PHOTONUCLEAR CONFERENCE at KARLSRUHE

A summary by ***L. Jackson Laslett*** *and* ***D. J. Zaffarano***

ALTHOUGH a show of hands at the 1959 Photonuclear Conference held at Meridan, New Hampshire, indicated that most participants preferred a respite until 1961, enthusiasm for a "small" meeting in 1960 was evident, and by early spring the organization of what proved to be the largest meeting yet held was initiated by K. H. Lindenberger and J. H. D. Jensen, of the University of Heidelberg, Germany. The conference met from August 18 to 22, and was sponsored jointly by the Karlsruhe Nuclear Reactor Company and the Heidelberg Academy of Science. The site was the Sportschule Schöneck, a school supported by the athletic clubs of the state of Baden, scenically situated on a hill overlooking Karlsruhe. Lecture halls, meals, and recreational facilities were available here for the attendees, as well as accommodations for about 50 (the remainder obtaining rooms in hotels and "Weinstuben" in the suburb of Durlach).

There were 109 registrants, including scientists from Australia, Belgium, Canada, France, Germany (41), Israel, Italy, the Netherlands, Scandinavia, the United Kingdom, the United States (28), and Yugoslavia. Written contributions were submitted from Japan. Owing evidently to unanticipated governmental delay, there were no representatives from the Soviet Union. It was also unfortunate that V. Weisskopf, D. Wilkinson, and P. Axel, who have contributed much to previous photonuclear conferences, did not attend this year.

The excellence of the planning for the meeting and the attention to details were continuously evident. A bound volume about two inches thick containing facsimiles of 59 contributed research papers and 28 summaries of current work at the institutions represented was given to each visitor on arrival. Photocopies of some papers, received only a few days earlier, were included. In the lecture hall, equipment was at hand to accommodate slides of five different sizes, which were shown by rear-projection in a partially darkened room to facilitate notetaking. Several transistorized wireless microphones were available, served by quick-footed graduate students from Heidelberg to members of the audience with things to say. Large hi-fi loudspeakers provided excellent audibility throughout the lecture hall. The precise operation of the Sportschule restaurant was also noted by some visitors, since at a table for six the number of rouladen and dumplings served in a stew, rolls, and sugar cubes appeared to be always exactly divisible by six. It seems hard to believe that a country which even requires that the champagne glasses be calibrated (100 cc) could have given us the uncertainty principle!

THE program, as presented by rapporteurs, covered the following topics: Recent Results on Photonuclear Reactions of Light Nuclei (R. Malvano, Turin); Recent Developments in the Theory of Photonuclear Reactions (G. E. Brown, Copenhagen); Comparison of Electron-Induced and Gamma-Induced Reactions (W. C. Barber, Stanford); Photonuclear Reactions on De-

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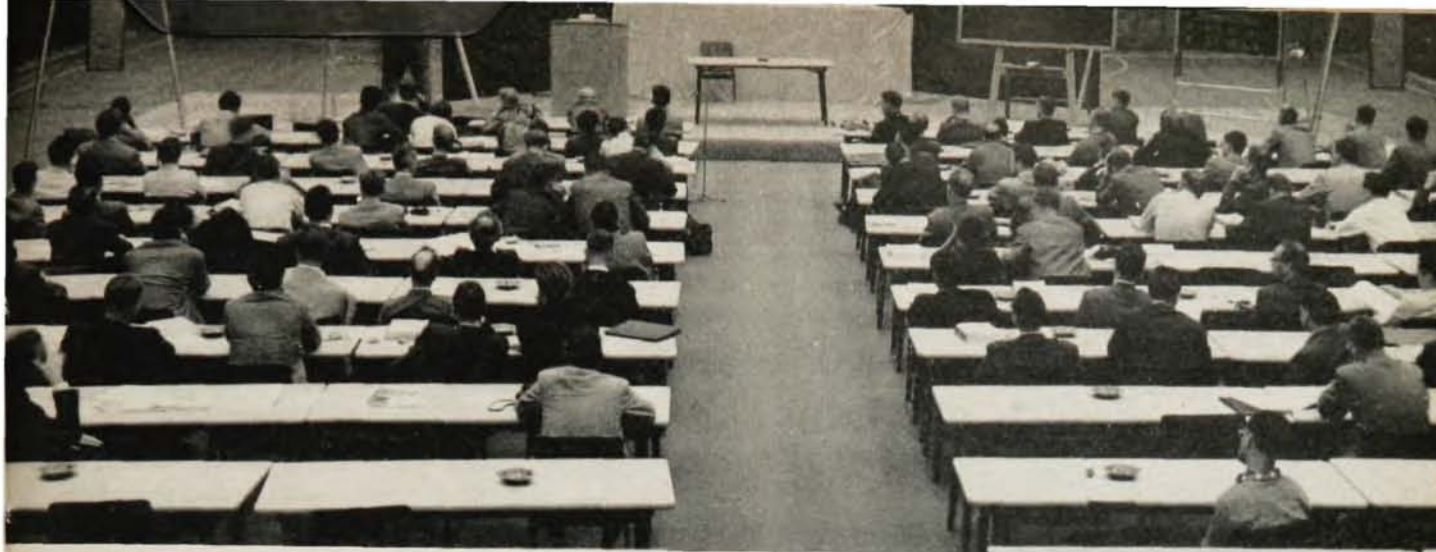


