NUCLEAR STRUCTURE THEORY

Annual Technical Progress Report

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Rochester, New York

MASTER

October 1, 1978 - September 30, 1979*

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Prepared for the United States Department of Energy under Contract

No. EY-76-S-02-2171

*Reporting period: contract period is January 1, 1979-December 31, 1979

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Abstract

This report summarizes progress during the past year in the following areas of nuclear structure and reaction theory:

Statistical spectroscopy, including: Random matrix methods, with applications to fluctuations in spectra and in strength distributions, and to problems of ergodicity; Group symmetries in spectral-distribution theory; Electromagnetic and β transitions.

Meson scattering and absorption by nuclei, including: general scattering theory with absorption, multiple scattering theory and its reactive content, statistical theory of absorption, theory of the absorption operator (TNN vertex), theory of NN scattering.

The random-matrix review whose completion was prematurely announced in last year's report has by now been completed, extra time having been devoted to new topics and technical advances in random-matrix theory and applications. Among these is the solution for the eigenvalue density of a specified Hamiltonian disturbed by a random operator of specified variance. If we think of the specified H as a schematic Hamiltonian, or one which otherwise incorporates collective or symmetry-preserving parts, its magnitude may be determined by standard spectral methods, and then the magnitude of the random operator follows from that and the magnitude of the original "true" H . This technique and the general solution found will have applications in calculating widths of collective states, in finding the conditions under which a collectivity "collapses", and so forth. Besides that, new measures, involving both ensemble and spectral averaging, have been found for energy-level fluctuations; these should sharpen somewhat the final conclusions concerning the agreement of experiment and theory. There are also new results for strength distributions, which have applications for example in the analysis of isobaric-analog resonances. A separate paper is being written about these matters.

The distribution of β -decay strengths has been worked out for allowed Gamow-Teller transitions. Very gratifying agreements have been found with the results of shell-model calculations (undertaken to assess the general accuracy of the spectral methods used) and with experimental results for ds -shell nuclei. A paper is being written on the theory and presently available results. Major extensions to heavier nuclei and forbidden transitions are planned by Dr. Kar, who is now moving to the University of Toronto.

Bounds and measures for electromagnetic transition strengths have been constructed and are being used now in the analysis of the data. It is hoped also to use them in order to assess the accuracy of various approximate sum rules which have been used similarly, and to give more accurate versions of the much-used Weisskopf units.

The representation of a Hamiltonian in terms of generators of chains of groups, described in last year's report, has been further studied via shell-model comparisons of the original Hamiltonian and its "trace-equivalent". Results are very satisfactory. A paper has been prepared.

The work described last year about the propagation of information by means of group invariants makes good progress. A paper is in preparation.

It seems appropriate to mention that the international conference on spectral distribution and moment methods in many-fermion systems, held at

Iowa State University, September 10-13, 1979, has been devoted largely to the work which originated here about ten years ago and to its extensions and applications made both here and in several other institutions.

Considerable effort has been devoted to the problems of interpreting the absorption of mesons (principally pions) by nuclei, and progress can be reported in several directions. This kind of reaction, which is beginning to receive more attention at the "meson factory" facilities at LAMPF, SIN, and TRIUMF, is of considerable interest for both its reaction theory and nuclear structure aspects. In this connection, one of us participated in the Workshop on Program Options in Intermediate Energy Physics held at Los Alamos, August 19-31, 1979, and chaired the panel (N-7) devoted to "Pion Absorption and Production Mechanisms." The recommendations of that panel for planning of future experiments in this subject, will be part of the final report of the Workshop, due this Fall.

We have almost completed a paper, mentioned in last year's report, in which a general theory of meson reactions with nuclei is presented, which treats scattering and absorption on an equal footing. The first application of this (coupled-channel) approach was reported by us several years ago, in the context of the problem of the πd scattering length, in T. Mizutani's doctoral thesis. One of the advantages of the method is that it appears to be quite practical for calculation, and is well adapted to the use of standard methods of scattering theory such as the Faddeev equations and the Watson multiple scattering expansion.

We had hoped to include in the same work, some applications to the use of the optical potential for analysis of pion elastic scattering on nuclei. The point is that the possibility of absorption as a major nonelastic reaction channel, has effects on the elastic scattering, through unitarity, and presumably on the optical potential as well. However, new theoretical work has shown us that the previous methods are not ideal for this problem, and has led us to what may be a more promising approach, which we are now pursuing. This follows on work first mentioned in last year's report about the *reactive content* of the optical potential. Our first results, reported in Physical Review Letters, was a sum rule which relates *inclusive* and *exclusive* scattering reactions, in the context of the first order approximation to the optical potential. This work has been expanded and continued, with new results reported in D. Schneider's doctoral thesis; papers are in preparation. We found that one could in fact include meson absorption channels in this approach, providing one made some rearrangements of the earlier coupled-channel methods of Mizutani. This seems

to provide a direct method of including, in a unitarily consistent manner, the effects of absorption channels in the pion-nucleus optical potential. A somewhat surprising result of this approach is the possibility that in high-energy reactions, much of the effect of absorption will not be seen directly in the optical potential, but is masked by the knockout channels, which are directly fed from the elastic channel, *before* most of the absorption takes place. This was discussed at the Houston Conference in March; further work is in progress.

