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NUCLEAR EXCITATIONS AND REACTION MECHANISMS

Report of Progress to 31 October 1973

Department of Physics

Brown University

Providence, Rhode Island

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ABSTRACT

A. (Fallieros). Inelastic electron scattering, derivation and application of sum rules for form factors and transition densities, response functions, fine structure studies and estimates of escape widths in photoneutron reactions, isovectors excitations and ground-state correlations in nuclei, and the connection between transition potentials and transition densities.

B. (Levin). Standing wave solutions to the Schrodinger and inhomogeneous equations; K-matrix elements; T and K operator equations for rearrangements; Heitler damping equation for identical particle scattering; multi-channel scattering theory; zero-range DWBA in the Mitra three-body model; electron-hydrogen collisions; metastable helium excitation by electron impact.

C. (Friar). Methodology for determining charge distributions from elastic electron scattering and muonic atom energy level data; relativistic corrections to charge form factors; dispersion corrections to elastic electron scattering; recoil corrections to muonic atom energy levels and to electron-nucleus scattering amplitudes; relativistic corrections to electron scattering, sum rules and electromagnetic energy shifts in nuclei.

1. SCOPE

The Nuclear Physics Program at Brown University currently includes five faculty members, two in experimental physics and the three theorists whose activities are described in this progress report. Although the experimental program is no longer funded by the AEC, the collaboration between the experimentalists and theorists (in the faculty-organized nuclear seminar, training of graduate students, discussions, etc.) continues.

The research work (completed or in progress) is presented separately in the following section. Parts A, B and C describe the work of Professors Fallieros, Levin and Friar. This work is carried on in the Barus and Holley Physics - Engineering Building. Numerical analyses have been done at Brown on the IBM System 360/67, at Waltham, Massachusetts, on the CDC 6600 computer, and at M.I.T.

CURRENT RESEARCH

2A. (Fallieros)

Inelastic electron scattering

Some of the results obtained in our work in this direction are summarized in publications 1, 2, 3, 4, 5 and 6. A more comprehensive publication is still anticipated both unifying the presentation of the results already obtained and introducing some new investigations. Among the new developments, not described in last years progress report or research proposal, we may mention the work on isoscalar, electric dipole transitions which was performed during the spring of 1973. The work has already been submitted and accepted for publication and will not be described here. Dr. T. J. Deal, who worked for his Ph.D. thesis on problems related to this program is partially continuing investigations in this direction at the University of Ohio where he is currently employed as a research associate.

Giant M1 resonances

This work was directly connected with the Ph.D. thesis research of Dr. R. M. Brill. Dr. Brill received his Ph.D. in 1973 and is currently employed by IBM. Part of this work was described in publications 7 and 8. Some other aspects will be considered in this year's research proposal.

Isovector excitations

Some results of our most recent work in this direction were included in publication 9. The preparation of the publication of other, previously obtained, results has been delayed by their completion in time with our investigations on electron scattering. The work on dipole states with non vanishing isospin in a self-conjugate nucleus (performed in collaboration with Prof. J. Vergados) does

exist in semifinal draft form waiting for final editorial improvements. Some progress was made in the work related to isospin and the random-phase approximation during this past summer. Dr. R. O. Akyüz who had worked in this direction for his Ph.D. thesis at Brown University revisited us for a period of four months supported by a grant from the Turkish Government. The work with him on single-particle states will be submitted for publication in the near future.

Effective strength of isospin independent interactions

This work was performed in collaboration with Dr. R. Broglia (Copenhagen) and is being prepared for publication. It involves the derivation of a relation between the effective strength of the isospin-independent part of the nuclear interactions and the transition densities and radiative strengths of isoscalar nuclear excitations. The resulting coupling constant leads to the determination of the characteristic energies of these excitations which compare very well with recent reports on the observation of e.g., isoscalar collective quadrupole states.

