MAR 16 1992

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Final Technical Report

on

Sub-Contract 9-X68-9118N - 1

Generation of Metastable Rare-Gas Beams

and

Studies of Electron-Metastable Collision Processes

Performance Period: January 1, 1990 - September 30, 1991

Vincent McKoy

A.A. Noyes Laboratory of Chemical Physics

California Institute of Technology

Pasadena, CA 91125

and

Sandor Trajmar

Jet Propulsion Laboratory

California Institute of Technology

Pasadena, CA 91125

MASTER

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Generation of Metastable Rare-Gas Beams

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Abstract

The basic goals of this research effort of designing, developing, and testing a high-flux, high-purity metastable rare-gas beam source suitable for measurements of electron-collisions have been achieved. Here we briefly describe the status of this effort. This effort will be pursued with support from other sources of funding and results of this subsequent effort will be made available to Los Alamos National Laboratory. On the theoretical side we have extended our procedure for calculating the cross sections for electron impact excitation of molecules to determine these cross sections for collisions with metastable states of molecules. As a relevant application we have studied the differential and integral cross sections for the $a\ ^1\Delta_g \rightarrow b\ ^1\Sigma_g^+$ transition in O_2 for which measurements (R.I. Hall and S. Trajmar, J. Phys. B 8, L293 (1975)) were available at a single energy (4.5 eV). The agreement between the calculated and measured values of these cross sections is encouraging and support the large value reported experimentally.

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The primary objective of this research effort was to develop a high-flux, high-purity metastable rare gas beam source suitable for studying electron collision cross sections and to initiate such measurements.

The major issues that had to be addressed were:

- (i) high-brightness ion source and ion extraction techniques
- (ii) efficient transport of ions under conditions of significant space charge
- (iii) conversion of ions to metastable atoms with high efficiency
- (iv) high-intensity, low-energy electron beam sources
- (v) laser-induced-fluorescence techniques for diagnostics of the metastable beams
- (vi) quantitative detection of metastable species
- (vii) electron-impact ionizer and ion detection systems

Details of the design of the laser-induced-fluorescence diagnostic procedures, plasma source and ion extraction, ion transport and focussing, ion to metastable neutral conversion, and fast-neutral atom detector were given in the Annual Technical Report for the period January-December 1989. From January 1, 1990 to September 30, 1991, our effort was concentrated on the gaseous, resonance-charge-exchange ion-to metastable converter, the fine tuning of the ion source and ion transport, the design and testing of the electron gun (for electron-impact ionization) and measurement of the electron-impact ionization of metastable Ne.

A conversion cell operating either with rare gas or alkali vapor (to convert rare gas ions into ground or metastable neutral atoms, respectively) was designed, built and tested. An ion current of about 30 μAmp , depending on ion species, was introduced into the converter and conversion to neutral atoms achieved. A neutral rare-gas beam containing about 50% ground state and 50% metastable Ne atoms was obtained with total target densities of about $5 \times 10^8 \text{ cm}^{-3}$ and $6 \times 10^6 \text{ cm}^{-3}$ at a distance of 2.5 cm and 22.5 cm away from the conversion cell, respectively.

A high-perveance magnetically collimated electron gun with scandium oxide cathode was designed, built, and tested. It produced an electron beam of about 400 $\mu\text{Amperes}$ in the 20 eV to few hundred electron-volt impact energy range and about 20 $\mu\text{Amperes}$ at 2 eV.

The apparatus was set up for the first electron collision measurement: ionization of metastable Ne atoms. Ne ions were converted in a Na vapor cell to metastable Ne. The neutral neon beam was transferred to the ionization region (ultra-high vacuum target chamber) and ionized by the electron beam. The ions were detected by a parallel plate analyzer and ion counting system as a function of electron impact energy. The ion signal was then converted to ionization cross sections.

A detailed description of the ion source and transfer optics is being prepared for publication in the Journal of Physics E. The procedure for the ionization measurements and results of measurements have been reported at the XVIIIth International Conference of the Physics of Electronic and Atomic Collisions, Brisbane, Australia, July 10-16, 1991 in the Book of Abstracts of Contributed papers, p. 166 and at the Joint Symposium on Electron and Ion Swarms and Low Energy Electron Scattering held at Bond University, Gold Coast, Australia, July 18-20, 1991, invited talk, Program and Abstracts of Papers, p. 17. A review chapter on electron collisions with excited atoms has been written and will appear in Advances in Atomic, Molecular and Optical Physics, edited by B. Bederson, Academic Press, 1992.

On the theoretical side we have extended our procedure, the Schwinger multichannel variational method, for calculating cross sections for electron-molecule collisions to determine these cross sections for metastable states of molecules. Very little is known about such cross sections other than that they can be

expected to be large. For molecules we are aware of only one such measurement, this being that by R. Hall and S. Trajmar on the cross sections for electron impact excitation of the $a^1\Delta_g \rightarrow b^1\Sigma_g^+$ transition of O_2 at 4.5 eV. Our calculated values of the differential cross sections for electron impact excitation of this excitation at 4.5 eV agree quite well with the measurements of Hall and Trajmar (J. Phy. B 8, L293 (1975)). The calculated value of $0.32 \text{ \AA}^2$ for the integral cross section confirms the larger magnitude expected for such excited state-excited state transitions. In contrast, the value of the cross section for excitation of the $X^3\Sigma_g^- \rightarrow a^1\Delta_g$ transition at 5 eV is about $0.02 \text{ \AA}^2$. Further studies of these cross sections for metastable targets are under way.