

PROTON RESONANCE SPECTROSCOPY

Final Performance Report

June, 1987 - May, 1996

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September, 1998

PREPARED FOR THE U. S. DEPARTMENT OF ENERGY

UNDER GRANT NUMBER DE-FG05-87ER40353

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Preface

This report gives a brief summary of accomplishments on Grant DE-FG05-87ER40353 during the period June, 1987 - May, 1996. Approximately 22 refereed papers were published with support from this grant; reprints are attached with this report. Topics studied include amplitude distributions in proton resonance reactions, chaos in nuclei, and tests of detailed balance and of parity violation with resonance reactions. Appendix I lists personnel and collaborators associated with this work, including the undergraduate students hired with grant funds, while Appendix II provides a list of talks, abstracts, dissertations and theses, etc. associated with the work supported by this grant.

1 Amplitude Distributions

We finished a long and successful study of reduced-width amplitude distributions in proton resonances. We provided the first experimental evidence to support the long-held assumption that these distributions would be gaussian [1, 2]. We also published two studies on entrance-channel amplitudes (our previous results had been on exit-channel amplitudes) and demonstrated that those channels also show the large correlations previously observed in exit-channel studies [3, 4].

2 Chaos

The study of chaos in quantum systems has been a field of major interest over the last decade or so, and our work has made significant contributions in its application to nuclei. We published an analysis of ^{26}Al which shows spacing distributions intermediate of those expected for either completely chaotic or completely regular behavior [5, 6]; this analysis also provided the first experimental test of the effect of broken symmetries on fluctuation properties. A similar study was published for ^{116}Sn , although over a smaller energy range, again showing intermediate behavior [7]. A study of average properties of low-lying states over a wide range of nuclides suggests that light nuclei are more chaotic at low energies while heavier nuclei are more regular [8]. The tests used in these analyses are extremely sensitive to the quality of the data, and we published a study which offers some quantitative tests of that sensitivity [9]. We began studies to establish a complete level scheme for ^{30}P , so that we could have a second case from the ground state to above the separation energy [10]; included in these studies was the design and installation of a Compton-suppressed spectrometer for use in proton capture measurements [11]. Because of the sensitivity of these tests to the quality of data, we have also searched for other possible signature; the Fourier transform has been suggested as one such tool, but our study showed that this would probably not be an appropriate signature for a single nuclide due to the small number of levels [12]. Work

was begun on a study of using reduced transition probability distributions as a signature of chaos. A general overview of this work was also published in a conference proceeding [13]. Work is continuing on establishing the level scheme of ^{30}P and on looking for other signatures of chaos.

3 Detailed Balance Tests with Proton Resonances

It has been realized in recent years that the study of symmetry-breaking with proton and neutron resonances can lead to significant enhancements. Many of the studies exploring such details are in very general terms. We have looked for potential applications of such tests which are known to be feasible because they have used experimental resonance parameters. One of these studies looked at how suitable the known (p,α) resonances in the s-d shell would be for tests of detailed balance. Our work shows that indeed someone wishing to improve limits on the violation of detailed balance should be able to do so without significant increases in experimental sensitivity. Several papers were published outlining these findings [14, 15, 16].

4 Parity Violation in Nuclear Resonance Reactions

Parity violation also is quite amenable to study with resonance reactions. Early measurements of a single resonance with neutron beams required detailed understanding of the angular distributions of various observables, and we provided calculations for several different possible experiments [17, 18]. Later we realized that measurements of parity violation in proton resonances could complement work with neutron resonances, and we began to explore the feasibility of such measurements. As with the detailed-balance calculations, we found that indeed such measurements are feasible [19, 20, 21]. We are in the process of preparing to measure longitudinal analyzing powers in the $^{31}\text{P}(p,\alpha)$ reaction.

5 Angular Correlation Calculations

A common theme in all of these measurements is the need to be able to interpret angular correlation measurements. For resonances this means that one must fit the data to a calculated correlation in order to extract the appropriate parameters. To assist us in this task, a Fortran program was written to provide algebraic calculations of various angular momentum coupling coefficients [22].

References (Refereed Papers)

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- [21] G. E. Mitchell and J. F. Shriner, Jr., Phys. Rev. C **54**, 371 (1996).

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Appendix I

Personnel

Faculty

J. F. Shriner, Jr.

Undergraduate Research Assistants

Name	Years Worked	Career Progress
C. T. Coburn	1988-1990	B. S. ,Physics, TTU, 1991 Graduate Student in Physics, State University of New York at Stony Brook
B. O. Faircloth	1992	B. S., Physics, TTU, 1996 Graduate Student in Electrical Engineering, Washington University
L. M. Fittje	1995	Electrical & Computer Engineering major, TTU
J. A. Hutchins	1995	Left school
E. A. Moore	1991	B. S., Physics, TTU 1994 M. S., University of Tennessee Currently employed by Altair Computing
J. P. Quesenberry	1993-94	TTU physics major
J. T. Slayton	1991-93	B. S., Physics, TTU 1995 M.B.A., TTU, 1997 Currently employed by Millikan
R. C. Spirko	1988	B. S., English, 1994
B. L. Winn	1989-1990	B. S., Physics, TTU, 1993 Graduate Student in Physics, State University of New York at Stony Brook
B. W. York	1990-1991	B. S., Physics, TTU, 1991 M. S., Aerospace Engineering, VPI, 1993 Currently employed by U. S. Government

