Electronic spectra of autoionization states of barium, observed in electron-atom collisions

I. S. Aleksakhin, A. S. Borovik, and I. P. Zapesochnyĭ

Uzhgorod State University
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Electron spectroscopy using the technique of intersecting electron and atom beams was used to study, for the first time, the spectra of electrons emitted by barium atoms. It is established that the discrete electron groups observed in the spectrum, with energies 6–16 eV, correspond to the decay of the excited autoionization states of Ba and Ba^+.

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We present in this communication the first results obtained on the excitation of autonionization states of barium by electron impact. We used an electron-spectroscopy procedure and the technique of intersecting electron and atom beams. To analyze the electron energy we used a 180-degree hemispherical electrostatic capacitor with resolution 0.05 eV. The electron spectra were registered at an angle 90° to the direction of motion of the intense electron beam. The detector of the emitted electrons was a channel-type electron multiplier.

Figure 1 shows the energy spectra of the electrons emitted by the barium atoms at incident-electron energies 110 and 500 eV, while Table I lists the energies of the emitted electrons. In view of the lack of reliable experimental and theoretical data on the energy positions of the autoionization states of barium, an experimental energy scale is given.

When the energy E_p of the incident electrons is increased from 110 to 500 eV, the character of the spectrum of the emitted electrons changes noticeably: the intensity of the lines in the spectrum decreases (by an approximate factor of two) and their number is reduced (to 35). The last fact can be understood if it is assumed that at energy $E_p = 110$ eV there are effectively excited the autoionization states corresponding both to optically allowed and to optically forbidden transitions from the ground state of the barium atoms. As a consequence of the resonant character of the excitation of the forbidden states, their role becomes negligible at an energy $E_p = 500$ eV.

To discuss the results, we consider first the most probable processes wherein the inner electrons of the barium atom are excited into autoionization states whose decay can lead to emission of discrete groups of eletrons:

$$\mathrm{Ba}\,(5p^6 6s^2) + e \;\rightarrow\; \mathrm{Ba}^*\,(5p^5 6s^2 nl) + e, \tag{1}$$

$$\mathrm{Ba}(5p^6 6s^2) + e \;\rightarrow\; \mathrm{Ba}^{+*}(5p^5 nl\, n'l') + 2e. \tag{2}$$

Each of the indicated autoionization states can decay with production of ions in either the ground or an excited state. This greatly complicates the interpretation of the electron spectra.

An analysis of the obtained spectra jointly with the available data[1-5] makes it possible to separate in them two groups of lines: group A with electron energy 11–16 eV and group B with energy 6–11 eV. The emitted electrons of group A are a manifestation of the decay of the excited atomic autoionization states (reaction 1) with production of the ion Ba^+. The line broadening

TABLE I. Energies of the electrons emitted in the decay of autoionization states of barium.

Number of lines in spectrum[1)]	E_e, eV[2)]	Number of lines in spectrum[1)]	E_e, eV[2)]	Number of lines in spectrum[1)]	E_e, eV[2)]
1	16,33	16	13,03	33	9,34
2_+	16,22	d	12,97	e	9,19
3	15,84	17	12,88	34	9,03
4	15,56	18	12,78	35_+	8,93
5_+	15,46	19_+	12,65	36_+	8,82
6_+	15,08	20_+	12,41	37_+	8,65
7_+	15,03	21	12,32	38_+	8,53
8_+	14,89	22	12,24	f	8,38
a	14,57	23_+	12,02	39_+	7,76
9_+	14,34	24_+	11,84	40_+	7,28
10	14,29	25	11,79	41_+	6,99
11	14,21	26_+	11,62	g	6,81
12	14,01	27_+	11,45	42_+	6,67
b	13,83	28	10,37	43_+	6,33
13	13,72	29_+	10,27	44_+	6,19
c	13,55	30_+	10,17	45_+	6,09
14	13,42	31_+	10,05	—	—
15_+	13,21	32_+	9,78	—	—

[1)]The subscript "+" indicates that these lines are present in the spectra at both 110 and 500 eV.
[2)]The absolute-energy error is ± 0.2 eV.

observed in this part of the spectrum is due to the fact that the autoionization states of the atoms decay not only with production of an ion in the ground state, but also in excited states.

