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TECHNICAL NOTE

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Multipole Plasma Source

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MULTIPOLE PLASMA SOURCE

ABSTRACT.

Plasma density of the order of 10^{11} cm^{-3} is produced in a cylindrical, magnetic multipole device. The central volume surrounding the axis, about 60 % of the total volume of chamber, is magnetic field free. The plasma obtained is uniform to 4 % at the cusp magnetic field of 600 gauss. Fractional ionisation of 20 % and a plasma density of the order of 10^{11} cm^{-3} have been achieved at a pressure of 2×10^{-5} torr. The confinement effect remains independent of electron emission for ionisation and drops down at higher background neutral densities. The plasma life time in this device is around 85 μsec at background pressure of 4×10^{-5} torr with a cusp magnetic field of 600 gauss. The capacity of this source to supply a maximum of 250 m A ion current was realised.

1. INTRODUCTION

Large, quiescent and uniform plasmas can be produced using multiple magnetic containment technique[1]. The magnetic field that exists only near the surface of the chamber reflects the ionizing electrons and hence increases the ionization efficiency. This report discusses the characteristics of such a plasma, essentially in a zero magnetic field. The large improvement in plasma generation efficiency, quiescence and uniformity together with the measurements on confinement, Turn-on and afterglow are reported specially as a function of cusp magnetic field. All the observations are made in air plasma.

2. DESIGN AND STRUCTURAL FEATURES

The experiment was performed in a chamber of diameter 12 cm and length 18 cm. The magnetic field was produced by circular coils surrounding chamber. By passing the current in alternate directions in neighbouring coils, the cusp configuration as shown in Fig. (1) was achieved. A field of about 600 gauss over five 35 cm azimuthal line cusps appears at 1.8×10^4 ampere turns. The introduction of mild steel rings between the coils enabled the cusp field to be sharper and intense and it resulted in minimising the losses. Also, the observations showed that volume with zero B field increased by the introduction of the M.S. rings in between the coils. The magnetic field inside the chamber and the effect of introduction of mild steel rings are shown in Fig.(2).

After a short period of operation there are seen visible **discolourations in** the form of thin lines running in the inside wall of the chamber all along the extended cusps indicating that electrons are reaching the pole faces through the extended loss cone in the cusp field.

The density and confinement measurements were made in the range of 10-15 amp current through tungsten filaments of 5 cm length with a discharge voltage above 50 volts. Observations at different steady values of pressure and field were made by means of **a disc** Langmuir probe with an exposed area of 0.2 cm^2 which had an arrangement for radial and axial movements.

3. EXPERIMENTAL RESULTS

a) Plasma density

The production rate can be written as

$$\left(\frac{\partial n}{\partial t}\right)_{prod} = \sigma(\varphi)\, n_0\, \ell_{eff}\, \frac{I_e}{e}$$

for $[\sigma(\varphi)\, n_0]^{-1} \gg V^{1/3}$ (i.e. when electron mean free patch is very much larger than chamber size).

$\sigma(\varphi)$ is the ionization cross-section of neutral gas atom to be ionized by an electron with kinetic energy $e\phi$. I_e' is the emission current.

ℓ_{eff} is the average emission electron path length (which depends on system geometry and plasma boundary properties). For the hypothetical case of total primary electron containment by electrostatic and magnetic fields this parameter becomes larger than the ionization mean free path $[\sigma(\phi)\, n_o]^{-1}$ and inversely proportion to n_o. With no electrostatic or magnetic containment the ℓ_{eff} becomes independent of the neutral density and is of the order of the chamber length. A set of measurements of plasma density was made with cusp field, neutral density, electron emission and discharge voltage as parameters. It is seen that, at a particular neutral density and cusp field, the plasma density is a linear function of electron emission current. The values of density are plotted against electron emission current for different values of cusp field in Fig.(3). It is worth to note the parallel nature of these lines which reflect the independence of the cusp field confinement with respect to the electron emission current. Fig.(4) shows the variation of plasma density with neutral density at different cusp magnetic fields. The logarithmic plots of n Vs n_o is a st. line. The index increases from 0.2 to 0.45 corresponding to a variation of magnetic field from 0 to 450 gauss indicating the increasing efficiency of ionisation with the cusp field. An empirical relation can hence be written as $n \propto n_o^x I_e$ where x is a factor sensitive to confinement.

b) <u>Fractional Ionization</u>.

The fractional ionisation is around 0.1 - 10 % at 4 x 10^{-5} torr, with a confining field of 450-600 G. The efficiency of ionization builds up by the presence of cusp field. It reaches a value of 20 % at 2 x 10^{-5} torr with a cusp field of 600 G. (a density of 2.6 x 10^{11} cm^{-3} at an no = 13.2 x 10^{11} cm^{-3}). The fractional ionization drops down rapidly with pressure. This is as expected, since $\frac{n}{n_0} \propto n_0^{x-1} I_e$ where x is a factor less than 1. The fractional ionisation at various neutral densities is shown in Fig.(5) for the cusp field of 450 Gauss. The graph shows an index of 0.55.

c) Electron Temperature:

The electron temperature was found to increase very slightly with magnetic cusp field at low pressures. (10^{-4} torr). At pressures above 10^{-4} torr plasma temperature is not affected by cusp field. The temperature vs. magnetic field curves are shown in Fig. (6) at different pressures. The increase in temperature at low pressures may be due to the following reason. At lower pressures, the discharge is lesser and hence the presence of negatively charged particle (electrons) becomes more. The presence of cusp field, since very effective in confining electrons at lower pressures, causes an increase in temperature. Fig.(7) shows that the plasma temperature decreases as the background neutral density increases.

d) Confinement effects:

The curves in Fig. (8) show an increase in density due to confining field. Also the shape of curves at different discharge voltage reveals that the confinement of primary electrons from the loss through walls is reduced considerably by even a small magnetic field at lower discharge voltages and hence the density curves tends to flatten with higher fields. On the other hand, at higher discharge voltages, the steepening continues throughout the region of operation (o to 600 G) since higher fields are necessary to confine energetic electrons effectively.

The confinement factor drops down with increase in pressure (Fig. (9)). There can be two reasons. First is that the plasma potential is more negative at lower pressures. The ions see a potential well and so it offers an electrostatic containment. Since this slightly increases with B (as shown in section 3(c) the confinement is higher. Secondly, as discussed in section 3 (b), the fractional ionization goes down with increasing pressure. The presence of more neutrals increases collisions and confinement by magnetic field becomes less effective.

e) Density profiles.

