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Final Report on Status a rogress

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Project No: 9750

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D.S. Saxon

Project Director

Department of Physics

University of California

Los Angeles 24, California

I. Introduction

The research program at UCLA in theoretical nuclear physics and in elementary particle and field theory is presently being supported by the Air Force Office of Scientific Research, The National Science Foundation, the Office of Ordinance Research and by a small direct grant of University funds. All those who have been supported in any way by AFOSR funds are included in the list in Part II.

The research activities in theoretical physics for 1960 and 1961 are described in the yearly reports for those years. Copies of the pertinent material are appended for reference (Appendices A and B). Research activities for 1962 are described in Part III and a list of publication is given in Part IV. Reprints are being sent under separate cover.

The University has also contributed to the program by its generous support of visiting lecturers. Although the University has been generous, it moves rather ponderously. One of the most important and least expensive uses of our extra-mural funds has been to provide us with an essential degree of flexibility in connection with visiting lecturers. Because the extra-mural funds are, practically speaking, under our direct control we can quickly take advantage of any opportunities to bring distinguished visitors to UCLA without the usual delays involved in the commitment of University Funds. This is done by temporarily committing contract funds, but in every case the university has eventually agreed to support these distinguished people.

All of us at UCLA have been pleased at the development of theoretical physics here. One measure of our progress is the increasing number of applications from well qualified post-doctoral students; this year we received about forty such applications. The extra-mural support we have been granted, and that of the AFOSR in particular, has played an essential role in this development.

II. Personnel

A Senior Investigators

R. J. Finkelstein
M. A. Melkanoff
S. A. Moszkowski
D. S. Saxon
R. Norton
N. Byers
C. Fronsdal

Past Staff Members and Extended Visitors (since 1959)

B

Herbert Fried	September 1958 - June 1961
Ian McCarthy	July 1959 - March 1960
Derek Pursey	September 1959 - June 1960, July - August 1961, July - August 1962
Jerzy Plebansky	September 1959 - June 1960
Taro Tamura	Summer 1960, Summer 1962
Jean Lascoux	Summer 1960
Peter Kaus	Summer 1960
Dale Kunz	September 1960 - June 1961
Kurt Symanzik	Fall 1960
Julian Schwinger	Spring 1961
Luigi Radicati	Summer 1961
Tatuya Sasakawa	August 1961 - August 1962
Harry Lehmann	September - October 1961
Eileen Flamm	November 1961 - April 1962
Hans Joos	September - December 1962

C

Graduate Students in Theoretical Physics

a. Ph.D.'s since 1959

	Name	Title of Thesis	Date	Sponsor
1.	Sylvan Katz	Study of the Configuration of a Plasma in an Axially Symmetric Magnetic Field	1959	Banos
2.	A. Russel Vernon	Large Amplitude Waves in a Collision-Free Plasma	1960	Banos
3.	Kenneth Schwartz	The Stability of the Diffuse Linear Pinch with an Anisotropic Pressure Tensor	1960	Banos
4.	Gerald G. Comisar	On the Structure of Strong Plasma Shock Waves in a Transverse Magnetic Field	1961	Banos
5.	Edward C. Taylor	The Theory of Wave Excitation in Bounded Rarified Plasmas	1962	Banos
6.	Fred A. Wolf	The Effect of Charge Separation on Nonlinear Waves in a Collision-Free Plasma	1962	Banos
7.	William Brown	An Approximation Method for Large Angle Scattering of High Energy Scalar and Vector Waves	1959	Saxon
8.	Reinhard P. Lipperheide	On the Theory of Nuclear Reactions	1961	Saxon
9.	Robert W. Hougardy	A Modified WKB Approximation and its Application to Wave Propagation	1961	Saxon
10.	Jacques J. Templin	Theory of Direct Interaction Inelastic Scattering	1961	Saxon
11.	Thomas Lenne	Distorted Wave Effects in Proton Inelastic Scattering	1962	Saxon
12.	Charles Dismukes	A Velocity Dependent p-p Potential Model	1962	Saxon
13.	William Sooy	Approximate Calculations of Scattering Phase Shifts	1962	Saxon

14.	William Ramsay	General Covariance and Elementary Particles	1962	Finkelste
15.	Leo Komai	Application of the Collective Model to Cd^{114}	1959	Moszkowsk
16.	Deo Choudhury	A Theoretical Investigation of Nuclear Reactions	1959	Moszkowsk
17.	Alex Rassey	Energy level Spectra of Nucleons in an Anisotropic Diffuse Nuclear Potential	1960	Moszkowsk
18.	Bruce Scott	Application of a Simplified Brueckner Technique to Nuclear Matter	1960	Moszkowsk.
19.	Paul Kelly	Nuclear Shell Model Analysis of Calcium Isotopes	1961	Moszkowsk:

b. Students presently doing research

Name	Sponsor
George Adomian	Saxon
Peter Collas	Norton
William Dunwoodie	Byers
Stanley Fenster	Byers
Edward Field	Banos
Ira Green	Moszkowski
William Hall	Fronsdal
David Hestenes	Finkelstein
Kenneth Knight	Norton
James MacGuire	Saxon
Richard McCray	Byers
Eugene Peressini	Moszkowski
Marvin Rensink	Byers
Hojat Rostami	Fronsdal
Tatsuro Sawada	Saxon
Judith Scott	Norton
Koji Tariushi	Moszkowski
Richard Treat	Fronsdal
Charles Troutman	Saxon
Daniel Wenger	Finkelstein

III. Current Research Activities

Assoc. Prof. N. Byers

1. Weak Interactions

In the light of recent developments - e.g., discovery of two neutrinos and possible violation of $\Delta S = \Delta Q$ rule - a re-examination of the possibilities of a theory of weak interactions mediated by vector bosons[1,2] is underway. Experimental consequences of various assumptions regarding the symmetry properties of the coupling of the bosons to the leptonic and non-leptonic currents are being calculated.

Electromagnetic corrections to isospin selection rules: With the aid of dispersion relations, we are calculating the K^+ -decay rate assuming $\Delta I = 1/2$ in the absence of electromagnetism. We assume a phenomenological model to calculate the strong and weak vertices. Model parameters are obtained from the K^o -decay rate and strong interaction experiments. The calculation is not expected to yield the correct K^+ -decay rate, but will yield some insight into electromagnetic violations of isospin selection rules. To obtain a non-vanishing rate, this calculation must take three particle intermediate states into account. It, therefore, will also increase our familiarity with two and three particle amplitudes. Resonant pion-pion and pion-kaon states will also be included and studied. These amplitudes may be "Reggeized" and their contributions studied from this point of view as well (with W. Dunwoodie).

