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EXCITATION OF AUTOIONIZING STATES IN POTASSIUM BY ELECTRON IMPACT

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The ejected-electron excitation functions for the $3p^53d4s\ ^4P_{3/2}$, ^4D_J lowest quartet and $3p^53d4s(^1P)^2P_{3/2}$ upper doublet autoionizing states in potassium have been measured with an energy resolution of 0.2 eV over the electron impact energy region from the lowest excitation threshold up to 500 eV. The detailed picture of the excitation dynamics of the $^4P_{3/2}$, ^4D_j and $^2P_{3/2}$ levels in the near-threshold impact energy region has been achieved due to the use of a small increment of the incident electron energy. An analysis of the data, including the consideration of resonance and cascade excitation processes, has been performed on the base of available experimental and theoretical data on the $3p^6$-excitation in potassium atoms.

INTRODUCTION

The pioneering experimental studies of electron impact ionization of alkali atoms performed by Aleksakhin and Zapesochny [1] have revealed an important role of autoionization in this process. As ionization processes play the dominant role in the different kinds of plasma, including laser plasma [2], their intense experimental and theoretical studies have been started in the middle of seventies (see e.g. [3, 4] and references therein). However, only a few works are known on measuring the electron impact excitation functions of core-excited autoionizing states in potassium. First such data were obtained for the $(3p^54s3d)^4F$ and $(3p^54s4p)^4D$ metastable states at the energy resolution of 0.3 and 0.08 eV, respectively [5, 6]. The strong resonances revealed in the threshold impact energy region were preliminarily attributed by the authors to the negative-ion states. Also, the role of cascade processes has been discussed in the excitation of the quartet states. The total excitation cross-section for the $(3p^54s^2)^2P_{1/2,3/2}$ lowest autoionizing doublet has been measured recently in [3, 7] with the energy spread of the incident electrons equal to 0.7 and 0.25 eV, respectively. Using the results of extended *R*-matrix calculations, a strong near-threshold structure has been attributed by the authors also to the negative-ion resonances. Later, these data have been analyzed with the aim to find the role of cascade processes in excitation of the $(3p^54s^2)^2P$ levels [8].

In the present work, we have studied the ejected-electron excitation functions for the $(3p^53d4s)^4P_{3/2}$,^4D_J lowest quartet and $3p^53d4s$ $(^1P)^2P_{3/2}$ upper doublet autoionizing states in potassium atoms in the impact energy region from the excitation threshold of levels up to 500 eV. By using an improved incident electron energy resolution of 0.2 eV and a small incremental step of the incident electron beam energy, the dynamics of electron impact excitation of the $^4P_{3/2}$, ^4D_J and $(^1P)^2P_{3/2}$ states was studied in detail, with analyzing the role of resonance and cascade excitation processes.

EXPERIMENTAL

Current measurements were performed on apparatus which consisted of a 127° electrostatic cylindrical monochromator, electron analyzer, and an atomic beam source (fig. 1). The monochromator with the mean radius of electron trajectory of 30 mm allowed obtaining an electron beam in the 16 ÷ 100 eV energy region with the intensity of 0.1 mkA and energy spread of 0.2 eV (FWHM) [9].

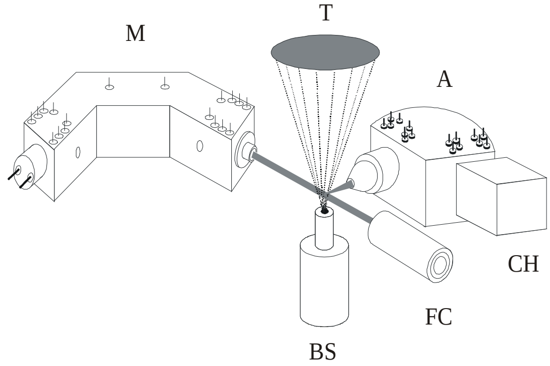

Figure 1. Electron spectrometer for measuring the ejected-electron spectra of metal vapours: M – incident electron monochromator; A – analyzer of ejected electrons; BS – vapour source; FC – Faraday cup; CH – secondary electron multiplier; T – vapour trap.

The ejected-electron analyser with the mean radius of 12.7 mm and the energy resolution of 0.15 eV was located at the observation angle of 75°. The resistively heated source of potassium vapours [10] provided their density in the interaction region of about 10^{12} at·cm^{-3}. The ejected-electron excitation functions have been obtained as an incident-electron energy dependence of line intensities corresponding to the electron decay of the $^4P_{3/2}$, ^4D_J and $(^1P)^2P_{3/2}$ autoionizing states. Note an essential peculiarity of such measurements – instead of measuring the intensity of a single line (as it is done in traditional optical measurements [11]), the whole ejected-electron spectrum (or its part) is measured for particular impact energy value. In the present work the spectra were measured step-by-step for different values of the incident electron energy. The intensity of the spectra was automatically normalized on the corresponding incident electron beam intensity by a “current-to-frequency” converter. All data acquisition procedure has been automatically controlled by the computerized detection system [12]. An uncertainty in estimation of the line intensity depended on the detected signal level providing the necessary statistics of the data acquisition. In present measurements, it did not exceed 20% for the lowest line intensities in potassium spectra. The incident-electron and ejected-electron energy scales were calibrated by using photoabsorption data [13] for the excitation threshold of the $(3p^54s^2)$ $^2P_{3/2}$ state at 18.722 eV. The uncertainties of both energy scales were estimated as ± 100 meV and ± 50 meV, respectively.

