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TENNESSEE UNIV KNOXVILLE

STRUCTURE OF MULTIPLY IONIZED HEAVY IONS AND ASSOCIATED COLLISI--ETC(U)

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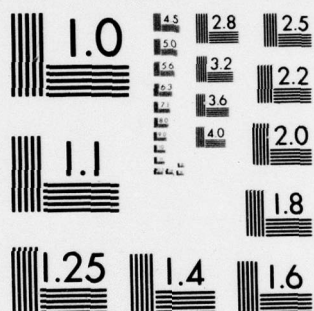
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1. Contract Description

Experiments on ion-atom and ion-molecule collisions using highly ionized projectiles are proposed. Electron ejection by these projectiles and decay of excited states of these ions by x-ray and also by electron emission processes are the processes most commonly observed in carrying out these experiments.

2. Scientific Problem

The most important unknown aspect of the proposed experiments is the role of single step, multiple electron ejection and excitation processes in the description of the aftermath of very violent collisions of highly ionized ions with target atoms and molecules. These multiple ejection, excitation, and rearrangement processes are most probable when the projectile charge is larger than that of the target atomic centers. The mechanisms of electron ejection to the continuum and of creation of states of high multiple excitation, high excitation energy, and high angular momentum are poorly understood and are fundamental objectives of study. Guidance from theory is minimal due to the complete lack of applicability of perturbation

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theory in such violent encounters. As this area of collisions physics has been very little studied, some of the proposed projects represent long term goals.

3. Scientific and Technical Approach

Our principal tools in carrying out such experiments are suitable heavy ion accelerators; electron spectrometers; x-ray, soft x-ray, and extreme ultraviolet spectrometers; and a variety of peripheral equipment associated with these devices. Typically, MeV projectile energies are used, although some molecular collision studies are carried out at keV collision energies. Binary encounters between projectiles and single target atoms or molecules are studied to yield maximal information about fundamental collision processes. Nuclear electronic detection and pulse processing techniques are heavily used in our experiments.

4. Progress

During the present contract year, a major new direction has been taken in our experiments. In our renewal proposal of one year ago, we mentioned four possible fates for electrons excited or ejected in single collision, multiple electron excitation by highly charged heavy ion impact: (a) target electron excitation to higher, bound or ionization continuum (target-centered) orbits; (b) projectile electron excitation to higher, bound projectile-centered states; (c) electron capture of target electrons into bound projectile-centered orbits; (d) population of projectile-centered continuum states through either capture of target electrons to the projectile-centered ionization continuum (ECC) or excitation of projectile electrons to these same states (electron loss to the continuum, ELC). Process (d) has

received comparatively little attention, though it often has as large or larger rates (cross-sections) than processes (a) - (c). Of the work done on topic (d) to date, most has involved either H or He beams in various gas and solid targets. The work we have initiated is unique in that it concerns higher projectile velocities, heavier projectiles, and more highly charged projectiles than ever used heretofore. The high projectile charge states should permit study of multiple electron transitions to such projectile-centered states, and this is a major long term goal.

Our initial efforts in this direction have occurred this past contract year, and have been very fruitful. Our technique permits examination of electron ejection to the projectile centered continuum by doing electron spectroscopy on the forward peak of ejected electrons accompanying projectile ions in both direction and speed. The number of such electrons and their spread in direction and speed are the quantities studied. Specifically, we have made three experimental discoveries during the present contract year:

- (a) a $Z^{2.2 \pm 0.2}$ projectile nuclear charge dependence for ECC by bare (fully ionized) projectiles undergoing single, charge transfer collisions in various dilute target gases, compared to a Z^3 dependence predicted by two different classes of ECC theory;
- (b) strong structure in the velocity spectrum of electrons in the vicinity of the projectile velocity for the ELC process, for some ion charge states (e.g. 4-electron oxygen; 2, 3, 4- electron silicon);
- (c) projectile and target material independence and projectile velocity independence of the shape of the velocity spectrum

of the forward-peaked electrons for projectiles traversing solid targets. This result is in conflict with both ECC descriptions and the so-called "wake-riding" solid state electronic description of the formation of the forward peak when fast ions penetrate solid media. These three principal accomplishments of the present contract year have all been reported in the journal Physical Review Letters (issues of April 10, August 17, and September 4, 1978).