The methods used to study the *reactive content* appear to have further application to nuclear reactions induced by pions, or indeed other high energy projectiles. Some cases are under investigation.

We have made some progress on a statistical theory of pion scattering and absorption by nuclei, which was mentioned in last year's report. Underlying our approach is the observation that for a large energy range of interest near the Δ resonance, say 100-300 MeV, the πN amplitude is large, leading thereby to multistep inelastic processes in a nuclear target, including emission of nuclear particles, and possible absorption of the pion. We treat the complicated nuclear transitions in a statistical manner, using assumptions motivated by the exciton model (used previously for pre-equilibrium nuclear reactions). Our statistical treatment which we base on an isobar model of πN scattering, maintains some of the quantum mechanical aspects of the pion problem, including off-shell propagation of the isobar (Δ). The central formal result is a transport equation for the Δ in the nuclear target. Solution of this equation leads to evaluation of the inclusive differential cross section for inelastic scattering, and the cross section for absorption. Special limiting cases are derived, which make connection to classical (gas) methods in the recent literature. A first paper is being written, and further work on the implications and applications of the theory is in progress.

Work has continued on a covariant treatment for the πN half-shell t -matrix based on dispersion theory. Earlier results were restricted to P -waves, with an approximate treatment of crossing symmetry and nucleon recoil. New calculations have been done which improve the treatment of these aspects, and thereby enable the inclusion of the πN S -waves in the calculation. Preliminary results were reported in Houston; more complete calculations are in progress and results will be prepared for publication. Applications to the problem of π -absorption in three-body relativistic (e.g. πd) scattering are being investigated.

Some work was done on a number of related problems involving relativistic theories of pion-nuclear interactions. The problem of the non-relativistic reduction of the pion absorption vertex, mentioned last year, was pursued but not completed. Comparison of calculation by Feynman-graph, Foldy-Wouthuysen transformation, and projection methods, is in progress. Some aspects of the singularities in Chew-Low theory in the context of Faddeev theory (for πd scattering) were examined, using Feynman-graph techniques. We were able to verify a conjecture in the literature on the proper treatment of singularities off-shell.

Lastly, the book on meson-nuclear physics, mentioned in the last few reports, has been completed and is now in press, to be published in 1980 by Wiley-Interscience, with the title: "Theory of Meson Interactions with Nuclei."

The work reported here includes that of D. Agassi, Senior Research Associate, M. Reiner, and A. Pandey, Research Associates, and five graduate students: T. Halemane, K. Kar, A. Manare, S. Rab and D. Schneider. During the year the Ph.D. degree was awarded to Mr. Kar, who has gone, as post-doctoral fellow, to the University of Toronto, and to Mr. Schneider, who has gone as research associate to the University of Maryland. Mr. Halemane will finish shortly and become research associate at Rutgers. Dr. Reiner has left to become Visiting Assistant Professor at VPI in Blacksburg, Virginia. Dr. Pandey, who received his degree here in December 1978, has been appointed Joliot-Curie Fellow at Orsay and will leave next August for that position.

Active collaboration has continued with persons at a number of other institutions, including: J. P. Draayer and B. D. Chang of Louisiana State University; S. S. M. Wong of the University of Toronto; T. Brody, J. G. Flores and P. A. Mello of the Instituto de Fisica of the National University of Mexico, T. Mizutani of the University of Liège, Belgium; J. M. Eisenberg of Tel Aviv University, Israel.

Through our research in collaboration with S. S. M. Wong at the University of Toronto, and J. P. Draayer and B. D. Chang at Louisiana State University, we have been aided by large grants of computer time by these institutions.

During the year we have had a number of visitors for periods of a few days to six weeks, in general supported in part by the contract. These have included J. P. Draayer of Louisiana State University, T. Mizutani of the University of Liège, Belgium, A. Rinat and S. Gurwitz of the Weizmann Institute of Science, Rehovoth, Israel, S. E. Khadkikar and J. C. Parikh of Physical Research Laboratory, Ahmedabad, India, O. Bohigas of Orsay, and J. M. Eisenberg of Tel Aviv University, Israel.

One of us has assumed duties of Associate Editor, in nuclear physics, for Physical Review C and the Physical Review Letters.

The co-principal investigators, Prof. J. B. French and Prof. D. S. Koltun, have devoted approximately two-thirds of their effort to the research project during the academic year.

