Is the Weak Axial-Vector Current Renormalized in Nuclei?

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The measured Gamow-Teller strength in ^{37}Ca β^+ decay, which has an unusually high energy release, differs significantly from shell-model predictions and also from the analogous strength inferred from the ^{37}Cl(p,n) reaction. This calls into question the claim, based primarily on shell-model analyses of low-energy-release β-decay rates and (p,n) cross sections, that g_A is significantly renormalized in complex nuclei.

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Because the weak axial-vector current is not conserved, there is no assurance that the β-decay axial-vector coupling constant g_A has the same value in complex nuclei as it does in the free nucleon where $g_A/g_V = -1.26$ (see Refs. [1-4]). In fact, it is widely believed that a substantial renormalization occurs in complex nuclei. This belief is largely based on shell-model analyses of two independent sets of data: Gamow-Teller (GT) β-decay rates, and intermediate-energy 0° (p,n) cross sections. For example, Brown and Wildenthal [5,6] compared 256 measured GT transition rates in the $A = 17$–39 nuclei with shell-model calculations and found that the measured B(GT) values were systematically smaller than those calculated using the free value of g_A/g_V. In fact, their calculations gave much better agreement with the data when g_A/g_V was set to ≈ -0.95. Wilkinson [2] made a similar analysis of β transitions in the $A = 6$–21 nuclei and found that $g_A/g_V \approx -1.13$.

However, β decays probe GT strength only within a typically narrow "window," set by the limited energy release in the decays. For example, the mean energy release of the transitions analyzed by Brown and Wildenthal was only 3.5 MeV. As most of the predicted GT strength is expected to lie at excitation energies well above the experimental window, conclusions about the renormalization are necessarily model dependent, i.e., they rely on the ability of the shell model to correctly predict the *energy dependence* of the GT strength distribution.

One can probe GT strength outside the β-decay window by analyzing forward-angle cross sections of intermediate-energy (p,n) reactions [7]. One assumes the validity of the distorted-wave impulse approximation in which the $L=0$ cross section, that dominates the 0° yield, is proportional to $B(q)$, where q is the momentum transfer [7,8]. The proportionality "constant," which is evaluated empirically, is found to have large, unexplained nucleus-to-nucleus variations [7]. The empirical $B(q)$'s are then extrapolated to $q=0$ to obtain B(GT) values. Although this procedure does not have the energy constraints of β decay, it too has a window set by the increasing background from $L>0$ multipolarities, quasifree $n+p$ scattering [9], multistep reaction mechanisms, etc. The boundaries of the (p,n) window are difficult to quantify, but are sufficiently wide to probe a noticeably larger fraction of the expected GT strength than is typically seen in β decay. When GT strengths estimated from (p,n) yields are compared to shell-model calculations, it is again found that the data are "quenched" with respect to the shell-model calculations [6].

In this paper we argue that the above evidence is biased, and that a careful analysis of the data does not necessarily support the notion that g_A is appreciably renormalized in the nuclear medium. The preceding Letter [10] describes our high-resolution, high-sensitivity measurement of GT strength in ^{37}Ca β^+ decay ($Q_{EC} = 11.64$ MeV). This decay has one of the largest energy releases of any nucleus with $A<40$ (complete $0\hbar\omega$ shell-model calculations are currently limited to nuclei with $A<40$)

