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The contributions to this conference, held in September 1987 at Fontevraud, France, are discussed under three general categories: the nuclear force problem, including the possible effects of quark structure; properties of few-nucleon systems, especially as probes of the nuclear force; and atomic and molecular few-body problems and calculational methods.

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THE TWELFTH EUROPEAN CONFERENCE ON FEW-BODY PHYSICS

Introduction

The Twelfth European Conference on Few-Body Physics was held at the Royal Abbey on Fontevraud in Fontevraud, France, from 30 August through 5 September 1987. About 150 participants discussed some of the most fundamental dynamical problems in the fields of nuclear and atomic physics. Participants were mostly from Western Europe, but, in all, 22 countries were represented from all continents except Australia.

The field of "few-body physics," as defined by the series of international and European conferences using this title, which started in the early 1960's, studies the quantum mechanical properties of simple systems – that is, nuclei, atoms, and molecules (and more recently clusters of quarks) that contain, or can be approximated by, a few "elementary" constituents. (See *ESN* 41-10:582-586[1987] for the most recent, related [few-body astronomy] ONRL coverage.) Both the structure of such systems – i.e., the bound-state properties – and the properties in collisions with like particles are of interest. Many phenomena that occur in more complex systems, i.e., "many-body systems," show up first in these simple systems. For example, the ionization of a hydrogen atom induced by a colliding electron is a "three-body" problem from which one could hope to learn about ionization of more complex atoms. Reactive and dissociative processes also occur in three-body systems, and their understanding can help in comprehending chemical and nuclear reactions in general.

The field of few-body physics is interdisciplinary, with particle, nuclear, atomic, and molecular physics, and chemistry being represented. The emphasis is on theory, but experimental work is also crucial, especially now in the "intermediate energy" nuclear physics area. In addition to understanding the basic physics of few-body nuclear and atomic systems, the development of calculational methods is an important part of this field. Calculational precision standards are high because the investigator desires to understand in detail the physics of these systems without residual error due to computation. Despite the fact that he is concerned usually with systems of only three or four constituents, the quantum mechanical calculations are extremely challenging. For example, to calculate the wave function of the tritium nucleus (triton) to, say, 1-percent error, requires 10-20 hours CPU time on a supercomputer.

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Overwhelmingly, nuclear physics problems, especially those concerning the nature of the nuclear force, have dominated the conferences in the field, and this was so at Fontevraud. However, the atomic and molecular physicists, who gave about 25 percent of the talks, had much to share with the nuclear people, and most of this had to do with the mutual interest in calculational methods. One particular class of calculational approaches, the so-called "hyperspherical" methods, found application ranging from the quark structure of nucleons to low-energy chemical reactions.

I have categorized the contributions to the conference into three fields: (1) the nuclear force problem, including the possible effects of quark structure; (2) properties of few-nucleon systems, especially as probes of the nuclear force; and (3) atomic and molecular few-body problems and calculational methods. I will now review the significant contributions in each of these fields presented at the conference.

Nuclear Force Problem

Unlike the field of atomic physics, where the basic underlying force between particles is governed by Coulomb's law, the force law between nucleons (i.e., neutrons and protons) is not completely known. The longest range part of the two-body force (i.e., the force between pairs) is well-fixed from meson-field theory and is governed by the exchange of mesons, much as the electromagnetic force is governed by the exchange of photons (i.e., the Coulomb force). Heavier mesons can also be exchanged, like ρ, ω, etc., and these can account for the strong attractive potential of ~ 100 MeV at intermediate distances (1 to 2 fm – i.e., 1 to 2×10^{-13} cm) and very strong repulsive potential at distances of less than 1 fm. The potentials constructed in this manner are called "one boson-exchange potentials" (OBEP). Since not all of the meson masses and coupling constants, which are the parameters of this theory, are fixed from particle-physics experiments, and also since fictional mesons are usually introduced to fit the two-body nucleon-nucleon scattering data, these potentials are really semi-phenomenological in nature. Over the years, however, most workers will agree that the OBEP approach gives a very efficient approach in representing at least the low-to-intermediate energy nucleon-nucleon data in terms of a potential.