2B. (Levin)

Since the submission of our last progress report, covering the twelve months to 1 November, 1972, two events not listed therein have occurred, altering the course of the research proposed for this current year. These were the beginning of a very fruitful collaboration with Professor D. J. Kouri of the University of Houston, now on leave at the Max-Planck-Institut in Göttingen; and the granting of an award to visit Delhi University, Delhi, India, during January and February 1973, under the auspices of the India-United States Exchange of Scientists Program. In addition to many valuable discussions with A. N. Mitra of Delhi Univ., this trip also included a three day visit to England and discussions with physicists at the University of Surrey and the Atomic Energy Research Establishment at Harwell.

As a result of both the collaboration with Kouri and these visits, some of the numerical work and detailed analysis for further three-body studies has been slowed or postponed, and a number of new areas investigated instead. Progress is indicated below, beginning with the work done in collaboration with Kouri, and ending with a discussion of projects mentioned in last year's renewal proposal. Work planned for the near and far future resulting from the collaboration with Kouri is discussed in our renewal proposal.

Non-reactive scattering

The standing wave solution $|\psi_k^0\rangle$ to the Schrödinger equation and the associated K-operator K are each defined by integral equations whose kernel contains a principal value Green's function. Formal solutions to these integral equations, though they can be written out, are difficult to understand because the principal value Green's function has no inverse. In particular, the "solutions" to these

equations one would write in analogy to those for the usual outgoing wave states and T operator are invalid, because the principal value Green's function has no Lippmann-Schwinger iteration. These results have been known for sometime.

However, no previous investigation of these latter quantities seems to have been made. Let us denote these non-solutions of the integral equations for $|\psi_k^0\rangle$ and K as $|\chi_k^0\rangle$ and $\tilde{K}$. We have shown that $|\chi_k^0\rangle$ and $\tilde{K}$ are very simply related to $|\psi_k^0\rangle$ and K , the relation being essentially that of a projection operator: $K = \tilde{K}P$ and $|\chi_k^0\rangle = P|\psi_k^0\rangle$. Since $|\chi_k^0\rangle$ and $\tilde{K}$ are explicit quantities and not defined by integral equations, they are in principle easily calculable. From them, $|\psi_k^0\rangle$ and K can be obtained.

We have shown for example that if $\delta_\ell(k)$ is the usual phase shift for energy $\hbar^2 k^2/2M$, then both on-shell and half-off-shell matrix partial wave matrix elements of $\tilde{K}$ and K obey $\langle q|\tilde{K}_\ell(k^2)|k\rangle = \cos^2 \delta_\ell(k) \langle q|K_\ell(k^2)|k\rangle$. Using this it is easy to obtain the full off-shell values of K_ℓ from those of $\tilde{K}_\ell$. The quantities $|\chi_k^0\rangle$ and $\tilde{K}$ have useful formal properties, and may be of aid in determining off-shell values of the T operator.

Two papers on this topic have been written with D. J. Kouri, one accepted for publication by Annals of Physics (C00-3235-21) and the other submitted to Physics Letters (C00-3235-28).

Identical particle collisions

In an article dealing with unitarity in the inhomogeneous equation method for identical particle scattering, standing wave solutions and their associated K operators, both including Pauli principle exchange effects resulting from the inhomogeneity, were discussed. Although the conclusions are correct, the quantities actually dealt with in that paper were the analogs for the identical particle case of $|\chi_k^0\rangle$ and $\tilde{K}$ mentioned in the preceding section. A paper pointing

out why the results are correct and discussing these analogs of $|\chi^0\rangle$ and $\bar{K}$ has been written with Kouri and submitted to Annals of Physics (COO-3235-22). The analysis follows closely that of COO-3235-21, since equations occurring in the two cases are similar in structure.

Coupled channel equations for rearrangement K and T operators

In the paper with Kouri noted above (COO-3235-22), a Heitler damping equation relating the symmetrized K and T operators $\mathcal{K}$ and $\mathcal{T}$, appearing in the identical particle case was postulated and shown to be valid because of unitarity. $\mathcal{K}$ and $\mathcal{T}$ are each linear combinations of direct (d) and exchange (e) or rearrangement K and T operators: $\mathcal{K} = K(d) - K(e)$ and $\mathcal{T} = T(d) - T(e)$. We were unable to derive this damping equation from any of the known formulations of the rearrangement scattering problem, nor from any we were able to invent at that time.

