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**Measurements of Scattering Processes in
Negative Ion - Atom Collisions**

Final Technical Report

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Thomas J. Kvale

Department of Physics and Astronomy
The University of Toledo
2801 West Bancroft Street
Toledo, OH 43606

Tel: (419) 530-2980
Fax: (419) 530-2723
email: tjk@physics.utoledo.edu

DOE Patent Clearance Granted
MP Dvorscak
Mark P. Dvorscak
(313) 252-2393
E-mail: mark.dvorscak@ch.doe.gov
Office of Intellectual Property Law
DOE Chicago Operations Office
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U.S. Department of Energy
Office of Energy Research, Office of Basic Energy Sciences
Division of Chemical Sciences, Fundamental Interactions Branch

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I. Introduction

This report describes the progress made on the research objectives during the DoE research grant (DE-FG02-95ER14530) in the years 01/1995 - 04/2000. Nine refereed and/or invited publications [1-9] were published during the period of this research grant. Papers 1-3 were published during this grant period, but were listed with the previous DoE grant number (DOE-FG05-88ER13971). In addition, three papers were presented at regional meetings [10-12], one paper was presented at an international conference [13], and seven papers were presented at national meetings [14-20] during this grant. The training of students was an important priority of this research project. One graduate student received his M.S.-Physics degree and another is working toward his Ph.D.-Physics on this research. Four undergraduate students have completed their senior research projects and five undergraduate students have completed summer research projects on the UT-P/NIELS facility. DOE Report Form F1332 cover sheets for papers and abstracts having DOE Document Numbers are appended to this report for reference.

The main research activity is to study various scattering processes which occur in H^- collisions with atomic (specifically, noble gas and atomic hydrogen) targets in the intermediate energy region. These processes include: elastic scattering, single- and double-electron detachment, and target excitation/ionization. During the past two years, the scope of the research project was expanded to include positively-charged ions (specifically, H^+) projectiles to allow for more complete comparisons with the H^- data. For the elastic and target inelastic processes where the projectile is scattered intact, the experimental technique of Ion Energy-Loss Spectroscopy (IELS) was employed to identify excitation to the final target state(s). In the target excitation process for $H^- +$ helium collisions, cross sections were measured and calculated (from a collaboration with C.E. Theodosiou) for the first time during this period. The motivation for this research is to obtain a better understanding of the inelastic processes for ion - atom collisions in the collision energy region where the collision evolves from molecular characteristics to atomic characteristics. To this end, the current measurements have provided total cross sections (TCS) and once the angular positioning apparatus is installed, the research will proceed to provide angular differential cross sections (ADCS).

An ancillary series of experiments concentrating on photodetachment studies have also been

performed during this period. Some of these experiments were listed in the Grant Proposal under the *Exploratory Experiments* section. The asymmetry parameter and electron affinity measurements were conducted in collaboration with Prof. J.S. Thompson at The University of Nevada, Reno. This research project has resulted in four refereed publications [5,6,8,9], and five papers presented at national meetings [16-20] during this reporting period. Another series of photodetachment experiments will be undertaken on a facility (PHOTO-2) being assembled at the Univ. of Toledo. These higher photon energy (VUV) experiments are a collaboration with J.S. Thompson (Univ. of Nevada, Reno) and D.G. Seely (Albion College, Albion, Michigan). Two papers were presented at regional conferences detailing this work [11,12].

II. Ion - Atom Collision Studies

The primary experiments conducted on the UT-P/NIELS during this reporting period are the target excitation cross section measurements in $H^- + \text{helium}$ collisions and electron capture measurements in $H^+ + \text{helium}$ collisions. The results from these studies are summarized below. Additional measurements for these collision systems are currently in progress. The previous experiments conducted on the UT-P/NIELS concentrated on single- and double-electron detachment studies. The major findings from these completed experiments were published in four papers [1-4] and summarized in two previous Three Year Technical Progress Reports DOE/ER/13971--23 and DOE/ER/14530--08. Because these results have been previously reported, only a brief synopsis of the detachment findings are listed below and the reader is referred to the publications for additional details.

A. Electron Detachment Cross Section Measurements

In the course of the electron detachment studies, it was found that the scattered beam growth curves contained slight curvatures which were well described by quadratic functions. The quadratic coefficients arise from multiple scattering of the projectile beam as it traverses the target gas. Even though the projectile beam is initially purely H^- , charge-changing collisions will produce non-negligible fractions of H^0 and H^+ ion beams. Because of this, the scattered beam fraction rate equations must include contributions from secondary processes and not just from the primary process. The correct solutions to the scattered beam rate equations are given in Equations 1 and 2 above for the atomic hydrogen and proton beam fractions, respectively. The scattered atomic

hydrogen beam fraction solution from the rate equations is:

$$F_0(\pi) = \sigma_{-10}\pi + \frac{1}{2}[\sigma_{-11}\sigma_{10} - \sigma_{-10}(\sigma_{-10} + \sigma_{-11} + \sigma_{01} + \sigma_{0-1})]\pi^2 + \dots$$

and the scattered proton beam fraction solution from the rate equations is:

$$F_1(\pi) = \sigma_{-11}\pi + \frac{1}{2}[\sigma_{-10}\sigma_{01} - \sigma_{-11}(\sigma_{-10} + \sigma_{-11} + \sigma_{10} + \sigma_{1-1})]\pi^2 + \dots$$

where F_q is the scattered beam fraction; π is the target thickness; and σ_{qr} is the total charge-changing cross section going from charge q to charge r . The resultant, reported cross sections compared favorably with those already in the literature.

B. Electron Capture Cross Section Measurements

In the course of the electron detachment studies, it was found that the scattered beam growth curves contained slight curvatures which were well described by quadratic functions. This finding was motivation for conducting the complementary experiments for electron capture processes in proton - helium collisions. These measurements are currently in progress, but the preliminary data indicate that the double electron capture cross section may be affected by a factor of two due to the data analysis method employed to analyze the growth curve data. Even though the projectile beam is initially purely H^+ , charge-changing collisions will produce non-negligible fractions of H^0 and H^- ion beams. Because of this, the scattered beam fraction rate equations must include contributions from secondary processes and not just from the primary process. The correct solutions to the scattered beam rate equations are given in Equations 3 and 4 for the atomic hydrogen and H^- beam fractions, respectively.

$$F_0(\pi) = \sigma_{10}\pi + \frac{1}{2}[\sigma_{1-1}\sigma_{-10} - \sigma_{10}(\sigma_{10} + \sigma_{1-1} + \sigma_{01} + \sigma_{0-1})]\pi^2 + \dots$$

$$F_{-1}(\pi) = \sigma_{1-1}\pi + \frac{1}{2}[\sigma_{10}\sigma_{0-1} - \sigma_{1-1}(\sigma_{1-1} + \sigma_{10} + \sigma_{-11} + \sigma_{-10})]\pi^2 + \dots$$

The resultant single capture cross sections compare favorably with those in the literature, but the double capture cross section is greatly affected by these secondary processes -- even in the tenuous target thicknesses.

