NEUTRON CAPTURE REACTIONS

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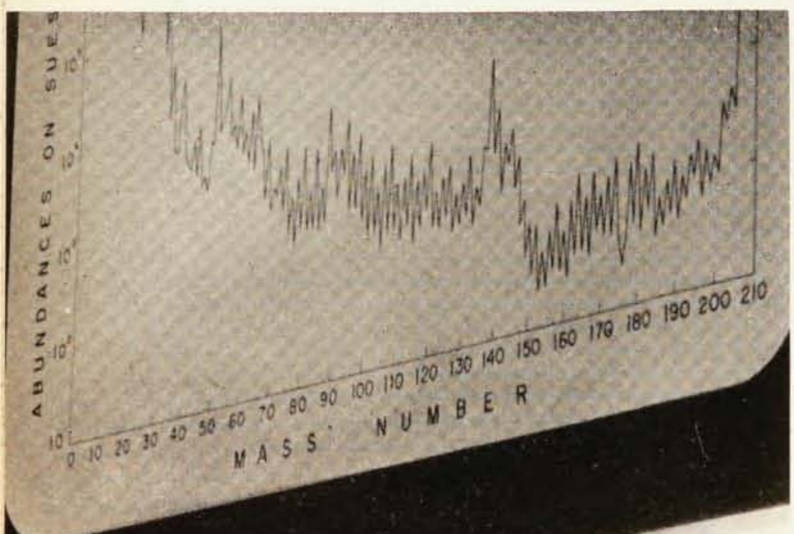


A. G. W. Cameron (Chalk River) discussed time scales for neutron capture in stellar bodies. *Photos by W. H. Regan.*

A TOPICAL conference of the American Physical Society was held at the Los Alamos Scientific Laboratory on October 1–3, 1959. The Conference on Neutron Capture Reactions was conducted in four nonoverlapping sessions with generally adequate time for discussion. The major Western Europe and Western Hemisphere laboratories with active groups working on slow neutron phenomena were represented. In all, there were some eighty visitors, nine of whom represented foreign laboratories. Thirty-nine technical papers were presented. The arrangements were handled by a local committee: H. T. Motz (chairman), R. E. Carter, B. C. Diven, J. Terrell, and C. W. Zabel.

The conference opened with a session on radiation widths, a topic introduced by an invited paper by D. J. Hughes (Brookhaven). After noting that most of the original motivation for capture gamma-ray work arose from a desire to determine spin and parity of initial states, Hughes devoted the bulk of his talk to the interesting and controversial topic of the distribution of radiation widths. In his view, it is remarkable how constant the widths are, quite in contrast to the situation for neutron widths. The former have a spread of $\pm 30\%$, whereas the ratio of the largest to smallest neutron width may be several hundred. This corresponds to a number of degrees of freedom, ν, for the appropriate chi-squared distribution (à la Porter and Thomas, Phys. Rev. **104**, 483, 1956) of 10–20 or even higher rather than 1–2. The data on radiation widths come from examining gamma transitions of nearly the full binding energy in such nuclei as W, Hg, Pt. Hughes emphasized the need for care in limiting the energy range of neutron capturing states so that no levels would be missed and for making comparisons with capture into levels of the same angular momentum.

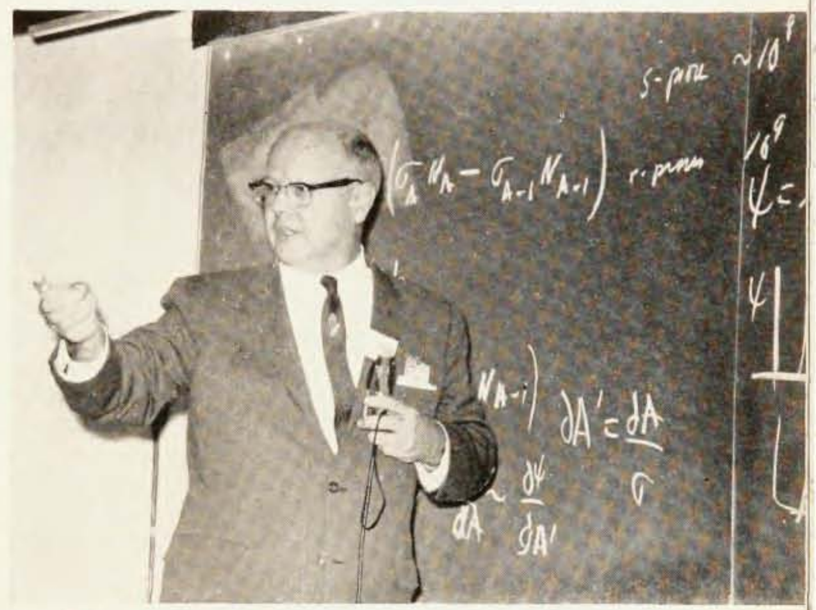
Subsequent papers from Argonne (Cote) and Harwell (Lynn) revealed how in some cases practically the same experimental data lead to different results for the width of the distribution. Generally, Harwell and Argonne report ratios of the largest to smallest width of 10:1 with a corresponding $\nu \simeq 3$. There was much general discussion of this subject. A number of possible experimental and interpretational difficulties were pointed out. One must watch resolution on both neutron and gamma energies, the possibility of cascade summing in the γ detector when only one transition is desired, the size of the sample of widths used, and whether they belong to the same J value. Hughes, for example, claimed that in the case of W^{184} the Argonne result of $\nu = 3$ could be increased to $\nu = 10$ by omitting three levels as $J = 0$ in a presumed $J = 1$ set and that this number of levels was reasonable on statistical expectancy.

