EFFECTIVE ELECTRON IMPACT EXCITATION AND IONIZATION CROSS SECTIONS FOR CESIUM, RUBIDIUM, AND POTASSIUM ATOMS IN THE PRE-THRESHOLD REGION

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Submitted to JETP editor June 2, 1966

J. Exptl. Theoret. Phys. (U.S.S.R.) 51, 1617-1621 (December, 1966)

The effective cross sections for resonance excitation of rubidium atoms (to the 5p level) and potassium atoms (to the 4p level) are measured in the pre-threshold electron energy region by the "trapped-electron" method. The slopes of the initial linear segments of the excitation curves are 2×10^{-14} cm^2/eV for Rb and 7.5×10^{-15} cm^2/eV for K. The effective ionization cross sections for Cs, Rb, and K atoms are measured in the pre-threshold electron energy region by the "trapped-ion" method. For these elements the slopes of the initial linear segments are respectively 1.7×10^{-16}, 2.7×10^{-16}, and 2.2×10^{-16} cm^2/eV.

THE extensive use of alkali metals in various branches of physics and technology requires a detailed study of their properties. One of the main problems in this study is the determination of the cross sections of inelastic interactions of electrons with alkali-metal atoms in the pre-threshold region of energies.

In our previous work[1] we determined the excitation cross section of cesium atoms by electron impact to the 6p level in the pre-threshold region by means of the "trapped-electron" method developed by Schulz.[2] The method described there has been used in this work to determine the electron impact resonance excitation cross sections of rubidium atoms (to the 5p level) and of potassium atoms (to the 4p level). After further analysis of the working principle of the device used in [1], it turned out that the device can also be utilized for measuring electron impact ionization cross sections of atoms in the pre-threshold region; this has been done for cesium, rubidium, and potassium.

1. EXCITATION

A comparatively small number of papers has been devoted to the problem of electron impact excitation of alkali-metal atoms. In [1] we have already dwelled briefly on those which considered the resonance excitation of cesium. The resonance excitation cross section of rubidium has recently been determined experimentally (by a spectroscopic method) by Zapesochnyĭ and Shimon,[3] and calculated theoretically by Vaĭnshteĭn et al.[4] Volkova and Devyatov[5] investigated the resonance excitation of potassium spectroscopically. This scant study of the electron impact excitation of alkali-metal atoms prompted us to return to this problem and utilize the new electronic method worked out by Schulz,[2] which differs in principle from the method used in [3,5], to determine the resonance excitation of cesium, rubidium, and potassium. Special attention has been accorded in our experiments to accurate measurement of the vapor pressure of the alkali metals which was determined from the thermionic saturation current obtained by thermal ionization of cesium, rubidium, and potassium on the incandescent surface of a tungsten filament.

The device which we used to measure the excitation cross sections of rubidium and potassium did not differ from that described in [1], except for the length of the collision chamber which was extended to 6.4 cm; this ensured a constant potential over 80 percent of the electron path. As in [1], the measurements were carried out in the single electron collision mode ($p = 10^{-5} - 0.5 \times 10^{-5}$ mm Hg). The energy spread of the exciting electrons did not exceed 0.15—0.2 eV.

The dependences of the excitation cross sections q_{exc} of rubidium atoms (to the 5p level) and of potassium atoms (to the 4p level) on the electron energy are given in Fig. 1 by curves 2 and 3 respectively. On the same Figure curve 1 shows the dependence $q_{exc}(V)$ for cesium (to the 6p level) which was obtained in [1]. The slopes a_{exc} of the initial linear sections of these dependences are given in the table. As indicated in [1], the

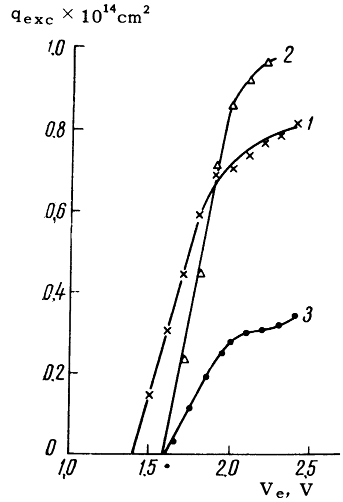

FIG. 1. Dependence of the cross section for excitation to the first resonance level of cesium (curve 1), ribidium (curve 2), and potassium (curve 3) atoms on the electron energy.