C. Target Excitation Cross Section Studies in $H^- + \text{Helium}$ Collisions

The main results from this period are the first excitation cross section measurements in the $H^- + \text{helium}$ collision system. The experimentally determined cross section for the $n=2$ excitation of helium was shown in previous Progress Reports for this grant. Also a collaboration with C.E. Theodosiou produced calculations for this process and for that of proton impact excitation of helium. The calculation used wavefunctions optimized to give accurate Generalized Oscillator Strengths and also accounted for the internal structure of H^- . One interesting feature from the calculation is the fact that at low collision energies, the excitation cross section for H^- impact is larger than the corresponding cross section for proton impact. This series of experiments are currently in progress on this facility.

D. UT-P/NIELS Apparatus

The UT-P/NIELS Apparatus has been designed and operated for two series of experiments. Full descriptions of it are included in the Progress Reports, so only a brief synopsis of it is included here for completeness. A Colutron ion source which produces low energy width ion beams has been installed on UT-P/NIELS. To date, it has produced proton beams of >10 nA as measured after the Wien Filter. The Wien Filter is used to select isotopically pure beams which are then accelerated up to the desired collision energy. This projectile beam then passes through a target cell where helium gas is admitted. The scattered projectile beam is then charge state analyzed by a laboratory magnet. The beams are then deflected according to their charge state into one of three detectors. The scattered projectile ion beam that has not undergone a charge changing collision is directed into a decelerator and finally into an electrostatic energy analyzer. The energy width of the incident beam is an important consideration and the Colutron ions sources typically produce energy width ion beams of less than 1eV. This is sufficient for the Ion Energy- Loss Spectroscopy measurements. The other instruments which affect the overall energy resolution of the apparatus include: the electrostatic ion zoom lens and energy analyzer; the electronics for setting a controllable dc potential on the accelerator terminal as referenced to the decelerator terminal; data acquisition electronics in the decelerator terminal; and a method for computer communication and control of those instruments.

III. Photodetachment Studies

A. Asymmetry Parameters in the Photoelectron Angular Distributions from Photodetachment of Negative Ions

Photoelectron angular distributions for the laser photodetachment processes have been measured at six wavelengths (energies) in the region 457.9 to 647.1 nm (2.71-1.92 eV) through a series of collaborative experiments at UNR. A negative ion beam having a typical kinetic energy of 10 keV was produced in a cesium sputter-type source and mass-selected with a 90° bending magnet. The mass-selected ion beam was subsequently crossed horizontally at 90° with a linearly polarized, continuous photon beam in the data acquisition chamber located approximately 4 m from the bending magnet. Photodetached electrons were collected at a lab angle of 45° below the laser-ion intersection plane. Angular distributions (which were used to determine the asymmetry parameters) were obtained by measuring the laboratory frame energy spectra of photodetached electrons as a function of the angle between the velocity vector of the ejected electrons and the polarization direction of the linearly polarized photon beam. The polarization direction of the laser beam was rotated with a double Fresnel rhomb ($\lambda/2$ retarder) while the photoelectron collection direction remained fixed. The photon beam was carefully positioned with respect to the negative ion beam to maximize the overlap between the interacting beams, while minimizing laser beam “walk” as the double Fresnel rhomb was rotated. The present measurements for the system $C^-(1s^2 2s^2 2p^3 \ ^4S) + h\nu - C(1s^2 2s^2 2p^2 \ ^3P) + e^-$ are in excellent agreement with those of Hall and Siegel [J. Chem. Phys. **48**, 943 (1968)], and are well-predicted by Cooper-Zare theory [J. Chem. Phys. **48**, 942 (1968)]. The agreement of the present C^- measurements with both the previous measurements and the Cooper-Zare theory suggests that the effects of final state interactions on the photoelectron angular distributions are small compared to the outgoing s- and d-wave interferences in influencing the spectral dependence of the asymmetry parameters for this system. These measurements have been published [5].

The spectral dependence of the angular distributions of photoelectrons produced by the single photon detachment of Al^- , Si^- , and P^- ions were also measured at discrete photon wavelengths ranging from 457.9 to 647.1 nm. The experimental results for Al^- are in very good agreement with a recent theoretical calculation [C.N. Liu and A.F. Starace, Private Communication (1996)] and have been published [6]. A third set of asymmetry parameter measurements have been conducted on Cu^- and Fe^- and a manuscript reporting these results is in preparation.

B. Electron Affinity Measurements

The electron affinity of lanthanum was measured for the first time by us during a series of collaborative experiments at UNR. The experiment involved photodetaching a 10 keV La^- ion beam by visible wavelength photons from a 25 Watt Ar-ion laser. The experimental setup was very similar to that used to acquire the asymmetry parameter measurements. Photoelectrons resulting from the ion-laser interaction were energy analyzed by a 160° spherical-sector electron spectrometer at a constant pass-energy of 20 eV and energy resolution of approximately 0.4% (determined from the full-width at half-maximum of the measured photoelectron spectra). The data support the hypothesis that structure of La^- includes both a long-lived, bound, excited state in addition to the ground state. These results have been published [8]. The electron affinity of indium was also measured by us [9]. These measurements were able to resolve the fine structure of In^- . The experimental arrangement was similar to that of the lanthanum measurements.

C. PHOTO-2 Apparatus

An apparatus (PHOTO-2) has been constructed during this grant for conducting a series of ancillary experiments listed in the *Exploratory Experiments* section of the grant. This apparatus consists of a 0 - 50kV positive ion accelerator; a alkali vapor charge exchange cell (CEX); a merging chamber; and electron energy analyzer chamber. A fraction of the positive ions from the accelerator will undergo electron capture collisions in the CEX, resulting in a fast negative ion beam. The exiting beams (positively charged, neutral, and negatively charged) then enter a beam merging chamber where the negative ion beam is deflected 30° and merged with the VUV photon beam from the laser. The ions then can interact with the photon beam over the distance they are merged (approx. 30 cm) prior to the electron energy analyzer. Photodetached electrons are energy analyzed by a hemispherical energy analyzer. The various residual ion, neutral, and photon beams exit through an aperture in the outer hemisphere of the analyzer and are detected by appropriate detectors. Six undergraduate students have contributed to this project to date. Mr. Jeffrey Book wrote the data acquisition code and performed an initial design of the Merging Beam Chamber. Ms. Sally Goff designed the magnetic field coils to null the earth's magnetic field throughout the 30 cm interaction volume. Mr. Kevin Chalut performed the final design of the Merging Beam Chamber. The optimal design from his study is one of a dodecapole lens configuration. A manuscript describing this device is in preparation. Mr. James Kraus modeled the CEX cell for producing the

negative ion beams. Mr. Nilkath Smrdelj designed an einzel lens system for producing a parallel negative ion beam throughout the interaction region. Finally, Mr. Raul Mery at the University of Nevada, performed a study predicting the final state populations of $\text{Be}^{-}({}^4\text{P})$ we should expect to enter the interaction region of the apparatus and be available for photodetachment.

