EFFECTS OF RECOMBINATION, ELECTRON WALL REFLECTION AND AMBIPOLAR DIFFUSION OF ELECTRONS IN A FLUID INFINIT PLASMA-WALL SHEATH MODEL[1]

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In the present paper the effects of space recombination and electron wall reflection are shown as they are resulting from the numerical solutions of a fluid stationary model for collisional sheath between an infinite plasma and an infinite insulated plane. Besides, the electron thermal approximation is compared with an ambipolar one.

1. MODELS OF AN INFINITE PLANE SHEATH

In papers [1] and (2] we presented plane models of a stationary sheath with cold parent gas and cold ions. The models consist

- of the basic equations: continuity equation, momentum transfer equation and Poisson equation,
- of the conditions in an undisturbed plasma,
- of the equality of ions and electrons flux densities at the fully absorbing wall.

The Boltzmann distribution of electrons, recombination with constant reaction rate and charge exchange and ionization with constant reaction frequencies are supposed.

Models equation systems were solved as initial tasks in dimensionless variables: $\xi = z/h$, $u = v/v_i$, $\eta = e\varphi/kT_-$, $x_+ = n_+/n_0$, $x_- = n_-/n_0$, $\Theta = ux_+$ with the normalized parameters: $A = h\nu_+/v_i$, $C = h\alpha/v_i$ $(B = C/A)$, where z is the coordinate, v is the drift velocity of ions, φ is the potential, n_+ and n_- is the ions and electron concentration, ν_+ is the collision frequency of ions with neutral particles, α is the frequency of direct ionization, $h = (\varepsilon_0 KT_-/e^2 n_0)^{1/2}$ is the Debye length, $v_i = (kT_-/m_+)^{1/2}$ is the sound speed of ions, $n_0 = \alpha/\beta$ is the concentration

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of ions, resp. electrons, in an undisturbed plasma far from the wall, β is the recombination coefficient.

Solutions were obtained for pairs of parameters:

$$(A, C) = (0.01 - 10, 0.1 - 1), (0.1 - 1, 0.01), (1, 0.001).$$

II. MODELS COMPARISON

Model [1] considers exclusively the thermal motion of electrons while in model [2] there is an additional assumption applied in the equation of continuity, according to which electrons are drawn to ions by a mechanism of ambipolar diffusion. By means of this the electron concentration increases and so does the number of ionization. Due to this, there should be a large number of slow ions in the sheath, e.g. smaller drift velocity of ions, which causes an increase of ion concentration.

Numerical solutions including ambipolar diffusion [2] were obtained so that the recombination was taken into consideration on the level of the fluid equations, while in the model without ambipolar assumption the recombination was taken into account already on the level of the kinetic equation [3]. The difference appears explicitly only in the momentum transfer equation for ions.

In [1] we evaluated, according to the numerical results, the relative significances of the particular members in the momentum transfer equation. From these it is evident that the influence of a different calculation of recombination is in the collisional sheath ($B = 0.01$) negligible. It results that, in a collisional regime, both models solutions can be compared from the point of view of various forms of electron motion (Fig. 1).

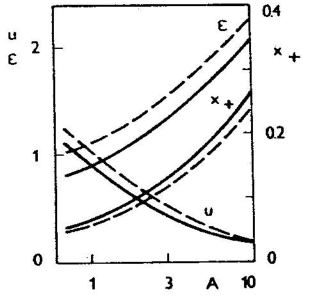

Fig. 1. Normalized values of electric field $\varepsilon = -d\eta/d\xi$, ions concentration x_+ and drift velocity of ions u at the wall in mercury plasma in dependence on collisional parameter A if $B = 0.01$.

III. SPACE RECOMBINATION

In contradiction to finite models [4, 5] including ionization, an infinite plane model of the electric sheath cannot function without taking into account space recombination.

The recombination term appears in the sheath model with cold ions explicitly only in the continuity equation, which has in dimensionless variables the form: $d\Theta/d\xi = Cx_- - Cx_-x_+$. The right-hand side of the equation gives the normalized effective creation of ions, resp. electrons, and has in the space of the sheath a local maximum decreasing close to the wall relatively rapidly to negligible values. Fig. 2a, b shows all types of dependences of the effective creation on the parameters.

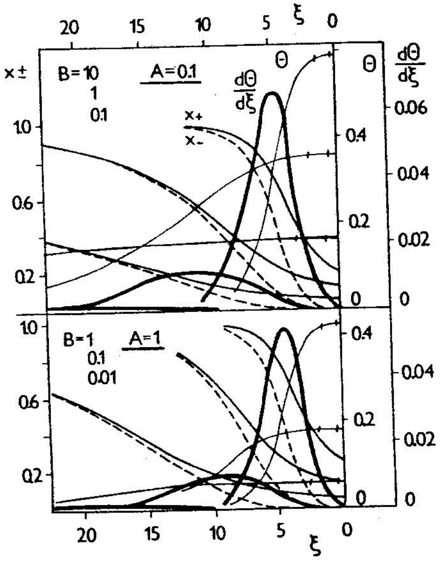

Fig. 2. Normalized space dependences:
——— (thick line) — effective creation $d\Theta/d\xi$,
——— (medium thick line) — ion concentration x_+,
- - - - - - (dashed line) electron concentration x_-,
——— (thin line) — ion flux density Θ.
$\xi = 0$ belongs to the fully absorbing wall in mercury plasma, marked points on Θ-curves show values at the fully absorbing wall: right — in argon, left — in hydrogen.

