NUCLEAR STRUCTURE

A report by **L. Grodzins**

THE International Conference on Nuclear Structure held at Queen's University in Kingston, Ontario, began at 8:45 a.m. on August 29th and ended at 12:00 p.m., September 3. The conference was limited in attendance to 400 (the number of seats in the auditorium) and up to (though, naturally, not including) the last day, the hall was full. The sessions, usually four per day, were consecutive, with four to six rapporteurs giving a summary talk in each session. Judging from the results, the rapporteur system works very well. Each rapporteur culled from the 250 submitted abstracts those relating to his subject—in some cases even discussing them—and presented the present status with a stress on recent work. The conference was overwhelming, alternately confusing and enlightening, and very tiring. (A seldom-considered virtue of simultaneous sessions of consuming interest is their built-in excuse for relaxing outside. Nevertheless, the impression carried away and still retained is that this was the most successful conference this reporter has yet attended. It accomplished its task, giving a fairly clear picture of the status of the present understanding of nuclear structure. That such a dynamic and broad subject could be well summarized is a tribute to the organizers of this conference—all but Weisskopf are members of the Chalk River National Laboratory and Queen's University—as well as to the uniformly high level of the talks.

There is little point in discussing in detail the specific papers, even if this were possible. By the time this report is published (or perhaps even submitted for publication) the Conference Report will already have appeared in print, since the organizing committee fully intended to publish the proceedings of the conference in October of 1960.* The warning went out to all rapporteurs that if copies of their talks were not handed in at the meeting, the editors, Bromley and Vogt, would do the writing themselves. Discussions following each session could be edited at the conference, and never again. The warnings were heeded; it was generally recognized that the value of early publication outweighed the importance of style and minute precision. With the need for details obviated, it remains but our task to report the highlights and the informalities.

UNDERSTANDING of nuclear structure has diverged in the past years. Old theories neither die nor fade away, but the old and the new live together in an uneasy coexistence; in some instances (e.g., the collective and independent particle models) the theories once appeared irreconcilable. Recently there have been a number of attempts either to find common ground among these theories or to amalgamate some of the basic ideas of one model with another, e.g., the inclusion of collective effects directly into the shell model theory. It was at this conference that the antagonists by and large affirmed their belief that no one model has universal application and that the fundamental tenets of the different models are not in conflict.

The conference opened with two talks on open problems in nuclear structure. In retrospect this may have been the only mistake the planning committee made. The speakers, Peierls and Wilkinson, should have discussed closed problems. It would have taken them far less time. Wilkinson, who brought along a finite but unbounded number of slides, said that he thought he had 45 hours rather than 45 minutes for his talk—this was in keeping with the abstract bulletin which indicated that the conference would run until September 30th instead of September 3rd. These stimulating talks were but a preview of things to come; no subsequent speaker felt that any problem was closed. Not only is the nuclear force not known but there is little understanding of the role of three-body forces, velocity-dependent forces, or tensor forces in nuclear reactions. There is an ever-broadening but as yet insufficient understanding of the internal structure of the nucleus and very little knowledge of the nuclear surface. In this last connection Wilkinson proffered the heady disclosure that K-meson capture takes place at the outer reaches of the nucleus and that this process may become an important tool for investigating the nuclear surface. With these two talks as a groundwork, the conference was on its way. It was organized so that the material was presented from the general to the specific. Starting with physical foundations of nuclear models

* The *Proceedings of the International Conference on Nuclear Structure* (edited by D. A. Bromley and E. W. Vogt, 990 pp., U. of Toronto Press, $16.75) were published, as planned, in October 1960.