IV. Current Areas of Research

A. Target Inelastic Cross Section Measurements

The acquisition of energy-loss spectra from ion-atom collisions is a very powerful experimental technique (IELS) which permits state-resolved, absolute, elastic and target excitation and ionization measurements. This series of experiments is the main motivation behind the construction of the UT-P/NIELS facility. The apparatus is designed so that the total cross sections for target excitation and ionization are obtained by a careful analysis of the signal intensities in the energy-loss spectra. The chosen experimental technique has the advantage that the total cross sections are obtained from measured quantities and the ratio of the scattered projectile ion beam at different energy-loss locations. As such, the deduced cross sections are absolute and free of normalization to other data or calculations. In addition to the total cross sections for discrete target state excitation, the energy-loss differential cross sections ($\partial\sigma/\partial\xi$) are obtained for target ionization processes without modification of the initial configuration of the apparatus. These experiments are currently in progress. The main goal of the apparatus is the measurement of cross sections that are differential in scattering angle (ADCS). The ADCS are stringent tests of our understanding of the important processes inherent in energetic ion-atom collisions. The angular and energy-loss capability of the apparatus will permit measuring the *true* elastic differential cross sections. The angular components are awaiting a convenient time for installation after the total cross section measurements are complete.

B. Photodetachment Measurements

There are two active series of ancillary experiments involving photodetachment measurements. The first series of experiments is the continued collaboration with Prof. Thompson at the University of Nevada, Reno on experiments being conducted at UNR. At least another trip is planned for collaborating at UNR this coming year. In that time, we plan to explore the electron affinities of additional lanthanide elements, as well as continue to expand the asymmetry parameter

measurements to additional elements and at additional photon energies. The second series of experiments is the multi-institution group working on the PHOTO-2 apparatus. It is anticipated that this apparatus will become operational this year.

V. Support of Students and Scientists

The training of young physicists is vital in order to adequately meet the energy challenges of tomorrow. This research project at the University of Toledo has been a source of involvement for many young scientists -- from the undergraduate students to graduate students to faculty collaborators at other colleges.

PROFESSIONAL SCIENTISTS

A collaboration continues to exist with Prof. David Seely, Assistant Professor of Physics, Physics Department, Albion College, Albion, Michigan. Prof. Seely is experienced in Ion Energy-Loss Spectroscopy and in coincidence studies. He has traveled to UT regularly throughout the academic years and spent a significant fraction of each of the past three summers here for collaboration on this project. A collaboration also existed during these past three years with Prof. Jeffrey Thompson, Assistant Professor of Physics, Physics Department, The University of Nevada, Reno. Prof. Kvale traveled to Reno several times for extended visits to collaborate on the photodetachment experiments at UNR during this grant.

GRADUATE STUDENTS

Yushan Lu *"Measurement of Total Cross Sections for H⁻ Impact Excitation of Helium Atoms,"*
 (M.S.-Physics, August 1995).

Gregory Hodges *"Measurement of Total Cross Sections for Proton Impact Excitation of Helium*
 Atoms," (M.S.-Physics, 1998 - present).

UNDERGRADUATE SENIOR RESEARCH PROJECTS:

Nilkath M. Smrdelj (B.S.E.P. - 1997), *"Ion Optics Lens for Negative Ion Accelerator,"*
 Engineering Physics Senior Project (1996 - 1997).

Robert Csontos (B.S. - in progress), *"The Design of a Low Energy-Spread Ion Source,"* Senior

Undergraduate Physics Research Project, (1994 -).

James Kraus (B.S. - 1999), "*The Design of Faraday Cups for Secondary Emission Coefficient Measurements*," Senior Undergraduate Physics Research Project, (1998 - 1999). James was named the **1999 Dept. of Physics and Astronomy Outstanding Undergraduate Student**.

Michael Brown (B.S. - 1999), "*Modeling a Hemispherical Geometry Ion Source*," Senior Undergraduate Physics Research Project, (1998 - 1999).

UNDERGRADUATE SUMMER RESEARCH PROJECTS:

Jeffrey Book "*Apparatus Control and Merging Plate Design for the Lund Photodetachment Experiment (LPE)*," NSF-REU, The Univ. of Missouri-Rolla, Rolla, MO, (1995).

Sally Goff "*Coil Design for the Photodetachment Experiment*," NSF-REU, Albion College, Albion, MI, (1996).

Kevin Chalut "*Using a Dodecapole Configuration in Deflecting an Ion Beam Through 30 Degrees*," NSF-REU and Albion Research Participation, Albion College, Albion, MI, (1997).

James Kraus "*Modeling a Charge Exchange Cell for Production of Negative Ion Beams*," NSF-REU University of Toledo, (1997).

Andrew Gleason "*The Preparation of the PHOTO-2 Apparatus for Planned Photodetachment Experiments*," NSF-REU and Albion Research Participation, Albion College, Albion, Michigan, (1998).

Michael Brown, "*Modeling a Hemispherical Geometry Ion Source*," University of Toledo, (1998).

VI. Summary

The initial target excitation measurements taken on the apparatus occurred in this three year reporting period. These measurements were the first measurements of the $n=2$ excitation by H^- ion impact. A collaboration with C.E. Theodosiou produced the first calculations of helium excitation by H^- impact to compare with the first measurements. The somewhat surprising low collision energy similarities between H^- impact and that of protons has convinced us to also undertake comparable measurements for H^+ impact excitation of helium. This experiment is currently being conducted on the UT-P/NIELS apparatus. Progress continues toward the upgrade of the facility to allow the angular motion capability of the accelerator.

The absolute single- and double-electron detachment total cross section measurements in the intermediate energy region for H^- collisions with noble gas targets were published in this period. The accuracies of the present cross sections compare favorably with those in the literature. In the course of the detachment measurements, slight curvatures were observed in the growth curves for tenuous target thicknesses. These curvatures can be explained by the secondary, charge-changing processes. As such, indirect tests were made of the other, significant cross sections in the $H^+ +$ noble gas collision systems. To our knowledge, this is the first time that a consistency check of this type has been conducted for this fundamental, atomic collision system.

The photodetachment experiments are proceeding well. The apparatus (PHOTO-2) being assembled at UT should be operational within one year. Photodetachment experiments are scheduled for it involving VUV and higher photon energies. The collaboration with Prof. Thompson at UNR has been very fruitful.

