4. B. P. Kaulakis, A. R. Chizhyunas, and V. I. Shvyadas, Litovskii Fiz. Sb., **XXIV**, No. 3, 48-58 (1984).
5. A. Z. Devdariani, A. N. Klyucharev, N. P. Penkin, and Yu. N. Sebyakin, Opt. Spektrosk., **64**, No. 3, 706-709 (1988).
6. L. P. Presnyakov and A. D. Ulantsev, Brief Reports on Physics, Moscow (1984), No. 1, pp. 38-43 (Sb. Nauch. Tr./Lebediev FIAN).
7. B. M. Smirnov, Excited Atoms [in Russian], Moscow (1982).
8. A. N. Klucharev and V. Vujnovic, Phys. Repts., **185**, No. 2, 55-81 (1990).
9. A. N. Klyucharev and N. N. Bezuglov, Excitation and Ionization Processes during Light Absorption [in Russian], Leningrad (1983).
10. V. S. Lebedev and V. S. Marchenko, Zh. Éksp. Teor. Fiz., **88**, 754-770 (1985).
11. B. P. Kaulakis, Pis'ma Zh. Éksp. Teor. Fiz., **47**, 300-302 (1988).
12. S. B. Zagrebin and A. V. Samson, Pis'ma Zh. Éksp. Teor. Fiz., **11**, 680-682 (1985).
13. S. B. Zagrebin and A. V. Samson, J. Phys. B: At. Mol. Phys., 11, L217-L220 (1985).
14. A. V. Samson, Opt. Spektrosk., **65**, No. 1, 242-243 (1988).
15. A. V. Samson, Opt. Spektrosk., **63**, No. 2, 440-442 (1987).
16. A. V. Samson, Khim. Fiz., **9**, No. 4, 573-575 (1990).
17. B. C. Johnson, M.-X. Wang, and J. Weiner, J. Phys. B: At. Mol. Phys., **21**, 2599-2607 (1988).
18. M. T. Djerad, M. Cheret, and F. Gounand, J. Phys. B: At. Mol. Phys., **20**, 3789-3799 (1987).
19. J. Keller, R. Bonanno, M.-X. Wang, M. S. de Vriens, and J. Weiner, Phys. Rev., **A33**, No. 3, 1612-1617 (1986).
20. B. V. Dobrolezh, A. N. Klyucharev, and A. B. Tsyganov, Proceedings of All-Union Seminar on "Ionization Processes Involving Excited Atoms," Leningrad (1988), pp. 22-23.

CHEMOIONIZATION IN A LOW TEMPERATURE PLASMA

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Ionization processes are considered in a low-temperature plasma which involve collisions of heavy particles leading to significant changes in the charged particle balance with ionization or recombination nonequilibrium. The possibilities for use of chemoionization processes in modern low temperature plasma physics applications such as gas laser active media, detection of oscillatory excitation in molecules, and optogalvanic spectroscopy are evaluated.

It follows from simple qualitative considerations that chemoionization processes will have the greatest effect on ionization kinetics in cases of alkali metals or atoms with a similar excited state term structure. For such systems, with their relatively uniform sequence of energy levels, excitation to a resonant level does not imply that the excited electron immediately enters the continuum – as a rule, the "tight spot" in these cases is located higher and the presence of an effective drain through the chemoionization channel from lower levels can have a significant effect on the net ionization rate. On the other hand, in the case of inert gas atoms the ionization rate is practically always limited by the rate of excitation of lower states with subsequent rapid ionization in electron–atom collisions.

It has been proposed previously that in a low temperature plasma chemoionization plays a significant role only in the initial stages of ionization development: in gas breakdown, in shock waves, etc. (see, for example, [1]). Dissociative recombination processes reduce the role of chemoionization. However there exists a situation in which chemoionization (through the molecular ion formation channel) is not accompanied by the reverse process of recombination; thus, at a temperature of the

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normal component of an alkali plasma $T \geq 1000$ K thermal dissociation of molecular ions occurs and their role in recombination kinetics decreases [2, 3].

Chemoionization processes which occur effectively in thermal collisions of atoms and molecules happen mainly because of the internal excitation energy. Thus, in a low temperature plasma where the potential energy stored in the excited states is several orders of magnitude greater than the energy of the electron gas the role of chemoionization can be quite significant. The clearest examples of this are plasma at cryogenic temperatures, post-luminescence plasma, and photoplasma.

The use of chemoionization reactions has recently been proposed for a number of nontraditional plasma physics applications. Thus, the photoprocess of impurity atom chemoionization can be considered as an alternative to the photoionization process as an effective mechanism for formation of primary charged particles in the preionization stage of a high pressure discharge in molecular gasses [3]. We will also note proposals for methods of detecting oscillatorily excited molecules, laser separation of isotopes, and laser optogalvanic spectroscopy based on chemoionization processes [4, 5].

We will note (following [6]) some of the most interesting concrete examples characterizing the role of chemoionization processes in the kinetics of a nonequilibrium low temperature plasma.

Plasma with ionization nonequilibrium:

the significant contribution to ionization of chemoionization reactions over a quite wide range of alkali plasma parameters in thermoemission energy converters;

formation of a population inversion in discharges in mixtures of inert gasses with metal vapors.

