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ISOTOPIC SPIN CONSERVATION AND BETA-GAMMA CIRCULAR POLARIZATION CORRELATION IN A^{41} AND Sc^{46}*

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Recently several experiments[1-4] have been performed which indicate that at least in the cases of the beta decay of Sc^{44}, Mn^{52}, and Sc^{46} the isotopic spin conservation law is poorly obeyed if obeyed at all. These experiments, which so far constitute the only evidence for this breakdown, measure the beta-gamma circular polarization correlation using the method introduced by Schopper[5] and Boehm and Wapstra[5] a few years ago. We have further investigated this situation in the case of A^{41}, whose decay is characterized by $\Delta J = 0$ and $\Delta T \neq 0$ (see Fig. 1). These conditions

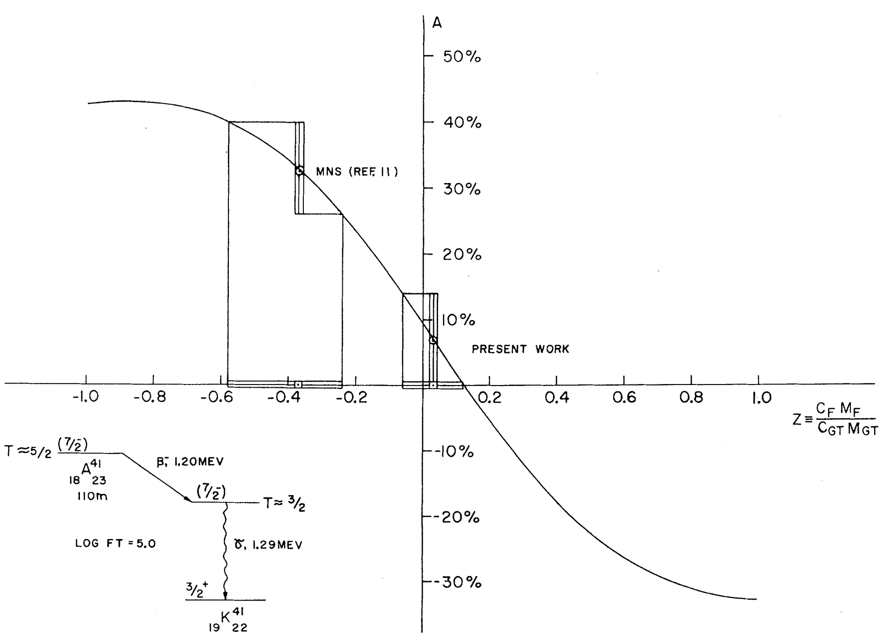

FIG. 1. A^{41} experimental asymmetry parameter as a function of Fermi to Gamow-Teller matrix element ratio. The solid curve is calculated using the $(V-A)$ theory (see reference 7). The isotopic spin assignments are approximate because of impurities introduced in the nuclear wave functions due to Coulomb effects (see references 5-7).

are necessary in order to identify the presence of a Fermi component in the beta decay with a violation of the isotopic spin conservation law. The question here is complicated by the possibility that meson exchange phenomena might effectively introduce isotopic-spin-nonconserving impurities into the beta interaction itself. These must be added to the effects due to neutron-proton mass and charge differences, which latter are customarily considered as at least approximately calculable in many cases.[6-8] The former source of isotopic-spin-nonconserving components has been shown to give zero contribution in the conserved vector-current theory proposed by Feynman and Gell-Mann.[7,9] Therefore in this case the Fermi to Gamow-Teller matrix element ratio should be predictable in those instances where the theoretical apparatus is adequate to give a reliable estimate for the perturbation in the nuclear wave functions produced by the purely nuclear effects mentioned above. In this way an experimental test of the validity of the conserved vector-current theory could be made.

A reconciliation of the theoretical predictions with the experimental evidence at this time in the approximately calculated[7,8] cases of Mn^{52} and Sc^{44} would require that the beta-decay interaction itself must introduce some isotopic-spin-nonconserving elements. In the case of A^{41} two measurements have been made, one of them at this laboratory (a preliminary account[10] of which has already been given) and the other one by Meyer-Kuckuk, Nierhaus, and Schmidt-Rohr (MNS).[11] A comparison of the two results is shown in Fig. 1, where it can be seen that the difference between them is great. In these experiments the essence of the measurement is the observation of the difference in counting rates for opposite directions of magnetization of the iron scatterer. We have used magnet cycling periods of 4 to 10 seconds, in contrast to periods of approximately 15 minutes that have previously been used. This basically eliminates effects due to source decay and gain drifts in the apparatus. (An extended description of the technique is in preparation.) In addition, our measurements for A^{41} (and Sc^{46} as well) were all interpolated between comparison runs of Na^{22} and Co^{60}. The

