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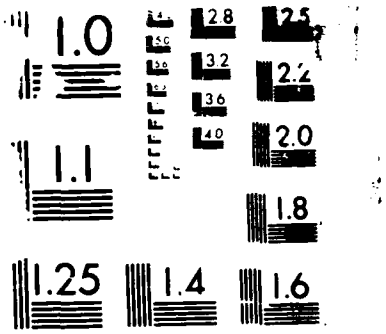
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Department of Physics and Astronomy
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Intense-field, auto-ionization, multiphoton ionization, above-threshold ionization; quasi-continuum, confluence; coherence; golden rule, surface scattering.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):
We describe the research activities carried out under grant AFOSR-81-0204 and continuations.

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COLLECTIVE EFFECTS IN INTENSE-FIELD ELECTRODYNAMICS 1981-1986

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MATTHEW J. KERPER
Chief, Technical Information Division

Final Report of Research Activities carried out under Grant No. AFOSR-81-0204 and continuations during the period 15 June 1981 - 14 June 1986

I. Comprehensive list of Reserach Objectives

To accumulate evidence for collective and coherent effects in the interaction of optical and near-optical radiation with matter, and to develop a theoretical understanding of these effects that is adequate for predictive modeling. The focus of this effort was on continuum transitions such as atomic ionization, molecular dissociation and broadband transitions in solids, where coherence phenomena are not commonly found.

II. Status of the Research

Research objectives were met. Unexpected coherence effects were identified and/or predictive modeling capabilities were developed in several areas. A summary of successful activities follows.

(i) Laser-assisted auto-ionization. It was determined[1] by studying simplified models that transitions to auto-ionizing levels of atoms have the capability to exhibit electron-photon coherence phenomena (until that time unexplored). The most striking of these phenomena is an analog of Autler-Townes splitting, which we showed to imply the possibility of atomic electron "trapping" in an auto-ionizing transition.[2] We further showed that electron trapping is also possible in a purely continuum-continuum transition.[3] The discovery of conditions for trapping is similar to finding a "go, no-go theorem". The trapping conditions identify a domain in which the physical phenomena (radiative absorption and electron emission in this case) are abruptly different from what is conventionally expected.

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(ii) Quenching of the Golden Rule of Decay Processes. We discovered[4] that Fermi's Golden Rule (for the transition rate between a discrete state and a very broad continuum) may break down. A breakdown can occur when the continuum is connected to another state different from the initial state. This is a trivial remark if the other state is discrete like the initial state but quite non-trivial if the other state is a member of a second continuum. This effect was apparently unknown in atomic physics. It appears that this theoretical discovery will have immediate application to experimental work with very high-power lasers now being undertaken[5] in several US and foreign laboratories -- Livermore, U. of Illinois, ATT Bell, U. of Rochester, U. of Bielefeld, C.E.N. de Saclay (Paris), F.O.M. Institute (Amsterdam), General Physics Institute (Moscow).

(iii) Enhanced Light Scattering near Metallic Surfaces. We have applied techniques developed under (i) above to treat coherently enhanced light scattering from molecules and macroscopic dipole "islands" located near to metallic surfaces[6], where recent experiments[7] have exhibited anomalously large cross sections. By including the influence of surface plasmon coupling to continuous degrees of freedom of the substrate material we computed the effect of quasi-Johnson noise as a coherence-destroying mechanism. The framework for futher modeling of such scattering situations was established.

References

1. K. Rzazewski and J.H. Eberly, Phys. Rev. Letters 47, 408 (1981); see also P. Zoller and P. Lambropoulos, Phys. Rev. A 24, 379 (1981).

2. K. Rzazewski and J.H. Eberly, ref. 1 and Phys. Rev. A 27, 2026 (1983); see also P.E. Coleman and P.L. Knight, J. Phys. B 15, L235 (1982) and 15, 1957(E) (1982); and Opt. Commun. 42, 171 (1982).

3. Z. Deng and J.H. Eberly, Phys. Rev. A 34, 2492 (1986).

4. Z. Deng and J.H. Eberly, Phys. Rev. Letters 53, 1810 (1984); and JOSA B 2, 486 (1985) and J. Phys. B 18, L287 (1985). See also Z. Bialynicka-Birula, J. Phys. B 17, 3019 (1984) and M. Edwards, L. Pan and L. Armstrong, Jr., J. Phys. B 18, 1927 (1985).

