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MEASUREMENTS OF ELECTRON ENERGY DISTRIBUTION IN AN ARGON POSITIVE COLUMN

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Abstract
The argon positive column plasma of a cold cathode glow discharge is studied using a pulsed single Langmuir Probe technique. It is observed that the energy distribution of the electrons in the positive column is non-Maxwellian at a gas pressure of 0.5 mbar. An increase in the gas pressure seems to make the distribution more Maxwellian.

Introduction

The glow discharge has long been utilised as a convenient plasma source for the investigations of fundamental plasma phenomena. It has also been widely used as a source of intense radiation for pumping gas laser as well as in analytical spectroscopy.

As a prerequisite to the theoretical study of the plasma processes such as excitation and ionization of neutral atoms and ions by electron impact in the glow discharge, it is essential to know the energy distribution of the electrons in the plasma obtained. It is for this reason that until recently, the measurement of the electron energy distribution function (EEDF) of the glow discharge is still the subject of numerous investigations[1,2].

The EEDF of a plasma is commonly determined from the electron retarding region of the single Langmuir probe characteristic as proposed by Druyvesteyn[3]. The EEDF of a plasma expressed in unit of per electron-volt is given by

$$f(eV) = \frac{\sqrt{(8meV)}}{An_e e^2} \frac{d^2 I_e}{dV^2}, \qquad (1)$$

where A is the probe area, m is the electronic mass, n_e is the electron density, e is the electronic charge, V is the probe potential with respect to the plasma and d^2I_e/dV^2 is the second derivative of the retardation region of the probe characteristic.

In this paper, a pulsed Langmuir probe system is used to obtain the probe characteristic of the positive column plasma of a cold cathode glow discharge. The use of a pulsed probe system enables us to obtain the probe characteristic of the plasma quickly so that the effect of fluctuation in the plasma condition can be eliminated.

The Glow Discharge System

The glow discharge studied here is of the cold-cathode type as shown schematically in Fig. 1a. The glass chamber is pumped to a base pressure of $\sim 10^{-4}$ mbar before argon

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gas is filled in to a pressure of several mbar. The cathode is made of stainless steel cylinder of 2 cm bore diameter and is 8 cm long. The anode is a stainless steel disc of 3 cm diameter and is positioned at a distance of 20.5 cm from the cathode. The discharge circuit is shown schematically in Fig. 1b. A 2.5 kV, 300 mA power supply is used to power the discharge. For the present set-up at an argon filling pressure of several mbar, the breakdown voltage is found to be of the order of 1.5 to 2.0 kV. After breakdown, the glow discharge is maintained at a source voltage of 1 kV. The voltage drop across the electrodes of the system when the discharge is on is in the range of (400 ± 30) volts, while the discharge current is of the order of 20 to 70 mA.

It is a well known fact that self-excited potential oscillations exist under certain conditions in an apparently steady glow discharge. Such oscillations may be detected by a Langmuir probe immersed in the plasma and constitute to the noise of the probe signal. This noise signal can be monitored by connecting the probe directly to the input of an oscilloscope. For the purpose of the present work, the glow discharge has been "tuned" so that the noise level is negligibly low compared to that of the probe signal. Such a condition has been obtained in the present system at a gas pressure in the range of 0.5 mbar to 2 mbar and a discharge current of above 50 mA. For discharges at too high or too low pressures, the probe signals are found to be superimposed with high frequency oscillations.

The Pulsed Langmuir Probe System

A schematic diagram of the pulsed single Langmuir probe system used is shown in Fig. 2. The probe, in plane geometry, is made from molybdenum wire with diameter of 0.8 mm. It is biased with respect to the anode and is situated at a distance of 5 cm axially from the anode. The biasing probe potential is varied from −80 volts to −20 volts with respect to the anode. This is done by using a pulse generator comprising a ramp voltage generator[4], which is capable of sweeping from 0 to 60 volts in 6.5 μs, connected in series with an 80 volts battery pack in reverse polarity. The current flowing in the probe circuit is monitored across a 50 ohms resistor.

In Fig. 2, C_s represents the stray capacitance between the probe wire and the anode disc of the discharge system. For a particular probe set-up the value of C_s is fixed and can be determined from the "background" probe signal obtained in the absence of the plasma such as that shown in Fig. 3. The signal monitored across the 50 ohms resistor (V_R) in this case represents the first derivative of the voltage pulse V_o output from the pulse generator. Thus the value of C_s can be calculated from the expression

$$C_s = V_R/50\left(\frac{dV_o}{dt}\right) \qquad (2)$$

For our system, the value of C_s is found to be $(3.4 \pm 0.5) \times 10^{-12}$ F.

