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A Photo-detachment Study of Binding Energies of La-

Lin Pan
Cedarville University, lpan@cedarville.edu

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Science and Mathematics Department, Cedarville University, Cedarville, OH 45314

Introduction

Despite that laser cooling of negative ions has seen proposed as an effective way of preparing ultra-cold antiprotons, no negative ion has yet been laser cooled. A big problem is few negative ions posses bound states of opposite parities that are related by electric dipole transition, the key for laser cooling.

Since the year of 2000, only three negative ion candidates have been identified for laser cooling: Os^-, Ce^- and La^-. Among them, La^- is the most promising because the laser-cooling transition is spin allowed while it is spin forbidden in the other two ions. This makes La^- perhaps the best candidate for efficient laser cooling.

To choose the right cooling laser, it's essential the transition energy for laser cooling be accurately determined. On the other hand, being the first element in the lanthanide row, the electron affinity (EA) and binding energies of La^- are interesting due to the experimental and theoretical challenges. A recent relativistic configuration interaction (RCI) calculation [1] on La^- indicated that La^- has 7 even-parity bound states ($5d^26s^2$) and 8 odd-parity bound states ($5d6s^26p$), and that the ground state is $5d^26s^2\ ^3F_2$ with EA of 545 meV. Earlier, a laser photoelectron energy spectroscopy study [2] of La^- in 1998 reported an EA of 470(+-20) meV and one BE value of 170(+-20) meV. Last year, a tunable infrared laser photo-detachment spectroscopy study [3] measured the laser cooling transition energy to be 399.42(3) meV and relative energy values of all 8 odd states and 2 even states of La^- to its ground state. A comparison to the RCI calculation [1] has shown a range of disagreement of 17 ~ 90 meV in the energy values. Also, EA was not determined in the most recent experiment.

The goal of this research is to further determine the EA and binding energies of La^- by computing and reproducing the photoelectron kinetic energy spectrum in the experimental plot [2]. In doing so, the main sources to the above-mentioned discrepancies can be identified.

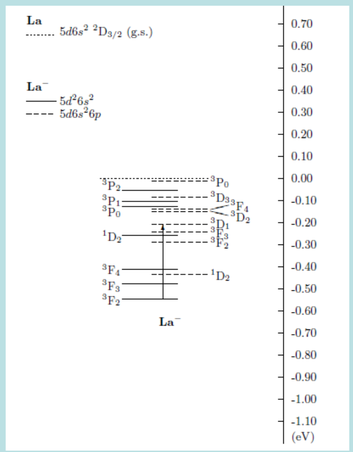

Figure 1. Bound states of La^- (RCI calculation [1]).

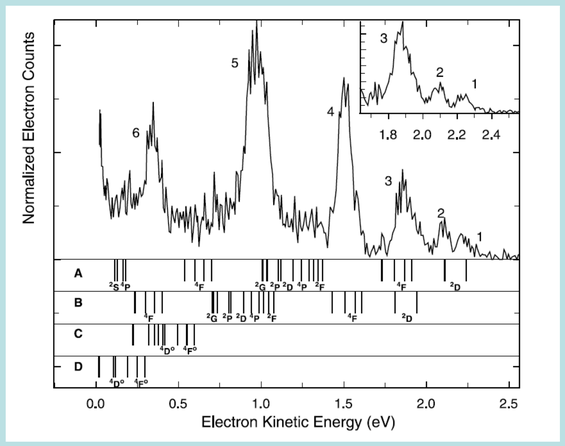

Figure 2. Experimental photoelectron spectrum of La^- [2].

Method

The following process represents the photo-detachment of a negative ion: $A^- + h\nu = A + e^-$ where A^- represents the initial bound state of the negative ion, $A + e^-$ represents the final continuum state, which consists of the neutral atom A plus a detached free electron. The photon energy is fixed to be 2.410 eV (about 514.5 nm) [3].

The wave functions for all the bound states are generated using the Relativistic Configuration Interaction (RCI) formalism [4]. The wave function of the continuum state is prepared by coupling the wave function of a free electron to the RCI wave function for the neutral atom A.

The partial cross section to each channel is calculated using [12], $\sigma = 4\pi^2\alpha\ a_0^2 \frac{df}{d\varepsilon}$ where df/dE is the differential oscillator strength for the electric dipole (E1) transition from an initial bound state to the final continuum state.

Progress and Results

1. The dominant candidates for all the 6 peaks in [2] have been identified by the calculation (see figure 3). Peak 1, 2, 3 and 6 are due to photo-detachment of La^- odd states, $5d6s^26p$. Peak #4, 5 are due to even states of $5d^2\ 6s^2$.
2. The interpretation of the photoelectron spectrum in [2] was false. The EA of La^- should be determined by peak 4, not peak 1 and 2 as done in [2]. The re-interpretation supports the RCI EA of 545 meV [1].
3. The RCI EA and binding energy values for the even states are moderately accurate, although a shift on the order of several tens of meV might be necessary to bring the simulated plot into agreement with the experimental one. This is shown by the agreement in the central positions of peaks 4 and 5, when one compares between the bottom plot in figure 4 to the experimental plot.
4. The RCI binding energy values for the odd states are too large, confirming the findings in [3]. The amount of desired shift is on the order of almost 100 meV. Figure 4 shows with the amounts of shift to states indicated in [3], the agreement in positions of peaks 1, 2, 3 have been improved.
5. Future work will focus on finding the desired amount of shit to all states in order to match the calculated peaks with experimental ones.

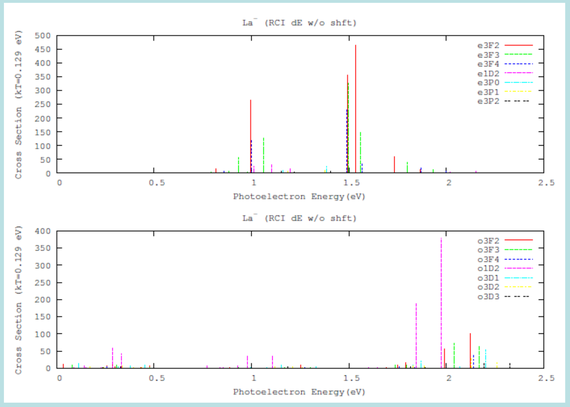

Figure 3. Calculated photoelectron spectrum using RCI energy values. The even states and the odd states are plotted separately to help identify candidates for the peaks in Figure 2.

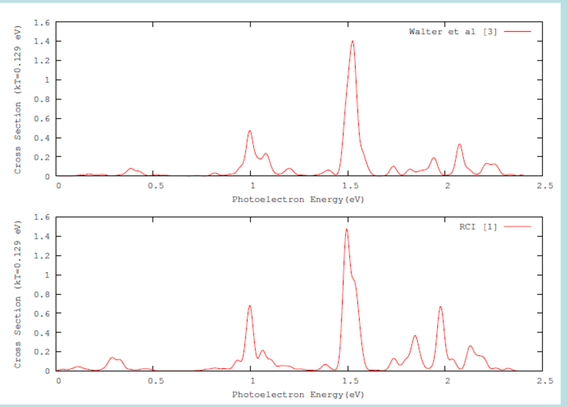

Figure 4. Calculated photoelectron spectrum. The top one uses RCI energy values but with shifts from [3]. The bottom one uses RCI energy values without shift.

References

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[2] A. M. Covington, D. Calabrese, J. S. Thompson, and T. J. Kvale, J. Phys. B 31, L855 (1998).
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[4] Donald R. Beck. RCI code (not published).