Another approach to the nuclear force problem gaining in popularity is to take the view that quantum

chromodynamics (QCD) provides the fundamental theory for the strong interaction of hadrons. Under this philosophy the dynamics between nucleons, which are entities consisting of triad combinations of quarks and antiquarks, can be understood in terms of the quark structure of the nucleons themselves and the interquark interaction, which is governed by "gluon exchange." The meson-exchange processes naturally come out of this picture as the mesons are merely ground or excited states of quark-antiquark pairs. Also, a strong short- range repulsion occurs between nucleons mainly because of the Pauli exclusion principle acting between the constituent fermion quarks.

Whatever approach one takes, many uncertainties and ambiguities exist. In the quark picture, one must extrapolate results obtained from QCD in the high-energy pertubative regime (many GeV or TeV) to a lower energy regime ($\lesssim$1 GeV) where pertubative QCD is definitely not applicable. Furthermore, the confining force between quarks (no free quarks have been found) is crucial, but as of the present this lacks a clear theoretical explanation, thus necessitating somewhat empirical models (e.g., "bag" models). Finally, no completely relativistic theory exists of the quark, meson, or nucleon dynamics (except the exact solution of the Bethe-Salpeter equation, which is, for the foreseeable future, computationally impossible). Relativity is clearly non-negligible in the energy regimes of interest – the many MeV or GeV regions. As a result of all the uncertainties, a quantity as simple as the triton binding energy, experimentally measured at 8.48 MeV, is theoretically uncertain by $\pm$10 to $\pm$15 percent depending on the force model.

At Fontevraud, most of the contributions concerning the nuclear force employed the "traditional" approach – i.e., the meson-theoretic approach. There were, however, many talks in which quark signatures were searched for either in theoretical calculations or experimental measurements. Furthermore, several contributions dealt with interquark dynamics or quark structure of nucleons and mesons themselves, thus defining "few-body" problems at a deeper level.

K. Holinde (University of Jülich, West Germany) presented the results of an effort by himself and collaborators (mostly at the University of Bonn, West Germany) to design a nucleon-nucleon potential scrupulously from meson-field theory. One- and two-meson exchange processes, but not fictional mesons, are taken into account in the design of the potential, as well as the relativistic momentum space form of the interaction. Momentum form factors are used in describing the nucleon-meson coupling constants, which takes into account the composite nature of the nucleons and mesons. In theory, the form factors can provide a link to the quark structure, but in practice here, as in other meson-theoretic potentials, they are treated as free parameters to fit the experimental nucleon-nucleon data.

To me, this potential, called the "Bonn potential," seems to be the most theoretically pure of the OBE class of potentials. Nevertheless, the Bonn potential generated a good deal of controversy at this conference. First of all the authors never carry out a detailed chi-square analysis of their fit to the nucleon-nucleon (N-N) scattering data (they "eyeball" it), so it is difficult to compare its quality to other models (it is probably worse). Also this two-body potential alone gives the correct triton binding energy of about 8.5 MeV. Most other OBE models give 7.4 to 7.8 MeV, attributing the difference with experiment to "three-body" forces, which are surely present. Presumably, the three-body forces would ruin the result for the triton binding energy predicted by the Bonn potential.

As the wealth of intermediate-energy (i.e., energies in the 400- to 1000-MeV range) N-N data grows, models of the N-N interaction that take into account pion production, and other processes such as $p + p \rightarrow \pi^+ + d$, etc., become necessary. Professor A. Rinat (Weizmann Institute of Science, Rehovot, Israel) showed how a coupled-channel approach – i.e., allowing for transitions between the two-nucleon (N-N) configuration, and the nucleon-delta (N-Δ) configuration (is a N-π resonance often viewed as an excited nucleon) based on separable N-π interactions – leads to satisfactory descriptions of N-N data above π production threshold. He also emphatically argued for the presence of dibaryon resonances in this data – a controversial issue over the past 10 years.