The density measurements were made by a movable probe. The axial variations of densityis shown in Fig. (10) for the case of 14 amp. filament heating current at 4 x 10^{-5} torr. Gradients at ends are due to the location of the filaments. The fluctuation reduces from 12 % to 4 % at a cusp field of 600 G. The effect of field in reducing the variation is observed at a lower field value also but to a lesser extent.

The field lines go to a depth of slightly more than 2 cm inside the chamber from inner walls (dia. 12 cm). The density measurements made radially at different conditions show that the density remains almost constant through out a cylinder of 6 cm diameter. The density falls off rapidly from r = 3 cm to r = 5 cm. This is a region where most of the electrons are turned back by the cusp field line. The cylinder of 9π cm^2 corssection remains field free and hence the plasma inside quiescent. The radial variations at different values of B are shown in Fig. (11). The overall noise level of the plasma gets reduced to less than 5 % in the presence of cusp field.

f) Turn-on and Afterglow measurements

Measurements were made at different pressures with 12 amp current through filaments with pulsed discharge voltage of -75 volts. The typical growth and decay curves have an exponential rise and fall. The turn-on and afterglow times at different pressures and intensity of cusp magnetic field are listed in table (1). It is found that the cusp field has a large positive effect in confining the plasma. Decay times of 60-70 μsec were observed at background densities of 1.4×10^{12} cm^{-3}. The table shows that the characteristic times fall off with pressure. This can be due to the fact that collisions become more in the presence of neutrals since the percentage of ionization is less and hence confinement less effective.

g) Life-time measurements.

It is observed that the plasma potential goes considerably negative at low pressures. The trend is seen in the floating potential going from a few volts negative at 10^{-4} torr to about

-60V at 4.0 x 10^{-5} torr. It is also likely that a higher negative potential must electrostatically confine ions in addition to any magnetic containment exists. This explains the fact that confinement becomes very effective at lower pressure. Also, this means that the life time of an ion in the steady state plasma might be considerably larger than the life-time measured in the afterglow.

To measure the life-time, the following mode was adopted. The discharge was maintained at 14A current through filament at 50 V. The pressure and field intensities were parameters of study. Over and above the d.c. discharge a pulsed discharge is produced. The pulse width was sufficiently larger compared to relaxation and growth times. This gives the falling of plasma density when discharge pulse falls to zero.

The life times were measured in this manner ensured electrostatic containment together with whatever magnetic containment that exists. Observed life times show these values to be greater than the after-glow life times. The life times at different pressures and field intensity are given in table 2. The table shows the increase of lifetime to 85 μsec at 4 x 10^{-5} torr with cusp intensity of 600 gauss. As observed in afterglow measurements the confinement time decreases as pressure increases.

4. ION EXTRACTION

At a pressure of 10^{-4} torr and discharge current 400 mA an ion current of 250 mA was extracted at 1 KV. The operation at higher pressure with a higher supply of discharge current will enable to reach a few amperes of ion current. This source provides a quiescent plasma source from which a large area ion beam with a low noise level can be extracted.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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2. W.L. Stirling, C.C. Tsai and P.M. Ryan; Rev.Sci.Inst.48,533 (77)
3. K.N. Leung, R.D. Collier, G.R. Taylor and R.E. Kribel; Appl. Phy. Lett. 31, 154 (77).

Turn - on					After-glow				
Pr.	0	300 G	450 G	600 G	Pr.	0	300 G	450 G	600 G
	(micro-seconds)					(Micro-seconds)			
0.04 μ	12	40	55	60	0.04	10	45	50	65
.1	10	25	35	45	0.1	8	25	35	40
0.2	7	18	25	30	0.2	6	15	25	35
0.4	5	8	12	15	0.4	4	6	10	12

Table 1 : Turn-on and Afterglow times.

Life-time measurements

Pressure	T (micro-seconds)			
	B = 0	B = 300 G	B = 450 G	B = 600 G
4×10^{-5} torr	10	60	75	85
8×10^{-5}	8	40	50	65
1×10^{-4}	7	35	45	50
2×10^{-4}	5	28	35	40
3×10^{-4}	4	20	25	35
4×10^{-4}	3	12	16	18