2. Strong Interactions

A close and fruitful collaboration between the High-Energy experimental group (under Professor Ticho's direction) and our group exists. As a result of this collaboration last year, reliable estimates for the K^+ -n scattering phase shifts for I = 0 are being obtained from K^+ -D scattering data with the aid of calculations using the 7090 IBM computer. Some properties of K-π scattering are being inferred from their measurements of pion production in K^+ -D and K^+-p collisions. The calculations for this work have been set up jointly by us and the experimentalists and are being carried out by members of the experimental group.

The recent discovery by Ticho's group of a Ξ -π resonance has stimulated us to study the general properties of angular correlation functions in the production and decay of unstable particles. Restrictions on these functions owing to general conservation laws (Parity and angular momentum) have been noted for certain cases by Yang[3], Capps[4] and Stapp and Gatto[5]. The underlying limitations on the structure of these correlation functions resulting from rotational and time reversal invariance and parity conservation has been studied and generalizations of the results hereto obtained have been found. In addition, new restrictions have been discovered which may allow for unambiguous determination of the spins of the decaying particles from data of the type that is presently available (with S. Fenster).

3. Meissner Effect in Superconductors

The discovery of quantized flux gave a striking confirmation of the pairing of electronic states first suggested by Cooper and made the basis of the Bardeen-Cooper - Schrieffer theory. During the year 1961-62, the penetration of static magnetic fields into superconductors was studied using the BCS theory in order to find deviations from the London penetration law. These deviations are expected to be appreciable when the energy gap is sufficiently small. A simple pairing theory of the type[6] used to explain quantized flux yields no such deviation. Both the pairing and the energy gap are essential features of a superconductor. Yang[7] has shown that pairing in systems obeying Fermi-Dirac statistics gives rise to long range order. Superfluids and superconductors exhibit such long range order. Both superfluids and superconductors have an "energy gap" in their excitation spectrum. Studies are now underway to investigate the connection between long range order and the existence of an energy gap (with M. Rensink).

References

1. N. Byers and R.E. Peierls, Il. Nuovo Cimento 10, 520 (1958).
2. T.D. Lee and C.N. Yang, Phys. Rev. 119, 1210 (1960).
3. C.N. Yang, Phys. Rev. 74, 764 (1948).
4. R.H. Capps, Phys. Rev. 122, 929 (1961).
5. R. Gatto and H.P. Stapp, Phys. Rev. 121, 1553 (1961).
6. N. Byers and C.N. Yang, Phys. Rev. Lett. 7, 46 (1961).
7. C.N. Yang, Rev. Mod. Phys. 34, 694 (1962).

Prof. R. Finkelstein

Elementary Particle Theory

1. General Covariance

Since the weak interactions are characterized by a handedness, Mach's principle suggests that physical space time is also characterized by a handedness, or torsion. If one tries to work out a theory of the strong interactions which respect parity, in a space which does not, one expects an inconsistency unless certain weak interactions, which also violate parity, are introduced. The preceding idea is the basis of a program for relating the weak to the strong interactions with the aid of the principle of general covariance.

An attempt has been made to explore in a systematic way the implications of general covariance for elementary particle theory. According to this program we investigate theories in which the parameters of the local Lorentz group and the local gauge group are arbitrarily position dependent. While the connection of the Lorentz group is associated with the gravitational field the connection of the gauge group is associated with the electromagnetic and weak vector [illegible].

There arise in this way certain kinds of theory which are less ad hoc than the usually discussed symmetry schemes. We hope in particular that these more natural theories may prove fruitful in the discussion of the hypothetical vector mesons responsible for the weak couplings.

It will be necessary to devise either lagrangian or nonlagrangian methods for extracting dynamical information from these quantized formulations of these theories.

2. High Energy Neutrino Experiments

Independent of the preceding approach,
it is planned to investigate the weak interactions with the aid of currently available techniques and in particular to concentrate on possibilities which are opened up by neutrino scattering at high energies.

Assoc. Prof. C. Fronsdal, Asst. Prof. R. Norton and Dr. K.T. Mahantappa

Joint Research Activities

Much of the current research of these investigators is being done in close collaboration and is discussed below: (additional research done by these investigators individually is listed separately)

Early in 1962 a program was initiated at UCLA aimed at obtaining a systematic theory of production phenomena in elementary particle collisions. The nature of this program is twofold; to develop the mathematical methods that are required, and to apply these methods to physical problems. Significant progress has already been achieved within the first part (Fronsdal, Norton and Mahanthappa, Phys. Rev. 127, 1847 (1962) and manuscript submitted for publication in Journal of Mathematical Physics.). Applications to particular physical processes have been started concurrently with the further development of the general theory. Before describing our methods we list the problems that are under active study.

1. Disintegration of the deuteron by neutrons. (with H. Rostami)

This is of interest mainly as a probe of the neutron-neutron interaction. It is of special concern to UCLA because one of our experimental groups (headed by Prof. York) is planning extensive measurements.

2. Disintegration of the deuteron by negative pions with gamma-emission.

This process also may serve as a probe of the neutron-neutron interaction. The experiment is going to be carried out at UCLA by a group headed by Prof. Haddock.

3. Pion production by protons or pions on protons. (with J. Knight)

A theory of pion production processes is essential for understanding the detailed structure of pion-nucleon scattering and photoproduction of pions. (Dr. Arnold, who joined UCLA this year, and Dr. Ball, who we hope will join the faculty next year, have both been working actively on this problem.) When the proposed pion factories come into operation both pion-nucleon scattering and pion production processes will become much better known, presenting an increasing challenge to improved theoretical analysis. (A proposal to build a pion factory at UCLA will soon be submitted to the U.S. Atomic Energy Commission.) Work on the influence of pion production on photoproduction is in progress.

4. Three-pion decay of the K-meson.

The theoretical analysis of such processes is beset with difficulties of the same nature as those that are encountered in production of particles. Our methods will allow us to treat precisely those aspects of the problem that had to be ignored in earlier treatments. Given an adequate theoretical analysis this decay may give important information about pion-pion scattering (in collaboration with J. Scott).

5. Analyticity in complex angular momentum.

Our methods allow a simple discussion of analyticity in angular momentum (Regge poles), for amplitudes of decay and of scattering of unstable particles. Analytic structures and threshold behaviour have been studied.

We now turn to a brief discussion of our methods.

The advent of the Mandelstam representation brought a revolution to the theoretical treatment of scattering of elementary particles, but no technique of similar power is known for production amplitudes or decay amplitudes. The difficulty in either case is the existence of complex singularities. We have found that representations not much more complicated than the Mandelstam representation, involving integrations over real contours only, are satisfied by important contributions to production and decay amplitudes. This makes it possible to give an adequate account of the complex singularities.