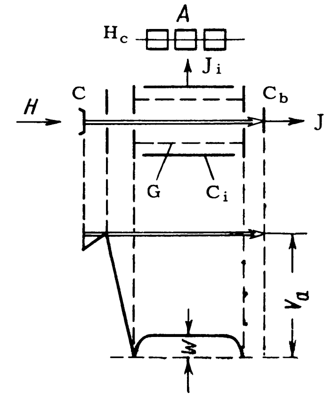

FIG. 2. Schematic diagram of the experimental device and its potential distribution.

values of q_{exc} obtained by us for cesium are in good quantitative agreement with the data of spectroscopic measurements carried out by Zapesochnyĭ and Shimon.[3] On the other hand, the values of q_{exc} for rubidium which follow from Fig. 1 have turned out to be larger by about a factor of 3 compared to those obtained in [3]. These same values of q_{exc} agree to within 50 per cent with the results of the theoretical calculation[4] by the Born method with allowance for the strong coupling of the 5s–5p–6p levels. We were unable to compare our values of q_{exc} for potassium with those of Volkova and Devyatov,[5] since they did not determine sufficiently clearly the pre-threshold part of the excitation function.

2. IONIZATION

A number of papers have been devoted to the problem of ionization of alkali-metal atoms by electron impact. In the first of these[6] a mass-spectrometric method was employed to measure the relative course of the ionization function of cesium, rubidium, and potassium in the region of electron energies from the threshold to 700 V. That paper does not contain absolute values of the ionization cross sections, and therefore the slope of the initial straight-line portion of the ionization function for cesium cited in von Engel's book[7] from the work of Tate and Smith[6] is arbitrary. Recently Brink[8] and McFarland and Kinney[9] determined the ionization cross sections of alkali-metal atoms in the range of high-energy electrons from 50 to 500 V, as well as their maximum values, by the technique of crossed electron and atomic beams. Finally, McFarland[10] carried out theoretical calculations of the ionization cross sections of cesium, rubidium, and potassium according to Gryzinski's method; the results of these turned out to be in good agreement with the experimental data presented in [8,9]. It follows from this short listing that the ionization cross sections of alkali-metal atoms for energies beyond the ionization optimum have been determined with sufficient accuracy, whereas their pre-threshold values remain practically unknown.

The experimental device with which we determined the pre-threshold values of the ionization cross sections of cesium, rubidium, and potassium atoms did not differ in its construction from that which we used in determining the resonance excitation cross section of these atoms.[1] Its schematic

Element	10^{14} a_{exc}, cm²/eV	10^{16} a_i, cm²/eV
Cs	1.5	1.7
Rb	2.0	2.7
K	0.75	2.2

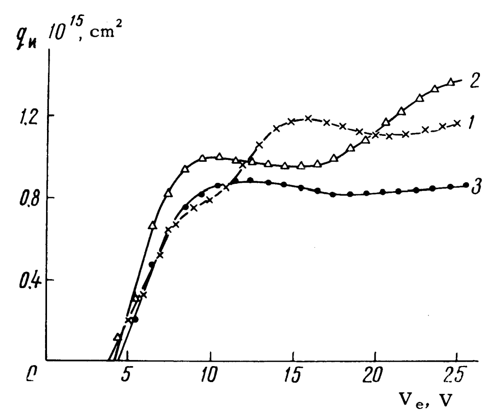

FIG. 3. Dependence of the ionization of cesium (curve 1), rubidium (curve 2), and potassium (curve 3) on the electron energy.

diagram and potential distribution are shown in Fig. 2. In this device C is the cathode, C_b is the electron-beam collector, C_i is the ion collector, G —a grid whose electrical transparency $\eta = W/V_{gi} = 0.1$ (V_{gi} —the voltage between the electrodes G and C_i). Unlike in the case of the excitation experiments, a negative voltage was applied between the grid G and the collector C_i; as a result of this a potential well W of opposite polarity (Fig. 2) — an "ion trap"—was produced in the ionization chamber. As can be seen from Fig. 2, the energy of the ionizing electrons in the chamber is $V_a - W$.