In collaboration with scientists at the GSI accelerator facility at Darmstadt, W. Germany, ELC was also studied for Kr^{26+} projectiles in Ar and C, and preliminary data on angular distributions of the forward peak of electrons near the forward direction was obtained.

Progress in a different area was also made, in collaboration with scientists at the Research Institute of Physics in Stockholm.

Our study of quantum beats in Lyman alpha emission subsequent to charge transfer to the $n = 2$ levels of hydrogen by fast (~ 2 au) protons in He, Ar, and O_2 revealed that population of $2s$ and $2p_0$ states is very coherent. Simply put, the electronic charge cloud formed in such collisions is neither stationary with respect to the emergent proton nor centered on it, but instead undergoes coherent electric dipole oscillations with respect to the position of the emergent proton. In a separate experiment using the same quantum beat apparatus, we found quantum beats in H_β emission following passage of H^+ , H_2^+ , and H_3^+ through thin carbon foils. As the patterns are quite different depending on the molecular structure of the projectile, interpretation of the changes in beat pattern owing to correlated interactions of the target fragments is possible.

5. DISCUSSION OF PRESENT AND PREVIOUS ONR-SUPPORTED RESEARCH

A. List of Publications on Research Accomplished under ONR Support, 1 November 1977 to date (present contract year, in inverse chronological order):

Books, Major Articles in Books, Reviews:

1. Structure and Collisions of Ions and Atoms, I. A. Sellin, ed. (Springer Verlag, Heidelberg, 1978).
2. Op. cit., Chapter 6, "Extensions of Beam Foil Spectroscopy."
3. "Optical, X-ray, and Auger Beam Foil Studies," in Methods of Experimental Physics, Vol. 14, P. Richard, ed. (Academic Press, New York), to be published in 1979.
4. "The Violent Many-Electron Chemistry of Highly Charged Ions," in Physics News - 1977, G. Present, ed. (American Institute of Physics, New York), p. 18 (1977).

Other Articles in Books, Major Journals, and Proceedings:

"Z, Velocity, and Target-Material Dependence of Convoy Electrons from Solids." Phys. Rev. Lett. 41, 712 (1978).

"Observation of Oscillatory (Interference?) Structure in the Forward Peak from Fast-Projectile Electron Loss," Phys. Rev. Lett. 41, 399, (1978).

"Continuum Electron Capture Dependence on Projectile Z and Velocity," Z. Physik A 286, 233 (1978).

"Z, Velocity, and Charge Dependence of Zero-Degree Electron 'Cusps' from Charge Transfer to Continuum States of Bare and Highly Ionized Projectiles," Phys. Rev. Lett. 40, 1020 (1978).

Invited paper, "Electron 'Cusp' Spectroscopy of the Forward Peak in Continuum Electron Capture and Loss in Gases and Solids," to be published in the Proceedings of the International Conference on Fast Ion Spectroscopy, Université de Lyon, by the Journal de Physique in 1979.

Creation of Mixed-Parity Excited States in $H(n=2)$ Following Single, Charge Transfer Collisions of Fast H^+ in Gases," to be published in the Proceedings of the Fifth International Conference on Beam-Foil Spectroscopy, Université de Lyon, by the Journal de Physique in 1979.

"Oscillator Strength Determinations for $\Delta n = 0$ Transitions in Be-like Ions of the Third Period Elements," to be published in the Proceedings of the Fifth International Conference on Beam-Foil Spectroscopy. Université de Lyon, by the Journal de Physique in 1979.