Assoc. Prof. C. Fronsdal

Research Activities (in addition to joint work with Norton and Mahantappa)

In axiomatic field theory one frequently encounters the problem of finding the most general function which vanishes in a certain region and whose Fourier transform also vanishes in a certain region. A novel method for solving such problems is under development. (in collaboration with W. Hall)

Asst. Prof. R. Norton

Research Activities (in addition to joint work with Fronsdal and Mahantappa)

Employing a priori reasonable approximations, the leptonic hyperon (i.e., Λ and Σ) decay rates can be calculated in terms of the rates for the $K\mu_2$ and Ke_3 decays and the coupling constants for the K and K* mesons to hyperons and nucleons. In order to check the results of this calculation for the Λ decay, the required K* coupling constant is being determined by extrapolation of the $\pi + p \longrightarrow \Lambda + K$ associated production data to the K* "pole". (with P. Collas)

Assoc. Prof. Michel A. Melkanoff

Current Research Activities

Optical Model

A. Applications of the Optical Model

1. Analysis of elastic scattering of deuterons against complex nuclei at intermediate energy (with T. Sawada).(One article in preparation.)

2. Analysis of elastic scattering of protons against selected nuclei at many energies:

   a) p - C at 30 to 40 Mev.

   b) p - Mg at 6 to 30 Mev.

   c) p - Cu at 5 to 30 Mev (Paper submitted to Padua Conference with Olkowsky and Nodvik.).

3. Applications of Optical Model Transmission coefficients to Statistical Model of Nucleon Reactions (paper submitted to Padua Conference with Mani).

4. Investigation of giant resonances predicted by optical models for protons and neutrons.

5. Calculation of electron scattering form factors from selected nuclei.

B. Fortran Programs

Several programs are being prepared for publication in Univ. of Calif. Press Publications in Automatic Computations.

a) SCAT6: FORTRAN program of optical model analyses of spin one particles against zero spin targets.

b) NGS and DGS: FORTRAN programs designed to optimize optical model analyses fits to scattering data by automatic simultaneous variation of the model parameters.

It should be pointed out that there have been numerous requests for these programs. The first publication in the series, SCAT4, which deals with optical model analyses of incident spin 1/2 particles, is about to enter into a third printing of 1500 copies after selling out 1400 copies in the previous two printings. California Press tells us that this is an unprecedented event.

C. Future Plans

Besides continuing with the program above, it is planned to apply the optical model to scattering of high energy deuterons, α particles, pions and K-mesons by means of automatic search programs, and to make an overall survey of nucleon scattering at a number of energies for representative nuclei.

Assoc. Prof. S. Moszkowski

1. Nuclear Many Body Problem (S. Moszkowski)

The problem of simulating the hard core in the nucleon-nucleon potential by a velocity-dependent but non-singular interaction was studied with special reference to the implications for nuclear matter calculations.

As was shown previously by others, it is possible to construct velocity-dependent potentials, which give the same S-wave phase-shift vs. energy as a static potential with a hard core, but such a potential will give several Mev-per-particle more binding of nuclear matter. We have shown that this difference can be directly attributed to the different behavior of the two-particle wavefunction at small interparticle spacing.

Also, both kinds of potential can be handled by the "separation method", in which the interaction is split into a short range and a long range part. The short range part contains all of the repulsion and just enough attraction to give no scattering in free space (for S-waves at a fixed energy). When this is done, the remaining long range part is a good approximation to the effective interaction and may be treated by perturbation theory.

2. Nuclear Surface (with E. Peressini)

According to the Thomas-Fermi approximation, the energy density at each point in a medium is a simple function of the local particle density (and independent of its gradient). We are investigating the accuracy of this approximation at the nuclear surface by several different methods. All these results obtained so far suggest that quantum mechanical corrections to the Thomas Fermi approximation are an order of magnitude smaller than might have been expected on the basis of dimensional arguments alone.

Also we have developed a simple modification of the Thomas-Fermi approximation which gives more accurate results for the sum of eigenvalues for particles in a diffuse well potential. A report is in preparation.

3. Two Dimensional Model

We have used a two dimensional analog of the nucleus in order to gain insight into various nuclear properties. This model contains surprisingly mar of the essential features of actual nuclei, such as saturation, shell structure, nuclear deformation and pairing. These calculations are comparatively simple if harmonic oscillator wavefunctions are used. It turns out that many relations which hold exactly in two dimensions hold very nearly in three dimensions. A report is in preparation.

4. Nuclear Models

A monograph on nuclear models is in preparation. This will be published by McGraw Hill Co.

5. Beta Decay

The manuscript for a monograph on beta decay (in collaboration with C.S. Wu) has been completed and will be submitted shortly to Interscience-Wiley Co.

D.S. Saxon

A. Optical Model

1. A systematic analysis of all available elastic scattering, polarization and total cross-section is underway. The theory of the optical model will therefore be used as a guide to help fix these parameters (with C. Troutman).

2. The relationship between local and non-local potential operators is being studied. It has been shown that an equivalence between local and non-local operators can be established provided the range of the non-locality is small compared to the over-all spatial dependence of the potential. Equivalence means that the local and non-local potentials give rise to the same asymptotic wavefunction (scattering). A paper is now in preparation.

3. A monograph on the optical model is in preparation. The first draft is about 2/3 completed (in collaboration with A.E.S. Green).

B. Direct Interactions

1. A semi-phenomenological calculation has been carried out using approximate distorted wavefunctions of the type suggested by McCarthy and Pursey but which include the focussing effects of the optical potentical. (with T. Menne)

2. Distorted wave calculations have been carried out in which spin-orbit terms are included in the distorting potential. (with J. Templin)

C. Nucleon-nucleon Interaction (with C. Dismukes)

A phenomenological analysis of nucleon-nucleon interactions has been carried out using a velocity dependent interaction instead of a hard-core, as just suggested by Peierls. The one pion exchange potential is used to fix the potential at large distances. The results are good and are being written up for publication.

D. Three and more body problem (with J. McGuire)

A simplified one dimensional three body problem has been found which can be solved exactly.

E. Approximation Methods for Scattering and Propagation (with R. Hougardy)

Propagation of electromagnetic waves in an anisotropic inhomogeneous medium has been studied. Some results were presented at the International Symposium on Electromagnetic Theory which took place in Copenhagen in June, 1962. A more detailed account is in preparation.

Dr. R.C. Arnold

A program is underway to gain some insight into both the symmetries and the dynamics of strong interactions through computational methods recently developed using the analytical properties of scattering and reaction amplitudes. The concept of analytical continuation in the complex angular momentum plane is combined with the known properties of the new unstable elementary particles. Assistance in the mathematical drudgery is obtained from the 7090 computer. Particular problems under study are concerned with the pion-nucleon, pion-hyperon and kaon-hyperon resonance formation, and multichannel reaction processes such as pion production in pion-nucleon collisions.

