

AD-A171 232

INVESTIGATIONS OF THE INTERACTIONS OF RADIATION WITH
MATTER(U) GEORGIA STATE UNIV ATLANTA S T MANSON
31 JUL 86 ARO-19944.18-PH DRAG29-83-K-0054

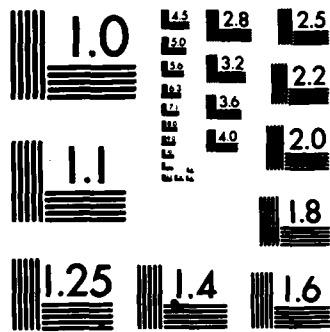
1/1

UNCLASSIFIED

F/G 20/8

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ARO 19944.18PH

2

INVESTIGATIONS OF THE INTERACTIONS
OF RADIATION WITH MATTER

FINAL REPORT

STEVEN T. MANSON

JULY 31, 1986

U.S. ARMY RESEARCH OFFICE

DAAG29 83 K 0054

GEORGIA STATE UNIVERSITY

DTIC
ELECTE
AUG 27 1986
S
D
B
AO

APPROVED FOR PUBLIC RELEASE:
DISTRIBUTION UNLIMITED

AD-A171 232

DTIC FILE COPY

86 8 26 191

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD-A171232

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER <i>ARO 19944.18-PH</i>	2. GOVT ACCESSION NO. N/A	3. RECIPIENT'S CATALOG NUMBER N/A
4. TITLE (and Subtitle) Investigations of the Interactions of Radiation with Matter	5. TYPE OF REPORT & PERIOD COVERED Final Report Mar 1983 - May 1986	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) Steven T. Manson	8. CONTRACT OR GRANT NUMBER(s) DAAG29-83-K-0054	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Georgia State University Atlanta, Georgia 30303	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office Post Office Box 12211 Research Triangle Park, NC 27709	12. REPORT DATE 31 July 1986	
	13. NUMBER OF PAGES 11	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) NA		
18. SUPPLEMENTARY NOTES The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Photoionization, photoabsorption, ionization, relativistic effects, inelastic collisions, excited states, x-rays, inner shells, ions, cross sections		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Work on the interaction of radiation with matter is described. In particular charged particle impact ionization of atoms and molecules is discussed, along with photoabsorption by excited states and ground state atoms, and properties of atomic ions. The relevance of the research to applications in radiation damage and protection, nuclear pumped and x-ray lasers, IR generation and detection, and atmospheric beam devices is pointed out.		

atoms by charged particle impact is relevant to the possibility of creating population inversions necessary to the working of an x-ray laser.

Thus ionization cross sections, of interest in a variety of applications, are needed. Many of those required are either unobtainable at the present level of experiment, or simply unavailable, thereby pointing out the need for theoretical estimates.

Our work has dealt with total cross sections, single differential cross sections (SDCS) or energy distribution of secondary electrons, double differential cross sections (DDCS) or energy and angular distribution of secondary electrons and multiple ionization cross sections. The total and SDCS are the primary results needed as input for the applied area, but the DDCS and multiple ionization cross sections are necessary to elucidate ionization mechanisms and to fully assess the validity of the calculational work.

One major project in this area has been to develop a semi-empirical model of SDCS which can be used to extend existing data. This model, based on the Bethe asymptotic form of the Born approximation, uses optical data which is more generally available than charged particle data. It has been quite successful in predicting the SDCS for ionization of atoms and molecules by protons and electrons.¹⁻⁴ We have also tackled the problem of ionization by ions which carry their own electrons; the general theory has been worked out⁵ and we are presently attempting to apply it.

At the more fundamental level, our work has proceeded in two different directions. First, we have been studying multiple ionization which, although relatively small for light atoms, dominates for the heavier ones. Our work⁶⁻⁹ has been concerned with elucidating the mechanisms that lead to multiple ionization. In one case⁷, we have discovered that the previous ideas of how multiple ionization took place were entirely incorrect; a process thought to be very rare actually dominates the double ionization of neon.