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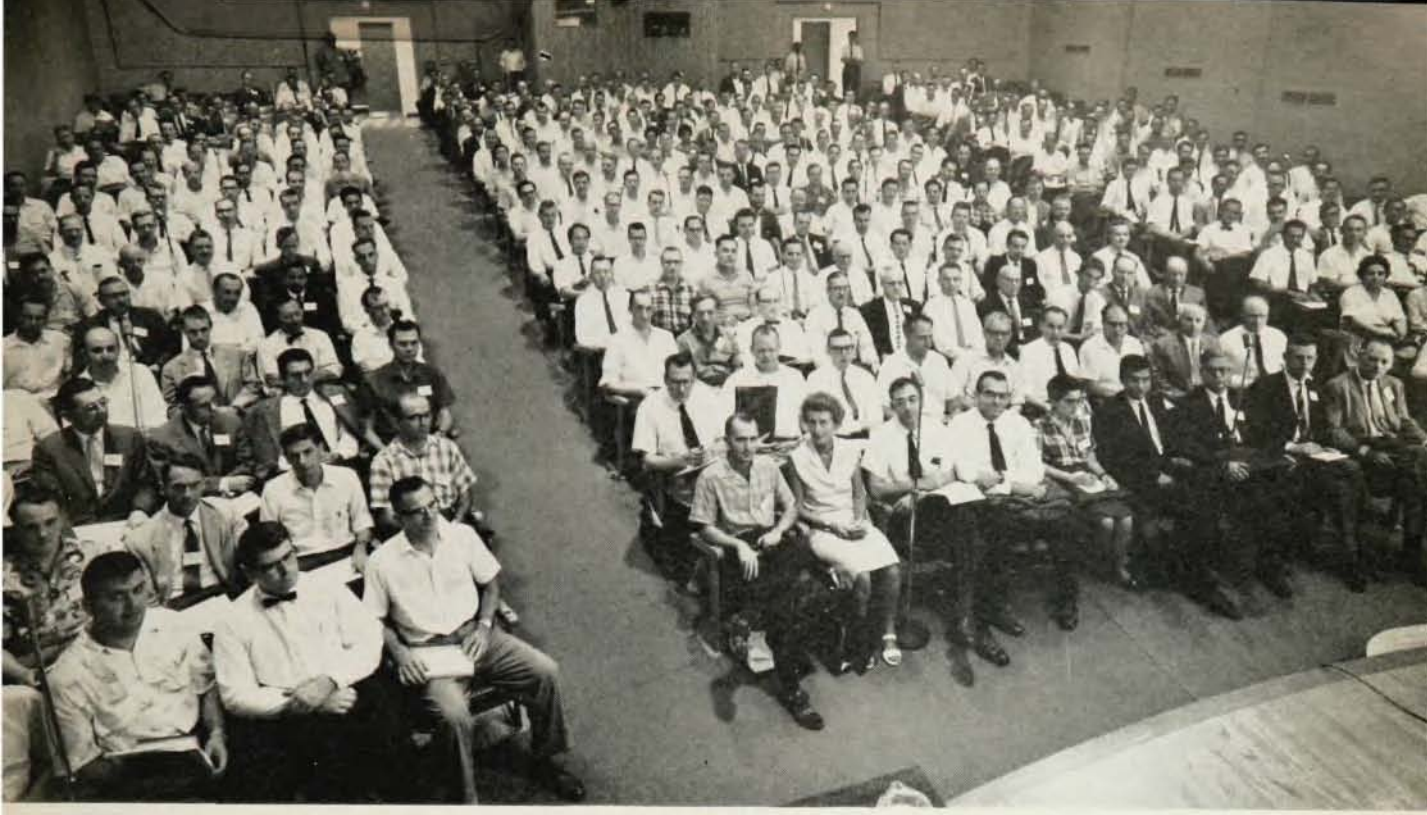

The opening session of the International Conference on Nuclear Structure.

and considerations of infinite and finite matter, it went on to gross properties of nuclear matter, then to nuclear reaction mechanisms, continued with specific properties of individual levels, and, finally, considered the statistical properties of nuclear levels and fission.

Some progress has been made by Brueckner and his collaborators towards calculating properties of finite nuclei, such as the average binding energy per particle, by Hartree-Folk type calculations using two-body interactions as determined by nucleon-nucleon scattering data. The difficulty here seems to be that there is no unique starting point—it was brought out in persistent discussion that there was considerable arbitrariness in the choice of potential used in this calculation—so that the importance of an agreement between the calculation and the experiment is not yet clear. The problem is forbiddingly complex, and this complexity is perhaps best illustrated by the following question and answer which took place during these talks.

Dr. R. E. Peierls, University of Birmingham: "If I understood you correctly, you said that the kind of model one would like to try—the velocity-dependent, nonsingular force which is good enough to apply in the perturbation theory—cannot work because it has too big a binding energy, which would be equivalent to taking the observed reaction matrix from free particles interacting, and putting it into the Hartree-Folk equation for the many-body problem. Did I understand that correctly?"