Dr. R. Bryan

Nucleon-Nucleon Scattering

Our current program involves the study of low energy (0 to 300 Mev) nucleon-nucleon scattering in terms of multi-pion resonances. The resonances are treated as particles, and predictions are made on the basis of the corresponding one-boson-exchange potentials, these inserted in the Schrödinger equation. Reasonable predictions have been made for P and higher angular momentum states in p-p scattering using the $J = 1^-$ ω and intermediate mesons, the pion, and a postulated $J = 0^+$ meson (with C. Dismukes and W. Ramsey). This study is now being extended to include n-p ($T = 0$) scattering over the same energy range (with E.L. Scott).

Dr. K. T. Mahantappa

The possibility that the large mass differences between the various baryons is due to the presence of vector bosons weakly coupled to a primary baryon has been explored.

A paper has been submitted to the Physical Review.

The analytical properties of the scattering amplitude in the complex angular momentum plane when the external masses are anomalous are being studied.

The Mandelstam representation is being used to study the amplitude for the process $\pi + \pi \to K + \bar{K}$. Numerical calculations will be carried out after making analytical approximations using N/D method. The results will be made use of in studying the Kaon form-factor.

Dr. S. Pandya

Nuclear Shell Model

An attempt was made to study the nature of the effective nucleon-nucleon interaction from an analysis of nuclear spectra somewhat more thoroughly than is usually done in shell model calculations. For this purpose, one of the best available cases today seems to be the oxygen isotopes. Spins and parities of 10 states in O^{18}, O^{19} and O^{20} are known. The analysis of the level spectra leads to a determination of the matrix elements of the effective interaction (assumed to be a two-body force) in various states of two neutrons. These matrix elements are further analysed in terms of Talmi Integrals of the effective potential. The results throw some light on the nature of the interaction in various angular momentum states of two particles (with isotopic spin unity). The interaction in even states appears to consist of a short-range attractive force plus a repulsive, non-singular core, a result more in line with our knowledge of nuclear forces than most shell model interactions considered up till now. The forces in the odd states are unfortunately not unambiguously determined, and it is pointed out that an experimental determination of $J = 3^+$ state in O^{18} would be very helpful in elucidation of this point.

It is intended now to undertake an extensive analysis of the energy level spectra in the regions $A = 18$-20, $A = 30$-34, and $A \sim 60$ in the framework of the nuclear shell model to study the relationship of the collective type spectra to configuration mixing and neutron-proton interactions. (with I. Green)

Publications by Staff Members

Dr. Nina Byers

1. "Interactions of Low-Energy Negative Pions with Nuclei," Phys. Rev. Vol. 107, 843-849, August 1, 1957.

2. "Two-State Model of Fermi Interactions," with R.E. Peierls, Il Nuovo Cimento, Vol. 10, 520-524 (1958).

3. "Energy and Angular Distributions of Mesonic Hyperfragment Decays," with W.N. Cottingham, Nuc. Phys. 11, 554-568 (1959)

4. "A Note Concerning the Magnetic Moment of the Muon," with F. Zachariasen, Il Nuovo Cimento, Vol. 18, 1289-1290 (1960).

5. "The Decay $\Sigma^0 \to \Lambda^0 + e^+ + e^-$ and the $\Sigma^0 - \Lambda^0$ relative Parity," Phys. Rev., Vol. 121, 281-282, January 1, 1961.

6. "Theoretical Considerations Concerning Quantized Magnetic Flux in Superconductors," with C.N. Yang, submitted for publication in Physical Review Letters.

7. "Parity Conservation in $\Sigma^0 \to \Lambda^0 + \gamma$. Il Nuovo Cimento, Vol.22, N.5 (1962).

Invited Paper

"Quantization of Magnetic Flux in Superconductors", Am.Phys. Soc., Los Angeles, December 1961.

Dr. R. Finkelstein

1. "Spacetime of the Elementary Particles," J. Math. Physics 1, 440-51 (Sept. 1960).

2. "Spinor Fields in Spaces with Torsion," Annals of Physics 12, 200-21 (February 1961).

3. "Elementary Interactions in Spaces with Torsion," Annals of Physics 15, 223-49, (August 1961).

4. "The Strong Couplings in a Space with Torsion," Annals of Physics 17, 379-403, (March 1962).

5. "The Weak and the Strong Couplings and General Covariance," Annals of Physics, (to appear, Nov.-Dec. 1962).

Invited Paper

"π-e Decay", Am. Phys. Soc., Los Angeles, December 1958.

Dr. C. Fronsdal

1. "Unitary Irreducible Representation of the Lorentz Group," Phys. Rev. 113, 1367 (1959).

2. "The Representations of the Lorentz Group in Quantum Mechanics," Part IV of a series of seminars given by members of the Theoretical Studies Division, CERN, Geneva.

3. "On the μ-meson Decay with Inner Bremsstrahlung," with H. Uberall, Phys. Rev. 113, 654 (1959).

4. "A Generally Relativistic Field Theory," Nuovo Cimento 13, 988 (1959).

5. "Completion and Embedding of the Schwarzschild Solution," Phys. Rev. 116, 788 (1959).

6. "On the μ-meson Decay," with S.L. Glashow, Phys. Rev. Letters 3, 570 (1959).

7. "Spin-Orbit Correlations in Bhabha Scattering," with B. Jaksic, Phys. Rev. 121, 916 (1961).

8. "Spin-Orbit Correlations in μ-e and $e^- - e^-$ Scattering," with A. Barut Phys. Rev. 120, 1861 (1960).

9. "Analyticity of Wightman Functions," Journ. Math. Physics 2, 748 (1961).

10. "On Simple Groups and Strong Interaction Symmetries," with R.E. Behrends, J. Dreitlein and D.W. Lee, Rev. Mod. Phys. 34, 1 (1962).

11. "The Many-Body Problem," Lecture notes from the 1961 Bergen Summer School W.A. Benjamin, N.Y. 1962. (Editor)

12. "Integral Representation for a Scattering Amplitude with Complex Singularities," with K.T. Mahanthappa and R.E. Norton, Phys. Rev. 127, 1847 (1962).

13. "More Integral Representations for Scattering Amplitudes with Complex Singularities," with R.E. Norton and K.T. Mahanthappa, submitted to Journal of Mathematical Physics, 1962.

14. "Weak Interactions," Lecture notes from the 1962 Bergen Summer School, W.A. Benjamin, N.Y., 1963. (Editor)

Invited Paper

1. "Group Theory and Application to Elementary Particles," Brandeis 1962 Summer School.

Dr. M. Melkanoff

1. "Optical Model Analysis of Elastic Scattering of 125-Mev K^+-Mesons in Nuclear Emulsion" (with Price, Stork, and Ticho), Phys. Rev. 113, 1303 (1959).

2. "Scattering of Deuterons and Heavier Particles," Proceedings of the International Conference on the Nuclear Optical Model, p. 207, Florida State University, Tallahassee, 1959.

3. "Optical Model Potential for K^--Mesons," (with Prowse and Stork) Phys. Rev. Let. 4, 183 (1960).