"A Systematic Study of the $2s^2 2p^k - 2s 2p^{k+1} - 2p^{k+2}$ Transitions in Multiply-Charged Cl Ions," to be published in the Proceedings of the Fifth International Conference on Beam-Foil Spectroscopy, Université de Lyon, by the Journal de Physique in 1979.

"Radiative Lifetimes of Highly Ionized and Foil-Excited Al," to be published in the Proceedings of the Fifth International Conference on Beam-Foil Spectroscopy, Université de Lyon, by the Journal de Physique in 1979.

"Observation of Mixed Parity Electric Dipole Oscillations in Charge-Transfer to the $n=2$ Hydrogen Levels by Fast Protons in Gases," submitted to Phys. Rev. Lett.

Invited Paper, "Electron Capture to Continuum States," to be published in the Proceedings of the Fifth Conference on Application of Small Accelerators, North Texas State University, November 6-8, 1978, in the February 1979 issue of IEEE Transactions on Nuclear Science.

Invited Paper, "Failure of Single Electron Descriptions of Molecular Orbital Collision Processes," to be published in the Proceedings of the Fifth Conference on Application of Small Accelerators, North Texas State University, November 6-8, 1978, in the February 1979 issue of IEEE Transactions on Nuclear Science.

Invited Paper, "A Scanning Proton Microprobe for Trace Element Analysis," to be published in the Proceedings of the Fifth Conference on Application of Small Accelerators, North Texas State University, November 6-8, 1978, in the February 1979 issue of IEEE Transactions on Nuclear Science.

"Many-electron Transitions in Violent Encounters of Highly Ionized Ions with Atoms and Molecules," Comments on Atomic and Molecular Physics 8, 112, 21 (1978).

"Observation of Quantum Beats in Gas-excited Helium Projectiles," Zeitschrift für Physik, A 283, 299 (1977).

"Radiative Lifetimes and Oscillator Strengths for Allowed Intra L-Shell Transitions in Multiply-Charged Chlorine Ions," Phys. Rev. A 18, 1476 (1978).

"Radiative Lifetimes and Oscillator Strengths for Allowed Transitions in Li-like and Be-like Silicon," Physica Scripta 18, 18 (1978).

"Oscillator Strengths of the $2s^2 S_{1/2} - 2p^2 P^{\circ}_{1/2} \quad 3/2$ Transitions in Fe XXIV and the $2s^2 \quad 1S_0 - 2s 2p^3 P_1$ Transition in Fe XXIII," Phys. Rev. A 18, 208 (1978).

"A Measurement of Oscillator Strengths for Solar XUV Flare Lines in Ni XVIII," Astrophysical J. 224, 1056 (1978).

"Radiative Lifetimes of the Low-lying Levels of Na-like Copper," Phys. Rev. A 16, 2008 (1977).

"Studies of Neon L-Shell Excitation by Impact of Highly Ionized Heavy Ions," Z. Physik A 283, 329 (1977).

"A Survey of Problems in Beam-Foil Spectroscopy of Iron and Copper at Energies from 16 to 110 MeV," Nucl. Inst. and Meth. 154, 169 (1978).

"An Experimental Survey of Electron Transfer in keV Collisions in Multiply Charged Ions with Atomic Hydrogen," p. 126 in Atomic Physics 5 (Proceedings of the Fifth International Conference on Atomic Physics, Berkeley, California, July 1976) edited by R. Marrus, M. Prior and H. Shugart, Plenum Press, New York, 1977.

"Many-Electron Aspects of Molecular Promotion in Ion-Atom Collisions: Production of Core-Excited States of Li in Li^+ - He Collisions," submitted to Phys. Rev. A.

"Radiative Lifetime Measurements at Grazing Incidence Wavelengths," (a section in an article on accelerator-based atomic physics to appear in Review of Modern Physics in 1979.)

Other Papers:

"Consequences for Parity Violation Experiments of Creation of Mixed-Parity Excited States in $\text{H}(n=2)$ Following Single Collisions of Fast H^+ in Gases," to be published in Bull. Am. Phys. Soc. in 1978.

