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DIFFUSION THEORY OF THE POSITIVE COLUMN IN HYDROGEN GLOW DISCHARGES WITH VARIABLE DEGREE OF DISSOCIATION

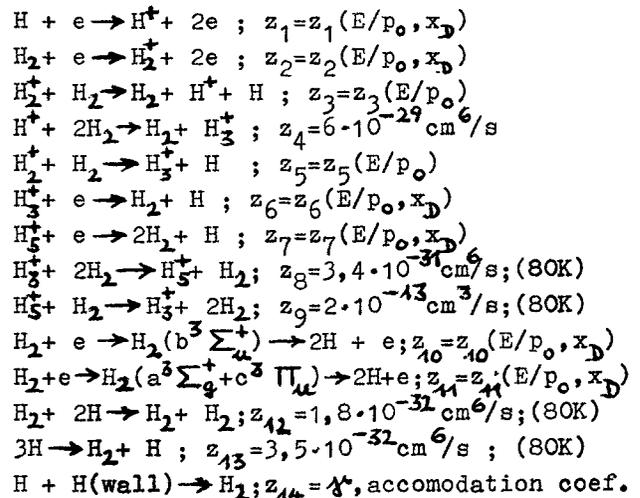
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INTRODUCTION:In connection with an increasing interest in plasma chemical reactions under non-isothermal conditions recently the classical SCHOTTKY diffusion theory of the positive column was extended to gases of varying material composition /1/. This extension resulted in a new viewpoint for the understanding of one of the most important problems in every column theory: the quantitative description of the electric characteristic of the discharge plasma. Till now the falling behaviour of the column characteristic was attributed mainly to such processes as deviations from the quasi-neutrality and the occurrence of the stepwise ionization. Now in the special case of the hydrogen discharge it was shown that the negative differential resistance of the column could be declared by the varying degree of dissociation in dependence on the discharge current. To calculate the electric characteristic on this basis a model of the discharge mechanism was used as a first step which neglected some appearing elementary processes. Now we have improved the model and extended the calculation to different gas pressures and different recombination conditions at the tube wall.

THEORETICAL MODEL:The starting-point of our calculations was the correct energy distribution function of the electrons in the H₂/H-mixture. This required the solution of the corresponding BOLTZMANN equation. Taking into account all important elastic and inelastic collisions between electrons and H₂ and H respectively (for details see /1//2/) the distribution function f(x_D, E/p₀) was calculated in the frame of usual approximations for different degrees of dissociation x_D=0...1 and different reduced electrical field strengths E/p₀=7...100 V/cm Torr. By this the transport coefficients and various collision rates of the electrons could be determined, too.

Contrary to /1/ in the kinetic model of the positive column now we have also considered the ion H₅⁺ besides the ions H⁺, H₂⁺ and H₃⁺. This expanded the process scheme altogether to the following 14 reaction channels:



The system of balance equations for the different particles H₁⁺, H₂⁺, H₃⁺, H₅⁺ and H (inclusive of some conditions for neutrality, current density and particle number) reads in differential form:

$$\begin{aligned}
 &\text{div}_r j_1^+ = n_e n_1 z_1 + n_2 n_2^+ z_3 - n_2^+ n_1^+ z_4 \\
 &\text{div}_r j_2^+ = n_e n_2 z_2 - n_2 n_2^+ z_3 - n_2 n_2^+ z_5 \\
 &\text{div}_r j_3^+ = n_e n_2^+ z_5 + n_2 n_1^+ z_4 + n_2 n_2^+ z_3 - n_e n_3^+ z_6 - n_2 n_3^+ z_8 \\
 &\text{div}_r j_5^+ = n_2 n_3^+ z_8 - n_e n_5^+ z_7 - n_2 n_5^+ z_9 \\
 &\text{with } j_k^+ = -b_k^+ (D_e/b_e) (n_k^+/n_e) (dn_e/dr); k=1, 2, 3, 5 \\
 &n_1^+ + n_2^+ + n_3^+ + n_5^+ = n_e ; (\text{neutrality condition}) \\
 &2n_e n_2 (z_{10} + z_{11}) + n_2 n_2^+ (z_3 + z_4) + n_e n_3^+ z_6 + n_e n_5^+ z_7 + \\
 &+ (j_1^+ + j_3^+ + j_5^+) \delta(r/r_0 - 1)/r_0 = n_e n_1 z_1 + 2n_1 n_2 z_{12}^+ \\
 &+ 2n_1^3 z_{13} + n_1 \delta^* \bar{c} \delta(r/r_0 - 1)/4r_0 \\
 &n_1 + n_2 = p_0 n_g ; (\text{open tube, large dead space}) \\
 &n_1/2 + n_2 = p_{0s} n_g ; (\text{closed tube, no dead space}) \\
 &j_D = n_e b_e E ; (\text{axial electric current density}) \\
 &(j: \text{current density}; z: \text{collision rate}; \\
 &n: \text{particle concentration}; r, r_0: \text{radius coordinate, tube radius}; b: \text{mobility}; D: \text{diffusion coefficient}; n_g = 3,54 \cdot 10^{16} \text{ cm}^{-3} \text{ Torr}^{-1}; p_0: \text{reduced pressure (0}^\circ\text{C)}; p_{0s}: \text{initial pressure}; \bar{c}: \text{thermal velocity}).
 \end{aligned}$$