In addition, we have delved into the DDCS for ion-atom collisions where the projectile brings in its own electrons¹⁰⁻¹² in an effort to understand all of the processes which lead to secondary electron emission. This work, in collaboration with an experimental group, has shown the importance of the simultaneous ionization of projectile and target.¹² This is very unexpected for high energy collisions and is causing us to re-examine the dynamics of such collisions.

Finally, in this area, we have made a study of inner shell ionization of light atoms by electrons with applications to analytic electron microscopy in mind.¹³ This study was presented in such a manner so that the results can be adapted to the experimental conditions of each particular instrument.

II. RELATIVISTIC EFFECTS IN PHOTOABSORPTION OF HEAVY ELEMENTS

Photoabsorption by heavy elements in the UV and x-ray range is of importance in the area of radiation physics generally, and specifically in the areas of radiation protection and shielding

of personnel and materials. While the situation is fairly well-understood for light elements, for heavy elements the situation is otherwise.

We have embarked upon a study of photoionization cross sections for high-Z atoms. This theoretical study was performed within the framework of the explicitly relativistic Dirac equation so as to incorporate the relativistic interactions a priori and not as perturbations.

A major focus in this study has been the relativistic effects on the most sensitive feature of the ionization probability (cross section), the point at which they are zero, known as Cooper minima.¹⁴ These minima are pervasive throughout the periodic table¹⁵ and profoundly affect the cross sections. Relativistic interactions split a single minimum into three. Our work has shown that this splitting can be huge.¹⁶⁻¹⁹ This result was originally found in relatively simple calculations, but we have performed much more sophisticated calculations which confirm it. The minima have a significant effect on photoelectron angular distributions, which are of importance in connection with radiation transport and the deposition of energy in biological tissue; they also affect branching ratios, which are of importance in such areas of isotope separation of heavy atoms (like uranium).

We have also been trying to unravel the various types of relativistic effects in photoionization.²⁰ The attempt here is to understand which aspect(s) of relativity are important in photoionization and which can be ignored. Basically, this effort

has been to ascertain the crucial interactions that must be included in a calculation to obtain quantitative accuracy.

III. PHOTOABSORPTION BY EXCITED STATES

Excited states of atoms are produced in quantity in hot environments, such as in the vicinity of an atmospheric thermonuclear blast; thus their properties are of interest. In addition, a detector in the IR range, with a quantum efficiency of unity, is now possible using lasers to excite atoms to states with ionization potentials in the IR range. Therefore, photoabsorption cross sections for excited atomic states are required.

In previous work,^{21,22} the general systematics of excited state photoionization emerged, along with a great profusion of minima (not present for ground states) which lead to transmission windows. Our investigations have been aimed at looking deeper into these minima²³⁻²⁶ by looking at new situations, and using more sophisticated calculations. Among this work was a major study on discrete and ionizing transitions for a number of excited states of the cesium atom.²⁶

We have also endeavored to compare with experiment wherever possible. For sodium, one measurement showed excellent agreement with our calculations,²⁷ and another seemed to validate the existence of these new minima²⁸ and also showed agreement with our calculations.

IV. PROPERTIES OF ATOMIC IONS

Positive ions are also produced in any very hot environment, as discussed above. Their properties are, therefore, of interest in this connection as well as in connection with the passage of a possible x-ray laser beam through the atmosphere.

Properties of atomic ions can be related to a small set of key parameters. One of these properties, the phase shift (or quantum defect) has been studied for all atomic ions for the first 37 members of the periodic table.^{29,30} This study has shown the systematics of changes as one goes to higher and higher stages of ionization; that the rich chemical differences of the neutral atoms rapidly disappear.²⁹ We have also found that our calculational method gave excellent agreement with experiment in the limited number of cases where experiment exists.²⁹ This led us to produce a tabulation of the results.³⁰

