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LABORATORY SIMULATION OF THE ELECTRODYNAMIC INTERACTIONS
OF A TETHERED SATELLITE WITH AN IONOSPHERIC PLASMA

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ABSTRACT

An improved experimental set-up in the Orleans Plasma Chamber (Lebreton et al., 1985) allowed investigations of the I-V characteristics of a conductive spherical body (10 cm diameter) in a plasma environment. Moreover the influence of a transversal magnetic field at 0.6 and 1.2 G has been investigated, for the first time, both on the sheath potential profile and current collection. Floating potential profiles have been measured at 16 different radial distances from the test body up to 9 body radii in 8 different angular positions. The test body potential could be increased in the range from -200 V up to +100 V. Preliminary results are shown and discussed in this presentation.

1.0 INTRODUCTION

In the first electrodynamic mission of the Tethered Satellite System (TSS), beyond experiments involved with the Core Equipment (Bonifazi, this issue), particular studies should be carried out in order to study the interaction of a conductive body at high potential (up to + 5 kV) with respect to the surrounding ionospheric plasma (Dobrowolny, 1985). Laboratory simulation of the interaction of a free flying satellite with the ionospheric plasma has been studied since the early sixties (Hall et al., 1964). A brief review of early laboratory investigations of bodies in flowing, rarefied plasmas is given by Stone (1981). Nevertheless the experimental conditions around the TSS will be different from those occurring around a free flying satellite. To our knowledge, the only work with probes at high potential (up to 1000 V) in a plasma chamber is that of Kawashima (1982) which however refers to high magnetic fields ($B = 500$ G) and higher plasma densities ($1.0E07$ - $1.0E08$ cm⁻³) with respect to those of the ionosphere at 250 km altitude (TSS). In a previous work (Lebreton et al., 1985) carried out with a less sophisticated set-up and without computer control, quite interesting results have been already shown for a test body of 10 cm diameter immersed in an homogeneous plasma at ionospheric densities ($1.0E06$ cm⁻³). Thus we will summarize here the experimental set-up, pointing out the modifications and improvements. The results here

achieved are only described in a preliminary way since detailed data analysis and theoretical interpretation will follow in a more complete work.

2.0 EXPERIMENTAL SET-UP

Figures 1 and 2 show the experimental set-up in the Orleans Plasma Chamber. For more details see Lebreton et al. 1985 and enclosed references. During our experiment the values obtained for plasma densities and electron temperatures correspond to typical values of the E- and F- regions of the ionosphere (see Table-1). An Ar-ion beam was produced by the ion source at 12 V acceleration potential in order to simulate the plasma impact velocity on the TSS (8 km/sec). The plasma confinement inside the vacuum chamber is achieved through a multipolar magnetic field system. The plasma potential obtained equals the potential of the vacuum chamber and a coils system allows the compensation of the Earth's magnetic field and the production of known field intensities up to a maximum of 1.2 G in axial or transversal direction with respect to the ion beam direction. The test body is situated in a fixed position inside the chamber (see figures 1 and 2) and is electrically connected with a power supply and an electrometer in order to obtain I-V characteristics in the range (-200 V, +100 V). A cross system consisting in 16 Langmuir probes ($r=0.3$ cm) situated at different distances from the test body from 0.2 to 9.4 test body radii can be rotated at 8 different angular positions. A total of 128 measurement points can be achieved in this way. A multiplexer time sharing, realized by means of high insulation resistance ($1.0E12$ Ohms) reed relays, allows the determination of I-V characteristics for each probe in a voltage range -10 V to 10 V. The power supplies connected to the test body, Langmuir probes position system and data acquisition are under computer control. The plasma characteristics were continuously monitored during the experiments by means of a reference spherical Langmuir probe and a mutual impedance probe located sideward at about one meter downstream from the test body. Table-1 shows experimental conditions compared with ionospheric ones.

3.0 EXPERIMENTAL RESULTS

3.1 Test body I-V characteristics

3.1.1 Negatively charged body

The current collected upon a conductive spherical body negatively polarized with respect to the ambient plasma, in an unmagnetized and in a magnetized plasma has been investigated during the first experiment (Lebreton et al., 1985). The I-V characteristic of a 10 cm diameter sphere has been measured under stable plasma conditions, quoted in table-1 under exp 1, for a test body potential ranging from 0 Volt up to - 125 Volt. The Ar-ion beam energy was 12 eV in order to simulate the TSS orbiting velocity of 8 km/s. An external magnetic field of 0.68 Gauss along the beam direction did not seem to modify the test body ion collection characteristic. This result has been interpreted as mainly due to the fact that Argon ion gyroradius was very large compared to the dimension of the test body. This result can still apply to the TSS satellite conditions during the first TSS electrodynamic mission. The same measurement has been repeated during the second experiment by using the same test body. In this case the test body potential has been extended up to - 200 Volt, and the magnetic field was transversal (0.6 and 1.2 Gauss) to the beam direction in order to simulate the TSS conditions. The result shown in figure 3 basically confirms that there is not magnetic field effect on ion collection upon a relatively highly polarized body immersed in a mesosonic plasma.

