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A topical conference of the American Physical Society on "Correlations of Particles Emitted in Nuclear Reactions" was held in Gatlinburg, Tennessee from 15-17 October. In addition to the APS the conference was sponsored by the Oak Ridge National Laboratory and the Nuclear Structure Subcommittee of the National Science Foundation and the National Research Council.

This was an unusual and fascinating conference. Though the subject appears both esoteric and recondite, almost every facet of nuclear reaction theory was touched upon at some point, with excursions into atomic physics and high-energy physics. The conference was fascinating because of the universality of the subject being discussed and unusual because while most of the participants were experimental physicists the long discussions were mainly about theoretical nuclear physics and fundamental quantum mechanical problems.

The conference might more appropriately have been named "The Three-Body Problem." The three-body problem is the most celebrated of all dynamical problems and has troubled physicists from the earliest days. In a few well-known systems such as the sun, earth, and moon and the helium atom accurate numerical solutions have been obtained by successive approximations. The approximations which make these examples relatively simple cannot be made in the three-body problem of nuclear physics since here the interacting particles have comparable masses and to make things worse they have forces of extreme complexity acting between them since they may often be sufficiently close together that their intrinsic structure becomes important. The hope however is the same: that the nuclear three-body system is capable of description in terms of two-body forces.

The bound three-body systems in nuclear physics, namely the H^3 and He^3 nuclei, have only static properties such as binding energy that can be used to test a theory. The dynamical structure of the system cannot be discovered from its static properties. At this conference three-body systems in excited states were under study. These excited states if they have sufficient energy can decay into three free particles; the kinematics of the decay reflects the internal dynamics of the system so that experiments can be performed which give information about specific dynamical configurations of the system.

C. Zupancic of the J. Stefan Institute in Ljubljana, Jugoslavia opened the conference with an introductory talk which he described as "suitable for first-year graduate students". He said that most of the phenomena under study had analogues in atomic physics where better approximations can be used. He chose as an example the scattering of photons by atoms. For very low energy photons the scattering occurs from the atom as a whole and no structure is revealed (Tyndall effect). For intermediate energy photons the Raman effect occurs: in the initial process the photon is scattered with reduced energy while the atom is left in a long-lived excited state which decays by emission of a second photon. At very high energies the incident photon is scattered from an individual electron in the atom and in a single-stage process both a reduced-energy photon and a recoil electron are emitted (Compton effect).

In nuclear physics the kinematic relationships between the three particles in the final state are more complicated than in the atomic analogues because the particles have comparable masses. It is necessary to find for each scattering event the energies and directions of all the particles emitted. Because energy and momentum conservation have to hold for the interaction as a whole it is only necessary to measure two of the particles; the energy and direction of the third can then be inferred. These energies are measured in the laboratory frame of reference which is rarely the one of interest, so it is necessary to choose frames of reference of likely importance and transform all the relevant momenta and energies to these frames. Which frames of reference are useful depends on the reaction mechanism. If the reaction proceeds by a sequential process by emitting one particle first leaving behind a long-lived state of two particles which later decays, it will be found that the total energy of the latter two particles measured in the rest frame of the center-of-mass of the pair is almost constant, the energy spread reflecting the lifetime of the two-body state via the uncertainty principle. If the reaction proceeds in this fashion well established procedures using the laws of conservation of angular momentum and parity can be used to find the properties of the two-body state. This type of reaction is dominated by the interaction between the two particles which form an almost bound state. In the nuclear analogue of the Compton effect (knockout reactions) the center-of-mass frame of the incident and struck particles is of prime importance. Furthermore the laboratory frame of reference is now significant since whatever remains after the particle is knocked out remains almost at rest in the laboratory. Zupancic stressed that as for the atomic interactions it is possible to choose experimental conditions (bombarding energy or counter angles) such that particular reaction mechanisms predominate and we usually pick situations where the mechanism is dominated by the two-body forces. However, in general several reaction mechanisms can contribute and interference effects will appear to complicate or in some cases assist the interpretation.

P. Swan, of the Rice University, described a theory of sequential decay processes which had been derived by Phillips, Griffy and Biedenharn by modifying the well-known final-state-interaction theory of Watson. The theory enables one, in sequential processes, to derive the decay behavior of the system from the cross-sections for elastic scattering of the two interacting particles, which can be measured in a separate experiment. This approach typifies the purpose of these studies and is essential since even in a sequential process the secondary two-body system may not be in a state of well-defined spin and parity. If such a theory can be proved to work it will be possible to use it in reverse and deduce from the three-body decay what the two-body interactions are. Thus one could deduce the interaction between two neutrons or two pions where scattering experiments are impossible.

G. C. Phillips, of the Rice University, presented a very detailed experimental study of the three-α-particle decay of excited states of C^{12}. A preliminary interpretation of these results was presented by I. Duck, also of the Rice University, who used the theory described by Swan. He startled the audience by emphatically stating his belief that the problem of three α-particles is the most important problem in nuclear physics today. This is true in the sense that the α-particles have no spin and thus, in so far as their internal structure is unimportant, the problem is far simpler both experimentally and theoretically than the more obviously fundamental three-nucleon problem. It is worth noting that it is identical in symmetry to the three-pion problem but much easier to study since the α-particle is stable and α-α scattering parameters may be fed into the calculations.

