EXPERIMENTAL INVESTIGATIONS
OF ELECTRON CAPTURE FROM
ATOMIC HYDROGEN AND DEUTERIUM
BY ALPHA PARTICLES

FINAL REPORT

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ABSTRACT

This report summarizes work performed at the University of Missouri-Rolla under DOE contract DE-FG02-84ER53188. We have succeeded in making state-selective measurements of charge capture by doubly-ionized helium colliding with ground-state neutral helium atoms, but failed to achieve our primary goal, which was to investigate atomic hydrogen targets. We discuss a number of ancillary experiments and calculations of relevance for fusion energy production that we have done. Reprints and preprints of publications resulting from this work are contained in an appendix.

FINAL REPORT

A. State-Selective Charge Capture Measurements.

The original goal of this work was to measure state-selective capture cross sections for the collision

where n is the helium ion's principal quantum number. The technique to be used was that of ion energy-loss spectroscopy¹, using the ion energy-loss spectrometer at the University of Missouri-Rolla. This spectrometer had to be modified by the insertion of a variable resistor assembly (VRA) between the accelerator and decelerator terminals, so that the energy loss or gain of a fast projectile that had changed charge could be measured. (The old configuration of the device allowed only non-charge-changing collisions to be studied.) This modification took the better part of three years, and has been discussed in detail in our quarterly and annual progress reports, as well as in Reference 2.

In 1988, we began to use the modified spectrometer to study the collision

where n' is the principal quantum number of the ionized target. We had decided that our first charge-capture measurements should be made with a target that was easier to handle experimentally. Even this simpler experiment proved to be rather difficult because of difficulties we had making stable beams of doubly-ionized helium for extended running times. A typical complete cross section measurement with the modified spectrometer would take about eight to ten hours, whereas the lifetime of the Colutron source we used to produce He^{++} was about five hours.

To solve this problem, we further modified the spectrometer, replacing its cylindrical electrostatic energy analyzer by a retarding field analyzer. (While this change did not improve ion source performance, it did allow measurements to be made more quickly, so that a five-hour source lifetime was sufficient.) Our modification worked well, and we were able to obtain state-selected cross section data

for reaction (2) at projectile velocities corresponding to 15, 30, and 45 keV/amu. These latter efforts have been discussed in detail in our previous reports. The results have also been accepted for publication in the Physical Review (see appendix). Our work with helium targets also resulted in one set of angular differential cross section data for double capture of electrons from He by He^{++} :

Our measurements for 30 keV projectile energies are the first angular differential results above 2 keV to our knowledge. They have been published in Reference 3. The few relevant theoretical calculations for processes (2) and (3) are in good agreement with our data. Victor Irby received a Ph.D. and Steve Yallaly received a Masters degree from the University of Missouri-Rolla for their work on this project.

While these collision studies were ongoing, we conducted a systematic investigation of ion sources in an attempt to improve the intensity and stability of our He^{++} beams. This work, a report of which we have submitted to the Reviews of Scientific Instruments , yielded some promising results, but has not yet resulted in a source that we have used to study collisions involving He^{++} projectiles.

Several preliminary runs with proton projectiles and our resistively heated atomic hydrogen target⁴ were made at low energy on a test bench facility. These showed promise for the investigation of collision (1), but because of scheduling constraints imposed by the NSF-funded project carried out on the main spectrometer (M. Schulz, principal investigator) and funding termination of this project, high energy H-target experiments have not commenced. It is the intention of Professor Schulz to make these measurements at some point in the future (see attached memo, Appendix B).

B. Studies of Electron Spectra in Ion-Atom Ionizing Collisions.

We have made experimental and theoretical studies of other processes relevant to fusion energy that were supported, in part, by this grant. These involve general ionizing collisions of the type

Here B is most typically H or He, A^{n+} is a bare ion ranging from H^+ to O^{8+} , and we are interested in the total ionization cross section or the cross sections differential in either the ejected electron energy E_e or angle θ .

Our studies were prompted by suggestions in the literature in 1983 and 1984 that a new kind of dynamical ionization mechanism, "saddle-point" ionization, might contribute significantly to the total ionization cross section in a variety of ion-atom collisions. This mechanism involves the "stranding" of the electron to be ionized on the saddle-point of Coulomb potential between the ionized target and the receding projectile. These suggestions led us to look for a signature of saddle point ionization as a peak in the forward-ejected electron energy spectra at a velocity corresponding to half that of the ionizing projectile, moving at a velocity v . While no clear features at $v/2$ were observed, other aspects of the ejected electron spectra led us to conclude that saddle point ionization can be an important dynamical effect, especially for low projectile energies.

This work led to the publication of eight papers. Reprints of these are contained in Appendix A. Of perhaps highest relevance to the fusion community are those by Rudd *et al.* and by V.D. Irby. The latter contains a derivation, based on simple classical ideas about saddle point dynamics, of the scaling laws for total cross sections for ionization of H and He by carbon and oxygen ions. These laws had been developed phenomenologically and used in the modeling of fusion plasmas⁵, but had not been understood theoretically until our work. We also assisted M.E. Rudd in the writing of his major review article on singly-differential electron energy spectra resulting from ion-atom collisions. This report will serve as a comprehensive guide to researchers in ionization physics for many years.

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APPENDIX A

Reprints and preprints of refereed publications
acknowledging support of this grant.

Reprints/preprints - removed

APPENDIX B

Memorandum from Prof. M. Schulz, University of
Missouri-Rolla, regarding future work in this area.

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June 10, 1993

MEMORANDUM TO: Dr. T.J. Gay, Dr. E.B. Hale

FROM: Dr. M. Schulz

RE: α - H Experiment

A handwritten signature in black ink, likely belonging to Dr. M. Schulz, written over the 'FROM' line.

This is to confirm that I am pursuing to do the α - H capture experiment which was initiated by you. Currently, the experiment cannot be done because of ongoing other projects and the need for further equipment development and purchases. However, the experiment will be done as soon as it becomes feasible.

MS/pc