3.1.2 Positively charged body

The electron current collected upon a conductive sphere immersed in a mesosonic plasma has been investigated in presence of a magnetic field. The maximum positive potential of the test body is limited by the plasma source capability. For the Orleans plasma chamber this corresponds to a maximum electron current of about 10 mA upon a conductive sphere of 10 cm diameter. During the first experiment (Lebreton et al., 1985) the I-V characteristic of the test body has been studied both in presence of no magnetic field and in presence of an axial (i.e., along the

beam direction) external magnetic field. The plasma conditions are those quoted in Table-1 under the label exp 1. The measurements shown in figure 4 clearly indicate a reduction of a factor of two in the electron current collection in presence of an external magnetic field of 0.68 Gauss under the same plasma conditions for B=0 G. It is worth noting that no change in the plasma conditions have been detected during the two data sets. The plots shown in figure 4 have been corrected by the function $N_e(V_p)/N_e(0V)$, where $N_e(V_p)$ and $N_e(0V)$ are respectively the electron density measured when the test body potential is V_p and 0 Volts.

The electron thermal current has been estimated by the relations:

$$(1) \quad I_{eo} = 1/4 N_e e V_{th} A$$

and

$$(2) \quad I_{eo} = 1/8 N_e V_{th} A$$

where N_e is the electron density, V_{th} the electron thermal velocity, e the unit charge, and A the geometrical area of the test body. The difference between relation (1) and (2) is a factor of two due to the channeling effect of the magnetic field. The electron gyroradius based on plasma conditions quoted in Table-1 results in 1.6 cm and satisfies the condition: electron gyroradius less than test body radius. No carefully test of the to date available models has been carried out. Nevertheless it worth noting that the model by Linson et al. (1982) foresees an electron current reduction of a factor of two when the effect of an external magnetic field has been taken into account. The paper by Linson considers a magnetic field aligned along the ion beam direction as we had during the first experiment.

During the second experiment the effect of a transversal magnetic field has been investigated for the first time. The plasma conditions are quoted in Table-1 under label exp 2. The reason to have a transversal magnetic field is that of simulate TSS satellite environmental conditions. In fact the induced emf across the TSS is $V \times B$, where V is the TSS orbiting velocity. We report here the preliminary results obtained by using the same test body of the first experiment. The electron current versus sphere potential for respectively 0 G, 0.6 G, and 1.2 G are shown in figure 4 or a test body potential ranging from zero up to 100

Volts. The plasma conditions were $N_e = 1.6E06 \text{ cm}^{-3}$, $T_e = 0.16 \text{ eV}$ which yield to an electron gyroradius of 2.5 cm ($B=0.6 \text{ G}$) and 1.25 cm ($B=1.2 \text{ G}$), respectively. In both cases the electron gyroradius is less than the test body radius. The electron thermal currents estimated by relations (1) and (2) yield $I_{eo} = 336 \text{ micro A}$ ($B=0$), and $I_{eo} = 168 \text{ micro A}$ ($B=0.6$ and $B=1.2 \text{ G}$). The plots shown in figure 5 are corrected by the function $N_e(V_p)/N_e(0V)$ as for figure 4. The plasma density variations versus test body potential during the second experiment are quoted in Table-2. The electron density has been measured by a mutual impedance probe and by a reference Langmuir probe. The trend of the electron current versus test body potential in presence of a transversal magnetic field clearly confirms the reduction of the electron current previously observed in presence of an axial magnetic field (see figure 4). Moreover higher magnetic fields seem to produce greater reduction of electron collection.

3.3 Sheath and near-sheath potential profile.

The sheath and near-sheath potential profile has been explored in 2 directions along the plasma flow : the upstream (ram) and the downstream (wake) directions.

This has been done only for negatively polarized test body during the first experiment (Lebreton et al. 1985). Two identical cylindrical Langmuir probes, spaced by 10 cm. along the radial direction, were translated at distances up to 25 cm. from the test body surface.

The floating potential contour upstream and downstream of a negatively polarized test body, under the same plasma conditions of fig.4, are shown in fig.6. The test body potential is -125 Volt and measurements without magnetic field and with $B=0.6 \text{ G}$ along the Ar^+ ion beam direction are compared in the figure.

The effect of an external magnetic field does not seem to modify the shape of the upstream sheath region but only the shape of the wake region.

The upstream region extends up to 3 times the test body radius and the floating potential of the probes reduces to 1-2% of the central body potential at 1.2 test body radii.

The wake region extends up to 5 test body radii without magnetic

field and reduces to 3 test body radii when $B=0.6$ G. At larger distances the floating potential is still offset by a few volt when compared to the unperturbed plasma potential which is very close to zero.

The floating potential of the probes reduces to 1-2% of the test body potential at 2.5 ($B=0$) and 3.0 ($B=0$) test body radii.

We should not attempt to interpret floating probe potential measurements in term of plasma potential since the floating potential may be very sensitive to a small change in the ion density or electron temperature, more precisely in the hot electrons flux (Lebreton et al. 1985).