Table 2 : Life-time measurements

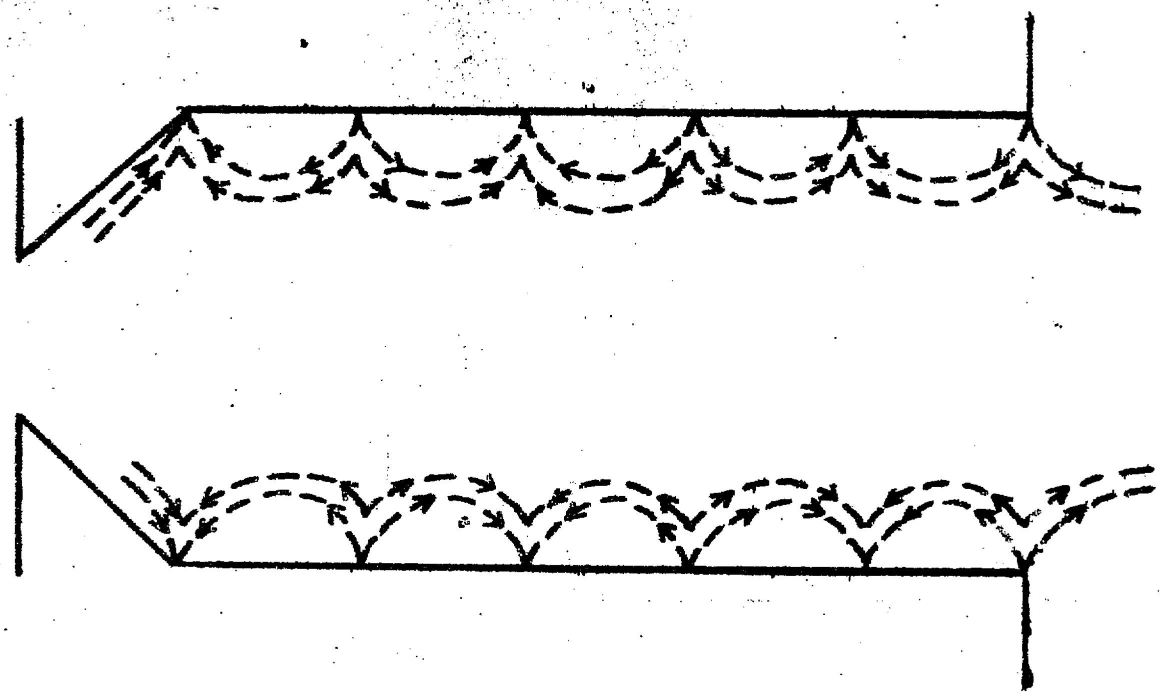


Fig.1

MAGNETIC FIELD INSIDE THE CHAMBER

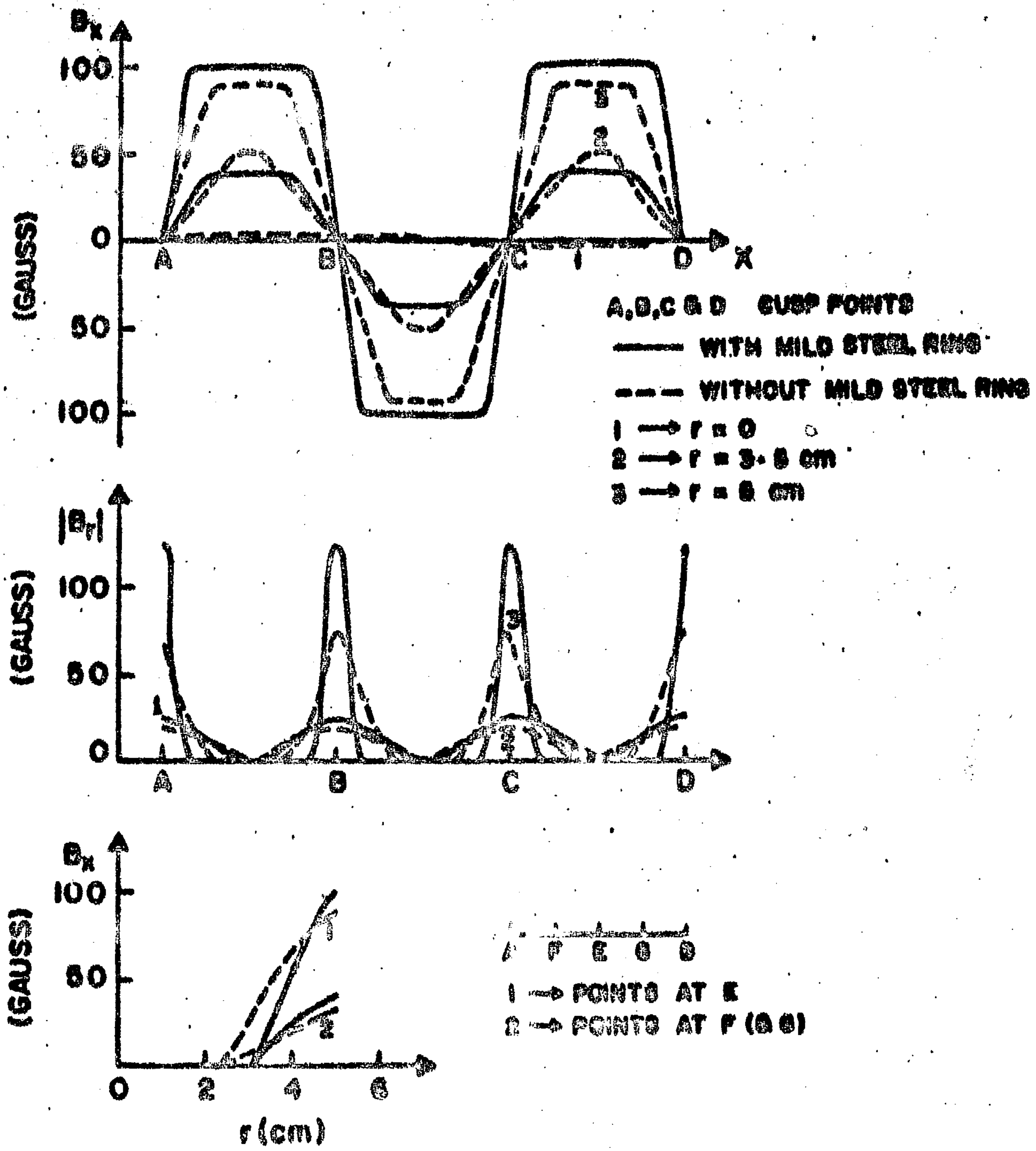
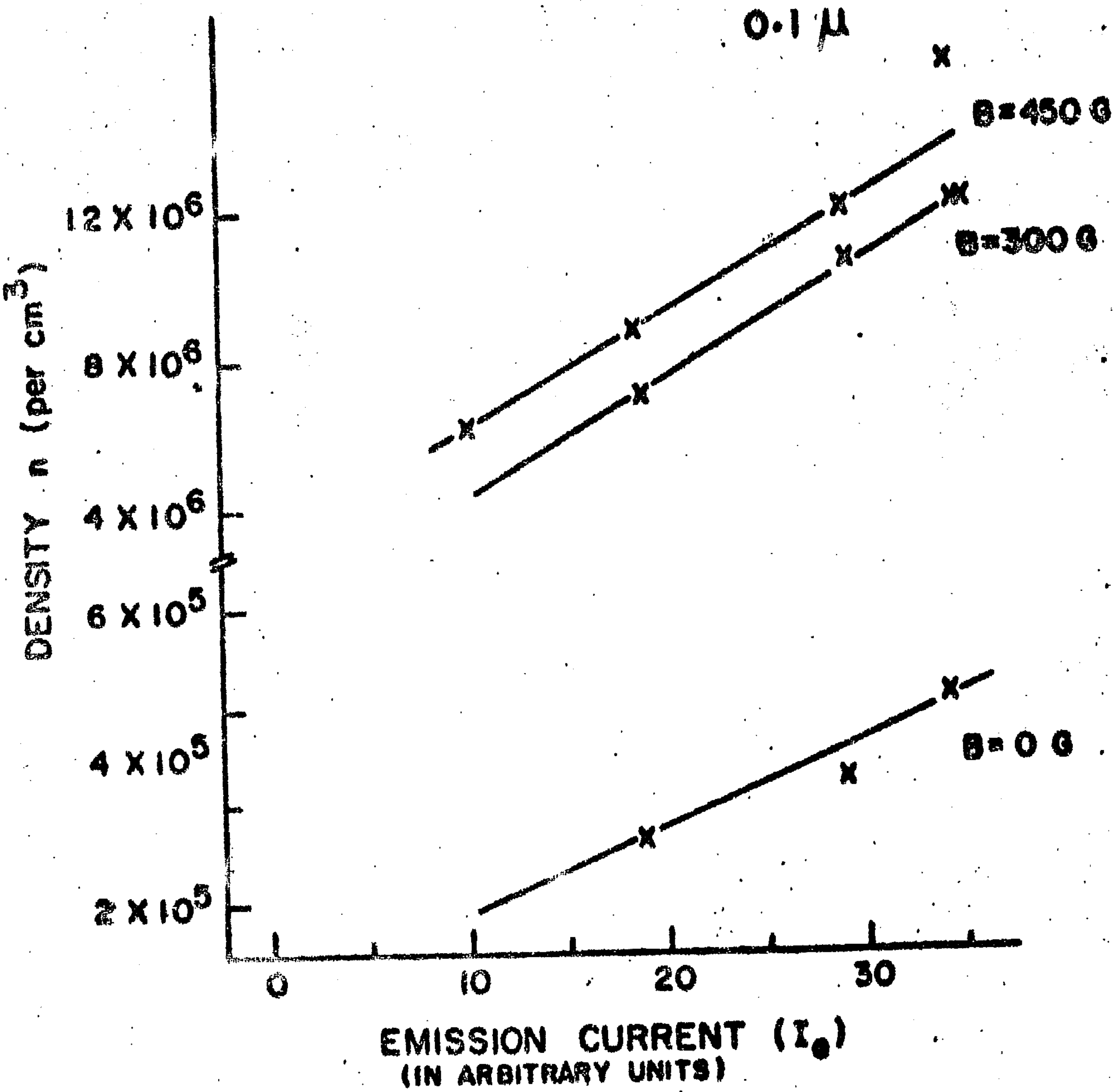