VII. References and Publications: Abstracts and Papers (01/1995 - 04/2000)

Note: Numbering system below are Reference Numbers in this Progress Report. DOE/ER boldtype numbers are DOE Document Numbers.

Refereed and Invited Publications

1. T.J. Kvale, J.S. Allen, X.D. Fang, A. Sen, and R. Matulioniene, "Single Electron Detachment Cross Sections for 5- to 50-keV H^- Ions Incident on Helium, Neon, and Argon Atoms," Phys. Rev. A51, 1351 (1995). (DOE/ER/13971--24)
2. T.J. Kvale, J.S. Allen, A. Sen, X.D. Fang, and R. Matulioniene, "Curvature in the Scattered Beam Growth Curves in $H^- + (He, Ne, and Ar)$ Collisions," Phys. Rev. A51, 1360 (1995). (DOE/ER/13971--25)
3. J.S. Allen, X.D. Fang, A. Sen, R. Matulioniene, and T.J. Kvale, "Double-Electron Detachment Cross Sections in Intermediate Energy H^- plus Noble-Gas Collisions," Phys. Rev. A52, 357 (1995). (DOE/ER/13971--26)
4. T.J. Kvale, A. Sen, and D.G. Seely, "Electron Detachment in Negative Ion - Atom and Molecule Collisions," Application of Accelerators in Research and Industry, Proceedings of the Fourteenth International Conference, AIP Conference Proceedings 392, J.L Duggan and I.L. Morgan, ed., AIP Press, p.23-5 (1997). (DOE/ER/14530--09)
5. D. Calabrese, A.M. Covington, D. Carpenter, J.S. Thompson, T.J. Kvale, and R. Collier, "Photoelectron Angular Distribution Measurements of C^- at Visible Wavelengths," J. Phys. B: At., Mol., Opt. Phys. 30, 4791 (1997). (DOE/ER/14530--10)
6. A.M. Covington, D. Calabrese, W.W. Williams, J.S. Thompson, and T.J. Kvale, "Experimental Measurements of Photoelectron Angular Distributions by Single-Photon Detachment of Al^- , Si^- , and P^- at Visible Photon Wavelengths," Phys. Rev. A 56, 4746 (1997). (DOE/ER/14530--14)
7. T.J. Kvale, and D.G. Seely, "An Apparatus for the Measurement of Various Scattering Processes in Intermediate Energy, Ion - Atom Collisions," Invited paper, Honorary Volume for Demetrios D. Raftopoulos, Proceedings of the Symposium Recent Advances in Mechanics, July 1998, E.E. Gdoutos, ed., Democritus University of Thrace, Greece, 535 (1998). (DOE/ER/14530--17)
8. A.M. Covington, D. Calabrese, J.S. Thompson, and T.J. Kvale, "Measurement of the Electron Affinity of Lanthanum," J. Phys. B. 31, L855, (1998). (DOE/ER/14530--18)
9. W.W. Williams, D.L. Carpenter, A.M. Covington, J.S. Thompson, T.J. Kvale, and D.G. Seely, "Fine-Structure-Resolved Laser-Photodetachment Spectroscopy of In^- ," Phys. Rev. A 58, 3582 (1998). (DOE/ER/14530--19)

Conference Abstracts

Ohio Section of the American Physical Society

10. Z. Constan, D.G. Seely, and T.J. Kvale, "Calculation of Atomic Beam Flow in Long Tubes," Bull. Am. Phys. Soc. **40**, 1475 (1995). (DOE/ER/14530--06)
11. D.G. Seely, K. Chalut, J.S. Thompson, and T.J. Kvale, "The Deflection of Charged Particles in an Electric Dodecapole Field," Bull. Am. Phys. Soc. **42**, 2292 (1997). (DOE/ER/14530--15)

Argonne Symposium for Undergraduates in Science, Engineering and Mathematics, Argonne National Laboratory

12. S.K. Goff, D.G. Seely, and T.J. Kvale, "Coil Design for a Photodetachment Experiment," Book of Abstracts, Seventh Annual Argonne Symposium for Undergraduates in Science, Engineering and Mathematics, Argonne National Laboratory, (1996). (DOE/ER/14530--07)

International Conference on the Application of Accelerators in Research and Industry-Denton, TX

13. T.J. Kvale, "Electron Detachment Processes in Intermediate Energy Negative Ion - Atom Collisions," Abstracts for the Fourteenth International Conference on the Application of Accelerators in Research and Industry, J.L. Duggan and I.L. Morgan, ed., University of North Texas, Denton, Texas, (1996). (DOE/ER/14530--05)

Division of Atomic, Molecular, and Optical Physics of the APS: DAMOP

14. T.J. Kvale, Yushan Lu, C.E. Theodosiou, and D.G. Seely, "Excitation of Helium to the $n=2$ States in Intermediate Energy $H^- + He$ Collisions," Bull. Am. Phys. Soc. **41**, 1074 (1996). (DOE/ER/14530--03)
15. D.G. Seely, A. Sen, and T.J. Kvale, "Measurements of Electron Detachment Cross Sections in 10-50 keV Impact Energy $H^- + CH_4$ Collisions," Bull. Am. Phys. Soc. **41**, 1138 (1996). (DOE/ER/14530--04)
16. D. Calabrese, A.M. Covington, D. Carpenter, J.S. Thompson, T.J. Kvale, and R. Collier, "Experimental Photoelectron Angular Distributions of C^- at Visible Wavelengths," Bull. Am. Phys. Soc. **42**, 1021 (1997). (DOE/ER/14530--11)
17. J.S. Thompson, D. Calabrese, A.M. Covington, W.W. Williams, and T.J. Kvale, "Photoelectron Angular Distribution Measurements of Transition Metal Ions, V^- , Fe^- , and Cu^- ," Bull. Am. Phys. Soc. **42**, 1022 (1997). (DOE/ER/14530--12)
18. A.M. Covington, D. Calabrese, W.W. Williams, J.S. Thompson, and T.J. Kvale, "Experimental Measurements of Photoelectron Angular Distributions of Al^- , Si^- , and P^- ," Bull. Am. Phys. Soc. **42**, 1022 (1997). (DOE/ER/14530--13)

19. A.M. Covington, D. Calabrese, J.S. Thompson, and T.J. Kvale, "*Measurement of the Electron Affinity of Lanthanum*," Bull. Am. Phys. Soc. **43**, 1355 (1998). (DOE/ER/14530--16)
20. J.S. Thompson, D.L. Carpenter, A.M. Covington, W.W. Williams, T.J. Kvale, and D.G. Seely, "*Measurement of the Electron Affinities of Indium and Thallium*," Bull. Am. Phys. Soc. **44**, 724 (1999). (DOE/ER/14530--20)

