DETERMINATION OF THE AXIAL COURSE OF CONCENTRATION OF ELECTRONS IN THE AFTERGLOW DISCHARGE IN FLOWING MERCURY VAPOURS[1])

ОПРЕДЕЛЕНИЕ АКСИАЛЬНОГО НАПРАВЛЕНИЯ КОНЦЕНТРАЦИИ ЭЛЕКТРОНОВ В ТЛЕЮЩЕМ РАЗРЯДЕ, ПРОТЕКАЮЩЕМ В ПОТОКЕ РТУТНОГО ПАРА

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The rapid development of flow lasers with cross rousing stimulated a more detailed inspection of the afterglow discharge in flowing space [1, 2]. As working media vapours of metals and especially vapours of mercury can be used.

For inspection of the afterglow discharge in the flowing vapours of mercury, a discharge tube of the glass SiAl (Fig. 1) was made in which the afterglow discharge was burning perpendicularly to the direction of the flow of the vapours. The flow was realized by the formation of the pressure gradient between the boiler V and the cooler CH. The temperature of the boiler was in the range of 384—406 K. The temperature of the cooler CH had the constant value of 281 K.

The discharge was burning between the iron electrodes A and K and it was blown towards the cooler by the vapours. To the movable mechanism of a holder Sp we could attach a thermistor or the Langmuir probes by means of which we could determine the temperature of the neutral vapours T_o, the temperature T_e and the concentration n_e of electrons as the function of the position in a discharge or current tube. The Langmuir probes were made of tungsten of a wire of 8×10^{-5} m in diameter and a length of 3×10^{-3} m.

The characteristics of the flowing vapours (temperature T_o, pressure p and velocity v) in the current tube were being determined by means of the thermistor 12 NR 15 attached to the movable holder Sp and by measuring a mass flow of mercury passing to the cooler in a calibrated measure M [3]. The temperature of the vapours of mercury T_o determined in this way and their velocity v as the function of the longitudinal coordinate x is designed in Fig. 2 for the initial temperature of mercury in the boiler $T_{or} = 395$ K.

The discharge realized in the discharge tube, as shown in Fig. 1, can be divided into two parts, the discharge in the discharge tube (the tube where the electrodes A and K are placed), and the discharge in the current tube. In the first part, i.e. in the discharge tube, the flowing vapours do not influence the afterglow discharge.

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From this part of discharge the electrons of a certain temperature move into the other part, into the current tube. We shall suppose that ionization in the current tube is carried out only in the place, where the current and discharge tubes coincide (in Fig. 1 dashed part). In the current tube the electrons proceed under the influence of electric forces of ions carried by the flowing vapours out of this area; by diffusion they concentrate on the walls of the current tube, and to close the electric circuit between the electrodes A and K, they get into the discharge tube where the electrode A is placed.

In Tab. 1 there are shown the properties of the afterglow discharge in the discharge tube determined from Schottky's theory of the positive column [4]. This theory holds for the pressure interval

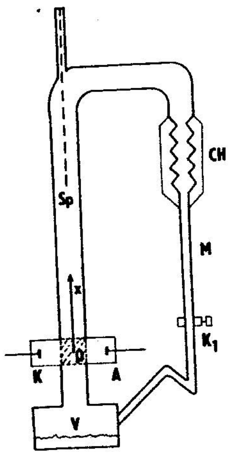

Fig. 2. The temperature T_v of the flowing vapours and their velocity v as the function of coordinate x.