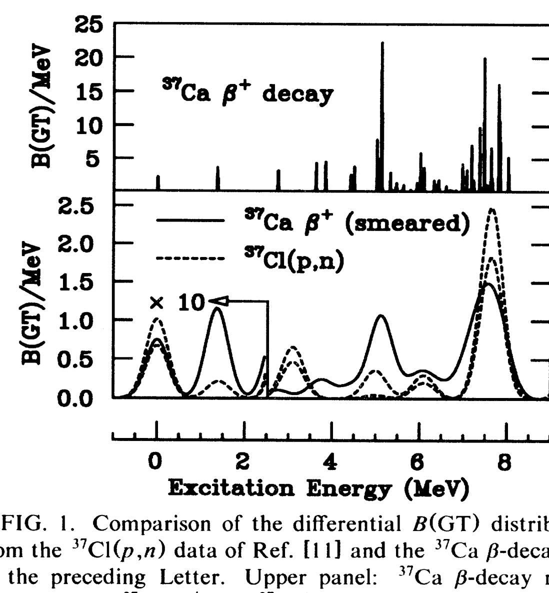

FIG. 1. Comparison of the differential B(GT) distributions from the ^{37}Cl(p,n) data of Ref. [11] and the ^{37}Ca β-decay data of the preceding Letter. Upper panel: ^{37}Ca β-decay results. Lower panel: ^{37}Ca β^+ and ^{37}Cl(p,n) GT transitions represented by Gaussians whose area is B(GT). The width of the (p,n) Gaussians reflects the 600-keV energy resolution of that experiment; the high-resolution ^{37}Ca results are plotted with widths of 600 keV to facilitate the comparison. Note the vertical scale change—the data at low E_x have been multiplied by a factor of 10.

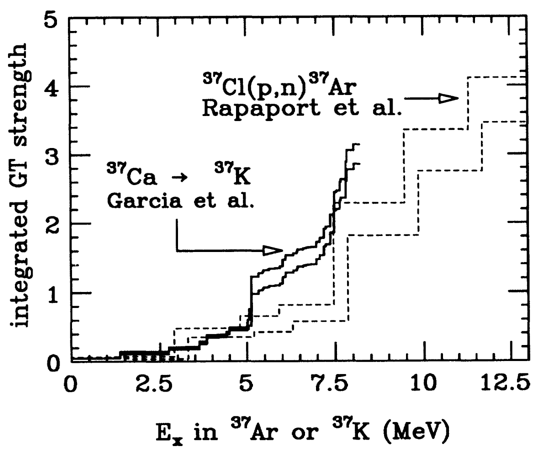

FIG. 2. Comparison of integrated B(GT) distributions from the ^{37}Cl(p,n) data of Ref. [11] and the ^{37}Ca data of the preceding Letter.

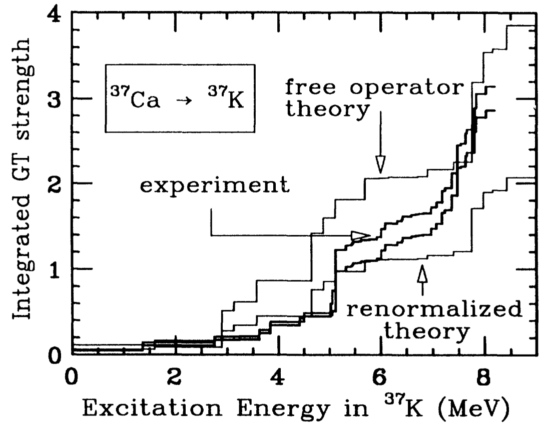

FIG. 3. Comparison of our measured B(GT) distribution for ^{37}Ca β^+ decays to shell-model calculations with free-nucleon ($g_A/g_V = -1.26$) and effective ($g_A/g_V = -0.95$) GT operators. The experimental lines show the $\pm 1\sigma$ error band. The free-operator shell-model strength integrated over all excitation energies is 14.3.

for which it is practical to study the isospin analog (p,n) reaction (i.e., the required target is stable).

