Meetings and Societies

Neutron Interactions with Nuclei

The International Conference on Neutron Interactions with Nuclei, which was held 9–13 September 1957 at Columbia University, New York, N.Y., was attended by 188 American physicists and 57 physicists from 12 other nations. There were representatives from the United Kingdom, Canada, Denmark, Sweden, Norway, the Netherlands, France, Italy, West Germany, Japan, the U.S.S.R., and India. The meeting started with a summary of the present situation in neutron physics, given in a paper by H. A. Bethe (Cornell University), entitled "The Present Status of Neutron Interactions with Nuclei," after which D. J. Hughes (Brookhaven National Laboratory) reviewed the field of low-energy neutron spectroscopy and R. F. Taschek (Los Alamos Scientific Laboratory) reviewed the status of measurements of high-energy neutron cross sections. There were half-day sessions on low-energy neutron spectroscopy, fission physics, the theoretical interpretation of neutron spectroscopy, the process of fission, and fast neutron total and differential cross sections, and there was a session on the gamma rays emitted after neutron capture.

An impressive development in the field of low-energy neutron spectroscopy was the vast quantity of data available from the multichannel time analyzers now in use in this field. As an example of this, L. J. Rainwater (Columbia University) presented results obtained with a multichannel analyzer in which 2000 points were taken simultaneously to produce a full curve of the neutron cross section versus energy all at one time. Large quantities of data obtained with the many 1000-channel analyzers in use throughout the world were also presented. With regard to the design and performance of experiments and the accumulation of data, the situation in this field is quite healthy.

Unfortunately, the situation with respect to the theory of the interactions of slow neutrons with nuclei is not as good, although significant progress has been made. However, it is still not possible to use the theory of the process to calculate with confidence results where experimental data do not exist.

The cloudy-crystal-ball model of the nucleus, in which the nucleus is assumed to be a sphere which can reflect and absorb neutrons, has been modified by changing the sphere to an ellipsoid. With this change, the calculated strength of the neutron interaction varies with the number of particles in the nucleus in a somewhat different way from what it does for a spherical nucleus, and the results calculated from the ellipsoidal nucleus agree much better with the experimental results than do those calculated on the basis of the spherical nucleus.

The ellipsoidal theory of the nucleus has been applied thus far only to low-energy neutrons where the neutron cannot change the total orbital angular momentum of the nucleus. Resonance levels in which the orbital angular momentum of the nucleus is unchanged are called *S* levels; those in which the nucleus is changed by 1 quantum $h/2\pi$ are called *p* levels; by 2 quanta, *d* levels; by 3 quanta, *f* levels, and so on. It is now clear experimentally that levels other than *S* levels must be taken into consideration in fitting theoretical curves to low-energy neutron data. It has now been clearly demonstrated experimentally by H. Newson (Duke University) that the density of resonance levels is proportional to $(2J+1)$, where J is the angular momentum of the compound nucleus.

Even though large quantities of experimental data are available on neutron resonances, more data must be accumulated and the theory must be improved considerably before one can calculate with confidence the cross section of any isotope at a particular energy or, for that matter, even the average cross section over a broad energy region.

In general, fission physics is in a much worse state than is neutron spectroscopy because of the great difficulties in the areas of both experiment and theory. Even though the experimental results have improved considerably in the last two years, there is still no self-consistent set of cross sections available. The fission cross section of uranium-235, which we would think would be the most accurately known because of its economic importance in reactor technology, is a subject of argument among the numerous physicists who have performed measurements of this quantity. Different results disagree by more than 16 percent, even though the accuracy of the measurement is thought to be about 2 percent.

The situation with respect to the resonance levels in the fissionable nuclei is even worse. It is usually possible to assume that all resonance levels in a particular nucleus are independent and thus to determine the parameters of the level independently. For the resonances of fissionable nuclei, each resonance seems to be connected in some way to the resonance next to it, and thus the problem of analysis becomes much more complicated.