A longitudinal 200—250 Oe magnetic field, as well as the negative potential on the electrode C_i prevented the electrons of the beam from falling on it. The positive ions produced in the chamber appeared in the potential well W, from which they could only impinge on the collector C_i. Modeling in an electrolytic trough showed that along 80 per cent of the length of the ionization chamber and along its radius W = const. This is the main advantage of the device we used, in which, unlike in the devices of Compton and Smith, [11] the energy of the ionizing electron remains unchanged over most of its path.

The dependences of the ionization cross sections q_i for cesium, rubidium, and potassium on the electron energy determined with the aid of this device are represented on Fig. 3 by curves 1, 2, and 3 respectively. The measurements were carried out in the mode of single electron collisions, which corresponds to an alkali-metal vapor pressure of $(1-5) \times 10^{-5}$ mm Hg. The latter value was, as in previous experiments, determined directly on the device from the thermionic saturation current from the surface of an incandescent tungsten filament (cf. the upper part of Fig. 2; H_c —tungsten filament cathode, A —anode). The employed electron current of the primary beam to the collector C_b of up to 10^{-6} A, and of the ion current to the collector C_i, up to 10^{-8} A, did not give rise to distortion of the potential in the collision chamber due to the effect of the space charge of electrons and ions (this was checked by a technique described in [1]). The monokineticity of the primary-beam electrons, determined from the half-width of the volt-ampere delay curve, was somewhat worse compared with that obtained by us in [1]: it amounted to ~ 0.3 eV for energies of the ionizing electrons of up to ~ 12 eV, and ~ 0.6 eV for energies of ionizing electrons between 12 and 25 eV. The measurements were made up to primary-beam electron energies smaller than the threshold for the production of doubly-charged ions.

The slopes a_i of the initial straight-line portions of the curves shown in Fig. 3 are given in the table.

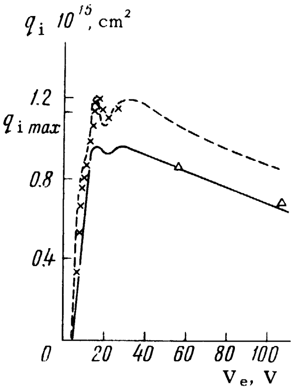

FIG. 4. Dependence of the ionization cross section of cesium atoms on the electron energy: crosses – data of this work; dashed curve – the relative course of the ionization curve [6]; continuous curve – theoretical [10]; triangles – data of [9].

As follows from the theoretical calculation, [10] the second rise observed on the curves presented in Fig. 3 is connected with the ionization of alkali-metal atoms of deeper energy states: for Cs—5p, for Rb—4p, and for K—3p. The size and position of the second rise are in good agreement with [10].

In Fig. 4 we compare the ionization cross sections obtained by us for cesium (crosses) with the data of the theoretical calculation of McFarland[10] (continuous curve), and with the relative course of the ionization function obtained by Tate and Smith,[6] normalized according to our data (dashed curve). In the same figure, we marked on the ordinate axis the maximum ionization cross section of cesium obtained by Brink[8] without indicating its position; the triangles on the right are the results of experimental measurements of McFarland and Kinney.[9] The values of the experimental cross sections shown in Fig. 4 which have been obtained at various energies of the ionizing electrons are in good agreement with the theoretical calculation.[10] The same extent of agreement is also observed for rubidium and potassium.

In conclusion the authors express their sincere gratitude to Professor N. D. Morgulis for directing the work.

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Translated by Z. Barnea
195