

THE ELECTRON ENERGY DISTRIBUTION IN NONSTATIONARY PLASMA COLUMN

N. M. EL NAGAR, A. S. GABRE and A. H. TURKEY

Physics Department, Assiut University, Egypt

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Abstract: The random and drift motion of electrons in nonstationary plasma obtained in a shock tube is studied using Boltzmann's relation and single Langmuir-Mott-Smith probe theory.

The electron energy distribution is proved to be Maxwellian in the framework of the runaway theory.

The electron temperature and electron density are calculated for argon and nitrogen as driver gasses in shock tube. The results of the present work are in good agreement with experimental data.

1. Introduction

Several attempts have been made to study the energy distribution of electrons in the plasma column of self maintained gas discharge where Boltzmann's relation and single Langmuir-Mott-Smith^{1,2,3)} probe theory are used. The results indicate that the electron energy distribution is Maxwellian.

Fucks and Theenhaus⁴⁾ studied the electron energy distribution of moving plasma generated in shock tube. They suggested that Langmuir probes could be used in nonstationary plasma to determine the electron temperature and density.

An attempt has been made in reference⁵⁾ to study the characteristics of plasma column produced in a pressure driven shock tube having ring cathode and rod anode using argon and nitrogen gas initially at a pressure of one Torr. The author suggested that the electron energy distribution is Maxwellian.

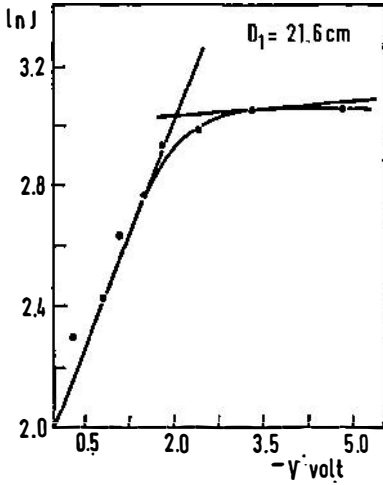


Fig. 1. Current-Voltage probe curve at distance $D_1 = 21.6$ cm, as the probe potential is negative.

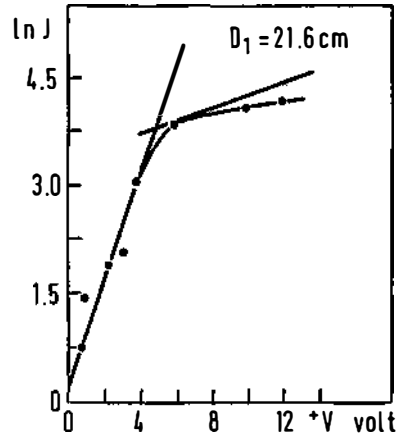


Fig. 2. Current-Voltage probe curve at distance $D_1 = 21.6$ cm, as the probe potential is positive.

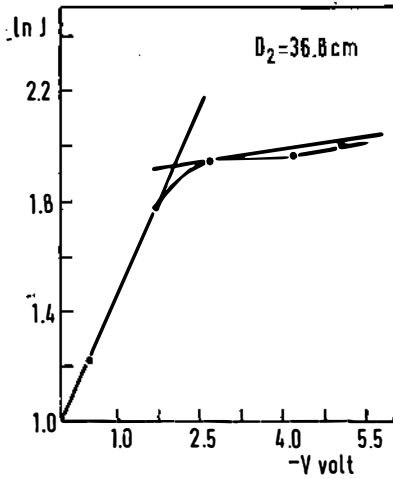


Fig. 3. Current-Voltage probe curve at distance $D_2 = 36.8$ cm, as the probe potential is negative.

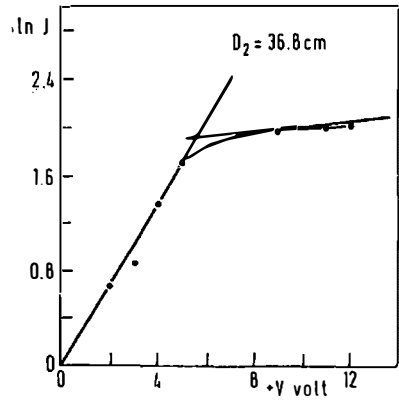


Fig. 4. Current-Voltage probe curve at distance $D_2 = 36.8$ cm, as the probe potential is positive.