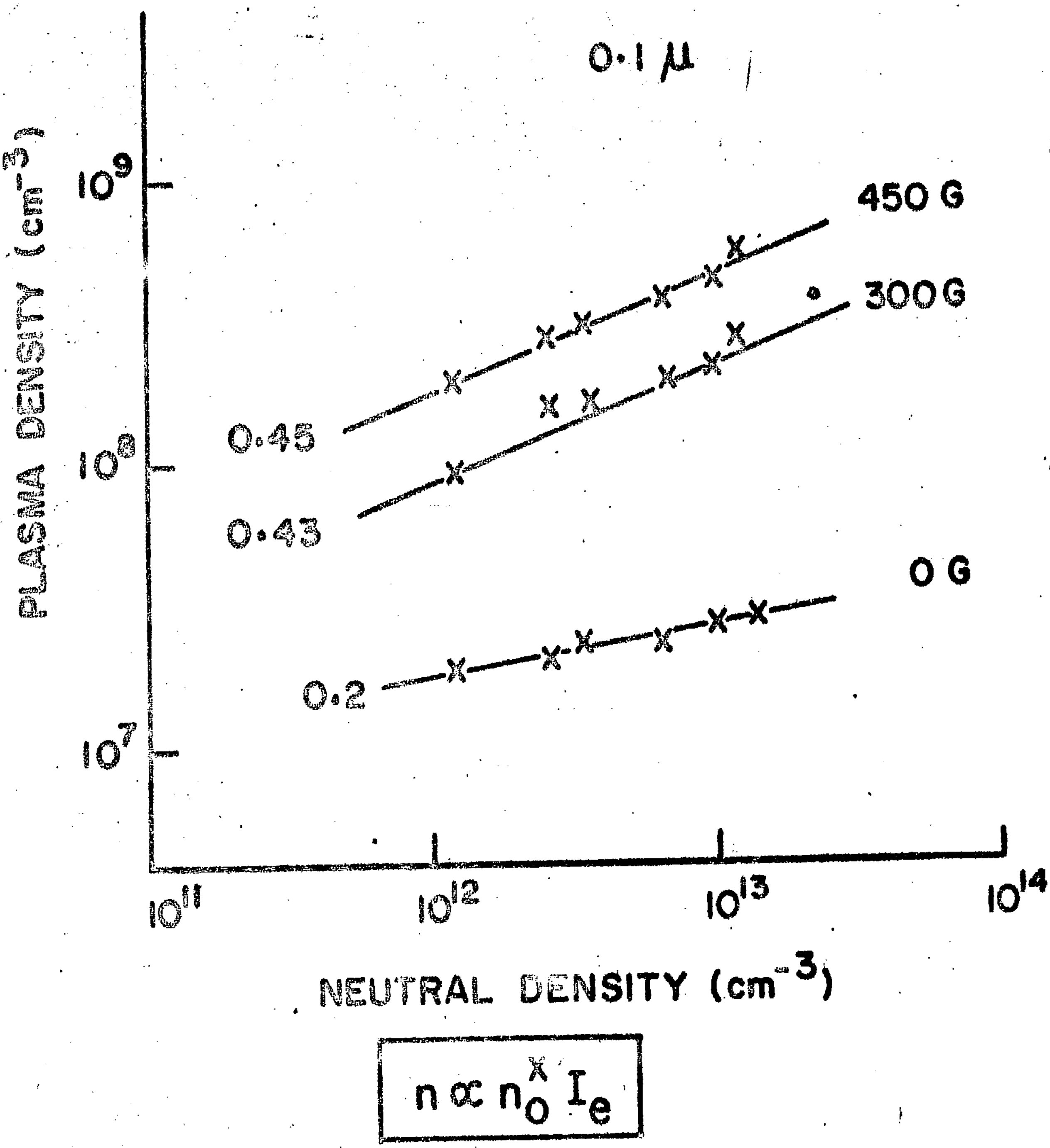
Fig.2



$$r_i \propto I_e$$

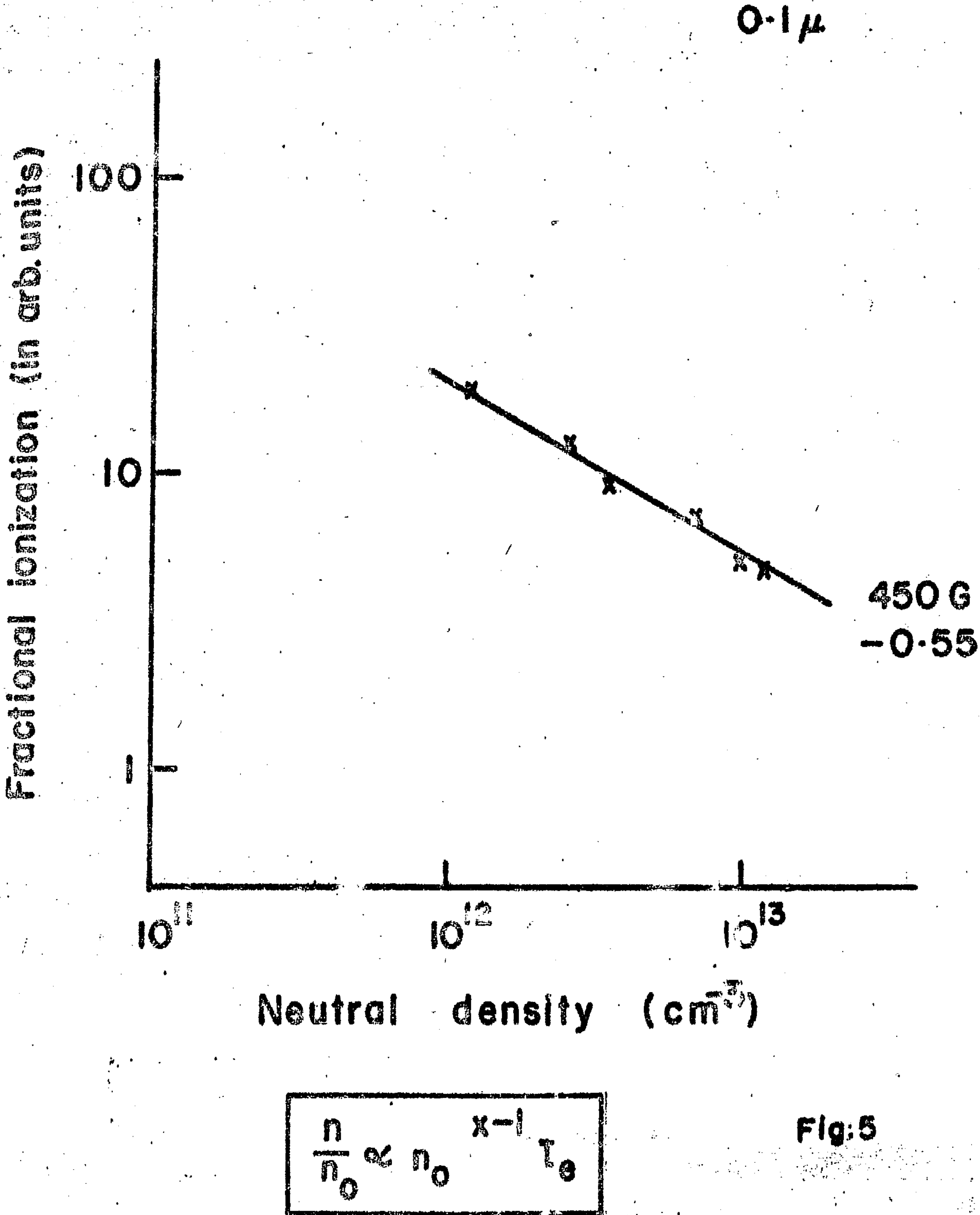
$$\frac{n_B}{n_{B=0}} \neq f(I_e)$$

Fig.3



0·1 μ
450 G
300G
0 G
0·45
0·43
0·2
10^9
10^8
10^7
10^{11}
10^{12}
10^{13}
10^{14}
PLASMA DENSITY (cm^{-3})
NEUTRAL DENSITY (cm^{-3})
$n \propto n_0^x I_e$

Fig. 4



0·1 μ
Fractional ionization (in arb. units)
100
10
1
450 G
−0·55
10^{11}
10^{12}
10^{13}
Neutral density (cm^{-3})
$\frac{n}{n_0} \propto n_0^{x-1} T_e$