P. Sauer (University of Hannover, West Germany) presented results of a model based on the field-theoretic treatment of couplings between two-body configurations containing nucleons, pions, and deltas for the processes $NN \rightarrow NN$, $NN \rightarrow NN\pi$, $NN \rightarrow \pi d$, $\pi d \rightarrow \pi d$ above pion production threshold. He achieved good fits to the total pion productions cross section, and cross sections for $p + p \rightarrow \pi + d$ and $\pi + d \rightarrow \pi + d$ up to 578 MeV. That such a simple model could fit this amount of data is impressive, but these systems were used pretty much as a calibration for some of the free parameters of the theory. The main use of Sauer's approach would be for more complex systems like $p + d \rightarrow \pi + p + p$, $p + d \pi^+ + {}^3H$, etc.

In an alternate, but related approach to the N-N problem above pion threshold, L. Mathelitsch (University of Graz, Austria) presented a three-body picture of the π-π-N (or N-N-π) system that takes into account relativistic kinematics and eliminates some spurious states of earlier attempts. This work gave an alternate explanation of the dibaryon resonances in the N-N data: the behavior of the phase shifts results from the threshold behavior corresponding to the opening of inelastic channels.

While the detailed theories of Rinat, Sauer, and Mathelitsch differed, as did their conclusions concerning the dibaryon resonances, those theories did illustrate the adequacy of the "traditional" approach at intermediate energies and that quarks did not have to be specifically taken into account.

One issue of major importance over the past 20 years has been the role of three- or many-nucleon forces – i.e., forces not directly attributable to the forces present in a free two-nucleon system. M. Robilotta (University of São Paulo, Brazil) presented a review talk outlining the construction of three-body nuclear forces over the years. As in the two-nucleon force problem, these forces come explicitly out of a meson field theory formulation, and perhaps at a deeper level, out of the quark structure of nucleons (and mesons). Professor Robilotta described how three-nucleon forces come out of the meson theory formulation, and the extrapolations needed to relate the theoretical parameters to experimentally measurable quantities of the N-N and π-N systems. A call here was sounded for consistency. Most of the parameters and form factors used to calculate the three-body force are also involved in formulating the two-body force. The standard procedure now is to use group A's three-body force with group B's two-body force in a calculation, say, of the triton binding energy. What is needed is to construct both two- and three-body forces from a unified theory, such as that of the Bonn potential, and then apply it to the calculation of nuclear properties. This would prevent erroneous conclusions from being drawn on the role of the two- and three-nucleon forces. Several works in this conference reported on specific results obtained from including three-body forces in nuclear calculations. (Some of these I will mention in the next section.) To my knowledge, however, no set of consistent calculations exists.

Finally, I will comment on several talks devoted to an even more fundamental problem than the nuclear force, and this has to do with few-body problems of interquark dynamics. Much less is known about quark interactions than even those between nucleons. Quark masses are not precisely determined. While one-particle (gluon)-exchange is believed to be important, the quark-confining force has little theoretical guidance, at least up to now. Y.Simonov (I.T.E.P., Moscow, USSR) and J.Namyslowski (University of Warsaw, Poland) indicated how linear confinement forces arise out of properties of then QCD vacuum, once one takes into account relativistic kinematics and also allows, according to Namyslowski, a "running" quark mass – i.e., a quark mass that varies with momentum. Simonov also reported on a series of calculations of the masses of one-quark (meson) and three-quark (baryon) systems, using one-gluon exchange and linear confining forces, which were in good agreement with experiment. M.Giannini (University of Genoa, Italy) explored the possibility of three-quark forces in baryons.

Properties of Few-Nucleon Systems

Since many force models exist with the same or similar quality in explaining two-nucleon data, the predicted properties of more complicated properties of few-nucleon systems are necessary to probe the differences between models.

