POST-COLLISION INTERACTION EFFECTS IN ELECTRON IMPACT EXCITATION OF AUTOIONIZING STATES IN LITHIUM

A.A.Borovik, V.N.Krasilinec

Institute of Electron Physics, Ukrainian National Academy of Sciences,
Universytetska St. 21, Uzhhorod, 88016, Ukraine
e-mail: iep@iep.uzhgorod.ua

The post-collision interaction (PCI) shift of lines has been observed for the first time in the ejected-electron spectra of the $(1s2s^2)^2S$, $(1s2s2p)^4P$, $1s(2s2p^3P)^2P$ and $1s(2s2p^1P)^2P$ autoionizing states in lithium atoms. The comparison of data is made with classical and semi-classical models of the PCI. The influence of the negative-ion resonances at the excitation threshold of autoionizing states is analyzed.

The near-threshold study of the electron impact excitation of autoionizing states is complicated by the effect, which is now known as "post-collision interaction" (PCI). It causes the lines in the ejected-electron spectrum to shift in position and to obtain broadened non-Gaussian shapes [1]. In the classical description of this effect, it is a result of the final-state Coulomb interaction of two outgoing particles – the low-energy scattered electron and the "fast" autoionizing electron- with the residual positive ion. During the last three decades the numerous investigations of the phenomena have been performed mainly for rare gases (e.g. [2,3] and references therein). For these gases the influence of the negative-ion resonances on the PCI has also been revealed (see [4] and references therein). To our knowledge, no works are known at all on the PCI effect in electron-impact excitation of autoionizing states in lithium and other alkali atoms.

In the present work we report on the preliminary results on the first observation of the PCI effect in the ejected-electron spectra of the $(1s2s^2)^2S$, $(1s2s2p)^4P$ $1s(2s2p^3P)^2P$ and $1s(2s2p^1P)^2P$ autoionizing states in lithium atoms. The measuring and data processing procedures were described earlier [5, 6]. Briefly, to reveal a shift and broadening of lines the ejected-electron spectra were precisely measured at an observation angle $\theta = 54.7^0$ with an experimental resolution $\Delta E \leq 0.2$ eV. The incident electron energy E_0 was varied from the excitation thresholds of levels up to 6 eV above. Note that special attention has been paid to the possible drift of the ejected-electron and incident electron energy scales.

Figure 1 shows the examples of spectra measured for the different values of E_0 in the ejected-electron energy region of the $(1s2s^2)^2S$, $(1s2s2p)^4P$, $1s(2s2p^3P)^2P$ and $1s(2s2p^1P)^2P$ autoionizing levels. As one can see, at the impact energy values close to the excitation threshold of levels all spectral lines are shifted in position relatively to their spectroscopic energies. However, it is important to note, that only the line arising from the electron decay of the $(1s2s^2)^2S$ state is shifted to the higher ejected-electron energies as it is predicted by the known classical and semiclassical models of PCI for the electron impact autoionization. For all other lines the shift has a negative sign - at threshold impact energies these lines are shifted to smaller energies than their spectroscopic values. Above 62 eV the shift of all lines becomes of the order of the uncertainty of the experimental energy scale (± 0.05 eV). One should note, that the measured shift of the line maximum $\Delta\varepsilon$ is caused not only by the shift of the line itself, but also by an apparent shift due to the limited energy resolution of the electron spectrometer [7]. This apparent shift is a result of the convolution of the asymmetric PCI line shape with the symmetric spectrometer function. We have estimated

the influence of this effect in present measurements by the convolution of our spectrometer function (the Gaussian with FWHM = 0.2 eV) with the PCI line shape of the width Γ=50; 100 and 150 meV. Even for the maximum width value of 150 meV the apparent shift amounts in the order of 30 meV and is smaller than the experimental uncertainty of the line shift estimation of ±50 meV (for the excess energies E_1<0.5 eV) and much smaller than the maximum shift value observed in spectra (see below).