Figures 1 and 2 compare the differential and integral B(GT) values from our ^{37}Ca β^+-decay work to those deduced from the ^{37}Cl(p,n) reaction by Rapaport *et al.* [11]. These should be identical to the extent that isospin is a good symmetry. We were surprised to find a significant disagreement between the two results—the β^+-decay results show $\approx 50\%$ more integrated B(GT) strength up to $E_x = 8$ MeV than was inferred from the (p,n) data. It is interesting that this extra 50% just accounts for the "missing" strength that is normally explained by the renormalization of g_A. Note that large fractional discrepancies occur throughout the excitation region common to the two experiments. We find it implausible that these large differences, ranging up to a factor of 4, can be due to isospin-violating effects. For example, the observed excitation energies of eight pairs of analogous positive-parity levels in ^{37}Ar and ^{37}K have an rms difference of only 50 keV. Isospin-violating differences in the B(GT) values are also expected to be small compared to the experimental discrepancies. Ormand and Brown [12] made a shell-model analysis of isospin-violating effects in the $A = 17$–39 nuclei, determining the isospin-violating single-particle energies and two-body matrix elements from excitation-energy data by the same techniques normally used to fix the isospin-conserving parameters of the conventional shell model. Ormand and Brown predict that the ^{37}Cl and ^{37}Ca B(GT)'s integrated up to $E_x = 8$ MeV are identical to within 2%. Thus, we have clear evidence for a significant problem with the B(GT)'s deduced from (p,n) data. Note that the problem is not just in the overall normalization, but also in the *relative strengths* of transitions in the *same nucleus.* Such effects cannot be explained by an inappropriate choice of parameters in the usual distorted-wave impulse approximation, but rather indicate difficulties with the $L = 0$ identification procedure [13] and/or the reaction model used to analyze the (p,n) data.

In Fig. 3 we compare our ^{37}Ca β-decay results to predictions of the $0\hbar\omega$ shell model of Brown and Wildenthal [5]. We find systematic and significant discrepancies that cannot be accounted for by a simple renormalization of the shell-model predictions. At $E_x < 5$ MeV we observe less strength than predicted by the shell model with free GT operators, while for $E_x > 5$ MeV the observed strength exceeds the prediction. A similar effect was observed by Borge *et al.* [14] in the high-energy-release β^+ decay of ^{33}Ar. These data indicate that the shell model, at a minimum, incorrectly describes the *distribution* of GT strength as a function of excitation energy. The same conclusion was drawn by Anderson *et al.* [9] who compared shell-model calculations to their (p,n) data on ^{20}Ne and ^{28}Si targets.

We tentatively consider two possible explanations for this failure of the shell model:

(1) g_A is not renormalized in the nuclear medium but there is a problem in the predicted *distribution* of GT strength, i.e., the residual two-body interaction used by Brown and Wildenthal pushes too much GT strength down to low energies. In a highly idealized Wigner model, where the nuclear forces are spin and isospin independent, the GT strength would be concentrated at the energy of the isobaric analog state. A realistic shell-model residual interaction spreads out this strength, pushing some of it down to low E_x, the only region where the majority of β-decay experiments could have detected it. In order to fit the data, dominated by low-lying transitions, with their wave functions, Brown and Wildenthal had to invoke a quenched g_A. However, when one examines β-decay data spanning a wide region above the analog state, one finds the strength that was incorrectly pushed to

lower energies.

(2) g_A is renormalized in the nuclear medium and two-particle–two-hole excitations omitted in the $0\hbar\omega$ calculation produce additional GT strength at high E_x. This is consistent with our observation that the number of GT transitions with $E_x < 8$ MeV is much larger than the number predicted by the $0\hbar\omega$ shell model. This scenario could be tested by measuring the GT yield in ^{37}Cl(n,p) which vanishes in the $0\hbar\omega$ model.

In summary, we argue that recent high-sensitivity β-decay data, spanning a wide range of excitation energy, show no evidence for the renormalization of g_A, but do reveal shortcomings both in the $0\hbar\omega$ shell model and in the (p,n) probes that were used to infer such renormalization. These results suggest that, before any firm conclusions can be drawn about the renormalization of g_A, additional work is required both on the shell model and on understanding the relation between (p,n) cross section and GT strength. In this regard, a careful remeasurement of the ^{37}Cl(p,n) reaction, including polarization-transfer data to help identify the $\Delta S=1$ cross section, would be particularly useful.

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