We have recently solved this problem by deriving new sets of coupled equations for the direct and rearrangement T operators, and then defining new coupled equations for the analogous K operators by replacing the outgoing wave Green's functions in the T equations with principal value Green's functions. This is a standard procedure in defining equations for K operators. The new equation can be put in matrix form involving operator matrices $\underline{K}$ and $\underline{T}$. It is easy to show that $\underline{K}$ and $\underline{T}$ obey a damping equation. We have used these coupled equations for $\underline{K}$ and $\underline{T}$ to redefine $K(d)$, $K(e)$, $T(d)$, and $T(e)$, and thus also $\mathcal{K}$ and $\mathcal{T}$. Using these new definitions, we have shown that $\mathcal{K}$ and $\mathcal{T}$ do obey the damping equation which was previously postulated on the general grounds of unitarity of the S matrix. A paper on this has been written with Kouri and submitted to Annals of Physics (COO-3235-27). In it we also discuss the inadequacy of all other approaches (of which we are aware) to the rearrangement K operator problem.

Coupled channel T and K operator approach to the three-body problem

Work seems to be complete on an application of our new coupled equation approach to the three-body problem. A rough draft of a paper on this has been written with Kouri; it includes discussions of the connectedness of the kernel in our Faddeev-like equations, of a Schwinger-like variational principle for $\underline{T}$, and equations for a matrix form of the Møller wave operator. We plan to submit this to Annals of Physics when a final version is at hand.

Vertex functions in few-body problems

In addition to many conversations with A. N. Mitra during January and February, 1973, on aspects of the three-body problem and multi-channel scattering, a collaborative effort on vertex functions in the two- and three-body systems was begun. The work stemmed from an investigation undertaken by Mitra sometime ago but not brought to completion. Our joint efforts helped conclude the present stage of work and led to a finished manuscript on the topic. Several interesting projects in this area have now been identified and may be pursued at some later time, but no further work is anticipated for the near future.

Zero range DWBA approximation in the Mitra three-body model

Numerical work on this problem was begun last year with Mr. Frank Crowne as a preliminary calculation for his Ph.D. studies on the three-body problem. Mr. Crowne subsequently decided not to continue in nuclear physics, and was replaced with Mr. Marc Mermelstein. Although Mermelstein is not working on the three-body problem, the numerical work has continued. Two energies have been considered: 1.78 MeV and 6.7 MeV. The results are computed for the first four partial waves: $\ell = 0, 1, 2, 3$. Results are complete for the 1.78 MeV case and for the $\ell = 0, 2$ portions of the $E = 6.7$ MeV case. However, convergence has not occurred for the other two 6.7 MeV case partial waves. The reason for this is

insufficient numerical accuracy using either double precision complex arithmetic on the Brown University IBM computer or single precision complex arithmetic using the CDC 6600 computer at Waltham, Mass. Similar lack of accuracy has occurred in other investigations involving numerical integration in the complex plane. To circumvent this problem, a double-precision complex arithmetic set of computer routines must be written for the CDC machine since none exist. It is hoped that this can be done in the near future and the calculations brought to an end. Our conclusion thus far is that zero range is not a good approximation, in contrast to the belief for the many-body stripping case.

Electron-hydrogen scattering

The application of the inhomogeneous equation method to the analysis of low energy $e^- + H$ scattering was begun several years ago with Mr. Paul Dahlgren as his Ph.D. thesis research. No work on this problem had been done since December, 1972, because of a long illness suffered by Mr. Dahlgren. Only in August 1973, was it finally diagnosed and properly treated. Mr. Dahlgren is now enthusiastically involved in research again, and it is anticipated that he will receive his Ph.D. in June 1974. Present results remain the same as in the 1972 progress report: except that in his most recent investigation, Dahlgren has found an error in the p-wave calculation; this may be the cause of the negative widths reported in 1972. We are now hopeful that all difficulties are in the past and that the research will be brought to a successful conclusion in the next three or four months.