The space charge region investigation has been carried out during the second experiment in the Orleans plasma chamber by using a more sophisticated set-up described in section 2. Unfortunately we are not able to show the measurements but only a typical output of the sixteen spherical Langmuir probes (radius 0.15 cm.), see fig.7, which allows investigation of the sheath in the range distance from 0.2 up to 9.4 test body radii.

This extension in the explored region should allow more detailed investigation of the wake region, moreover in this case the space charge region exploration was not limited to the ram and wake directions but extended to 8 angular position over the 360 degrees region.

4.0 CONCLUSIONS

In a plasma chamber reproducing the electrodynamic tethered satellite environmental conditions (see Table -1-), we have measured the I-V characterist of a spherical conductive test body of 10 cm. diameter and explored its sheath and near sheath regions.

This investigation has been carried out through two successive experimental set-ups.

The main results can be summarized as follow :

the presence of an axial magnetic field of 0.68 G reduces by a factor about 2 the electron current collected upon the test body, but not the ion current, when the test body potential varies from -125 V up to +50 V.

This investigation has been repeated by extending the test body potential range from -200 V up to +100 V and using a transversal

magnetic field of 0.6 G and 1.2 G, respectively.

These measurements practically confirm the previous results and clearly indicate a decreasing of the electron current collection for increasing magnetic fields.

The investigation of the sheath and near-sheath around the test body up to about 10 test body radii in 8 different angular position over the 360 degrees field will be reported in a future paper now in progress.

FIGURE CAPTIONS

FIG.1 Set-up of the first experiment. A spherical conductive body of 10 cm diameter is located at the centrum of the Orleans plasma chamber. LP are the cylindrical Langmuir probes by which the plasma parameters are continuously monitored (LP) at the bottom of the chamber, and the floating potential contours around the test body can be measured, the two LP which can be radially translated and rotated by remote control with respect to the sphere.

FIG.2 Set-up of the second experiment. The same test body of the first experiment is located at the centrum of the Orleans plasma chamber. At the right-hand upper corner is shown the mutual impedance probe by which the plasma parameters are continuously monitored. At the left-hand upper corner is shown the Langmuir probe of reference for plasma parameters monitoring. At the bottom is shown the cross system on which the 16 Langmuir probes are located up to radial distances of 9 test body radii.

FIG.3 Ion current collection versus test body potential under plasma conditions quoted in Table-1 under label exp 2. The black dots refer to a zero magnetic field, while the triangles and squares to a transversal magnetic field of 0.6 and 1.2 Gauss, respectively.

FIG.4 Electron current collected under plasma conditions quoted in Table-1 under label exp 1. The upper curve refers to a zero magnetic field while the lower curve to an axial magnetic field of 0.68 Gauss.

FIG.5 Electron current collected upon a 10 cm diameter sphere under plasma conditions quoted in Table-1 under label exp 2. The black dots, triangles, and squares refer to zero, 0.6 G, and 1.2 G transversal magnetic field, respectively.

FIG.6

Floating potential contours upstream and downstream a negatively polarized test body under the plasma conditions quoted in Table-1 under label exp 1.

FIG.7

Example of the I-V characteristics of the 16 Langmuir probes located radially with respect to the test body. Each Langmuir probe characteristic is plotted in log ang linear scale for a potential range from -10 V to 10 V.

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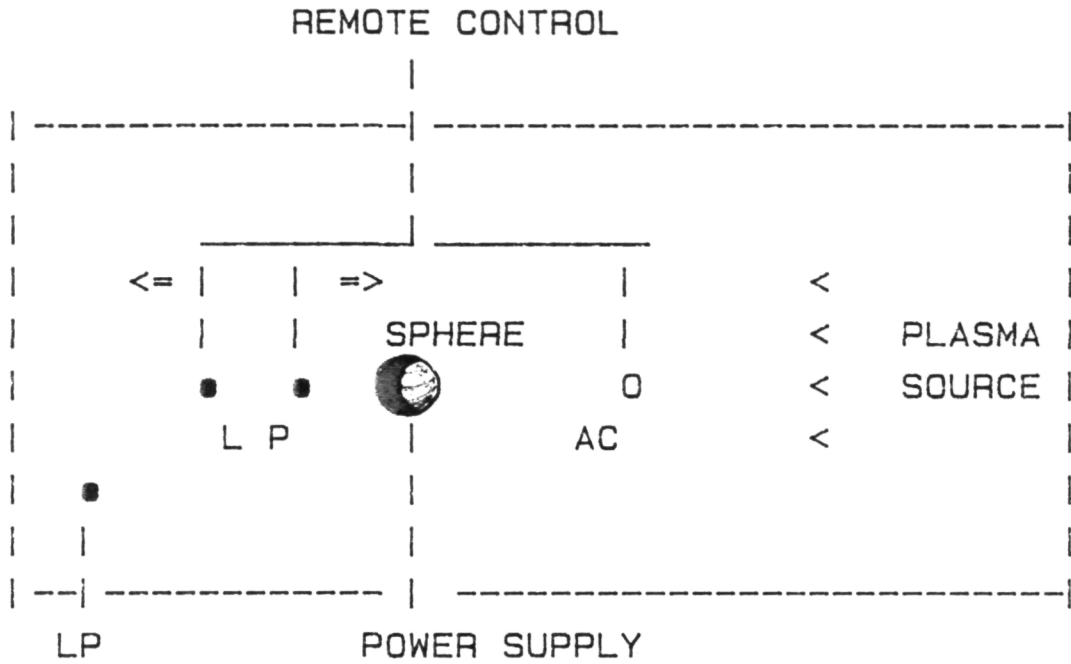