The meeting place was the gymnasium of the Sportschule Schöneck.

formed Nuclei (E. G. Fuller, National Bureau of Standards); Experimental Evidence Concerning Photonuclear Reactions Above the Giant Resonance (J. H. Smith, Urbana); Theory of Photonuclear Reactions Above the Giant Resonance (M. Danos, NBS); New Experimental Techniques (H. W. Koch, NBS); Semi-Conductor Charged-Particle Detectors (G. Dearnaley, Harwell); Summary (A. Kerman, Massachusetts Institute of Technology).

A note of optimism was sounded for the conference when G. E. Brown reviewed the progress which has been made during the past year in the theoretical understanding of the formation of a "dipole state" in nuclei, which is responsible for the giant resonance in photon absorption. A schematic model for the photoabsorption process is proposed in which a particle undergoing ejection and the hole produced thereby in a nuclear shell interact to modify the usual single-particle excitations. A dispersion-type secular equation is obtained for the characteristic values of the energy of the nuclear states produced, and a graphical solution indicates that most of the resulting energy values are "trapped" in the region of the basic single-particle states, while one root becomes considerably greater. This dipole state then is formed by a linear combination of Wilkinson (single-particle) states plus the particle-hole pair interaction. Better agreement with the dipole sum rule is obtained if ground-state interactions are considered, so that one visualizes the possible occurrence of the nucleus in a virtually excited state at the moment the photon enters. Calculations have been made for O^{16} which verify the resonance energies and dipole strengths seen by experiment in this nucleus. Additional work is being done to remove the restriction of zero-range forces, and the calculations are being extended to the calcium nucleus. More detailed cross-section data for the reaction Ca^{40} (γ, p) K^{39} and its inverse, K^{39} (p, γ) Ca^{40}, would be very useful. In subsequent discussion, M. Danos (NBS) agreed that the foregoing viewpoint developed by Elliott, Flowers, Brown, and Bosterli is indeed a reasonable extension of the strict independent-particle treatment as advocated by Wilkinson, but that a tremendous gap remains to be bridged before a connection can be established with the hydrodynamical description of photonuclear interactions given by Goldhaber, Teller, Steinwedel, Jensen, and Danos.

