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[1] itself, the PO distance computed on the basis of the observed moment of inertia is 1.85A. 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 $104\pm3°$ assumed by Gilliam, Edwards, and Gordy is too large.

While the $J=2\rightarrow3$ transition has been observed, measurements on this line have not been completed.

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† 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.

[1] Gilliam, Edwards, and Gordy, Phys. Rev. 75, 1014 (1949).

β-Decay and the Nuclear Shell Model

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THE application of the nuclear shell model[1–4] leads to an almost complete understanding of the allowed or forbidden character of β-decays. The results find their simplest expression in the spin-orbit coupling scheme.[3,4]

For *odd-A* nuclei the following rules can be formulated:[5]

(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 γ-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[1,2] 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 β-decay is in preparation.

[1] E. Feenberg and K. C. Hammack, Phys. Rev. 75, 1877 (1949).
[2] L. W. Nordheim, Phys. Rev. 75, 1894 (1949).
[3] M. G. Mayer, Phys. Rev. 75, 1969 (1949); (material to be published).
[4] Haxel, Jensen and Suess, Phys. Rev. 75, 1766 (1949).
[5] 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 (α_i-1) extra electrons where α_i is the intrinsic α of the collector. Experimental evidence indicates that values of α_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.[1] While this theory explains values of α frequently observed, it is limited to values of (α_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 (α_i-1), the added electron charge density would cancel the hole charge density leaving no net charge to enhance the field emission.[2] This leads to a maximum value of 3 for α_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[3] required to produce high α values and the stability, rather than exponential increase, of α 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.[4] Suppose that there is a thin layer *M* (for "multiplying") of *p*-type material separating the collector region C, taken to be n-type from the base B. This base-collector structure resembles an n–p–n transistor, similar to a p–n–p transistor. Holes arriving at M will be held by a "hook" in the potential energy curve and will bias the p–n junction M–C forward and provoke an electron flow from C into M. If M is thin, the electrons will diffuse through it and fall through the potential drop across B–M; B–M is an n–p junction biased in reverse by the collector voltage. The theory of p–n–p transistors can be applied to this process and it can be seen that very high values of α can arise in this way.

I am indebted to many of my colleagues for discussions of theories and experiments related to high values of α.

[1] J. Bardeen and W. H. Brattain, Phys. Rev. **75**, 1208 (1949).
[2] This reasoning is very similar to that of L. P. Hunter, Phys. Rev. **77**, 558 (1950).
[3] W. G. Pfann, personal communication.
[4] W. Shockley, Bell Sys. Tech. J. **28**, 435 (1949).

Internal Conversion Coefficients for Co^{60}

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RECENTLY several papers[1,2] have appeared in which the results of elaborate calculations of internal conversion coefficients are given. These are believed to be accurate to a few percent. It was our purpose in undertaking this investigation to attain sufficient accuracy in the experimental determinations to provide a significant test of the theory. For this reason we selected for our first experiments Co^{60} for which the gamma-rays are known to be quadrupole from angular correlation experiments.[3]

The measurements were made by means of a double-coil, thin-lens spectrometer in which considerable care had been taken to reduce the background due to scattering. For the setting used in these experiments the transmission was 2.40 percent and the half-width about 3.0 percent. Since it was necessary for us to use sources of slightly different diameters (ranging from 4.45 to 5.50 mm) we calibrated half-width against source diameter and found a slight increase with source diameter. Accurate knowledge of the half-width is essential to the integration of the β-spectrum. In measuring the transmission of the spectrometer we used the β-spectrum of several Co^{60} sources which had been calibrated by coincidence measurements. Because of window effects our data were not good below about 120 kev and we reconstructed the momentum plot by extrapolating to zero the straight Fermi plot (allowed) observed at higher energies. The end point for the β-spectrum was found to be 318.7±4.0 kev. The Co^{60} used was high specific activity material obtained from the Oak Ridge National Laboratory and was mounted on a 3-ply laminated backing (zapon-Formvar-zapon) and then covered with a single zapon film. Each of these films was less than 30 $\mu g/cm^2$. The three strongest sources were less than 0.20 mg/cm^2; the other three used, less than 0.016 mg/cm^2. Effects due to source charging were eliminated. The spectrometer was calibrated against the crystal spectrograph values[4] for the Co^{60} gamma-ray lines.