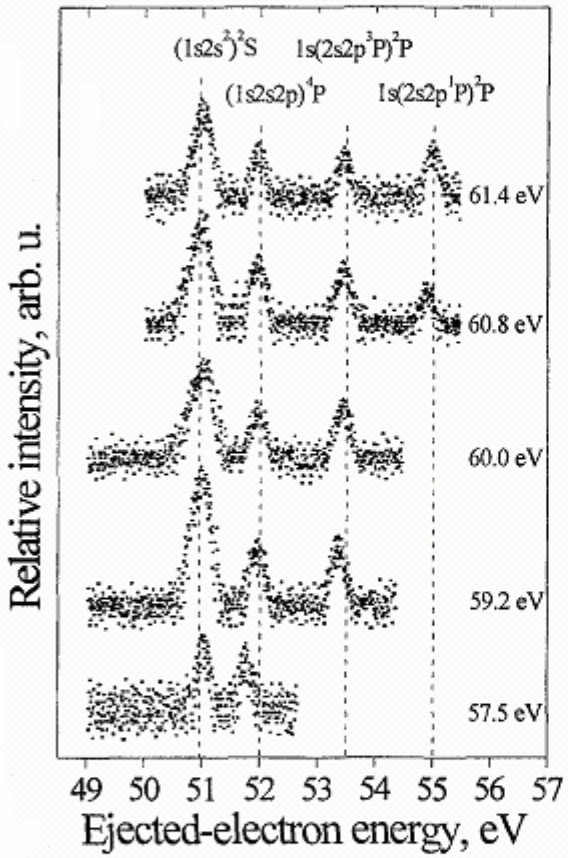

Fig. 1. Ejected-electron spectra of lithium atoms measured at different values of the incident electron energy. Dashed lines mark the spectroscopic position of the ejected-electron lines.

Figure 2 shows the shift $\Delta\varepsilon$ as a function of the excess energy $E_1 = E_{inc} - E_{exc}$, where E_{inc} is the incident electron energy, E_{exc} is the excitation energy of the autoionizing level. As can be seen, the maximum shift value lies in the range of 0.2÷0.3 eV. One should note the sharp increase of the shift (at least by factor of two) for the $(1s2s^2)^2S$ state at the excess energy of 0.6 eV.

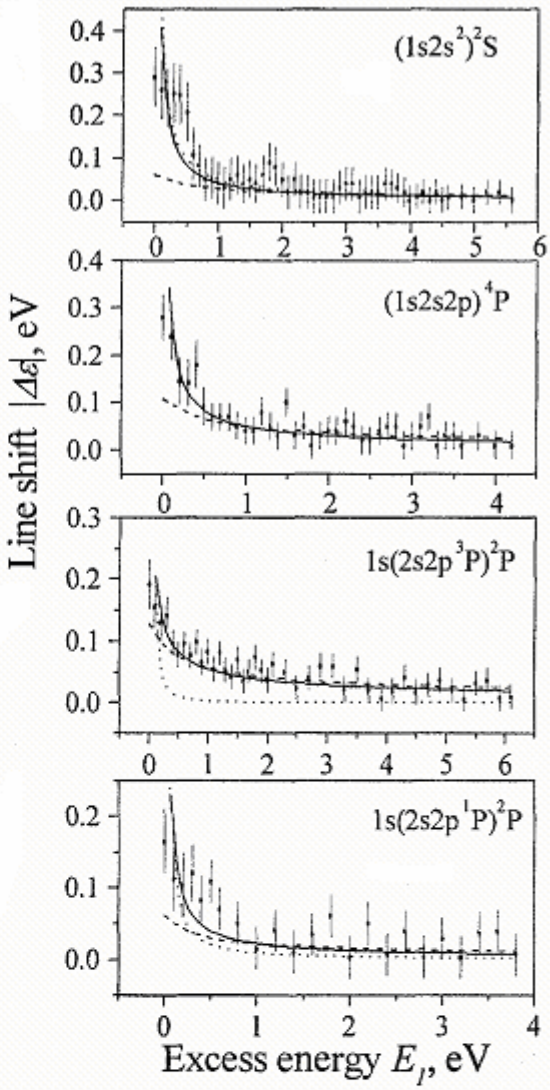

Fig. 2. A plot of the line shift $\Delta\varepsilon$ against the excess energy E_1: dots – as determined in present measurements; dotted line - fit by formula (1) with one fitting parameter n; solid line - fit by formula (1) with two fitting parameters Γ, n; dashed line – fit by formula (2) with one fitting parameter Γ.