The main few-nucleon systems used for these purposes are the deuteron (d, or ^{2}H), the triton (t, or ^{3}H), and the α particle (α, or ^{4}He). Both the static properties (e.g., binding energies, magnetic moments, charge radii, etc.) and nonstatic properties (e.g., cross sections from elastic or inelastic electron scattering, or scattering of nucleons, deuterons, etc.) may yield valuable information about the nuclear force. While the static properties of the deuteron, particularly the binding energy and quadrupole moment, are usually fit by force models, the nonstatic properties – e.g., elastic and inelastic electron scattering form factors – can be very valuable probes. Unfortunately, there were not many new results reported at Fontevraud on nonstatic deuteron properties, but there was much reported on ^{3}H, ^{3}He, and ^{4}He.

One reason these light nuclei are such important probes is that in many cases the properties are almost exactly calculable given a nuclear force model. This is most true in calculations of the triton wave function, but calculations of the α particle also are now approaching a computational error of only a few percent. This is not to minimize the huge amount of computation needed even to calculate the triton to, say, 1 percent error.

The main question one wants to answer is: which properties of light nuclei help pin down the nuclear force characteristics? The answer is important in either choosing the "correct" model or to design experiments which can help answer this. Also, considerable effort is being expended to perform experiments in which meson or quark degrees of freedom will explicitly show up.

J. Friar (Los Alamos Laboratory, New Mexico) gave a fairly extensive review on triton and ^{3}He calculations and their dependence on the inputted nuclear force. The triton and ^{3}He wave functions are now calculable to better than 1 percent in accuracy (for a given force model), thanks to the considerable effort put forth by the Los Alamos/University of Iowa collaboration in which Dr. Friar is involved. Other groups, with different calculational procedures, are reaching similar accuracy, and certain trends are now evident. One is that most standard nuclear force models, using the OBEP procedure, underbind the triton by about 10 percent. (The one exception is the Bonn potential.) If one adds a realistic three-body force, then the triton becomes overbound by up to 5 percent, but this figure really depends sensitively on whose three-body force one uses. Dr. Friar emphasized the earlier call for a consistent treatment of two- and three-body forces. He also discussed the idea of "scaling" in triton properties – that is, if one plots various predicted static and nonstatic properties of ^{3}H or ^{3}He versus the triton binding energy, the results usually fall on a narrow linear band, regardless of the nuclear force model or three-body force used. Furthermore, this band usually includes the experimental point. The implication is that whatever the

defect is that prevents one from getting the correct triton binding energy, if this defect is cured, a whole host of triton and ^{3}He properties will also fall into line. The one exception is the charge density of ^{3}He at the center of the nucleus. The experimental point is rather greatly depressed whereas any force model predicts a fairly gentle peak. This shows up in a large second maximum in the experimentally measured electron-scattering charge form factor of ^{3}He, which has never been satisfactorily explained by theory. Is this an explicit quark effect? No one knows.

Y.Akaishi (University of Hokkaido, Japan) presented the results of calculations for ^{4}He wave functions. The inaccuracies of such calculations are now evidentially down to a few percent, which is a significant computational achievement. Historically, the discrepancies between theory and experiment in ^{4}He have mirrored those in the triton and ^{3}He – predictions of the binding energy are too low and those of the central charge density are too high. This is still true. Akaishi, however, pointed out previously unused tools in distinguishing nuclear force models, and that those are the properties of an excited α particle. On the basis of his calculations, he suggested that the excitation energy is a sensitive probe of the three-body force. He also outlined how momentum distributions, important for the analysis of inelastic electron scattering experiments, could be obtained from his calculational procedure (the so-called "ATMS" method). The actual momentum distributions were referred to by speakers analyzing such processes, which I will now describe.

Electron scattering experiments on these light nuclei, whether they be elastic or inelastic, provide reliable probes of nuclear structure because, for the most part, the interaction between the electrons and nucleons is known – Coulomb's and Biot-Savart's laws. In elastic scattering experiments, charge and magnetic form factors are extracted, while momentum distributions come into play in inelastic scattering or electrodisintegration of the nucleus.

