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Submitted by

Atomic and Nuclear Science Laboratory
Department of Physics
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Manhattan, Kansas 66506

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I. RESEARCH SUMMARY

This report covers the period from 1 March 1976 to 31 July 1976. The support herein includes the last three months of work on ERDA contract E(11-1)-2130, which terminated 31 May 1976, as well as the work on ERDA SRSA Contract E(11-1)-2753 which supports all the experimental and theoretical atomic physics research since 1 June 1976.

This five month period has been one of continued progress in our efforts to understand the processes leading to electron capture, ionization, vacancy filling via natural decay, and charge transfer in both solid and gas media. It has been shown that the cross sections for K-shell ionization in thin solid targets are dependent on target thickness and incident charge state. Even though charge equilibrium is reached in vanishingly thin foils the K-shell equilibrium is reached in $\sim 100 \mu\text{g}/\text{cm}^2$ for projectiles in the range of $Z = 10$ to $Z = 35$. The data has been explained in terms of the fraction of beam with 0, 1 and 2 K vacancies as a function of projectile depth. It has also been shown that the mechanism for the decay of double K-vacancy states produced in ion-atom collisions by double electron jumps proceeds by "shake down." Another double electron jump transition, radiative electron rearrangement (RER), has been observed and quantitatively explained in terms of final state configuration mixing. The study of the impact parameter dependence of K vacancies has been extended to the nearly symmetric Cl-Ar case. The rotational coupling model predicts fairly well the observed dependence. The K-shell x-ray production cross sections for C, N and O on Ni, Rb, Ag and Sb have been reported as well as the Auger electron production cross sections for C, N, O, F and Cl on Ne gas. The effect of K-vacancy sharing is particularly realized in the F-Cl measurements. The study of electron capture has continued with the measurement of electron capture of H^+ from Ar and He. The Ar results are complete and disagree with theoretical predictions. The simpler system of H^+ - He will hopefully shed some light on this disagreement. A systematic study of the dependence of the argon K-vacancy production on projectile atomic number and charge state has been made. The cross sections for electron capture from helium by bare nuclei with $5 \leq Z \leq 9$ have also been measured at energies

between 0.3 and 3.0 MeV/amu. The experimental study of polarization fractions of radiation emitted following electron capture to excited states has continued. The determination of metastable helium-like ions in high velocity ion beams has been attempted through the charge state dependence of projectile K x-ray production in a gas and similarly through the charge state dependence of target K x-ray production in thin solids.

Heavy ion nuclear experiments were continued at a moderate level with the study of deformation lengths from scattering of strongly interacting projectiles and of elastic scattering of ${}^9\text{Be} + {}^{12}\text{C}$ near the Coulomb barrier.

The theoretical work accomplished and/or begun during this contract period concentrated on new spectroscopic results as well as collision mechanism involving heavy ions and highly stripped atomic species. Theoretical x-ray and autoionization rates for four-electron ions with $2s^n 2p^m$ configuration have been calculated. Branching ratios of two-electron, one-photon transitions have been calculated for double K-vacancy states and for single K-, multiple L-vacancy states. The effects of relaxation and continuum interaction on KLL Auger spectra are being calculated. The $1s-2s$ excitation in hydrogenic targets by electron impact have been calculated. $\text{H}^+ + \text{Ar}$ differential cross sections have been computed as well as Coulomb ionization in H^+ on H, He, Ne and Ar collisions.

II. LABORATORY OPERATION

A layout of the tandem Van de Graaff at Kansas State University is given in Fig. 1. Through the reporting period February 1, 1976 to July 31, 1976 the tandem Van de Graaff accelerator has been operating at its recommended voltage. During this period the tandem has had vertical instabilities in low-energy ion beams. This was thought to be caused by dust bridges developing across the belt spacers inside the accelerator, the dust coming from the belt itself. Upon opening the tandem on May 20, 1976 we found that the charging belt was bad. This belt had a total of 4,528 hours of service on it. After replacing the charging belt with a new black belt purchased from High Voltage Engineering Corporation, Burlington, Massachusetts, we no longer have the vertical instabilities in the low-energy beams. This indicates to us that the old type peach charging belt installed in January, 1975 was probably not of high quality.

Down time through this reporting period of February 1, 1976 through July 31, 1976 was 470 hours. Of the 470 hours, 271 hours were used for the installation of the new charging belt. The remaining 199 hours were for periodic maintenance of items such as foils, collector screens, column resistors, etc.