"Molecular Modulation of $\text{H}(n=4)$ Quantum Beats Following Single Foil Excitation of H^+ , H_2^+ and H_3^+ Beams," to be published in Bull. Am. Phys. Soc. in 1978.

"Search for Correlation Effects Between Multiple Electron Loss to Continuum Events in High Energy O^{4+} - Ar Collisions," to be published in Bull. Am. Phys. Soc. in 1978.

"Observation of Strong Structure in the Forward Peak from Fast-Projectile Electron Loss," to be published in Bull. Am. Phys. Soc. in 1978.

"Systematics of Continuum Capture and Loss by Bare and Highly Ionized H, C, O and Si Projectile Ions Traversing He, Ne, and Ar Targets," to be published in Bull. Am. Phys. Soc. in 1978.

"Electron Capture to Continuum States by Bare Projectile Ions," to be published in Bull. Am. Phys. Soc. in 1978.

"Time-Resolved Spectroscopic Measurements on Multiply-Charged Si, P, and Cl Ions." Tenth Conference of the European Group on Atomic Spectroscopy, Munich, Germany, July 11-14, 1978. Book of Abstracts, p. 63.

"Projectile Charge State Dependence of Zero Degree 'Cusps' from C^{q+} ($q = 4-6$) and O^{q+} ($q = 4-8$) Traversing Ar at 1.6 MeV/A to 2.8 MeV/A," Bull. Am. Phys. Soc. 23, 513 (1978).

"Charge Transfer to Continuum States of Bare and Highly Ionized Projectiles," Bull. Am. Phys. Soc. 23, 512 (1978).

"Z Dependence and Velocity Dependence of Zero Degree Electron 'Cusps' from C^{6+} and O^{8+} Traversing Ar at 1.6 MeV/A to 2.8 MeV/A," Bull. Am. Phys. Soc. 23, 512 (1978).

"Projectile Velocity Dependence of Li-Core Excitation in Single Collisions with He Targets," Bull. Am. Phys. Soc. 23, 513 (1978).

"Lebensdauer messung von Metastabilen Zuständen mit verzögerter Koinzidenz nach Anregung mit gepulstem UNILAC - Strahl," In Beitrag für GSI-Nachrichten 2-78 (1978).

"Lebensdauer metastabiler Dreielektronen-Zustände mit einer Koinzidenz Technik," Verhandl., Deutsche Physikalische Gesellschaft, February, 1978, 424 (1978).

"Stark Shifts and Broadening of Auger Lines of Highly Ionized Atoms in Molecules After Heavy Ion Impact," Bull. Am. Phys. Soc. 22, 1320 (1977).

"Quantum Beat Method Of Measuring Alignments in Single Ion-Atom Collisions," Bull. Am. Phys. Soc. 22, 1320 (1977).

"Metastable Auger Emitter Lifetimes by a Delayed Coincidence Technique," Bull. Am. Phys. Soc. 22, 1320 (1977).

"Radiative Lifetime Measurements on the $n = 2$ Levels of Al XI and P XII," Bull. Am. Phys. Soc. 22, 1321 (1977).

"Target Specificity Effects on the Production of Core-Excited States of Li and Li^+ for 10 to 50 keV Collisions of Li^+ with Gas Targets," Bull. Am. Phys. Soc. 22, 1334 (1977).

"Decay Studies of $n = 3$ Transitions in Sodiumlike Bromine," Bull. Am. Phys. Soc. 22, 1321 (1977).

"Lifetimes of the $2p^2\ ^2P_{1/2\ 3/2}$ States of Fe XXIV and the $2s2p\ ^3P_1^o$ State of Fe XXIII," Bull. Am. Phys. Soc. 22, 1322 (1977).

"Lifetimes and Oscillator Strengths for $\Delta n = 0$ Dipole Transitions in C-, N-, O-, and F-like Chlorine," Bull. Am. Phys. Soc. 22, 1321 (1977).

