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Abstract

Formation of strong double layers has been observed experimentally in a magnetised plasma column maintained by a plasma source. The magnetic field is approximately axially homogeneous except in a region at the anode where the electric current flows into a magnetic mirror. The double layer has a stationary position only in the region of non-uniform magnetic field or at the aperture separating the source and the plasma column. It is characterized by a negative differential resistance in the current-voltage characteristic of the device. The parameter space, where the double layer exists, has been studied as well as the corresponding potential profiles and fluctuation spectra.

The electric current and the axial electric field are oppositely directed between the plasma source and a potential minimum which is formed in the region of inhomogeneous magnetic field. Electron reflection by the resulting potential barrier is found to be an important current limitation mechanism.

1. Introduction

Potential drops along the magnetic field lines and the formation of electric double layers attract an increasing interest. However, rather few laboratory investigations of these phenomena seem to have been made in non-uniform magnetic fields (Hatakeyama et al. 1980, Stenzel et al. 1981, Stenzel et al. 1983, Nakamura et al. 1984, Alport et al. 1986). The present study describes experimental observations of current saturation and the formation of strong double layers in a cylindrical argon plasma column at low density. The plasma column is maintained by a plasma source at the cathode end, and a double layer is formed by applying a voltage drop between the source and a plane anode.

The magnetic field is approximately uniform except in a region at the anode where the electric current flows into a magnetic mirror. The formation of V-shaped double layers and the excitation of ion-cyclotron waves have recently been studied in this type of device in a similar magnetic field configuration to that used here (Alport et al. 1986). As in the case of an axially homogeneous magnetic field the double layer evolves from an anode sheath (Torvén and Andersson 1979, Torvén and Lindberg 1980, Andersson 1981, Andersson and Sörensen 1983). Similar double layers have also been observed in unmagnetized plasma at higher densities (Sanduloviciu and Lozneanu 1986).

Here we shall report some new results concerning the properties of the double layer, which has a stationary position only in the region of non-uniform magnetic field, and the limitation of the electric current which is of importance for the double layer formation. Measurements show that the current and the axial electric field are oppositely directed in a region between the source and a potential minimum which forms in the region of non-uniform magnetic field. Electron reflection in the resulting potential barrier between the source and the minimum is found to be an important current limitation mechanism, and a process maintaining this barrier is discussed. A similar current limitation mechanism has also been observed recently in a triple plasma device (Lindberg and Torvén 1983, Carpenter _et al_. 1984, Torvén _et al_. 1985, Carpenter and Torvén 1986). Between the minimum and the anode the applied voltage drops off in an anode sheath or in a double layer which shields off the anode voltage from the remaining part of the plasma.

Experimentally determined current-voltage characteristics are compared with calculated characteristics obtained from the electron fluxes transmitted between the source and the potential minimum for different values of the anode voltage. The fluxes are calculated on the assumption that the axial electric field and the magnetic mirror force determine the electron motion. The calculated characteristics have the same principal shape as the measured ones, but there is a discrepancy indicating that other processes are involved. Fluctuations are shown to be one important mechanism, and further investigations of these are necessary to understand the current transport.

Regular oscillations are also excited, and they have been interpreted as azimuthally propagating drift waves rather than ion cyclotron waves as reported by Alport _et al_. (1986) who used a small anode diameter giving radial profiles differing from those in this experiment.

2. The experimental device

The experiments were made with the UML-2 plasma device at the University of Montreal. In this device a cylindrical plasma column is maintained in a steady state by a plasma source at the cathode end. The bracketed figures below refer to various details of the device as shown in Fig.1. The plasma in the source is generated by a d.c. discharge of a few ampères between an indirectly heated oxide cathode (4) with a diameter of 75 mm and a tungsten grid anode (5). Argon is continously fed into the source through a valve (13). The main vacuum chamber (1) is of pyrex glass and has a diameter of 15 cm and a length of 1.5 m. The chamber is pumped by two diffusion pumps (2,3) to reduce the argon pressure there and thereby reduce effects of ionization. The plasma source is isolated from the main vacuum chamber by an "iris diaphragm" (9). This has a variable diameter, which has been chosen between 1 and 2 cm in the present study to obtain a pressure difference and to reduce the cross-section of the plasma column. The argon pressure close to the pump (3) was 0.3 mTorr and 0.5 mTorr close to the pump (2).

Plasma from the source penetrates into the chamber, and a plasma column is formed between the source and the movable anode (6). The diameter of the column can be varied by varying the diaphragm diameter. The plasma is radially confined by a magnetic field (Magnion solenoid (8)) which is approximately uniform and equal to 350 Gauss in the region between the diaphragm and the right end ot the solenoid. There the axial field strength decreased towards the anode and assumed a value of 100 Gauss at the anode surface (Fig.2). The anode diameter is so large that a magnetic field line passing the edge of the diaphragm hits the anode surface.

As will be shown in the next section there is a sharply localized potential drop of the order of kT_e/e at the diaphragm. This potential drop accelerates ions into the chamber. The current free plasma column has inwardly directed radial field, and the radial potential drop between the symmetry axis and the edge of the plasma column is of about the same magnitude as the potential drop at the diaphragm.

In spite of the ion confining radial electric field many ions should be lost as they move from the source to the anode. It seems likely that such losses cause the fairly large density gradient along the column (Fig.3a). The electron number density in the column is proportional to the source discharge current, and the density in the column near the potential minimum was varied between $2 \cdot 10^{15}$ and 10^{16} m^{-3} in the experiments. The electron temperature, as obtained from Langmuir probe measurements, also decreases somewhat towards the anode. Examples of radial profiles are shown in Fig.3b. There is an appreciable plasma density also for radii larger than the diaphragm radius as discussed further in the next section.

Plasma potentials were measured by sampling and averaging the floating potential of an axially and radially movable electron emitting probe (12) with a filament radius of 0.1 mm and a length of 10 mm. An axially movable (12) and a radially movable (11) cylindrical Langmuir probe were also available.

Typical numerical values of some parameters are Debye length $\lambda_{DE} \approx 0.15$ mm, electron gyro radius $\varrho_e \approx 0.2$ mm, plasma frequency $\omega_p \approx 5$ GHz, and electron cyclotron frequency $\omega_{ce} \approx 6.5$ GHz.

We have observed similar results to those reported here in the following parameter space: Source discharge current 1 to 5 A, argon pressure in the chamber 0.1 to 1 mTorr, magnetic field strength 100 to 600 Gauss, diaphragm diameter 1 to 2 cm, and anode diameter 9 to 14 cm. All the double layers were observed when $\lambda_{DE} \approx \varrho_e$ and $\omega_p \leqslant \omega_{ce}$.

3. Properties of the double layer and the current carrying plasma column

A typical example of a current-voltage characteristic is shown in Fig.4a. When the anode voltage U_a is increased from floating potential (-15 V) up to $U_a = U_m \approx 4$ V, the current I increases monotonically from zero up to a maximum, $I = I_m$. Then it drops sharply and varies little up to $U_a \approx \Phi_{DL} \approx 33$ V, when a double layer with a voltage drop Φ_{DL} forms in this case. Fig.4b shows the corresponding axial potential profiles for some different values of U_a. Φ_{DL} and U_m are independent of the plasma density in the range explored. The local plasma potential at some distance from the anode surface is not much perturbed by the anode voltage. It varies only a few volts when U_a is increased from -15 V up 33 V, and the voltage drop between the anode and the plasma is essentially concentrated to an anode sheath or to the double layer which shield off the anode voltage from the remaining part of the plasma column.

As discussed further below oscillations and fluctuations are present, and the measured values are time averages. The anode voltage is determined by a low impedance power supply and is approximately time-independent.