DoE CONFERENCE ABSTRACTS and PRESENTATIONS

21. T.J. Kvale, "*Measurements of Scattering Processes in Negative Ion - Atom Collisions*," Program and Abstracts, Sixteenth Atomic Physics Program Workshop, U.S. Department of Energy, San Antonio, Texas, (1995).
22. T.J. Kvale, "*Measurements of Scattering Processes in Negative Ion - Atom Collisions*," Program and Abstracts, Seventeenth Atomic Physics Program Workshop, U.S. Department of Energy, Fullerton, California, (1996).
23. "*Scattering Processes in Negative Ion - Atom Collisions*," Invited talk, U.S. Dept. of Energy Atomic Physics Program Workshop, Fullerton, California, (October 1996).
24. T.J. Kvale, "*Measurements of Scattering Processes in Ion - Atom Collisions and Photodetachment Processes*," Program and Abstracts, Eighteenth Atomic Physics Program Workshop, U.S. Department of Energy, Chantilly, Virginia, p. 123-5 (1997).
25. "*Scattering Processes in Ion - Atom Collisions and Photodetachment Processes*," Invited poster, U.S. Dept. of Energy Atomic Physics Program Workshop, Chantilly, Virginia, (September 1997).
26. T.J. Kvale, "*Measurements of Scattering Processes in Ion - Atom Collisions and Photodetachment Processes*," Program and Abstracts, Nineteenth Atomic Physics Program Workshop, U.S. Department of Energy, Ellicott City, Maryland, p. 172-6 (1998).

INVITED PRESENTATIONS: (outside of DoE)

27. "*Electron Detachment in Intermediate Energy Negative Ion - Atom Collisions*," Invited talk, Fourteenth International Conference on the Application of Accelerators in Research and Industry (CAARI96), J.L. Duggan, Co-Chairman, University of North Texas, Denton, Texas (November 1996).
28. "*Charge-Changing Processes in Ion - Atom Collisions*," Department of Physics

Colloquium, Indiana University of Pennsylvania, (November 1997).

29. "*Photodetachment of Negative Ions by Visible Wavelength Photons*," Department of Physics and Astronomy Colloquium, University of Toledo, (November 1997).
30. "*The Study of Electron Detachment Processes in Negative Ion - Atom and Molecule Collisions*," Invited talk, Department of Bioengineering, Seminar and Reception in Special Recognition of the Honorary Volume for Professor Demetrios D. Raftopoulos, The University of Toledo, (March 1999).

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Document Numbers for Grant: DE-FG02-95ER14530
Thomas J. Kvale

- DOE/ER/14530 -- 01:** T.J. Kvale, "*Measurements of Scattering Processes in Negative Ion - Atom Collisions*," Technical Progress Report: 01 April 1995 - 31 March 1996 (Year 1).
- DOE/ER/14530 -- 02:** T.J. Kvale, "*Measurements of Scattering Processes in Negative Ion - Atom Collisions*," Technical Progress Report: 01 April 1996 - 31 March 1997 (Year 2).
- DOE/ER/14530 -- 03:** T.J. Kvale, Yushan Lu, C.E. Theodosiou, and D.G. Seely, "*Excitation of helium to the $n=2$ states in intermediate energy $H^- + He$ collisions*," Bull. Am. Phys. Soc. **41**, 1074 (1996).
- DOE/ER/14530 -- 04:** D.G. Seely, A. Sen, and T.J. Kvale, "*Measurements of electron detachment cross sections in 10-50 keV impact energy $H^- + CH_4$ collisions*," Bull. Am. Phys. Soc. **41**, 1138 (1996).
- DOE/ER/14530 -- 05:** T.J. Kvale, "*Electron detachment cross sections in intermediate energy negative ion - atom collisions*," Book of Abstracts, 14th International Conference on the Application of accelerators in Research and Industry, University of North Texas, Denton, TX, November (1996).
- DOE/ER/14530--06:** Z. Constan, D.G. Seely, and T.J. Kvale, "*Calculation of Atomic Beam Flow in Long Tubes*," Bull. Am. Phys. Soc. **40**, 1475 (1995).
- DOE/ER/14530--07:** S.K. Goff, D.G. Seely, and T.J. Kvale, "*Coil Design for a Photodetachment Experiment*," Book of Abstracts, Seventh Annual Argonne Symposium for Undergraduates in Science, Engineering and Mathematics, Argonne National Laboratory, (1996).
- DOE/ER/14530--08:** T.J. Kvale, "*Measurements of Scattering Processes in Negative Ion - Atom Collisions*," Three Year Technical Progress Report 01/1995 - 04/1998, (1997).
- DOE/ER/14530--09:** T.J. Kvale, A. Sen, and D.G. Seely, "*Electron Detachment in Negative Ion - Atom and Molecule Collisions*," Application of Accelerators in Research and Industry, Proceedings of the Fourteenth International Conference, AIP Conference Proceedings 392, J.L Duggan and I.L. Morgan, ed., AIP Press, p.23-5 (1997).

- DOE/ER/14530--10:** D. Calabrese, A.M. Covington, D. Carpenter, J.S. Thompson, T.J. Kvale, and R. Collier, "*Photoelectron Angular Distribution Measurements of C^- at Visible Wavelengths*," J. Phys. B: At., Mol., Opt. Phys. **30**, 4791 (1997).
- DOE/ER/14530--11:** D. Calabrese, A.M. Covington, D. Carpenter, J.S. Thompson, T.J. Kvale, and R. Collier, "*Experimental Photoelectron Angular Distributions of C^- at Visible Wavelengths*," Bull. Am. Phys. Soc. **42**, 1021 (1997).
- DOE/ER/14530--12:** J.S. Thompson, D. Calabrese, A.M. Covington, W.W. Williams, and T.J. Kvale, "*Photoelectron Angular Distribution Measurements of Transition Metal Ions, V^- , Fe^- , and Cu^-* ," Bull. Am. Phys. Soc. **42**, 1022 (1997).
- DOE/ER/14530--13:** A.M. Covington, D. Calabrese, W.W. Williams, J.S. Thompson, and T.J. Kvale, "*Experimental Measurements of Photoelectron Angular Distributions of Al^- , Si^- , and P^-* ," Bull. Am. Phys. Soc. **42**, 1022 (1997).
- DOE/ER/14530--14:** A.M. Covington, D. Calabrese, W.W. Williams, J.S. Thompson, and T.J. Kvale, "*Measurements of photoelectron angular distributions by single-photon detachment of Al^- , Si^- , and P^- at visible wavelengths*," Phys. Rev. A **56**, 4746 (1997).
- DOE/ER/14530--15:** D.G. Seely, K. Chalut, J.S. Thompson, and T.J. Kvale, "*The Deflection of Charged Particles in an Electric Dodecapole Field*," Bull. Am. Phys. Soc. **42**, 2292 (1997).
- DOE/ER/14530--16:** A.M. Covington, D. Calabrese, J.S. Thompson, and T.J. Kvale, "*Measurement of the Electron Affinity of Lanthanum*," Bull. Am. Phys. Soc. **43**, 1355 (1998).
- DOE/ER/14530--17:** T.J. Kvale, and D.G. Seely, "*An Apparatus for the Measurement of Various Scattering Processes in Intermediate Energy, Ion - Atom Collisions*," Invited paper, Honorary Volume for Demetrios D. Raftopoulos, Proceedings of the Symposium Recent Advances in Mechanics, July 1998, E.E. Gdoutos, ed., Democritus University of Thrace, Greece, 535 (1998).
- DOE/ER/14530--18:** A.M. Covington, D. Calabrese, J.S. Thompson, and T.J. Kvale, "*Measurement of the Electron Affinity of Lanthanum*," J. Phys. B. **31**, L855, (1998).
- DOE/ER/14530--19:** W.W. Williams, D.L. Carpenter, A.M. Covington, J.S. Thompson, T.J. Kvale, and D.G. Seely, "*Fine-Structure-Resolved Laser-Photodetachment Spectroscopy of In^-* ," Phys. Rev. A **58**, 3582 (1998).
- DOE/ER/14530--20:** J.S. Thompson, D.L. Carpenter, A.M. Covington, W.W. Williams, T.J. Kvale, and D.G. Seely, "*Measurement of the Electron Affinities of Indium and Thallium*," Bull. Am. Phys. Soc. **44**, 724 (1999).
- DOE/ER/14530--21:** T.J. Kvale, "*Measurements of Scattering Processes in Negative Ion - Atom Collisions*," Final Technical Progress Report 01/1995 - 04/2000 (12/2000).

