**Publ. Astron. Obs. Belgrade No. 84 (2008), 29 - 33** *Contributed Paper*

# CONTRIBUTION OF AUTOIONIZING PROCESS INTO POTASSIUM ATOM IONIZATION BY ELECTRONS

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**Abstract.** Ionization cross-section of potassium atom by electrons is studied in the range from the ionization threshold to 26 eV. A resonance structure in the ionization cross-section is observed near 19 eV related to the contribution of autoionizing states. The energy position of the structure is shown to be in a good agreement with the one predicted theoretically (Roy and Rai 1973), though its absolute value is much smaller. Besides, the determined autoionizing contribution into the potassium atom ionization cross-section correlates well with the recently measured (Evrij et al. 2005) total autoionizing cross-section.

## 1. INTRODUCTION

It is known (Brink 1962) that potassium atom ionization can proceed in two independent channels. The mechanism of simple ionization corresponds to the transition of a valence electron from the ground state of $3p^5 4s$ configuration to a continuum with the formation of an ionic ground state $3p^6$ which can be also achieved by autoionizing via the excited $3p^5 4s^2$ state of the atom. The threshold of the second process is about 19 eV; at this value a break is revealed in the potassium atom ionization curve (Zapesochny and Aleksakhin 1968).

Roy and Rai (1973) were the first to take into account the contribution of the autoionizing processes into the total ionization cross-section. As a result, a fine structure in the potassium atom ionization function was revealed which had not been observed experimentally before.

Measurements of potassium atom ionization cross-section by electrons (Nygaard 1975), performed using the crossed-beam technique, give the experimental confirmation of the calculation data. In these studies the length of the overlap area of the atomic and the electron beam was 25 mm, this being much higher than in the preceding experiments of other authors. As stated by the author, this is one of the reasons explaining why they were able to observe the structure at 19 eV, not observed in other experiments. Note that the energy values at which Nygaard (1975) observed the autoionizing peaks, are in a good agreement with those of Roy and Rai (1973); however, this is not the case for the theoretically predicted absolute cross-section value.

Recently a crossed-beam experiment (Evrij et al. 2005), using a $127^o$ electrostatic cylindrical analyser, enabled the total autoionizing cross-section to be determined from the spectra of the emitted electrons, measured at the angle $54.7^o$ for various incident electron energies. The authors supposed that the autoionizing contribution into the ionization cross-section should be somewhat higher than the one observed by Nygaard (1975). Additional studies were required to check this statement.

Here we report on the studies of total cross-section of potassium atom ionization by slow monoenergetic electrons in the near-threshold energy range. A considerable attention was paid to the range from 18 to 23 eV where the highest autoionizing contribution should be expected.

## 2. EXPERIMENT

The studies were performed using a setup with a vapour-filled cell. An electron beam from an oxide cathode was formed by a hypocycloidal electron monochromator (a detailed description is given by Romanyuk et al. 1993), passed through the vapour-filled cell and was detected by a deep Faraday cup. A uniform axial magnetic field with a strength of about 150 OE, formed by Helmholtz rings, was applied for the spectrometer functioning. Due to a rather small intensity of the useful signal near the ionization threshold, the incident electron current was chosen within $0.5 \div 1$ $\mu A$. The electron energy spread in the beam did not exceed 0.20 eV (FWHM).

Potassium vapour was delivered to the cell from a separate reservoir whose temperature was kept by $30^o C$ below that of the vapour-filled cell in order to avoid precipitation of the substance under investigation on the spectrometer surface that could finally result in undesirable changes of the contact potential difference during the measurements.

A positive ion detector was located directly inside the cell and was performed as a flat electrode, protected by a metal grid and located at a distance of 5 mm from the electron beam. Positive ions were ejected from the interaction area by a slight electric field ($\sim$ 1.5 V) and detected by a V7-30 picoammeter. Using a voltage-to-currency converter, the analog signal from the picoammeter was transformed into pulses for subsequent storage by the registration system.

## 3. RESULTS AND DISCUSSION

Figure 1 shows the obtained energy dependence of total ionization cross-section for the potassium atom in the energy range from the threshold to 26 eV. The curve obtained by Nygaard (1975) is also shown for comparison, our data at $E = 8.5$ eV being normalized by this curve. A rather good agreement with our results is seen to be observed.

The energy dependence of the ionization cross-section was measured by scanning over the electron energy with a step of 0.05 eV and acquisition time at each point of $\sim 3-5$ s. The energy scale was set from the initial part of the $I-V$ characteristic of the electron current at the primary beam collector and from the spectroscopic threshold of the atom ionization ($E_i = 4.34$ eV) (NIST AtData). The position of the atom ionization threshold was determined by linear extrapolation of the experimentally measured initial part of the ionization curve and corrected using the method proposed by Lossing et al. (1971).

As seen from Figure 1, the ionization cross-section increases rather steeply near the threshold (from 4.34 to 8 eV) and at 8.5 eV a distinct maximum is observed, followed

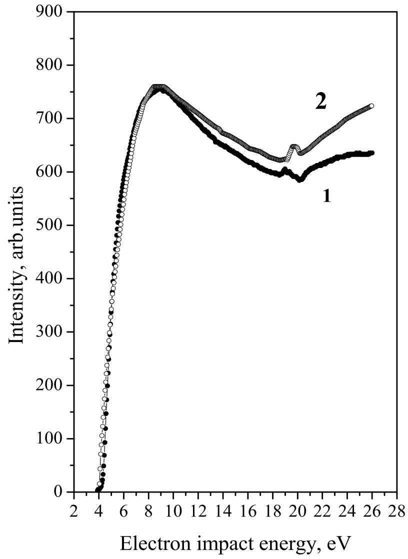


Figure 1: Potassium atom ionization cross-section: curve 1 - our experimental data, curve 2 - data of Nygaard (1975).

by a gradual decrease to the energy of $\sim 18$ eV, at $E \sim 19$ eV a slight maximum is observed, again followed by the cross-section increase.