In the balance of the H atoms the terms with the delta function represent the tube wall localized production and loss processes by recombination. Radial changes of the

H and H₂ concentration are neglected. After radial averaging of the basic equations for different pressures (0,3...5 Torr) and different accommodation coefficients (10⁻⁷...10⁻²) the axial electric field strength E, the relative portion of the various ions $\alpha_k = \bar{n}_k^+ / \bar{n}_e$ and the degree of dissociation $x_D = n_1 / (n_1 + n_2)$ were calculated in dependence on the discharge current. At this calculation the gas temperature was set constant (80K) and we used for the radial distribution of the charge carriers a BESSEL profile.

RESULTS: Figs. 1 and 2 compare the importance of the various kinds of ions at different pressures. The H₅⁺ ions are entirely insignificant at low pressures but gain considerable importance at higher pressures. On the other hand the molecular ion H₂⁺ always plays only a subordinate role in the ionic budget. Fig. 3 shows the increase of the degree of dissociation with increasing current. At low pressures small currents can already produce nearly complete dissociation. At higher pressures x_D decreases but the absolute concentration of H atoms is relative independent on the pressure. Especially at low currents and relative low pressures the accommodation coefficient γ influences considerably the degree of dissociation (Fig. 4). Small values of γ relate to low temperatures at clear tube wall. Also a special coating of the wall (for instance with phosphite) reduces γ . The region of γ shown in Fig. 4 corresponds to the really occurring values under different conditions.

Finally Figs. 5 and 6 show examples of the calculated electric characteristic of the positive column in hydrogen. Contrary to all the other figures number 6 also contains results for the case of an open discharge tube (large dead space). The negative slope of the characteristic is caused by the transfer of the positive column from a prevailing molecular (H₂) discharge at low currents to states with a considerable atomic component at high currents. In consequence of the small degree of dissociation at high gas pressure the character-

istic remains flat in this case.

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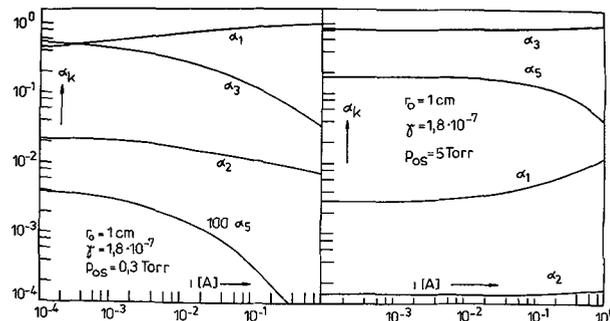


Fig. 1

Fig. 2

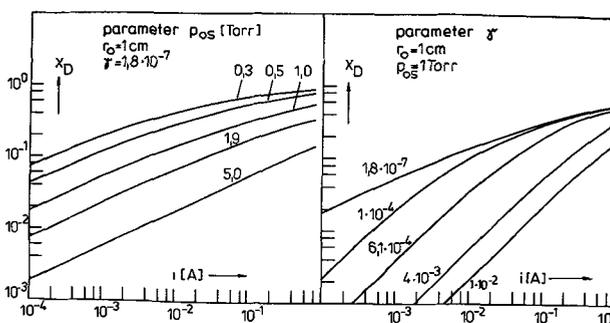


Fig. 3

Fig. 4

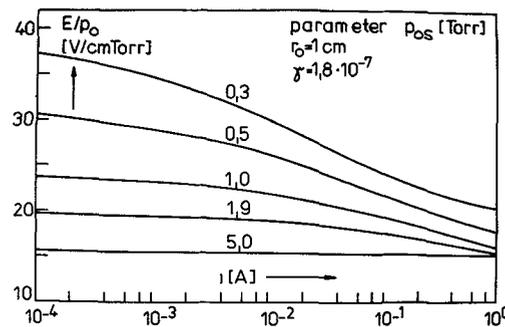


Fig. 5

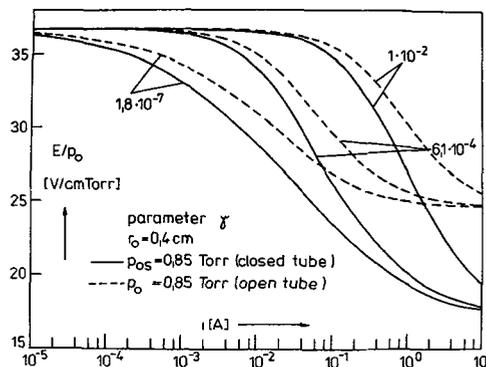


Fig. 6