The double layer evolves from an anode sheath. Ionization within the sheath is of importance for the double layer formation, because the ionization mean free path for electrons accelerated in the sheath is of the order of $(m_i/m_e)^{1/2}d$ or smaller (Torvén and Andersson 1979). Here m_i and m_e are the ion and electron masses, and d is the thickness of the anode sheath. Further investigations of the double layer formation have been presented by Andersson (1981), Andersson and Sörensen (1983), and Alport _et al_. (1986). Ionization by fast electrons which have been accelerated in the double layer, also maintains the new plasma (anode plasma) that separates the double layer and the anode. The plasma on the low potential side (cathode plasma) is still maintained by the source and has an inwardly directed electric field as in the current free column. In the anode plasma, however, the radial electric field is directed outward.

The cathode plasma is characterized by a drop in the luminosity at a radius roughly coinciding with the diaphragm radius R_d. A conspicuous phenomenon is the radial expansion of the luminosity at the double layer. However, the radial density profile in the cathode plasma is not characterized by a sharp density drop for $r = R_d$, but it is broader and similar to the profile shown in Fig.3b. The broadening may be due to electrons that have drifted radially and become trapped between the grounded diaphragm plate and the potential minimum. Only electrons with axial velocities corresponding to energies less than about 1 eV may be trapped in this way. At the minimum the potential increases with the radius, and the trapped electrons will eventually be able to pass the minimum, as they drift radially outward, and give rise to light emission when they have been accelerated up to a sufficiently high energy by the double layer. As has been shown elsewhere (Torvén and Lindberg 1980) the radial density profile in the cathode plasma also differs insignificantly from the one at the double layer for $r > R_d$. Although radial density profiles do not give any evidence of a radial plasma expansion at the double layer, some expansion may possibly occur if there is an enhanced radial electron drift due to the high frequency fluctuations excited close to the double layer (Torvén and Lindberg 1980, Lindberg 1982, Alport et al. 1986).

Examples of axial double layer potential profiles are given in Fig.5 showing that the stationary position of the double layer moves towards the source when U_a is increased. However, there is no stationary position for the double layer in the region of axially homogeneous magnetic field when the magnetic field is sufficiently strong ($B_0 \geqslant 200$ Gauss) showing that the boundary conditions for a stationary double layer cannot be fulfilled there. This may be due to the fact that an increase of the magnetic field strength gives a plasma column with a smaller axial density gradient, and it should be more difficult to satisfy the boundary conditions the more homogeneous the plasma is.

When U_a is increased sufficiently, the double layer finally finds a new stationary position at the diaphragm. Then no ions but only energetic electrons are injected into the chamber, and all the ions in the plasma column must be produced by ionization. The current can then be increased to large values at about constant voltage so the discharge behaves as an arc discharge. The double layer at the diaphragm is of the same type as the double sheaths observed long ago in arc discharges at a constriction in the discharge channel (e.g. Schönhuber 1958).

An interesting intermediate state can also exist. This is characterized by large amplitude current and voltage fluctuations which indicate that the double layer "jumps" randomly between the diaphragm and any position in the region of inhomogeneous magnetic field. Further investigations are required to show whether this phenomenon can be described by propagating double layers.

The potential level in the source is approximately independent of U_a and close to 5 V in the case considered. There is a sharp potential drop of the order of kT_e/e at the diaphragm. As shown in Fig.6a, the potential then decreases up to a minimum. This is assumed at the anode surface when $U_a < \Phi_p$ and in front of the anode sheath or the double layer, when $U_a > \Phi_p$. Here Φ_p is local plasma potential at some distance from the anode. The corresponding current-voltage characteristic is shown in Fig.6b. The electric current and the axial electric field are accordingly oppositely directed all the way between the diaphragm and the minimum. The potential decrease along the plasma column can be understod in terms of radial ion losses which give an ion number density decreasing towards the anode. When radial electron losses are neglected as a first approximation, a corresponding decrease of the electron number density is obtained if the potential decreases towards the anode, and quasineutrality can then be maintained.

The potential drop at the diaphragm, which also is associated with a step-like density drop, can be understood in a similar way. The potential of the diaphragm plate is below the source plasma potential so the plate receives the saturation ion flux from the source plasma. The radial electric field on the source side of the plate has not been measured, but it should be directed outward there so ions may be deviated radially to hit the plate instead of passing the diaphragm. Enhanced ion losses are therefore likely, and an axial potential drop must then develop to give approximately the same decrease of the electron number density so that quasineutrality can be maintained in the chamber. The potential drop at the diaphragm decreases, when the diaphragm diameter is increased, and it vanishes only when this equals the diameter of the grid anode in the source.

Harmonic oscillations with discrete frequencies in the range 5 to 20 kHz can be already observed in the region $U_a < U_m$ where the plasma still is quiescent (Fig.4 and 6). They were detected on the floating potential of a Langmuir probe and observed in the region of uniform as well as non-uniform magnetic field. The oscillations have been interpreted as azimuthally propagating drift-waves excited by the azimuthal electron drift velocity which exists due to the radial density gradient. It should be noted that the observations of ion-cyclotron waves in a similar device reported by Alport <u>et al</u>. (1986) were made when the anode diameter was smaller than the diameter of the plasma column. This gives radial density and potential profiles that differ strongly from the radial profiles in this experiment, and different types of wave excitation can be expected. Also it is of interest to note that it may be difficult to distinguish wave modes from relaxation oscillations (cf. Popa <u>et al</u>., 1985, for the case of ion-cyclotron oscillations).

For increasing current and mostly for $U_a \geqslant U_m$ no discrete modes exist locally. When the sharp current drop occurs (Fig.4a and 6b), a new spectrum of fluctuations from a few kHz up to 1 MHz is excited. The level of the current fluctuations is about an order of magnitude larger for $U_a > U_m$ than for $U_a < U_m$. The spectrum of current fluctuations is a decreasing function of the frequency. Peak amplitudes up to 1 V in the plasma potential were observed and current fluctuations up to 50% of the time averaged current. After the double layer formation the current fluctuations decrease to some ten percent of the average. A further increase of U_a leads to the large amplitude fluctuations that may possibly be connected with propagating double layers as already mentioned.

The current-voltage characteristics also have regions showing a negative differential resistance. In general this may lead to excitation of relaxation oscillations at a frequency close to the resonance frequency of the current circuit (e.g. Carpenter et al. 1984). This frequency is of the order of 1 MHz or larger in the present experiment because it is determined by the stray inductance and the stray capacitance only. For such high frequencies the d.c. characteristic should be quite irrelevant, and it seems unlikely that the oscillations and fluctuations reported here are influenced by the negative differential resistance of the characteristics.

An interesting feature of the characteristic is the sharp current drop for $U_a \geqslant U_m$. The current drop cannot be interpreted in terms of anomalous resistivity of the plasma column. Since the average current and the average electric field are oppositely directed, any resistivity connecting these quantities will be negative. However, for $U_a \approx U_m$ the anode potential is always close to the fixed potential of the source plasma, so the fluctuating state appears when ions from the source no longer can reach the anode but start to be reflected. This should give an ion distribution function in the plasma column consisting of two oppositely directed "beam" distributions in addition to trapped ions formed by charge exchange collisions. An instability may accordingly develop for $U_a > U_m$, and it may lead to increased radial ion losses. Following the arguments already used the average potential of the column should then decrease relative to the source because then the electron number density will also decrease, and quasineutrality must be maintained in the column. Thus the level of the potential minimum, Φ_m, decreases as observed experimentally since the potential level Φ_s in the source plasma is independent of U_a and the shape of the profiles varies little with U_a.

The variation of the height of the electron reflecting potential barrier $\Phi_s - \Phi_m$ should be an important current controlling mechanism since this height partly determines the fraction of the source electron flux that can pass the minimum and reach the anode. $\Phi_s - \Phi_m$ is a function of U_a since Φ_m varies with U_a, and this function can be determined experimentally from measurements like those presented in Fig.4 and 6. These diagrams show immediately that Φ_m is correlated to the current which increases, when Φ_m increases, and decreases when Φ_m decreases.

