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Abstract

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IONIZATION OF FAST NEUTRAL POTASSIUM ATOMS IN COLLISIONS WITH ARGON ATOMS AND WITH HYDROGEN, NITROGEN, AND OXYGEN MOLECULES

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At present there is great interest in the study of phenomena of atomic collisions and, in particular, collisions “close to slow”ones (^1). One of the processes of this type is the ionization of fast (in the sense that their velocities are much greater than thermal velocities) neutral atoms in collisions with atoms and molecules of gases. The study of this process is of interest not only for the theory of atomic collisions, but, moreover, may be important for understanding the occurrence of ionization during the motion, for example, of meteors in the upper layers of the atmosphere.

Fig. 1. Schematic of the apparatus: 1 –thermionic source; 2 –focusing system; 3 –collimator; 4 –charge-exchange chamber; 5, 6 –electrodes in the charge-exchange chamber; 7 –deflecting capacitor; 8 –circular aperture, $d = 4$ mm; 9 –collision chamber; 10 –Faraday cylinder; 11 –capacitor; 12 –side receiver; 13, 13′ –slits $d = 0.8$ mm; 14 –circular aperture, $d = 2$ mm; 15 –tube for gas admission; H_1 and H_2 –pump connections.

The present work is devoted to the study of the ionization of fast potassium atoms with energies from 100 to 2000 eV in collisions with argon atoms and with hydrogen, nitrogen, and oxygen molecules. The ionization potentials of the gases used are considerably higher than the ionization potential of potassium. It could therefore be expected that, in the selected energy range, the predominant process should be ionization of fast potassium atoms according to the scheme:

$$\vec{K} + A \rightarrow \vec{K}^{+} + e + A. \tag{1}$$

The effect was observed by recording fast positive ions $\vec{K}^{+}$.

A schematic of our experimental apparatus is given in Fig. 1. A beam of positive potassium ions, obtained from thermionic source 1,

was focused by means of the electrode system 2, and then collimated by slits 13 and 13′. The dimensions of all apertures for the passage of particles after the collimator were chosen with allowance for the natural geometrical divergence of the beams. In chamber 4, resonant charge exchange took place, with conversion of positive potassium ions into fast neutral atoms. The flux of the latter, I_n, was measured by measuring the current of slow positive ions formed in charge exchange (2). By means of capacitor 7, positive ions that had not undergone charge exchange were deflected to the side, while the beam of neutral atoms passed through diaphragm 8 into collision chamber 9.

To fill the collision chamber we used the following gases: spectrally pure argon; hydrogen purified by passage through a heated palladium tube; technical nitrogen purified of oxygen impurity by passage over heated copper turnings; and oxygen obtained by heating potassium permanganate. An ionization manometer was used to measure the pressure. The residual pressure with the source operating and chamber 4 (with potassium) heated was $5 \div 8 \cdot 10^{-6}$ mm Hg, and after very prolonged conditioning of the apparatus it could be reduced to $2 \div 3 \cdot 10^{-6}$ mm Hg. The working gas pressure in the collision chamber when measuring the effect was $\sim 3 \div 5 \cdot 10^{-4}$ mm Hg. The pressure difference between chamber 9 and the rest of the apparatus was $1 : 15$, and when working with hydrogen, $\sim 1 : 6$.

After a preliminary check of the operation of the apparatus, we placed potassium in chamber 4 and obtained a flux of neutral atoms. In the absence of gas in the collision chamber and with the beam of primary positive ions deflected aside, fast positive ions could be directed to collector 12 by means of capacitor 11; these ions were apparently formed as a result of ionization of fast atoms in the residual gas (or, which seems less probable, when fast atoms struck the edges of diaphragms). An electrometer amplifier with a sensitivity of $2 \cdot 10^{-15}$ A/div. was connected to collector 12. When gas was admitted into chamber 9, the current i to collector 12 increased with increasing pressure p, and when working with molecular gases it considerably exceeded the "background" (in the case of argon the "background" could amount to about 10% of the effect). The current i was measured when there was no transverse electric field in charge-exchange chamber 4, i.e., not simultaneously with I_n. The ratio i/I_n depended linearly on p and did not depend on I_n when I_n varied over the range of currents used by us. In this connection, collisions under the conditions of our experiments could be regarded as single collisions. Since the ratio i/I_n did not exceed 4%, we used the following simplified formula to determine the effective cross sections:

$$Q = \frac{i}{I_\mathrm{n} + i} \, \frac{1}{3.31 \cdot 10^{16} px}, \tag{2}$$

where x is the path length of the fast atoms in the gas.

Fig. 2. Effective cross sections Q for the ionization process of fast potassium atoms as a function of their energy T and velocity v.

Figure 2: Fig. 2. Effective cross sections Q for the ionization process of fast potassium atoms as a function of their energy T and velocity v.

The mean random relative error in determining Q was somewhat larger for measurements in argon (because of the appreciable background) and in oxygen (owing to the impossibility of measuring its pressure with an ionization manometer), but even in these cases it was about $\pm 10\%$. We could allow for some systematic errors (different for different gases) connected with the fact that the flux of fast atoms was measured at the beginning of their path, and our apparatus was not adapted to take into account scattering of neutral atoms through large angles during ionization. Bearing in mind the low probability of scattering of ions through large angles, it may be assumed that this effect did not play a large role under the conditions of our experiments.

The results of the measurements are given in Fig. 2, where the effective cross sections Q are presented as functions of the energy T and velocity v of the fast atoms.

In the energy interval from 100 to 2000 eV, the effective ionization cross sections of fast potassium atoms have values of 10^{-15}–10^{-17} cm^2 and increase with increasing T. The magnitude of the effect increases in going from argon to molecular gases, and among the latter in going from hydrogen to the heavier gases. The curves for the effect in argon, hydrogen, and nitrogen have experimental thresholds, below which the ionization process was not observed at the sensitivity of our measuring circuit. According to Massey' s "adiabatic hypothesis" (^{1}), the cross sections of inelastic processes should be small in atomic collisions that are close to slow ones. In this connection it is of interest to note the rather large values of the cross sections of the process we observed—ionization of fast potassium atoms—at comparatively low energies of the latter.

Fig. 2. Effective cross sections Q for the ionization process of fast potassium atoms as a function of their energy T and velocity v

In conclusion, we wish to express our deep gratitude to Prof. V. M. Dukel' skii for suggesting the topic and for valuable advice in carrying out the work.

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Note: Figure translations are in progress. See original paper for figures.