– B increasing, A = const.: Increasing ionization frequency causes an increase of the effective creation intensity. Simultaneously the peak is contracting and approaching the wall;
– A increasing, B = const.: At the same parallel increase of collision frequency together with ionization frequency, considering the case of constant collision frequency, the dependence is weaker;
– A increasing, C = const.: The increase of collision frequency leads to an altogether weaker effective creation. The intensity and width are lower, the peak is approaching the wall.

The values x_+ give, thanks to the used normalization, directly the ratio of the number of recombinations to the number of ionizations. The maximum of effective creation appears at relatively big values of x_+ ($x_+ \in (0.2, 0.9)$) (Fig. 2).

According to the space distribution of $d\Theta/d\xi$, x_+ and x_- (Fig. 2) we can divide the area of a plasma adjacent to an insulating wall roughly into three zones:

1. An infinite zone deep in the plasma, where the numbers of ionization and recombination collisions are equal.
2. A zone determined by the width of a local maximum of effective creation, where the number of ionizations is of course bigger than the number of recombinations, but the importance of recombination by ions flux formation is, due to the big values of x_+, significant.
3. A narrow zone close to the wall, where — in consequence of small values of x_- — recombination as well as ionization collisions are negligible. (Values of normalized electron concentration at the fully absorbing wall are (10^{-2}, 10^{-4}) for hydrogen, (10^{-3}, 10^{-5}) for mercury [1]). The width of this zone is for gases with smaller masses narrower and simultaneously it is reduced by electron reflection at the wall (see further).

IV. ELECTRON REFLECTION AT THE WALL

A maximum ion flux density will fall at the wall in the case, when the coefficient of electron reflection $\varkappa_e$ finding in the condition at the wall [6]

$$\frac{1+\varkappa_e}{1-\varkappa_e}\,\frac{ux_+}{x_-}=\left(\frac{2m_+}{\pi m_-}\right)^{1/2} \tag{1}$$

is zero, e.g. if the wall is fully absorbing.

The numerical solutions of models were reached by an extrapolation method from plasma towards the wall and stopped after fulfilling the condition (1), when $\varkappa_e = 0$. For every $\varkappa_e > 0$ the condition (1) is fulfilled sooner, e.g. the plasma-wall sheath is narrower and, due to this, also the absolute differences of the values of sheath characteristics at the wall and those at the area of undisturbed plasma are smaller than in the case of $\varkappa_e = 0$.

Non-zero reflection of electrons at the wall implies an increase of electron concentration in the space and by this also an increase of ionizataion. Therefore the influence of the wall reflection is manifested stronger in cases when either the ionization frequency (parameter C) or the ratio of the ionization collisions to the collisions of ions with neutrals in the undisturbed plasma (parameter B) or both are bigger.

The electron reflection influences mostly the potential of the wall, for mercury and $\varkappa_e = 0.9$ regarding the case of $\varkappa_e = 0$ as follows: for $(A, B) \in (10, 0.01—0.1)$ less than 1%, for $(A, B) = (0.01, 100)$ up to 40%.

In (Fig. 2) on every curve of the normalized ion flux density Θ, there are two marked points, which belong to the values of the fully absorbing wall in hydrogen and argon. Thus the values ξ belonging to these points give the wall location relative to a hydrogen, resp. argon undisturbed plasma for a case of zero reflection at the wall. According to normalized condition (1), the same values belong to the wall in mercury plasma if the electron reflection at the wall is 87% points on the left, or 38% points on the right. Similarly the points of wall in the hydrogen plasma at zero electron reflection [1] belong at the same time to the wall in the argon plasma if the wall reflection is 73%.

REFERENCES

[1] Teplanová, K.: Acta Phys. Univ. Comen. *XXVIII.* (1987). Fluid model
[2] Teplanová, K., Košinár, I., Maratišovitš, V.: Acta Phys. Slov. 32 (1982), 235.
[3] Teplanová, K.: Acta Phys. Univ. Comen. *XXV* (1984), 131.
[4] Franklin, R. N.: *Plasma Phenomena in Gas Discharges.* Clarendon Press, Oxford (1976).
[5] Valentini, H. B.: Beitr. Plasmaphys. 21 (1981), 29.
[6] Martišovitš, V.: Acta Phys. Slov. 29 (1979), 133.

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ЭФФЕКТЫ РЕКОМБИНАЦИИ, ОТРАЖЕНИЯ ЭЛЕКТРОНОВ ОТ СТЕНКИ И АМБИПОЛЯРНАЯ ДИФФУЗИЯ ЭЛЕКТРОНОВ В МОДЕЛИ БЕСКОНЕЧНОЙ ЖИДКОЙ ПЛАЗМЫ С БЕСКОНЕЧНОЙ ОБОЛОЧКОЙ В ВИДЕ СТЕНКИ

В данной работе показано, как эффекты пространственной рекомбинации и отражения электронов от стенки можно получить из численных решений стационарной модели для границы между бесконечной плазмой и бесконечной изолированной плоскостью. Кроме того, проведено сравнение электронной термической аппроксимации с амбиполярной.