APPENDIX:

**DOE Form F1332 Cover Sheets
for Papers and Abstracts
having DOE Document Numbers**

U.S. DEPARTMENT OF ENERGY
RECOMMENDATIONS FOR THE ANNOUNCEMENT AND DISTRIBUTION
OF DEPARTMENT OF ENERGY (DOE) SCIENTIFIC AND TECHNICAL INFORMATION (STI)
(See instructions on reverse side. Use plain bond paper if additional space is needed for explanations.)

PART I (DOE, DOE Contractors, Grantees, and Awardees complete)

A. Product/Report Data

1. (Award) Contract No. **DE-FG02-95ER14530**
2. Title: **Measurements of Scattering Processes in Negative Ion - Atom Collisions**

3. Product/Report Description

- a. Report (complete all that apply)
(1) Print Nonprint (specify) _____
(2) Quarterly Semiannual Annual Final
 Topical Phase I Phase II
 Other (specify) _____

Technical Progress Report: (Year 1)

- Dates covered 04/1995 thru 03/1996
 b. Conference/Meeting/Presentation (complete all that apply)
(1) Print Nonprint (specify) _____
 Published Proceedings
 Other

(2) Conference Title (no abbreviations)

Location (city/state/country)

Date(s) (m/d/y) / / thru (m/d/y) / /
Sponsor

- c. Software — Additional forms are required. Follow instructions on the back of this form.
 d. Other (Provide complete description)

B. Patent Information

Yes No

- Is any new equipment, process, or material disclosed? If yes, identify page numbers _____
 Has an invention disclosure been submitted? If yes, identify the disclosure number and to whom it was submitted. Disclosure number _____ Submitted to _____
 Are there patent-related objections to the release of this STI product? If so, state the objections. _____

C. Contact (Person knowledgeable of content)

Name: Thomas J. Kvale
Phone: (419) 530-2980
Position: Professor of Physics
Organization: The University of Toledo

PART II (DOE, DOE Contractors complete/or as instructed by DOE contracting officer)

A. DOE Identifiers

1. Product/Report Nos. **DOE/ER/14530--01**
2. Funding Office(s) (Note: Essential data) **Chicago**

B. Copies for Transmittal to AD-21 (OSTI)

(STI must be of sufficient quality for microfilming/copying.)

1. One for classified processing
 2. (number) for standard classified distribution
 3. Two for unclassified processing
 4. (number) for standard unclassified distribution
 5. UC/C Category
 6. Additional instructions/explanations _____

(Do not identify Sigma categories for Nuclear Weapons Data reports, and do not provide additional instructions that are inconsistent with C below.)

C. Recommendation ("X" at least one)

1. Program/Standard Announcement/Distribution (Available to U.S. and foreign public)

2. Classified (Standard Announcement only)
 3. Special Handling (Legal basis must be noted below.)
 a. Unclassified Controlled Nuclear Information (UCNI)
 b. Export Control/ITAR/EAR
 c. Temporary hold pending patent review
 d. Translations of copyrighted material
 e. Small Business Innovation Research (SBIR)
 f. Commercializable Information
 (1) Proprietary
 (2) Protected CRADA information
Release date / /
 (3) Other (explain) _____

 4. Program Directed Special Handling (copy attached)

D. Releasing Official

- A. Patent Clearance ("X" one)
 Has been submitted for DOE patent clearance
 DOE patent clearance has been granted
B. Released by
(Name) _____
(Signature) _____
(Phone) _____
(Date) _____

U.S. DEPARTMENT OF ENERGY
RECOMMENDATIONS FOR THE ANNOUNCEMENT AND DISTRIBUTION
OF DEPARTMENT OF ENERGY (DOE) SCIENTIFIC AND TECHNICAL INFORMATION (STI)
(See instructions on reverse side. Use plain bond paper if additional space is needed for explanations.)

PART I (DOE, DOE Contractors, Grantees, and Awardees complete)

A. Product/Report Data

1. (Award) Contract No. **DE-FG02-95ER14530**
2. Title: **Measurements of Scattering Processes in Negative Ion - Atom Collisions**

3. Product/Report Description

- a. Report (complete all that apply)
(1) Print Nonprint (specify) _____
(2) Quarterly Semiannual Annual Final
 Topical Phase I Phase II
 Other (specify) _____

Technical Progress Report: (Year 2)

Dates covered 04/1996 thru 03/1997

- b. Conference/Meeting/Presentation (complete all that apply)
(1) Print Nonprint (specify) _____
 Published Proceedings
 Other

(2) Conference Title (no abbreviations)

Location (city/state/country)

Date(s) (m/d/y) / / thru (m/d/y) / /
Sponsor

- c. Software — Additional forms are required. Follow instructions on the back of this form.
 d. Other (Provide complete description)

B. Patent Information

Yes No

- Is any new equipment, process, or material disclosed? If yes, identify page numbers _____
 Has an invention disclosure been submitted? If yes, identify the disclosure number and to whom it was submitted. Disclosure number _____ Submitted to _____
 Are there patent-related objections to the release of this STI product? If so, state the objections. _____

C. Contact (Person knowledgeable of content)

Name: Thomas J. Kvale
Phone: (419) 530-2980
Position: Professor of Physics
Organization: The University of Toledo

PART II (DOE, DOE Contractors complete/or as instructed by DOE contracting officer)

A. DOE Identifiers

1. Product/Report Nos. **DOE/ER/14530--02**
2. Funding Office(s) (Note: Essential data) **Chicago**

B. Copies for Transmittal to AD-21 (OSTI)

(STI must be of sufficient quality for microfilming/copying.)