We have made a first check of this correlation by assuming that source electrons with a half-Maxwellian distribution function are emitted into the chamber at the potential level Φ_s. The corresponding axial electron current at the symmetry axis is then given by

$$j_o = \Delta A e n_o \left(2 kT_e/\pi m_e\right)^{1/2} \qquad (1)$$

Here n_o is the electron number density in the flux emitted from the source and ΔA is a surface element. We can assume that the transmitted current is reduced by electron reflection due to the electric field only in a region between the source and a point z_1 close to the right end of the solenoid. For $z_1 < z < z_A$, where z_A is the coordinate of the anode surface, the electric potential $\Phi(z)$ has a minimum for $z = z_m$, and the electron reflection is determined by the minimum value of the "effective potential"

$$\Psi(z) = \Phi(z) - (\mu/e)\, B(z) \qquad (2)$$

$B(z)$ is the magnitude of the axial component of the magnetic field, e the positive elementary charge, and $\mu = (1/2)\, m\, v_\perp^2(z)/B(z)$ the magnetic moment. The position of the minimum of $\Psi(z)$ will therefore in general coincide with the minimum of $\Phi(z)$ for $\mu = 0$ only. With increasing transverse velocity of the injected electrons the position of the minimum will move towards z_1, and finally the minimum may disappear so that all electrons reaching z_1 with a sufficiently large transverse velocity are transmitted independent of their parallel velocity. The transmitted electron current will therefore in general depend on the spatial distribution of $\Phi(z)$ and $B(z)$ in the whole interval $z_1 < z < z_m$ (Raadu 1986).

To get an estimate we shall here approximate $\Phi(z)$ and $B(z)$ by straight lines in the interval $z_1 < z < z_m$. This seems to be a good approximation as shown by the straight line approximations in Fig.2 and Fig.4b for $z_1 = -13$. Then the minimum is always assumed at the boundary $z = z_m$. By integrating over the appropriate region of the phase space we find that the electron current transmitted to the anode through a surface element close to the symmetry axis is given by

$$j = j_o \exp(-\varphi_m)\, [1 + \frac{1-\exp(-\alpha\varphi'_m)}{\alpha}] \qquad (3)$$

Here $\varphi_m = e(\Phi_s-\Phi_m)/kT_e$, $\alpha = R/(1-R)$, and $R = B_m/B_o \leq 1$. B_m is the axial magnetic field strength at the potential minimum the position of which varies with U_a. Using experimental values of B_m, φ_m and kT_e (4 eV) we have calculated j as a function of U_a. This function has been compared with the measured current-voltage characteristics by assuming that the measured current is proportional to j. The proportionality constant is adjusted so that the calculated current fits the experimentally determined current for $U_a = U_m$. As seen from Fig.7 the calculated current shows a similar behaviour to the measured one, but its profile around the current maximum is much broader than the measured one. This result shows that reflection of electrons by the variable potential barrier is an important mechanism for controlling the current, but it also indicates that other processes not included in the calculation are of importance.

One obvious objection against the calculation is the use of time-averaged values of φ_m and B_m. The latter will fluctuate, too, because of fluctuations in the position of the minimum. For oscillation periods larger than the electron transit time, (3) would still be valid if φ_m and B_m are replaced by $\varphi_m + \varphi_1(t)$ and $B_m + B_1(t)$, where φ_1 and B_1 represent the fluctuations. The time averaged current will then be given by an average of the right hand side of (3). Due to the non-linearity the averaging would strongly modify the current if the amplitudes of φ_1 and B_1 are large, and the current would depend on the fluctuation amplitudes as well.

There are also other possible reasons for the discrepancy. High frequency fluctuations with periods shorter than the electron transit time have not been investigated here. They may give rise to increased electron losses to the grounded diffusion pumps. It should also be noted that (3) is valid at the symmetry axis only whereas the measured anode current is determined by a three-dimensional structure.

4. Conclusions

Strong double layers ($e\Phi_{DL}/kT_e \geqslant 10$) have been observed in an argon plasma column in an axially symmetric magnetic field with an axial field gradient in a region at the anode. For not too weak magnetic fields the double layer assumes a stationary position only in the region of inhomogeneous magnetic field. However, for a sufficiently high anode voltage a transition to an arc discharge occurs, and then the double layer has another stationary position at the diaphragm separating the source and the plasma column.

The diameter of the plasma column is larger than the diaphragm diameter, and a possible mechanism for the radial expansion is trapping of electrons between the diaphragm plate and a potential minimum which forms in the region of non-uniform magnetic field.

The electric field and the current are oppositely directed between the source and the potential minimum. Electron reflection in the resulting potential barrier has been shown to be an important current limitation mechanism, and the variation of the height of the barrier has been correlated to measured current--voltage characteristics which show regions of current saturation and negative differential resistance. A probable process maintaining the potential barrier is radial ion losses, and variations of these may cause the variable height of the barrier. Waves and fluctuations are excited, and further investigations of these are required to understand the current transport in the plasma.

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Figure captions

Fig. 1 Schematic picture of the experimental device. A plasma column is maintained between the diaphragm (9) and the anode (6) by a source where plasma is generated by a discharge between the oxide cathode (4) and the grid anode (5).

Fig. 2 Normalized axial magnetic field strength at the right end of the solenoid, B_0 being the value in the center. The axial gradient has a maximum at the end of the solenoid, which is used as zero point for the axial length scale. The dashed straight line represents the approximation used to derive Equation (3).

Fig. 3 (a) Axial profiles of the electron number density and the electron temperature measured at the symmetry axis. The position -100 is 50 cm from the diaphragm, and the anode position is marked by an arrow.

(b) Normalized radial density and electron temperature profiles.

Source discharge current 3 A, chamber pressure 0.3 mTorr, B_0 = 350 Gauss, diaphragm diameter 1.5 cm, and anode potential floating.

Fig. 4 (a) Time averaged current-voltage characteristic for the plasma column. The anode voltage is given relative to ground. The vertical bars indicate the peak-to-peak amplitudes of the current fluctuations in the different regions of the characteristic. There is a small hysterisis at the critical voltage for double layer formation. At the transition to an arc discharge the double layer "jumps" to the diaphragm separating the source and the plasma column.

(b) Axial potential profiles corresponding to some different values of the anode voltage (U_a) in Fig.4a. The dashed straight lines represent the approximations used to derive Equation (3).

The plasma parameters are the same as in Fig.3.

Fig.5 Axial potential profiles for two different anode voltages when a double layer has formed. The time averaged potential drop over the double layer, Φ_{DL}, is approximately equal to U_a, and the potential drop fluctuates with peak-to-peak amplitudes up to 25% of Φ_{DL}. The plasma parameters are the same as in Fig.3.

Fig.6 (a) Axial profiles of the plasma potential at the symmetry axis. The position of the diaphragm is -150. The differences between the source plasma potential and the left end points of the curves give approximately the potential drops at the diaphragm because the potentials are approximately constant between -150 and -100.
(b) The corresponding time averaged current-voltage characteristic. The plasma parameters are the same as in Fig.3 except the diaphragm diameter which is 1.15 cm.

Fig.7 Current voltage characteristic calculated from equation (3) (dashed line) by fitting to the experimental curve (full line) at the current maximum.