Fig:5

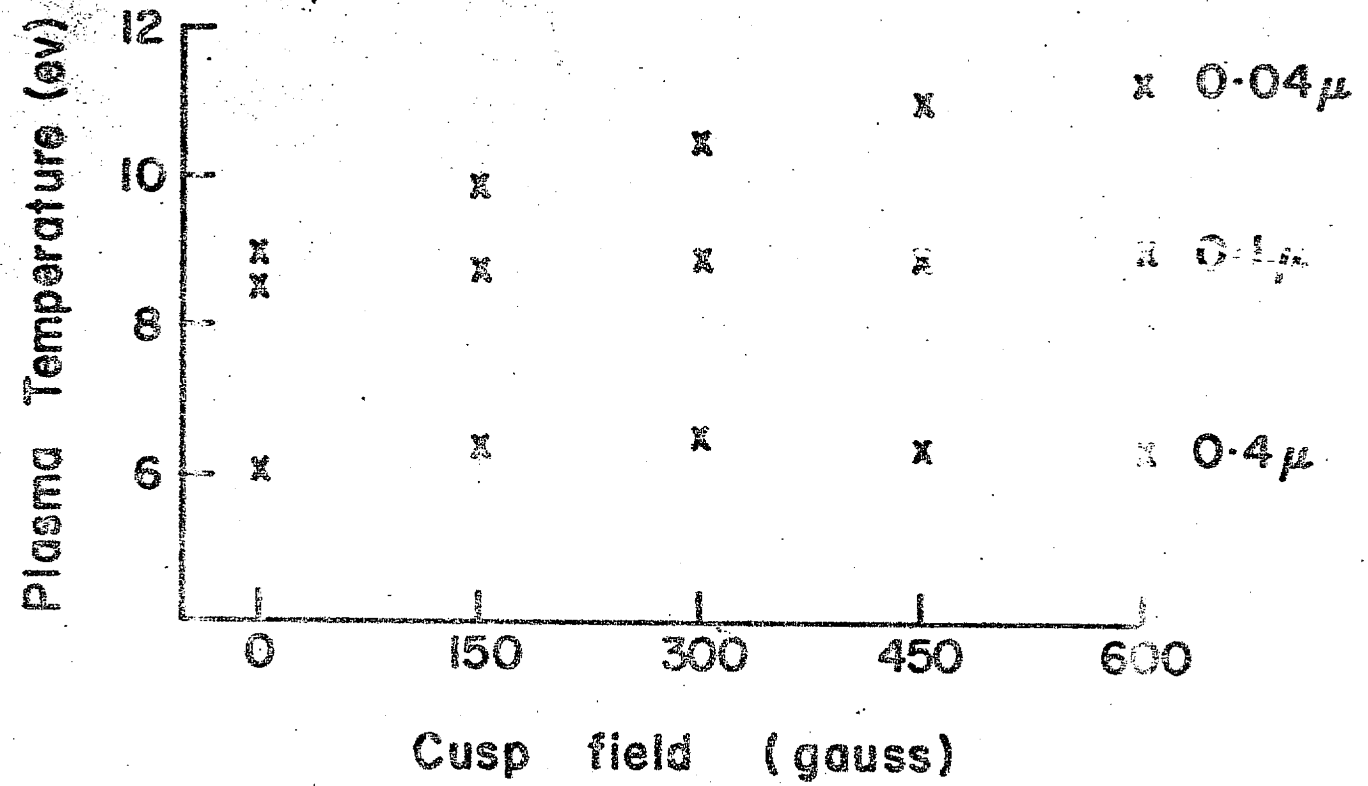
