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Abstract

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RADIAL DISTRIBUTION OF THE PLASMA OF A POSITIVE COLUMN IN A MAGNETIC FIELD

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The positive column of a gas discharge, when a longitudinal magnetic field is applied with a strength exceeding a certain critical value H_c, becomes unstable (^{1,2}). In a strong magnetic field, when the strength $H \gg H_c$, the motion of the plasma has a turbulent-convective character. A semiquantitative treatment of such a turbulent column was carried out in the work of B. B. Kadomtsev (^{3}). In it assumptions are made which do not follow from a rigorous theory and which require experimental verification.

In the present work the distribution $n(r)$ of the plasma concentration over the radius is investigated. The profile of such a distribution, calculated under the assumption of a constant mixing length, differs substantially from the profile of the laminar state (^{3}).

The measurements were carried out in a glass tube 150 cm long with an internal diameter of 55 mm. Its middle section, 80 cm long, was in a magnetic field with strength H up to 1500 oersted. The thermocathode was located at a distance of 50 cm from the edge of the solenoid. In the tube there was a spherical platinum probe (diameter 1.35 mm), which moved along the cross section of the tube, and two cylindrical probes at a distance of 45 cm from one another for measuring the longitudinal electric field $E_\parallel$. The movable probe was located at a distance of 42 cm from the end of the solenoid and in all measurements was in the homogeneous part of the column, which was checked visually. The measurements were carried out in helium at a current of 0.5 A.

The plasma density was found from the ion branches of the probe characteristics ($^{4-6}$). The scatter of the concentration values found at different negative probe potentials in each case did not exceed 5%. More significant was the error associated with the inaccuracy in determining the position of the probe relative to the concentration maximum, which could deviate from the tube axis by 1-2 mm.

Figure 1 shows the dependence of $E_\parallel$ on H for $p = 2 \cdot 10^{-2}$ mm Hg. In this case, at $H = 8H_c$, $(\Omega\tau)_i = 5 \div 6$, and the turbulent convection of the plasma to the walls exceeds ordinary ambipolar diffusion by approximately 3 orders of

Fig. 1

Figure 1: Fig. 1

magnitude. The distribution $n(r)$ for this regime is shown in Fig. 2 by points. The theoretical curve of Kadomtsev is also given there.

In (^{3}) the simplest boundary condition at the tube walls was adopted: $n_w = 0$. In reality, near the walls n_w is of the order of the pulsation of the concentration n'. The condition of conservation of the diffusion flux at the walls (in the notation of (^{3})) is:

$$nU = Ul^2 \frac{1}{n}\left(\frac{dn}{dr}\right)^2 \quad \text{or} \quad \frac{1}{l} = \left(\frac{1}{n}\frac{dn}{dr}\right)_w . \tag{1}$$

At $l = 0.15a$ (where a is the tube radius), it follows from the form of the theoretical curve and from (1) that n must go to zero at the extrapolated value of the radius $R = 1.3a$. As can be seen from Fig. 2, the curve drawn with allowance for the indicated extrapolation agrees well with the experimental points.

Under conditions of anisotropy of the electron motion, the form of the curve $n(r)$ is substantially affected by the magnetic focusing of the discharge near the cathode end of the solenoid. The greater the ratio of the longitudinal velocity to the transverse velocity, the farther from the end the column becomes uniform along its length. In our case, when turbulent transport to the walls is comparable with ambipolar diffusion in the absence of a magnetic field, this distance did not exceed 3-4 tube diameters. To prove that end effects do not influence the obtained distribution $n(r)$, the measurements were repeated on a tube in which the cathode part outside the solenoid had a diameter of 95 mm. Although the visible cross section of the plasma cord at the edge of the solenoid then became twice as large ($\simeq 2$ cm), the form of $n(r)$ did not change substantially (see Fig. 2).

Fig. 1. Dependence of the longitudinal electric field E on H. 1 –for $ap = 5.5 \cdot 10^{-2}$ cm $\cdot$ mm Hg; 2 –for $ap = 5.5 \cdot 10^{-1}$ cm $\cdot$ mm Hg.

Contraction of the discharge can occur in the presence of volume recombination, if T_e falls from the axis toward the walls (7). In our case this cause plays no role, since at $n_e \simeq 10^{10}$ cm^{-3} and a high rate of plasma loss to the walls, recombination in the volume may be neglected. Strong turbulent mixing should promote equalization of T_e over the cross section; moreover, the radial field, in contrast to the discharge at $H = 0$, accelerates electrons toward the walls. This is seen from Fig. 3, which shows the change in the "floating" potential of the probe when it is moved along the radius.

Fig. 2. Radial distribution of the concentration $n(r)$ at $ap = 5.5 \cdot 10^{-2}$ cm $\cdot$ mm Hg. 1 –at $H = 1500$ Oe (open circles –values obtained on the tube with a thickened cathode end); 2 –at $H = 0$.

Fig. 2

Figure 2: Fig. 2

Fig. 3

Figure 3: Fig. 3

Fig. 3. “Floating” potential of the probe as a function of distance from the tube axis at $ap = 5.5 \cdot 10^{-2}$ cm $\cdot$ mm Hg. 1 —at $H = 0$; 2 —at $H = 1500$ Oe.

Fig. 4. Radial distribution of the concentration at $ap = 5.5 \cdot 10^{-1}$ cm $\cdot$ mm Hg. 1 —at $H = 1500$ Oe; 2 —at $H = 400$ Oe; 3 —at $H = 500$ Oe.

The distribution $n(r)$ was also measured at different magnetic-field strengths and a pressure of $2 \cdot 10^{-1}$ mm Hg. The dependence $E_{\|}(H)$ for such a pressure is shown in Fig. 1. The curves of Fig. 1 agree well with the calculated values of $E_{\|}$ and of the critical magnetic field (3, 8).

In Fig. 4, $n(r)$ is shown near H_c and at $H \simeq 3H_c$. All the curves are close to a Bessel function of zero order—the theoretical curve for classical diffusion in a homogeneous positive column. Meanwhile, at $H \simeq 3H_c$ the motion of electrons already occurs due to turbulent convection, and $E_{\|}$ is close to saturation. Apparently, in this case the plasma distribution is determined by the ions, which are still only weakly magnetized: $(\Omega\tau)_i = 0.5$.

Thus, under conditions in which the influence of end effects at the solenoid ends is excluded, the experiment confirms the theoretical dependences of $n(r)$ for both turbulent and classical diffusion.

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REFERENCES

1. B. Lehnert, Report P/146 on the 2-nd Intern. Conf. on the Peaceful Uses of the Atomic Energy, Geneva, 1958.
2. B. B. Kadomtsev, A. V. Nedospasov, J. Nucl. Energy, C, 1, 230 (1960).

Fig. 4

Figure 4: Fig. 4

3. B. B. Kadomtsev, ZhTF, 31, 1273 (1961).
4. V. L. Granovskii, *Electric Current in Gas*, 1952.
5. Yu. M. Gakan, V. I. Perel' , DAN, 91, 1321 (1953); 95, 765 (1954); ZhETF, 29, 261 (1955).
6. A. Guthrie, R. Wakerling, *The Characteristics of Electrical Discharge in Magnetic Field*, N. Y., 1949.
7. I. A. Vasil' eva, *Radio Engineering and Electronics*, 5, 2015 (1960).
8. V. L. Vdovin, A. V. Nedospasov, ZhTF, 32, 817 (1962).

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