EXPERIMENT UML 2

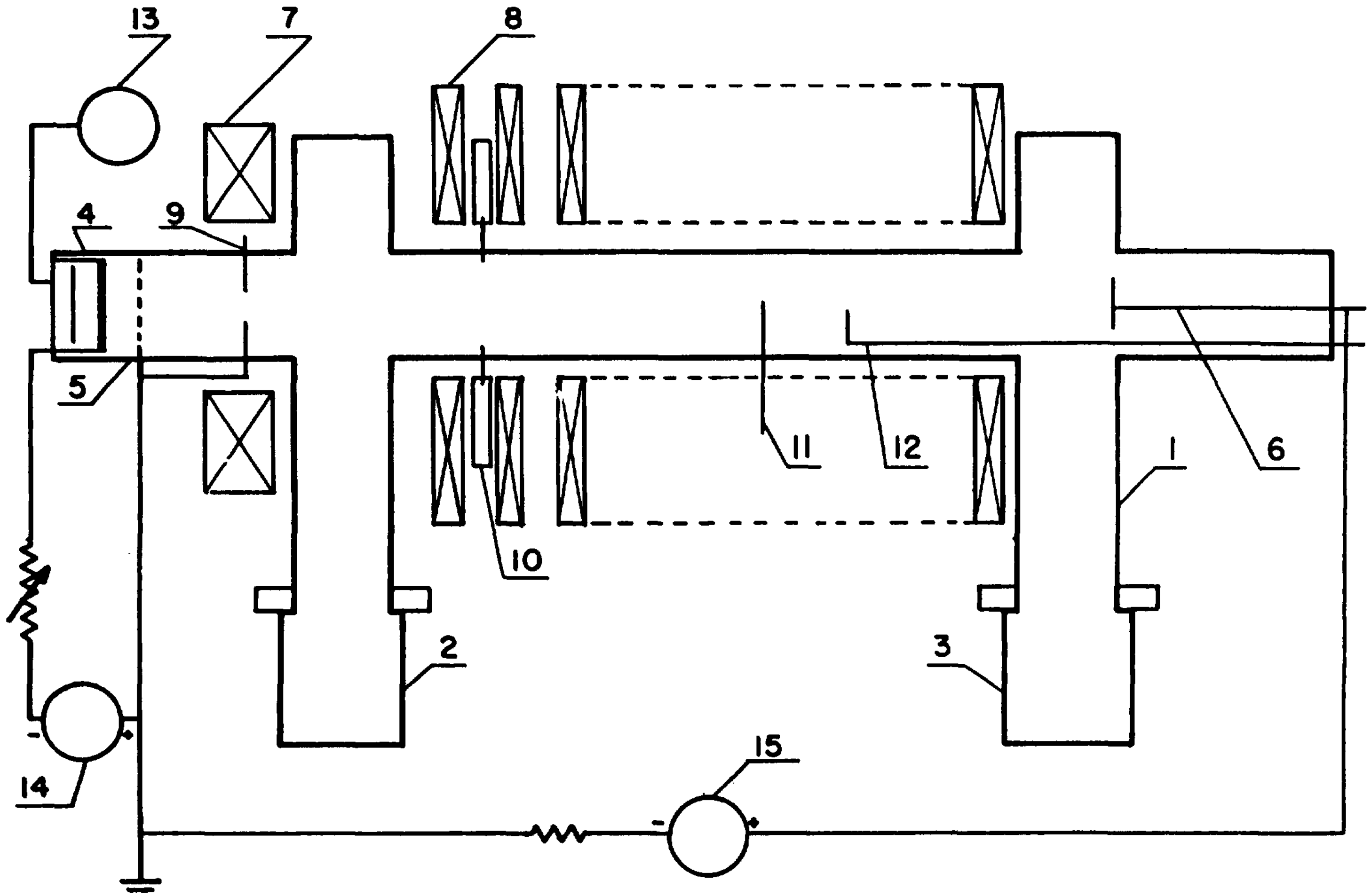
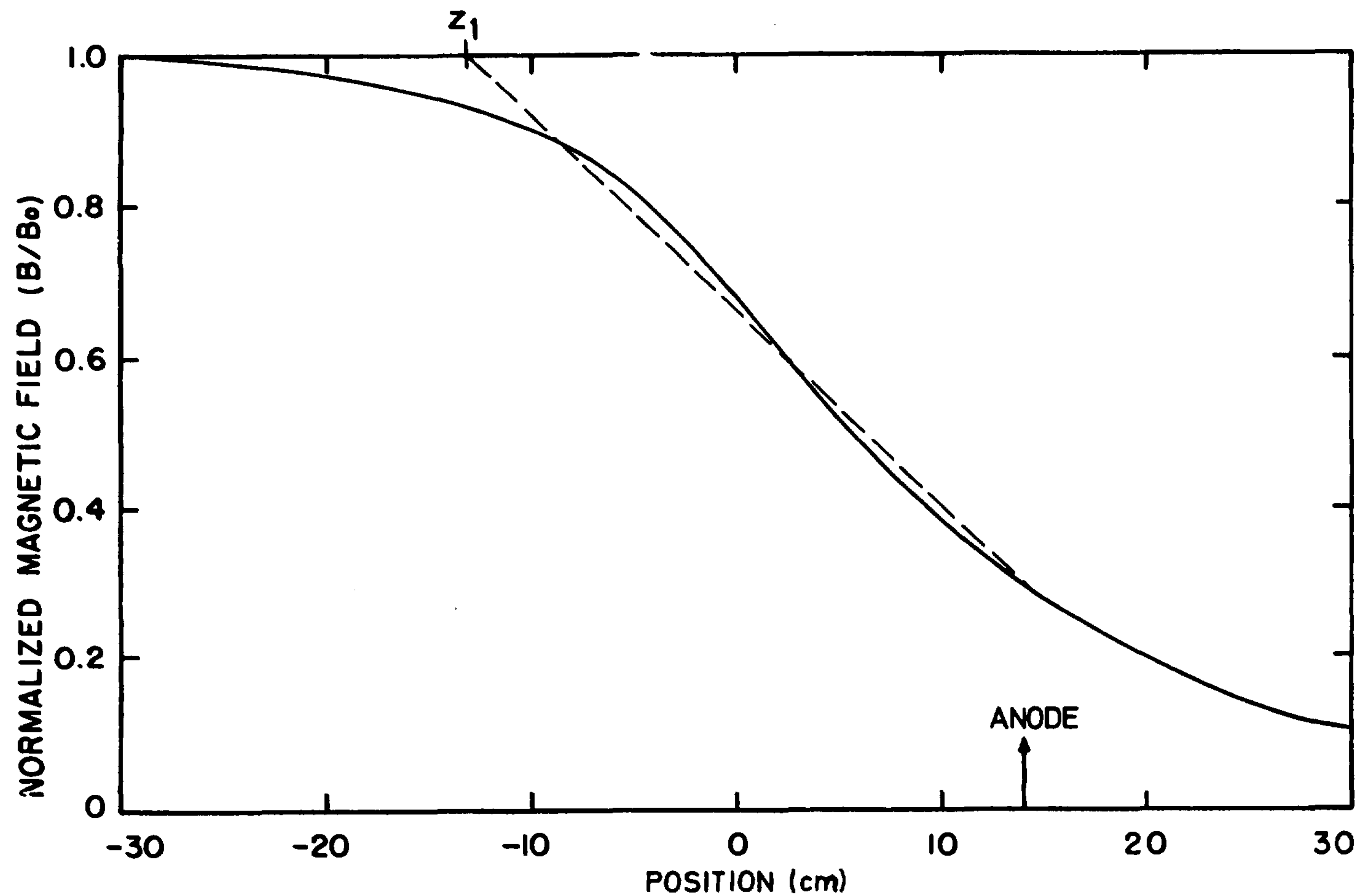


Fig. 1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1.0
0.8
0.6
0.4
0.2
0
-30
-20
-10
0
10
20
30
POSITION (cm)
z1
ANODE