5. For example, see L.A. Lompre, A. L'Huillier, G. Mainfray and C. Manus, JOSA B 2, 1906 (1985) for recent experimental work at Saclay, and references to earlier work elsewhere.

6. D. Agassi and J.H Eberly, Phys. Rev. Letters 54, 34 (1985); and Phys. Rev. A 34, 2843 (1986).

7. See, for example, W.R. Holland and D.G. Hall, Phys. Rev. Letters 52, 1041 (1984).

III. Cumulative chronological list of journal publications

1. K. Rzazewski and J.H. Eberly
   Confluence of bound-free coherences in laser-induced autonization
   Phys. Rev. Letters 47, 408 (1981).

2. J.H. Eberly, J.J. Yeh and C.M. Bowden
   Interrupted Coarse-Grained Theory of Quasi-Continuum Photoexcitation
   Chem. Phys. Letters 86, 76 (1982)

3. J.J. Yeh, C.M. Bowden and J.H. Eberly
   Interrupted coarse-grained theory of unimolecular relaxation and stimulated recurrences in photoexcitation of a quasi-continuum
   J. Chem. Phys. 76, 5936 (1982).

4. J.H. Eberly, K. Rzazewski and D. Agassi
   Influence of Relaxation on Laser-Inducd Autoionization
   Phys. Rev. Lett. 49, 693 (1982).

5. K. Rzazewski, J. Lewenstein and J.H. Eberly
   Threshold effects in strong-field photodetachment
   J. Phys. B 15, L661 (1982).

6. K. Rzazewski and J.H. Eberly
   Photoexcitation of an autoionizing resonance in the presence of off-diagonal relaxation
   Phys. Rev. A 27, 2026 (1983).

7. J.W. Haus, K. Rzazewski and J.H. Eberly
   Laser-induced auto-ionization in an inhomogeneously broadened medium
   Optics Comm. 46, 191 (1983)

8. C.M. Bowden and J.H. Eberly
   Aspects of Interrupted Coarse-Graining in Stimulated Excitation of Vibronic Bands
   in Coupled Nonlinear Oscillators, edited by J. Chandra and A.C. Scott (North-Holland Publishing Co., Amsterdam 1983), pp. 115-124.

9. D. Agassi, K. Rzazewski and J.H. Eberly
   Effects of collisional broadening and radiative recombination on the time dependence of initial state population of a photoexcited autoionizing atom
   Phys. Rev. A 28, 3648-3650 (1983).

10. Z. Deng and J.H. Eberly
    Double-resonance effects in strong-field autoionization
    JOSA-B 1, 102-107 (1984).

11. J.W. Haus, K. Rzazewski and J.H. Eberly
Laser-Induced Autoionization: Inhomogeneous Linewidth and Broad-band Laser
in Coherence and Quantum Optics V, edited by L. Mandel and E. Wolf (Plenum, New York, 1984), p.195.

12. Z. Deng and J.H. Eberly
Effect of coherent continuum-continuum relaxation and saturation in multiphoton ionization
Phys. Rev. Lett. 53, 1810 (1984).

13. D. Agassi and J.H. Eberly
Effect of surface dynamical fluctuations on light scattering by a nearby dipole
Phys. Rev. Lett. 54, 34 (1986).

14. E. Kyrölä and J.H. Eberly
Quasicontinuum effects in molecular excitation
J. Chem. Phys. 82, 1841 (1985).

15. Z. Deng and J.H. Eberly
Multiphoton absorption above ionization threshold by atoms in strong laser fields
JOSA B 2, 486 (1985).

16. Z. Deng and J.H. Eberly
Variation of Index in ATI Processes in Fundamentals of Laser Interactions, edited by F. Ehlotzky
(Springer, Berlin, 1985), p. 287.