The two negative ion sources on the tandem have been used successfully through the reporting period. The diode source had one failure in which a roughing pump belt broke and contaminated the source with oil. The source including acceleration column was completely dismantled and cleaned. The usual beams of H, CN, O, F, S, Cl, Br and I were in use. The Cs ion sputter source was used for ~ 1200 hours during this period producing beams of H, Li, Be, B, C, AlO, Si, Ni and Cu. Through routine cleaning of the source very reliable operation was maintained. The ionizer was replaced twice because of a hole burnt through it. It is believed that backstreaming electrons which are normally suppressed are causing the damage. A bad connector on the suppressor has been identified as the culprit.

ACCELERATOR LABORATORY
KANSAS STATE UNIVERSITY
DEPARTMENT OF PHYSICS
FLOOR PLAN

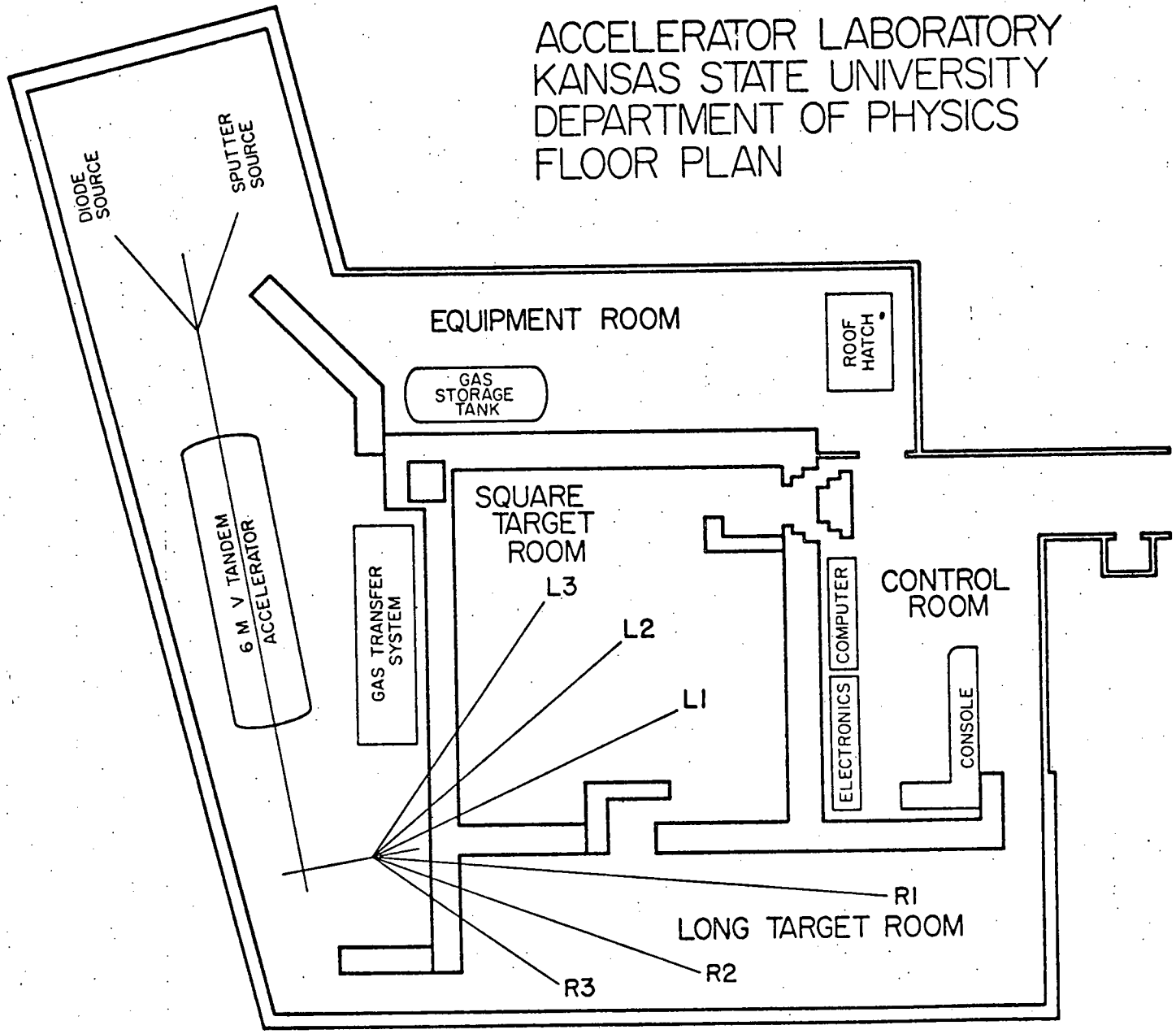


Fig. 1

The 3 MV Van de Graaff has been in operation a total of 500 hours during this reporting period. During this same period the machine itself was opened only three times for routine maintenance. Additions to the facility include a new beam line equipped for differential pumping of gas targets for single-collision experiments and a movable radiation shielding wall at the rear of the accelerator. A new pumping station for the tube and magnet wave guide has been ordered and will be installed during July of this year.