J. H. D. Jensen (above) and K. H. Lindenberger (below) were cochairmen of the conference.

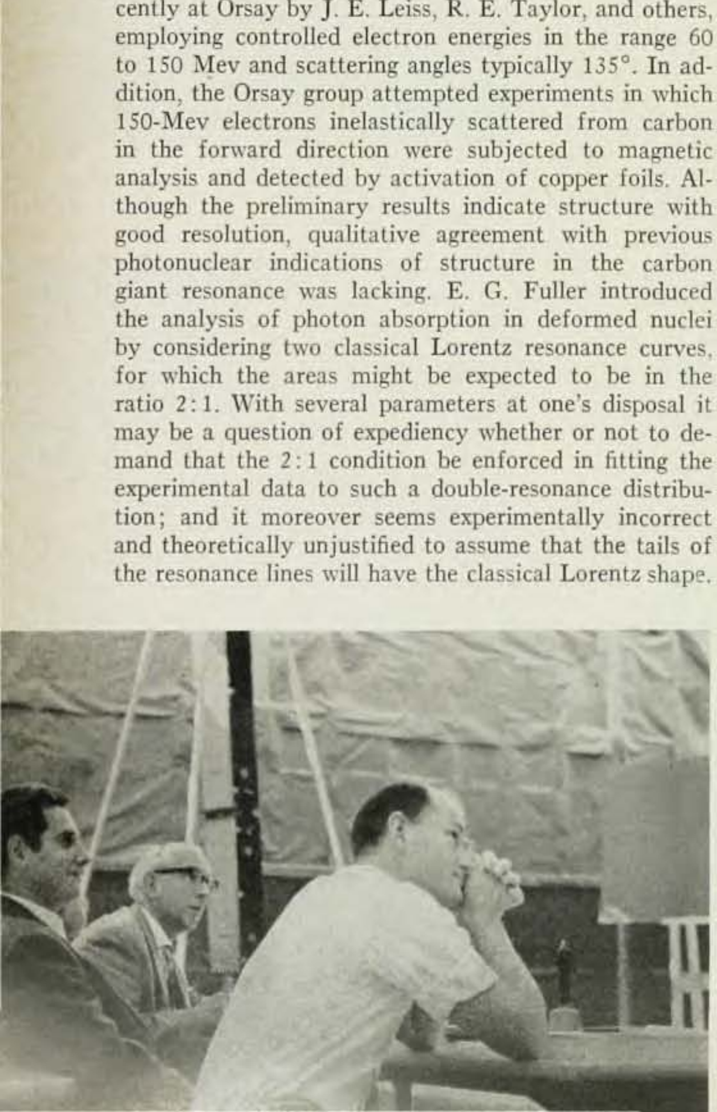
A summary of electron-induced nuclear reaction studies by C. Barber (Stanford) made evident the value of these particles as opposed to photons for examination of electromagnetic interactions. The photons transferred in electron scattering are *virtual*, and thus the unique relation between energy transfer and momentum transfer need not apply. The momentum transfer, q, enters then as another variable, and is established by the angle and energy at which the recoil electron is observed. The properties of a particular energy level selected by electron excitation can be studied by angular distribution measurements of the secondary electrons, as suggested by Huus and Winther, giving a sharp test of the character of the multipolarity of the de-excitation radiation emitted.

Technically, the electron experiments promise to be rewarding, as they permit measurements to be made with precise control and high resolution. It is true, however, that in inelastic scattering the scattered electrons which are of interest must be distinguished not just from the numerous but well-defined elastically scattered electrons but also from those which have undergone radiative scattering. For this reason the recent work done at Stanford University with 42-Mev electrons presumably could be improved by going to scattering angles larger than the 160° limit typically employed at present. The available Stanford results include information for targets of Li^6 (separated), Be, C, Si, and Pb, and transitions other than E-1 were frequently found. Similar work has been performed recently at Orsay by J. E. Leiss, R. E. Taylor, and others, employing controlled electron energies in the range 60 to 150 Mev and scattering angles typically 135°. In addition, the Orsay group attempted experiments in which 150-Mev electrons inelastically scattered from carbon in the forward direction were subjected to magnetic analysis and detected by activation of copper foils. Although the preliminary results indicate structure with good resolution, qualitative agreement with previous photonuclear indications of structure in the carbon giant resonance was lacking. E. G. Fuller introduced the analysis of photon absorption in deformed nuclei by considering two classical Lorentz resonance curves, for which the areas might be expected to be in the ratio 2:1. With several parameters at one's disposal it may be a question of expediency whether or not to demand that the 2:1 condition be enforced in fitting the experimental data to such a double-resonance distribution; and it moreover seems experimentally incorrect and theoretically unjustified to assume that the tails of the resonance lines will have the classical Lorentz shape. The ratio of the energies of the two resonance lines, however, should be related, in this picture, to the quadrupole moment of the nucleus. Also of interest are experiments on the scattering of photons by deformed nuclei, the results being interpretable in terms of a tensor and scalar polarizability. The relative prominence of these two contributions will depend on the angular resolution employed in the experiments. Complications are also introduced by the presence of rotational structure.