Dr. K. A. Brueckner, University of California: "You did, and I've probably overstated the situation slightly."

After attaining this high mark, the first day was finished with a discussion of the finite nucleus by De Shalit. He pointed out that nuclear magnetic moment measurements may be used to distinguish between the effects of residual interactions, i.e., configuration mixing, from effective moments arising from the quenching of the free nuclear moment inside nuclear matter. The comparison of the magnetic moments of K^{39} and K^{40} indicates that, in this instance at least, quenching is the dominant factor.

THE following day was largely devoted to discussing the gross properties of matter and their interpretations in terms of the optical model. The optical model works surprisingly well, "explaining" a wealth of data on total, shape elastic, and reaction cross sections. Much emphasis was placed on the interpretation of data in terms of the optical model in which the incoming and outgoing particles are considered from the distorted wave point of view. The speakers admonished that calculations must be carried out in great detail before it is possible to say that the optical model does not explain data in which parameters fluctuate slowly. In particular, the older interpretation of forward and backward scattering maxima as arising from direct interactions and compound nuclear formation, respectively, is certainly not always valid. Direct interactions can yield backward maxima and compound nuclear formation can account for some forward maxima. The overlap region of these two models was not discussed and remains an open problem. In the region in which

The organizing committee and session chairmen were, left to right: E. B. Paul, W. T. Sharp, D. A. Bromley, E. W. Vogt, A. Bohr, V. F. Weisskopf, A. P. Komar, B. H. Flowers, W. B. Lewis, D. R. Inglis, R. E. Peierls, B. B. Kinsey, R. F. Taschek, H. E. Gove, G. A. Bartholomew, R. L. Graham, and L. G. Elliott.

the direct interaction model is generally applicable, there is no important failure, at the present time, of the distorted wave Born approximation. Nevertheless, as Saxon pointed out, none of the parameters are fixed nor are they well understood. All speakers again emphasized the need for much more data on charged and uncharged particle reactions, using polarized and unpolarized beams, and for the necessity of carrying out much more detailed calculations with greater variation of parameters.

A number of significant experiments were reported at the conference. The one which excited the most comment was described by Almquist. In an investigation conducted by Almquist, Bromley, and Kuehner, using the Tandem Van de Graaff accelerator, evidence was found for a quasi-molecule ($C^{12} + C^{12}$) formation. In a series of reactions using C^{12} as bombarding particles, they obtained level structure in the ($C^{12} + C^{12}$) reaction and in no other. Several theories have been postulated to explain this level structure—the level widths being 100–200 kev. The mechanism is not yet understood though there was general agreement that the deformability of the carbon nucleus plays an important role in this quasi-molecular formation.

This may be as good a place as any to insert the note that the Chalk River groups, using the Tandem Van de Graaff, have been among the most productive and stimulating in the field of nuclear reactions, so it was indeed fitting that this conference should have been organized by them.

The next day, Wednesday, a boat excursion was organized and the sessions forsook Queen's University for the Thousand Islands. It was made clear that this was indeed to be regarded as a session—the definition of a session is apparently any gathering in which wives who are not also physicists are excluded. Such wives who came along to the conference had their own excursion to a different part of the Islands. It might be worthwhile to report on an observation made at that time, which could have important application at future meetings. Two boats took the conferees to the Islands, one provided with liquid refreshments, the other with none. This reporter went to the Islands on the second and came back on the first. The experimental fact is that a great deal more physics is discussed when liquid refreshments are provided than when they are not. (A corollary observation based on vast researches by many physicists on many and varied excursions with and without liquid refreshments is that the amount, the intensity, and the depth of physics discussions is little if at all affected by the presence or absence of wives.)

THURSDAY, devoted to properties of individual levels, contained several important contributions. Elliott discussed the similar collective and shell model effects which may be obtained by each of three currently fashionable models. The Nielson calculations, as is well known, can yield single-particle plus collective aspects by considering single-particle orbits in a "cranked" deformed potential. It also may be possible to get such effects by considering a cluster model; that is, the correlations are introduced by resonating groups. Third, Elliott showed that collective effects can arise when an attractive force is introduced in a degenerate oscillator configuration. Mottelson, urged on by Chairman Aage Bohr, vigorously presented their collective theory based on a long-range force responsible for the nuclear deformation away from closed shells and a short-range pairing force which leads to spherical nuclei at closed shells. This talk was particularly stimulating since Mottelson indicated numerous predictions of the level structure phenomena which follow from this model. The fundamentalists, also urged on by Chairman Bohr, waved their hands and decried the hand waving that modelists do to justify their calculations. Yet all seem to be agreed that pairing forces must necessarily be considered in a fundamental attack on the problem of nuclear levels. The degree with which theory can