Electron-helium scattering

Application of the inhomogeneous equation method to the analysis of excitation of the 2^3S metastable state of He by electron impact was begun with Dr. Jean Bergeron when he was here as a research associate in 1971-72. A one and one-half day collaboration was held at Laval University in Quebec during August, at which

time matrix elements occurring in the calculation were checked and the details of the numerical integration procedure discussed. Bergeron expected to have some numerical results during November 1973; it is hoped that all results will be available by the end of the contract year. A more detailed discussion of the problem is given in the 1972 progress report.

Extensions of the coupled channel T operator method

Work on various aspects of the coupled channel T and K operator method is presently being pursued and planned for the future. These include the relation between our $\bar{K}$ operator and the symmetric part of the T operator studied by Bařanger et. al.; numerical studies of $\bar{K}$ and its matrix elements for soluble potentials; the relation of coupled channel T operators for the three-body problem to those of Alt et. al.; numerical studies of our approach to the three-body problem, most likely using separable potentials; extensions of the three-body work to final states in which all three particles are unbound and to the case where Coulomb potentials act; investigations of threshold effects using the coupled channel T operators, with possible application to $e^- + H$ ionization; and studies of bounds and minimum principles involving the coupled channel T and K operator equations.

Other work

As noted in the introductory paragraphs under 2B, other work has been slowed or temporarily postponed. Some additional progress on the collaborative paper with Dr. D. P. Bouldin and Dr. R. E. Johnson on the validity of the separable approximation to the neutron-proton potential for the many-body stripping problem has been made. It is hoped to finish this paper in the next few months. Slight progress has been made since last year's report on the inclusion of the deuteron

D state in the three-body model of stripping. This work will be held in abeyance until the build-up of research problem on multi-channel scattering is reduced. Other research listed in the 1972 renewal proposal such as that on the weakly bound projectile has similarly been postponed.

2C. (Friar)

Since Prof. Friar's participation in the contract began only fifteen months ago, this year's progress report will overlap with the report of last year to some extent. A number of investigations were in various stages of completion at that time, having been initiated at M.I.T. (see Progress Report 1972). During the preceding year several of these were completed and submitted for publication while new investigations have been initiated, in several cases completed.

The determination of the nuclear charge distribution from elastic electron scattering and muonic x-rays.

A procedure has been developed for determining those features of a nuclear charge distribution which are specified by elastic electron scattering data and muonic atom energy level transition data. Since the data are necessarily finite in number, a complete specification of the charge density is impossible. In particular, only those Fourier components of the charge density which are contained in the electron scattering data set are well specified, the others being practically unconstrained. The lowest Fourier components are tightly constrained by the muonic atom data, which are extremely sensitive to the nuclear size. An economical procedure for "determining" the density is to expand the density in a Fourier series and use the data to calculate the best values of those Fourier coefficients which are sensitive to the data, while specifying those higher components which are unconstrained by the data by means of simple physical assumptions. Errors of the density generated by the statistical errors in the data can therefore be calculated, and used to compare and contrast various models of the nuclear density.

The procedure has been applied to ^{208}Pb , in an extensive analysis of the effect of systematic and random errors on the density. In particular, it was

found that much of the central depression found in previous analyses could be removed by changing the normalization of the cross-sections by a few percent. In addition, there is little evidence for a ripple in the ^{208}Pb density. (This work was submitted for publication during the current year and recently appeared, J. L. Friar and J. W. Negele, Nucl. Phys. A212, 93 (1973).