During the period since our last progress report, significant improvements have been made in our laboratory PDP-15 on-line computer system. First, an improved foreground-background monitor was placed in operation. This monitor virtually eliminates the possibility of the foreground user and background user interfering with each other during the simultaneous use of shared DEC tape handlers. Second, a flaw in our data acquisition program was discovered and remedied. This flaw had made it possible to accept up to 30 unwanted counts into a total spectrum. Although the effect of this flaw was undetectable in almost all uses, its repair could have marginal effects on very low-statistics data. Finally, a new buffer memory for the 9-track tape deck was acquired and installed. In addition, an improved handler was written and installed which makes it possible for Fortran users to read and write multifile ANSI standard tapes compatible with the university computing center. In addition, the new handler allows the user to read non-file oriented tapes such as those produced by other analyzers' magnetic tape recording equipment. This addition will, in the future, allow reliable, large-volume, high-speed communication between the 3 MV accelerator lab, the tandem accelerator lab, and the university computing center.

The PDP-15 computer hardware operated without major failure. Due to the age of the system, a fair amount of maintenance was required however. Both the foreground and background scopes were sent back to the manufacturer for refurbishing. The deck tape guides were worn and had to be replaced and a new keyboard was installed on one of the decwriters. A new multisteping controller was designed and constructed with the feature of automatic dead time correction.

Installation of new equipment for experiments includes a second vacuum pumping station for L2 beam line to allow for two scattering chambers in series. A new pump was also installed on L1 to replace a turbo pump which induced undesired vibrations on the beam line. A new Li(Si) x-ray detector has been received but not operating according to specifications. An adjustment will be sought from the manufacturer.

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III. PUBLICATIONS FOR PERIOD 1 FEBRUARY 1976 TO 31 JULY 1976

1. Differential Cross Sections for Electron Capture from Argon by 6-MeV Protons
C. L. Cocke, J. R. Macdonald, B. Curnutte, S. L. Varghese, and R. Randall, Phys. Rev. Letters 36, 782 (1976).
2. Heavy-Ion-Produced High-Resolution Si-K-X-Ray Spectra from a Gas and a Solid
R. L. Kauffman, K. A. Jamison, Tom J. Gray, and Patrick Richard, Phys. Rev. Letters 36, 1074 (1976).
3. Origin of Two-Electron, One-Photon K-X-Ray Transitions
T. Aberg, K. A. Jamison, and Patrick Richard, Phys. Rev. Letters 37, 63 (1976).
4. Experimental Impact-Parameter-Dependence Probabilities for K-Shell Vacancy Production by Fast Heavy-Ion Projectiles
R. R. Randall, J. A. Bednar, B. Curnutte and C. L. Cocke, Phys. Rev. A 13, 204 (1976).
5. Single-Electron Born Approximations for Charge Transfer from Multielectron Atoms to Protons
K. Omidvar, J. E. Golden, J. H. McGuire, and L. Weaver, Phys. Rev. A 13, 500 (1976).
6. Glauber Cross Sections for Inner-Shell Ionization in Multielectron Targets by Electron Impact
J. E. Golden and J. H. McGuire, Phys. Rev. A 13, 1012 (1976).
7. K-Shell X-Ray Production Cross Sections for ^{12}C , ^{14}N , and ^{16}O Ions on Ni, Rb, Ag and Sb: 0.4 - 2.4 MeV/amu
Tom J. Gray, Patrick Richard, Robert L. Kauffman, T. C. Holloway, R. K. Gardner, G. M. Light and J. Guertin, Phys. Rev. A 13, 1344 (1976).
8. K-Shell Auger-Electron Production Cross Sections from Ion Bombardment
C. W. Woods, R. L. Kauffman, K. A. Jamison, N. Stolterfoht, and Patrick Richard, Phys. Rev. A 13, 1358 (1976).
9. Projectile Charge Dependence of the Ionization of Atomic Hydrogen by Alpha Particles and Protons Using the Glauber Approximation
J. E. Golden and J. H. McGuire, J. Phys. B: Atom. Molec. Phys. 9, L11 (1976).
10. Energy Loss of Low-Energy ^{40}Ca Ions in Carbon
K. C. Shane, H. Laumer and G. G. Seaman, J. of Applied Physics 47, 2286 (1976).
11. Relative Multiple Ionization Cross Sections of Neon by Different Projectiles
C. P. Bhalla, Beam-Foil Spectroscopy, Vol. 2, Collisional and Radiative Processes, ed. by I. A. Sellin and D. J. Pegg (Plenum Press, New York, 1976) p. 629