4. "T = 0 K^+ Nucleon Phase Shifts Based on Optical Model" (with Prowse, Stork, and Ticho) Phys. Rev. Let. 5, 108 (1960).

5. "A FORTRAN Program for Elastic Scattering Analyses with the Nuclear Optical Model," (with Nodvik, Saxon, and Cantor), Univ. of Calif. Press Publications in Automatic Computations, 1961.

6. "On the Shape of the Imaginary Part of the Optical Model Potential," (with Nodvik and Saxon), Proceedings of the Rutherford Jubilee International Conference, Manchester, 1961, p. 411.

7. "Optical Model Analysis of Elastic Scattering of Protons on Carbon at Intermediate Energies," (with Nodvik and Duke), Phys. Rev. 125, 975 (1962).

8. "Optical Model Analysis of 260-Mev K^+-Meson Elastic Scattering," (with Helmy, Prowse, and Stork), Phys. Rev. 127, 254 (1962).

9. "Artificial Languages and Natural Languages," This is a chapter in the book, "Natural Language and the Computer", edited by Paul Garvin, McGraw-Hill. (to be published)

10. "Optical Model Parameters for the Interaction of Intermediate Energy Deuterons with Nuclei," (with Sawada and Cindro), Phys. Let. 2, 98 (1962).

11. "Investigation of Optical Model Surface Absorption Based on Intermediate Energy p-Cu data," (with Olkowsky and Nodvik), submitted to the International Symposium on Direct Interactions and Nuclear Reaction Mechanisms, Padua (1962).

12. "Statistical Model Calculations of Neutron Induced Reactions in Medium Weight Nuclei," (with Mani), Proceedings of the International Symposium on Direct Interactions and Nuclear Reaction Mechanisms, Padua (1962), (to be published)

Dr. S. Moszkowski

1. Proton-Neutron Interaction and the (p,n) Reaction in Mirror Nuclei," Phys. Rev. Letters 3, 98 (1959).

2. "Superfluidity of Nuclear Matter," with R.L. Mills, A.M. Sessler, D.G. Shankland, Phys. Rev. Letters 3, 381 (1959).

3. "Theories for Angular Distributions in Low Energy Nuclear Reactions," (series of six lectures presented at the Lawrence Radiation Laboratory, Livermore, California in 1958) edited by J. Benveniste and E.H. Schwarcz. UCRL 5701. Printed for the U.S. Atomic Energy Commission, 1959.

4. "Nuclear Forces and the Properties of Nuclear Matter," with B.L. Scott, Annals of Physics, Vol. 11, 65 (1960).

5. "Calculation of Matrix Elements in the Beta-decays Sc^{44} and Mn^{52}," with P.S. Kelly, Zeitschrift für Physik 158, 304 (1960).

6. "Hole-Hole Interactions and the Properties of Nuclear Matter," with A.M. Sessler, Nuclear Physics 18, 559-571 (1960).

7. "Imaginary Part of the Optical Potential in Nuclear Matter," with J. Sawicki, Nuclear Physics 21, 456-461 (1960).

8. "Energy of a Low Density Neutron Gas," with P.C. Sood, Nuclear Physics 21, 582-594 (1960).

9. "Nuclear Coupling Schemes with S-State Interactions,"Proceedings of Kingston Conf. on Nuclear Structure, p. 502-505 (August, 1960).

10. "The Tensor Interaction and Nuclear Matter," with Bruce Scott, Annals of Physics, Vol. 14, 107-119 (1961).

11. "Systematics of Beta-decay Matrix Elements," Proceedings of the Rutherford Jubilee Conference, Manchester, England, 689-695, Heywood, Co., 1962.

12. "Nuclear Matter Calculations using the Separation Method," with B.L. Scott, Nuc. Phys. 29, 665-671 (1962).

13. "Binding Energy of Lambda Particles in Nuclear Matter using the Separation Method," with P.C. Sood and M. Taherzadeh (Nuovo Cimento, 23, 168-172, (1962).

14. "On the Energy Distribution of Terms and Line Arrays in Atomic Spectra," Prog. Theo. Phys. 28, 1-23 (1962).

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15. "Theory of Multipole Radiation," Chapter XI of Alpha, Beta and Gamma Ray Spectroscopy," edited by K. Siegbahn, North Holland Publishing Company, Amsterdam, in press.

16. "On the Simulation of the Hard Core by a Velocity Dependence," Physical Review, February 15, 1963.

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1. "Nuclear Forces and the Properties of Nuclear Matter," American Physical Society, New York, January 1960.

2. "Systematics of Beta Decay Matrix Elements," Rutherford Jubilee Conference, Manchester, 1961.

Dr. Richard Norton

1. "Complete Set of Dispersion Relations For A Class of Fixed Source Meson Theories," with Abraham Klein, Phys. Rev. 109, 584 (1958).

2. "Significance of the Redundant Solutions of the Low-Wick Equation," with Abraham Klein, Phys. Rev. 109, 991 (1958).

3. "Consequences of A Pseudovector Coupling and the Universal β-Decay," with W.K.R. Watson, Phys. Rev. 110, 996 (1958).

4. "Commutation Rules and Spurious Eigenstates in Soluble Field Theories," with W.K.R. Watson, Phys. Rev. 116, 1957 (1959).

5. "Runaway Modes In Model Field Theories," with Sidney Coleman, Phys. Rev. 125, 1422 (1962).

6. "K* and K Meson Pole Contributions To Leptonic Λ Decay," Phys. Rev. 126, 1216 (1962).

7. See C. Fronsdal, Ref.12.

8. See C. Fronsdal, Ref.13.

Dr. D. Saxon

1. "Analysis of Elastic Cross Section and Polarization of 10 Mev Proton," (with J.S. Nodvik) Phys. Rev. 117, 1539, 1960.

2. "Proceedings of the International Conference of the Nuclear Optical Model," (Edited with A.E.S. Green and C.E. Porter) Florida State University, Studies No. 32 (March, 1959).

3. "Modified WKB Methods for the Propagation and Scattering of Electromagnetic Waves," IRE Trans. on Ant. and Prop., AP-7, Sp. Supp. (December 1959).

4. "Determination of the Forward Scattering Amplitude from the Optical Model Potential in the High-Energy Limit," (with R. Lipperheide) Phys. Rev. 120, 1458-1459 (Nov. 15, 1960).

5. "The Parameters of the Optical Model Potential and their Physical Interpretation," Proc. Intl. Conf. Nuclear Structure, Kingston (1960), Pg. 197-208.

6. Contributor to: Project Sorrento Report (classified), Leonard Lieberman, editor, University of California, Scripps Inst. Oceanography (1960).

7. See M. Melkanoff, Ref. 5.

8. See M. Melkanoff, Ref. 6.

9. "Propagation of Electromagnetic Waves in an Anisotropic Medium," (with R.W. Hougardy) Symposium on Electromagnetic Theory and Antennae, Copenhagen (1962).