Four talks were given on the subject of electron inelastic scattering and electrodisintegration, and related topics. First, J.Mathiot (European High-Energy Research Center [CERN], Geneva, Switzerland) reviewed the theory of "meson exchange currents." These are modifications to the electromagnetic interaction, coming from relativistic field theory, when both electromagnetic and strong (e.g., nuclear) interactions are present. These involve the so-called "meson degrees of freedom," much as the two- and three-nucleon forces do, with the same uncertainties attendant. In addition to reviewing the theory of the exchange currents, Mathiot denoted their influence on the elastic electron scattering form factors of ^{2}H, ^{3}H, and ^{3}He (as did another speaker, J. Martino of Centre d'Etude d'Energie Nucléaire [CEN], Saclay, France). Exchange currents are very important in understanding fairly high energy elastic electron-scattering experiments on ^{2}H, ^{3}H, ^{3}He, but do not nearly begin to explain the large second maximum in ^{3}He. The other speakers included the effect of exchange currents in their talks on inelastic electron scattering.

P. De Witt Huberts (the Netherland's National Institute for Nuclear Physics and High Energy [NIKHEF]) and J. Laget (CEN Saclay) dealt with the question of correlations, three-body forces, and possible quark effect showing up e,e'p reactions on ^{3}He and ^{4}He (i.e., electrodisintegration). DeWitt Huberts mainly analyzed experimental results and emphasized momentum distributions, while Laget emphasized calculations and theory. Their conclusions were similar. Conventional models (i.e., two-body forces plus meson exchange currents) explain the data reasonably well, at least up to momentum transfer of about 600 MeV/c. No quark effects are evident. Either higher energy experiments or more complex experiments (like $\pi^+ + {}^3\text{He} \rightarrow p + p + p$) would be needed to distinguish different models or quark signatures. Suggestions were given for the types of experiments needed, mainly for the next generation of electron accelerators at CEBAF (planned for Newport News, Virginia), Saclay, and NIKEF (Amsterdam).

Near the end of the conference, C. Ciofi Degli Atti (Physics Laboratory, Rome, Italy) used an alternate mathematical object – the spectral function – to analyze similar processes as discussed by the above speakers. However, he presented an important additional feature. Deep inelastic electron scattering experiments (i.e., inelastic scattering with very high energy exchange between the electron and nucleus) gave spectral functions, consistent with the so-called "EMC effect" – i.e., a situation where a nucleon swells in size when it is inside a nucleus as compared to its size when it is alone. The EMC effect is currently a very controversial issue in nuclear physics, with some claiming this is a quark effect and others claiming it can be explained by conventional models or relativity.

While the current experimental data on the sub-GeV range does not evidentially probe quark structure, P.Mulders (NIKHEF) argued, on theoretical grounds, that quark structure of nucleons cannot be neglected and will eventually show up. His arguments mainly relied on the fermion nature of quarks and the resultant generation of exchange forces (due to the Pauli Exclusion Principle). However, in electron-scattering processes, the overall effect is reproduced by conventional exchange current theory. He suggested, though, that in deep inelastic electron scattering, the Fermi smearing of quarks could explain the EMC effect.

In addition to probing two-, three-, or four-nucleon systems with electrons, one could use collisions between nucleons and these systems as well. The disadvantage is that the nucleon/nucleus interaction is uncertain. Also, accurate collision calculations are much harder to perform than bound state calculations. On the other hand,

there could be increased sensitivity to the nuclear interaction, especially over certain "hot spots" of phase space.

W.Plessas (University of Graz, Austria) presented calculations of n-d scattering observables, at low energy (< 100 MeV), for various nuclear force models. His calculations employed "separable" approximations – i.e., the matrix elements of the potential are approximated by a sum of a few factorable terms. Scattering cross sections were found to be very insensitive to the force model, but spin transfer coefficients, measured in polarization experiments, were much more sensitive. H. Witala (University of Bochum, West Germany) came to similar conclusions from calculations of the reaction $n + d \rightarrow n + n + p$ in the same energy range.