17. Z. Deng and J.H. Eberly
Variation of above-threshold ionization power law behaviour
J. Phys. B 18, L287 (1985).

18. Z. Deng and J.H. Eberly
Coherent Trapping in Continuum-Continuum Transitions
Phys. Rev. A 34, 2492 (1986)

19. D. Agassi and J.H. Eberly
Dressed-Resonance Representation for Strong Photoexcitation of Continuum States with Application to Laser-Enhanced Autoionization
Phys. Rev. A 34, 2843 (1986)

20. J.H. Eberly
Essential States in Multiphoton Ionization and Electron Scattering in Quantum Optics, edited by A. Kujawski and M. Lewenstein
D. Reidel Publ. Co. (Amsterdam, 1986), p. 126

21. L. Pan, L. Armstrong, Jr., and J.H. Eberly
Comments on the Effect of the Ponderomotive Potential in the Above-Threshold Ionization Processes
JOSA B 3, 1319 (1986)

IV. List of professional personnel, with advanced degrees, name of recipient, title of thesis, date of degree

Sr. Res. Associates

Dr. F.T. Hioe, Dr. K. Rzazewski, Dr. D. Agassi, Dr. J. Javanainen

Sr. Visiting Scholar (no salary)

Lu Qiseng

Res. Assistant

Z. Deng, received Ph.D. degree June 1986, thesis:

"Multiphoton Ionization in Strong Radiation Fields"

V. Interactions (Coupling Activities):

(i) Spoken papers:

1981

1. "Confluence of Coherences in Strong Laser-Induced Auto-Ionization" (with K. Rzazewski)
   Invited Paper
   Workshop on Photoionization of Excited Atoms and Molecules
   JILA, University of Colorado and National Bureau of Standards
   Boulder, CO

2. "Nonlinear Coherence Effects in Photoionization Near to Threshold" (with K. Rzazewski)
   Invited Paper
   Workshop of Photoionization of Excited Atoms and Molecules
   JILA, University of Colorado and National Bureau of Standards
   Boulder, CO

3. "Coherence and Interference in Strong-Field Photo-Induced Bound-Free Transitions" (with K. Rzazewski)
   Contributed paper
   European Conference on Atomic Physics
   Heidelberg, WEST GERMANY

4. "Theory of Pure Quasi-Continuum Effects in Molecular Dynamics"
   Seminar Lecture, Department of Physics
   Warsaw University
   Warsaw, POLAND

5. "Autoionization in Strong Laser Fields"
   Seminar Lecture in Atomic Physics
   Department of Physics
   Imperial College of Science and Technology
   London, ENGLAND

6. "Theory of Quasi-Continuum Recurrence Effects"
   Contributed Paper FC 5 (with J.J. Yeh and C.M. Bowden)
   Annual Meeting of Division of Electron and Atomic Physics of the A.P.S., Bull. Am. Phys. Soc. 26, 1327 (1981) New York, New York

1982

7. "Quantum Interferences in Laser-Induced Auto-Ionization"
   Atomic Physics Seminar
   New York University
   New York, NY

8. "Coherence in Auto-Ionization"
   Physics Lecture
   Department of Physics
   University of Arkansas
   Fayetteville, AR 72701

9. "Scattered spectra and coherent electronic recombination in bound-free transitions, a model for laser-induced auto-ionization"
Seminar lecture
Istituto Aldo Pontremoli, Universita di Milano
Milan, ITALY

10. "Scattered spectra in bound-free transitions, a model for laser-induced auto-ionization"
Seminar lecture
National Institute of Optics
Florence, ITALY

1983

11. "Time Dependence of Initial State Population of a Photo-Ionizing Atom, Including Collisional Relaxation and Radiative Recombination" (with K. Rzazewski and D. Agassi), paper AB 6
Contributed paper, annual mtg. of Divn. of Elec. and Atomic Physics of A.P.S.

12. "Two-Laser Resonances in Photo-Induced Auto-Ionization or Predissociation", (with Zhifang Deng), paper AB 13
Contributed paper, annual mtg. of Divn. of Elec. and Atomic Physics of A.P.S.