Continued - Saxon

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1. "Modified WKB Methods for the Propagation and Scattering of Electromagnetic Waves," International Symposium (URSI) on Electromagnetic Theory, University of Torouke, Torouke, Canada (June 1959).

2. "The Optical Model Parameters and their Physical Significance," International Conf. on Nuclear Structure, Queen's University, Kingston, Ontario, Canada (Aug. 1960).

3. "Recent Views of the Nucleus," Amer. Assoc. Phys. Teachers, San Luis Obispo (Aug. 1960).

Dr. R. Arnold

1. "Scattering of Negative Mesons by Hydrogen at 130 and 152 Mev (with U.E. Kruse), Phys. Rev. 116, 1008 (Nov. 15, 1959).

2. "Vector Mesons and the KN, $\bar{K}N$ Interactions," (with J.J. Sakurai), to be published in Phys. Rev., 1962 (Abstract appeared in Phys. Rev. Letters November 1, 1962).

3. "Pion-Nucleon Interactions in the Intermediate Energy Range," (Thesis, U. of Chicago), submitted to Phys. Rev. for publication, Dec. 1962.

Dr. R. Bryan

1. "Semiphenomenological Theory of $^{+}$ Hyperon-Proton Scattering up to 150 Mev," R.A. Bryan, J.J. de Swart, R.E. Marshak, P.S. Signell, Phys. Rev. Letters 1, 70 (1958).

2. "New Semiphenomenological Proton-Proton Potential," R.A. Bryan, Il Nuovo Cimento 16, 895 (1960).

3. "Boundary Condition Model for Proton-Proton Scattering," D.P. Saylor, R.A. Bryan, and R.E. Marshak, Phys. Rev. Letters 5, 266 (1960).

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Dr. K. Mahanthappa

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3. "Multiple Photon Production in Quantum Electrodynamics," Phys. Rev. 126, 329 (1962).

4. "Expectation Value Formalism in Quantum Field Theory I," (with Bakshi), J. of Math. Phys., in press.

5. "Expectation Value Formalism in Quantum Field Theory II," (with Bakshi), J. of Math. Phys., in press.

6. See C. Fronsdal, Ref. 12.

7. "Baryon Mass Splitting and Weak and Strong Couplings," (with Ramsay) preprint, Phys. Rev., in pres .

8. See C. Fronsdal, Ref. 13.

Dr. S. Pandya

1. "The Unified Model for Si^{29}," Prog. Theor. Phys. 21, 431 (1959).

2. "Collective Vibrations in P^{31}," (with V.K. Thankappan), Nuclear Physics 19, 303 (1960).

3. "Collective Vibrations in Si^{30}," (with V.K. Thankappan), Nuclear Physics (submitted for publication), in press.

4. "Nuclear Spectroscopy with Non-local Potentials," (with A.N. Mitra), Nuclear Physics 20, 455 (1960).

5. "Nuclear Interactions in the Shell Model," (with S.K. Shah), Nuclear Physics 24, 326 (1961).

6. "A Shell Model Calculation for Scattering of Electrons by Be^{9}," (with Y.R. Waghmare), Prog. Theor. Phys. 25, 822 (1961).

7. "A Study of Effective Nuclear Interactions in Finite Nuclei," (with S.K. Shah), Nuclear Physics (submitted for publication), 38, 420,(1962).

8. "Separable Non-local Interactions in Nuclei," (with V.L. Narasimham and S.K. Shah), Nuclear Physics 33, 529 (1962).

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b. Publications by past Staff members and extended visitors

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2. H. M. Fried and D. R. Yennie , "Higher Order Terms in the Lamb Shift Calculation," Phys. Rev. Lett. 4, 583, 1960.

3. H. M. Fried, "Example of a Soluble Field Theory with Finite Charge Renormalization," Phys. Rev. 118, 1427, 1960.

4. H. M. Fried, "Formal Paradox in Quantum Electrodynamics," Phys. Rev. 118, 1642, 1960.

5. H. M. Fried and D. L. Pursey, "On the Proof of Parametric Dispersion Relations," Phys. Rev. 124, 1281, 1961.

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11. I. E. McCarthy and D. S. Prowse, "A model for the Interpretation of K^- Meson capture at rest in complex nuclei," Nucl. Phys. 17, 96, 1960.

12. I. E. McCarthy and D. J. Prowse, "Question of Nucleon Clusters in the Nuclear Surface," Phys. Rev. Lett. 4, 367, 1960.

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22. T. Tamura and D.C. Choudhury, "Inelastic Scattering by Various Nuclei," Phys. Rev. 113, 552, 1959.

c. Publications by Students

(not coauthored with staff member)

1. G. G. Comisar, "On the Structure of Strong Plasma Shock Waves in a Transverse Magnetic Field," Physics of Fluids, in press.

2. S. Fenster, "An Investigation of Coulomb Scattering Amplitudes in the Complex Angular Momentum Plane," Nucl. Phys. 38, 638, 1962.

3. S. Katz, "Configuration of a Plasma in an Axially Symmetric Magnetic Field," Physics of Fluids 4, 204, 1961.

4. R. Lipperheide, "On the Theory of Nuclear Reactions," Ann. of Phys. 17, 114, 1962.

5. T. Menne, "Distorted Wave Effects in Proton Inelastic Scattering," Nucl. Phys. 36, 656, 1962 and proceedings of 1962 Padua conference on Nuclear Reactions.

6. W. Ramsey, "p-p higher Partial Waves and the 3-meson Model," submitted to Phys. Rev.

Appendix A

Research Activities (1960 yearly report)

A. Nuclear Physics

1.) Optical Model Calculations of Scattering and Polarizations.

An automatic search routine has been developed by M. Melkanoff in collaboration with J.S. Nodvik of the University of Southern California. This routine minimizes the deviation from experiment (chi-squared) by finding the shape of the chi-squared surface in the optical model parameter space and then proceeding along the gradient to the minimum. With this new feature, the UCLA optical model analysis program appears to be the fastest, most precise and most powerful program available anywhere. It takes only a few hours to accomplish what was formerly a full summers work, and the results are more precise. A systematic and definitive analysis of all available experimental elastic scattering and polarization data is now underway and various suggested forms of the optical model potential are being compared in order to determine the extent to which the data distinguishes among them. (M. Melkanoff, in collaboration with J.S. Nodvik). Isotopic effects and possible N-Z symmetry terms are also being examined (J. Templin and M. Melkanoff). In addition, the routine is being used to analyze deuteron scattering (C. Dismukes and M. Melkanoff, in collaboration with T. Sawada).

2.) Alpha Particles Direct Interactions.