12. Relativistic Contributions to Transition Energies in NiI and CuI Isoelectronic Sequences
C. P. Bhalla, C. L. Cocke, and S. L. Varghese, Beam-Foil Spectroscopy, Vol. 1, Atomic Structure and Lifetimes, ed. by I. A. Sellin and D. J. Pegg (Plenum Press, New York, 1976) p. 111.
13. Lifetimes and Fluorescence Yields of Three-Electron Ions
C. P. Bhalla and A. H. Gabriel, Beam-Foil Spectroscopy, Vol. 1, Atomic Structure and Lifetimes, ed. by I. A. Sellin and D. J. Pegg (Plenum Press, New York, 1976) p. 121.
14. Lifetime Measurement of the 3P_1 State of Helium-Like Sulphur
S. L. Varghese, C. L. Cocke, B. Curnutte and R. R. Randall, Beam-Foil Spectroscopy, Vol. 1, Atomic Structure and Lifetimes, ed. by I. A. Sellin and D. J. Pegg (Plenum Press, New York, 1976) p. 299.
15. X Rays from Foil-Excited Beams at Tandem Energies
C. L. Cocke, Beam-Foil Spectroscopy, Vol. 1, Atomic Structure and Lifetimes, ed. by I. A. Sellin and D. J. Pegg (Plenum Press, New York, 1976) p. 283.
16. Experimental Studies of Target and Projectile X Radiation in High Velocity Atomic Collisions
James R. Macdonald, IX International Conference on the Physics of Electronic and Atomic Collisions, ed. by J. S. Risley and R. Geballe (Univ. of Washington Press, Seattle, 1976) p. 408.
17. Mössbauer Effect Studies of $\text{Fe}(\text{phen})_2(\text{NCBH}_3)_2$ - A Spin Triplet
S. Yeh, K. F. Purcell and John S. Eck, Physics Letters **57A**, 80 (1976).

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IV. PAPERS SUBMITTED FOR PUBLICATION

1. Role of Residual K-Shell Vacancies in Solid Target X-ray Cross Sections, Tom J. Gray, Patrick Richard, K. A. Jamison, J. M. Hall, and R. K. Gardner, submitted to Physical Review A.
2. Single-Photon Two-Electron Rearrangement Transitions, K. A. Jamison, J. M. Hall, J. Oltjen, C. W. Woods, Robert L. Kauffman, Tom J. Gray and Patrick Richard, submitted to Physical Review A.
3. Lifetimes of Low-Energy States in ^{21}Ne , G. G. Seaman, D. J. Crozier, J. C. Legg, and K. C. Shane, submitted to Nuclear Physics.
4. Bridging Cyanide in $\text{Fe}(\text{phen})_2(\text{NCBH}_3)_2$ - A Spin Triplet, S. M. Yeh, K. F. Purcell, and J. S. Eck, submitted to Journal of the American Chemical Society.
5. Dissipative Forces and Quantum Mechanics, John S. Eck and W. J. Thompson, accepted for publication in American Journal of Physics.
6. Cross Sections for Atomic K-Shell Ionization by Proton Impact in the Single Particle Glauber Approximation, J. E. Golden and J. H. McGuire, submitted to Physical Review A.
7. Differential Cross Sections for Ionization of Atomic Hydrogen by 25 - 200 keV Protons, J. T. Park, J. E. Aldag, J. M. George, J. L. Peacher, and J. H. McGuire, submitted to Physical Review A.
8. Theoretical X-Ray and Autoionization Rates for Four-Electron Ions with $2s^n 2p^m$ Configurations, M. Ahmed, S. C. Soong and C. P. Bhalla, submitted to International Conference on the Physics of X-Ray Spectra, National Bureau of Standards, Aug 30 - Sept. 2, 1976.
9. Effects of Relaxation and Continuum Interaction on the Neon KLL Auger Spectrum, G. Howat, T. Aberg and O. Goscinski, submitted to International Conference on the Physics of X-Ray Spectra, National Bureau of Standards, Aug. 30 - Sept. 2, 1976.
10. Multielectron Transitions in K X-Ray Spectra of Ion-Atom Collisions, T. Aberg, submitted to International Conference on the Physics of X-Ray Spectra, National Bureau of Standards, Aug 30 - Sept. 2, 1976.