"Decay Measurements on the $n = 2$ States of Li-, Be-, and B-like Chlorine," Bull. Am. Phys. Soc. 22, 1321 (1977).

"Oscillator Strengths for the Principal Resonance Transitions in Si XI and XII," Bull. Am. Phys. Soc. 22, 1321 (1977).

B. List of Publications on Research Accomplished Under Previous ONR Support:
Articles in Major Journals and Proceedings (in inverse chronological order):

Books, Major Articles in Books, Reviews:

1. Beam Foil Spectroscopy: Vol. 1, Atomic Structure and Lifetimes, Vol. 2, Collisional and Radiative Interactions, I. A. Sellin and D. J. Pegg, eds., Plenum Press, New York (1976).
2. "Highly Ionized Ions," in Advances in Atomic and Molecular Physics, Vol. 12, D. R. Bates and B. Bederson, eds., Academic Press, New York (1976), p. 215.
3. "Measurement of Auger Lifetimes and Energy Levels by Projectile Electron Spectroscopy," in Topics in Current Physics, Vol I: Beam-Foil Spectroscopy, S. Bashkin, ed., Springer-Verlag, Heidelberg (1976), Chap. 10, p. 265.

Other Articles in Books, Major Journals and Proceedings:

"Spin-dependent Excitation of Autoionizing States of Li Produced in Collisions with Noble Gas Targets," in Proceedings, Tenth International Conference on the Physics of Electronic and Atomic Collisions, M. Barat, J. Reinhardt, and G. Watel, eds. (Commissariat a l'Energie Atomique, Paris), p. 1014 (1977).

"Neon Characteristic X-ray Production in Neon-Neon Collisions as a Function of Incident Projectile Charge State," in Proceedings, Tenth International Conference on the Physics of Electronic and Atomic Collisions, M. Barat, J. Reinhardt, and G. Watel, eds. (Commissariat a l'Energie Atomique, Paris), p. 894 (1977).

"Recoil Ion Spectroscopy in the XUV-Soft X-ray Region Following Heavy Ion Impact on Thin Gas Targets," in Proceedings, Tenth International Conference on the Physics of Electronic and Atomic Collisions, M. Barat, J. Reinhardt, and G. Watel, eds. (Commissariat a l'Energie Atomique, Paris), p. 634 (1977).

"High Resolution Studies of Extensive Ne L-Shell Excitation by Energetic Heavy Ion Impact," in Proceedings, Tenth International Conference on the Physics of Electronic and Atomic Collisions, M. Barat, J. Reinhardt, and G. Watel, eds. (Commissariat a l'Energie Atomique, Paris), p. 632 (1977).

"Overcoming the Doppler Limitation in Beam-Foil Experiments by Target Ion Spectroscopy," in Proceedings, Fourth Conference on Scientific and Industrial Applications of Small Accelerators, J. L. Duggan and I. L. Morgan, eds. (International Association of Electrical and Electronic Engineers, Report 76 CH 1175-9 NPS, New York), p. 319 (1977).

"Intensity Modulations in the Decay of the $3^2P_{1/2}$ Level in the Sodiumlike Ion, Cu^{18+} ," Phys. Rev. Lett. **38**, 1471 (1977).

"Oscillator Strengths for In-Shell ($\Delta n = 0$) Dipole Transitions in Li- and Be-like Sulfur," Phys. Rev. A15, 1958 (1977).

"The Splitting and Oscillator Strengths for the $2s^2S-2p^2P^0$ Doublet in Lithiumlike Sulfur," Astrophysical J. 214, 331 (1977).

"Production of Soft X-Ray Emitting Slow Multiply Charged Ions: Recoil Ion Spectroscopy," Phys. Lett. 61A, 107 (1977).

"Projectile Charge-State Dependence in K-Shell Ionization of Neon, Silicon, and Argon Gases by Lithium Projectiles," Physics Lett. 60A, 292 (1977).