Calculational Methods and Atomic and Molecular Few-Body Physics

This conference was dominated by nuclear physicists, and this is traditional in the few-body field in Europe. In the US there is more participation by atomic physicists and theoretical chemists. In fact, in an APS symposium on the subject held at Crystal City, Virginia, last April and also at the Gordon Conference held in Wolfeboro, New Hampshire, in August, about 50 percent of the talks were on few-body problems in atomic physics and chemistry. Nevertheless, in the present conference there was at least one talk in the atomic and molecular field at almost every plenary session, and these accounted for about 25 percent of the talks (but a much lower percentage attendance by physicists in these fields).

There is no doubt that few-body problems play a very fundamental role in atomic and molecular physics; you cannot get any more basic than the hydrogen atom, for example. The main link between nuclear physicists, atomic physicists, and theoretical chemists in this field is that all are interested in calculating structure properties (of nuclei, atoms, and molecules) and scattering and reactions between these entities. Nuclear physicists in this field have emphasized momentum-space integral equation methods because it is precisely the momentum-dependent part of the nuclear force – coming from relativity, meson theory, or quarks – that is of so much interest. On the other hand, the forces in atomic physics and chemistry, whether it is the Coulomb interaction or some potential surface cooked up by your local friendly quantum chemist, are local (i.e., depend only on the positions of the particles), so r-space methods have dominated. Momentum-space calculations involve the manipulation of huge, nonbanded matrices. However, thanks to the work of Faddeev (a Russian) in the early 1960's, and others, it is quite straightforward to apply these methods to the bound state, scattering, and reactions, including dissociation. The r-space methods typically involve coupled differential equations where the matrices involved have a banded structure, which is advantageous numerically. However, boundary conditions for quantal reactive scattering and dissociation are notoriously difficult to handle, and this is virtually an unsolved problem. Clearly, chemists should listen to the nuclear physicists in problems involving reactions or dissociation. Conversely, "traditional" nuclear physicists i.e., those not interested in exotic meson or quark effects (which are still satisfactory in understanding 90 percent of nuclear physics), should learn how to apply some of the very efficient r-space techniques developed by chemists in certain problems.

One class of techniques employed in all of the three fields mentioned is that involving hyperspherical coordinates. The technique of hyperspherical coordinates is a many-dimensional extension of the spherical coordinates used in three-dimensional problems. The analogue to spherical harmonics – hyperspherical harmonics – also exists and was the subject of several talks at this conference as well as at a preconference workshop. Hyperspherical coordinate methods, usually used in the so-called hyperradial "adiabatic" approximation, have led to important advances in understanding atomic spectra for doubly excited states. This method also has shown some promise for efficiently solving reactive scattering problems. Hyperspherical harmonic methods, usually regarded with fear and distrust by atomic physicists, have been examined mostly in nuclear physics contexts, but several talks at this conference, notably those by Simonov and Giannini, successfully applied these methods to quark problems.

A. Rau (Louisiana State University and A&M, Baton Rouge) reviewed the information obtained from hyperspherical methods applied to doubly excited states of atoms, notably He**. Thanks to much development of the adiabatic method by U.Fano and J.Macek, and others, a whole new classification scheme has emerged for doubly excited helium (and H^-) when the usual independent-particle model fails. Rau indicated the reasons for the success of this approach, and the circumstances when it might break down, namely, for doubly excited states near the double ionization threshold. In this case he also indicated that an alternative approach using hyperspherical coordinates, namely, Wannier Theory, very well describes these states. Furthermore, this approach predicts the threshold energy power-law-dependence of the double ionization cross section, $\delta \sim E^{1.127}$, in agreement with experiment, but not with other conventional atomic physics techniques. This has generated some controversy in the atomic physics community.