REFERENCES

1. J.H. Miller, L.H. Toburen, and S.T. Manson, *Phys. Rev. A* 27, 1337 (1983).
2. J.H. Miller and S.T. Manson, *Phys. Rev. A* 29, 2435 (1984).
3. J.H. Miller and S.T. Manson, *J. Chem. Phys.* 80, 5631 (1984).
4. S.T. Manson and J.H. Miller. Proceedings of the Workshop on Electronic and Ionic Collision Cross Sections Needed in the Modelling of Radiation Interactions with Matter, Ed. M. Inokuti Argonne National Laboratory Report ANL-84-28 (1984), p. 63.
5. S.T. Manson and J.H. Miller, XIV ICPEAC Abstracts of Papers (Palo Alto, 1985) p. 410.
6. L.H. Toburen, R.D. DuBois, and S.T. Manson, *IEEE Trans. Nuc. Sci.* NS-30, 923 (1983).
7. S.T. Manson, R.D. Dubois, and L.H. Toburen, *Phys. Rev. Letters* 51, 1542 (1983).
8. R.D. DuBois, L.H. Toburen, and S.T. Manson, XIII ICPEAC Abstracts of Papers (Berlin, 1983) p. 414.
9. R.D. Dubois, L.H. Toburen, and S.T. Manson in X-Ray and Inner-Shell Process in Atoms, Molecules and Solids, eds. A. Meisel and J. Finster, (Karl-Marx Universitat, Leipzig, 1984), p. 58.
10. S.T. Manson in High Energy Ion-Atom Collisions 2, eds. D. Berenyi and G. Hock (Akademiai Kiado, Budapest, 1985), p. 15.
11. R.D. DuBois and S.T. Manson, XIV ICPEAC Abstracts of Papers (Palo Alto, 1985) p. 408.
12. R.D. DuBois and S.T. Manson, *Phys. Rev. Letters* (submitted).
13. M. Inokuti and S.T. Manson, in Electron Beam Interactions with Solids for Microscopy, Microanalysis and Microlithography, eds. D.F. Kyser, H. Niedrig, D.E Newbury, and R. Shimizu (Scanning Electron Microscopy, Inc., AMF O'Hare, IL, 1983), p. 1.
14. J.W. Cooper, *Phys. Rev.* 128, 681 (1962).
15. S.T. Manson and J.W. Cooper, *Phys. Rev.* 165, 126 (1968).

16. S.T. Manson, C.J. Lee, R.H. Pratt, I.B. Goldberg, B.R. Tambe, and A. Ron, XIII ICPEAC Abstracts of Papers (Berlin, 1983), p. 13.
17. P.C. Deshmukh and S.T. Manson, Phys. Rev. A 32, 3109 (1986).
18. P.C. Deshmukh, V. Radojevic, and S.T. Manson, Phys. Letters (accepted).
19. S.T. Manson and S.K. Bhattacharya, Australian J. Phys. (accepted).
20. R.H. Pratt, A. Ron, S.T. Manson, S.D. Oh, XIII ICPEAC Abstracts of Papers (Berlin, 1983), p. 14.
21. A.Z. Msezane and S.T. Manson, Phys. Rev. Lett. 48, 473 (1982).
22. J. Lahiri and S.T. Manson, Phys. Rev. Lett. 48, 614 (1982).
23. J. Lahiri and S.T. Manson, XIII ICPEAC Abstracts of Papers (Berlin, 1983), p. 8.
24. A.Z. Msezane and S.T. Manson, XIII ICPEAC Abstracts of Papers (Berlin, 1983), p. 9.
25. A. Msezane and S.T. Manson, Phys. Rev. A 30, 1795 (1984).
26. J. Lahiri and S.T. Manson, Phys. Rev. A 33, 3151 (1986).
27. J.M. Preses, C.E. Burkhardt, R.L. Corey, D.L. Earsom, T.L. Daulton, W.P. Garver, J.J. Leventhal, A.Z. Msezane, and S.T. Manson, Phys. Rev. A 32, 1264 (1985).
28. A.Z. Msezane and S.T. Manson, XIV ICPEAC Abstracts of Papers (Palo Alto, 1985), p. 21.
29. C.E. Theodosiou, S.T. Manson and M. Inokuti, Phys. Rev. A (accepted).
30. C.E. Theodosiou, M. Inokuti and S.T. Manson, At. Data Nuc. Data Tab. (accepted).