FIGURE 1 : FIRST EXPERIMENT SET-UP

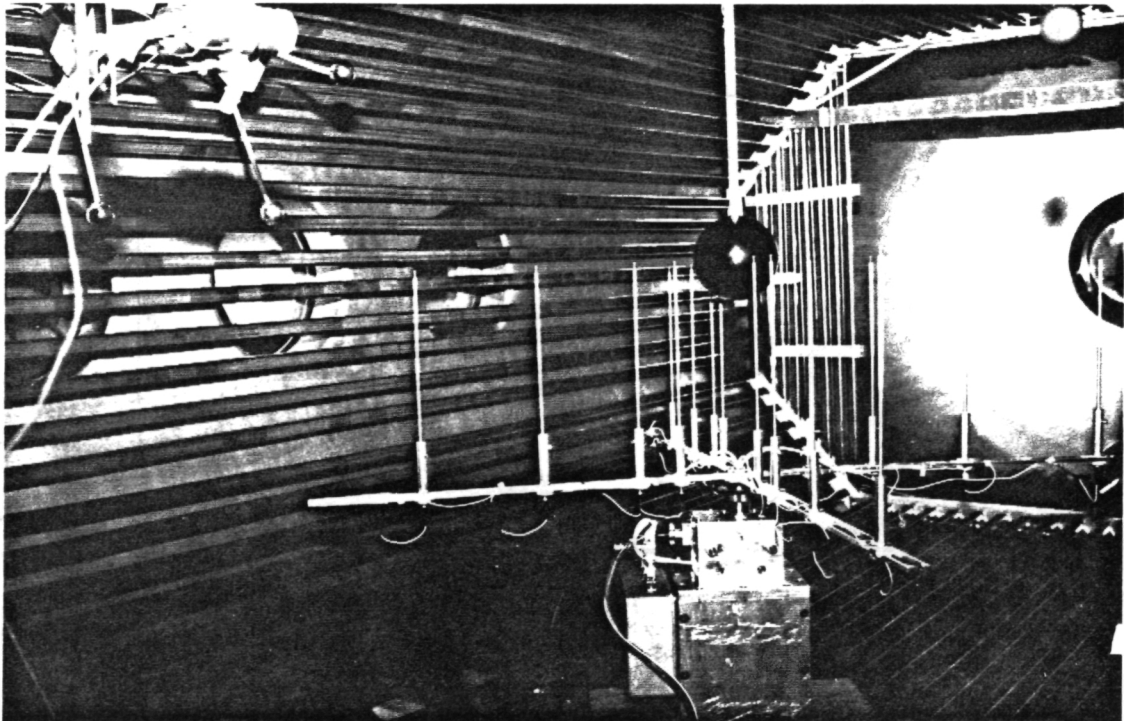


FIGURE 2 : SECOND