"Charge Dependence of K X-Ray Production in Nearly Symmetric Collisions of Highly Ionized S and Cl Ions in Gases," Phys. Rev. A14, 1997 (1976).

"Radiative Lifetimes and Transition Probabilities for Electric-dipole $\Delta n = 0$ Transitions in Highly Stripped Sulfur Ions," Phys. Rev. A14, 1036 (1976).

"Dipole Oscillator Strengths for $\Delta n = 0$ Transitions in Highly Ionized Sulfur," Physics Lett. 58A, 349 (1976).

"Strong Isotope Dependence of K-Vacancy Production in Slow Ne^+-Ne Collisions," Phys. Rev. Lett. 37, 984 (1976).

"Differences in the Production of Non-Characteristic Radiation in Gaseous and Solid Targets," Phys. Rev. Lett. 36, 1574 (1976).

"An Experimental Survey of Electron Transfer in keV Collisions in Multiply Charged Ions with Atomic Hydrogen," in Proceedings of the Fifth International Conference on Atomic Physics, R. Marrus, M. H. Prior, and H. A. Shugart, eds., University of California, Berkeley, California (1976), p. 126.

"Lifetimes and Transition Rates for Allowed In-Shell Transitions in Highly Stripped Sulfur," in Proceedings of the Fifth International Conference on Atomic Physics, R. Marrus, M. H. Prior, and H. A. Shugart, eds., University of California, Berkeley, California (1976), p. 166.

"Polarization Measurements on the Non-Characteristic Radiation Emitted from Collisions Between High Energy Aluminum Ions," Phys. Letters A56, 89 (1976).

"Applications of Beam-Foil Spectroscopy to Atomic Collisions in Solids," Nucl. Inst. and Meth. 132, 397 (1976).

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"Extreme Ultraviolet Spectra of Highly Stripped Si Ions," in Beam-Foil Spectroscopy: Heavy Ion Atomic Physics, I. A. Sellin and D. J. Pegg, eds., Plenum Press, New York (1976), Vol. 1, p. 321.

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"Photon Energy Dependence of the Asymmetry of Non-Characteristic X-Radiation in Si-Al and Al-Al Collisions," in Electronic and Atomic Collisions, J. S. Risley and R. Geballe, eds., University of Washington Press, Seattle, p. 312 (1975).

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"Symmetric Ion-Atom Collisions at Medium Energies: Non-Characteristic Radiation," Phys. Rev. A **11**, 468 (1975).

"Charge State Dependence of Si K X-Ray Production in Solid and Gaseous Targets by 40 MeV Oxygen Ion Impact," in Atomic Collisions in Solids, S. Datz, ed., Plenum Press, New York (1975), p. 461.

"Lifetimes of the Metastable Autoionizing $(1s2s2p)^4\text{P}_{5/2}$ States of Lithiumlike Al^{10+} and Si^{11+} Ions; Comparisons with theory over the Isoelectronic sequence $Z = 8-18$," Phys. Rev. A **11**, 468 (1975).

"Variation of the Anisotropy of the Non-Characteristic X-Rays Emitted from Fast Ion-Atom Collisions," in Proceedings of the Third Conference on Applications of Small Accelerators, ERDA CONF-74 1040 P1, p. 78 (1975).

"Symmetric Ion-Atom Collisions at Medium Energies: Characteristic X-Rays," Phys. Rev. A11, 135 (1975).

"Projectile Electron Emission Spectroscopy on Optically Inaccessible Autoionizing States in the Alkali Metals," Physics Lett. 50A, 447 (1975).

"Observation of Large and Strongly Energy Dependent Directional Anisotropies in Non-Characteristic K X-Rays Emitted in Heavy Ion Collisions," Phys. Rev. Lett. 34, 64 (1975).

"Characterization of Charge States of Energetic Ions in Solids from Associated K X-Ray Production, Phys. Rev. Lett. 33, 733 (1974).