A discussion of the relationship of the density determined in the manner discussed above and Hartree-Fock calculations of this density has also been completed. Modern Hartree-Fock calculations produce only a very minor wine-bottle depression of the density, although minor ripples do appear in the density as well as a small bump (density maximum) near $r=0$. The bump is reproduced in the density determined in the manner described above. If the Hartree-Fock calculations are believable, cross-section normalization errors probably led to the wine-bottle shape deduced by earlier calculations. (J. L. Friar and J. W. Negele, Comments on Particle and Nuclear Physics, to be published).
(This work performed in collaboration with Dr. J. W. Negele/MIT)

Relativistic corrections to electron scattering

Since modern electron machines are capable of generating very precise scattering data, it is highly desirable to have theories with which these data are analyzed equally precise. Among the corrections which must be applied to our usual nuclear physics treatment of the nuclear charge distribution is the effect of relativity, which produces additional pieces of the nuclear charge form factor which are of order $(v/c)^2$ or $(1/\text{mass})^2$ compared to a non-relativistic treatment. Small contributions to the nucleon's charge distribution arise from zitterbewegung and from the spin-orbit interaction. In addition there are corrections which must be made because the recoiling nucleus is Lorentz-contracted

after it is struck in the lab. There are also corrections due to the Thomas precession of spins during the period when the nucleus is being accelerated. The effect of these and other relativistic phenomena on the charge distribution was considered and a detailed study of electron-deuteron elastic scattering was made. (J. L. Friar, Ann. Physics (N.Y.) 81, 1973). Application of these ideas to other than elastic scattering is being considered.

Recoil effects in the lepton-nucleus interaction

To a first approximation, the interaction of an electron or muon with a nucleus (taken to be spin-0⁺ for simplicity) is the instantaneous Coulomb interaction of the lepton with the static nuclear charge distribution. Indeed, in the limit that the nuclear mass, M_c , becomes infinite, the above prescription is exact (neglecting quantum electrodynamic effects). The contributions of order $(1/M_c)$ are called recoil corrections. A subset of these corrections can be shown to be generated by the Breit interaction of the lepton with the nucleus, which reflects the kinematic effect of nuclear motion $\frac{\vec{p}^2}{2M_c}$, plus the dynamical effects of the retardation of the electric (Coulomb) potential and the magnetic interaction of the lepton with the nuclear convection current. The effect of this interaction on the energy levels of the bound states and on the scattering amplitude generated from the continuum states has been investigated.

Within the framework of first order perturbation theory (about the static Coulomb result), a simple expression has been derived for the shift in the binding energy of the atomic energy levels, using a number of hypervirial relations. Most of this shift is equivalent to changing the lepton mass to the usual reduced mass. The remaining pieces are the Breit-Brown result⁽¹⁾ and a correction which vanishes for a point nucleus. This entire correction for the case of muonic

^{208}Pb was evaluated numerically and found to be about the size of present errors in the data. (J. L. Friar and J. W. Negele, Phys. Lett. 46B, 5 (1973)).

The effect of recoil on the scattering process has been investigated using the Breit interaction both from the framework of a perturbation about the static Coulomb result and in second order perturbation theory (in $z\alpha$). It has been found that in the point-charge limit the scattering cross-section in the center-of-mass system is unchanged to order $(1/\text{mass})$ for high energy electrons, but that a correction must be applied for an extended nucleus. The latter term is a correction to the work of Foldy, Ford and Yennie.⁽²⁾ Within the framework of a perturbation expansion in the electromagnetic coupling constant $z\alpha$, the origin of the cancellation of the $(1/M_c)$ terms in the scattering amplitude for point nuclei has been studied. An intricate cancellation of both dynamical and kinematical terms is shown to produce the null result. Numerical results are presented for electron ^{16}O elastic scattering (J. L. Friar, manuscript in preparation and to be submitted to Annals of Physics).