Since most of the gamma transitions have been observed with NaI detectors, there is not only the possibility of summing cascade transitions but also of failing to resolve two transitions to final states of small separation. One could not help being impressed, as Lynn remarked, at the very careful work of the Argonne group in unfolding the detector response for two lines of small energy difference.

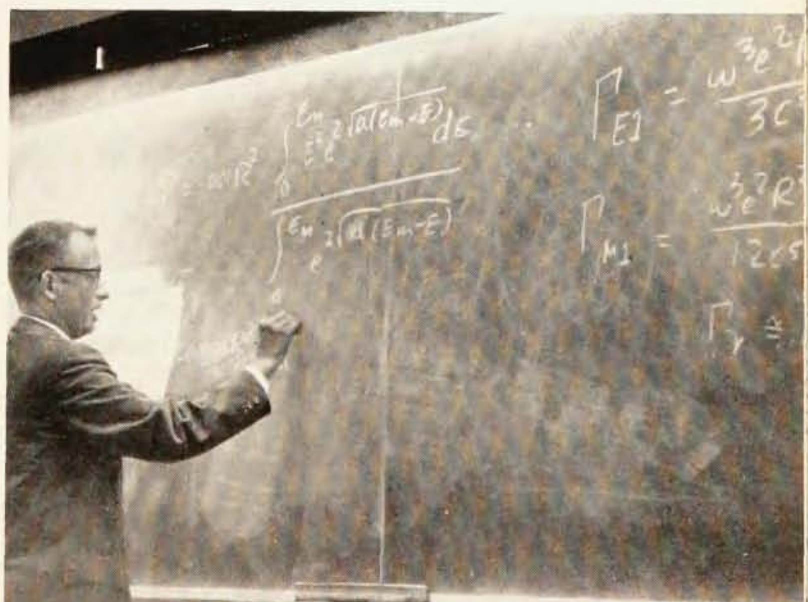
Work reported from Saclay (Julien), Columbia (Rosen), and Oak Ridge also expanded the range of knowledge of spin values and of neutron and radiation widths for a number of nuclides. It is apparent, however, that many more measurements will be required to bring needed certainty in experimental data and consensus in interpretation. Nevertheless, the sense of progress in mastering difficult experimental techniques and the rapid gain in knowledge in a relatively short time is noteworthy. These methods of γ-ray observation promise to surpass the older partial-width methods of determining the properties of resonance levels and have the added advantage of contributing to decay-scheme information.

The second session of the conference was devoted to neutron capture cross sections primarily in the kilovolt region. The various papers were representative of the different possible techniques: (a) detection of neutron loss by the sphere transmission method, (b) formation of quantitatively identifiable radioactive isotope (activation method), and (c) measurement of the total gamma-ray energy emitted. Reports were heard from Argonne, Duke, Livermore, Los Alamos, Oak Ridge, and Wisconsin. Where two methods have been employed on the same problem there is fairly satisfactory agreement except in some activation measurements. An excellent invited summary paper by J. H. Gibbons (Oak Ridge) closed the session. Gibbons pointed out that a veritable explosion in techniques had occurred during the past year which now provided information on capture in dozens of nuclei from a few kev into the Mev energy range. Refinements in handling data, especially the importance of corrections for resonance self-protection and multiple scattering, have brought over-all agreement to the order of $\pm 15\%$ where a few years ago there were discrepancies of a factor 10. One has learned important numbers for astrophysics and reactor problems and for nuclear theory, especially theory dealing with average properties. One is able to follow s-wave capture as a function of energy and mass number, A, and see the onset of p-wave effects including an apparent double maximum in the p-wave strength function as one varies A and

P. A. Maldaur (Argonne)



W. A. Fowler (Caltech)



James Terrell (LASL)

S. L. Whetstone (LASL), left, describes equipment used in time-of-flight measurements of fission-fragment velocities to E. S. Troubetzkoy (NDA).

the indication of *d*-wave contribution in the 100-kev region. It appeared to be the consensus of the participants in this session that at long last it was possible to feel a real sense of accomplishment, a proper and needed fortification for much hard, careful work that remains to be done.