EXPERIMENT SET-UP

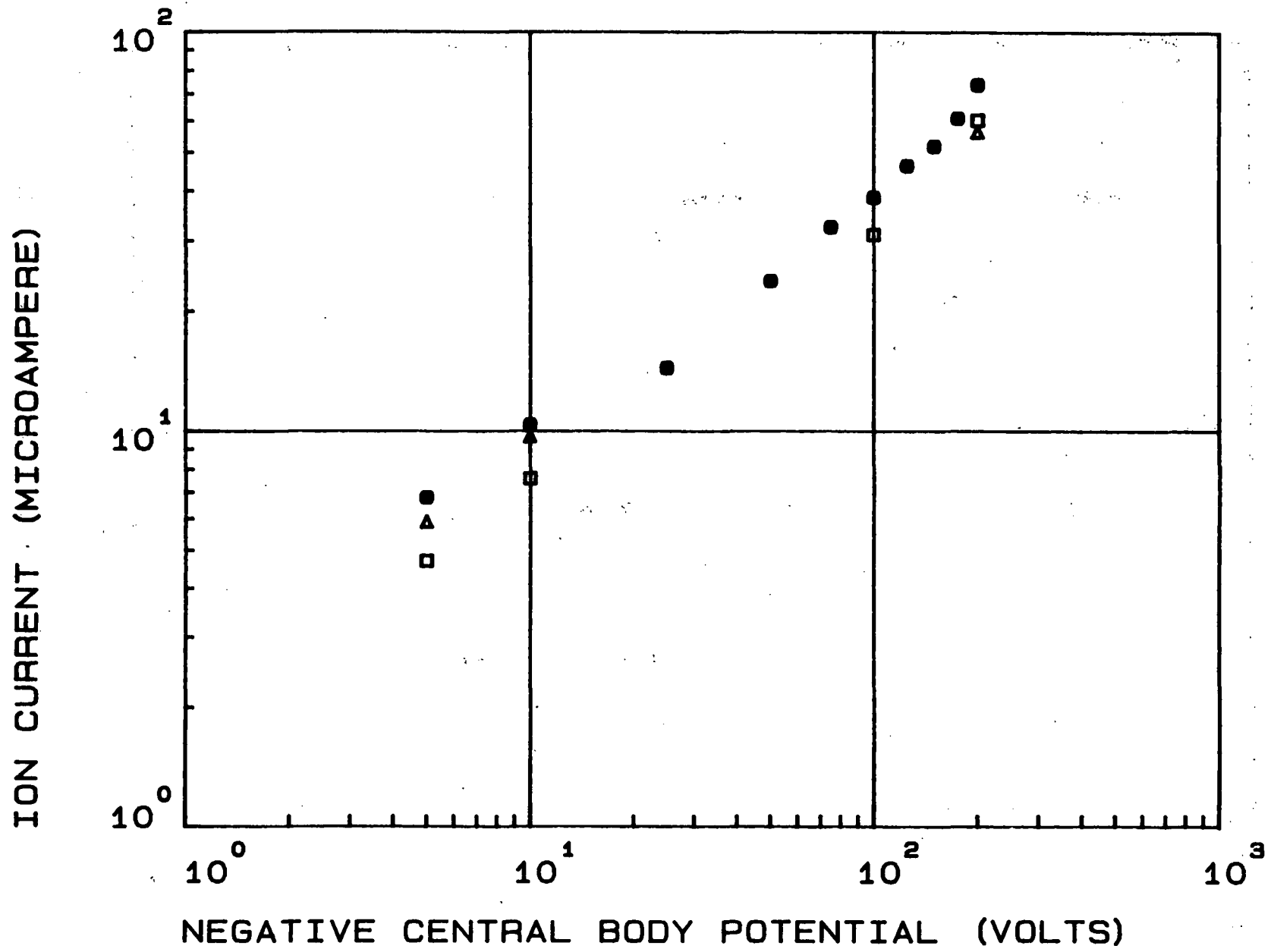
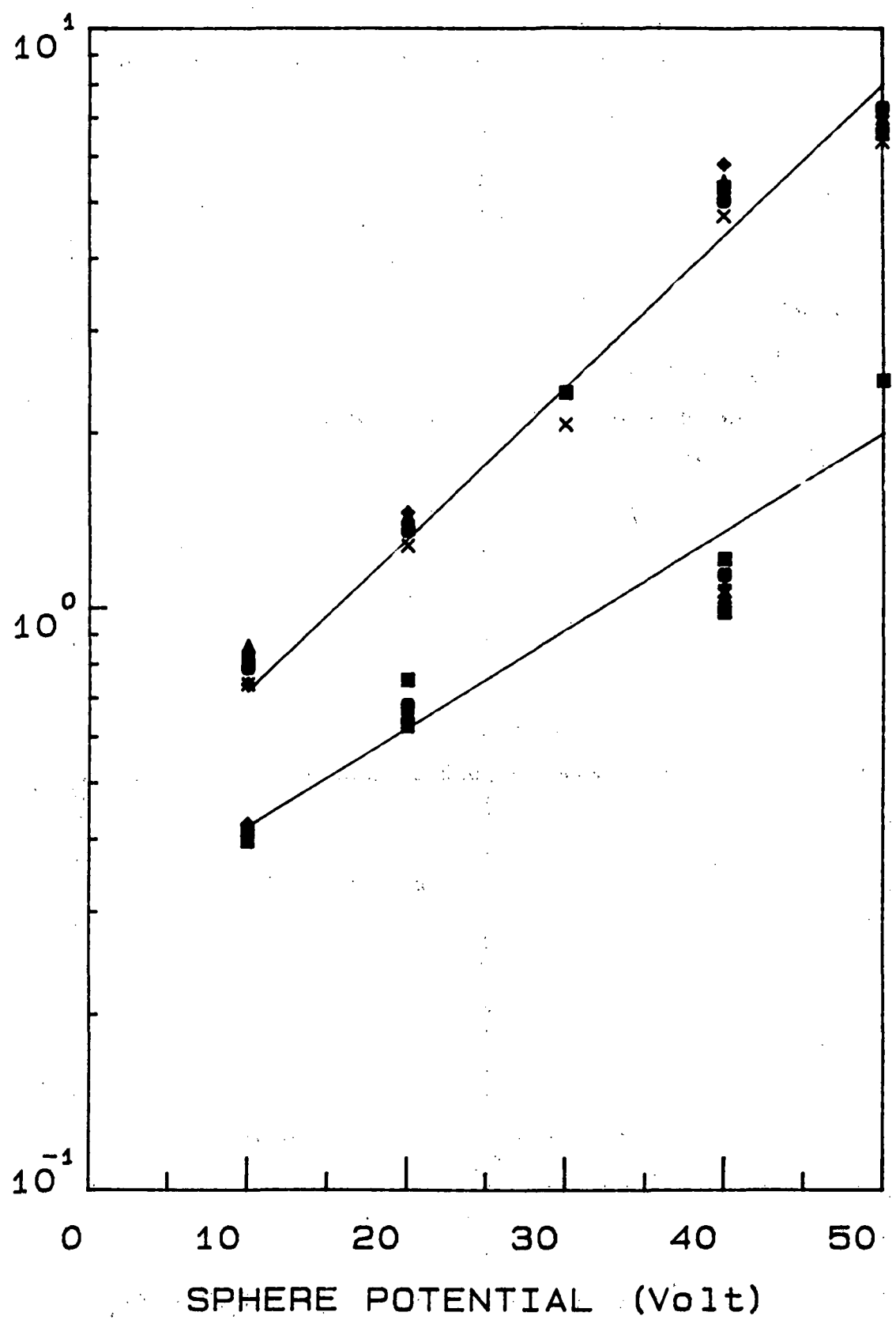


