# Indiana Conference on Nuclear Spectroscopy and the Shell Model

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THE CONFERENCE was held at Indiana University, May 14–16, 1953. It was initiated and organized by A. C. G. Mitchell, head of the Indiana University Physics Department, and was supported by the Office of Naval Research. Over one hundred representatives of twenty-seven laboratories attended. The four sessions were presided over by Gregory Breit, Martin Deutsch, Eugene Greuling, and D. R. Hamilton. Twenty-five lectures introduced the topics for informal discussion.

The discussions were concentrated on interpreting the vast accumulation of data, obtained by nuclear spectroscopy and allied techniques, concerning the behavior of transforming nuclei and their radiations.

*Discussions of the Nuclear Model.* The primary basis of interpretation was the shell model. However, this has to be greatly elaborated and supplemented beyond its primitive, initial form, owing to the growing refinement of the data.

Initially, only states of nuclei containing odd numbers of nucleons were determined. These were taken as completely characterized when the last odd nucleon was assigned to an orbit; all the paired like nucleons were regarded as inert. Obviously, the model could be extended to nuclei with even numbers of nucleons only by considering the coupling of at least the last two nucleons to determine the state. The more detailed evidence on the nature of actual nuclear states forces the consideration of all the nucleons in at least the last orbital, for some of the states.

Particular members of the paired like nucleons, the famous "magic numbers" 2, 8, 20 (28), 50, 82, and 126, show extra stability: each may be regarded as completing a particularly inert core, in the nuclei containing it. The extra nuclei form a sort of "atmospheric" envelope, stratified into orbital shells.

Before the advent of the shell model, at least the heavier nuclei were treated as deformable "liquid drops" with some success. This model naturally failed to exhibit the marked shell effects which are observed, hence now the liquid drop treatment is accorded only to the magic number core, usually lumped together with the lower, filled shells of the "atmosphere." An excitation of the nucleus may still involve only the nucleons in the last, unfilled shells, as supposed in applications of the pure shell model. However, "tidal waves" in the fluid core can now be conceived to be induced by the "atmospheric" motions. The so-called collective model of the nucleus treats some states as arising from a coupled motion of core and "atmosphere."

Not all these details which have come to light play significant roles in every experiment. The interpretations made at the conference exhibited every stage of the above picture, according to the elaboration of detail demanded by the individual experiments. Thus, only the orbit of the *last odd* nucleon needed to be considered in interpreting many of the facts. Examples given the most attention were:

1) L. Nordheim showed the existence of a significant difference in the allowed beta decays of two types of odd nuclei. If the transforming nucleon is the *last odd* one of both the parent and daughter nuclei then a comparatively rapid decay ensues. The second type is never as rapid: "rearrangement" transitions, in which a pair of like nucleons must be broken up and a new pair formed. [A case ($Kr^{85}$) of very marked delay by rearrangement was pointed out earlier by Goldhaber.]

2) H. Richards described experiments determining which excitations of a given nucleus involve only the *last odd* nucleon, and which engage the core. Protons are scattered inelastically from filled-shell nuclei. A wide resonance shows up at each energy which characterizes a single particle state of excitation, of the joint proton-target nucleus system. The longer-lived states in which the whole nucleus shares the excitation energies show distinctly narrower resonances.

3) M. Goldhaber compared odd nuclei which differ only in the number of neutron pairs underlying the *last odd* nucleon. The energy differences between single particle orbits in these nuclei vary smoothly as the neutron pairs are added in the given series. Quite reasonably, the orbits which come closest to the core are affected the most when it changes. J. Mihelich described an experiment in which a whole series of nuclei differing only by neutron pairs are obtained at once. This was the high-energy proton bombardment of gold, which yields the series by ejecting 1, 3, 5, or 7 neutrons.

Nuclei with both an odd neutron and an odd proton present the problem of the coupling between these in determining the nuclear state.

4) Nordheim showed that the coupling depends on whether each odd particle spins in the same or opposite direction to the orbital rotation. If the two odd

nucleons behave differently in this respect then they tend to cancel each other's angular momentum. Such nuclei have allowed beta decay to the spinless states of their daughters. If the two odd nucleons align themselves relative to their orbits in a like way, then a state of high angular momentum is produced. Such nuclei prefer to decay to highly spinning, excited states of their daughters to avoid overcoming the large angular momenta.