It is reasonable to ascribe the first maximum in the ionization curve at 8.5 eV to the direct ionization of the s-electron as follows:

$$A + e \rightarrow A_s^+ + 2e, \qquad (1)$$

where $A$ and $A_s^+$ are a neutral atom and a conventional ion, respectively.

Note that the position of this maximum in our curve agrees well with the data of Zapesochny and Aleksakhin (1968) and Nygaard (1975).

In the energy dependence of the potassium atom ionization cross-section we have observed a structure with a maximum near 19 eV, which have not been observed in earlier experiments (Zapesochny and Aleksakhin 1968, Brink 1962). However, it was clearly revealed by Nygaard (1975). The absence of this structure in the study by Zapesochny and Aleksakhin (1968) can be explained by the incident electron energy scanning with a large step. Nygaard (1975) ascribes the appearance of this structure to the excitation of $3p^5 4s^2\ ^2P_{3/2,1/2}$ levels (at 18.72 and 18.98 eV) with subsequent decay and emission of electrons.

In order to determine the energy position and character of this structure more accurately as well as to determine its contribution into the ionization cross-section, we have additionally performed thorough measurements of the ionization function in the energy range from 19 to 23 eV with a smaller step of energy scan and higher acquisition time at each point. The parameters of the observed cross-section features were determined using the approximation method with a fitting function in the framework

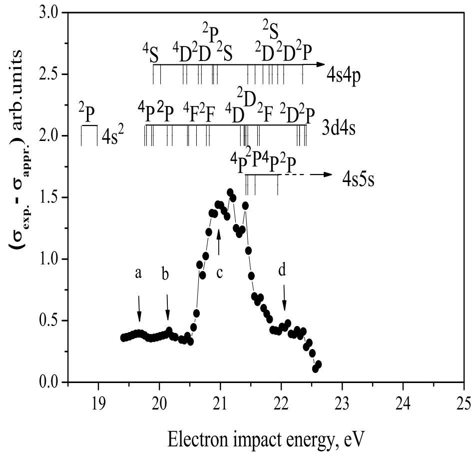


Figure 2: Structure in the total ionization cross-section.

of Origin 7.5 with subsequent subtraction of the smoothed curve from the measured one ($\sigma_{exp.} - \sigma_{appr.}$). The obtained ($\sigma_{exp.} - \sigma_{appr.}$) curve is shown in Figure 2. The positions and notations of the lowest $3p^5n_1l_1n_2l_2$ autoionizing levels (Mansfield and Ottley 1979, NIST AtData) are also shown in the figure. It is seen that for the collision energies below 20.5 eV the decay of $3p^54s^2\ ^2P$ and $3p^53d4s\ ^4P$ levels contributes to the ionization cross-section. The predominant feature is observed above 20.5 eV. Evidently, this results from the strong resonance excitation of the lowest $3p^53d4s\ ^4F,^2F$ and $^4D$ autoionizing levels (Evrij et al. 2005 and references therein). These levels and, partially, autoionizing quartets of the $3p^54s4p$ configurations mainly determine the potassium atom ionization in the whole collision energy range 20.5-24.4 eV. It is also seen from Figure 2 that in the range from 19 to 23 eV four well-resolved features ($a, b, c$, and $d$) are revealed, located at 19.55, 20.07, 21, and 22.04 eV, respectively. The a feature can be attributed to the formation and decay of a short-lived state of the negative ion at 19.47 eV, observed at the excitation of the $3p^54s^2\ ^2P_{3/2}$ level (Borovik et al. 2005).

The $d$ feature corresponds to the negative ion resonance state, observed at 22.09 eV in the excitation function of the $3p^53d4s\ ^4D$ level (Borovik et al. 2005).

In Figure 3 our results are compared with the data of Evrij et al. (2005). Our data are normalized with respect to those of Evrij et al. (2005) at $E = 21$ eV. A good agreement of these data is seen to be observed. This agreement in the range from 19 to 22.5 eV once more demonstrates the presence of the autoionizing process contribution into the ionization cross-section.

Thus, the measurements performed have shown that the autoionizing contribution is clearly revealed in the cross-section of potassium atom ionization by electrons in the energy from 19 to 23 eV. However, the comparison has shown this contribution to be smaller than the one predicted theoretically (Roy and Rai 1973).

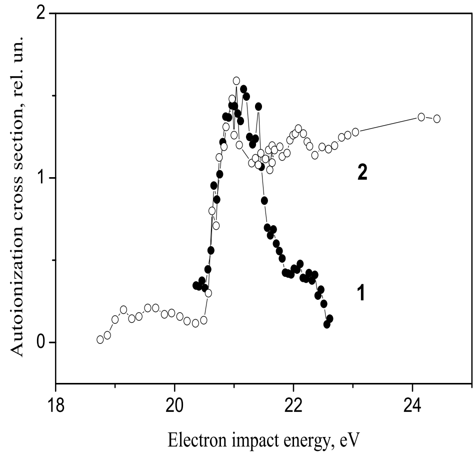


Figure 3: Comparison of the structure, revealed in the total ionization cross-section, with the total autoionizing cross-section by Evrij et al. (2005).

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