1. One for classified processing
 2. (number) for standard classified distribution
 3. Two for unclassified processing
 4. (number) for standard unclassified distribution
 5. UC/C Category _____
 6. Additional instructions/explanations _____

(Do not identify Sigma categories for Nuclear Weapons Data reports, and do not provide additional instructions that are inconsistent with C below.)

C. Recommendation ("X" at least one)

1. Program/Standard Announcement/Distribution
(Available to U.S. and foreign public)

2. Classified (Standard Announcement only)
 3. Special Handling (Legal basis must be noted below.)
 a. Unclassified Controlled Nuclear Information (UCNI)
 b. Export Control/ITAR/EAR
 c. Temporary hold pending patent review
 d. Translations of copyrighted material
 e. Small Business Innovation Research (SBIR)
 f. Commercializable Information
 (1) Proprietary
 (2) Protected CRADA information
Release date / / _____
 (3) Other (explain) _____

4. Program Directed Special Handling (copy attached)

D. Releasing Official

A. Patent Clearance ("X" one)

- Has been submitted for DOE patent clearance
 DOE patent clearance has been granted

B. Released by

(Name) _____
(Signature) _____
(Phone) _____
(Date) _____

U.S. DEPARTMENT OF ENERGY
RECOMMENDATIONS FOR THE ANNOUNCEMENT AND DISTRIBUTION
OF DEPARTMENT OF ENERGY (DOE) SCIENTIFIC AND TECHNICAL INFORMATION (STI)
(See instructions on reverse side. Use plain bond paper if additional space is needed for explanations.)

PART I (DOE, DOE Contractors, Grantees, and Awardees complete)

A. Product/Report Data

1. (Award) Contract No. **DE-FG02-95ER14530**
2. Title: **Excitation of Helium to the n=2 States in Intermediate Energy H⁻ + He Collisions**

3. Product/Report Description

- a. Report (complete all that apply)
(1) Print Nonprint (specify) _____
(2) Quarterly Semiannual Annual Final
 Topical Phase I Phase II
 Other (specify) _____

Dates covered _____ thru _____

- b. Conference/Meeting/Presentation (complete all that apply)
(1) Print Nonprint (specify) _____
 Published Proceedings
 Other _____

- (2) Conference Title (no abbreviations)
1996 DAMOP Meeting of The American Physical Society

Location (city/state/country)
Ann Arbor, MI USA

Date(s) (m/d/y) **05/15/1996** thru (m/d/y) **05/18/1996**
Sponsor
American Physical Society

- c. Software — Additional forms are required. Follow instructions on the back of this form.
 d. Other (Provide complete description)

B. Patent Information

- Yes No
 Is any new equipment, process, or material disclosed?
If yes, identify page numbers _____
 Has an invention disclosure been submitted?
If yes, identify the disclosure number and to whom it was submitted. Disclosure number _____
Submitted to _____
 Are there patent-related objections to the release of this STI product? If so, state the objections. _____

C. Contact (Person knowledgeable of content)

Name: **Thomas J. Kvale**
Phone: **(419) 530-2980**
Position: **Professor of Physics**
Organization: **The University of Toledo**

PART II (DOE, DOE Contractors complete/or as instructed by DOE contracting officer)

A. DOE Identifiers

1. Product/Report Nos. **DOE/ER/14530--03**
2. Funding Office(s) (Note: Essential data) **Chicago**

B. Copies for Transmittal to AD-21 (OSTI)

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 2. (number) for standard classified distribution
 3. Two for unclassified processing
 4. (number) for standard unclassified distribution
 5. UC/C Category _____
 6. Additional instructions/explanations _____

(Do not identify Sigma categories for Nuclear Weapons Data reports, and do not provide additional instructions that are inconsistent with C below.)

C. Recommendation ("X" at least one)

1. Program/Standard Announcement/Distribution
(Available to U.S. and foreign public)

2. Classified (Standard Announcement only)
 3. Special Handling (Legal basis must be noted below.)
 a. Unclassified Controlled Nuclear Information (UCNI)
 b. Export Control/ITAR/EAR
 c. Temporary hold pending patent review
 d. Translations of copyrighted material
 e. Small Business Innovation Research (SBIR)
 f. Commercializable Information
 (1) Proprietary
 (2) Protected CRADA information
Release date ____/____/____
 (3) Other (explain) _____

4. Program Directed Special Handling (copy attached)

D. Releasing Official

- A. Patent Clearance ("X" one)
 Has been submitted for DOE patent clearance
 DOE patent clearance has been granted
B. Released by
(Name) _____
(Signature) _____
(Phone) _____
(Date) _____

U.S. DEPARTMENT OF ENERGY
RECOMMENDATIONS FOR THE ANNOUNCEMENT AND DISTRIBUTION
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(See instructions on reverse side. Use plain bond paper if additional space is needed for explanations.)

PART I (DOE, DOE Contractors, Grantees, and Awardees complete)

A. Product/Report Data

1. (Award) Contract No. **DE-FG02-95ER14530**
2. Title: **Measurements of Electron Detachment Cross Sections
in Intermediate Energy H⁻ + CH₄ Collisions**

3. Product/Report Description

- a. Report (complete all that apply)
(1) Print Nonprint (specify) _____
(2) Quarterly Semiannual Annual Final
 Topical Phase I Phase II
 Other (specify) _____

Dates covered _____ thru _____

- b. Conference/Meeting/Presentation (complete all that apply)
(1) Print Nonprint (specify) _____
 Published Proceedings
 Other _____

- (2) Conference Title (no abbreviations)
1996 DAMOP Meeting of The American Physical Society

Location (city/state/country)
Ann Arbor, MI USA

Date(s) (m/d/y) **05/15/1996** thru (m/d/y) **05/18/1996**
Sponsor
American Physical Society

- c. Software — Additional forms are required. Follow instructions on the back of this form.
 d. Other (Provide complete description)

B. Patent information

- Yes No
 Is any new equipment, process, or material disclosed?
If yes, identify page numbers _____
 Has an invention disclosure been submitted?
If yes, identify the disclosure number and to whom it was submitted. Disclosure number _____
Submitted to _____
 Are there patent-related objections to the release of this STI product? If so, state the objections. _____

C. Contact (Person knowledgeable of content)

Name: **Thomas J. Kvale**
Phone: **(419) 530-2980**
Position: **Professor of Physics**
Organization: **The University of Toledo**