5) P. Hough described an experiment which determines directly the kind of orbit which a neutron enters when attached to a nucleus. If the neutron is one stripped from a deuteron bombarding the nucleus, then the freed proton's direction reveals the character of the neutron's new orbit. When the nucleus already has an odd proton, then it is found that the neutron, although entering its expected orbit, spends a few per cent of its time in an orbit of lower momentum.

Evidence about some nuclear states can be understood only if it is supposed that *all* the nucleons in unfilled shells participate in determining the character of the state in question.

6) E. Feenberg showed how an outstanding difficulty of the shell theory can be cleared up in this way. If only the odd proton of $F^{19}$ is held responsible for its observed spin and magnetic moment, then it must be ascribed a spherically symmetric distribution (S orbit). Yet other nuclei, with equivalent proton or neutron numbers, show that the proton should prefer a higher angular momentum (a d orbit). Now, if *all* the protons which would go into the d orbit are considered together, then this preferred d-orbit assignment works as well as the S-orbit in yielding the correct spin and magnetic moment.

7) M. Mayer showed a striking correlation, between rates of favored beta decay and magnetic moments, which can be obtained by considering contributions of *all* the nucleons to the state character. Both the decay rates and the magnetic moments are extremely sensitive to similar details about the nuclear states. Each type of data shows erratic deviations from the expectations based on necessarily oversimplified state models. However, these two types of erratic deviations are now shown to be closely correlated with each other, qualitatively and quantitatively.

8) A long-standing difficulty for the shell model has been the explanation of why only a certain well-defined group of nuclei shows a favored rate of beta decay. Mayer pointed out that all unfavored decays involve nuclear states which should be determined by at least three like nucleons. The various states which these form differ markedly in symmetry from states into which they decay, high degrees of symmetry being encouraged by the charge independence of nuclear forces. The great alterations needed to transform one type of symmetry to another are supposed responsible for the transformation's being unfavored (violation of isotopic spin conservation).

The gross liquid drop picture of the nucleus is still adequate for understanding fission.

9) J. Brolley described experiments in which fast neutrons were sent against fissionable nuclei. The neutron, as might be expected, induces fore-and-aft oscillations in the "liquid drop" nucleus. This was shown by the preferential ejection of the fission fragments along the direction of the impinging neutrons.

The *collective* motion of fluid *core* and extra-core nucleons clarified many problems.

10) G. Scharff-Goldhaber demonstrated that practically all nuclei with even numbers of neutrons and protons have lowest excitations into even states with two units of angular momentum; the next higher excited states have four units of angular momentum in about a third of the cases, and two units again in another third. K. Ford showed that the *collective* model leads one to expect a first excitation consisting of a *core* rotation with just the two units of momentum found. Four units is one of the alternatives for the second excited state, depending on the extra-core nucleons available for excitation.

11) Goldhaber presented a striking analysis of an odd nucleus ($Mo^{93}$) which behaves like the even nuclei described in (10). $Mo^{93}$ is exceptional in that it has a highly excited state with a long duration (isomer), yet it has just one neutron outside a magic number core. The long-lived isomers otherwise occur only just *before* the completion of such a core. It seems that it is the extra neutron that is inert during the pertinent excitations of $Mo^{93}$. The *core* meanwhile goes through the excitations (two, four, and eight units of spin) characteristic of an even nucleus, minus the extra neutron.

12) Scharff-Goldhaber also showed that the first excitations of the even-even nuclei need the most energy when there are fewest nucleons outside the magic number cores. The energy needed is uniformly very low when there are many extra-core nucleons. This conforms to Ford's expectations based on the *collective* model. Many extra-core nucleons pulling tidally on the *core* make it more easily deformable and excitable.

13) Ford also discussed the effect of the *collective* motion on the magnetic moments that deviate from expectations based on single nucleons outside an inert core. Ford could account roughly for the deviations, but only with the added presumption that the presence of many nucleons suppresses the magnetic effects of the meson clouds around each nucleon.

14) *Core* excitation also shows up in the experiments discussed by Hough (5): as a large background (30 to 50 per cent) of isotropically ejected protons. Breit pointed out how large an effect the interference of those protons may have, with the protons analyzed by Hough.