Table I. Results for A^{41} and Sc^{46} with relevant correction factors. The results for the comparison standards, Co^{60} and Na^{22}, are also shown. The raw result (e_γ) is given in the second column. The third, fourth, fifth, and sixth columns are the correction factors for γ-γ coincidences (K_G), polarization efficiency variation (K_P), backscattering (K_B), and the v/c variation with beta-energy (K_v), respectively. K_P was taken to be unity by definition in the case of Co^{60}. Column seven gives the relative asymmetry parameter (p_A) on the basis of the corrected results. Column eight gives the absolute asymmetry parameter (A) with the assumption that A is +1/3 for Na^{22} and -1/3 for Co^{60}. The results of all the Sc^{46} sources were averaged together in this column with the exception of Sc^{46} V (see text). Similarly the results for all the Co^{60} runs were averaged with the Na^{22} result, excluding Co^{60} II (see text). Column nine then gives the final matrix element ratio corresponding to the values of A in column eight using the (V-A) interaction theory.

Source	e_γ	K_G	K_P	K_B	K_v	p_A	A	Measured C_VM_V/C_AM_A
Na^{22} [a]	+0.319 ±0.036	1.05	0.98	1.01	$(0.73)^{-1}$	+0.452 ±0.051	+1/3	...
Co^{60} I[b] and III	-0.224 ±0.018	1.21	1.00	1.01	$(0.66)^{-1}$	-0.414 ±0.035	-1/3	...
A^{41} [c]	+0.06 ±0.07	none	0.98	1.30	$(0.90)^{-1}$	+0.09 ±0.09	+7% ±7%	+3% ±9%
Sc^{46} I[a]	+0.091 ±0.048	1.10	1.08	1.04	$(0.68)^{-1}$	+0.165 ±0.087		
Sc^{46} II[a]	-0.004 ±0.026	1.10	1.08	1.04	$(0.68)^{-1}$	-0.008 ±0.049		
Sc^{46} III[a]	+0.084 ±0.036	1.10	1.08	1.04	$(0.68)^{-1}$	+0.153 ±0.066		
Sc^{46} IV[b]	+0.072 ±0.021	1.10	1.08	1.01	$(0.68)^{-1}$	+0.132 ±0.038		
Sc^{46} V[d]	+0.031 ±0.021	1.10	1.08	1.58	$(0.68)^{-1}$	+0.086 ±0.058	...	...
Sc^{46} VI[e]	+0.071 ±0.023	1.10	1.08	1.17	$(0.68)^{-1}$	+0.130 ±0.042	+8.5% ±1.7%	0% ±2%
Co^{60} II[f]	-0.096 ±0.030	1.21	1.00	1.58	$(0.66)^{-1}$	-0.277 ±0.087	...	...

[a] Vacuum-volatilized onto 1/2-mil aluminum.
[b] Evaporated in air on 1-mil Mylar.
[c] Glass cylinder 1 cm in diam containing activated argon. End-window thickness ≈ 6 mg/cm².
[d] Vacuum-volatilized onto thick platinum.
[e] Vacuum-volatilized onto thick graphite.
[f] Electroplated onto thick platinum.

purpose was to avoid a theoretical calculation of the magnet polarization efficiency by taking advantage of the fact that the gamma rays of interest in all four of the radioisotopes of concern in this work are of about the same energy. In the cases of Na^{22} and Co^{60} accurate measurements to date indicate that the asymmetry parameter is very close to plus one-third and minus one-third, respectively. Thus by using these two cases as standards and making a small correction for the change in the efficiency of the polarization detector due to the slight difference of energy between the gamma rays, one can obviate more or less completely the magnet scattering calculation which in general is not only tedious but also somewhat unreliable. In Table I we present a summary of the A^{41} and Co^{60} results with the relevant corrections. The significant final result, which is the matrix-element ratio described above, is of course dependent on the particular beta interaction form assumed, and here we have taken the (by now) almost conventional (V-A) interaction. Since our results indicate a very small value for the Fermi matrix element, the departure of the C_V/C_A ratio from unity is not of great importance. On the other hand, the results of the MNS measurement[11] indicate a Fermi matrix element which is almost an order of magnitude larger. At present we have no ready explanation for this discrepancy.

Turning now to the case of Sc^{46}, in Fig. 2 we present a comparison between our results and the experimental results obtained previous to ours. Since our Sc^{46} answer was at such large variance with so many different experiments, it was felt mandatory to do as painstaking a job as possible in this case. As a result we made a measurement on six different scandium sources prepared by four different methods (Table I). The results of the cobalt and sodium runs bracketing the scandium and argon runs are shown in Table I. Actually there were three Co^{60} sources (I, II, and III); I and III were prepared identically and differ only in that Co^{60} I was used as an "interlacing" standard throughout the work with both A^{41} and Sc^{46}. The same is true for the Na^{22} source. Co^{60} III was independently prepared and run at the end of the whole experiment as a final check. Sc^{46} V and Co^{60} II were investigated in order to gauge the effect of back-scattering on the measured polarization, but were omitted in the final averaging since the connection between the back-scattering correction and the polarization correction is not yet completely understood. However, the inclusion of either or both of these results would not affect the basic conclusions of the experiment.