Collaborators

A. A. Adams	North Carolina State University and Triangle Universities Nuclear Laboratory
E. G. Bilpuch	Duke University and TUNL
C. R. Bybee	North Carolina State University and TUNL
J. S. Bull	Duke University and TUNL
J. M. Drake	North Carolina State University and TUNL

P. M. Endt	Utrecht University
D. F. Fang	Fudan University
S. C. Frankle	North Carolina State University and TUNL
C. A. Grossmann	North Carolina State University and TUNL
M. A. LaBonte	North Carolina State University and TUNL
L. K. McLean	North Carolina State University and TUNL
G. E. Mitchell	North Carolina State University and TUNL
E. F. Moore	North Carolina State University and TUNL
S. Raman	Oak Ridge National Laboratory
N. R. Roberson	Duke University and TUNL
W. E. Ormand	University of Tennessee and Oak Ridge National Laboratory
J. R. Vanhoy	Duke University, TUNL, and University of Kentucky
G. A. Vavrina	North Carolina State University and TUNL
T. von Egidy	Technische Universität München
P. M. Wallace	Duke University and TUNL
C. R. Westerfeldt	Duke University and TUNL
W. S. Wilburn	Duke University and TUNL

Appendix II

Dissertations and Theses Supervised

Stephanie Cate Frankle, "Nuclear Resonance Spectroscopy in ^{30}P ," Ph.D. degree, North Carolina State University, 1991. Supervisors – G. E. Mitchell and J. F. Shriner, Jr.

Charles Randall Bybee, "Fourier Transform as Signature of Chaos in Nuclei and Data Acquisition for Compton-Suppressed Spectrometer," Ph.D. degree, North Carolina State University, 1995. Supervisors – G. E. Mitchell and J. F. Shriner, Jr.

Matthew Alyn LaBonte, "Angular Distribution Study of the $^{29}\text{Si}(p,\gamma)$ Reaction," M.S. degree, North Carolina State University, 1995. Supervisors – G. E. Mitchell and J. F. Shriner, Jr.

Invited Talks

"Energy Level Fluctuations in ^{26}Al ," Workshop on Chaotic Phenomena in Nuclei and Atoms, Bad Honnef, Germany, 1989.

"Random Matrix Theory Applied to Nuclear Energy Levels," Second Drexel Workshop on Quantum Nonintegrability, Philadelphia, PA, 1989.

"Chaos in Nuclear Level Schemes," Seventh International Symposium on Capture Gamma-ray Spectroscopy and Related Topics, Pacific Grove, CA, 1990.

"A Compton-suppressed Spectrometer for Studies of Chaos in Nuclei," J. F. Shriner, Jr., Thirteenth International Conference on the Application of Accelerators in Research and Industry, Denton, TX, 1994.

Abstracts

"Are Resonance Amplitudes Gaussian?" J. F. Shriner, Jr., G. E. Mitchell, and E. G. Bilpuch, B.A.P.S. **32**, 1562 (1987).

"Testing the Porter-Thomas Distribution," J. F. Shriner, Jr., G. E. Mitchell, and E. G. Bilpuch, B.A.P.S. **32**, 2145 (1987).

"Amplitude and Width Correlations in ^{40}Ca ," J. S. Bull, C. R. Westerfeldt, E. G. Bilpuch, J. F. Shriner, Jr., and G. E. Mitchell, B.A.P.S. **32**, 2145 (1987).

"Tests of Chaotic Behavior in ^{26}Al ," J. F. Shriner, Jr., G. E. Mitchell, and E. G. Bilpuch, B.A.P.S. **33**, 1563 (1988).

"A Study of Entrance Channel Correlations in ^{40}Ca ," J. S. Bull, C. R. Westerfeldt, E. G.

Bilpuch, J. F. Shriner, Jr., and G. E. Mitchell, B.A.P.S. **33**, 2194 (1988).

"Resonances in ^{30}P ," S. C. Frankle, G. E. Mitchell, J. F. Shriner, Jr., C. R. Westerfeldt, and E. G. Bilpuch, B.A.P.S. **34**, 2361 (1989).

"A Search for Proton Resonances Suitable for Tests of Detailed Balance Violation," J. M. Drake, G. E. Mitchell, C. R. Bybee, J. F. Shriner, Jr., and E. G. Bilpuch, B.A.P.S. **36**, 2729 (1991).

"A Compton-suppression Spectrometer for the Study of $^{29}\text{Si}(p,\gamma)$," C. R. Bybee, J. M. Drake, G. E. Mitchell, S. S. Patterson, J. F. Shriner, Jr., E. G. Bilpuch, and C. R. Westerfeldt, B.A.P.S. **36**, 2730 (1991).