Electromagnetic energy shifts in nuclei

The shift in energy of a nucleus due to the electromagnetic interactions of its constituents is formally calculated in lowest order perturbation theory (ve^2) from the Feynman-Cottingham⁽³⁾ formula. Relating various parts of this formula to the amplitude for forward virtual Compton scattering, a non-relativistic reduction of the charge and current matrix elements in this amplitude is made to order $(1/\text{mass})^2$. To this order relativistic corrections to the usual non-relativistic result appear. Upon simplification, it is seen that the electromagnetic mass shift is proportional to integrals over sum rules which are in principle obtainable from electron scattering. Upon evaluating these sum rules to order $(1/\text{mass})^2$, including the relativistic corrections, it is found that the electromagnetic mass shift contains terms which are just the expectation value

of the Breit interaction of the nucleons between unperturbed nuclear ground states. The remaining terms are nucleon self-mass contributions plus Lamb-shift terms very similar to those originally considered by Bethe⁽⁴⁾ in a non-relativistic treatment of the Hydrogen atom. The effect of exchange currents in the Compton amplitude and their relation to charge-symmetry breaking forces is briefly discussed. Possible application of the sum-rule formula to "evaluating" the Coulomb energy of ^3He is discussed. (J. L. Friar, manuscript in preparation).

Dispersion corrections to electron scattering

Virtual excitation of the nucleus by a passing electron is a correction which must be made to the usual static Coulomb treatment of electron-nucleus scattering. The dispersion corrections due to virtual Coulomb excitation, have been previously calculated using the closure approximation and the Harmonic Oscillator Shell Model (HOSM). The validity of the closure approximation has now been investigated by including first-order corrections to the closure approximation obtained by means of sum-rule arguments. The average excitation energy is found to be small, approximately one shell spacing. This and other evidence indicates that the corrected closure approximation is probably a good approximation to the exact result if the shell model potential is taken to be energy independent. (J. L. Friar and M. Rosen, manuscript in preparation).

3. OTHER ACTIVITIES

The following invited lectures were given by members of the group.

"Isospin in the Giant Resonance"

(S. Fallieros, Invited paper, International Conference on Photonuclear Reactions and Applications, March 1973).

"Electron Scattering from Nuclei"

(S. Fallieros, SUNY, Buffalo, April 1973).

"Doorway States in Electron Scattering"

(S. Fallieros, Brookhaven National Laboratory, June 1973).

"Sum Rules and Form Factors for Nuclear Electroexcitation"

(T. J. Deal, University of Mass., November 1973).

"The Giant M1 Resonance in ^{208}Pb "

(R. M. Brill, APS Meeting, January 1973).

"The Giant M1 Resonance in ^{208}Pb "

(R. M. Brill, Brookhaven National Laboratory, February 1973).

"Application of 3-body Methods to Deuteron Stripping Processes"

(F. S. Levin, Delhi University Lecture, January 15, 1973).

"Effects of Pauli Principle Exchange on Unitarity"

(F. S. Levin, Delhi University Lecture, January 22, 1973).

"On the Validity of the Distorted Wave Approximation for Deuteron

Stripping" (F. S. Levin, Panjab University Seminar, January 27, 1973).

"Standing Waves and Reaction Matrices in Scattering Theory"

(F. S. Levin, Delhi University Lecture, February 6, 1973).

"On the Validity of DWBA for Deuteron Stripping"

(F. S. Levin, Udaipur University Colloquium, February 10, 1973).

"Some New Effects of Pauli Principle Exchange in Electron-Hydrogen Collisions" (F. S. Levin, Tata Institute for Fundamental Research Seminar, February 12, 1973).

"On the Validity of the Distorted-Wave Approximation for Deuteron Stripping" (F. S. Levin, University of Rhode Island Colloquium, March 6, 1973).

"Relativistic Corrections to Electron Scattering"

(J. L. Friar, Argonne National Laboratory, February 1973).

"Determination of the Nuclear Charge Density from Electron Scattering and Muonic Atoms X-ray Data" (J. L. Friar, Los Alamos Scientific Lab. August 1973).

"Determination of Elastic and Inelastic Charge Form Factors from Available Data"

"Dispersion and Recoil Corrections"

"Relativistic Effects on Elastic and Inelastic Electron Scattering"

(J. L. Friar, Summer Study-Meeting on Electromagnetic Interactions, IKO/Amsterdam, August, September 1973).