Although it is difficult to determine the effective thickness of a beta source, microscopic examination of all the sources indicated that the best Co^{60} source was much thicker than any of the scandium sources. A further test of the source thicknesses was obtained by measuring the beta spectrum in a magnetic spectrometer. The Kurie

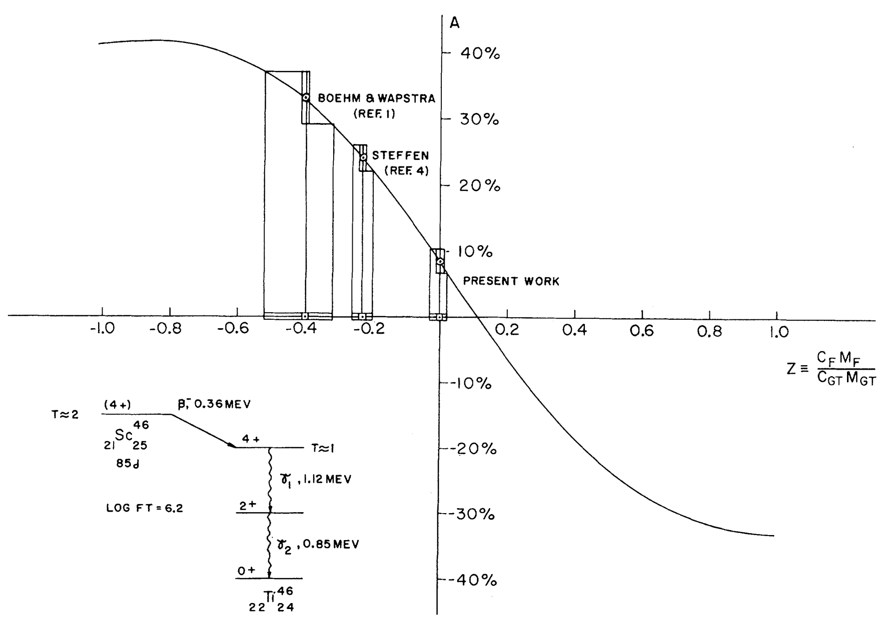

FIG. 2. Sc^{46} experimental asymmetry parameter as a function of Fermi to Gamow-Teller matrix element ratio. The solid curve is calculated using the (V-A) theory (see reference 7). The isotopic spin assignments are approximate because of impurities introduced in the nuclear wave functions due to Coulomb effects (see references 5-7). A complete tabulation of all the experimental results to date on this isotope is given in Steffen's paper (see reference 4).

plots of the Sc IV and Co I sources were linear down to 100 kev and about 2% high at 70 kev, while the Sc VI source on thick carbon showed the curvature typical of sources with large backscattering. The deviation at 100 kev was approximately 10%. The emphasis on the source-making part of the experiment is due to the fact that we could not discover any other factor in our technique which differed in any important way from the techniques utilized in the other measurements. Furthermore the close similarity in both beta and gamma energies between Sc^{46} and Co^{60} indicated that whatever caused the large difference in the measured polarization would have to be resident in the source preparation, if we regard the effect as spurious. But in view of the remarks made above concerning the appearance of the sources as well as the Kurie plot results, it is felt that source quality cannot finally be invoked to explain the Co^{60} - Sc^{46} difference. The vindication of the rapid-alternation method[10] is in the results for Co^{60} and Na^{22}, which are close to the same absolute value (Table I, column 8) with different signs, exactly as would be expected. In Fig. 2, the zero value for the abscissa in the present Sc^{46} measurement is compatible with the isotopic spin conservation law, and therefore with the conserved vector-current theory as well, as explained above. The same conclusions, although with considerably less accuracy, may be drawn from our A^{41} results shown in Fig. 1. In view of the fact that for small polarization, such as we feel we have measured here, one can make sensitive measurements of the Fermi-matrix element contribution with only an approximate knowledge of the polarization efficiency, it is clearly worthwhile to obtain as accurate a value for the polarization as time and patience will permit. We hope to repeat the A^{41} measurement in the near future. In addition, measurements on Mn^{52} and Na^{24} are in preparation. For A^{41} theoretical calculations[12] imply that the conservation law should be better obeyed than the results of Meyer-Kuckuk et al.[11] would indicate. In the other two cases, theory and experiment are again at variance except in one instance.[6,7,13,14]

A complete report of this work describing the technique in full detail as well as incorporating later results is in preparation.

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