*Discussions of the Laws of Beta-Radiation.* 1) R. Sherr summarized the evidence that beta decay is allowed, and even favored, between spinless nuclear states. Such transformations require either a *scalar* or a *vector* form of coupling law between nucleons and beta particles (Fermi coupling). This must be added to the well-established Gamow-Teller coupling (*tensor* or *axial vector* form of law). Mayer (7) also had evidence for the two types of coupling. Only the Gamow-Teller type can be correlated with magnetic moments and she found that a Fermi coupling contribution had first to be subtracted before she found her strong correlations between decay rates and magnetic moments.

2) E. Konopinski summarized the evidence that the particular forms of the two couplings are the *scalar* and *tensor,* and not the polar or axial vector forms. His earlier evidence, promulgated with Mahmoud, was based largely on the statistical sharing of energy exhibited in certain types of transitions (once forbidden). Measured correlations between the decay fragments of helium definitely now support the tensor over axial vector form of Gamow-Teller coupling.

3) Konopinski also discussed the pros and cons of the single piece of evidence (spectrum of RaE) that a third component of coupling, a *pseudoscalar* form, must also be added to the beta interaction. The third component is needed to interfere destructively with the others, to account for the slow decay of RaE (as well as for the peculiar spectrum). H. Brysk presented calculations showing that destructive interference in RaE entails constructive interference in $Tl^{206}$ and, indeed, the latter element has the shorter life expected from this. Nordheim showed that the observed once-forbidden transitions with no spin change are faster than those with a change of spin. This added speed can be attributed to the *pseudoscalar* component, which acts in once-forbidden transitions only when there is no change of spin.

4) L. Langer described a measurement of an electron spectrum (distribution in energy) which, if correctly interpreted, may lend support to Konopinski and Mahmoud's interpretation of once-forbidden transitions (2). However, this measurement ($Sb^{124}$) is complicated by disagreements about the gamma rays emitted with the beta particles. E. Tomlinson includes two 700-kv gamma rays in his decay scheme for $Sb^{124}$, whereas Langer has evidence for only one. F. Metzger reported gamma-gamma coincidence measurements in support of Tomlinson's scheme.

5) Konopinski further discussed the results of carrying over the beta decay law, in the form found, to the decay of muons. He first presented theoretical arguments that the two neutral particles ejected in muon decay are like neutrinos. The result is a prediction of an ejected electron energy distribution which agrees with some of the mutually contradictory measurements (those finding the fewest high-energy electrons).

*Discussions of the Laws of Gamma Radiation.* Unlike the laws of beta radiation, the basic laws of electromagnetic radiations are well known. The problems arise in the attempts to apply them correctly. When the nucleus is regarded as a classical distribution of charges and currents, then certain expectations arise: radiations which carry off the more angular momenta should be the weaker; the magnetic type of radiation is expected to be only as strong as the electric type which carries off one more unit of angular momentum. In more realistic pictures of nuclei, the classical relation between electric and magnetic radiations is lost; this is to be expected, for example, when one considers the extra contributions to magnetic radiation to be expected from the intrinsic magnetic moments of individual nucleons. One has well-defined expectations only when the radiation is attributed to transitions between single particle states. Hence the comparisons with the facts are usually made against the single particle model.

1) A. Sunyar demonstrated that the single particle expectations greatly overestimate the rate of electric dipole radiation (the electric type which carries off one unit of angular momentum). To do this, he identified nine transitions, of the type in question, which follow after beta decay.

2) Goldhaber pointed out that magnetic gamma radiations are an approximately constant factor weaker than as predicted by the single particle model. Their variation with energy closely parallels that of the model. On the other hand, the electric types of radiation vary erratically. This has consequences for the mixtures of electric and magnetic radiations which may occur. Most often, both types are about equally strong when they have the same multipolarity (dipole, quadrupole, etc., an index of the maximum angular momentum carried off). This accounts for the comparative rarity of mixtures, since both cannot occur in a given transition when they have the *same* multipole character. However, because of the erratic behavior of the electric intensities, some mixtures do occur. Sometimes the classical expectations of an electric multipole mixture with the next lower magnetic multipole occurs. More recent is the finding that also, in some cases, the electric multipole is mixed with the next *higher* magnetic multipole.

3) Mihelich described a neat experimental method for comparing multipolarities. He compares the efficiency with which the gamma rays kick out atomic electrons from two types of orbits ($L_I$ against $L_{II, III}$). The ratio of ejections from one type of orbit to the other is small for electric quadrupole radiation, large for magnetic dipole radiations. A ratio approaching unity is a sensitive indication that the gamma radiation is a mixture of the two kinds.