FIGURE 3

ELECTRON CURRENT (mA) . SPHERE RADIUS=5. cm



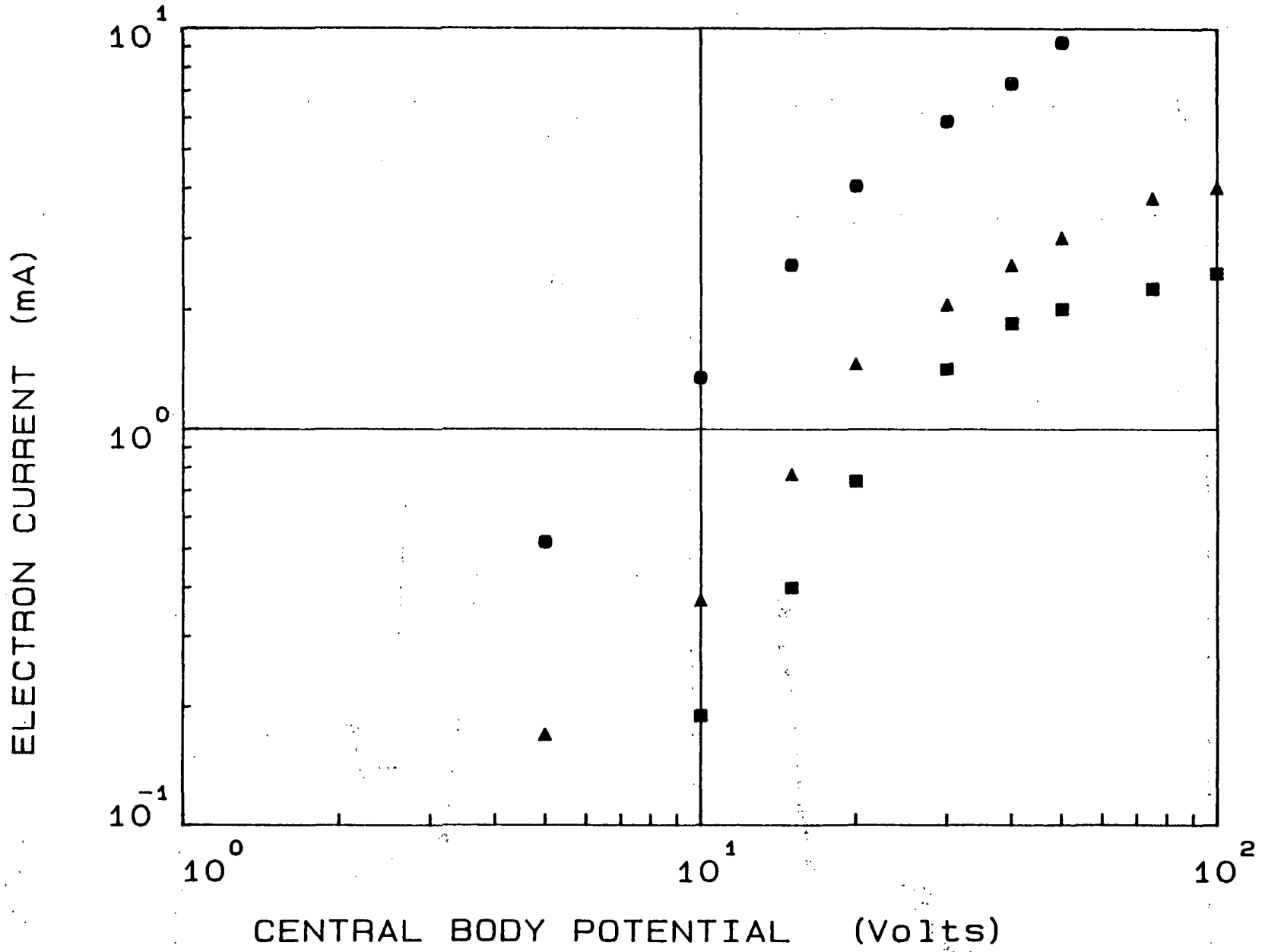


FIGURE 5

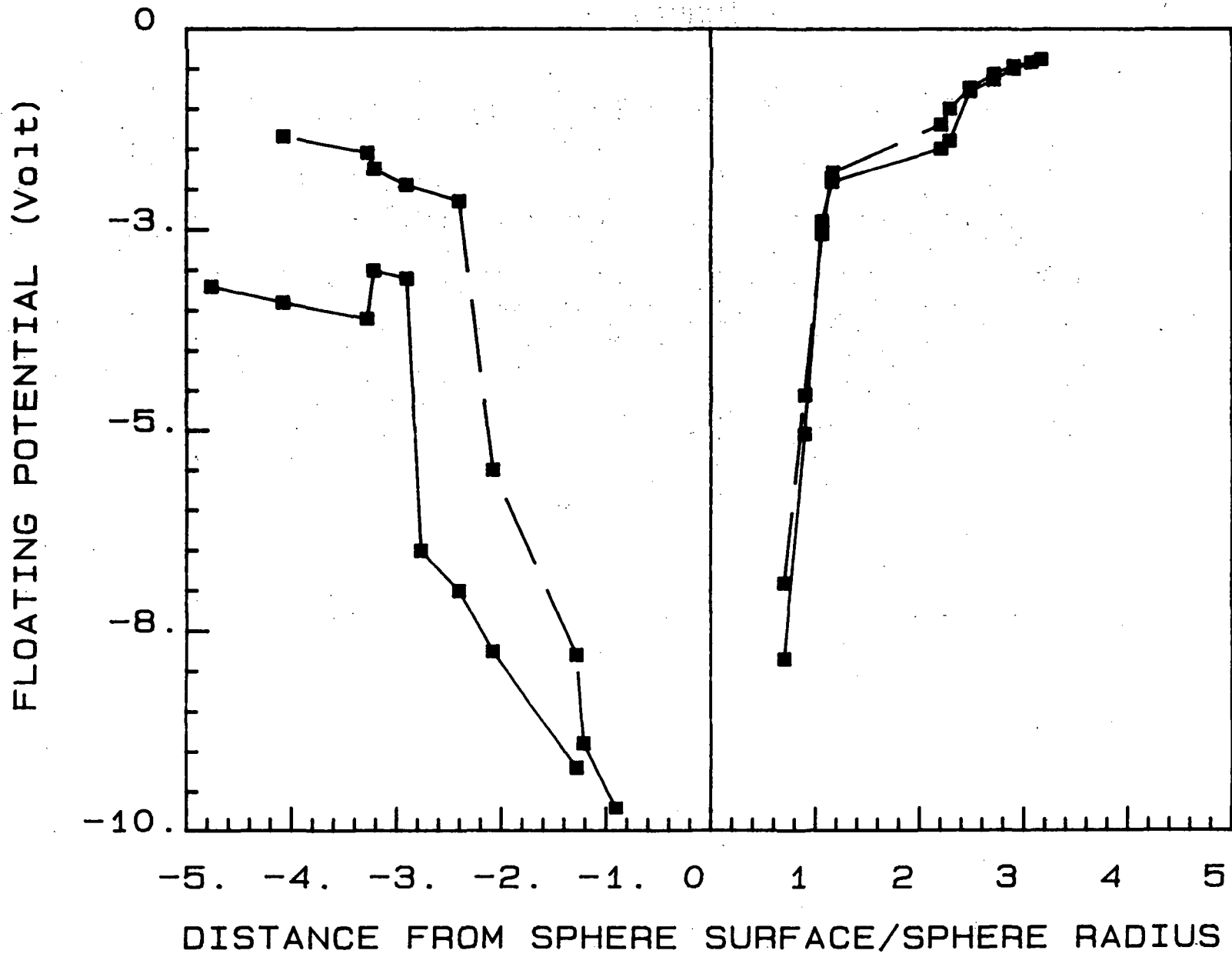


FIGURE 6

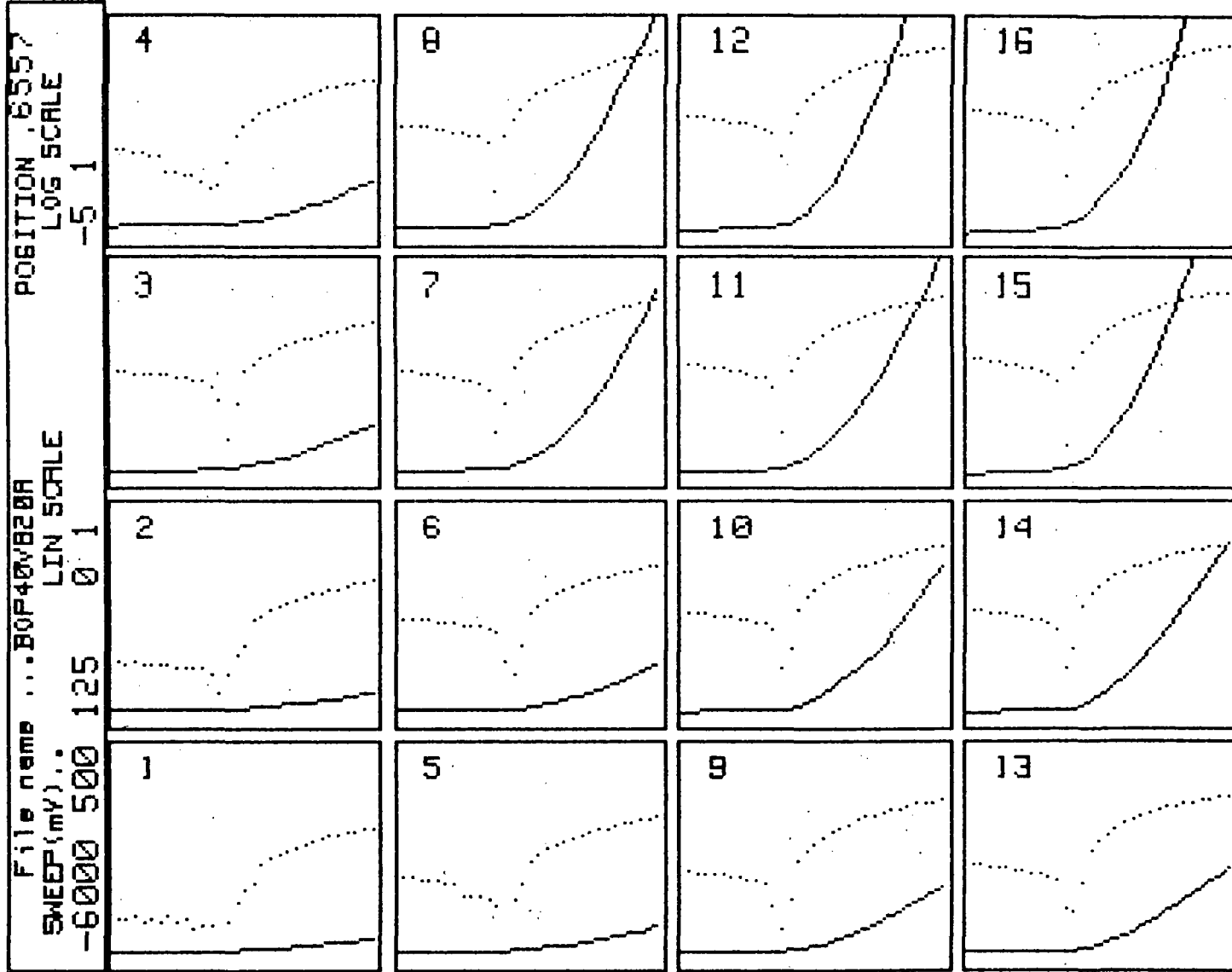


FIGURE 7

	LABORATORY			IONOSPHERE
	RANGE	EXP-1	EXP-2	250 Km
NEUTRAL DENSITY (T_{00r})	-4 TO 10 ⁻⁷	10 ⁻⁵	10 ⁻⁵	10 ⁻⁷
PLASMA DENSITY (e/cm^3)	4 TO 10 ⁷	3.4 TO 10 ⁵	1.8 TO 10 ⁶	4 TO 10 ⁵
ELECTRON TEMPERATURE (K)	500 TO 2000	1340	1850	1700