Table 1

Probe position $D_1 = 21.6$ cm	Slope	T_e (Theor.) K	T_e (Exp.) K
Probe potential is positive	0.7	$1.65 \cdot 10^4$	$1.624 \cdot 10^4$
Probe potential is negative	0.6	$1.66 \cdot 10^4$	$1.624 \cdot 10^4$
T_e average		$1.655 \cdot 10^4$	$1.624 \cdot 10^4$

Table 2

Probe position $D_2 = 36.8$ cm	Slope	T_e (Theor.) K	T_e (exp.) K
Probe potential is positive	0.52	$2.29 \cdot 10^4$	$2.32 \cdot 10^4$
Probe potential is negative	0.45	$2.39 \cdot 10^4$	$2.32 \cdot 10^4$
T_e average		$2.34 \cdot 10^4$	$2.32 \cdot 10^4$

The aim of the present work is to determine the temperature and concentration of electrons in plasma column obtained in shock tube, to search for a satisfactory explanation of the energy distribution of electrons in moving plasma, and to find to what extent one can use the runaway theory in the study of moving plasma.

2. Results and discussion

Electron temperature in shock tube. To determine the temperature of electrons in plasma column produced in the same pressure driven shock tube as used in Ref. ⁶⁾, we use Langmuir-Mott-Smith single probe theory. The logarithm of the electron current j_e to the probe is a linear function of the probe voltage to the plasma (V). Boltzmann's equation relates the electron current density (j_{es}) to the random electron current density of the plasma (j_{ep})

$$j_{es} = j_{ep} e^{-eV/kT_e}, \quad (1)$$

where k is Boltzmann constant and e the electron charge. Taking the natural logarithm of each side of equation (1)

$$\ln j_{es} = \ln j_{ep} - eV/kT_e. \quad (2)$$

If the electron energy distribution in moving plasma obeys Maxwell law, the plot of $\ln j_{es}$ against V starts as a straight line of slope e/kT_e , and abruptly becomes horizontal when the probe potential reaches the plasma potential. The absolute temperature T_e can be determined from the slope of the straight line portion. The results obtained are plotted in Figs. 1—4, and the data are recorded in Table (1, 2). T_e is $1.65 \cdot 10^4$ K and $2.34 \cdot 10^4$ K at probe distance 21.6 cm and 36.8 cm from anode, respectively.

The electron density in shock tube. The electron density is calculated using the equation

$$j_p = e n_e \sqrt{\frac{k T_e}{2\pi m_e}}$$

where j_p is the probe current density. It is obtained at the end of the straight line portion of the current voltage curve of Langmuir probe where the electrons in the nonstationary plasma column have a Maxwellian velocity distribution. Our results are compared in Tables (3, 4) with the experimental data previously obtained in Ref. 5).

Table 3

Probe position $D_1 = 21.6$ cm	I_p mA	j_p mA/cm ²	T_e (Theor.) K	n_e (Theor.) cm ⁻³	n_e (Exp.) cm ⁻³
Probe potential is positive	14.9	256.9	$1.65 \cdot 10^4$	$6.2 \cdot 10^{12}$	$6.1 \cdot 10^{12}$
Probe potential is negative	17.7	305.17	$1.66 \cdot 10^4$	$5.99 \cdot 10^{12}$	$6.1 \cdot 10^{12}$

Table 4

Probe position $D_2 = 36.8$ cm	I_p mA	j_p mA/cm ²	T_e (Theor.) K	n_e (Theor.) cm ⁻³	n_e (Exp.) cm ⁻³
Probe potential is positive	6.9	118.97	$2.29 \cdot 10^4$	$2.15 \cdot 10^{12}$	$2.2 \cdot 10^{12}$
Probe potential is negative	7	120.69	$2.39 \cdot 10^4$	$2.18 \cdot 10^{12}$	$2.2 \cdot 10^{12}$