Two papers, from Ames (Iowa) and Lund (Sweden), were concerned with the abundance of photodeuterons relative to photoprotons, a topic which appears to have been plagued by rather variable experimental results during the past decade. The earlier work, based on grain counting in nuclear emulsions, on range and curvature measurements in a cloud chamber, or on interpretation of (γ, d) and (γ, n, p) excitation functions, was reviewed. Following a suggestion of S. A. E. Johansson (Lund), the recent work reported at the conference by D. J. Zaffarano and B. Fordman for 45- and 30-Mev bremsstrahlung incident on a thin copper target employed magnetic deflection of the charged particles in vacuo and measurement of the direction and range of tracks formed in nuclear emulsion detectors. By using the range to define energy, the particle trajectory in the uniform field is reconstructed to determine whether or not it originated at the target under the alternate p, d assumptions. This method appears capable of permitting a quite definite decision concerning the mass of each recorded particle. As would be expected from a simple statistical theory, the experimental data did not show photodeuterons to be present in any great abundance, an upper limit of two or three percent being set to the deuteron/proton ratio. In response to a question by H. Medicus (Rensselaer), it appeared that the geometrical arrangement of the Lund work was such that the photoprotons were selected primarily in the forward direction, but that the Ames work covered angles in the range 30° to 90° from the incident beam direction. Although this evidence thus strongly indicates the production of photodeuterons from copper to be highly improbable for bremsstrahlung energies not exceeding 45 Mev, Medicus remarked that some provisional results recently communicated to him suggest that the question may still be an open one in the case of an antimony target.

Photonuclear phenomena above the giant resonance were enthusiastically summarized by J. H. Smith (Urbana). In his review he found it helpful to subdivide the energy region into three somewhat overlapping intervals as follows:

30–100 Mev, immediately above the giant resonance, where single-particle direct interactions may be prominent;



M. Danos, P. Brix, and J. H. Smith

80–300 Mev, in which a description based on the quasi-deuteron model may be useful;
200–1100 Mev, in which mesonic effects could be significant.

The quasi deuteron was proposed by Levinger to explain photon absorption in the intermediate region, and may be rationalized classically as follows: In order for a high-energy photon to transfer energy to a particle, that particle must already have had its escape momentum in the nucleus. At 30–40-Mev excitation, not very many nucleons can have sufficient momentum. However, two nucleons colliding with each other at the instant a photon appears can have sufficient momenta to absorb the photon energy and both particles may be ejected. The simultaneous emission of proton pairs, observed by Smith, is somewhat more puzzling, since there would be no effective dipole moment in a quasi diproton. (E. L. Iloff and H. M. Mahmoud, Ames, have shown that the results of Smith can qualitatively be explained by a three-body interaction, in which a neutron and two protons are involved.) In the region of applicability of the quasi deuteron, one might hope to find the average center-of-mass energy for a p, n pair in the nucleus from the width of the observed energy distributions, and information concerning the frequency of close p, n interactions from the magnitude of the cross-sections. Results at the moment appear to be somewhat at variance with a momentum distribution for a quasi deuteron, which one might imagine to be similar to a Gaussian

$$\left[\alpha\, p^2 \exp\left(\frac{-p^2}{2mE_0}\right)\right],$$

since the observational data seem to suggest a strong peaking at the low-momentum end of the deduced distribution. In a discussion of the theoretical aspects of photonuclear work above the giant resonance, M. Danos indicated that with good experiments and tedious analysis, one may aspire to measure transition densities for single-particle phenomena, to obtain some information about configuration mixing, and to learn the magnitude and energy dependence of magnetic transitions (with exchange-current contributions). In all cases a careful analysis seems essential. Thus in the case of a single-particle description, the results of the initial absorption process will be influenced by subsequent processes which may occur in the passage of the photo particle through nuclear matter and may make it appropriate to invoke the cloudy-crystal-ball model at this point. It was also remarked that the multipole description for quasi deuterons is rather more complicated for an extended nucleus than for the case of deuterium itself, and that analysis of photonuclear interactions in terms of effective charge is also more complicated for multipoles than for the simple dipole case. From the discussion at this session and at others, it moreover was evident that the precise statement, application, and utility of sum rules were unclear in many quarters, and it is consequently proposed to devote explicit attention to this topic at the next photonuclear conference in 1961.

L. Katz, J. R. Atkinson, and R. N. H. Haslam

IN the area of new instrumentation, as reviewed by H. W. Koch, one of the most pertinent developments is the annihilation of positrons-in-flight to produce monoenergetic photons of controllable energy. This technique has been actively pursued by groups working with linear accelerators at Saclay, Harwell, and Livermore. The Livermore work is characterized by the special feature that the positrons are produced at the mid-point of the linear accelerator and further accelerated by the final section, which is operated directly out of phase with respect to the first. In much of the work, however, the relatively narrow photon line arising from annihilation-in-flight is accompanied by a lower-energy continuous distribution which arises from bremsstrahlung and which necessarily complicates analysis of the experimental results. The yield of essentially monoenergetic photons produced in an experimental arrangement designed for good resolution also may be somewhat limited, a value of 10^{-10} possibly being representative of a reasonable photon/electron ratio. In a typical setup (as at Saclay), positrons might be formed in a Pt target 2.2 cm thick, and after magnetic analysis and focusing, annihilation would occur in a 1-mm Li target. To implement electron and photonuclear research, the NBS currently is planning the acquisition of a 100-Mev linear accelerator, with a 40-kw peak beam power (duty factor $\sim 2 \times 10^{-3}$), which will operate in the L-band region and will be installed at a depth below ground level somewhat in excess of 30 feet.

