

evaluation of the dipole moment although this uncertainty should not exceed two percent.

If the  $PF_3$  group in the  $POF_3$  molecule is assumed to have the same dimensional configuration as was assumed for the  $PF_3$  molecule<sup>1</sup> itself, the PO distance computed on the basis of the observed moment of inertia is 1.85Å. This abnormally large value suggests that either the configuration of the  $PF_3$  group in these two molecules differs, or that the FPF angle of  $104 \pm 3^\circ$  assumed by Gilliam, Edwards, and Gordy is too large.

While the  $J=2 \rightarrow 3$  transition has been observed, measurements on this line have not been completed.

\* This paper is part of a thesis submitted to the University of Tennessee in partial fulfillment of the requirements for a master of science degree in physics. The writer is indebted to Dr. D. F. Smith for his valuable assistance and guidance.

† This document is based on work performed for the Atomic Energy Commission by Carbide and Carbon Chemicals Division, Union Carbide and Carbon Corporation, at Oak Ridge, Tennessee.

<sup>1</sup> Gilliam, Edwards, and Gordy, Phys. Rev. **75**, 1014 (1949).

### $\beta$ -Decay and the Nuclear Shell Model

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February 27, 1950

THE application of the nuclear shell model<sup>1-4</sup> leads to an almost complete understanding of the allowed or forbidden character of  $\beta$ -decays. The results find their simplest expression in the spin-orbit coupling scheme.<sup>3,4</sup>

For *odd-A* nuclei the following rules can be formulated:<sup>5</sup>

(1) The straggling of  $ft$  values is much reduced when the transitions are sorted out according to type.

(2) The mirror nuclei for a very distinct super-allowed group.

(3) Normal allowed transitions are those in which the assigned orbital momentum is unchanged, irrespective whether  $\Delta I=0$  or 1 (i.e., Gamow-Teller selection rules). The values of  $\log(ft)$  range mostly from 4.8 to 5.5.

(4) Transitions with  $\Delta L=2$ ,  $\Delta I=1$  (allowed according to G.T. rules) have definitely higher  $ft$  values, comparable to the first forbidden group.

(5) Transitions with  $\Delta L=1$  (i.e., change in parity) and  $\Delta I=0, 1$  are first forbidden with  $\log(ft)$  mostly in the range 6.5 to 7.5, but with some stragglers.

(6) Transitions with  $\Delta L=1$ ;  $\Delta I=2$  have definitely higher  $\log(ft)$  values, mostly between 8 and 9 (compare Shull and Feenberg, reference 5).

(7) Higher forbidden transitions have  $\log(ft)$  values  $>9$ .

(8) There is no discernible trend towards higher  $ft$  values with increasing mass number.

There are some ambiguities in the interpretations, but no direct contradictions in over 100 cases where sufficient information is available.

The *even-A* nuclei present a somewhat more complex situation. The even-even nuclei have, to all our knowledge, zero spin, while in odd-odd nuclei there is a coupling of neutron and proton groups each with spins.

In the cases where the transition goes to the ground state, the, say, odd neutron is transformed into a proton which has to pair up with the already present odd proton to give zero spin. The orbital assignments can then be taken from the data on odd-*A* nuclei. If this is done, the  $ft$  values fall into exactly the same classification as given. This demands that in this class of transitions the spins of the neutron and proton groups must have antiparallel orientations, giving minimum resultant spin.

There is another class of nuclei in which one must assume the resultant spin to be high (compare  $Na^{22}$ ,  $Lu^{176}$ ). They are characterized by decay schemes with series  $\gamma$ -rays sometimes of great complexity. The following empirical rule distinguishes the nuclei which belong to the two classes.

(9) If the odd proton and neutron groups have different relative orientation of intrinsic spin and orbital momentum (that is,  $I_1=L_1+1/2$ ;  $I_2=L_2-1/2$ ) then the total spin is  $|I_1-I_2|$ . If they have the same relative orientation (that is, both  $I=L+1/2$  or both  $I=L-1/2$ ), then they combine to a high resultant spin.

This rule can also be expressed by saying that the intrinsic spins of the odd proton and neutron line up parallel as in the deuteron under maintenance of the  $j-j$  coupling. It cannot yet be decided, however, whether the neutron and proton spins in the high class are actually parallel.

The rule is confirmed in about 60 clear cases. The two exceptions are  $Li^6$ , which should have spin 3 like  $B^{10}$ , and  $K^{40}$  whose  $D_{3/2}F_{7/2}$  configuration should give spin 2, while 4 is observed and required to explain its lifetime.

The existence of rule 9 shows that the neutron and proton configurations in odd-odd nuclei are largely independent of each other. The same conclusion is indicated by the persistence of the isomeric rule<sup>1,2</sup> for odd-odd nuclei, which suggests strongly that most isomeric states are due to competition of orbits within one group (protons or neutrons) while isomerism produced by a large resultant spin of neutrons and protons seems to be comparatively rare.

An extensive paper showing the complete material on  $\beta$ -decay is in preparation.

<sup>1</sup> E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949).

<sup>2</sup> L. W. Nordheim, Phys. Rev. **75**, 1894 (1949).

<sup>3</sup> M. G. Mayer, Phys. Rev. **75**, 1969 (1949); (material to be published).

<sup>4</sup> Haxel, Jensen and Suess, Phys. Rev. **75**, 1766 (1949).

<sup>5</sup> Based on independent surveys with substantially the same results by M. G. Mayer and S. Moszkowski, and the author. The latter's work covers also even-*A* nuclei. The findings of Feenberg and Hammack, reference 1, and F. B. Shull and E. Feenberg, Phys. Rev. **75**, 1768 (1949), are also in complete agreement with the rules given here.

### Theories of High Values of Alpha for Collector Contacts on Germanium

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March 17, 1950

THE collector point contact of a type-A transistor shows current multiplication in the sense that a hole arriving at the collector may lead to the emission of  $(\alpha_i - 1)$  extra electrons where  $\alpha_i$  is the intrinsic  $\alpha$  of the collector. Experimental evidence indicates that values of  $\alpha_i$  at least as large as 10 occur.

Bardeen and Brattain have proposed that the space charge of holes passing through the barrier layer produces an increase in electron current through an enhanced field emission effect.<sup>1</sup> While this theory explains values of  $\alpha$  frequently observed, it is limited to values of  $(\alpha_i - 1)$  not much larger than  $b$ , where  $b$  is the ratio of electron mobility to hole mobility moving through the barrier. This limit is set by the condition that for this value of  $(\alpha_i - 1)$ , the added electron charge density would cancel the hole charge density leaving no net charge to enhance the field emission.<sup>2</sup> This leads to a maximum value of 3 for  $\alpha_i$  using J. R. Haynes' value of 1700 and 3600  $cm^2/volt-sec.$  for the drift mobilities. Patch effects may raise this value somewhat, but not up to the larger experimental values.

Generation of secondary electrons by energetic holes has been proposed. This can be rejected because of the low collector voltages observed by W. G. Pfann<sup>3</sup> required to produce high  $\alpha$  values and the stability, rather than exponential increase, of  $\alpha$  with increasing collector voltage.

Two theories are presented below, both based on mechanisms using the charge of the holes.

*Trap theory.* If the barrier region contains a density of traps capable of holding holes, then in effect the value of  $b$  will be increased in this region and the hole space charge enhanced.

*p-n hook theory.* We shall describe this theory in connection with its possible application in *p-n-p* transistors.<sup>4</sup> Suppose that there is a thin layer  $M$  (for "multiplying") of *p*-type material