NUCLEAR STRUCTURE AT HIGH SPIN, EXCITATION, AND MOMENTUM TRANSFER

EDITOR: HERMANN NANN

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NUCLEAR STRUCTURE AT HIGH SPIN, EXCITATION, AND MOMENTUM TRANSFER

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PREFACE

As it is now tradition, the fifth annual fall workshop organized by the Indiana University Cyclotron Facility was held at McCormick's Creek State Park. Again, the pastoral setting of the park at the peak of Indiana's beautiful fall colors provided the backdrop for informal discussions and exchange of results and ideas.

The theme of the workshop was "Nuclear Structure at High Spin, Excitation, and Momentum Transfer". The speakers covered an extensive array of topics at the forefront of current research. Experimental research into nuclear structure exploiting different probes and reactions for one common purpose (implied in the workshop title) were discussed. A range of theoretical approaches to nuclear structure were presented. The advancements in the field are clearly being driven by new experimental facilities and large-scale computing techniques.

The scientific program of the workshop was structured into six sessions, each devoted to a particular topic. At the end of each session a critical examination of the presentations was given by expert reviewers. This modus operandi contributed much to a lively discussion.

The workshop was clearly successful in bringing the electromagnetic and hadronic interaction physics and the related communities together. There is vigorous activity going on in both areas, and increasingly, inter-probe comparisons are being undertaken to extract complementary information on nuclear structure.

Among the many people who have contributed their time and effort to the organization of the workshop I would like to specially thank Diana McGovern for her central role in dealing with the nitty-gritty of the workshop arrangements. From the early planning stages, Chuck Foster, Laurie Hicks, Phil Thompson, Becky Westerfield, and Bob Woodley not only dedicated a sizeable fraction of their time to this workshop, but their experience from earlier workshops proved invaluable. I greatly appreciate their effort and commend them for their enthusiasm. I also wish to thank Kent Berglund for the photographs that grace these proceedings. The help of T. Throwe and the graduate students J. Adams, S. Aziz, V. Cupps, M. Fatyga, W. Fox, J. Gering, J. Goodwin, E. Korkmaz, D. Low, J. Miranda, K. Pitts, B. Raue, and J. Templon for driving people to and from the airports and for taping the talks and discussions of the workshop is greatly appreciated.

Thanks are also due to the Harshaw-Filtrol Corporation for its financial contribution toward the expenses of the social functions.

Finally, I want to thank the speakers, reviewers, session chairmen and all participants for their active role that made the workshop worth the effort.

Bloomington, Indiana
January, 1986

Hermann Nann

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SESSION A

NUCLEAR STRUCTURE SEEN BY MEDIUM ENERGY PROBES

RELATIVISTIC EFFECTS IN NUCLEAR PHYSICS

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ABSTRACT

Relativistic corrections to the nonrelativistic nuclear many-body problem are treated in perturbation theory, beginning from a zero-order wave function in which nucleons are in positive energy states in a plane-wave representation. Corrections arise from virtual pairs. Two important relativistic effects arise: (1) A repulsive term in the energy per particle $(\delta\bar{\varepsilon})_{rel} = 2.4(\rho/\rho_o)^{8/3}$ MeV, where ρ_o is nuclear matter density, comes from the virtual pair terms. This term can equivalently be viewed as coming from a density-dependent correction to the mass of the exchanged scalar boson. (2) The nucleon-nucleon spin-orbit interaction is modified. Effectively, the nucleon mass which enters into this interaction is changed locally by scalar fields which connect to virtual pair states.

When treated consistently, relativistic effects represent small corrections to the nonrelativistic many-body problem, and can easily be grafted on to the latter. In this way one can exploit the nonrelativistic many-body calculations, which have been carried out with much more detailed and sophisticated treatment of correlations than in the relativistic formulation.

In high-energy reactions, which are treated only briefly here, the modification of the spin-orbit term has important consequences.

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INTRODUCTION

Considerable effort is presently being expended to derive an effective meson theory from QCD. The nucleon is then obtained as a soliton solution in this (nonlinear) meson theory. From the effective Lagrangians coupling mesons and nucleons, one constructs a field theory for the many-body system. This relativistic field theory is a necessary link between the effective Lagrangian and the highly successful nonrelativistic Fermi liquid theory which is used to describe nuclear structure. In this talk, I wish to discuss this link and what we have learned from relativistic field theory, in particular, where relativity adds new aspects to the description of nuclear structure.

Two excellent and extensive reviews on the role of relativity in nuclear physics are appearing. The first one, by Serot and Walecka[1] summarize efforts in making a relativistic Hartree theory, essentially a mean field theory, which have gone on over many years. The authors call this theory "Quantum Hadrodynamics." The second one, a book by Celenza and Shakin on relativistic nuclear physics, to be published by World Scientific Press, reviews[2] the developments in giving a theoretical foundation to the highly successful Dirac phenomenology begun chiefly by Bunny Clark[3] and collaborators at Ohio State.

Last winter a workshop on Dirac phenomenology was held in Los Alamos. A senior-diplomat style critique by John Negele[4] will soon appear in Comments.

Because of considerable success in the scattering field, Dirac phenomenology and relativistic theories are now being applied in nuclear structure physics, often in a haphazard fashion, disregarding what we know about nuclear structure. As an outsider to the above developments, but with some credentials for having participated in the formulation of the relativistic many-body theory in atomic physics, I would like to take stock of the relativistic developments. Most of the work reported in the following was done together with Wolfram Weise. We plan to publish a review later.

2. Relativistic Mean Field Theory

Relativistic mean field theory seems to be the natural generalization of Hartree-Fock theory to include relativity. Most of the past work has been carried out in Hartree theory, and I shall defer comments on the Fock part.

One must be careful in generalizing nonrelativistic many-body theory to a relativistic one. As Brown and Ravenhall pointed out[5], and this point has been developed more recently by Sucher[6], one can easily get into trouble with a relativistic many-body wave function. Let me illustrate: Suppose one has an A-particle product wave function of Hartree type, as often used. This wave function is generally written down, without explicitly expressing the knowledge that negative-energy nucleon states are filled. Thus, there exist an infinite number of other A-particle states of identical energy, in which two of the particles have interacted, one going to a positive-energy continuum state and the other to a negative-energy state. Consequently, strictly speaking, one cannot write down a localized A-particle state, because it will exist in a continuum of degenerate delocalized states. Through processes like autoionization, the localized state will dissolve, spreading over all space.

In some sense, we have erected a straw man, which we will now proceed to knock down. But in a deeper sense, one sees that "Quantum Hadrodynamics" can only be a complete theory, if in further extensions to take into account correlations of two-body nature, it is accompanied by projection operators specifying that negative-energy states are full; i.e., it must go over towards a real field theory. (In field-theoretical equations like the Bethe-Salpeter one, there is no trouble with the "Brown-Ravenhall disease" because projection operators correctly define this situation.)