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V. ABSTRACTS OF CONTRIBUTED PAPERS

1. "A Universal Curve for DWBA Calculations of 1s-2s Excitation in Hydrogenic Targets of Arbitrary Nuclear Charge" P. R. Simony, J. H. McGuire, J. E. Golden, and J. R. Junker, BAPS 21, 574 (1976).
- ✓ 2. "Difficulties in the Theory of Atomic Charge Transfer" J. H. McGuire, BAPS 21, 548 (1976).
3. "Angular Distributions in Charge Transfer from an Atomic K-Shell to an Incident Proton" J. E. Golden, J. H. McGuire, L. Weaver, and K. Omidvar, BAPS 21, 548 (1976).
4. "A Study of Effective Cu K-x-ray Production Resulting from Cl-Ion Bombardment" Tom J. Gray, Patrick Richard, K. A. Jamison, and J. M. Hall, BAPS 21, 651 (1976).
5. "Anisotropy of Characteristic K-Shell X Rays from Heavy-Ion-Atom Collisions" L. D. Ellsworth, J. R. Macdonald, E. Salzborn, and J. A. Guffey, BAPS 21, 651 (1976).
6. "Origin of Two-Electron, One-Photon K X-ray Transitions" Patrick Richard, T. Aberg, and K. A. Jamison, BAPS 21, 651 (1976).
- ✓ 7. "Deformation Lengths from Scattering of Strongly Interacting Projectiles" W. J. Thompson and J. S. Eck, European Physical Society Conference Proceedings on Radial Shape of Nuclei in Cracow, Poland (June 1976).
8. "Classical and Quantal Aspects of Dissipative Forces" John S. Eck and W. J. Thompson, BAPS 21, 511 (1976).
- ✓ 9. "Study of Elastic Scattering of $^9\text{Be} + ^{12}\text{C}$ Near the Coulomb Barrier" John S. Eck and Tom J. Gray, BAPS 21, 555 (1976).
- ✓ 10. "Differential Cross Sections for Electron Capture from Argon by 6 MeV Protons" C. L. Cocke, J. R. Macdonald, B. Curnutte, S. L. Varghese, and R. Randall, BAPS 21, 548 (1976).
11. "Impact Parameter Dependence of K-Vacancy Production in Cl-Ar Collisions" R. Randall, C. L. Cocke, S. L. Varghese, and B. Curnutte, BAPS 21, 689 (1976).
12. "Investigation of the $^{13}\text{C}(^{13}\text{C},\alpha\gamma)^{22}\text{Ne}$ Reaction" E. W. Dreyer, G. G. Seaman, and J. C. Legg, BAPS 21, 555 (1976).

between 0.3 and 3.0 MeV/amu. The experimental study of polarization fractions of radiation emitted following electron capture to excited states has continued. The determination of metastable helium-like ions in high velocity ion beams has been attempted through the charge state dependence of projectile K x-ray production in a gas and similarly through the charge state dependence of target K x-ray production in thin solids.

Heavy ion nuclear experiments were continued at a moderate level with the study of deformation lengths from scattering of strongly interacting projectiles and of elastic scattering of ${}^9\text{Be} + {}^{12}\text{C}$ near the Coulomb barrier.

The theoretical work accomplished and/or begun during this contract period concentrated on new spectroscopic results as well as collision mechanism involving heavy ions and highly stripped atomic species. Theoretical x-ray and autoionization rates for four-electron ions with $2s^n 2p^m$ configuration have been calculated. Branching ratios of two-electron, one-photon transitions have been calculated for double K-vacancy states and for single K-, multiple L-vacancy states. The effects of relaxation and continuum interaction on KLL Auger spectra are being calculated. The $1s-2s$ excitation in hydrogenic targets by electron impact have been calculated. $\text{H}^+ + \text{Ar}$ differential cross sections have been computed as well as Coulomb ionization in H^+ on H, He, Ne and Ar collisions.