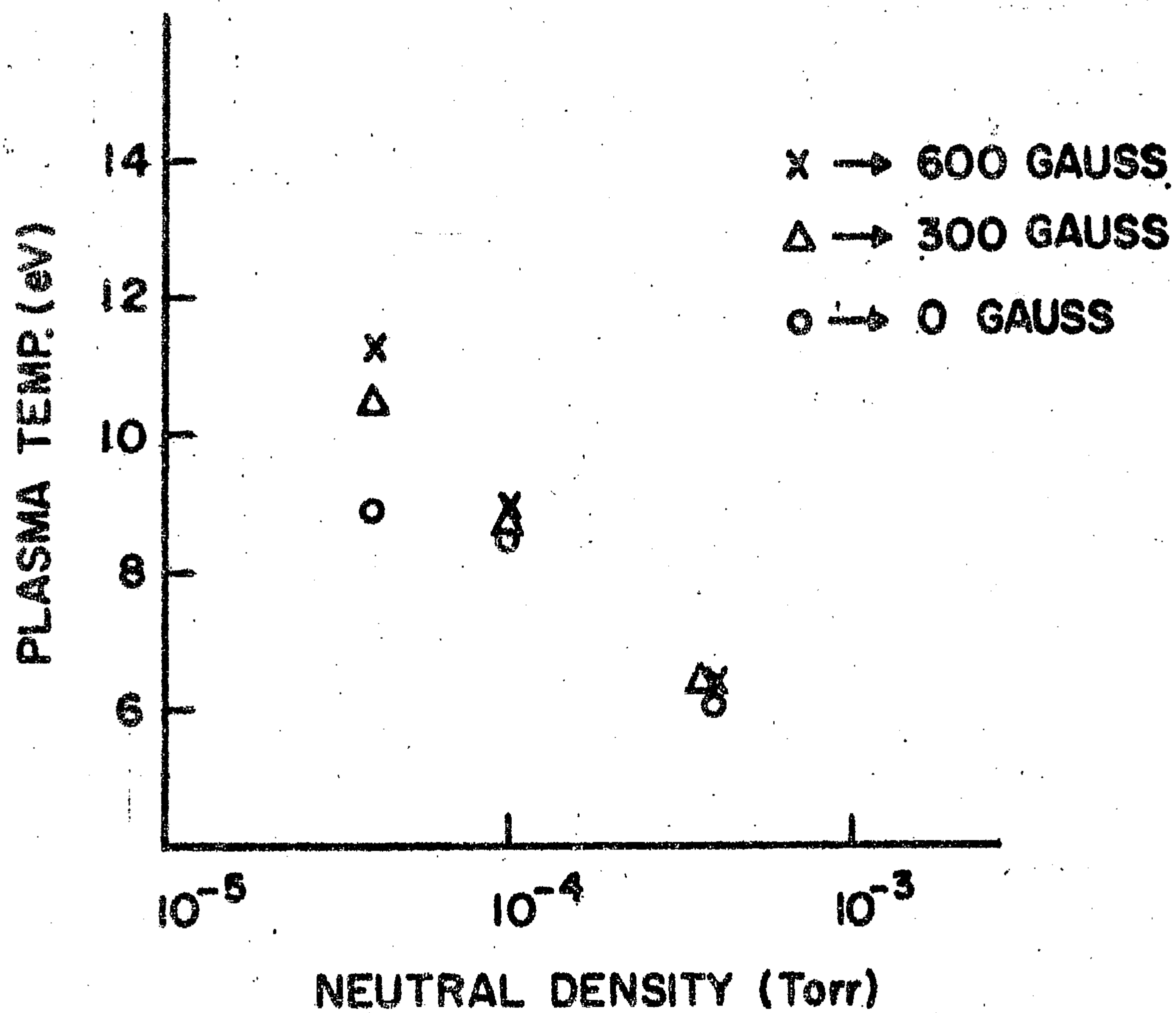
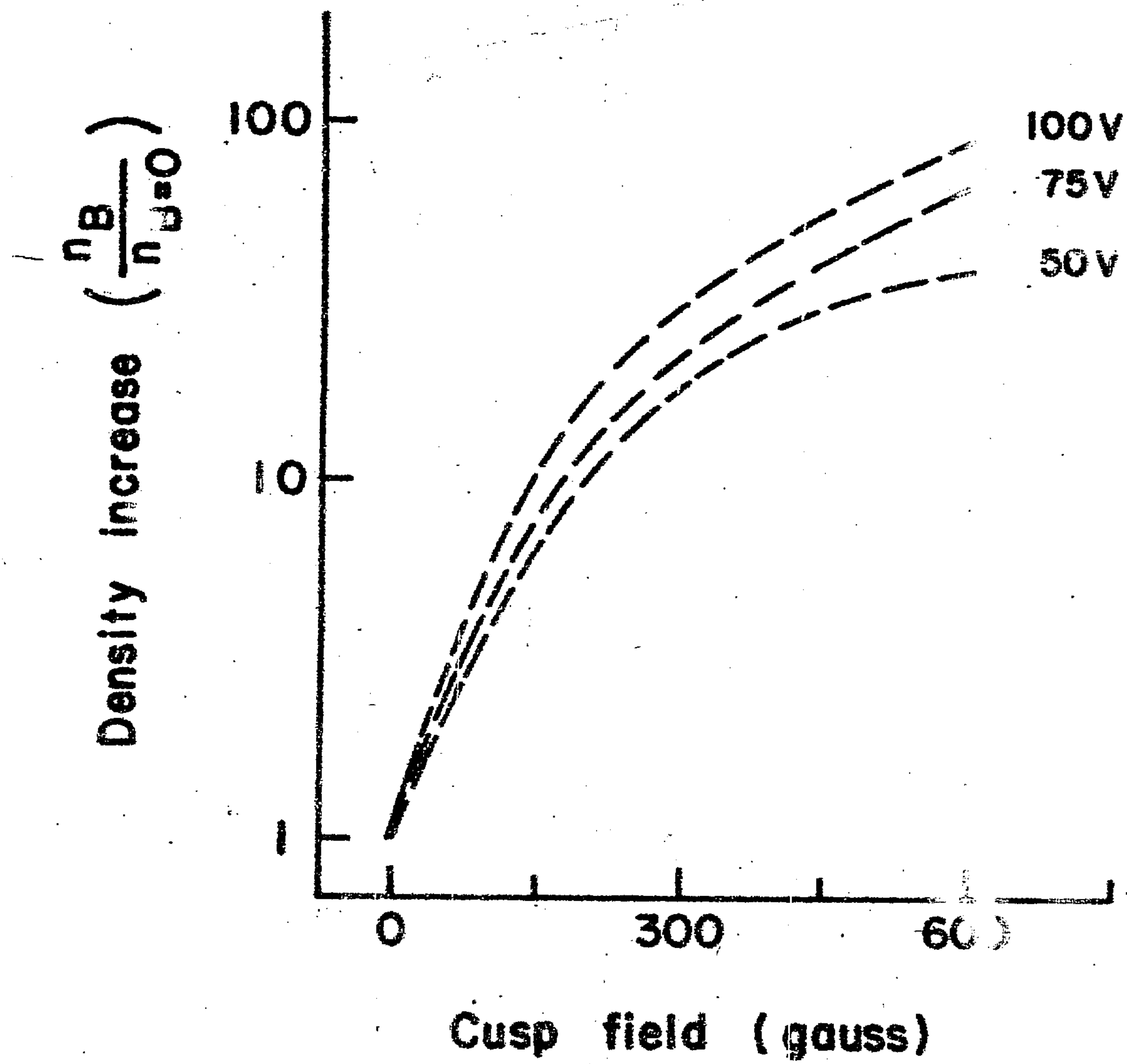

