Observation of dielectronic recombination of the potassium ion

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We observed and investigated, for the first time ever, the phenomena of dielectric recombination of a potassium ion in intersecting electron and ion beams by detecting the 72.3 and 75.5 nm radiation that accompanies this process.

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It is known that recombination of positive ions with electrons takes on a number of forms: recombination with emission, dissociative recombination (in the case of molecular ions), recombination in triple collisions, etc. A most interesting phenomenon is the so-called dielectronic recombination, when the ion + electron system goes over from the continuum into a bond state of equal energy, fired by a transition to a level that lies lower than the ionization limit of the given atom.

Until recently, the dielectronic recombination was investigated for the most part theoretically.[1,2] It follows from these studies that dielectronic recombination plays a substantial role in the phenomena that occur in astrophysical plasma. So far, however, there are no direct experimental studies of this phenomenon.

We report here the results of an experimental investigation of dielectronic recombination under conditions of intersecting electron and ion beams. A beam of K^+ ions of energy 1 keV and current 2 μA was produced by a surface-ionization source. An electron beam with current density 2×10^{-3} A/cm^2 and energy inhomogeneity $\sim$2 eV was formed by a three-electrode gun. The beams crossed at right angles under conditions of high vacuum (10^{-8} Torr). The radiation produced as a result of the collisions of the ions with the electrons was separated with a Seya–Namioka vacuum monochromator based on a half-meter diffraction grating.[3] The radiation detector was a secondary electron multiplier of the channel type.

Owing to a relatively low concentration of the ions in the region of the collisions with the electrons ($\sim 10^7$ cm^{-3}), it was necessary to register the useful signal against an appreciable background. For a reliable separation of the signal from the background we used the procedure of modulating the two beams with rectangular phase-shifted pulses and the technique of registration of the radiation in the regime where individual photoelectrons are counted.[4]

As a result of numerous experiments it was observed that at electron energies below the threshold of excitation of the resonance lines of the potassium ions, radi-

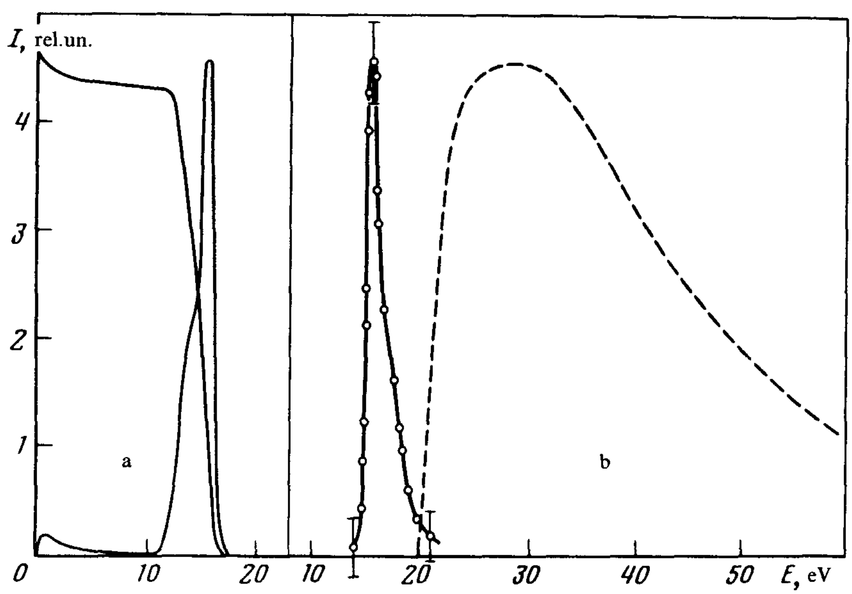

FIG. 1. a) Delay curve and distribution function of the electron beam in energy; b) excitation function of the 72.3 nm line; dashed—excitation function of the same line from Ref. 6.

ation is observed at wavelengths 72.3 and 75.5 nm. It was established that this radiation is produced only in the presence of K^+ ions in the region of the collisions with the electrons. At the same time, it turned out that no lines with these excitation thresholds are present in the known spectral tables, for example in Ref. 5.