A semi-phenomenological theory has been developed for the treatment of the inelastic scattering of alpha particles by complex nuclei. Born approximation is used but the initial and final state alpha particle wave functions are taken to be distorted by the optical model potential. A simple approximation is used for the distorted wave functions near the nucleus which reproduces the main features of the accurately computed wave functions. Good agreement with experiment is obtained. A manuscript has been submitted to the Physical Review. (D. Pursey, in collaboration with I.E. McCarthy)

3.) Inelastic Scattering of Nucleons

The approximation method developed for the treatment of alpha particle scattering, as described in 2.) above, is being extended to the case of nucleon inelastic scattering. A more refined treatment is required in which focusing effects of the optical model potential are taken into account. (D. Pursey, in collaboration with I. E. McCarthy and T. Menne)

At the same time a much more ambitious and detailed treatment of inelastic scattering is underway using exact optical model wave functions. Spin-orbit terms are included so that polarizations can be predicted. An IBM 709 program is now nearly finished. Use will be made of the automatic search routine described in 1.) above. (J. Templin., M.Melkanoff and D. Saxon).

4.) Theory of the Optical Model

A self-consistent theory of the optical model potential for elastic and inelastic scattering is being developed. Exchange and center of mass terms are included. A discussion of the determination of the forward scattering amplitude at high energies from the optical model potential has been published, Phys. Rev. 120, 1458 (1960). (R. Lipperheide and D. Saxon).

5.) Nucleon - Nucleon Interaction

A simple phenomenological form of the two nucleon interaction is being investigated. The question of velocity dependent interactions is also being examined (C. Dismukes and S. Moszkowski).

6.) Scattering of Systems with Arbitrary Spin

Generalized WKB approximations are under investigation. Results have been obtained for the scattering of fermions, the first case considered (I. Alexandrov and D. Saxon).

7.) Nuclear Many Body Problem

The many body problem of the finite nucleus is being investigated. The Moszkowski-Scott approximation to the Brueckner theory, previously applied to an infinite nuclear medium, is used. Brueckner's approximation, in which the density dependance of the reaction matrix is obtained from an infinite nuclear medium calculation, is avoided. (S. Kohler and S. Moszkowski)

8.) Spin-Orbit S plitting of Nuclear Levels

Several authors [1,2,3,] have attempted to account for the spin orbit splitting in energy levels of nuclei in terms of the two body spin orbit potentials [4,5,6] derived from scattering data. These calculations have not met with too great a success. The best calculation is that of Tauber and Wu who use harmonic oscillator function with Jastrow-type[7] correlation functions and attempt to calculate the binding energy of O^{15} and O^{16} and the resulting spin orbit splitting in O^{15}. Their splitting, which is too large by a factor of three is primarily a result of too high a nuclear density. Adjusting the size of their spin orbit matrix elements to a nuclear density given by elastic electron scattering experiments[8] results in a spin orbit splitting near that observed experimentally. The calculations are being extended to the cases of other nucleons in the 1P shell, O^{17} and Ca^{41}. (P.D.Kunz and S. Moszkowski).

1. B.P. Nigam and M.K. Sunderesan, Phys. Rev. 111, 284 (1958).
2. J.Sawicki and R. Falk, Nuc. Phys. 11, 368 (1959).
3. G.E. Tauber and Ta-You Wu, Nuc. Phys. 16, 545 (1960).
4. P.S. Signell and R.E. Marshak, Phys. Rev. 106, 832 (1957).
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6. J.L. Gammel and R.M. Thaler, Phys. Rev. 107, 1337 (1957).
7. R. Jastrow, Phys. Rev. 98, 1479 (1955)
8. U. Meyer-Berkhout, K.W. Ford, and A.E.S.Green, Annals of Physics 8, 119 (1959).

B. Field Theory and Elementary Particles

1.) Space time of the Elementary Particles

A program is under way to investigate, within the frame work of a generally covariant quantum field theory, the possibility that the space-time continuum is characterized by a torsion or handedness.

The first results have been published in J. Math. Phys. 1, 440 (1960) and a second paper is scheduled to appear soon in Annals of Physics. These two papers contain some of the basic ideas and show how the strong couplings might be associated with the torsion of space, similar to the way in which the gravitational interactions are associated with its curvature. A third paper describes a space-time structure which gives a faithful representation of the strong interactions and the iso spin group, and suggests a detailed description of the weak interactions as well (R. Finkelstein). The electromagnetic properties of the intermediate boson which follow from the above formulation are also under investigation (W. Ramsey and R.Finkelstein).

2.) Unified Theory of Weak Interactions and Electromagnetism

A unified theory of the weak interactions and electromagnetism in which the photon and the intermediate meson of β-decay are regarded as different states of the same particle, is under investigation. This idea had been suggested before by Ward and Salam, Nuovo Cimento 11, (1959), but in a form which led to certain inconsistencies- the most glaring of these being that the leptons did not have their experimentally observed helicities. A modified version of the Ward-Salam theory was constructed which does not have this helicity problem, and which also is readily extendable to include the non-strangeness changing part of the hyperon decays.

There are a number of as yet unanswered questions:

(a) Does the theory predict a large enough mass for the intermediate meson to guarantee the weakness of the weak interactions?

(b) Is the theory renormalizable? Ward and Salam originally claimed that their theory was renormalizable, but this was later shown to be wrong.

(c) What can one do about the strangeness changing processes?

A paper on this work has been submitted for presentation at the American Physical Society meetings at Berkeley. (R. Norton and P. Kaus in collaboration with W.K.R. Watson)

3.) Runaway Solutions

A study has been made of the various ways a theory with runaway solutions can be modified so as to eliminate the runaway properties without at the same time altering the desirable features. Although this work has been confined mostly to a study of linear field theories, it was motivated by the idea that at least one of the procedures may be extendable to non linear theories and could conceivably lead to a modified, improved version of a physical theory such as quantum electrodynamics.

A manuscript on this research will be submitted for publication shortly. This work was carried out mainly at the California Institute of Technology. (R.Norton, in collaboration with S. Coleman)

4.) Form Invariance in Quantum Electrodynamics

All possible groups of linear transformations which leave the physical results of the theory unchanged were investigated from a general point of view. Of particular interest were the transformation properties of such quantities as charge, mass and commutation vector under the Pauli transformations. An outline of results was presented at the January 1960 meeting of the American Physical Society in New York: a detailed paper will be submitted to Il Nuovo Cimento (J. Plebanski and D. Pursey).

5.) Multi-fermion Theory of Quantum Electrodynamics

The Pais-Uhlenbeck treatment of theories with higher derivitives was re-examined using Schwinger's action principle. It was proved that the indefinite metric of the theory follows from first principles. A paper is being prepared for publication in the Physical Review. (J.Plebanski, in collaboration with H. Fried)

6.) Simple Model of a Field Theory

A simple model which preserves the mathematical features of real interactions was studied. The model contains only one boson and two fermions, without momentum dependence, but with as general an interaction as possible. The model appears to be soluble and solutions have been obtained in some special cases. (J. Plebanski)

7.) Velocity Dependence of Gravitational Interactions

The gravitational interaction between two bodies moving at high velocity has been studied. Examination of the simplest cases appears to indicate a velocity dependence of gravitational forces (J. Plebanski).