12
10
8
6
Plasma Temprature (ev)
0
150
300
450
600
Cusp field (gauss)
0·04μ
0·4μ

Fig.6



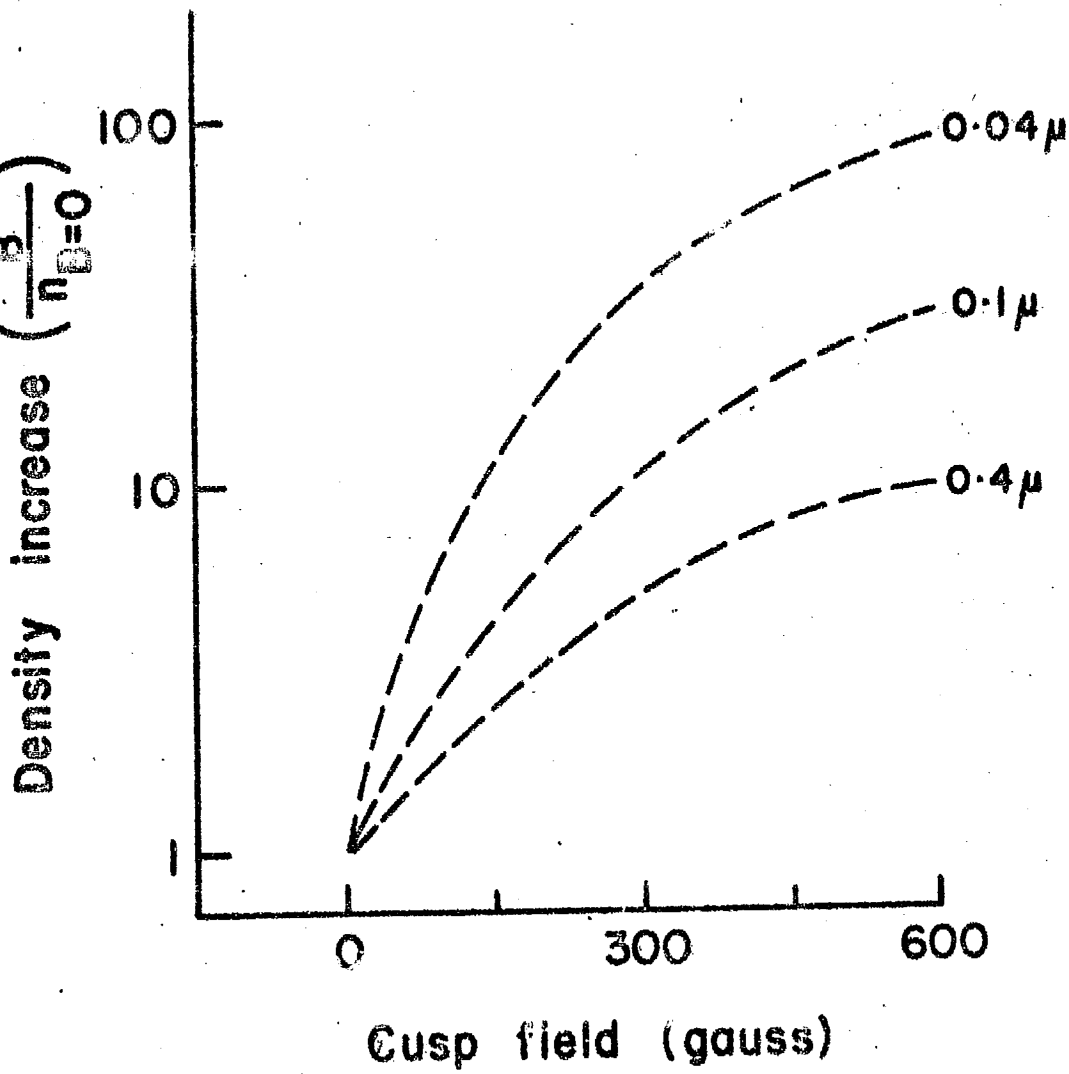
14
12
10
8
6
PLASMA TEMP. (eV)
X → 600 GAUSS
Δ → 300 GAUSS
o → 0 GAUSS
10^-5
10^-4
10^-3
NEUTRAL DENSITY (Torr)

Fig. 7



100
10
1
100 V
75 V
50 V
0
300
600
Cusp field (gauss)
Density increase $\left(\frac{n_B}{n_{B=0}}\right)$

Fig. 8



100
10
1
0·04 μ
0·1 μ
0·4 μ
0
300
600
Density increase $\left(\frac{n_B}{n_{B=0}}\right)$
Cusp field (gauss)