PUBLICATIONS BASED ON WORK SUPPORTED BY THE U.S. ARMY
RESEARCH OFFICE UNDER THE PRESENT GRANT DAAG29-83-K-0054

March, 1983 - May, 1986

1. "Photoelectron and Auger Spectroscopy," S. B. Hagstron, M. O. Krause, and S. T. Manson in Applications of Atomic Physics Vol. IV - Condensed Matter, S. Datz ed. (Academic Press, N. Y., 1983), pp. 450-544.
2. "Differential Cross Sections for Ionization of Helium, Neon and Argon by High-Velocity Ions," J. H. Miller, L. H. Toburen, and S. T. Manson, Phys. Rev. A 27, 1337-1344 (1983).
3. "Multiple Ionization of Atomic Targets by Proton Impact," L. H. Toburen, R. D. DuBois, and S. T. Manson, IEEE Trans. Nuc. Sci. NS-30, 923-927 (1983).
4. "Photoionization of Magnesium in the Relativistic Random Phase Approximation," P. C. Deshmukh and S. T. Manson Phys. Rev. A 28, 209-217 (1983).
5. "Multiple Ionization Mechanisms in Fast Proton Neon Collision," S. T. Manson, R. D. Dubois, and L. H. Toburen, Phys. Rev. Letters 51, 1542-1545 (1983).
6. "Zeros in Dipole Matrix Elements of Photoionization of Excited Alkali Atoms," J. Lahiri and S. T. Manson, XIII ICPEAC Abstracts of Papers (Berlin, 1983), p. 8.
7. "Cross Sections for the Photoionization of Excited d-states of Alkali Atoms: Hartree-Fock Calculations," A. Z. Msezane and S. T. Manson, XIII ICPEAC Abstracts of Papers (Berlin, 1983), p. 9.
8. "Photoionization of High-Z Atoms: Relativistic Effects on Cooper Minima in the 6p Subshell," S. T. Manson, C. J. Lee, R. H. Pratt, I. B. Goldberg, B. R. Tambe, and A. Ron, XIII ICPEAC Abstracts of Papers (Berlin, 1983), p. 13.
9. "Znl Dependence of Cancellation of Relativistic and Retardation Effects in Photoionization," R. H. Pratt, A. Ron, S. T. Manson, S. D. Oh, XIII ICPEAC Abstracts of Papers (Berlin, 1983), p. 14.
10. "Double Ionization Mechanisms in $H^+ + Ne$ Collisions," R. D. DuBois, L. H. Toburen, and S. T. Manson, XIII ICPEAC Abstracts of Papers (Berlin, 1983) p. 414.