In the presence of the glow discharge plasma, the current flowing in the probe circuit is given by

$$I_p = V_R/R - C_s\left(\frac{dV_o}{dt} - \frac{dV_R}{dt}\right), \qquad (3)$$

where R = 50 ohms. The second term on the right hand side of Eq. (3) is the component of the current that is flowing through the stray capacitor C_s. From Eq. (3) above, the probe current I_p as a function of time can be deduced from the oscillogram of $V_R(t)$ while the probe potential $V_p(t)$ can be calculated from $V_p = V_o - V_R$. The single Langmuir probe characteristic can then be deduced by mapping $I_p(t)$ and $V_p(t)$ in time. An example of a set of $V_o(t)$ and $V_R(t)$ oscillograms and the corresponding probe characteristic obtained by this method is illustrated in Fig. 4.

Note that the plateau region in the $V_R(t)$ waveform corresponds to the ion saturation region of the probe characteristic.

Results and Discussions

The discharge corresponding to the probe characteristic in Fig. 4 has been obtained under the following conditions: argon filling pressure P = 0.5 mbar, discharge current I_a = 56 mA and voltage drop across the electrodes V_a = 380V. In order to deduce the electron energy distribution functions of the plasma, the electron current drawn by the probe I_e is obtained by subtracting the ion saturation current from I_p. The plot of $I_e - V_p$, together with its first and second derivatives, are shown in Fig. 5. The plasma potential ϕ_s is determined from the maximum of dI_e/dV_p to be 373.8V.

To deduce the electron energy distribution of the plasma, we need only to consider the region between V_p = 370.6V and the plasma potential. We also note that the potential V in Eq. (1) is given by $(\phi_s - V_p)$ and $d^2I_e/dV^2 \equiv d^2I_e/dV_p{}^2$ since ϕ_s is a constant of the plasma. With reference to Fig. 5 and by using Eq. (1), we then obtain the required EEDF as shown in Fig. 6. The mean energy of the electrons computed from the distribution in Fig. 6 is $\bar{\epsilon}_e$ = 1.6 eV. Comparison of the measured distribution with Maxwellian distribution at kT_e = 1.0 eV ($\epsilon_e = 3\ kT_e/2$) shows that the electron energy distribution of the positive column plasma obtained at a pressure of 0.5 mbar in the argon glow discharge is non-Maxwellian. When the base pressure of the discharge is increased from P = 0.5 mbar to 2 mbar, however, the distribution becomes more Maxwellian as can be seen from Fig. 7. This is possible since at higher gas pressure, the collision cross-section of the electrons is expected to increase.

Since the EEDF of the argon positive column plasma obtained in the present set-up is non-Maxwellian, the usual method[5] of determining the electron temperature from the probe characteristic cannot be applied here. In this case, T_e is obtained from the mean electron energy, $\bar{\epsilon}_e$ by the relation

$$\bar{\epsilon}_e = \frac{3}{2}kT_e \qquad (4)$$

For the argon glow discharge at P = 0.5 mbar, we obtain $T_e \simeq$ 1 eV while for similar discharge at P = 2 mbar, $T_e \simeq$ 1.7 eV.

Conclusion

From the pulsed Langmuir probe study of an argon glow discharge, it is found that the electron energy distribution of the positive column is non-Maxwellian. This suggests that the determination of the electron temperature from the electron retardation region of the probe characteristic is incorrect, since the classical probe theory is not applicable for a non-Maxwellian plasma. For a proper implementation of the Langmuir probe technique, particularly the single probe, it is a good practice to obtain first the electron energy distribution of the plasma concerned to confirm the validity of classical probe theory.