predict energy levels and transition probabilities was emphasized by a talk by Davidov, who has now enlarged his ellipsoidal model of the nucleus to include vibrations without change of shape. Using this three-parameter theory, he has shown that one can get amazingly good agreement with data from all parts of the periodic table. Here, too, it is clear that his and the Copenhagen School's approach are coming closer and closer together. The feeling is that they are two not too different views of exactly the same problem. Moreover, it was made clear that a great deal more experimentation is needed before very definite decisions can be made about these models.

The general mood of the conference was well illustrated by the discussions on giant resonance. It was made clear that photonuclear processes no longer need separate conferences but fall logically into place as one more reaction. The data is being accumulated at a faster pace and with greater precision; fine structure is being observed and more accurate energy values are being determined. The theory, or rather theories, explain the gross properties quite well. However, there is not yet sufficient experimental information to decide among the different models describing this effect.

FRIDAY evening was the time for the formal banquet, held at the Royal Military College. The highlights of the inevitable speeches were talks by Wilkinson and Lipkin. Lipkin's psychoanalysis of physicists will appear in the Conference Report. It may even include some of the ink blots he used for his tests. Wilkinson disclosed a number of the secrets of the trade of slidesmanship: the art and science of being one up on both the projectionist and the audience. He dealt briefly with the well-known opening move reserved for the conscientious projectionist who has, in anticipation, inserted slides one and two. It is acceptable form to call for slide three. Wilkinson then elaborated briefly on the much copied Oxford ploy in which the lettering on the slide is put on so that the slide has no correct position, and spent most of his time discussing what he called "the Russian gambit". In this maneuver, used for the first time at this conference, the speaker, during the middle of his talk and after a lengthy respite between slides, calls, "Next slide, please." The projectionist pushes the holder over. Nothing appears on the screen. This is, of course, because the slide is completely blank. The speaker calls, patiently, "Next slide, please." The projectionist, sure he put the slide in long ago, looks on the screen, sees nothing, becomes unsure, grabs the next slide, puts it in the empty position of the holder, and slides it into position. Nothing appears on the screen. This slide, too, is blank. On further urging by the speaker, who keeps calling, "Next slide, please," the projectionist bangs the slide-holder back and forth with growing doubt of his senses. The projectionist, usually a graduate student and always an experimentalist, then tests his senses by sticking his finger through the opening where the slide should be. The point is that just there, there is a hole in the slide. It is unnecessary to describe the further nuances of this gambit: suffice it to say that the projectionist is reduced to a state of abject servility, which is, of course, the aim of the speaker.

Meeting of rapporteurs to organize material. *Top photo,* at table in foreground: V. F. Weisskopf, K. A. Brueckner, C. Bloch, and A. De Shalit; table, left background, B. B. Kinsey, D. A. Bromley, N. Austern, R. M. Eisberg, S. Yoshida, and A. Zucker; table, right background, H. E. Gove, J. P. Elliott, E. B. Paul, D. R. Inglis. *Below,* J. S. Levinger, L. Katz, T. Ericson, J. P. Schiffer, R. E. Peierls, and J. A. Harvey.

TO summarize a conference of summaries is hardly a simple task. Weisskopf did it superlatively. The main question—what is the force between nucleons?—is not answered. It has become necessary to find phenomenological models, and these models simplify and overstress particular aspects. The independent particle model, the optical model, the collective model, direct interactions, and statistical theories, are all with us explaining nuclear structure. What is at the same time both surprising and disquieting is that they explain the data so well: surprising because the models are relatively simple, the data quite complex; disquieting because answers which are based on not too much knowledge, but which fit the facts as we have them now, must mean that the phenomena are in a sense trivial. We have not yet probed the problems which will differentiate.

There was, all told, a great deal of light shed in August. A clear picture of the present status of nuclear structure was presented. No questions seemed to have been answered, but a large number of detailed problems were elucidated, and it was evident that there has been a great consolidation in the past few years among the models which try to explain the rapidly accumulating data.