Simultaneously with observing the spectrum we investigated the energy dependence of the intensity of this radiation. Fig. 1b shows the excitation function of the line with $\lambda = 72.3$ nm. A signal of magnitude less than 1 count/sec was separated from the detector noise, which in this case was the main source of the background, at a signal/noise ratio 1/1–1/20. Each experimental point was measured 7–10 times with exposures from 300 to 1000 sec, followed by averaging. The vertical segments indicate the mean squared measurement error.

As is seen from Fig. 1, the energy dependence has a resonant character with a maximum at 15.5 eV, and the radiation was observed in a narrow energy band (~ 5 eV) of the incident electrons. Even at 20.5 eV, which corresponds to the excitation threshold of the resonance levels, the intensity of this radiation drops practically to zero (see Fig. 2). It was also established that with changing monoenergetic properties of the electron beam the width of the observed excitation function of the line changes accordingly. Fig. 1a shows the beam-electron energy distribution function obtained by graphically differentiating the delay curve. A comparison of the observed excitation function of the spectral line with the electron energy distribution function shows them to have a mirrorlike similarity, with approximately equal width at half maximum. This form of the excitation function of the spectral lines in electron–ion processes, as far as we know from the literature, has been observed here for the first time.

It must be noted that in earlier investigations of the excitation of potassium in electron–atom collisions, Bogachev[6] observed radiation at the same wavelengths. He

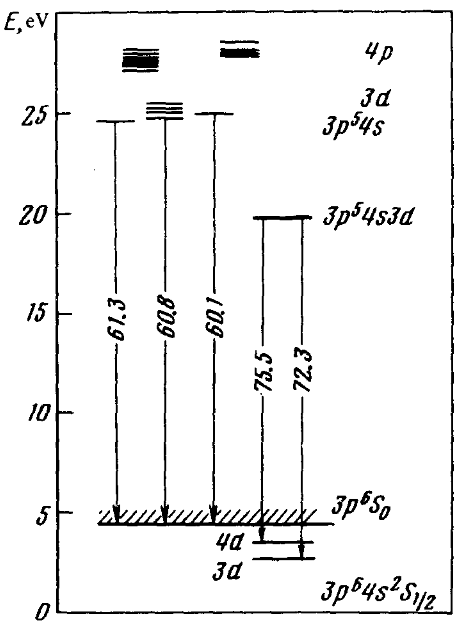

FIG. 2. Level scheme of potassium.

investigated in detail the energy dependence of the radiation with $\lambda = 72.3$ nm, which differs substantially in form from that obtained by us (see Fig. 1b). He attributes this radiation to radiative decay of the autoionization state produced as a result of excitation of the *p*-electron of the potassium atom, i.e.,

$$K(3p^6 4s) + e \rightarrow K^{**}(3p^5 3d 4s) + e \rightarrow K^*(3p^6 3d) + e + h\nu , \quad (1)$$

where K* and K** are the excited and superexcited states of the atom (see the level scheme in Fig. 2). The threshold of this reaction, which was determined by him experimentally, is 19.8 eV. In the case of the electron–ion collisions, on the other hand, the maximum of the excitation of the 72.3 nm line takes place at an electron energy 15.5 eV. This is lower than the threshold of the process (1) indicated above precisely by the value of the ionization potential of the potassium atom (4.34 eV).

Thus, the aggregate of the established facts—that the radiation is due to the interaction of electrons with potassium ions, that this radiation is produced at an electron-beam energy 15.5 eV, and that the intensity of this radiation has a resonant energy dependence—gives grounds for assuming that this radiation is the result of capture of the bombarding electron by the potassium ion on an autoionization level of the atom, with simultaneous excitation of a *p* electron, i.e., the result of dielectronic recombination

$$K^+(3p^6) + e \rightarrow K^{**}(3p^5 3d 4s) \rightarrow K^*(3p^6 3d) + h\nu . \quad (2)$$

The second line with $\lambda = 75.5$ nm, which is of lower intensity, corresponds to decay of a superexcited state of potassium to the $3p^6 4d$ level.

A comparison of the intensities of the lines investigated by us with the intensities of the resonant 60.1, 60.8, and 61.3 nm lines of the ion (see Fig. 2), which were also investigated by us, shows that they are of the same order. Thus, at least for the potassium ion, the probability of capture of an electron in dielectronic recombination and the probability of direct excitation of its resonance levels by electron impact are of the same order of magnitude.

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