Fig. 9

Axial density profile

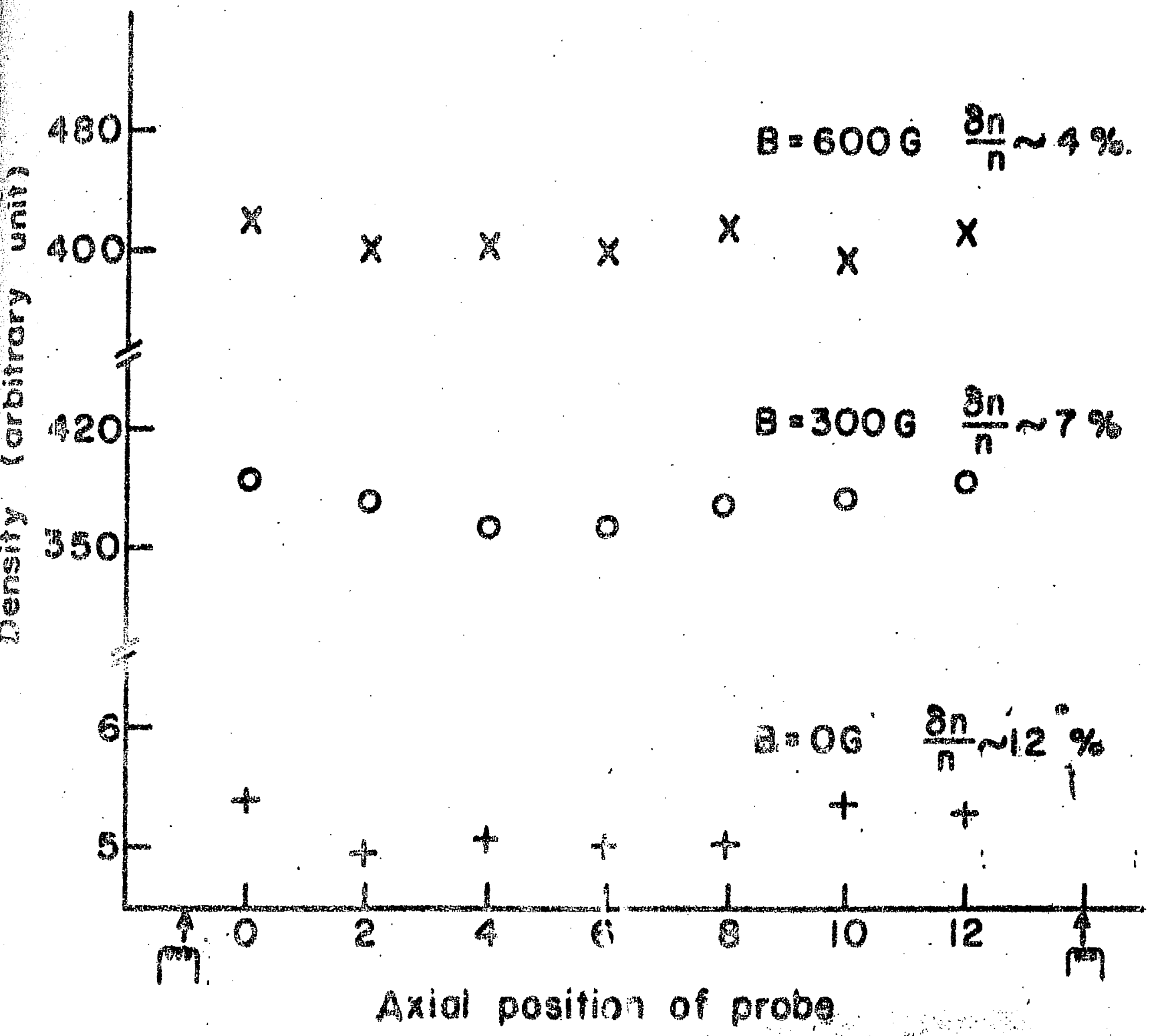


Fig 10

Radial density profile

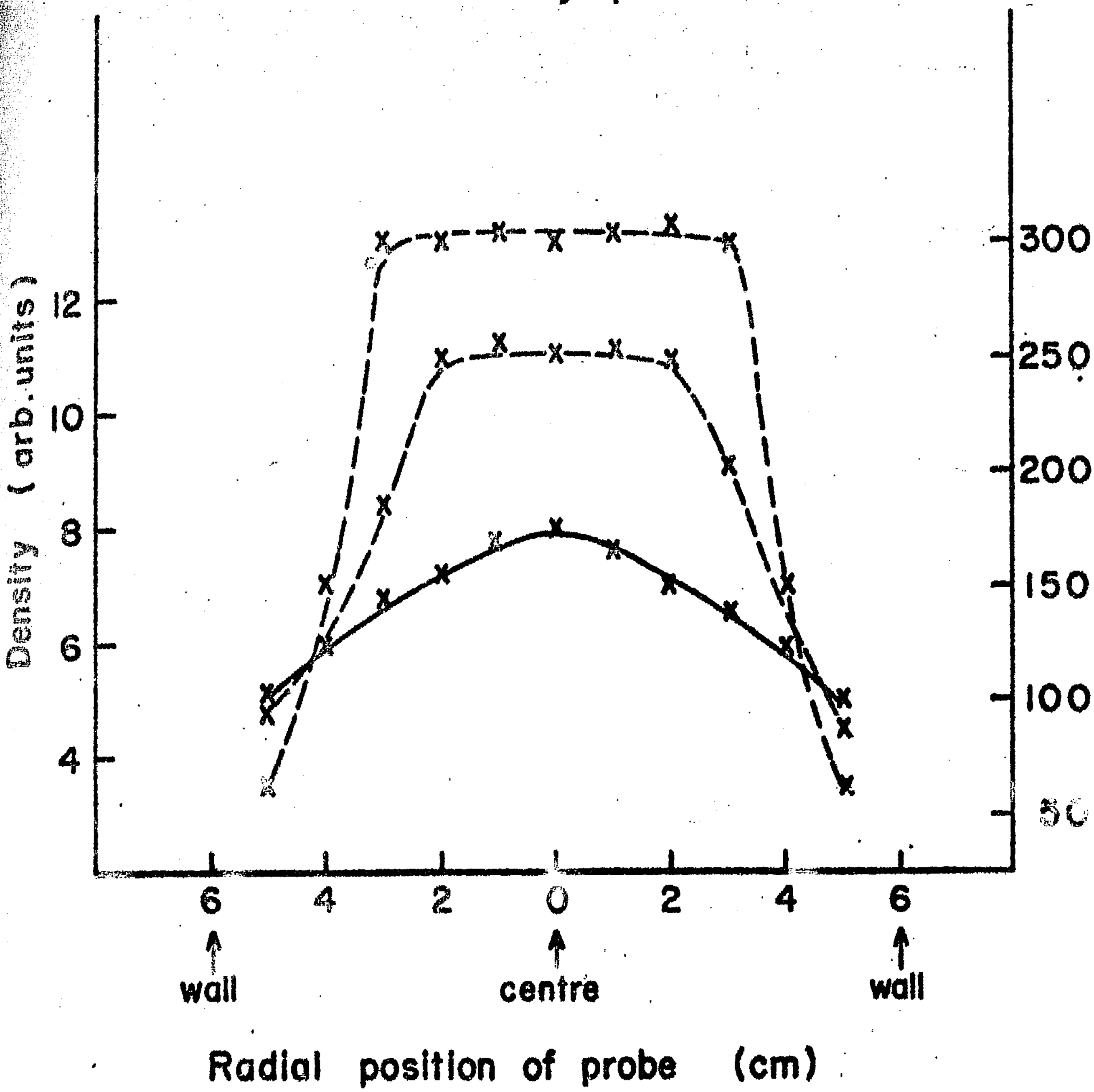


Fig.11