8.) Special Coordinates in General Relativity

An important proof was completed showing the independence of physical conclusions on special choice of coordinates. The method makes use of the projection of physical data to observers at infinity by means of light rays. This work will be published in Acta Physics Dolamca (J. Plebanski).

Appendix B

Research Activities (1961 yearly report)

A) Nuclear Structure

1) Nucleon-Nucleon Potential

The proton-proton interaction is being examined from the standpoint of pion resonances. The pion and the $J = 1^-$ ρ and ω mesons are taken into account in the model. In addition, a $J = 0^+$ meson is introduced in order to provide the necessary attraction in the interaction. Good qualitative agreement with experiment over the 0 - 300 Mev pp scattering energy range has been obtained. (R. Bryan, in collaboration with W. Ramsey and C. Dismukes).

2) Nuclear Many-Body Problem

The separation method described in the previous annual report has been applied to the study of the nucleus O^{16}. Brueckner's approximation, in which the density dependence of the reaction matrix is obtained from an infinite medium calculation, was avoided. Fairly good agreement with the experimental binding energy and radius was obtained. (Kohler). Work on the derivation of the nuclear surface thickness and surface energy from a more basic two-body interaction has continued. The effect of changing particle density at the nuclear surface on the density of kinetic and potential energy (i.e., the inhomogenity effect) has been studied and found to be much smaller than expected on the basis of dimensional arguments alone. (S. Moszkowski in collaboration with L. Wilets).

The Moszkowski-Scott separation method has been reexamined in the case of tensor forces. A simpler formalism has been developed for treating the states of coupled angular momenta. As a consequence, the short-range t-matrix now exhibits the same behavior with respect to variation of the separation distance in the $^3S_1$ state as in the $^1S_0$ state. (R. Bryan).

3) Nuclear Coupling Schemes

It was shown by Kisslinger and Sorenson that many features of nuclear spectra can be explained quantitatively by assuming the effect of interactions can be separated into 1) an average potential, which determines the position of single particle levels, 2) a quadrupole interaction which leads to deformations and 3) a pairing interaction which leads to a special favoring, energetically, of 0_+ states in even-even nuclei.

We are attempting to calculate the magnitudes of the parameters used in the Kisslinger-Sorenson model starting from the more basic two-body interaction and also to see to what extent additional effects must be introduced for a realistic understanding of many-particle coupling schemes. Considerable insight into this problem has been attained with help of a two-dimensional model. (S. Moszkowski)

Quantum mechanical corrections to the cranking model value of the nuclear moment of inertia are being investigated. It appears that such corrections may be quite appreciable, especially in light nuclei. (T. Sasakawa).

4) Optical Model and Scattering Theory

Inelastic scattering of medium-energy nucleons from various atomic nuclei is being investigated using the distorted-wave Born approximation. J. Templin is using a partial-wave expansion of the distorted, optical-model wave functions in order to calculate the differential cross section and polarization of the inelastically-scattered nucleons. Comparison has been made with experiment and the results are being prepared for publication. T. Menne has used the idea of McCarthy and Pursey to express the distorted wave function in a simple, analytical form. A check against experiment has been made and good results for the differential cross section were obtained except in the forward direction. A preliminary report of these investigations has been submitted to Nuclear Physics.

B. Superconductivity

Flux quantization in superconductors was shown to follow from fundamental principles of quantum mechanics and the electron-electron correlations proposed in the Bardeen, Schrieffer, and Cooper theory of superconductivity. This work showed that the current carrying states in multiply-connected superconductors were thermodynamically stable. (N. Byers in collaboration with C.N. Yang.).

A derivation of the Meissner effect based on the same principles was obtained. The derivation yields in first approximation the London value for the depth to which a magnetic field penetrates into a superconductor. It is now being carried out in a higher approximation to obtain corrections to this value. (N. Byers).

C. Field Theory and Elementary Particles

1) General Covariance and the Elementary Interactions

The investigation of generally covariant theories with gauge groups is being continued. There is in press (Annals of Physics) a paper on the strong couplings and in manuscript a discussion of the weak couplings. (R. Finkelstein and W. Ramsay).

2) Representations of Lie Groups in Elementary Particle Physics

Work on the representations of Lie groups is being continued. The beginning of this work is being published in the January issue of Reviews of Modern Physics. (C. Fronsdal in collaboration with J. Dreitlein of Stanford Univ.)

3) Vertex Function

The properties of the vertex functions in axiomatic field theory are being studied. An attempt is being made to extend results obtained by others in the case of massless particles, to the more general case of particles with mass. (C. Fronsdal and D. Hall)

4) Parametric Dispersion Relations

The parametric dispersion relations (conjectured by Nishijima on the basis of perturbation theory) were shown to exist for at least the special case of decay processes, and related parametric relations have been proven for the more interesting cases of scattering and production. (H. Fried and D. Pursey).

5) Regge Poles

The relativistic generalization of the analysis of potential scattering by Regge is under investigation. (N. Byers).

6) Approximations to Unitarity

An independent investigation of functional techniques was begun for the purpose of formulating approximations to unitarity. (H. Fried).

7) Model Field Theories

(iii) The structure of the determinantal function $D(E) = \det\left(\frac{E - H}{E - H_o}\right)$ is being sought in order to understand the validity of Levinsin's theorem for theories with multiple channels or production amplitudes. (Norton)

8) Production Amplitudes

An attempt is being made to construct a theory of production amplitudes, in particular π production in π-N scattering. The basis of this work is an approximate generalized Mandelstam representation, based on a Cini-Fubini type of approximation. (Fronsdal, Norton, and Mahanthappa).

9) Multiple Production of Bosons

Some progress has been made on these problems with the use of techniques developed by Schwinger. Three papers are in press (two in J. Math. Phys. and the third in Phys. Rev.). (K. T. Mahanthappa).

10) Weak Interactions

a) The cross-section for the resonant production of very high energy electrons by neutrons was calculated on the assumption of an intermediate boson. A previous calculation was in error. (N. Byers).

b) A calculation by methods of dispersion theory has been performed in an attempt to correlate the rate of decay $\Lambda \rightarrow p + e + \bar{\gamma}$ with the rates of the two other decay processes $K \rightarrow \mu + \nu$ and $K \rightarrow \pi + e + \bar{\gamma}$. (Norton).

c) A calculation, similar in procedure to that above, is at present in progress to obtain the rate $K' \rightarrow \mu^{+} + e^{+} + e^{-}$. (Norton).