The values we obtain for the coefficients of conversion in the K, L, M shells together (unresolved) for the two gamma-rays from Co^{60} and the theoretical values[1] of the conversion coefficients for electric quadrupole radiation in the K shell are shown in Table I.

For all other types of radiation the conversion coefficients differ from those for EQ by a factor of at least two. Supposing the $L+M$ conversion and screening effects to contribute about 10 percent, our results classify both gamma-rays as electric quadrupole. Comparison with angular correlation measurements[3] then fixes the spins and parities of the three nuclear levels involved as: 0, 2, 4; same (even).

TABLE I. Internal conversion in excited states of Ni^{60}.

E (Mev)	$\alpha_{exp}\times10^4$	Theoretical value: $\alpha_K^{(2)}\times10^4$
1.1715	1.733±0.061	1.545
1.3316	1.286±0.035	1.175

Although agreement between theory and experiment seems quite good, more exact comparison cannot be made until the theoretical values for the effects of $L+M$ conversion and screening have been calculated. The present results are in agreement with those published by Deutsch and Siegbahn[5] within the relatively large error of the latter; however, the classification of both gamma-rays now seems unambiguous.

[1] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **76**, 184 (1949).
[2] J. R. Reitz, Phys. Rev. **77**, 10 (1950).
[3] E. L. Brady and M. Deutsch, Phys. Rev. **74**, 1541 (1948).
[4] Lind, Brown, and Du Mond, Phys. Rev. **76**, 591 (1949).
[5] M. Deutsch and K. Siegbahn, Phys. Rev. **77**, 680 (1950).

Comment on Mobility Anomalies in Germanium

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IT appears probable that the simple theory of spherical energy surfaces in the Brillouin zone for both holes and electrons in germanium may have to be modified in view of experimental results on mobility and magneto-resistance.

In this letter we shall quote the results of three methods of determining mobility:

Drift mobility. The technique of obtaining the mobility of injected current carriers in germanium by the direct measurement of their transit times over known distances and under the influence of known electric fields has been improved so that measurements with an error of less than 5 percent are obtained. This improvement over earlier equipment[1,2] consists largely in the substitution of pulse techniques for d.c. measurements leading to an unambiguous determination of transit time. The measurements include data on samples of both n- and p-type single crystals as well as on crystals grown by different techniques.

Hall mobility. Only under certain simplifying assumptions is $(8/3\pi)R\sigma$ theoretically equal to the mobility. We shall refer to the experimentally determined value of $R\sigma$ as the *Hall mobility.* Hall mobilities were obtained using the identical samples described above, excepting that the electron mobility values were obtained on n-type material and hole mobility on p-type, the reverse of the drift experiment. The most probable values for $(8/3\pi)$ times the Hall mobility are 1700 cm^2/volt-sec. for holes and 2600 cm^2/volt-sec. for electrons[3] although the experimental accuracy of this method is equal to that of the drift method, the spread in mobility values from sample to sample is much larger, being 1600 to 2200 cm^2/volt-sec. for holes and 2400 to 2900 cm^2/volt-sec. for electrons. (We do not find the large spreads or very high values reported by Dunlap.[4])

Conductivity mobility. Samples of germanium with radioactively determined concentrations of added antimony were found to have a conductivity which was linear in the added antimony and corresponded[5] to the mobility given in Table I. The experimental uncertainty in this work was quite large, due in part to grain boundary effects for which corrections were attempted. Agreement between drift and conductivity mobility is to be expected unless electron-hole collisions are important or appreciable trapping is involved, neither of which is probable for germanium.

TABLE I. Mobilities in cm^2/volt-sec. in germanium.

	$(8/3\pi)\times$Hall mobility	Drift mobility	Conductivity mobility
Electrons	2600±300	3600±180	3350±400
Holes	1700+500−100	1700±90	——

An interpretation, planned for later publication, of the Hall coefficient formula[5a] shows that the Hall mobility may be much