Fig. 2

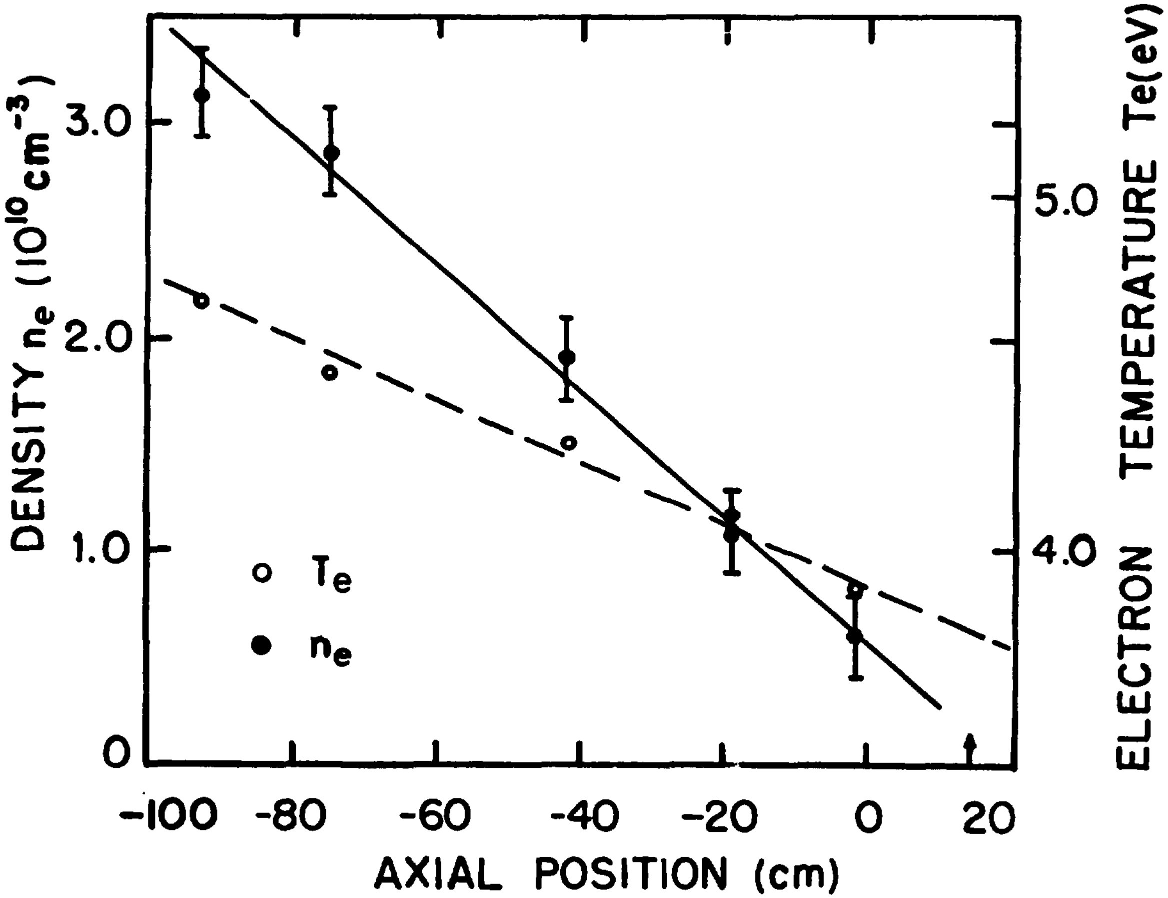

DENSITY n_e (10^{10} cm^{-3})
3.0
2.0
1.0
0
ELECTRON TEMPERATURE Te(eV)
5.0
4.0
○ T_e
● n_e
−100
-80
-60
-40
-20
0
20
AXIAL POSITION (cm)