4. PERSONNEL

Professor S. Fallicros

Associate Professor F. S. Levin

Assistant Professor J. L. Friar

Summer Visitor: Dr. R. Ö. Akyüz (June-October 1973)

Graduate Assistants: R. M. Brill (N.S.F. trainee; presently at IBM)

T. J. Deal (to June 1972)

F. J. Crowne (1 Feb. to 31 May 1973)

M. D. Mermelstein (1 June to 31 Jan. 1974)

P. W. Dahlgren

YEAR'S PUBLICATIONS

1. T. J. Deal and S. Fallieros, Models and Sum Rules for Nuclear Transition Densities, Phys. Rev. C7, 1709 (1973).
2. T. J. Deal and S. Fallieros, Electroexcitation Form Factors and Fixed Multipolarity Sum Rules, Physics Letters, 44B, 224 (1973).
3. S. Fallieros, Doorway States and Inelastic Electron Scattering, P. 185 in Nuclear Structure Studies Using Electron Scattering and Photoreactions, ed. by K. Shoda and H. Ui, Tohoku University Publication Vol. 5, 1972.
4. B. Goulard, T. J. Deal and S. Fallieros, Isoscalar Transition Densities for Isovector Nuclear Excitations, accepted for publication in Canadian Journal Phys., June 1973.
5. T. J. Deal, Sum Rules, Nuclear Structure and Form Factors for Isoscalar Electroexcitations, Ph.D. thesis and technical report, Brown Univ., 1972.
6. T. J. Deal, Isoscalar Dipole Resonances, accepted for publication in Nuclear Phys. July 1973.
7. R. M. Brill, Doorway States and the Giant M1 Resonance in ^{208}Pb , Ph.D. thesis and technical report, Brown University, 1972.
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9. S. Fallieros, Isospin in the Giant Resonance, p. 401 in Photonuclear Reactions and Applications, Ed. by B. L. Berman, Univ. of California, 1973.
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14. F. S. Levin and H. Feshbach, Reaction Dynamics (Gordon and Breach, N.Y. 1973), Lectures given at the Xth Latin American School of Physics, Mexico, 1968: pp. 1 - 167 by Levin, pp. 171 - 216 by Feshbach.
15. D. J. Kouri and F. S. Levin, On Standing Wave Solutions to the Schrödinger Equation, Annals of Physics (in press).

16. D. J. Kouri and F. S. Levin, On Standing Wave Solutions to the Inhomogeneous Equation for Identical Particle Scattering, submitted to Annals of Physics.
17. D. J. Kouri and F. S. Levin, On Channel T and K Operators and the Heitler Damping Equation for Identical Particle Scattering, submitted to Annals of Physics.
18. D. J. Kouri and F. S. Levin, A New Method for Determining K Matrix Elements, submitted to Physics Letters.
19. J. L. Friar, Relativistic Corrections to Electron Scattering by ^2H , $^3\text{H}_e$ and $^4\text{H}_e$, Ann. Phys. (NY) 81, 332 (1973).
20. J. L. Friar and J. W. Negele, The Determination of the Nuclear Charge Distribution of ^{208}Pb from Elastic Electron Scattering and Muonic X-rays, Nucl. Phys. A212, 93 (1973).
21. J. L. Friar and J. W. Negele, Breit Equation Analysis of Recoil Corrections to Muonic Atom Energy Levels, Phys. Letters 46B, 5 (1973).
22. J. L. Friar and J. W. Negele, Elastic Electron Scattering, Muonic X-rays, and the Charge Distribution of ^{208}Pb , submitted to Comments on Particle and Nuclear Physics.
23. J. L. Friar and J. W. Negele, The Determination of the Charge Distribution of ^{208}Pb from Elastic Electron Scattering and Muonic X-rays, Proceedings of the International Conference on Nuclear Physics (Munich, 1973), Volume 1, P. 630, North-Holland Publishing Co., Amsterdam (1973).

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