Ionic composition in a potassium-nitrogen discharge plasma

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The mass spectrum of the ions in a mixed K–N_2 plasma was investigated in a wide range of pressures. In addition to the different potassium and nitrogen ions, we observed here the complex ions KN_2^+ and an influence of the nitrogen on the formation of the K_2^+ ions; the possible nature of these phenomena is discussed.

We investigated the ion content of a two-component discharge plasma produced, in the first stage, in a mixture of potassium vapor at a pressure p in the range $\approx 10^{-6}$ to 10^{-2} mm Hg, and molecular nitrogen at a pressure in the region of $P \approx 0-1$ mm Hg; the source of the plasma was an arc discharge with incandescent cathode, the discharge current being $I = 10-60$ mA. We used the MKh-7301 single-pole mass analyzer, similar to that used in[1] to investigate a pure nitrogen plasma. In parallel, an investigation was carried out (by Klapchenko) of the electric properties and parameters of a potassium-nitrogen plasma, similar to the investigation described in part by us in[2] for the case of a cesium-hydrogen plasma. The measurements described below were carried out at $I = 20$ mA; the plasma produced thereby had the following parameters, all dependent on the values of p and P: a) electron density n_e in the range $\approx 10^9 - 10^{10}$ cm^{-3}, b) "temperature" of slow electron group $T_e \approx 10\,000 - 40\,000$ °K, although the total spectrum of the electron energies was quite complicated, and c) electric field intensity $E \approx 1.5-6.0$ V/cm.

The figures show logarithmic-scale plots, against p (Fig. 1) and against P (Fig. 2), of the relative intensity $J = J/\Sigma J$ of the following output signals, those produced by the ions extracted directly from the plasma, namely N_1^+ (curve 1), N_2^+ (curve 2), K_1^{39+} (curve 3), K_2^{78+} (curve 4), and KN_2^+ (curve 5); in the first case $P = 0.1$ mm Hg, and in the second $p = 1.5 \times 10^{-5}$ mm Hg. In the central region of Fig. 1, the plasma was somewhat stratified. In addition to these ions we measured also the behavior of the observed ions N_3^+, N_4^+, K_1^{41+}, and K_2^{80+}, but this will not be reported for the time being. Measurements of the function $j = f(I)$ in our range of values of I, at the indicated values of p and P, have shown that this function varies relatively little.

It is seen clearly from these figures that the plasma goes over continuously, in a sufficiently wide range of each of the quantities p and P, from a state with predominant ionization of the nitrogen with negligible potassium admixture to a state with predominant ionization of the potassium alone in neutral nitrogen. This transition is accompanied by a corresponding lowering of the quantities E and T_e and an increase of n_e. These extreme states of Fig. 1 should, of course, differ from the pure nitrogen state and pure potassium state, without a second component. These measurements then show that in a similar plasma one observes also the complex ions KN_2^+, in addition to various ions of its components.[1,3] Similar ions were observed also in[4], but under entirely different (non-plasma) conditions.

It would be natural to expect here the onset of the ion-molecular reaction $K^+ + 2N_2 \rightarrow KN_2^+ L N_2$; in our case, however, this reaction cannot explain the results. In fact, from the balance equation between the rates of formation of these ions and their recombinations on the walls of the apparatus (which determines their vanishing under these conditions), namely $\beta_1 n_1 n_M^2 = \beta_2 n_2$, it

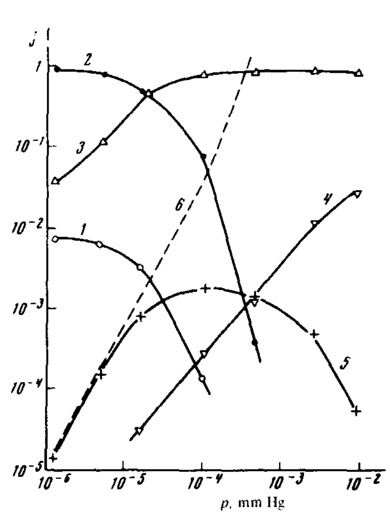

FIG. 1.

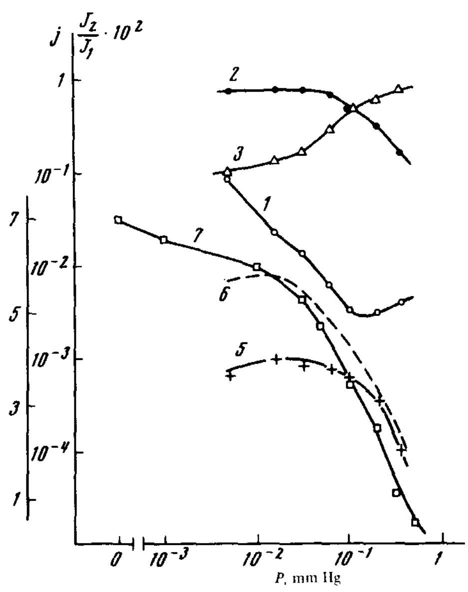

FIG. 2.

follows (at $p_2 \approx$ const) that the ratio of the concentrations of the ions KN_2^+ and K^+ should be $n_2/n_1 \sim j_2/j_1 \sim n_M^2 \sim P^2$. However, the experimental plot of $j_2/j_1 = f(P)$, shown by the dashed curve 6 in Fig. 2, has nothing in common with the aforementioned ratio.

The situation is somewhat better, from a purely qualitative point of view, when the associative reaction $K + N_2^* \to KN_2^+ + e$, is used, for example, with participation of nitrogen molecules N_2^* is an electron-excited metastable state ($\mathcal{E}^* = 6.23$ eV), produced at a rate approximately proportional to that of the N_2^* ions. In this case we obtain the expression $n_2/n_M^* \sim n_2/n_M^* \sim j_2/j_M^+ \sim n_k \sim p$, which is quite close to the experimental plot $j_2/j_M^+ = f(p)$ shown by dashed curve 6 of Fig. 1. However, a complete explanation of this question is still a matter for the future.

Finally, curve 7 of Fig. 2 shows that the ratio J_2/J_1 of the molecular and atomic potassium ion, at $p = 10^{-2}$ mm Hg, decreases rapidly with increasing P. This circumstance can obviously serve as a definite argument indicating that the molecular K_2^+ ions are produced under such conditions predominantly by associative ionization with participation of excited potassium atoms, and not via ion conversion,[3] for in this case the rate of the quenching of their excitation by the molecular nitrogen increases.

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