RESULTS

In figure 2, the ejected-electron excitation functions for the $(3p^53d4s)^4P_{3/2},^4D_J$ and $3p^53d4s(^1P)^2P_{3/2}$ autoionizing states in potassium atoms are shown in an incident electron energy region from the excitation thresholds of levels up to 500 eV. The excitation thresholds for these states are known to be 19.79; 21.42 and 22.42 eV, respectively [14] (marked in figure 2 by dashed lines). Note, as it follows from the comparison of ejected-electron spectra measured at low impact energies [15], the $^4P_{3/2}$ line dominates in the spectra. Therefore, the measured excitation function of this level has a minimal influence from the close lying fine-structure components. The same is valid for the $(^1P)^2P_{3/2}$ state. The excitation function for the ^4D_J states, on the other hand, reflects the summary excitation of all *J*-components, due to their much closer energy position and comparable excitation cross sections. As it can be seen, the excitation functions for the quartet states possess a resonance-like shape with main maxima at 27.7 eV ($^4P_{3/2}$) and 30.6 eV (^4D_J). Both functions start with well resolved near-threshold resonances at 21.1 and 21.5 eV, respectively. On the other hand, the excitation function of the $3p^54s3d(^1P)^2P_{3/2}$ doublet state starts with a step-like rise of the cross section just above the excitation threshold (see arrow). Above 25 eV there is a smooth rise of the cross section up to the maximum value at about 140 eV. The data in the region 40÷50 eV

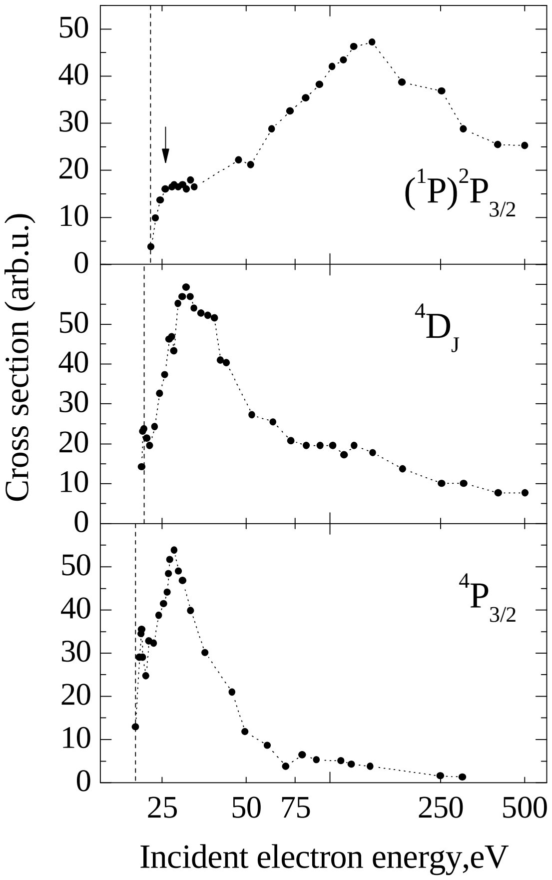

Figure 2. The ejected-electron excitation functions for the $3p^54s3d$ autoionizing states. Vertical dashed lines mark the excitation thresholds of the states.

were omitted from the present consideration due to the strong influence from the energy loss-spectra.

DISCUSSION

The following excitation and decay processes should be considered in an analysis of the electron impact excitation of the $3p^54s3d$ states in potassium, i.e.

$$K(3p^64s) + e_{inc} \rightarrow K^*(3p^54s3d) + e_{sc} \qquad (1)$$

$$\rightarrow K^*(3p^5n_1l_1n_2l_2) + e_{sc} \qquad (2)$$

$$\downarrow$$

$$K^*(3p^54snl) + h\nu$$

$$\rightarrow K^-(3p^54s3d)\varepsilon \qquad (3)$$

$$\downarrow$$

$$K^*(3p^54s3d) + e_{sc}$$

Process (1) is the direct electron impact excitation of the $3p^54s3d$ autoionizing configuration. Process (2) describes the excitation of the $3p^54s3d$ states through the cascade population by the radiative transitions from the $3p^5n_1l_1n_2l_2$ high-lying autoionizing states. Finally, process (3) represents the resonance excitation of autoionizing states due to the electron decay of the negative-ion states. Below we will consider processes (1) ÷ (3) aiming to find their role in excitation of the $(3p^53d4s)\ ^4P_{3/2}$, ^4D_J and $(^1P)^2P_{3/2}$ states.