Plasma with recombination nonequilibrium:

effect of chemoionization processes on the rate of change of electron concentration and temperature in post-luminescence of weakly ionized inert gas plasmas;

enrichment of the electron distribution function over energy by fast electrons in a post-luminescence plasma caused by an increase in the role of step processes in population of excited states, with the resulting possibility of changing the very character of the nonequilibrium;

formation of an anomalous potential jump at the wall due to fast electrons initiated by the chemoionization processes in a current-free plasma;

clearing of lower laser levels due to impurity ionization through a chemoionization channel.

The latest achievements in the technology of controlling atomic properties in the beams of laser systems for cooling and maintenance of cold ions and neutral atoms have allowed experiments to study chemoionization processes with energies of relative particle motion corresponding to a temperature of tens of K to mK and lower. Description of collision dynamics in this energy region requires use of a full quantum treatment of nucleus motion, whence, in particular, there follows the existence of hf oscillations in the electron chemoionization spectrum. This has been confirmed experimentally for the case of collisions of metastable helium atoms with an effective temperature of the order of 20 K. The first data published on chemoionization sections for a temperature of the order of mK indicate values three orders of magnitude higher than for the range 20-2400 K. However the reliability of quantitative interpretation of results from such experiments will obviously require special consideration. Results of these first experiments performed with "cold" atoms demonstrate great promise for collision physics in the cryogenic temperature region with participation of atoms, molecules, and clusters. In a cryogenic plasma with its record concentrations of metastable atoms the role of chemoionization processes can thus be very significant.

We will also note that in all cases use of data from the literature on chemoionization constants for low temperature plasma conditions requires a preliminary analysis. This is due to the possibility of a marked difference in the atomic velocity distribution function in the plasma and, for example, in beam experiments on chemoionization.

In conclusion, we will consider the possibility of using chemoionization processes in resonant ionization spectroscopy. By this term we understand the complex of processes and approaches directed at solution of concrete practical problems, for example, detection of individual atoms and molecules, or laser separation of isotopes. The method assumes that resonantly excited particles are converted into atomic or molecular ions, in particular, through the chemoionization channel. When applied to low temperature plasma conditions, practically the same resonant ionization spectroscopy mechanisms are termed optogalvanic or optoelectric effects, which manifest themselves through change in ionization, electrical, and oscillatory properties of the plasma [7]. At present optogalvanic methods are being used to obtain data on products of plasmochemical reactions, for spectroanalytical purposes, and as detectors of laser radiation. Also included here is the specific case of light-induced current in a rarefied gas, where as a result of absorption of monochromatic radiation the excited particles formed have a directed velocity due to the Doppler effect. Under these conditions observation of the optogalvanic effect (current induced by light) does not require application of an external potential difference across the gap containing the vapor.

LITERATURE CITED

1. A. N. Klyucharev and N. N. Bezuglov, Atomic Excitation and Ionization Processes upon Light Absorption [in Russian], Leningrad (1983).
2. A. A. Kudryavtsev, Teplofiz. Vys. Temp., **25**, 1041-1049 (1987).
3. A. N. Klyucharev and M. A. Yanson, Elementary Processes in Alkali Metal Plasmas [in Russian], Moscow (1988).
4. I. M. Beterov, V. L. Kurochkin, and N. V. Fateev, Khim. Fiz., 1, 957-966 (1982).
5. I. M. Beterov and N. V. Fateev, Reports to the VI All-Union Conference on Low Temperature Plasma [in Russian], Leningrad (1983), pp. 31-33.
6. N. B. Kolokolov and A. A. Kudryavtsev, in: B. M. Smirnov, ed., Plasma Chemistry, 15th ed. [in Russian], Moscow (1989), pp. 127-163.
7. I. M. Beterov, A. V. Eletskii, and B. M. Smirnov, Usp. Fiz. Nauk, **155**, 265-296 (1988).

ELEMENTARY PROCESSES IN PREBREAKDOWN PHENOMENA IN THE ATMOSPHERE

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The effect of negative oxygen ion destruction upon breakdown conditions in atmospheric air is analyzed. It is shown that ozone accumulation due to plasmochemical reactions occurring in ionized air produces a reduction in the breakdown voltage, related to negative O^- ion destruction upon collision with ozone molecules under realistic conditions. A relationship is derived for electric field breakdown intensity and ozone molecule lifetime for the real atmosphere.

The simplest condition for electrical breakdown in the atmosphere, as in any other electronegative gas, requires equality of the electron collision molecule ionization rate to the rate of electron attachment to molecules. According to this condition the breakdown electrical field intensity for dry air under normal conditions is 25.5 kV/cm. However the phenomenon of large scale electrical breakdown in the real atmosphere, i.e., lightning, can occur at significantly lower electric field intensities. One cause of reduced electrical strength of the air atmosphere is related to the medium's chemical composition, involving plasmochemical processes under the action of an external electric field. This leads to a change in the balance between the processes of formation and neutralization of free electrons, which opens, in particular, channels for the destruction of negative ions, the presence of which encourages breakdown conditions. Below we will analyze in detail this mechanism for reduction in electrical strength of atmospheric air with consideration of plasmochemical formation of ozone molecules and processes occurring with participation of such molecules. Special attention will be given to analysis of available information on the characteristics of these elementary processes and selection of the most reliable data.

In analyzing this phenomenon we will consider the following processes:

$$e + O_2(N_2) \rightarrow 2e + O_2^+(N_2^+), \tag{1}$$

$$e + O_2 \rightarrow O^- + O, \tag{2}$$

$$O^- + O_2^+(N_2^+) \rightarrow O + O_2(N_2), \tag{3}$$

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