ON THE DIFFUSION OF ELECTRONS IN A MAGNETIC FIELD

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The experimental data concerning the anomalously large mobility of electrons across a magnetic field is discussed. It is shown that the distribution of the concentration of the secondary plasma of a discharge with an incandescent cathode is practically independent of the electron transverse diffusion coefficient, and therefore cannot be used to explain the mechanism of diffusion. An estimation is made of the electron diffusion coefficient from the value of the electron current density at the anode, which confirms the presence of an anomalously large transverse mobility.

As a result of the study of experimental data on a discharge with an incandescent cathode in a strong longitudinal magnetic field, D. Bohm [1] suggested the hypothesis that under the conditions of such a discharge, a new, uninvestigated mechanism for the transverse movement of the electrons is considerably more effective than the diffusion by collision.

In particular, one of the arguments in favor of the anomalously large transverse mobility of electrons is the result of the analysis of probe characteristics. Assuming that the diffusion of electrons takes place by collision, Bohm obtained for the ratio of the electron to ion current in the probe $I_e/I_i$ the value 4-5, while the $I_e/I_i$ ratio measured under the corresponding conditions attained 20-35. Although Bohm's calculations do not lay claim to great accuracy, nevertheless, it is not very likely that they can give a reduced value of $I_e/I_i$, and therefore, they should not be considered.

Another experimental fact which Bohm used as evidence of the anomalously large transverse mobility of electrons is that the decrease in the concentration of the plasma with the distance from the beam of primary electrons takes place more slowly than expected. An approximate theoretical analysis of the distribution of the secondary plasma concentration (outside the primary electron beam) has been carried out in the two-dimensional case. Using conditions of quasi-neutrality treating the transverse motion of electrons and ions as a diffusion process, and neglecting the ionization in the secondary plasma, Bohm obtained the following expression for the characteristic length $x_0$ on which the concentration decreases $e$ times as one moves away from the primary beam

$$x_0 = \sqrt{\frac{(T_e+T_i)L}{\beta T_e + \gamma T_i}}$$

where $T_e$ and $T_i$ are the temperatures of the ions and electrons in units of potential; $D_e$ and $D_i$ are the ion and electron transverse diffusion coefficients. The coefficients $\beta$ and $\gamma$ relate the ion current density at the anode $j_a^i$ and the electron current density at the anode $j_a^e$ to the plasma concentration $n$:

$$j_a^i = \beta n; \quad j_a^e = \gamma n.$$  \hspace{1cm} (2)

Bohm obtained, in place of (1), the expression

$$x_0 \approx \sqrt{\left(1 + \frac{T_e}{T_i}\right) \frac{DP}{\gamma}}$$

Therefore, according to (4), the measurement of $x_0$ allows one to estimate the electron transverse mobility coefficient. Comparing the measured value of $x_0$ with the value calculated from (4) and assuming that ordinary diffusion takes place, Bohm discovered a lack of agreement between theory and experiment. It turned out that the electron diffusion coefficient calculated from (4) exceeds the collision diffusion coefficient by two orders of magnitude.

In his work A. Simon [2, 3] obtained an expression for $x_0$ substantially different from (4)

$$x_0 \approx \frac{L}{\pi} \sqrt{\frac{D_e}{D_{as}}},$$

where $L$ is the length of the primary electron beam.
where \( D_{\text{am}} \) is the longitudinal ambipolar diffusion coefficient.

Comparing the measured value of \( x_0 \) to that calculated from (5), Simon found satisfactory agreement. It turned out, also, that as the magnetic field intensity increased, \( x_0 \) decreased proportionally to \( 1/H \). On this basis, Simon believed that in the experiments he was considering, the diffusion of both the ions and the electrons took place in accordance with the well-known ideas, and that it was not necessary to assume the existence of an anomalously large electron transverse mobility as Bohm had done.

Simon, however, ignored the results of the above-mentioned probe measurements. Moreover, one can hardly, in general, determine the electron diffusion coefficient on the basis of a measurement of the characteristic length \( x_0 \) under conditions of a discharge of the type which Simon and Bohm had in mind.

The purpose of the present article is to show that under certain conditions the distribution of the secondary plasma concentration does not depend on the value of the electron diffusion coefficient, but is determined mainly by the picture of the ion motion. Owing to this, it may be supposed that Bohm and Simon were in error when they took the data on the plasma concentration distribution to explain the mechanism of the transverse diffusion of electrons.

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\varphi = T \ln \frac{v_-}{v_+}
\]

(6) should hold, where \( \varphi \) is the potential of the plasma with respect to the anode; \( v_- \) and \( v_+ \) are the mean longitudinal velocities of the electrons and ions (6) is a consequence of the equality of the currents at the anode; \( j_- = j_+ \). At the same time, for the transverse diffusion to be ambipolar, the potential \( \varphi \), as one moves away from the primary beam, should increase to a value of the order of \( T_+ \), which is incompatible with (6) for an equipotential anode, since the temperature of the electrons \( T_+ \) in a strong magnetic field should decrease comparatively rapidly outside the primary beam, owing to the cooling of the electron gas.

For experimental evidence of the assumption one may use the results of the measurement of the currents going to the anode in the secondary plasma as obtained by the author and shown in Figs. 2 and 3. These figures show the current distribution on the anode surface, measured by means of a probe in the shape of a disk 1 mm in diameter, which was placed in the plane of the anode and moved perpendicularly to the magnetic field. The primary current had a diameter of 5 mm.

![Diagram of discharge chamber](image)

**Fig. 1.** Diagram of discharge chamber.
- K) cathode; A) anode; P) primary beam; S) probe.

![Current distribution in the cross section of the discharge](image)

**Fig. 2.** Current distribution in the cross section of the discharge (\( I_p = 200 \text{ mA}; V_p = 80 \text{ V}; H = 2300 \text{ oe}; p = 2 \cdot 10^{-3} \text{ mm Hg} \)).