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I. Introduction

This report describes progress made during the final three-year grant period 1997-2000. During this period we experimentally investigated the structure and dynamics of negative ions by detaching the outermost electron in controlled processes induced by photon-, electron- and heavy particle-impact. In this manner we studied, at a fundamental level, the role of electron correlation in the structure and dynamics of simple, few-particle atomic systems. Our measurements have provided sensitive tests of the ability of theory to go beyond the independent electron model.

In our photodetachment work, a laser beam was mated with a fast, monoenergetic beams of negative ions, either in a crossed or collinear interaction geometry. Selective detection of either the detached photoelectrons or the residual atoms allowed us to isolate specific final state channels and thereby study partial cross sections. The detected particles were efficiently collected in the forward direction. We used a saturation method to make absolute measurements of photodetachment cross sections. Of particular interest, however, was the resonance structure that modulates photodetachment cross sections in the vicinity of thresholds. The resonances arise from the decay of doubly excited states that are bound to excited states of the parent atoms. The energies and widths of these highly correlated states have been determined from analysis of the associated resonances. Many doubly excited states were discovered in our work. Threshold behavior was also studied in order to determine the range of validity of the Wigner law.

In the heavy particle impact detachment work, we passed fast beams of negative ions through gaseous targets. The motivation for these studies was our interest in very lowly excited resonances. Such states can be produced in the non-selective collisions process. We observed, for the first time, two shape resonances and a virtual resonance. The use of a fast ion beam technique allowed us to study the extremely low energy electrons that were ejected in the autodetaching decay of these resonances. The energies of these electrons were significantly amplified in the laboratory frame since they were emitted by fast moving ions. The low energy electrons were also kinematically peaked in the forward direction. We exploited this fact by using the technique of zero-degree electron spectroscopy in our measurements.

In the work on electron-impact detachment of negative ions we used a magnetic storage ring as our source of fast negative ions. Negative ions of molecules and clusters were passed through an electron target that also cooled the ions. Residual neutral particles produced in detachment and dissocition process were detected with high efficiency. Absolute cross sections can be measured with this technique. The low energy region in the vicinity of the threshold was of particular interest since this is where resonances associated with doubly charged negative ions, or dianions, are expected to be observed if they are formed in the collision process.

II. Photodetachment of C^-

A crossed laser-ion beam apparatus was used in theses experiments. Energy analysis was performed on the photodetached electrons in order to isolate particular decay channels. Photodetachment cross sections were measured by use of a saturation technique. The yield

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of photoelectrons was studies as a function of the laser flux. Asymmetry parameters were determined by studying the angular dependence of the electron yield using plane polarized laser light and a double Fresnel rhomb to rotate the plane of polarization. This project formed the basis of the Ph.D thesis of graduate student William Brandon. The final results can be found in two papers [1,2].

III. Photodetachment of Ca^-

The same crossed beam apparatus was used to study the photodetachment of Ca^- in the visible. This loosely bound ion was first discovered by our group in 1987. The strong correlation poses a challenge to both experimentalists and theorists. In this grant period we measured the absolute cross section at 1.90 and 2.08 eV. The enrgy of 1.90 eV was chosen because it was at the threshold for the opening of the ^3Pkp channel. At 2.08 eV, both the ^3Pkp and the $^1Sks,d$ channels are open. The measurements disagree with the predictions of R-matrix theory. The measurements also enabled us to establish an absolute scale for the relative total cross section data of Walter and Peterson [3]. In addition, we measured asymmetry parameters at the two energies. The final results can be found in two papers [4,5].

IV. Photodetachment of He^-

We have made a spectroscopic study of the He^- ion in the ultraviolet using a collinear laser-ion beam apparatus. A state-selective detection scheme, based on resonance ionization, was used to detected the excited He atoms that were a product of the photodetachment process. The high resolution technique allows us to make measurements that are both highly selective and sensitive. We studied the partial photodetachment cross section via the 3^3Pkp channel over a spectral range 2.9-4.3 eV. We were able to determine the energies and widths of 15 previously unobserved doubly excited states. Details of this work and other measurements on the He^- ion can be in three papers [6,7,8].

V. Photodetachment of Li^-

We have investigated the partial photodetachment cross section of the Li^- ion in the uv region. Many resonances associted with highly correlated, doubly excited states were observed. We have studied the similarites and differences between the resonance spectra of the quasi-two-electron ion Li^- and the pure two-electron ion H^-. Our most recent measurements below the n=6 thresholds of Li demonstrate the breakdown of the propensity rules derived for the H^- spectrum. We also investigated a "mirroring effect" in two different partial cross sections. This interesting phenomenon was subsequently studied theoretically. The results of this work can be found in two papers [9].

VI. Photodetachment of Na^-

The partial cross section for photodetachment of this ion via the 4^3Skp channel was investigated over the spectral range 4.6-4.9 eV. The energies and widths of four previously unobserved doubly excited states were ontained from these measurements. The details can be found in a recent paper [10].

VII. Photodetachment of K^-

This project consisted of two parts. In one experiment we measured the electron affinity of the K atom with a precision that was more than an order of magnitude better than any previous measurement. Details can be found in a recent paper [11]. In another experiment we studied the rich spectrum of resonances in the photodetachment cross section in the vicinity of the K(5^2D, 7^2S, 5^2F) thresholds. Many previously unobserved doubly excited states were found. The results have been published in a recent paper [12].

VIII. Heavy Particle Detachment of Li^- and B^-

We have re-examined our previous measurements of resonant structure in the heavy particle collisional detachment cross sections for Li^- and B^- projectile ions incident on atomic gas targets. In both ions, a shape resonance has been observed. In addition, a large peak was observed in the Li^- cross section at an energy in the laboratory frame corresponding to zero energy in the ion frame.In order to eliminate contributions from double detachment processess, we have recently measured the detached electron in coincidence with the scattered neutral atom. We have deterimined that the large resonance at "zero energy" is most likely associated with the decay of a virtual state. Details will be published in the near future.

IX. Electron detachment of C_4^-

Heavy ion storage rings have greatly facilitated the investigation of electron-ion interactions, especially at low ion frame energies. We recently observed a doubly charged negative ion cluster C_4^- .This dianionic state was observed as a resonance in the electron-impact detachment cross section.

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