Fig. 3a

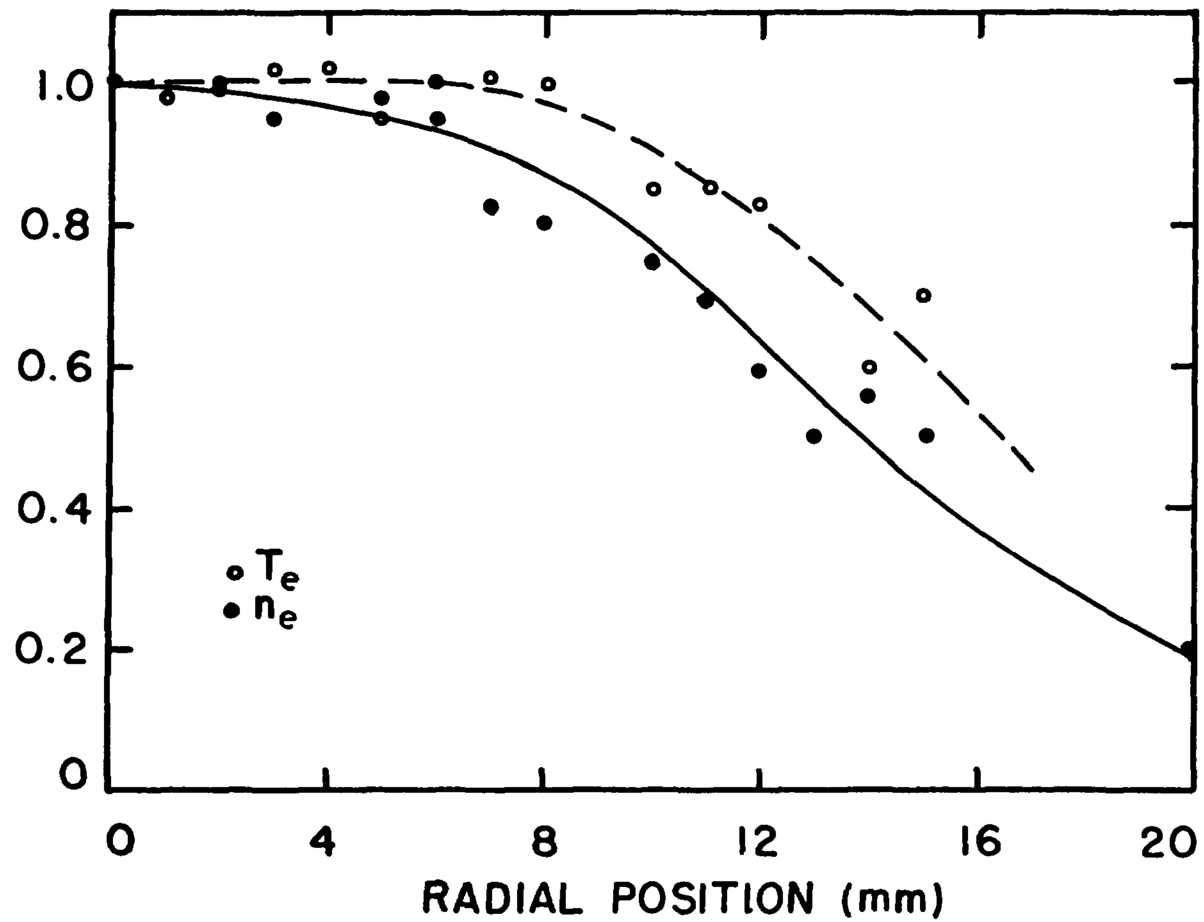
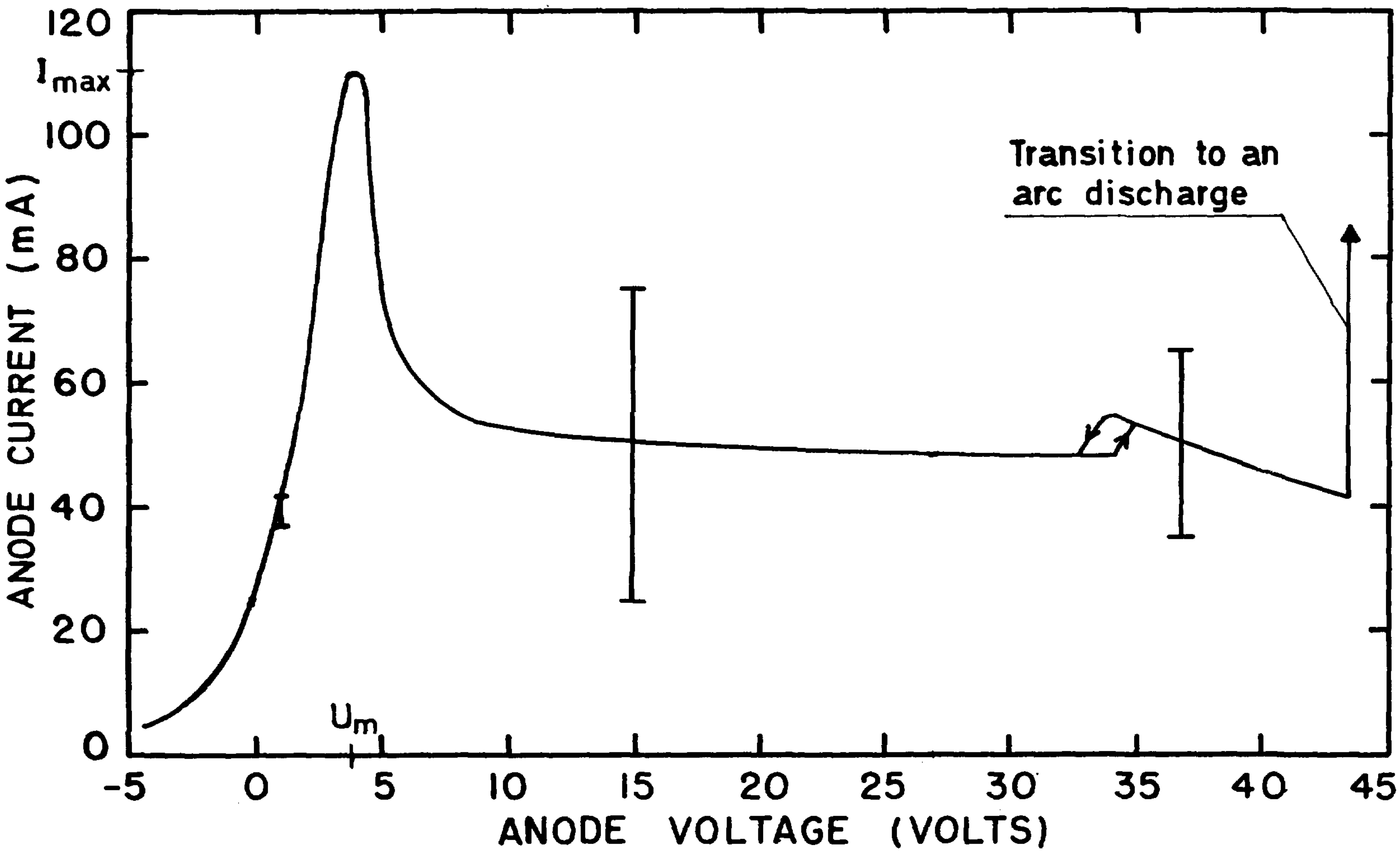
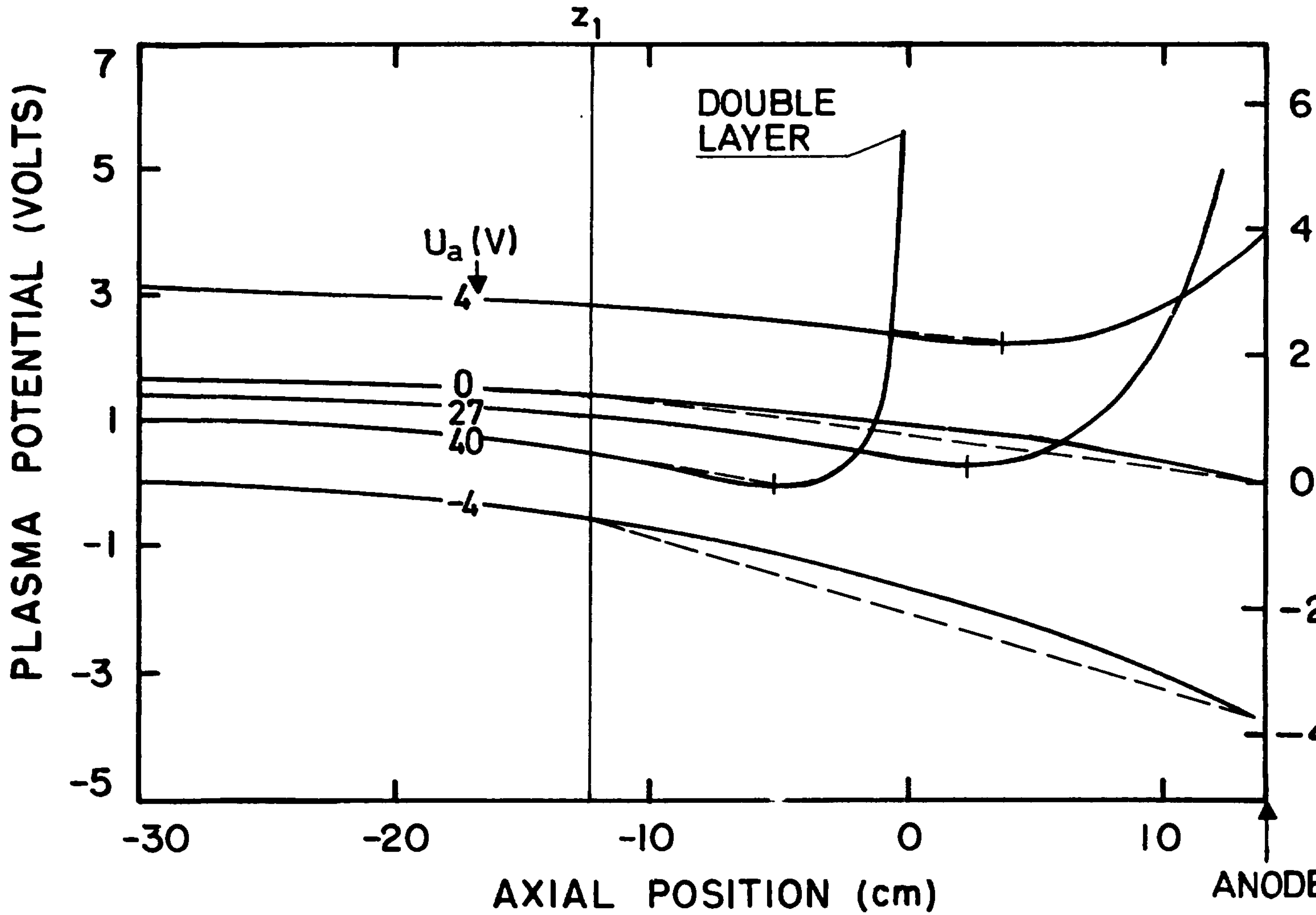


Fig.3b



120
I_{max}
100
80
60
40
20
0
ANODE CURRENT (mA)
Transition to an
arc discharge
U_m
-5
0
5
10
15
20
25
30
35
40
45
ANODE VOLTAGE (VOLTS)

Fig.4a



z1
DOUBLE LAYER
U_a (V)
4
0
27
40
-4
PLASMA POTENTIAL (VOLTS)
7
5
3
1
-1
-3
-5
6
4
2
0
-2
-4
-30
-20
-10
0
10
AXIAL POSITION (cm)
ANODE

