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RYDBERG STATES IN MULTIPLY CHARGED IONS

Progress Report

for the period August 1, 1992 - April 30, 1993

A. Eugene Livingston

Principal Investigator

**University of Notre Dame
Notre Dame, Indiana 46556**

May 1993

Prepared for

**THE U. S. DEPARTMENT OF ENERGY
OFFICE OF BASIC ENERGY SCIENCES
DIVISION OF CHEMICAL SCIENCES**

GRANT NO. DE-FG02-92ER14283

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ABSTRACT

This report summarizes the research progress in accelerator-based studies of atomic structure and decay characteristics of excited states in multiply charged ions supported by DOE grant DE-FG02-92ER14283 from August 1, 1992, through April 30, 1993. This work involves spectroscopic measurements in the visible to the extreme ultraviolet wavelength regions of atomic transitions involving Rydberg states and low-lying excited states in selected multiply charged ions. These investigations are of both fundamental and applied interest. Of fundamental importance are tests of long range electron-ion interactions and many-body electron correlations in Rydberg states, sensitivity to relativistic effects in the energy structures of few-electron ions, and tests of accurate many-body calculations of transition probabilities. Of applied interest are the application of these results to the understanding of laboratory and astrophysical plasmas and of detailed atomic structure and decay properties in highly charged ions.

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Research completed and in progress during this project period includes measurements and interpretations of Be-like Rydberg state structures and detection of additional Rydberg transitions in several multiply charged ions; investigations of relativistic structures of $n=2$ fine structure states in highly-charged He-like ions, including a new measurement in He-like Ar^{16+} ; lifetime measurements of intercombination transitions in highly-charged bromine ions; measurement of the forbidden M1 decay in H-like Kr^{35+} ; and improvement and extension of precision beam-laser lifetime measurements in atomic cesium. Technological advances include application of position-sensitive microchannel-plate detectors for vacuum-ultraviolet spectroscopy of multiply charged ions, and implementation of diode laser excitation in the beam-laser measurements. The experiments initiated during this project period utilized accelerator facilities at the University of Notre Dame (Tandem), and at Argonne National Laboratory (ATLAS and BLASE). The time devoted to this project by the principal investigator is 20% during the academic year and 100% during two summer months each year.

Rydberg transition structures for high angular momentum states of Be-like Si^{10+} have been initiated using ultraviolet spectroscopy of an excited fast beam at the Notre Dame tandem accelerator. Spectra of the $n = 7-8$, $8-9$, and $9-10$ transitions have been obtained for angular momentum states $L > 4$. The unperturbed highest angular momentum state energies may be formulated in terms of a core polarization model of long range electron-ion interactions. The lower L states exhibit perturbations due to mixing with core-excited levels. Rydberg transitions between the core-excited states have also been identified, and these radiative branches are found to be partially suppressed by autoionization effects at high principal quantum number n . We have performed multi-configuration Dirac-Fock calculations of these Rydberg state fine structures for comparison with our measurements. We also apply our measurements to test the validity of core polarization models for Rydberg state structures in highly-charged ions. Finally, we have compared our measurements with many body perturbation theory calculations for the unperturbed highest L states. The comparisons suggest the need for improvements in the various atomic calculations. Preliminary reports on these studies have been presented [1], and additional results will be presented at the Reno DAMOP meeting.

Our precision measurements of $1s2s\ ^3S - 1s2p\ ^3P$ transition energies in He-like ions as a test of newly available relativistic and QED corrections [2] have been extended to the Ar^{16+} system. Beam-foil excitation of energetic argon ions at the ATLAS facility has yielded the first high quality spectra of these $2s-2p$ transitions in He-like argon. These spectra have been obtained using position-sensitive microchannel plate detection. Previous measurements using recoil-ion techniques provided very marginal spectroscopic results that disagreed with theory. Preliminary analysis of our data indicates excellent agreement with new relativistic atomic structure calculations. The results to date will be presented at the Reno DAMOP meeting.

Position-sensitive detection has also been employed to perform simultaneous lifetime measurements for an array of intercombination transitions in multiply ionized bromine, using beam-foil excitation at ATLAS. Prompt spectra revealed the presence of both low-lying excited state transitions and highly-excited Rydberg transitions in $Br^{22+} - Br^{24+}$ ions with lifetimes <100 ps. Delayed spectra contained only the long-lived "forbidden" intercombination transitions with lifetimes $\sim$ few ns. A preliminary report has been presented [1] and a paper is in final preparation.

The lifetime of the $2s\ ^2S_{1/2}$ state in H-like Kr^{35+} has been measured by beam-foil excitation of 30 MeV/u ions at the MSU (NSCL) Cyclotron. Detection of both the single photon and the two-photon x-ray decay branches has provided the first determination of the branching ratio for this state as a sensitive test of the relativistic corrections to the decay rate [3].

Our precision beam-laser lifetime measurements on the first excited ($6p\ ^2P$) state in the cesium atom have advanced by several improvements to the apparatus and measurement techniques. The measurements have been initiated at the BLASE accelerator at Argonne using diode laser excitation systems and cooled infrared detectors [4]. We have recently improved our lifetime precision capabilities by a factor of two to $\sim 0.5\%$ for the $^2P_{3/2}$ state, and we have undertaken measurements on the other fine structure level, $^2P_{1/2}$. These results provide tests of recent relativistic many-body calculations of the transition matrix elements that are needed for interpretation of current PNC experiments in atomic cesium.

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