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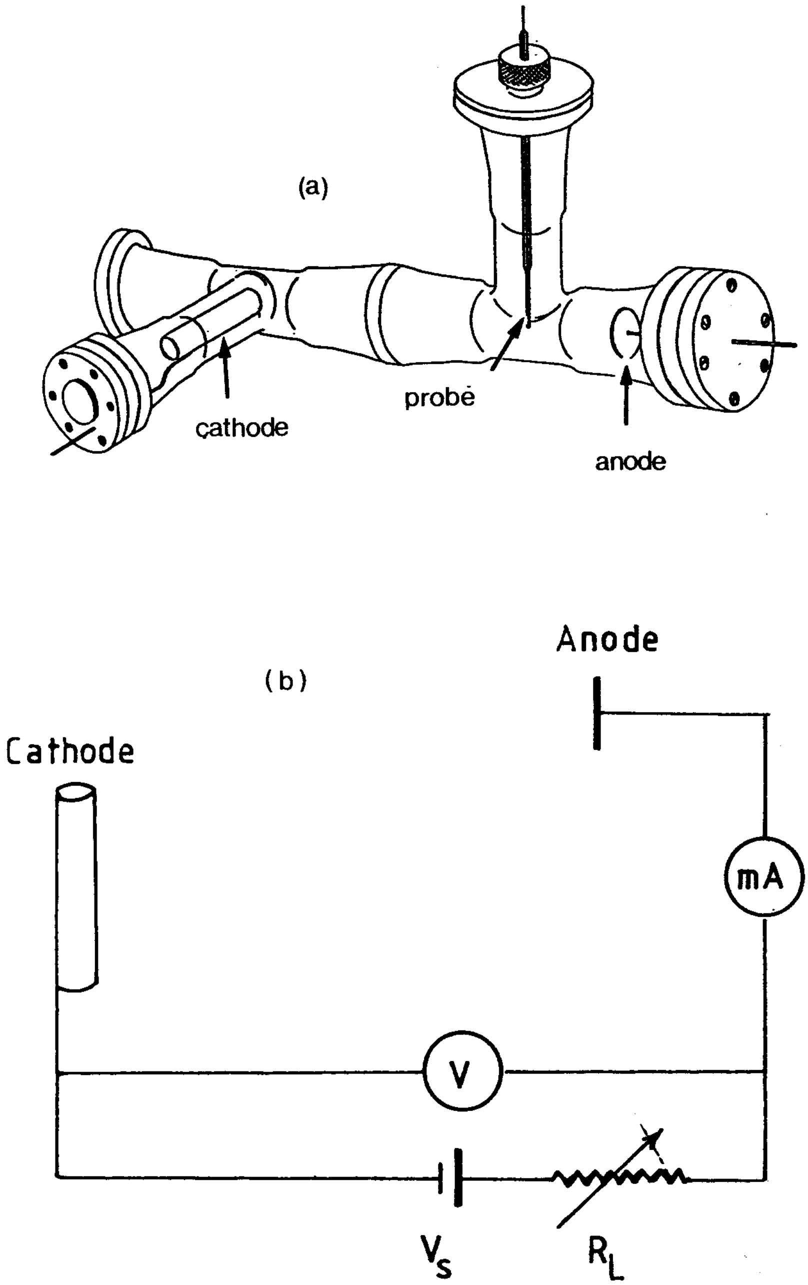


Fig. 1 (a) The cold cathode glow discharge tube.
(b) Schematic of the glow discharge circuit.