Looked at from the theoretical point of view, the fission process can be assumed to occur through many different channels or through just a few. These channels have now been identified, in Bohr's collective model, with the levels in the transition state nucleus, whose angular momenta and parity correspond to the parameters of the compound nuclear levels formed by the capture of a neutron. If fission can occur through only a few channels, then one expects to find that the resonance levels are connected with one another, but if it can occur through a large number of channels, then the levels should be independent. It is now clear from the experimental results that the number of channels allowable is fairly small. In the case of uranium-233, the number appears to be 1; in that of plutonium-239, it is probably 1; but in that of uranium-235, the present data are not yet self-consistent. It is also clear that the quantum mechanical barrier penetration is a useful concept in explaining qualitatively the character of the fission process, but the details of fission are certainly not well explained.

In fast-neutron physics it was clear that the spherical, cloudy-crystal-ball model of the nucleus could fit the gross aspects of the experimental results at energies below a few million electron volts but that it certainly does not fit in detail. In particular, H. H. Barschall (University of Wisconsin) presented a paper showing that the present cloudy-crystal-ball theory did not fit the results of his experiments with polarized neutrons. Theoretical results in which a spin orbit coupling was introduced were also presented at the conference, to take account of polarization, but the theoretical calculations did not agree with the experimental results. Although the theory is probably capable of taking these effects into consideration, considerably more work must be done, both theoretically and experimentally, before the situation is well understood. It was generally agreed that studies of polarized neutrons are a wide-open field.

Many of the new significant experimental results came from the application of two relatively new techniques to neutron spectroscopy. The two techniques are (i) the use of 100-percent efficient detectors with extremely large liquid scintillators and (ii) the fast-neutron time-of-flight technique. The application of these techniques has made it possible to do experiments that were conceived many years ago but languished unperformed because their execution was then beyond the hopes of even the wildest dreamer.

The application of the time-of-flight technique to measurements of inelastic scattering of neutrons has produced some clear data which can be compared with theory. Previously, the data available with the older techniques were very sparse, and no general check of the theory could be made. An excellent review of some of the older techniques and of the data obtainable was presented by Joan Freeman (Harwell, England). In this field the theorist is well ahead of the experimentalist. Most of the experimental results are well explained by existing theory. Considerably more experimental data must be accumulated in order to fill out the theory and check its more critical points, but in general the situation is satisfactory.

The application of the 100-percent efficient liquid scintillator was beautifully demonstrated by J. Terrell (Los Alamos), who measured the distribution of the number of neutrons emitted when a nucleus fissions, and by B. Diven (Los Alamos), who directly measured capture cross sections—a measurement which was previously possible only for nuclei which resulted in a relatively long-lived radioactive isotope.

The results of a large number of experiments with fast neutrons in which all available techniques were used pointed up one of the current controversies in the theory of nuclear reactions—namely, direct interaction versus compound nucleus. According to the direct interaction theory, a particle reacts with only one particle in the nucleus, whereas, according to the compound nucleus theory, a particle is absorbed by the nucleus and loses its identity completely, and then the excited nucleus gets rid of its excess energy by some process which has nothing to do with the way in which the compound nucleus was formed. It is now clear that, in the energy region up to a few million electron volts, compound nucleus formation is predominant. However, at higher energies the situation is not clearly understood, and the process that actually takes place is probably a combination of both direct interaction and compound nucleus formation.

One fact that emerged in the discussion was that many people had been interpreting their data erroneously. Compound nucleus theory predicts that the angular distribution of particles emitted by the compound nucleus should be symmetrical about 90°, whereas direct interaction theory predicts that the angular distribution should be peaked in the forward direction. When the experimental results showed that the results were not symmetrical about 90°, the results were interpreted in terms of direct interaction. At the conference several people pointed out that it was possible to have angular distributions which were not symmetrical about 90° without an interpretation of direct interaction being required. If the statistical assumption that many levels are involved in an observed cross section is not valid, then it is possible to have interference between nearby levels that would destroy the symmetry about 90°. Reinterpretation of experimental results, with more careful attention to the interference process, should give us a better idea of how the nuclear reactions proceed. Thus, we must study angular distributions as a function of the energy of the incident particle to see how the nuclear reaction changes from compound nucleus formation at low energies to direct interaction at higher energies, since it is clear that the reaction process goes principally by direct interaction at very high energies.