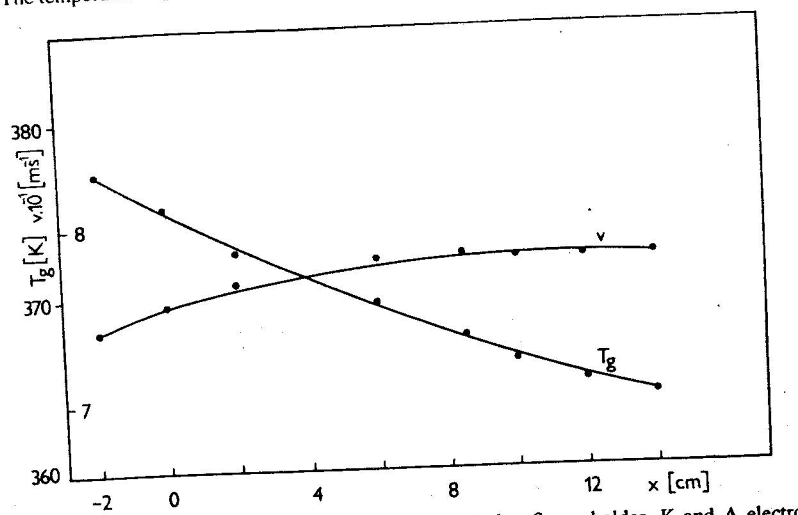

Fig. 1. The experimental apparatus. V — boiler, CH — cooler, Sp — holder, K and A electrodes, M — calibrated measure.

$p = 1.3 - 1.3 \times 10^3$ Pa [4]. The characteristics were counted for the temperature of the vapours $T_v = 375$ K, the pressure $p = 42$ Pa, the radius of the tube $R = 2.7 \times 10^{-2}$ m and the discharge current $i = 50$ mA. The properties indicated by the index exp are the properties determined experimentally by means of Langmuir's probes under the same conditions (N_e in Tab. 1 indicates the concentration of electrons belonging to the whole cross section of the discharge tube).

Table 1

$T_{e\,theor} \times 10^{-3}$ [K]	$T_{e\,exp} \times 10^{-3}$ [K]	$N_{e\,theor} \times 10^{-13}$ [m^{-3}]	$N_{e\,exp} \times 10^{-13}$ [m^{-3}]
11.4	12.0	3.8	3.4

For counting the axial course of concentration of electrons in the current tube where the afterglow discharge is directly influenced by the flowing vapours, we shall use the continuity equation modified for the flowing space in the form

$$\mathrm{div}\,(-Da \, . \, \mathrm{grad}\, n + \boldsymbol{v} \, . \, n) - z_i \, . \, n + \alpha \, . \, n^2 = 0, \quad (1)$$

where α is the coefficient of recombination, z_i is the coefficient of ionization, $n = n_i = n_e$ in the case of quasineutrality is the concentration of electrons [3]. Equation (1) will be simplified by omitting the coefficient of recombination α due to its small value [5]. Further we shall simplify equation (1) by the assumption that the coefficients $\boldsymbol{v}$, T_e, p and the coefficient of ambipolar difusion Da in the considered interval of discharge burning do not depend on their position. The equation (1) transcribed into the cylindrical coordinates and by the introduction of the axial symmetry around the axis x will have the form

$$Da\left(\frac{\partial^2 n}{\partial r^2} + \frac{1}{r}\frac{\partial n}{\partial r} + \frac{\partial^2 n}{\partial x^2}\right) + z_i \cdot n - v_x \cdot \frac{\mathrm{d}n}{\mathrm{d}x} = 0. \quad (2)$$

By separating the unknowns equation (2) will be divided into

$$\frac{\mathrm{d}^2 n}{\mathrm{d}r^2} + \frac{1}{r}\frac{\mathrm{d}n}{\mathrm{d}r} + A \cdot n = 0 \quad (3)$$

$$\frac{\mathrm{d}^2 n}{\mathrm{d}x^2} - \frac{vx}{Da} \cdot \frac{\mathrm{d}n}{\mathrm{d}x} + \left(\frac{z_i}{Da} - A\right) n = 0. \quad (4)$$

The solution of equation (3) is the Bessel function J_0

$$n(r) = n(0) J_0(r\sqrt{A}). \quad (5)$$

In the first approach we can consider the concentration of electrons on the walls of the discharge tube to be zero, and thus

$$A = \left(\frac{2.405}{R}\right)^2. \quad (6)$$

To solve this equation we must know the course of the coefficient of ionization z_i as the function of the coordinate x. We shall model the function $z_i(x)$ as $z_i(x) = z_{i\,max}(x)$ for the area where ionization still takes place and $z_i(x) = 0$ outside of this area. The coefficient of ionization z_i is taken from (4) and the coefficient of ambipolar difusion is taken from (6).