Fig. 4b

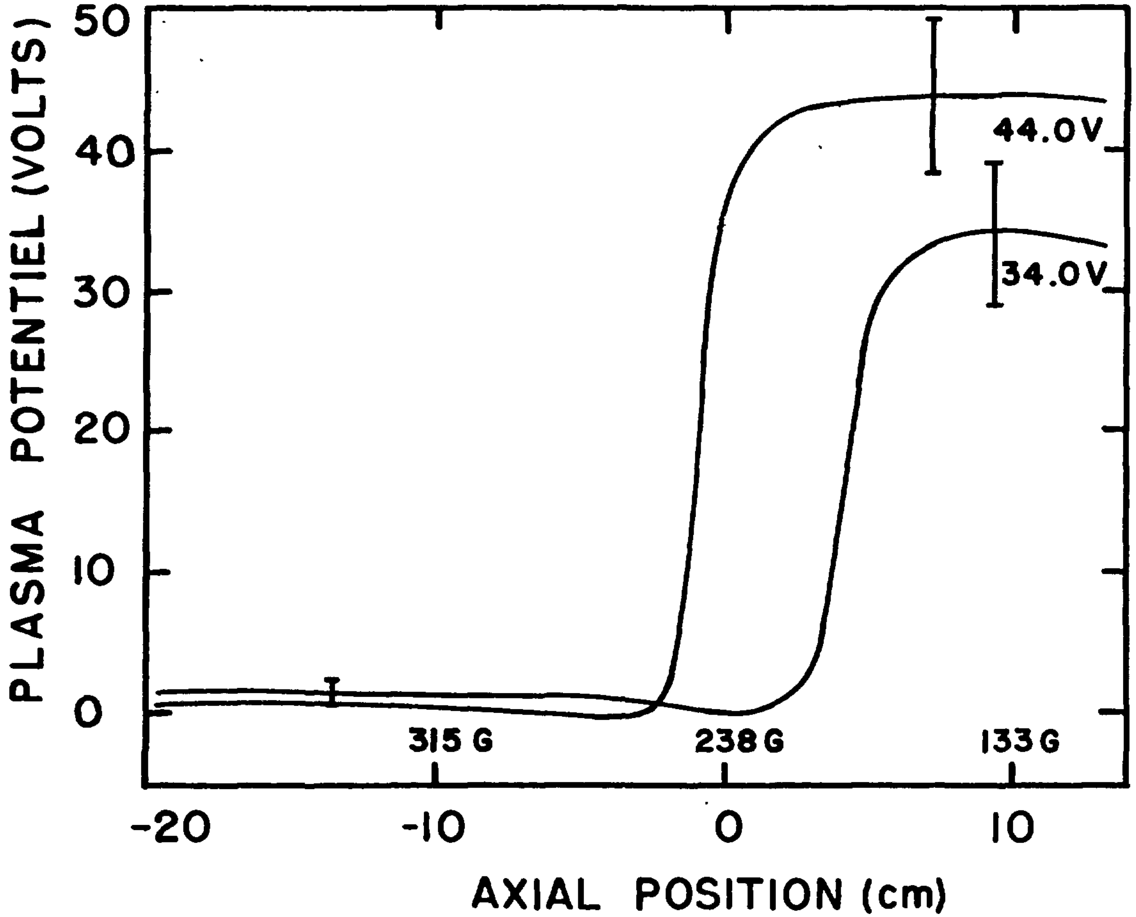
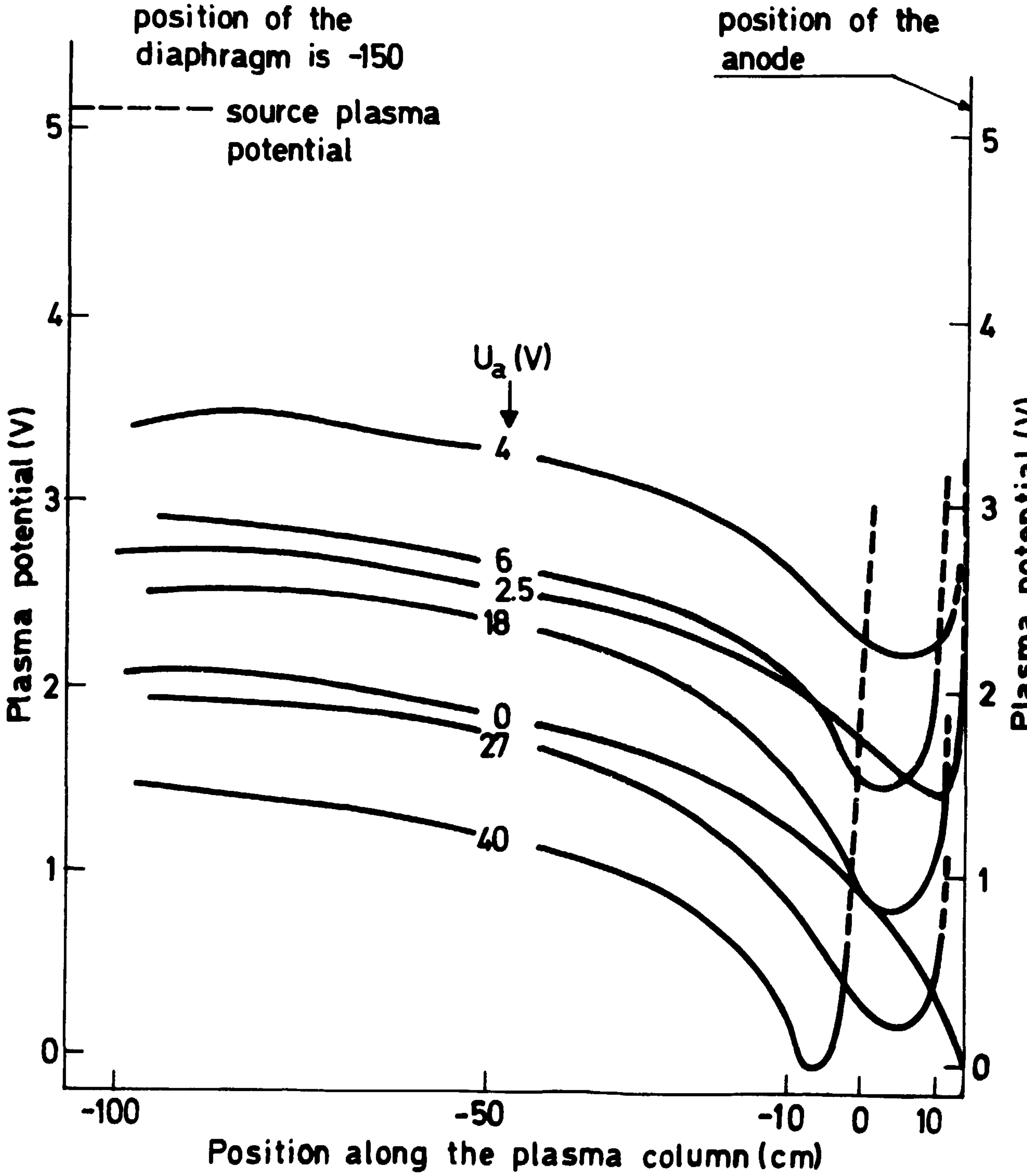

PLASMA POTENTIEL (VOLTS)
50
40
30
20
10
0
44.0V
34.0V
315 G
238 G
133 G
-20
-10
0
10
AXIAL POSITION (cm)