The planners of the conference thought it would be interesting and instructive to have a session devoted to astrophysics since neutron capture processes are so vital to current theories of nucleogenesis of the elements. This turned out to be a happy thought for two interesting invited papers by W. A. Fowler (California Institute of Technology) and A. G. W. Cameron (Chalk River) were most stimulating. There was enough difference in opinion between the two authors to stimulate not only the listeners but each other. In addition to surveying the current status of theory and experiment, both speakers made specific suggestions for needed experimental data. For example, Fowler noted the importance of cross-section data on the lead isotopes in order to obtain better age data by subtracting out the proper amount of primordial lead. Cameron called attention to the need for more data on the neutron-rich isotopes. It was obvious, of course, from the postulated temperatures that cross-section values in the kilovolt region are fundamental to these stellar processes.

The last session, Saturday morning, was devoted to gamma-ray spectra and included two invited papers. In the first, J. E. Lynn (Harwell) discussed anomalous radiative capture in the resonance region. The anomalies appear as abnormally strong transitions to the ground or low-lying states of the compound nucleus. The effect is noticed in Hg and Cu, for example, and among light elements. It was pointed out that the strong-interaction-compound-nucleus picture could explain such behavior only by unlikely fortuitous fluctuations in matrix elements. On the other hand, a direct capture process associated with a $3p$ neutron vacancy which becomes filled at about $A = 100$ and a $2p$ vacancy in the lower mass region appears to be a likely explanation. In the very light mass region one suspects an effect arising from the large level spacing. Detailed calculations were reported directed toward more complete understanding of the mechanism. For instance, one tries to separate this capture process into a hard sphere part and a resonance channel part. In the latter one thinks of a direct capture of the neutron as it approaches or leaves the target nucleus as distinguished from capture after penetrating inside and amalgamating with the target to form the compound system. One must, of course, include contributions from distant as well as near-by channels. It is claimed that the hard sphere part generally proves adequate in regions of A of 24–40 and 56–76 but that channel capture is required in the 40–57 region. It was suggested that a difference between the compound nucleus picture of complete amalgamation and these other capture mechanisms might be revealed by a change in gamma spectrum as the neutron energy is varied in the region between sharp resonances. Additional argument for direct capture processes was given by C. K. Bockelman (Yale) who explored in some detail the correspondence between n,γ processes and the (d,p) reaction.

The second invited paper, by G. A. Bartholomew (Chalk River), reviewed nearly a dozen experimental cases of anomalously strong gamma transitions, especially among nuclei known to exhibit collective excitation. Although there are a number of puzzles in the data, it was concluded that the evidence does indeed suggest a direct capture process.

Other papers in this session were devoted to capture gamma spectra in specific nuclei including precision measurement of the energy of the proton-neutron capture gamma ray. On the latter there is an unresolved discrepancy of 6 kev between the Argonne and Los Alamos results on the binding energy of the deuteron.

Two experimental demonstrations during the conference deserve mention. The first was the resonance capture of rain clouds by Los Alamos. This phenomenon began the day before the conference and had a mean-life of the same magnitude. Local hosts were sorely disappointed at this failure of New Mexico weather to live up to the normal of sunny, warm fall days and were chagrined at the transportation difficulties which bad flying weather introduced. The second demonstration related to a chain reaction in a trash basket, presumably initiated by a cigarette. Particle radiation of an odiferous variety was noticed for some period which could not be attributed to discussions which, though sometimes warm, were not acrimonious. The source was finally discovered before any very short wavelength radiation was emitted and the reaction was brought on a decaying period by the introduction of appropriate absorbers in the waste basket.

In addition to the sessions, late afternoon tours of the Physics Division of the Laboratory were arranged as part of the program. A dinner was held for the conferees at The Lodge on the evening of October 2. The after-dinner speaker was Dr. Fred Wendorf, Associate Director of Research, Museum of New Mexico, Santa Fe, who described the ancient cultures of the American Southwest. Although all present found his discussion most interesting, the majority of the numerous questions which followed appeared to come from foreign visitors from east of the Mississippi.