"Autoionization Lifetimes of the Metastable $(1s2s2p)^4P_{5/2}$ State in the Lithiumlike Ions Al^{10+} , Si^{11+} , and S^{13+} ," published in Proceedings, The Fourth International Conference on Atomic Physics, Heidelberg, Heidelberg Univ. Press, Heidelberg, W. Germany (1974), p. 79.

"XUV Spectra of Highly Ionized Fluorine and Oxygen," Phys. Rev. A 10, 745 (1974).

"New Lines in the XUV Spectrum of Heliumlike Fluorine," Physics Letters 47A, 469 (1974).

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"Observation of K X-Rays from Highly Ionized States of Neon Produced by 40 MeV Cl^{+7} , Cl^{+11} , and Cl^{+13} Beams," Phys. Rev. A9, 1470 (1974).

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"One- and Two-Electron Excited States Produced by Electron Exchange, Excitation, and Electron Capture in Collisions of Fluorine Ions in Argon Gas at 34.8 MeV," Phys. Rev. Lett. 31, 684 (1973).

"Exponential Projectile Charge Dependence of Ar K and Ne X-Ray Production by Fast, Highly-Ionized Argon Beams in Thin Neon Targets," Phys. Rev. Lett. 30, 1289 (1973).

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"Metastable States of Highly Excited Heavy Ions," in Atomic Physics 3, Plenum Press, London, p. 327 (1973).

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"Metastable Autoionizing States in Sodium-like Chlorine," Phys. Rev. Lett. 28, 1615 (1972).

"Metastable Autoionizing States of Highly Excited Heavy Ions," Phys. Rev. Lett. 28, 1229 (1972).

Other Papers:

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Invited paper, "Multiple Electron Rearrangement in Heavy Ion-Atom Collisions," presented at the Gordon Research Conference on Atomic Physics, Wolfsborough, New Hampshire, July 1977.

Invited paper, "Charge Exchange in Slow Collisions," presented at the Gordon Research Conference on Atomic Physics, Wolfsborough, New Hampshire, July 1977.

"Recoil Ion Spectroscopy: Reduction of Doppler Shifts and Spreads in Fast Beam Experiments," Bull. Am. Phys. Soc. 22, 610 (1977).

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"Der $2s^2S-2p^2P^0$ Doublettübergang in Li-ähnlichem Schwefel," Verhandl., Deutsche Physikalische Gesellschaft 2/1977, 500 (1977).

"Lebensdauern und Oszillatörenstärken von $n = 2$ Zuständen in Be-ähnlichem S," Verhandl., Deutsche Physikalische Gesellschaft 2/1977, 500 (1977).

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"An Application of the Beam Foil Method to Transitions of Astrophysical Interest," presented at the American Physical Society Topical Conference on Atomic Processes in High Temperature Plasmas, Knoxville, February 1977.

"Decay Studies of $n = 3$ States of Sodiumlike Copper Using Foil Excitation," presented at the American Physical Society Topical Conference on Atomic Processes in High Temperature Plasmas, Knoxville, February 1977.

Invited paper, "High Ionization-Excitation States of Ne^{q+} Ions and their Mass-Dependent Symmetric Collision Interactions," presented at the Annual Meeting of the American Physical Society, Division of Electron and Atomic Physics, Lincoln, Nebraska, December 1976, Bull. Am. Phys. Soc. 21, 1250 (1976).

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"Electron Spectra from Autoionizing States of Highly Stripped Oxygen and Fluorine," Bull. Am. Phys. Soc. 20, 679 (1975).

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"Charge State Dependence of X-Ray Production of Collisions of Ni (~ 1 MeV/amu) with SiH_4 ," Bull. Am. Phys. Soc. 20, 639 (1975).

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Proceedings of the ORNL Heavy-Ion Summer Study Oak Ridge, Tennessee, AEC
CONF-720669, 551 (1972).

6. Graduate Students, Postdoctoral Personnel, and Associated Investigators

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