Two closely related talks were presented by J. Lindenberg (Aarhus University, Denmark) and J. Launay (Meudon Observatory, France) on the use of hyperspherical coordinate methods, based on the adiabatic approximation, in quantum reactive scattering problems like $H + H^2 \rightarrow H^2 + H$, $H + F^2 \rightarrow HF + F$, $H + D2 \rightarrow HD + D$, etc. Many theoretical chemists have attempted to solve these problems, using different coor-

dinate systems, but have been generally thwarted in the realistic three- dimensional regime because of the proliferation of coupled equations in conjunction with severe boundary condition matching problems. (It is evident here that theory lags experiment because experimental molecular beam studies of "simple" reactive processes won the 1986 Chemistry Nobel Prize for Lee, Polanyi, and Herschbach.) Evidentially, use of hyperspherical coordinates eliminates most of the matching problem, and also is more efficient in terms of the number of basis functions needed than other methods. But this has been tested only in benchmark one-dimensional problems. In three dimensions a new problem arises – the problem of "near avoided crossings" of adiabatic potential energy curves. This leads to near singular behavior of matrix elements needed in this calculation, and is more severe the more basis are the states one uses. So even with the hyperspherical method, a solution to the reactive scattering problem seems far off. It has occurred to me, however, that in "traditional" three-body nuclear reaction problems, where the number of basis states needed could be quite small (because there is only one two-nucleon bound state as opposed to hundreds or thousands for H_2, HF, HD, etc.), the methods described by Lindenberg and Launay could be much more efficient than current methods.

In another set of contributions, the matter of successfully treating two-body correlations – that is, the tendency of two particles within a many-body system (i.e., nucleus, atom, or molecule) to repel or attract each other – in conjunction with hyperspherical harmonic methods was discussed. The inefficient treatment of correlations is the reason the hyperspherical harmonic method is held in such disdain in the atomic physics community as well as by some nuclear physicists. M. Haftel (Naval Research Laboratory, Washington, DC), in collaboration with V.Mandelzweig (the Hebrew University, Jerusalem, Israel), presented results showing that by including Jastrow correlations functions before expanding wave functions in hyperspherical harmonics, one can obtain extremely accurate wave functions for the helium atom. So a bad method of calculation suddenly becomes a very good one.

Talks by H. Fiedeldey and S. Sophianos (University of South Africa, Pretoria) presented an alternate approach to this problem. By marrying certain ideas from the properties of the hyperspherical harmonic expansion, and also from the Faddeev equation formulation of the three-body problems, they derive (along with the conference co-organizer, M. Fabredela Ripelle) a single two-dimensional integral equation describing bound states for any number of particles. Purportedly, all two-body correlations (but not three-body or more correlations) are accurately included. While solving two-dimensional integral equations is no picnic, and the method is not exact, rather encouraging results were reported for the triton and alpha particle. The precision was very good, at least by nuclear physics standards, and according to its proponents would not seriously degrade for a many-body ($N > 4$) system. While this approach is not seriously competitive with variational procedures for three-body atomic systems, the fact that it does not become much more complicated for a many-body system gives hope that one could use it successfully for heavier nuclei or many-electron atoms.

Conclusions

As a former researcher in the field of few-body nuclear physics (I now concentrate more on molecular collisions), I was left after this conference with the impression that the basic questions raised a decade or more ago about the nuclear force are still unanswered. There are a plethora of force models, and calculations are much more accurate now because one is not afraid to use a supercomputer. Much has been learned about the sensitivities of predictions concerning the triton or alpha particle to various aspects of the nuclear force (three-body forces, meson exchange currents, etc.), and experiments have helped delineate their roles also. Still, one cannot explain, for example, why the properties of a nucleus as simple as ^3H cannot be predicted in agreement with experiment. It does seem, though, that the explicit quark structure of nucleons does not play an important role in any of the low- or intermediate-energy phenomena considered at this conference.

While atomic and molecular few-body problems were definitely a sidelight at this conference, the common interest in hyperspherical coordinate methods, I believe, was indicated and should be encouraged by future conference organizers in this field.