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Final report

for the period July 1, 1978 to June 30, 1994

EXCITATION OF ATOMS AND MOLECULES IN COLLISIONS WITH HIGHLY CHARGED IONS

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I. INTRODUCTION

This report summarizes progress in research supported by DOE Grant DE-FG05-84ER13262 during the period July 1, 1978 to June 30, 1994. Contained herein are a summary of the final year's work, the names of students and postdoctoral associates who have participated in work performed under this grant, and a list of publications which evolved from completed projects.

II. SUMMARY OF ACCOMPLISHMENTS

This research program has focused on a variety of topics involving the interaction of fast heavy-ions with matter. Recent activity has centered about investigations of ion-atom and ion-molecule collisions. The particular areas of interest included (a) atomic charge transfer mechanisms, (b) ionization and fragmentation of molecules, (c) charge distributions of ions interacting with gases and solids, (d) inner-shell ionization and decay processes, and (e) atomic structure of few-electron ions. This year's activities have concentrated on the investigation of L x-rays produced during the passage of energetic Xe and Kr ions through solid targets, the measurement of charge distributions for noble gas recoil-ions created in 8 MeV/u Xe, Kr, and Ar collisions, and the delineation of double-foil effects on the charge distributions of Xe ions emerging from carbon targets. Work on a major project concerning the dependence of electron ionization and capture cross sections for diatomic molecules on the orientation of the internuclear axis had to be postponed because of the failure of a major component of the 3-D imaging detector system employed in this study. This component (a fiberoptic with phosphor screen) has now been replaced, and new results are expected to be obtained early in the 1994-95 project year with the support of another funding agency.

Spectra of L x-rays from Xe (6 and 8 MeV/u) and Kr (6 and 12 MeV/u) ions traveling in a variety of solid targets have been measured with a curved crystal spectrometer. The Xe L x-ray structure displayed a striking dependence on the target atomic number over the Z_2 range from 3 to 10. For low-Z_2 targets, the Xe spectra were characterized by partially resolved peaks which broadened and merged together as the target atomic number increased beyond $Z_2 = 6$. The main components were identified to be $L\alpha_1$ and $L\beta_1$ pairs from projectile initial states having 1 to 4 L-shell vacancies. Detailed spectral analysis provided estimates of the average projectile charges and the average L- and M-electron populations inside the solids.

In the case of Kr projectiles, relatively well-resolved L x-ray structure associated with transitions to the L-shell from the M-, N-, and O-shells was observed. Preliminary analysis of the spectra indicated that the relative subshell population distributions and fluorescence yields were about the same for each of the shells. The relative intensities of various components in the spectra directly reflected the projectile charge distributions. Target L x-ray spectra produced by the interaction of 6 MeV/u Kr ions with Rb, Mo, and La also were examined. These spectra were characterized by several sharp lines adjacent to or superimposed upon one or more very broad peaks. The sharp lines were found to be $L\alpha$, $L\beta_1$, and $L\beta_{2,15}$ lines fluoresced by the high fluxes of photons produced inside the targets with energies just above the L absorption edges. The broad peaks were due to L x-rays from target atoms having multiple L- and M-vacancies produced by ion-atom collisions.

Charge distributions of noble gas recoil-ions produced in collisions with 8 MeV/u Xe, Kr, and Ar projectiles have been measured for two incident charge states. The lower-charged projectiles were employed to explore the systematics of collisions in which target ionization

was accompanied by electron loss from the projectile (LI) while the higher-charged projectiles probed collisions in which target ionization was accompanied by electron capture by the projectile (CI). The average recoil-ion charges were much higher for the CI collisions than for the LI collisions. In addition, the CI charge distributions obtained with projectiles having charges $\geq 32+$ were found to be charge state independent, suggesting that the ionization probabilities for the outer-electrons have reached a saturation limit.

Charge distributions of 8 MeV/u Xe ions emerging from thin carbon foils were measured as a function of target thickness using an analyzing magnet and a one-dimensional position-sensitive microchannel plate detector. It was noticed that charge distributions obtained with a combination of two carbon foils sandwiched together differed from those obtained with single carbon foils of the same total thickness. Moreover, it was found that the resulting charge distribution depended on the relative ordering of the two foils. A simple model was developed in an effort to understand this effect. The model was based upon the integrated rate equation expressing the thickness dependence of the average charge in terms of average ionization and capture cross sections with an additional term to represent the thickness dependence of post-foil charge multiplication by Auger decay. The predictions of this model agreed quite well with the measurements and also accounted for the fact that the average charge was higher when the thinner foil was first in line.

The numerous projects completed in previous years under this grant are well documented in past progress reports and in the publications listed in Section IV of this report.

III. STUDENTS AND POSTDOCTORAL ASSOCIATES

A. Ph. D STUDENTS

Name	Ph.D Dissertation Title
Gabriel Sampoll-Ramirez	*Dissociation of Multicharged Molecular Ions Produced in Collisions with 96 MeV Ar^{14+}* (1991)
Richard J. Maurer	*Ionization and Fragmentation of Molecular Gases in Collisions with MeV/amu Heavy Ions* (1988)
Bryan B. Bandong	*K X-ray Decay of Multiple-Vacancy States Produced in Various Oxygen Compounds by Energetic, Heavy-ion Collisions* (1988)
John A. Demarest	*Extreme Ultraviolet Beam-Foil Spectroscopy of Highly Ionized Neon and Argon* (1985)
Todd L. Hardt	*Inner-shell Ionization of Intermediate- and High-Z Elements with Fast Heavy Charged Particles* (1975)
Tien Keh Li	*Energy Shifts and Relative Intensities of K X-rays Produced in Fast Heavy Charged Particle Collisions* (1973)

B. MASTERS STUDENTS

Name	Masters Thesis Title
Richard J. Maurer	*Energy Shifts and Collisional Broadening of 2p-1s Transitions in 2-MeV/amu H- and He-like Ne, Mg, and S Ions traveling in Solids* (1983)
Blake I. Sonobe	*Projectile Energy Dependence of Aluminum and Silicon K Alpha X-ray Satellites* (1978)
John A. Demarest	*Comparison of Heavy Ion-Induced K X-ray Satellite Spectra from Gases and Solids* (1977)

C. POSTDOCTORAL ASSOCIATES

Name	Year
Vladimir Horvat	1989 - present
Ramakrishnan Parameswaran	1992-94
Marin Chabot	1990-91
Karine Wohrer	1990-91
Bryan Bandong	1988-90
Oded Heber	1987-89
Gui-Ju Yu	1986-88
Cunet Can	1985-87
Jozsef Pálinkás	1983-85
Greg J. Pedrazzini	1982-85
K. Parthasaradhi	1981-83
Oswald Benka	1980-82
Arnold Langenberg	1978-80

IV. PUBLICATIONS

J. A. Demarest and R. L. Watson, "Ion-Excited K X-ray Satellite Spectra of Si, S, Cl and Ar in the Gas Phase", Phys. Rev. A17, 1302-1313 (1978).

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