"Nuclear Resonance Spectroscopy in ^{30}P ," S. C. Frankle, G. E. Mitchell, J. F. Shriner, Jr., E. G. Bilpuch, and C. R. Westerfeldt, B.A.P.S. **37**, 922 (1992).

"Application of Fourier Transform Techniques to Quantum Chaos Studies in Nuclear Physics," C. R. Bybee, G. E. Mitchell, J. F. Shriner, Jr., and E. G. Bilpuch, B.A.P.S. **37**, 1676 (1992).

"A Detailed Balance Study of Time Reversal Invariance with Interfering Resonances," J. M. Drake, C. R. Bybee, G. E. Mitchell, J. F. Shriner, Jr., and E. G. Bilpuch, B.A.P.S. **37**, 1676 (1992).

"Possible Charged Particle Studies of Parity Violation in Compound Nuclear Resonances," J. F. Shriner, Jr., G. E. Mitchell, and E. G. Bilpuch, B.A.P.S. **38**, 913 (1993).

"Possible Tests of Parity Violation with Charged Particle Resonances," J. F. Shriner, Jr., G. E. Mitchell, and E. G. Bilpuch, B.A.P.S. **38**, 1803 (1993).

"Possible Tests of Detailed Balance with Interfering Proton Resonances," J. M. Drake, C. R. Bybee, G. E. Mitchell, J. F. Shriner, Jr., and E. G. Bilpuch, B.A.P.S. **38**, 1804 (1993).

"Shell-Model Transition Strengths in ^{22}Na ," A. A. Adams, G. E. Mitchell, J. F. Shriner, Jr., W. E. Ormand, and E. G. Bilpuch, B.A.P.S. **38**, 2171 (1993).

"Shell-Model Transition Strengths in ^{22}Na ," A. A. Adams, G. E. Mitchell, J. F. Shriner, Jr., W. E. Ormand, and E. G. Bilpuch, B.A.P.S. **39**, 1824 (1994).

"A Compton-Suppressed Spectrometer for the Study of $^{29}\text{Si}(p,\gamma)$," G. A. Vavrina, C. R. Bybee, J. M. Drake, G. E. Mitchell, E. F. Moore, J. F. Shriner, Jr., E. G. Bilpuch, P. M. Wallace, and C. R. Westerfeldt, B.A.P.S. **39**, 1825 (1994).

"A High Resolution Study of $^{29}\text{Si}(p,\gamma)$," P. M. Wallace, E. G. Bilpuch, C. R. Westerfeldt, C. R. Bybee, J. M. Drake, M. A. LaBonte, G. E. Mitchell, E. F. Moore, G. A. Vavrina, and

J. F. Shriner, Jr., B.A.P.S. **39**, 1825 (1994).

"Possible Tests of Parity Violation with Charged Particle Resonances," J. F. Shriner, Jr. and G. E. Mitchell, B.A.P.S. **40**, 1634 (1995).

"Parity Violation in Charged Particle Resonances," W. S. Wilburn, N. R. Roberson, G. E. Mitchell, and J. F. Shriner, Jr., B.A.P.S. **41**, 914 (1996).

"A High Resolution Study of ^{30}P ," P. M. Wallace, E. G. Bilpuch, C. R. Westerfeldt, G. E. Mitchell, E. F. Moore, G. A. Vavrina, and J. F. Shriner, Jr., B.A.P.S. **41**, 984 (1996).

Technical Report

"The TUNL High Resolution Laboratory System and Operating Procedure," C. R. Westerfeldt, J. F. Shriner, Jr., and G. A. Vavrina.

Seminars Presented

"Chaos in the Nucleus?," Florida State University, 1989.

"Chaos in the Atomic Nucleus," University of the South, 1989.

"Chaos in the Atomic Nucleus?," Ohio University, 1990.

"Chaos in the Nucleus?," Oak Ridge National Laboratory, 1991.

"Chaos in the Nucleus?," University of Kentucky, 1992.

"Search for Chaos in ^{30}P ," Tennessee Technological University, 1994.

"Search for Chaos in ^{30}P ," University of the South, 1994.

Undergraduate Publications

"Examination of 2^+ Resonances in $p + ^{27}\text{Al}$ in the Proton Energy Range 0.9-3.0 MeV," C. T. Coburn, *Proceedings of the Fourth National Conference on Undergraduate Research*, Vol. I, ed. K. M. Whatley, University of North Carolina Asheville, 1990, pp. 264-269.

"Parity Dependence of Level Densities in ^{49}V ," B. W. York, *Proceedings of the Fifth National Conference on Undergraduate Research*, Vol. I, ed. K. M. Whatley, University of North Carolina Asheville, 1990, pp. 471-476

"Parity Dependence in Level Density of ^{48}Ti ," J. P. Quesenberry, in *Proceedings of the National Conference on Undergraduate Research*, Vol. II, University of North Carolina Asheville (Asheville), 1995, p. 799.