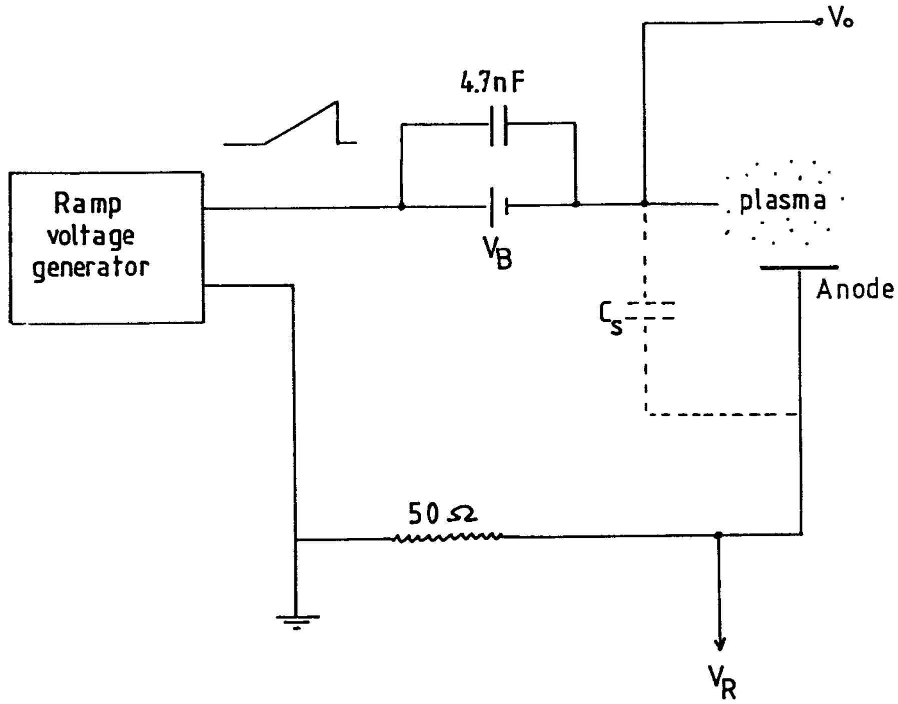


Fig. 2 Schematic diagram of the pulsed single Langmuir probe circuit.

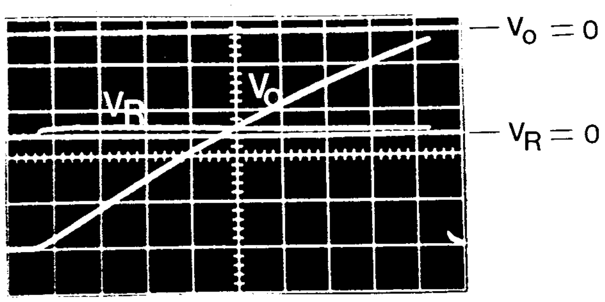
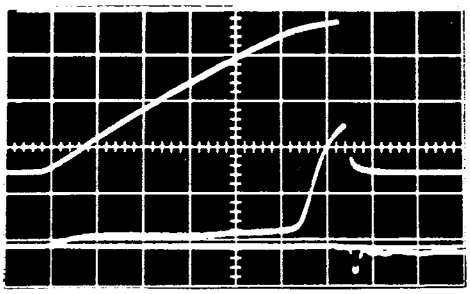


Fig. 3 Oscillograms of the probe sweeping voltage $V_0(t)$ and the voltage across the 50Ω resistor $V_R(t)$ obtained without plasma.

(a)



(b)

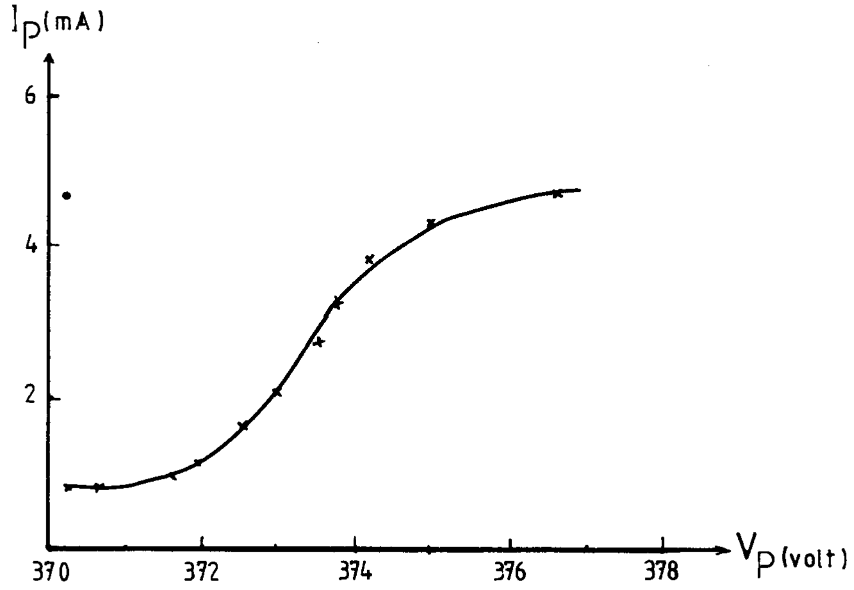


Fig. 4 (a) Oscillograms of $V_0(t)$ and $V_R(t)$ obtained for a discharge at P = 0.5 mbar and discharge current I_a = 56 mA.
(b) Probe characteristic deduced from the oscillograms in (a).