The equation so formed was solved for the temperature of electrons $T_e = 11.4 \times 10^3$ K (see Tab. 1), the pressure of the vapours $p = 42$ Pa, and the temperature $T_v = 375$ K and thus the course of the function $n_N(x)$ normed to the unit was determined. The absolute value of the function $n(x)$ was determined by solving the charge conservation equation.

Now let us consider the plane containing the x-axis and perpendicular to the drawing plane. Then from the charge conservation law it follows that the flow of charged particles passing through this plane must be equal to the discharge current. Mathematically we can write

$$i = 2e_0 \int_{-\infty}^{+\infty} \int_0^R K n_N(x) J_0\left(2.405 \frac{r}{R}\right) v_e(r)\, r \, dx \, dr, \qquad (7)$$

where $v_e(r)$ is the velocity of electrons. It is difficult to solve the integral in (7) because we do not know the course of the function $v_e(r)$. We shall suppose that $v_e(r)$ is the constant equal in its value in an arbitrary section of the plane cross to its value in the axis of the current tube. Then

$$v_e(r) = K_e \, . \, E_r, \qquad (8)$$

where E_r is the radial electric field and K_e is the coefficient of mobility of electrons taken from (4).

The function thus counted

$$n(x) = n_N(x) K \qquad (9)$$

is plotted in Fig. 3 by the dashed line.

From Fig. 3 we can see a good agreement between the experimentally determined axial course of the concentration of electrons.

The method of counting is simple. Its disadvantages lies in fact that it is impossible to count for all the given characteristics the axial course of concentration of electrons. The limit is the consequence of the condition that the expression

$$v - 4Da(z_i - A \, . \, Da) \qquad (10)$$

is equal to or greater than zero. The expression (10) is necessary for solving equation (4).

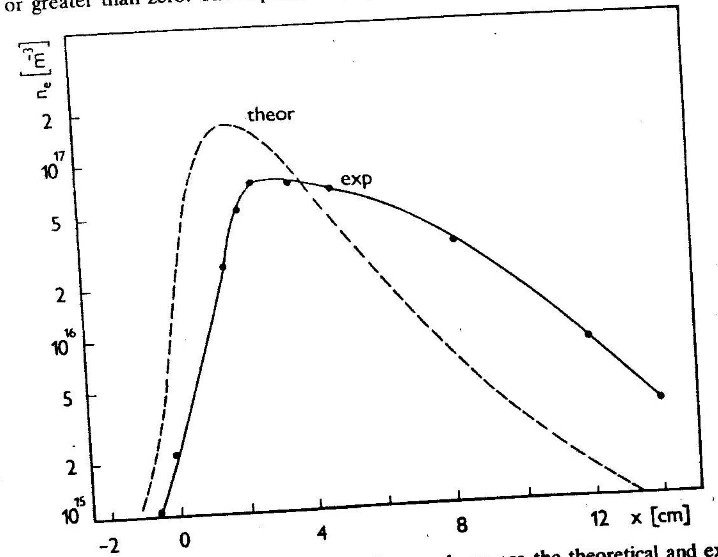

Fig. 3. The corse of concentration of electrons. Theor and exp are the theoretical and experimental curves for $p = 42$ Pa, $T_g = 375$ K, $v = 81$ ms^{-1}, $T_e = 11.4 \times 10^3$ K.

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