We have compared our experimental results both with the classical [8] and semi-classical [9] models of the PCI. In the classical description, the most probable value of the line shift $\Delta\varepsilon$ is given simply by [10]:

$$\Delta\varepsilon = a(E_{inc} - E_{exc})^n = aE_1^n \qquad (1)$$

where a is the constant proportional to the width Γ of the autoionizing state. In general case, the constant a perhaps depends also on other properties of the state (e.g. polarizability or Stark shifting). In the original simple model of Barker and Berry [8] the exponent n has the value of –0.5, while in subsequent

investigations on helium and neon atoms [11] the best least-squares fit for $\Delta\varepsilon$ has been achieved with n varied between –1.0 and –1.22 depending on the state considered. In our case the least-square fitting results by using formula (1) with n as a fitting parameter are shown by a dotted line in Fig. 2 for the $(1s2s^2)^2S$, $1s(2s2p^3P)^2P$ and $1s(2s2p^1P)^2P$ levels. For a we have used the widths of these levels of 50 meV, 2.6 meV and 8.8 meV known from previous works [12-14]. As can be seen, for the ^2S state the best fit was obtained at the exponent value of –0.94. For the $(^3P)^2P$- and $(^1P)^2P$ states it was impossible to achieve a similar result by using the known width values for these levels. That was a reason to perform the fit of data for these and the $(1s2s2p)^4P$ levels by using the width Γ as an additional fitting parameter. These results are shown in Fig. 2 by a solid line. It can be seen that in this case the fitting curves are much closer to the experimental points. However, for the $((^3P)^2P)$ and $((^1P)^2P)$ levels the resulting width Γ of 54 meV and 22 meV, respectively, are essentially higher than their spectroscopic values. The $\Gamma \approx 50$ meV obtained for the ^4P level is too large, if the quartet character of this level is taken into account.

In the semi-classical model [9] developed for describing the interaction of two outgoing electrons at low excess energies E_1, the relation between the shift $\Delta\varepsilon$ and E_1 is given (in a.u.) by the formula

$$\Gamma [2 (E_1 + \Delta\varepsilon)]^{1/2} - 4 \Delta\varepsilon (E_1 + \Delta\varepsilon) - \Delta\varepsilon^2 = 0 \qquad (2)$$

By using the width Γ as a fitting parameter we have fitted our experimental results by formula (2) (see the dashed line in Fig. 2).

The best fits were achieved at the Γ values of 15 meV, 27 meV, 31 and 47 meV for the $(1s2s^2)^2S$, $(1s2s2p)^4P$, $1s(2s2p^3P)^2P$ and $1s(2s2p^1P)^2P$ levels, respectively. These data are remarkably lower than those obtained by formula (1).

As also can be seen, for the excess energies of $E_1 > 1$ eV all theories are in a good agreement with the experiment. However, for $E_1 < 0.6 \div 0.7$ eV a remarkable difference exists between the theory and experimental points. In order to find the possible explanation of it as well as of the negative sign of the PCI shift observed for the levels from the 1s2s2p configuration we have analyzed the near-threshold electron-impact excitation of the lowest autoionizing levels in lithium.

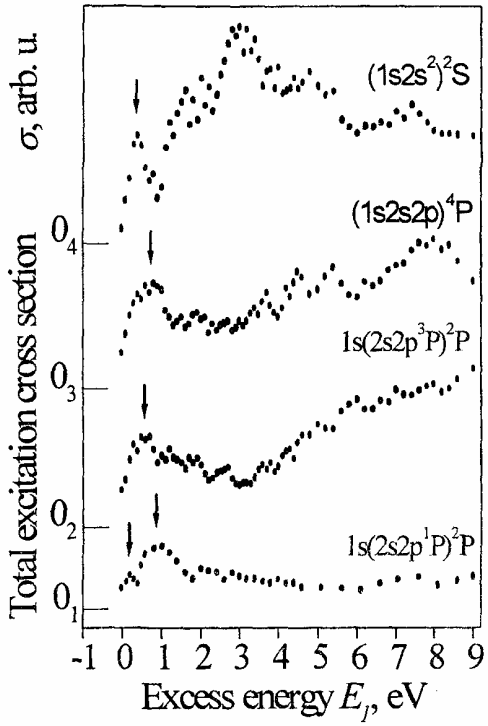

Fig. 3. The near-threshold part of ejected-electron excitation functions for the autoionizing states in lithium. Arrows mark the near-threshold resonances.