13. "Nonexponential Decay in Laser-Enhanced Photo-Detachment" (with K. Rzazewski)
Invited Paper
International Symposium on Unstable States
University of Colorado
Boulder, CO 80309

14. "Induced Autoionization: Inhomogeneous Linewidth and Broadband Laser" (with J.W. Haus and K. Rzazewski), paper MDb3
Contributed paper
Fifth Rochester Conferences on Coherence and Quantum Optics
University of Rochester
Rochester, NY 14627

15. "Atoms and Photons in Resonance"
Keynote Lecture
Sixth National Quantum Electronics Conference
University of Sussex
Brighton, ENGLAND

1984

16. "Laser-Enhanced Auto-Ionization and Dressed Resonances" (with D. Agassi)
Invited Paper
Second Topical Meeting on Laser Techniques in the Extreme Ultraviolet
Boulder, CO

17. "Two-Channel Excitation of a Quasi-Continuum"
Colloquim Lecture
University of Texas at Dallas
Richardson, TX

18. "Two-Channel Excitation of a Quasi-Continuum"
Colloquium Lecture
Institute of Physics of the Polish Academy of Science
Warsaw, POLAND

19. "Coupling of Two-Level Coherence to the Quasicontinuum"
(with E. Kryölä), paper AC 5
Contributed paper, annual mtg. of Div. of Elec. and Atomic Physics of A.P.S.
University of Connecticut
Storrs, CT

20. "Coherent Damping in the Continuum and the Breakdown of Fermi's Golden Rule" (with Z. Deng)
Invited Paper
US-Japan Seminar on Coherence, Incoherence and Chaos in Quantum Electronics
Nara, JAPAN

21. "ATI Effects in a Theory with Completely Structureless Continua"
(with Z. Deng)
Contributed paper
International Conference on Multiphoton Processes III
Iraklion, Crete, GREECE

22. "Theory of Above-Threshold Ionization and Free-Free Saturation"
Atomic Physics Seminar
New York University
New York, NY

23. "The Saturation of Fermi's Golden Rule"
Graduate Research Seminar
Department of Physics and Astronomy
University of Rochester
Rochester, NY

24. "Theoretical Problems in Quantum Optics: Photons and Atoms, Molecules and Surfaces"
Research Overview
Institute of Optics, University of Rochester
Rochester, NY

25. "Continuum-Continuum Relaxation and Saturation in Multiphoton Ionization"
Atomic Physics Seminar
Oak Ridge National Laboratory
Oak Ridge, TN

26. "Above-Threshold Ionization, A Simple Dynamical Theory"
Atomic Physics Seminar
J.I.L.A., University of Colorado
Boulder, CO

1985

27. "Coherence and saturation in continuum-continuum transitions"
Theoretical seminar
Max-Planck-Inst. f. Quantenoptik
Garching, WEST GERMANY

28. "Variation of k index in ATI processes" (with Z. Deng)
Contributed paper
Seminar on Fundamentals of Laser Interactions
Obergurgl (Ötztal) AUSTRIA

29. "Coherence and saturation in atomic and molecular continuum transitions"
Physics colloquium
Tata Institute of Fundamental Research
Bombay, INDIA

30. "Coherence and saturation in atomic and molecular continuum transitions"
Theoretical physics seminar
University of Hyderabad
Hyderabad, INDIA

31. "Windows of chaos in the AGM model for molecular photoabsorption"
Quantum Optics Seminar/Schloss Ringberg Workshop
Univ. of Munich and M.P. Inst. f. Quantenoptik
Rottach-Egern, WEST GERMANY

32. "Coherence theory of transitions among continuum states of atoms and molecules"
Physics seminar
Instituto di Elletronica Quantistica
Consiglio Nazionale delle Richerche
Florence, ITALY

33. "Theory of saturation in free-free transitions, and the connection with photo-ionization experiments at high laser intensity"
Theoretical seminar
Instituto di Chimica Quantistica ed Energetica Molecolare
Consiglio Nazionale delle Ricerche
Pisa, ITALY

34. "Essential states in multiphoton ionization and electron-atom scattering"
Special theoretical physics seminar
University of Bielefeld
Bielefeld, WEST GERMANY

35. "Saturation and coherence in continuum transitions"
Laser physics seminar
Imperial College
London, ENGLAND