The runaway theory. Results of Langmuir-Mott-Smith probe theory show that the electron energy distribution is Maxwellian. It appears to be risky to assume that a Maxwell distribution for velocities exists in moving plasma such that created in shock tube, but H. Dreicer⁶⁾ gave a satisfactory explanation when he studied the problem of runaway electrons in a plasma. One assumes with Dreicer that the mutual electron interactions maintain a Maxwellian velocity displaced in velocity space. The effect of the drag force is similar to that of a fictitious electric field E_v ,

$$E_v = C \Psi_{(z)}, \tag{3}$$

where

$$\Psi_{(z)} = \frac{\varepsilon_{(z)} - z(d\varepsilon/dz)}{z^2}.$$

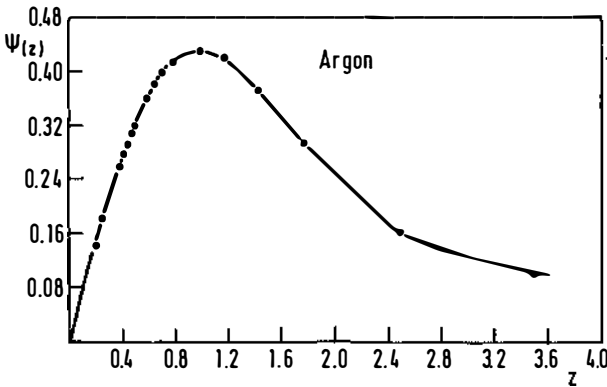


Fig. 5. Variation of the dynamical friction $\Psi_{(z)}$, with z ; the ratio of relative drift velocity to the electron thermal velocity, for argon gas.

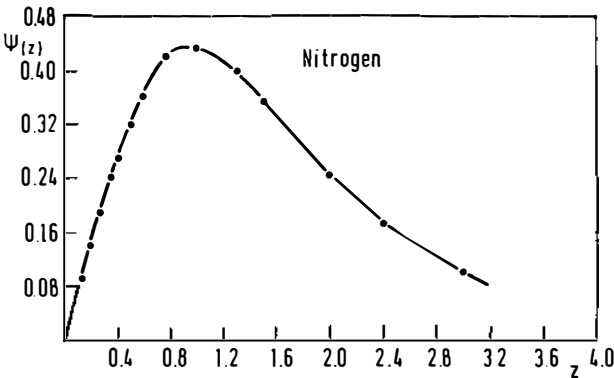


Fig. 6. Variation of the dynamical friction $\Psi_{(z)}$, with z ; the ratio of relative drift velocity to the electron thermal velocity, for nitrogen gas.

$\Psi_{(z)}$ is called the dynamical friction function, z is the ratio of the electron drift velocity to the most probable thermal velocity of the electrons $\sqrt{2k T_e/m_e}$. $\Psi_{(1)}$ is the dynamical friction function for $z = 1$, i. e. the drift velocity is equal to the thermal velocity, which causes the whole Maxwell distribution to shift in velocity space in the direction of applied electric field. This process of detachment in an electric field occurs because of the sudden change of the electric field, and because of the sudden transition between the driver section and the expansion section of the shock tube. The change in the electric field must balance the dynamical friction function or velocity dependent drag force caused by collision between electrons and ions.

To verify the values of drift velocities previously measured experimentally, which are $7 \cdot 10^4$ and $12 \cdot 10^4$ cm/sec, for argon and nitrogen gases respectively, one assumes different values of thermal velocities for each gas separately and calculates z , ε_z , $d\varepsilon/dz$. The results obtained are shown in Figs. 5 and 6. The curves indicate that the variation of $\Psi_{(z)}$ with z greatly resembles the previously obtained by Dreicer. This proves that the runaway theory can be verified in moving plasma obtained in shock tube.

References

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