Figure 3 shows the near-threshold parts of the ejected-electron excitation functions measured in the same experiments and reported earlier [5]. As one can see, the main feature of these data is the presence of the strong negative-ion resonances just at the excitation threshold of levels (see arrows). Such correlation of both data, to our opinion, points out the strong influence of these resonances on the PCI process in the near-threshold impact energy region. If a negative-ion resonance is present at the excitation threshold of the autoionizing state, the PCI process in this case will be caused not only by the Coulomb interaction of the scattered electron (described as a spherical wave) and the autoionizing electron, but of two

autoionizing electrons arising from the following two-step decay process:

$$Li^{-}**(1s2snl,\mathcal{E}l) \rightarrow Li**(1s2snl) + e^{1}_{ej} \rightarrow$$
$$\rightarrow Li^{+}(1s^{2}) + e^{1}_{ej} + e^{2}_{ej} \quad . \qquad (3)$$

As a result, both ejected electrons will have the fixed orbital moments l_1 and l_2 and their interaction, to the large extent, will be strongly correlated at the threshold impact energies. At present it is difficult to give some details of such physical model and we hope that the results presented in this work will act as a stimulant for the first theoretical studies of the PCI effect in lithium atoms.

The authors thank Dr S. Ricz (ATOMKI, Hungary) and Dr E. Remeta for fruitful discussions and suggestions.

References

1. P.J.Hicks, S.Cvejanovic, J.Comer, F.H.Read, J.M.Sharp, *Vacuum* **24**, 573 (1974).
2. F.H.Read, *Radiat. Res.* **64**, 23 (1975).
3. M.Yu.Kuchiev, S.A.Sheinerman, *Uspekhi Fiz. Nauk* **158,** 353 (1989).
4. P.J.M. Van der Burgt, J. van Eck, H.G.M.Heidemann, *J. Phys.B* **19**, 2015 (1986).
5. A.A.Borovik, V.N. Krasilinec, *J. Phys. B* **32,** 1941 (1999).
6. O.O.Borovik, *Ukr. J. Phys.* **45,** 1270 (2000).
7. P.van der Straten, R.Morgenstern, A.Niehaus, *Z. Phys. D* **8**, 35 (1988).
8. R.B.Barker, H.W.Berry, *Phys. Rev.* **151**, 14 (1966).
9. A.Niehaus, *J. Phys. B* **10,** 1845 (1977).
10. G.C.King, F.H.Read, R.C.Bradford, *J. Phys. B* **8**, 2210 (1975).
11. D.G.Wilden, P.J.Hicks, J.Comer, *J. Phys. B* **10**, 1477 (1977).
12. P.Ziem, R.Bruch, N.Stolterfoht, *J. Phys. B* **8**, L480 (1975).
13. H.Cederquist, S. Manervik, *J. Phys. B* **15**, L807 (1982).
14. H.G.Berry, J.Desesquelles, M.Dufay, *Phys. Lett. A* **36**, 237 (1971).

ЕФЕКТ ВЗАЄМОДІЇ ПІСЛЯ ЗІТКНЕННЯ ПРИ ЗБУДЖЕННІ АВТОІОНІЗАЦІЙНИХ СТАНІВ ЛІТІЮ ЕЛЕКТРОННИМ УДАРОМ

О.О.Боровик, В.М.Красилинець

Інститут електронної фізики НАН України,
вул. Університетська, 21, Ужгород 88016
e-mail: iep@iep.uzhgorod.ua

Зміщення ліній внаслідок взаємодії після зіткнення (ВПЗ) вперше спостерігалося в спектрах ежектованих електронів для $(1s2s^2)^2S$, $(1s2s2p)^4P$, $1s(2s2p^3P)^2P$ і $1s(2s2p^1P)^2P$ автоіонізаційних станів атома літію. Проводиться порівняння даних з класичною і напівкласичною моделями ВПЗ. Аналізується вплив резонансів негативного іона у порозі збудження автоіонізаційних станів.