36. "Coherence and saturation in continuum-continuum transitions and connection with recent photo-ionization experiments"
Physics colloquium
University of Essen
Essen, WEST GERMANY

37. "Essential-states theory of multiphoton ionization above threshold"
Atomic physics seminar
Institute of Physics, Latvian Academy of Science
Riga (Salaspils), USSR

38. "Photons, atoms and electrons above threshold"
Theoretical seminar
Technische Universität München

39. "Diagonal matrix elements and free-free transitions in ATI Processes"
Special atomic physics seminar
C.E.N. de Saclay
Saclay, FRANCE

40. "Continuum saturation and above-threshold photoabsorption"
Invited paper
12th All-Union Conference on Coherent and Non-linear Optics
Moscow, USSR

41. "Essential states in high-intensity scattering and multiphoton ionization"
Invited paper
Sixth International School of Coherent Optics
Ustron, POLAND

42. "A Proposal for generating tunable XUV radiation via above-threshold multiphoton ionization"
Special seminar
Laboratory of Laser Energetics
University of Rochester
Rochester, NY

43. "Theory of above-threshold ionization"
Atomic Phsics Special Seminar
Lawrence Livermore National Laboratory
Livermore, CA

44. "Orders of magnitude and experimental puzzles"
Special Lecture on Laser Spectroscopy at the High-Intensity Frontier
Dept. of Physics and Astronomy
University of New Mexico
Albuquerque, NM

45. "Continuum saturation -- Is it observed?"
Special Lecture on Laser Spectroscopy at the High-Intensity Frontier
Dept. of Physics and Astronomy
University of New Mexico
Albuquerque, NM

1986

46. "Laser Spectroscopy at the High-Intensity Frontier"
Colloquium Lecture, Applied Physics
Stanford University
Stanford, CA

47. "Quantum Optics and the High-Intensity Frontier"
Invited Lecture
Conference on Lasers, Molecules and Methods
Center for Nonlinear Studies
Los Alamos, NM

47. "Quantum Optical Approachs to the Problem of Atoms and Electrons in Intense Fields"
Invited Lecture
Topical Meeting on Multiple Excitations of Atoms
Seattle, WA

(ii) Advisory activities, contacts with other Institutes/Laboratories:

During the grant period the Principal Investigator served variously as consultant/visiting scientist/advisor to other Institutes and Laboratories on the grant topic as well as other topics. These other Institues and Laboratories included: US Naval Surface Weapons Center (White Oak), Lawrence Livermore National Laboratory, US Army Missile Command (Redstone Arsenal), Optics Section Imperial College (London), Max-Planck Institut für Quantenoptik (Munich), Los Alamos National Laboratory, Institute for Defense Analyses. Occasions where grant research was discussed at length included:

1983

Lawrence Livermore National Laboratory (LLNL), several visits during year, discussions principally with Dr. B.W. Shore on a number of subjects, including coherence in auto-ionization transitions.

US Army Missile Command (AMICOM), exchange of visits with Dr. Charles M. Bowden to discuss continuum transitions and quasi-continuum modeling of continuum transitions.

Optics Section Imperial College, month of July, discussions with research group of Dr. P.L. Knight about quasi-continuum and continuum transition modeling.

1984

LLNL, several visits during year, discussion with Dr. B.W. Shore and group of Dr. A. Hazi n the topic of intense-laser ionization effects and quenching of Golden Rule.

AMICOM, exchange of visits with Dr. C.M. Bowden concerning quasi-continuum modeling.

1985

Max-Planck-Institut für Quantenoptik, extended consultations as Visiting Scientist and Senior Humboldt Fellow, with theoretical research group of Dr. P. Meystre, particularly with Dr. J. Javanainen and Dr. A. Dulcic, about coherence effects in intense-laser ionization transitions.

LLNL, several visits, discussions with Dr. B.W. Shore, Dr. A. Szöke, and others concerning coherence in transitions to above-ionization-threshold electron energy states.

1986

LLNL, several visits, discussions with Dr. B.W. Shore, Dr. K. Kulander and others on the subject of coherence effects in photo-electron spectra.

VI. New discoveries/patents:

None other than scientific advances detailed above.

VII. Additional statements/information which can help evaluation:

None.

END

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