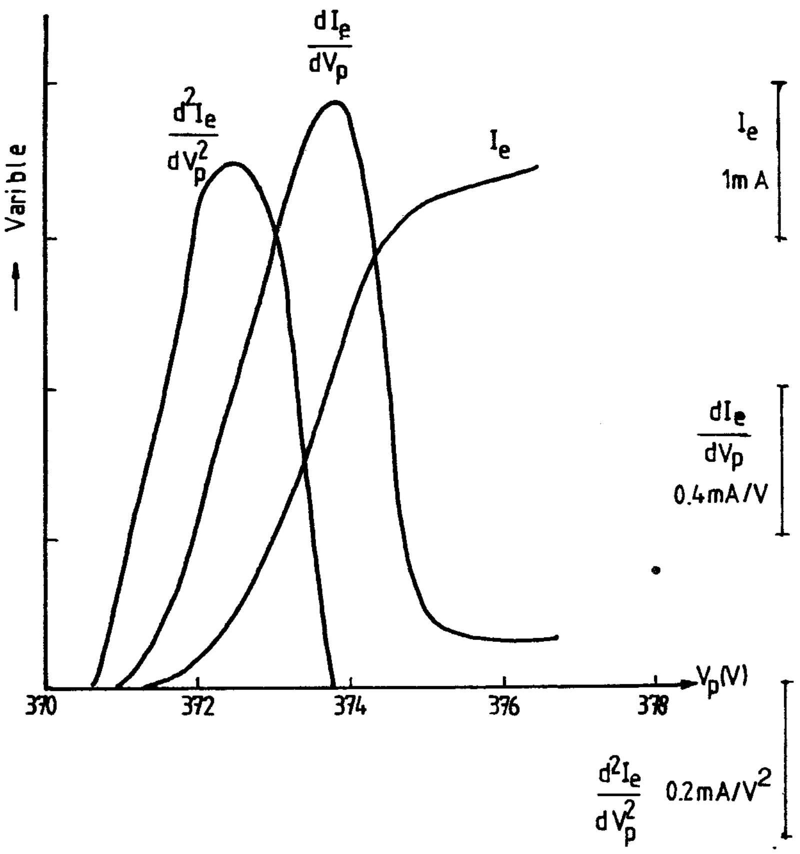


Fig. 5 Graphs of I_e, dI_e/dV_p and d^2I_e/dV_p^2 as functions of V_p deduced from Fig. 4.