The final session of the meeting dealt with the gamma rays emitted after neutron capture and in the reverse process—a topic which has long been neglected in the study of neutron interactions with nuclei. In this session G. A. Bartholomew (Chalk River, Canada) summarized the situation in this field and pointed out that significant results can be obtained with much higher resolution in order to separate various levels and determine the level structure. L. V. Grochev (Academy of Sciences of the U.S.S.R.) reported some of his results, obtained by means of a high-resolution gamma ray spectrometer. He showed how significant results could be obtained. He was able to interpret his results for the light elements in terms of direct capture of a neutron into shell model states. In heavy even-even nuclei, the existence of rotational bands at an energy around 1 Mev was inferred from the existence of strong γ-ray lines of about this energy. (Capture is about 8 Mev, and the shell and collective model have usually only been successful in exploring levels near the ground state of the nucleus.)

H. Schultz (Yale University) presented some results on the energy distribution of gamma rays, from neutrons captured by a particular neutron resonance, and B. Trumpy (Kjeller, Norway) presented results of polarization measurements. Both of these techniques promise to give some information on the spins of levels. The extension and refinement of these techniques promise to give a wealth of new experimental information and a more fundamental understanding of the capture process in terms of nuclear models.

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Forthcoming Events

March

1. Junior Solar Symposium, Tempe, Ariz. (Association for Applied Solar Energy, 3424 N. Central Ave., Phoenix, Ariz.)

1–3. National Wildlife Federation, St. Louis, Mo. (E. F. Swift, NWF, 232 Carroll St., NW, Washington 12.)

3. Wildlife Soc., annual, St. Louis, Mo. (D. L. Leedy, U.S. Fish and Wildlife Service, Washington 25.)

5–6. Gas Conditioning Conf., 7th annual, Norman, Okla. (M. L. Powers, Extension Div., Univ. of Oklahoma, Norman.)

6–8. Fundamental Cancer Research, 12th annual, Houston, Tex. (W. K. Sinclair, M. D. Anderson Hospital and Tumor Inst., Univ. of Texas, Houston 25.)

9–14. International College of Surgeons, 11th biennial cong., Los Angeles, Calif. (K. A. Meyer, 1516 Lake Shore Dr., Chicago 10, Ill.)

10–13. American Assoc. of Petroleum Geologists, annual, Los Angeles, Calif. (R. H. Dott, AAPG, Box 979, Tulsa 1, Okla.)

10–13. Society of Economic Paleontologists and Mineralogists, annual, Los Angeles, Calif. (R. H. Dott, Box 979, Tulsa, Okla.)

16–21. Nuclear Engineering and Science Cong., Chicago, Ill. (D. I. Cooper, *Nucleonics,* 330 W. 42 St., New York.)

17–21. National Assoc. of Corrosion Engineers, 14th annual, San Francisco, Calif. (NACE, Southern Standard Bldg., Houston 2, Tex.)

18–20. Amino Acids and Peptides, Ciba Foundation symp. (by invitation), London, England. (G. E. W. Wolstenholme, 41 Portland Pl., London, W.1.)

20–22. Michigan Acad. of Science, Arts and Letters, annual, Ann Arbor. (R. F. Haugh, Dept. of English, Univ. of Michigan, Ann Arbor.)

20–22. Pulmonary Circulation Conf., Chicago, Ill. (Wright Adams, Chicago Heart Assoc., 69 W. Washington St., Chicago 2.)

20–23. International Assoc. for Dental Research, annual, Detroit, Mich. (D. Y. Burrill, Northwestern Univ. Dental School, 311 E. Chicago Ave., Chicago 11, Ill.

23–26. American Assoc. of Dental Schools, annual, Detroit, Mich. (M. W. McCrea, 42 S. Greene St., Baltimore 1, Md.)

(See issue of 24 January for comprehensive list)