Observation of radiative transitions between lithium-atom auto-ionization states excited by an electron beam

I. S. Aleksakhin, G. G. Bogachev, I. P. Zapesochnyĭ, and S. Yu. Ugrin
Uzhgorod State University

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Experiments with intersecting beams of slow electrons and lithium atoms reveal the excitation of several spectral lines (193.1, 198.5, 204.0, 217.3, 233.7, and 293.4 nm) which correspond to transitions between auto-ionization states of the lithium atom.

Hopes for the development of lasers for vacuum-UV and ultrasoft x-ray regions have recently been pinned on the auto-ionization states of alkali atoms that can undergo radiative decay.[1,2] The radiative decays of auto-ionization states of K, Rb, and Cs atoms in the vacuum-UV region were originally studied[3] by means of the electron-impact excitation of these atoms. The emission observed in those experiments, however, corresponds to transitions for which only the upper level is an auto-ionization level: The lower level is one of the ordinary levels of the neutral atom. Similar transitions in the Li and Na atoms were found subsequently.[4] In addition, lines in the region 180–300 nm in experiments with a hollow cathode[5] and in beam-film experiments[6] have been attributed by the authors to transitions between auto-ionization states. However, there was no direct proof of this identification. A definitive answer to this question requires experiments on the interaction of monoenergetic electrons with atoms. Such experiments were the purpose of the present study, in which we measured the spectra in the near vacuum-UV region (120–360 nm) in collisions of lithium atoms with a beam of electrons of adjustable energy.

The experimental apparatus with intersecting electron and atomic beams is similar to that described in Ref. 3. The dispersive element in the Seya-Namioka vacuum monochromator is an aluminum-coated replica, protected by a layer of magnesium fluoride. The emission is detected by an FÉU-142 photomultiplier.

Careful measurements of the spectra excited at various electron energies revealed two groups of comparatively intense lines in the wavelength interval studied: a short-wavelength group (140–180 nm) and a long-wavelength group (230–330 nm). In addition, there were several fainter lines, lying for the most part between these two groups. Figure 1 shows a typical spectrum, at an energy of 100 eV of the bombarding electrons.

Analysis of the experimental parameters and results convinces us that all the lines observed in the spectrum belong to the lithium atom or to lithium ions. Working from tables[7] of atomic spectral lines, we can easily identify most of the lines of the long-wavelength group as lines of the main series LiI $2s$-np ($n = 3$–11), and the lines of the short-wavelength group can be identified as LiII lines. The other lines are not listed in the tables of Ref. 7, but for six of them, namely 193.1, 198.5, 204.0, 217.3, 233.7, and

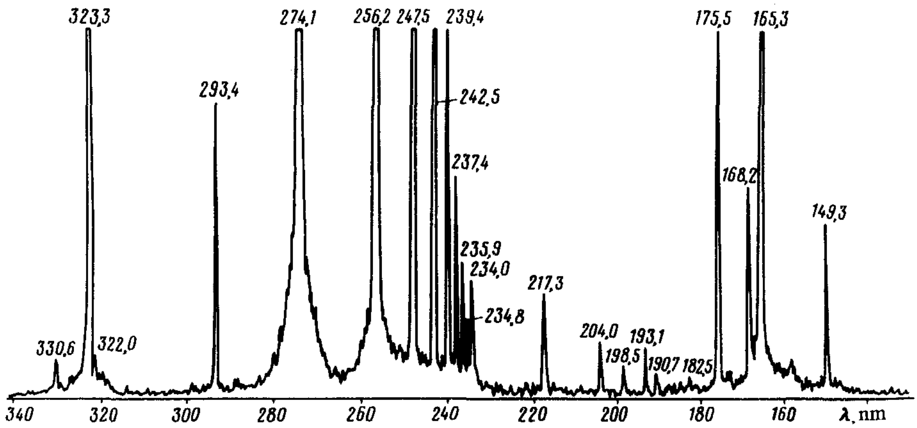

FIG. 1. Spectrum of lithium at an energy of 100 eV of the bombarding electrons.

293.4 nm, we can offer a fairly definite identification. These lines are excited at energies well above the ionization potential of the atom but below the thresholds for the excitation of LiII lines. The excitation energies found experimentally for the first five lines are 63 ± 1.0 eV, while that for the line at 293.4 nm is 61.5 ± 0.5 eV. The excitation energies of these spectral lines are such that the initial levels for these lines evidently could belong to only the system of auto-ionization states of the lithium atom.[8] Since the energy gaps corresponding to these lines are no more than 6 eV, their lower levels are also auto-ionization levels (the lowest known auto-ionization state, $1s2s^2\ ^2S$, has an energy of 56.35 eV).

We thus conclude that these lines are the result of a combination in the system of auto-ionization states of the lithium atom. We might note that the wavelengths of several of these lines coincide with the wavelengths of some lines which were observed

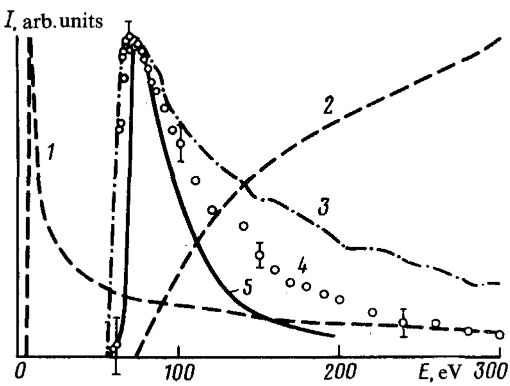

FIG. 2. Excitation functions of lithium lines. 1—LiI 247.5 nm ($2s^2S$–$6p^2P^0$); 2—LiII 165.3 nm ($2p^3P^0$–$3s^3S$); 3—LiI** 20.75 nm ($2p^2P^0$–$1s2p^2\ ^2P$) (Ref. 4); 4—LiI** 293.4 nm (present experiments); 5—LiI** 57.41 eV (line of the electron spectrum corresponding to the state $1s2s2p^4P^0$) (Ref. 9).

in Refs. 5 and 6 and which were attributed to transitions from the quartet auto-ionization levels of the $1s2sns$ and $1s2snd$ configurations to a $(1s2s2p)^4P^0$ metastable auto-ionization level.

For the most intense of these lines (293.4 nm), we were able to measure the excitation function; it is shown by curve 4 in Fig. 2. Shown for comparison in this figure are some typical excitation functions which we measured for ordinary LiI and LiII lines. We see that the excitation function for the 293.4-nm line differs markedly in shape from the excitation functions of the lines of both LiI and LiII. It follows that the shape of the excitation function may be an important criterion for identifying the particular system to which a spectral line belongs.

Furthermore, the literature has data on the excitation functions of auto-ionization states of the lithium atoms that have been found through studies of the radiative decay[4] and electronic decay.[9] The curve that we found is generally similar to the excitation functions of the quartet[9] and doublet optically forbidden auto-ionization[4,9] states. Figure 2 compares three such curves. We see that the nature of the rise near the threshold, the position of the main maximum, and the subsequent behavior of all three curves are roughly the same. This fact, combined with the agreement of the wavelengths observed in the present experiments with those reported in Refs. 5 and 6, which we have already mentioned, allows a very confident assertion that these lines are, in fact, the results of transitions between auto-ionization states of the lithium atom.

The spectral lines corresponding to transitions between auto-ionization states have a significant intensity. At an electron energy of 70 eV, the most prominent of these lines, 293.4 nm, is comparable in intensity to the doublet of the main series of the lithium atom at 237.4 nm $(2s^2S_{1/2} - 9p^2P^0{}_{1/2,3/2})$.

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