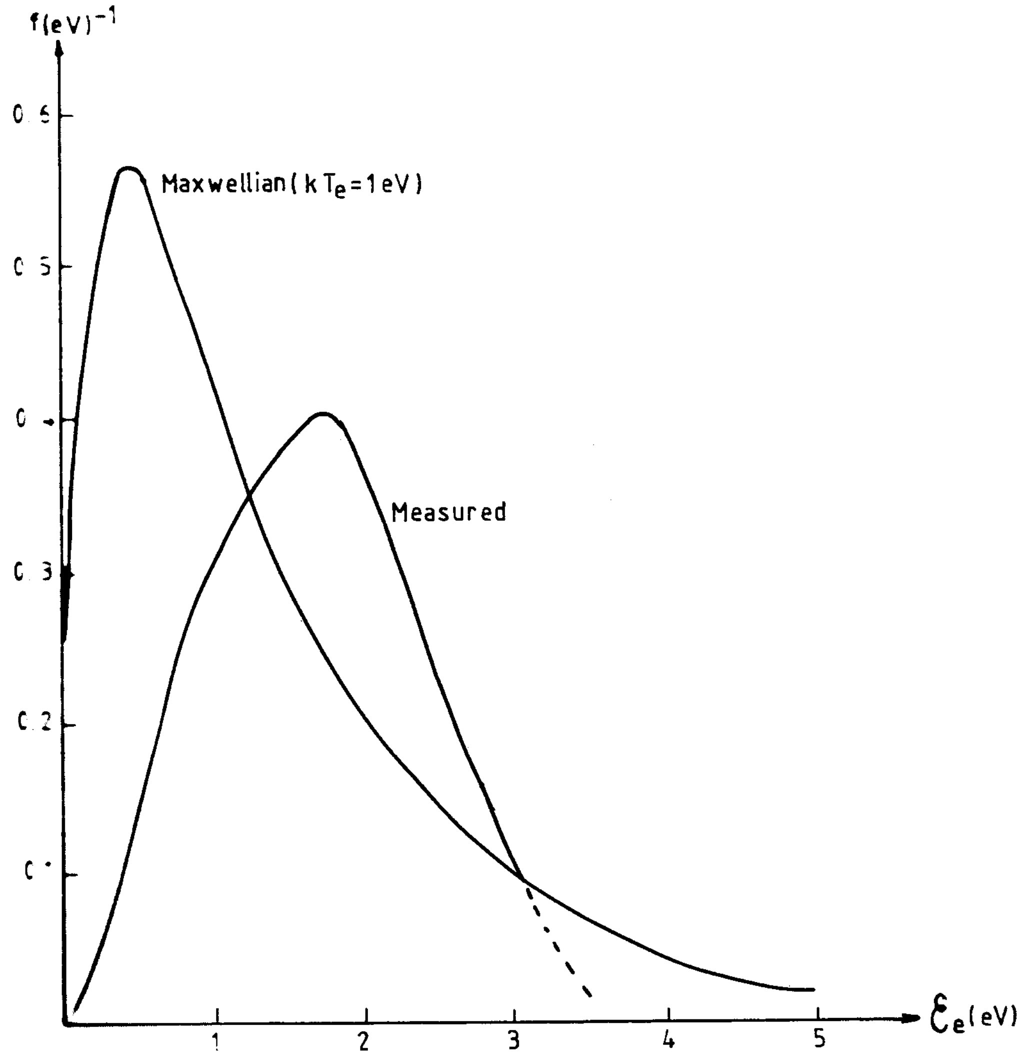


Fig. 6 The electron energy distribution for the discharge of Fig. 4. The correspond-ing Maxwell distribution at kT_e = 1.0 eV is also shown for comparison.

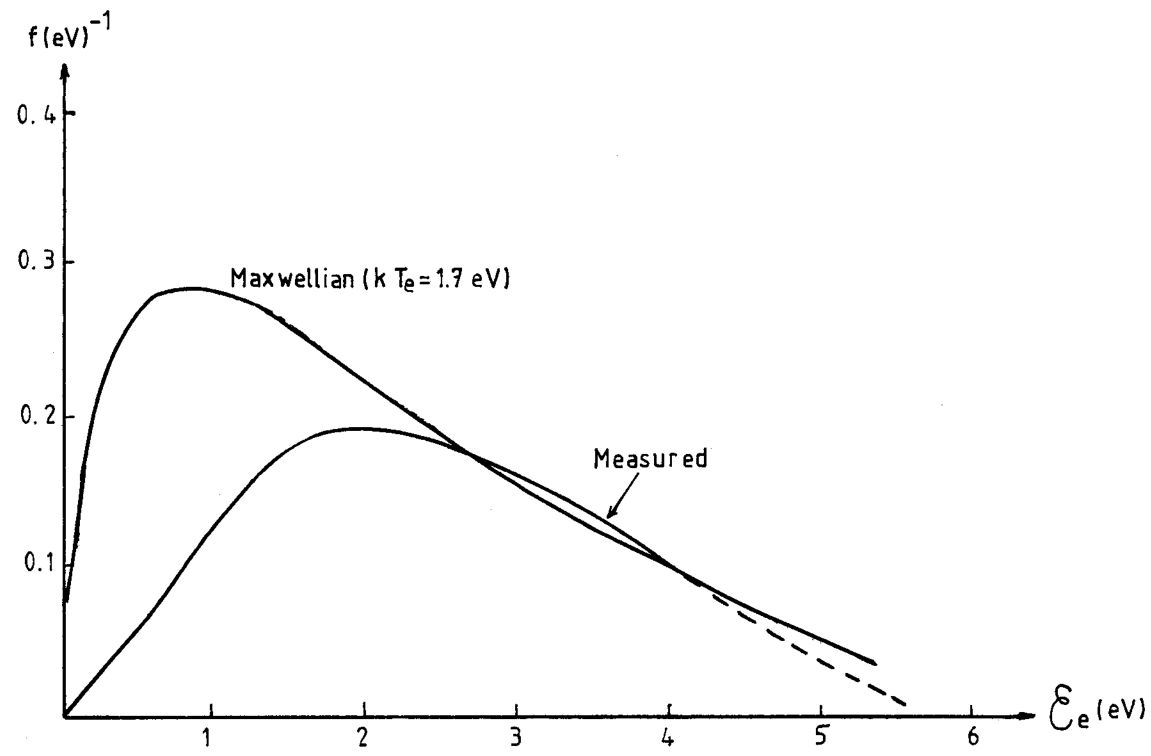


Fig. 7 The electron energy distribution for a discharge at P = 2 mbar and I_a = 56 mA. The corresponding Maxwell distribution is also shown.