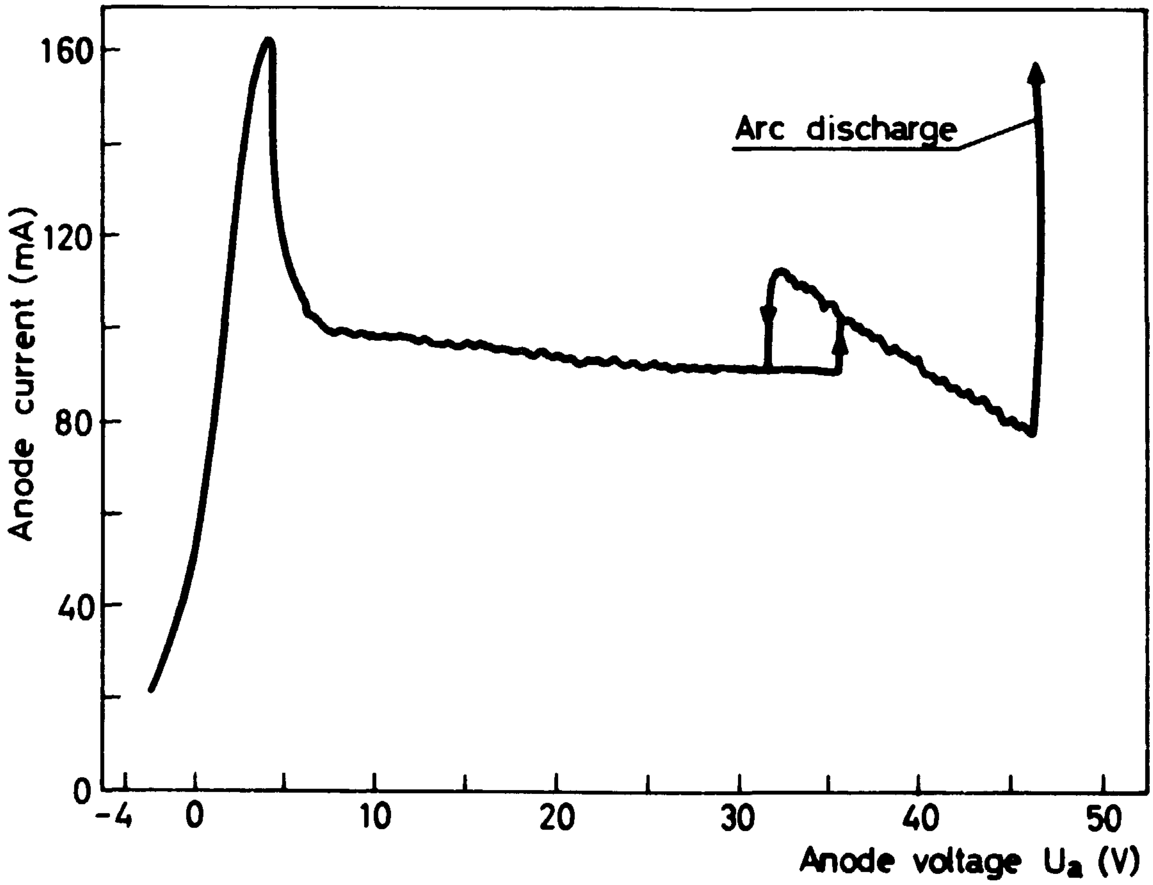
Fig. 5

Fig.6a



position of the diaphragm is -150
position of the anode
source plasma potential
Plasma potential (V)
Plasma potential (V)
U_a (V)
4
6
2.5
18
0
27
40
5
4
3
2
1
0
-100
-50
-10
0
10
Position along the plasma column (cm)

Fig.6b



160
120
80
40
0
Anode current (mA)
Arc discharge
-4
0
10
20
30
40
50
Anode voltage U_a (V)

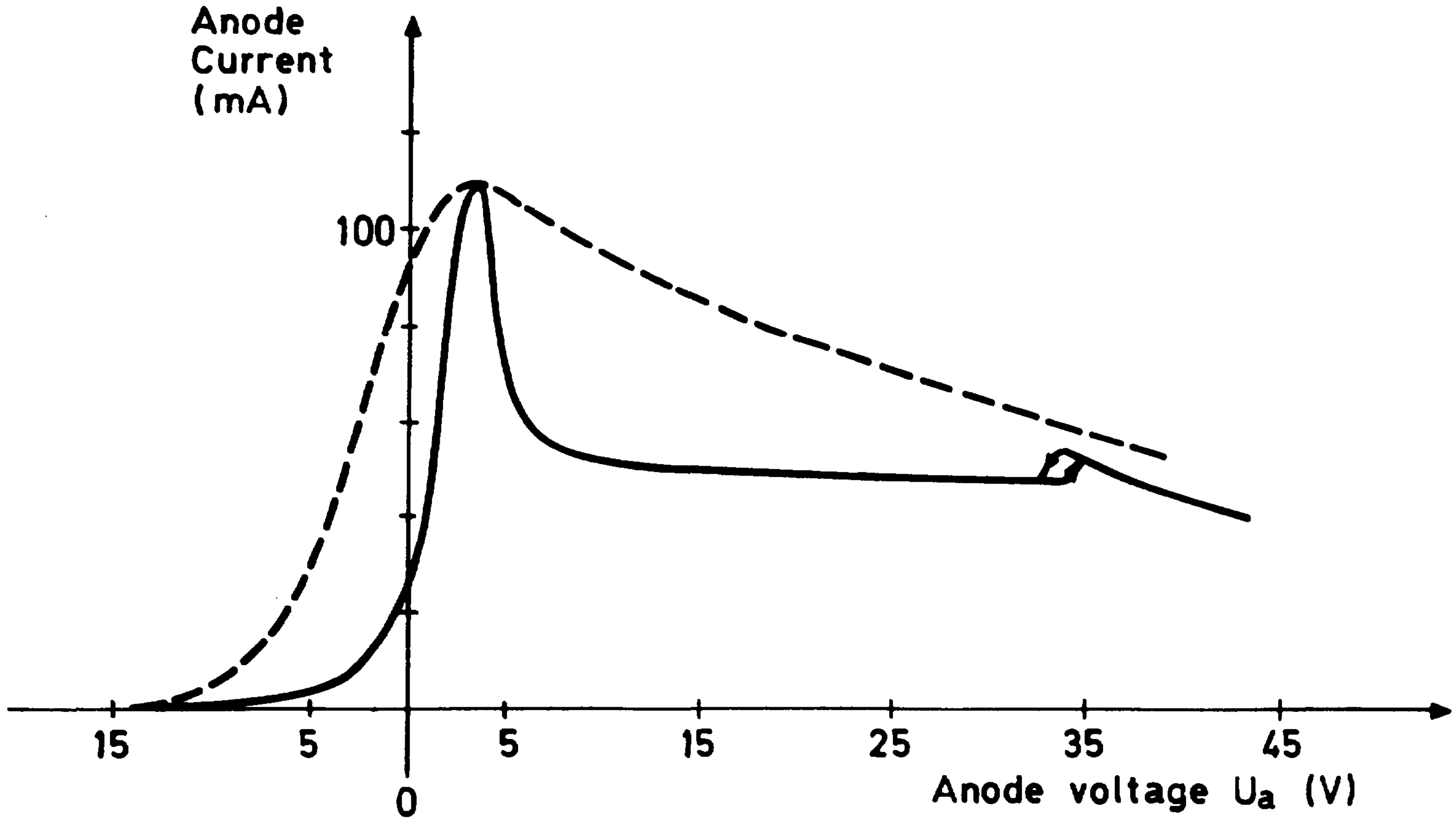


Fig. 7

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CURRENT LIMITATION AND FORMATION OF PLASMA DOUBLE LAYERS IN A NON-UNIFORM MAGNETIC FIELD

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July 1986, 25 pp. incl. ill. in English

Formation of strong double layers has been observed experimentally in a magnetised plasma column maintained by a plasma source. The magnetic field is approximately axially homogeneous except in a region at the anode where the electric current flows into a magnetic mirror. The double layer has a stationary position only in the region of non-uniform magnetic field or at the aperture separating the source and the plasma column. It is characterized by a negative differential resistance in the current-voltage characteristic of the device. The parameter space, where the double layer exists, has been studied as well as the corresponding potential profiles and fluctuation spectra.

The electric current and the axial electric field are oppositely directed between the plasma source and a potential minimum which is formed in the region of inhomogeneous magnetic field. Electron reflection by the resulting potential barrier is found to be an important current limitation mechanism.

Key words: Laboratory plasma, Current limitation, Potential minimum, Double layer, Non-uniform magnetic field, Fluctuations, Azimuthal drift waves.