In the session on knockout reactions, experiments analogous to Compton scattering were described. M. Riou of the Joliot-Curie Laboratory at Orsay, France described a type of experiment of great elegance. A nucleus is bombarded with 150 MeV to 400 MeV protons and events are studied in which two high-energy protons are emitted at angles and energies near to those at which they would appear if the incoming beam had been scattered by free protons. The results are analysed as a two-body collision between the incoming and struck protons. Experimentally it is found that the struck protons have well-defined binding energies in the nucleus, and that these energies vary from nucleus to nucleus in a way which gives strong support to the shell model of nuclei; furthermore it is possible to find from the kinematics what momentum the struck proton originally had in the nucleus. The momentum distributions thus found once more correspond closely to shell-model ideas of nuclear structure. These knockout reactions have been very fruitful but for further progress significant improvements in accelerator design are needed.

I. E. McCarthy of the University of California at Davis showed how these (p,2p) reactions can be analysed in detail with high-speed computers. He said that it is possible not only to find the wave function of the struck protons but to show that the interaction between the incident and struck protons is in fact slightly different from the interaction between two free protons: the proton-proton interaction has to be of shorter range inside the nucleus. This is a suggestion of considerable significance for our understanding of nuclear reactions and it is to be hoped that it will be followed up by other studies. In the same session J. R. Mines of the University of Liverpool, England attempted to show how to describe (d,p) stripping reactions when the final state of the nucleus is unstable. In studying this problem he found it necessary to reexamine the fundamental assumptions of the distorted-wave Born Approximation.

An entire session of the conference was devoted to invited papers mainly of a pedagogical nature on high-energy physics. The speakers were W. Selove of the University of Pennsylvania, R. K. Adair of Yale University and J. D. Jackson of the University of Illinois. The chairman of this session was R. H. Dalitz of the Clarendon Laboratory, Oxford. The speakers outlined the way many particle final states are studied in high-energy physics where the proper description is of great importance since the particles involved are usually unstable and it is only from the many particle reactions that information on two-particle interactions can be obtained.

It is interesting to compare the methods of approach used in high-energy and nuclear physics. The aims are the same but the types of data that can be obtained are quite different, being determined by the very different techniques that have to be used. At high energies the bubble chamber is universally used. This gives an overall picture of the reaction however many particles are emitted. The experimenter has no choice however but to scan all the photographs taken to pick out the few that are of interest. With present methods the scanning and measurement of photographs is very slow and after months of effort several tens of thousands of events may have been measured out of which maybe a hundred or so may be in the kinematic configuration of major interest. An imminent breakthrough in automatic photograph analysis is, fortunately, expected. The nuclear physicist, by contrast, has no direction-sensitive detectors with good energy resolution. He has to make his counters small enough to define the direction precisely. With these small counters he can only study a minute proportion of the possible kinematic configurations needed to study a three-body reaction as a whole. Four- or more-body reactions cannot be studied because the counting-rates become too low but they cannot be excluded and produce an unwelcome background in the energy spectra. Here, too, there is hope: one method applicable for three-body processes was described by E. Norbeck of the University of Iowa who showed results obtained using a new type of solid-state detector which is sensitive to the location at which a particle enters it.

These technical differences lead to different methods of data analysis. The high-energy physicist is forced in most cases to average his data over variables assumed not to be significant in order to obtain statistical accuracy. With the poor statistics it is impossible to test many of the assumptions. The nuclear physicist on the other hand has to pick out only the events he can interpret. There was discussion about whether the averaging procedure does not in some instances produce misleading results due to interference phenomena. This may be a question that can be answered more easily by a specific nuclear physics experiment designed to test it than by the laborious accumulation of sufficient data at high energies to reveal an effect which might at the end be negligible.

The unity of nuclear and high-energy physics was emphasized by the speakers. The different jargons used do, however, seem to hinder communication. For example 'overlap integral' and 'coupling constant' were revealed to be essentially the same, and in a 'surface interaction' one gets 'peripheral production'. The high points in the linguistics struggle was reached in an earlier session when a speaker unwarily spoke of a particle being 'precipitated' out of a system and G. M. Temmer, the chairman, cautioned him to take care 'otherwise the high-energy people will call us all chemists'. The nuclear physicists present were however, delighted to hear that their favorite tools, the optical model and the distorted-wave Born Approximation, are now being used in high-energy physics, while the high-energy physicists were intrigued at the enthusiasm of nuclear physicists for polology.

The final session of the conference was on few-nucleon problems. P. F. Donovan of the Bell Telephone Laboratories described some beautiful work done by a group working with the Brookhaven 60-inch cyclotron. The experimental techniques of this group are a model for all. The events recorded are displayed on a two-dimensional pulse-height analyser with oscilloscope display. The analyser is coupled to a computer which can use any reaction theory to simulate experimental data for direct comparison with experiment on the oscilloscope. The group has lightheartedly called the system PASER: Publication Amplification with Simulated Experimental Results. Donovan presented some real results on a number of reactions. Two of these stand out. In the bombardment of deuterium with deuterons there is a large peak in counting-rate for events in which the target deuteron is broken up and its neutron is left stationary in the laboratory. The shape of this peak was fit very satisfactorily with a Chew-Low dispersion theoretical analysis, probably the first really convincing fit to be obtained by this method. In the bombardments of deuterium by He^3 events were picked out in which the final state contained tritons and protons with low relative energies. The yield showed two peaks which were later shown by W. E. Meyerhof of Stanford University to be consistent with the observed cross-sections for free proton-triton scattering.

The final session was further notable for the presentation by Y. Y. Yam of results obtained by a group led by R. D. Amado at the University of Pennsylvania. This group used a high-speed computer to attack the three-nucleon problem numerically, making significant gains by writing the nucleon-nucleon potential in a convenient form. The calculations, which could not even have been considered a few years ago, gave good fits to the binding energies of H^3 and He^3 and to the n-d and p-d low-energy scattering. This report caused a great deal of excitement and the conference ended on a note of optimism.

The conference proceedings will be published in Reviews of Modern Physics.

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