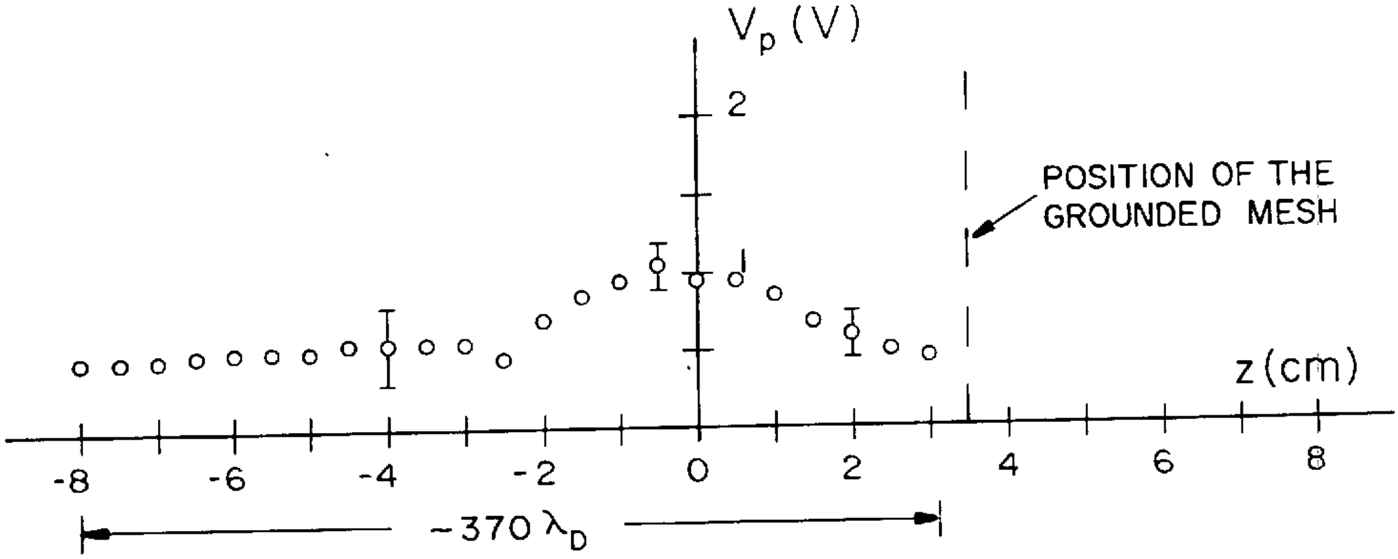
V_p (V)
2
POSITION OF THE GROUNDED MESH
z (cm)
-8
-6
-4
-2
0
2
4
6
8
~370 λ_D

Figure 7