11. "Cross Sections for Inelastic Scattering of Electrons by Atoms - Selected Topics Related to Electron Microscopy," M Inokuti and S. T. Manson, in Electron Beam Interactions with Solids for Microscopy, Microanalysis and Microlithography, eds. D. F. Kyser, H. Niedrig, D. E. Newbury, and R. Shimizu (Scanning Electron Microscopy, Inc., AMF O'Hare, IL, 1983), pp. 1-17.
12. "Recent Progress and Problems in the Theory of VUV Photoionization of Atoms", S. T. Manson, Annals of the Israeli Physical Society 6, 517-526 (1983).
13. "Electron Ejection Cross Sections in Electron and Ion Impact Ionization: Ab Initio and Semiempirical Calculations," S. T. Manson and J. H. Miller. Proceedings of the Workshop on Electronic and Ionic Collision Cross Sections Needed in the Modeling of Radiation Interactions with Matter, Ed. M. Inokuti Argonne National Laboratory Report ANL-84-28 (1984), pp. 63-72.
14. "Differential Cross Sections for Ionization of Helium, Neon, and Argon by Fast Electrons," J. H. Miller and S. T. Manson, Phys. Rev. A 29, 2435-2439 (1984).
15. "Differential Cross Sections for Ionization of Methane, Ammonia and Water Vapor by High Velocity Ions," J. H. Miller and S. T. Manson, J. Chem. Phys. 80, 5631-5638 (1984).
16. "Photoionization of Excited 3d States in Na and K: Investigation of the $\ell + \ell - 1$ Zeros," A. Msezane and S. T. Manson, Phys. Rev. A 30, 1795-1799 (1984).
17. "Insights from Related Observations," S. T. Manson, Workshop Report on New Directions in Soft X-ray Photoabsorption, ed. N. K. Del Grande, Lawrence Livermore National Laboratory Report Conf-8404181(1984), pp. 58-63.
18. "Inner Shell Contribution to Multiple Ionization in Ion-Atom Collisions," R. D. DuBois, L. H. Toburen, and S. T. Manson in X-Ray and Inner-Shell Process in Atoms, Molecules and Solids, eds. A. Meisel and J. Finster, (Karl-Marx-Universitat, Leipzig, 1984), pp. 145-154.
19. "Theoretical Studies of Electron Emission in Ion-Atom Collisions: Bare and Structured Projectiles," S. T. Manson in High Energy Ion-Atom Collisions 2, eds. D. Berenyi and G. Hock (Akademiai Kiado, Budapest, 1985), pp. 15-29.
20. Selected Bibliography on Atomic Collisions," E. W. McDaniel, M. R. Flannery, E. W. Thomas, and S. T. Manson, At. Data Nuc. Data Tables, 33, 1-148 (1985).

21. "Photoionization of the Excited 3p State of Sodium: Experiment and Theory," J. M. Preses, C. E. Burkhardt, R. L. Corey, D. L. Earsom, T. L. Daulton, W. P. Garver, J. J. Leventhal, A. Z. Msezane, and S. T. Manson, *Phys. Rev. A* 32, 1264-1266 (1985).
22. "Photoionization of the Excited Na 4d State, A. Z. Msezane and S. T. Manson, XIV ICPEAC Abstracts of Papers (Palo Alto, 1985), p. 21.
23. "Electron Ejection in He⁺ - He Collisions: Experiment and Theory," R. D. DuBois and S. T. Manson, XIV ICPEAC Abstracts of Papers (Palo Alto, 1985) p. 408.
24. "Electron Ejection in Ion-Atom Collisions: Bethe-Born Theory for Structure Incident Ions," S. T. Manson and J. H. Miller, XIV ICPEAC Abstracts of Papers (Palo Alto, 1985) p. 410.
25. "Application of the Relativistic Random-Phase Approximation to Xe 5s Photoionization," P. C. Deshmukh and S. T. Manson, *Phys. Rev. A* 32, 3109 (1986).
26. "Relativistic Splitting of Cooper Minima in Radon: A Relativistic-Random Phase Approximation Study", P. C. Deshmukh, V. Radojevic, and S. T. Manson, *Phys. Letters* (accepted).
27. "Oscillator-Strength Distributions for Discrete and Continuum Transitions of Excited States of Cesium," J. Lahiri and S.T. Manson, *Phys. Rev. A* 33, 3151-3165 (1986).
28. "Spectral and Electron-Collision Properties of Atomic Ions: Threshold Phase Shifts," C.E. Theodosiou, S.T. Manson and M. Inokuti, *Phys. Rev. A* (accepted).
29. "Quantum Defect Values for Positive Atomic Ions," C.E. Theodosiou, M. Inokuti and S.T. Manson, *At. Data Nuc. Data Tab.* (accepted).
30. "Photoionization of Unusual States of Matter: Atomic Ions, Excited States, and Open-Shell Atoms," S.T. Manson and S.K. Bhattacharya, *Australian J. Phys.* (accepted).
31. "A Coincidence Study of Doubly Differential Cross Sections: Projectile Ionization in He⁺ - He Collisions," R.D. DuBois and S.T. Manson, *Phys. Rev. Letters* (submitted).

END

DTIC

9-86