A second technique for working, in effect, with monoenergetic photons is, of course, that in which electrons extracted from an accelerator are magnetically analyzed after radiation and put in coincidence with the reaction particle of an ensuing photonuclear reaction. This method, which is similar to an early Cornell technique, has recently received attention at the University of Illinois.

A second topic mentioned by Koch was the use of large crystal spectrometers, surrounded by appropriate

R. N. H. Haslam, H. J. Lipkin, and P. Demos

A. Kerman and B. M. Spicer

anticoincidence devices to eliminate spurious results, to determine the giant resonance dip in total absorption measurements. This type of work, which has received attention at NBS and at Yale, reveals the giant resonance beyond doubt, but better resolution would be very desirable. In this connection it may be noted that in an earlier session E. G. Fuller reported that measurements of total absorption in oxygen were made at the Lebedev Institute with the aid of a pair spectrometer. The preliminary results were in semiquantitative agreement with Pennsylvania work, a sharp absorption peak being found at 22.6 Mev, of peak cross section equal to 61 mb, with an integrated cross section of 12.5 Mev-mb.

A third experimental technique which aroused considerable interest at the conference was the use at Hamburg and Heidelberg of pulse-shape discrimination to distinguish proton from electron signals in thallium-activated CsI scintillators. In one series of experiments described in a postdeadline paper submitted from Heidelberg, use of the discrimination effected a reduction of the gamma-ray and electron background by a factor somewhat greater than 200 and permitted significant energy measurements to be made on the photoprotons produced in O^{16} by irradiation with 32-Mev bremsstrahlung.

THE conference dates were planned to include a week end, during which excursions were arranged to nearby points of scenic interest, to the physical and technical institutes in Heidelberg and Karlsruhe, and to the new Karlsruhe Nuclear Research Center (operated by the Karlsruhe Nuclear Reactor Company) at Leopoldshafen, seven miles north of the city. The conferees were guests of the Kernforschungszentrum at a banquet held in the luxurious Stadthalle in Karlsruhe, which was attended by the Bürgermeister. The festivities were concluded by the presentation of a postdeadline paper by H. J. Lipkin (Rehovoth) entitled "Experimental Studies of Infinite Nuclear Matter". He stressed the difficulties involved in finding suitable targets and containers, but observed that modern field-theoretic techniques make it possible to reduce the infinite volumes involved by renormalization. He noted that the Copenhagen group has already pointed out that the expected results can probably be explained by pairing forces and specificity (as invoked several times during the conference by G. E. Brown to explain the dipole resonance state).

Following a tradition established by V. Weisskopf, an excellent summary talk was given by A. Kerman. He pointed out that progress had been made in the last year to bring the study of photonuclear phenomena into closer rapport with other areas of nuclear physics. The relevance of studying inverse reactions, such as p, γ processes, and relating these to photonuclear reactions through use of the principle of detailed balance was emphasized more than once during the conference. It was recognized, however, that the study of these inverse processes in many cases would require proton energies greater than those available with tandem electrostatic generators and that, in such cases, recourse to somewhat less convenient experiments with variable energy cyclotrons would be unavoidable. Considerable interest was evidenced in the revival of research involving, in effect, the use of monoenergetic radiation, in the promising work which can be done with high-performance linear accelerators, and in the significant results which may be obtained from studies of electron-induced reactions.

To experimentalists who have struggled patiently with the problems involved in unfolding nuclear information wrapped in the benighting cloak of an uncertain bremsstrahlung spectrum, it is gratifying that theorists are finally giving us assurance that they can cope with the details of the giant resonance, and encouragement to look for fine structure with the light elements. The question of absolute energy scales for betatrons and synchrotrons may be solved by the use of electron spin-resonance magnetic field detectors just developed at NBS and Illinois which operate in space-varying magnetic fields. The new techniques for obtaining monochromatic photons and for utilizing direct electron excitation, and the advent of solid-state detectors which can detect protons in the presence of a high radiation field of scattered x rays and neutrons, give promise for a profitable year of work, and we look forward with some excitement to the next international photonuclear conference which will probably be held again in New Hampshire next August.