Reports and Publications:

1. C. R. Countee, J. P. Draayer, T. R. Halemane and K. Kar
Shell-Model Studies of Statistical Approximations to Model Interactions
To be submitted to Nuclear Physics (COO-2171-191) UR-718
2. J. B. French
Statistical Nuclear Spectroscopy
Proceedings of the NSF Workshop on Nuclear Structure, Gull Lake, 1979
Springer (Berlin), in press (COO-2171-192) UR-719
3. J. B. French
Spectral Distribution Theory
Proceedings of International Conference on Moment Methods, Ames, Iowa
(1979), Plenum (N.Y.) in press (COO-2171-193) UR-720
4. J. B. French and A. Pandey
Statistical Properties of Many-Particle Spectra: IV
To be submitted to Annals of Physics (COO-2171-194) UR-721
5. D. S. Koltun and D. M. Schneider
Reactive Content of the First-Order Optical Potential
Physical Review Letters 42, 211 (1979) (COO-2171-188) UR-681
6. D. S. Koltun
An Overview of Absorption and Production of Mesons
in Meson-Nuclear Physics - 1979 (Houston) ed. E. V. Hungerford III,
(A.I.P. New York, 1979) p. 87 (COO-2171-189) UR-696
7. D. Agassi
A Statistical Approach to Energy Dissipation in Highly Deformed
Nuclear Systems,
Proceedings of 2nd Physics Symposium, Oaxtepec, Mexico (1979) p.1
(COO-2171-195) UR-722
8. D. Agassi and D. S. Koltun
Statistical Theory of Pion Nucleus Scattering Near the (3,3) Region
in Meson-Nuclear Physics - 1979 (Houston), ed. E. V. Hungerford III,
(A.I.P., New York, 1979) p. 601 (COO-2171-196) UR-723
9. M. J. Reiner
A Theory of the Half-Shell TM T-Matrix
in Meson-Nuclear Physics - 1979 (Houston) ed. E. V. Hungerford III,
(A.I.P., New York, 1979) p.57 (COO-2171-197) UR-724
10. D. M. Schneider
Relations Between Optical Potentials and Nonelastic Reactions for
High Energy Nuclear Scattering (COO-2171-190) UR-715
11. Annual Technical Progress Report for Period October 1, 1977 -
September 30, 1978 (COO-2171-182) UR-671

Invited Talks and Lectures:

1. J. B. French
Statistical Nuclear Spectroscopy
Lectures at NSF Workshop on Nuclear Structure, Michigan State University,
August - September 1979
(See Report No. 2)
2. J. B. French
i) Elementary Principles of Spectral Distributions
ii) Current Topics in Statistical Nuclear Spectroscopy
Lectures at International Conference on Moment Methods in Many-Fermion
Systems, Iowa State University, September 1979
(See Report No. 3)
3. J. B. French
Review of Statistical Spectroscopy
Invited Talk at Adriatic Europhysics Study Conference in Nuclear Physics
Hvar, Yugoslavia, October 1-5, 1979
4. D. S. Koltun
An Overview of Absorption and Production of Mesons
Invited Talk at 2nd Conference on Meson-Nuclear Physics,
Houston, March 1979
(See Report No. 6)
5. D. Agassi
A Statistical Approach to Energy Dissipation in Highly Deformed Nuclear
Systems
2nd Physics Symposium, Oaxtepec, Mexico (1979)
(See Report No. 7)
6. D. Agassi
Statistical Theory of Pion Nucleus Scattering Near the (3,c) Region
Invited Talk at 2nd Conference on Meson-Nuclear Physics,
Houston, March 1979
(See Report No. 8).

Book

J. M. Eisenberg and D. S. Koltun
Theory of Meson Interactions with Nuclei
Wiley-Interscience (1980)

In press

Doctoral Dissertations

1. A. Pandey
Fluctuation, Stationarity and Ergodic Properties of Random-Matrix Ensembles
(1978)
2. D. M. Schneider
Relations Between Optical Potentials and Nonelastic Reactions for High
Energy Nuclear Scattering
(1979)
(See Report No. 9)
3. K. Kar
A Statistical Method for the Study of Beta-Decay Giant Resonances
(1979)

Papers published since the last report, but listed previously as reports:

1. A. Pandey and J. B. French
Binary Correlations in Random-Matrix Spectra
Jour. Phys. A12, L83 (1979) (COO-2171-186) UR-675
2. J. B. French, P. A. Mello and A. Pandey
Ergodic Behavior in the Statistical Theory of Nuclear Reactions
Phys. Lett. 80B, 17 (1978) (COO-2171-181) UR-664
3. T. R. Halemane, K. Kar and J. P. Draayer
Simple Approximations and Symmetry Measures for Model Interactions
Nucl. Phys. A311, 301 (1978) (COO-2171-180) UR-661
4. A. Pandey
Statistical Properties of Many Particle Spectra
III: Ergodic Behavior in Random-Matrix Ensembles
Ann. Phys. (N.Y.) 119, 170 (1979) (COO-2171-179) UR-660
5. J. B. French and J. P. Draayer
Symmetries and Statistical Behavior in Many-Fermion Spaces,
in Group Theoretical Methods in Physics, W. Beiglbock, A. Böhm and
E. Takasugi, eds; Springer (Berlin) 1979 (COO-2171-184) UR-673