The lines of group B with energy 6–11 eV, in contrast to group A, are more strongly pronounced in the spectra. The corresponding autoionization states are the result of ionization of the p^6 electron of the barium atom (reaction 2). In this case, the most intense lines at energies 7.76 eV (No. 39) and 9.78 eV (No. 32) correspond to the decay of ionic autoionization states with energies 22.97 and 24.99 eV. The energy of the highest ionic autoionization states of barium, determined from the spectrum in group B, is 25.58 eV (No. 28), which is less than the energy of the first excited state of Ba^{++}.[6] It follows therefore that the autoionization states of the ion Ba^+ decay only to the ground state of the doubly charged ion Ba^{++}. It is the absence of multiple decay channels which explains in this case the "purity" of the spectrum in group B.

A comparison of the line intensities in groups A and B shows that the most effectively excited are the autoionization states of the ion Ba^+, which decay with production of Ba^{++}. This fact confirms the previously advanced hypothesis[1,4] that the ionic autoionization states plays the dominant role in the production of Ba^{++} in electron-atom collisions.

As to the discrete groups of electrons *a*—*g*, which are present in the spectrum II ($E_p = 500$

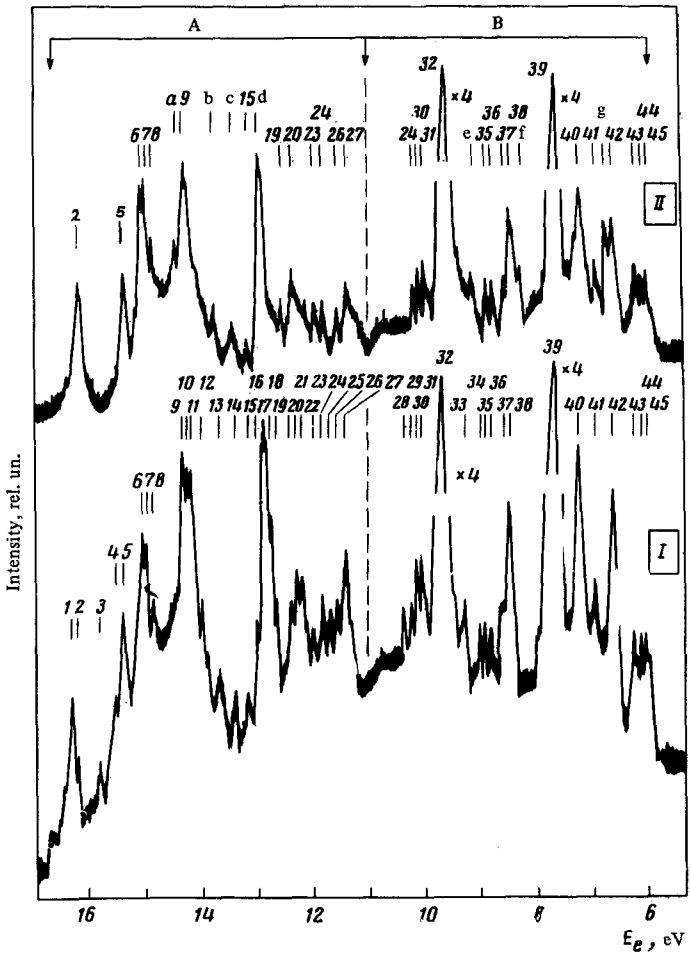

FIG. 1. Spectra of electrons emitted by barium atoms at incident-electron energies $E_p = 110$eV (I) and $E_p = 500$ eV (II).

eV), they stem possibly from the decay of autoionization states resulting from excitation of the deeper $5s^2$ and $4d^{10}$ electrons of the barium atom.

A more detailed analysis of the energy positions of the autoionization states of barium and their classification will be carried out after a study is made of the spectra of the emitted electrons in the region of the threshold excitation energies.

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