PART II (DOE, DOE Contractors complete/or as instructed by DOE contracting officer)

A. DOE Identifiers

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2. Funding Office(s) (Note: Essential data) **Chicago**

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 2. (number) for standard classified distribution
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 4. (number) for standard unclassified distribution
 5. UC/C Category _____
 6. Additional instructions/explanations _____

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C. Recommendation ("X" at least one)

1. Program/Standard Announcement/Distribution
(Available to U.S. and foreign public)

2. Classified (Standard Announcement only)
 3. Special Handling (Legal basis must be noted below.)
 a. Unclassified Controlled Nuclear Information (UCNI)
 b. Export Control/ITAR/EAR
 c. Temporary hold pending patent review
 d. Translations of copyrighted material
 e. Small Business Innovation Research (SBIR)
 f. Commercializable Information
 (1) Proprietary
 (2) Protected CRADA information
Release date / /
 (3) Other (explain) _____
 4. Program Directed Special Handling (copy attached)

D. Releasing Official

- A. Patent Clearance ("X" one)
 Has been submitted for DOE patent clearance
 DOE patent clearance has been granted
B. Released by
(Name) _____
(Signature) _____
(Phone) _____
(Date) _____

U.S. DEPARTMENT OF ENERGY
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PART I (DOE, DOE Contractors, Grantees, and Awardees complete)

A. Product/Report Data

1. (Award) Contract No. **DE-FG02-95ER14530**
2. Title: **Electron Detachment Cross Sections in Intermediate Energy Negative Ion - Atom Collisions**

3. Product/Report Description

- a. Report (complete all that apply)
(1) Print Nonprint (specify) _____
(2) Quarterly Semiannual Annual Final
 Topical Phase I Phase II
 Other (specify) _____

Dates covered _____ thru _____

- b. Conference/Meeting/Presentation (complete all that apply)
(1) Print Nonprint (specify) _____
 Published Proceedings
 Other _____

(2) Conference Title (no abbreviations) **FOURTEENTH INTERNATIONAL CONFERENCE ON THE APPLICATION OF ACCELERATORS IN RESEARCH AND INDUSTRY**

Location (city/state/country)
Denton, TX USA

Date(s) (m/d/y) **11/06/1996 thru (m/d/y) 11/09/1996**
Sponsor

American Physical Society

- c. Software — Additional forms are required. Follow instructions on the back of this form.
 d. Other (Provide complete description)

B. Patent Information

- Yes No
 Is any new equipment, process, or material disclosed?
If yes, identify page numbers _____
 Has an invention disclosure been submitted?
If yes, identify the disclosure number and to whom it was submitted. Disclosure number _____
Submitted to _____
 Are there patent-related objections to the release of this STI product? If so, state the objections. _____

C. Contact (Person knowledgeable of content)

Name: **Thomas J. Kvale**
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Position: **Professor of Physics**
Organization: **The University of Toledo**

PART II (DOE, DOE Contractors complete/or as instructed by DOE contracting officer)

A. DOE Identifiers

1. Product/Report Nos. **DOE/ER/14530--05**
2. Funding Office(s) (Note: Essential data) **Chicago**

B. Copies for Transmittal to AD-21 (OSTI)

(STI must be of sufficient quality for microfilming/copying.)

1. One for classified processing
 2. (number) for standard classified distribution
 3. Two for unclassified processing
 4. (number) for standard unclassified distribution
 5. UC/C Category
 6. Additional instructions/explanations _____

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(Available to U.S. and foreign public)

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 c. Temporary hold pending patent review
 d. Translations of copyrighted material
 e. Small Business Innovation Research (SBIR)
 f. Commercializable Information
 (1) Proprietary
 (2) Protected CRADA information
Release date ____/____/____
 (3) Other (explain) _____

4. Program Directed Special Handling (copy attached)

D. Releasing Official

- A. Patent Clearance ("X" one)
 Has been submitted for DOE patent clearance
 DOE patent clearance has been granted
B. Released by
(Name) _____
(Signature) _____
(Phone) _____
(Date) _____

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PART I (DOE, DOE Contractors, Grantees, and Awardees complete)

A. Product/Report Data

1. (Award) Contract No. **DE-FG02-95ER14530**
2. Title: **Calculation of Atomic Beam Flow in Long Tubes**

3. Product/Report Description

- a. Report (complete all that apply)
(1) Print Nonprint (specify) _____
(2) Quarterly Semiannual Annual Final
 Topical Phase I Phase II
 Other (specify) _____

Dates covered _____ thru _____

b. Conference/Meeting/Presentation (complete all that apply)

- (1) Print Nonprint (specify) _____
 Published Proceedings
 Other _____

(2) Conference Title (no abbreviations)

Fall 1994 OHIO Section Meeting of The American Physical Society

Location (city/state/country)

Toledo, OH USA

Date(s) (m/d/y) 10/14/1994 thru (m/d/y) 10/15/1994

Sponsor

American Physical Society

- c. Software — Additional forms are required. Follow instructions on the back of this form.
 d. Other (Provide complete description)

B. Patent Information

Yes No

- Is any new equipment, process, or material disclosed? If yes, identify page numbers _____
 Has an invention disclosure been submitted? If yes, identify the disclosure number and to whom it was submitted. Disclosure number _____ Submitted to _____
 Are there patent-related objections to the release of this STI product? If so, state the objections. _____

C. Contact (Person knowledgeable of content)

Name: Thomas J. Kvale
Phone: (419) 530-2980
Position: Professor of Physics
Organization: The University of Toledo

PART II (DOE, DOE Contractors complete/or as instructed by DOE contracting officer)

A. DOE Identifiers

1. Product/Report Nos. **DOE/ER/14530-06**
2. Funding Office(s) (Note: Essential data) **Chicago**

B. Copies for Transmittal to AD-21 (OSTI)

(STI must be of sufficient quality for microfilming/copying.)

1. One for classified processing
 2. (number) for standard classified distribution
 3. Two for unclassified processing
 4. (number) for standard unclassified distribution
 5. UC/C Category _____
 6. Additional instructions/explanations _____

(Do not identify Sigma categories for Nuclear Weapons Data reports, and do not provide additional instructions that are inconsistent with C below.)

C. Recommendation ("X" at least one)

1. Program/Standard Announcement/Distribution (Available to U.S. and foreign public)

2. Classified (Standard Announcement only)
 3. Special Handling (Legal basis must be noted below.)
 a. Unclassified Controlled Nuclear Information (UCNI)
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Release date ____ / ____ / ____
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4. Program Directed Special Handling (copy attached)

D. Releasing Official

A. Patent Clearance ("X" one)

- Has been submitted for DOE patent clearance
 DOE patent clearance has been granted

B. Released by

(Name) _____
(Signature) _____
(Phone) _____
(Date) _____