A conspicuous example of the refinements being achieved in nuclear spectroscopy are the measurements of directional correlations between successive radiations.

4) R. Steffen described experiments on the directional correlation of successive gamma radiations. This turns out to be very sensitive to small degrees of mixing of the radiations. He found examples of both the types mentioned by Goldhaber (2). He stressed that the strong admixture of electric quadrupole radiation with magnetic dipole is evidence of core excitation, as discussed by Ford.

5) M. Rose suggested a means of avoiding one difficulty which besets the correlation of successive radiations. The difficulty is that the nucleus may be randomly disoriented by external effects in the stage between the successive radiations. He suggests using the ratio of the gamma-gamma correlations, to correlations between one gamma ray and an atomic electron kicked out by the second. Both types of correlations are identically affected by the nuclear disorientation.

6) Rose also discussed the very sensitive method of correlating the *direction* of one gamma ray with the *polarization* orientation of the other. He laid down the general rules for interpreting such measurements.

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A more comprehensive report of the above proceedings has been prepared. A limited number of copies are available at the Indiana University Physics Department.

# Walter T. Swingle: 1871—1952

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WALTER T. SWINGLE was one of the most inspiring men who ever entered my life, and the lives of many others. Personally, I owe to him my first lesson in botany at the age of 7, my first job, in the Department of Agriculture, at the age of 17, and my first knowledge of the fact that science is more than experimentation.

David Fairchild recently reminded me of the little intellectual sanctuary which I claimed as my own, beneath the seminar table in my childhood home. There, ensconced, refusing to come out at my mother's command, I heard Dr. Swingle tell of the date palm which he hoped to introduce into America, and later did; of the Chinese trifoliate orange which he thought would be excellent stock for the grafting of the sweet orange, as it was; of the mangosteen, "fruit of the gods" he called it; and I took a solemn vow to taste of it, and 40 years later did so; of Java coffee, Egyptian cotton, and bacteria—for Swingle was as much a plant pathologist as he was a horticulturist. The discussions at the seminar table under which I sat had often to do with plant diseases, Merton White taking the side of the fungi and Erwin Smith holding out for the bacteria, the argument having to do with the cause of pear blight. "Willie," Dr. Swingle said to me, "every particle of dust in the air is covered with bacteria." Dr. Fairchild has said that he, too, first heard of bacteria from Dr. Swingle. The isolation of anthrax and immunity through inoculation had been accomplished only ten years previously by Pasteur. What, I am sure, was the first culture transfer room ever to be constructed in America was made by Swingle and Fairchild in 1890 at the Kansas State Agricultural College, where they were students together. It was an old piano box lined with cotton cloth soaked in a solution of corrosive sublimate. Into this supposedly septic box these two alternately crawled.

Among his many plant interests those of the orange and the date occupied most of Swingle's time. I recall with pleasure one citrus hybrid, the citrange, for I was then the only American boy who had had citrange-ade. The citrange was a cross between the sweet orange and the trifoliate orange. Better known is the hybrid between the tangerine and the grapefruit, which yielded the tangelo, now extensively grown in Florida. It should be remembered that in Swingle's earliest years the orange, date, and fig were mere names in America. In writing to Fairchild from Florida about 1892, Swingle described the orange tree as "something like an oak with bright yellow fruits hanging from its branches." Swingle's work on citrus not only took him on many long journeys in the Orient, but on another pleasant journey, that of marriage with Maude Kellerman, who had demonstrated the practicability of keeping pollen viable long enough to ship halfway around the world (before the days of air mail!), thus bridging the time between flowering periods of different species.

Swingle's work with the date and his treatise on date culture, which is a classic, have so overshadowed his other work that most of it is unknown except to his closest friends. His comparative studies in ecology in Algeria, Arizona, and California, and his introduction of the fig insect, *Blastophaga,* from Algeria into California, which made possible the successful culture of the Smyrna fig, are widely known, but who has heard of his interest in optics which resulted in his persuading Zeiss to make a lens of diamond based solely on Swingle's calculations? And who knows of his work in ultraviolet photography, in which I had a hand? He had me set up a complete equipment of which the cytologist, Yamaguchi, was to have charge, but Yamaguchi never got farther east than Chamberlain's laboratory in Chicago.

Swingle saw the applicability of every brand of science that would conceivably throw light on a bio-