ION TEMPERATURE (K)	300	300	300	1200
ION MASS	40 (Ar)	40 (Ar)	40 (Ar)	24
ION FLOW (ORBITAL VEL.) (km/s)	5 TO 50	8	8	7.75
STATIC B FIELD (Gauss)	0 TO 2	0.88	0.8 & 1.2	0.35
DEBYE LENGTH (cm)	0.1 TO 1.7	0.47	0.47	0.45
ELECTRON GYRORADIUS (cm)	>0.1	1	2.3 & 1.2	2
ION GYRORADIUS (m)	>10	50	50 & 25	100
PLASMA FREQUENCY (MHz)	1 TO 30	5.25	10	5.75
ELECTRON GYROFREQUENCY (MHz)	0 TO 5	0 & 1.8	22.4 & 11.7	1

TABLE 1: PLASMA PARAMETERS IN THE LABORATORY AND IN THE IONOSPHERE

VOLTS	ELECTRON DENSITY X 10 ⁶ (cm ⁻³)		
	B= 0 G	B= 0.6 G	B= 1.2 G
-200.	1.23	1.28	1.54
-175.	1.23		
-150.	1.30		
-125.	1.30		
-100.	1.36	1.54	1.70
-75.	1.36		
-50.	1.44		
-25.	1.52		
0.	1.63	1.70	2.02
5.	1.15	1.52	
10.	0.87	1.36	1.90
15.	0.63	1.21	1.64
20.	0.60	1.01	1.24
30.	0.56	0.97	1.19
40.	0.52	0.91	1.19
50.	0.44	0.85	1.12
75.		0.85	1.05
100.		0.78	0.72

Table-2-

Electron density versus test body potential for external magnetic field 0.0, 0.6, and 1.2 Gauss.