As it follows from the comparison of functions, their general shape agrees well with the character of corresponding excitation transition – spin-exchange for the $^4P_{3/2}$, ^4D_J quartet states and dipole for the $(^1P)^2P_{3/2}$ state. Hence, process (1) determines completely the excitation of the $(3p^53d4s)$ $^4P_{3/2}$, ^4D_J and $(^1P)^2P_{3/2}$ states over the whole impact energy region studied in the present work. In this case processes (2) and (3) may be considered only as some contributions to the main direct excitation process.

It is well known that in the excitation functions the cascade transitions manifest themselves as a distinct rise of the cross section located close to the excitation threshold of cascading levels. In accordance with our previous analysis [6, 8], the contribution from cascade transitions (process 2) to excitation of the low-lying quartet states in potassium may be expected only from the radiative decay of the $3p^54s4p$ quartet levels lying between 20 eV and 20.6 eV. Due to the high excitation energy of the $(3p^53d4s)^4D_J$ level at 21.42 eV, such transitions can not influence the excitation of this level. The present data also do not reveal any remarkable cascade features at higher impact energies (see figure 2). The cascade contribution into the $(3p^53d4s)\ ^4P_{3/2}$ level, on the other hand, could be revealed in the initial part of its excitation function, in particular in the low-energy wing of the near-threshold resonance at 21.1 eV. However, in order to reveal this process, the additional measurements should be performed with a smaller incremental step of the electron impact energy.

The presence of the resonance features in all measured excitation functions just confirms the earlier observations [5-7] of the important role of negative-ions in electron impact excitation of the $3p^6$-subshell in potassium. The threshold resonance at 21.1 eV, observed in the excitation function for the $(3p^5 3d4s)$ $^4P_{3/2}$, level may reflect the formation of a negative-ion state with a tentative configuration $3p^5 3d4s^2$. The same negative-ion configuration could also be responsible for the presence of the threshold resonance at 21.5 eV in the excitation of the $(3p^5 3d4s)^4D_J$ level.

The near-threshold behaviour of the excitation cross section for the $3p^5 3d4s$ $(^1P)^2P_{3/2}$ high-lying level points out the competitive role of the resonance and cascade processes. Indeed, the observed resonance-like rise of the cross-section may be attributed both to the mixture of close-lying negative-ion resonances and to the cascade transitions, including those of resonance type, lying in the energy region 23÷30 eV. Unfortunately, at present there are no data on such processes in potassium at these energies.

CONCLUSIONS

In the present work, the electron impact excitation of the $(3p^5 3d4s)$ $^4P_{3/2}$, ^4D_J and $(^1P)^2P_{3/2}$ autoionizing states in potassium atoms has been studied over the impact energy region from the lowest excitation threshold up to 500 eV at the incident electron energy resolution of 0.2 eV. The analysis of the data has shown that for all states considered the direct excitation process dominates over the whole impact energy region. The resonance features observed in the near-threshold region of the excitation functions point out the presence of strong negative-ion resonances in the excitation of all considered levels. In case of the $(3p^5 3d4s)$ $^4P_{3/2}$, ^4D_J quartet levels, these resonances can be tentatively attributed to the $3p^5 3d4s^2$ configuration of negative potassium ion. For the $3p^5 3d4s(^1P)^2P_{3/2}$ level the cascade transitions may also influence its excitation at threshold energies.

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ЗБУДЖЕННЯ АВТОІОНІЗАЦІЙНИХ СТАНІВ КАЛІЮ ЕЛЕКТРОННИМ УДАРОМ

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Одержані функції збудження для $3p^53d4s\ ^4P_{3/2}$, ^4D_J квартетних- та $3p^53d4s(^1P)^2P_{3/2}$ дублетного автоіонізаційних рівнів атомів калію із енергетичною роздільною здатністю 0.2 еВ в діапазоні енергій налітаючих електронів від найнижчого порогу збудження до 500 еВ. Завдяки малому кроку зміни енергії електронів, що налітають, вперше отримана детальна картина динаміки збудження $^4P_{3/2}$, ^4D_J та $^2P_{3/2}$ рівнів в області біля енергетичного порогу їх збудження. Аналіз одержаних результатів, включаючи розгляд резонансних і каскадних процесів, проведено на основі наявних експериментальних та теоретичних даних зі збудження $3p^6$ оболонки атомів калію. Показано, що у всіх досліджених рівнів домінуючим є процес прямого одноелектронного збудження з основного стану атома калію. Не виявлено прямого впливу каскадних процесів. У біляпороговій області енергій зіткнень квартетні рівні збуджуються виключно через утворення та наступний розпад станів негативного іону калію з ймовірною конфігурацією $3p^53d4s^2$. Для стану $(^1P)^2P_{3/2}$ поряд із резонансним збудженням певну роль можуть відігравати також каскадні процеси.