Superallowed Beta Decay of Nuclei with A ∃ 62:
The Limiting Effect of Weak Gamow-Teller Branches

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Our program to sharpen the CKM unitarity test by improving our knowledge of the charge-dependent corrections to superallowed *ft*-values [1] has focused on the ∃-decay of nuclei in two different mass regions: T_Z = -1 even-even nuclei with 18#A#42 and T_Z = 0 odd-odd nuclei with 62#A#74. The first region has the advantage that it lies in the same shell-model space as that of many of the currently well-known superallowed emitters; its disadvantage is that the measurement of branching ratios for transitions to states in an odd-odd daughter presents a formidable challenge [2]. Since the T_Z = 0 nuclei in the second region decay to states in even-even daughters, they were expected to have considerably simpler decay schemes. In fact, the T_Z = 0 superallowed emitters with A#54 all have ∃99.94% of their decay strength concentrated in the superallowed branch. Such a branching ratio can easily be determined with high precision.

However, the ∃-delayed (-rays observed from the decays of ^{62}Ga [3] and ^{74}Rb [4] show more complexity than had been anticipated. This has prompted us to mount a series of shell model calculations for decays of the four (4*n*+2) nuclei with 62#A#74 and, for comparison purposes, the three cases with 46#A#54 where precise data already exist. We find that, as with the lighter odd-odd T_Z = 0 nuclei, we expect their superallowed branch to the ground state in their daughter to be predominant; however, unlike the lighter cases, that branch will not constitute ∃99.94% of the total decay rate, but instead will amount to ~99.0% for 62#A#74. What makes this difference critical is that the remaining ~1% ∃-decay strength is expected to be spread over numerous Gamow-Teller transitions, of which all those stronger than, say, 0.01% will have to be identified and measured in order for the superallowed branching ratio to be determined to the required 0.1% precision. The existence of these Gamow-Teller branches simply follows from the fact that, as one moves to heavier and heavier T_Z = 0 nuclei in the same A = (4*n* + 2) sequence, the ∃-decay *Q*-value increases, thus opening up a larger energy window for ∃ decay. At the same time, the density of 1^+ states in the daughter also increases, as does their structural complexity, with the result that weak Gamow-Teller branches become abundant. The deleterious effects of numerous weak Gamow-Teller transitions have been remarked in the study of much heavier exotic nuclei [5] but their potential impact on precise superallowed *ft*-values has not been noted before.

Our calculations were only intended to be illustrative, so our model spaces were kept fairly modest. For 46#A#54, we took a ^{40}Ca core with a $(f_{7/2})^{n-r}$ $(p_{3/2},f_{5/2},p_{1/2})^r$ model space truncated to *r*#3. We used standard effective interactions, KB3 [6, 7] and FPM13 [8], but, because of the truncations, we readjusted their centroids to reproduce the experimental splitting between the ground-state 0^+ and the first-excited 0^+ state, a key datum for superallowed beta decay.

For nuclei with 62#A#74, we use the model space $(p_{3/2},f_{5/2},p_{1/2})^n$, which is built on a ^{56}Ni core with an effective interaction from Koops and Glaudemans [9] based on the modified surface-delta interaction (MSDI). For A = 62, 66 and 70, this interaction puts the excited 0^+ close to its observed location, but in ^{74}Kr it fails badly, placing the state at 2.5 MeV, compared to the experimentally known 0.5 MeV excitation. Thus, for A = 74, it is essential to include configurations involving the $g_{9/2}$, $d_{5/2}$ and possibly the $g_{7/2}$ orbitals. Such calculations quickly become unmanageable, so we limited the *d,g*-shell occupation to two nucleons and tuned the effective interaction (MSDI') to reproduce the energy of the first-excited 0^+ state.

Table I: Summed Gamow-Teller branching fractions in the superallowed decay of selected A = 4*n*+2 nuclei.

Parent nucleus	Q_{EC} MeV	Shell model	# of 1^+ states	Total GT % branching
^{46}V	7.05	FPMI3	7	0.027
		KB3	10	0.020
^{50}Mn	7.63	FPMI3	16	0.013
		KB3	35	0.019
^{54}Co	8.24	FPMI3	23	0.006
		KB3	75	0.024
^{62}Ga	9.17	MSDI	110	0.28
^{66}As	9.57	MSDI	255	0.67
^{70}Br	9.97	MSDI	325	1.59
^{74}Rb	10.4	MSDI	180	0.72
		MSDI'	>400	0.92

In Table I we present the results of these shell-model calculations. In the fourth column, we identify how many 1^+ states in the daughter $T_z = 1$ nuclei are calculated to have an excitation energy less than the Q_{EC}-value. For each of these 1^+ states we computed the Gamow-Tellertransition probability. We then summed these branching ratios over all the 1^+ states in the *Q*-value window and present the results in column five.

For the three well-known cases with 46#A#54, there are relatively few Gamow-Teller transitions predicted, and their total strength is a barely significant 0.025% (or less) of the total ∃-decay. This is in excellent qualitative agreement with experiment [10]. The total Gamow-Teller branching observed is 0.011% (in one branch), 0.058% (in two) and #0.001% for the decays of ^{46}V, ^{50}Mn and ^{54}Co respectively. These branches are already incorporated in the current analysis [11] of superallowed ∃-decay data. Thus, our calculations offer no correction whatsoever to those data.

However, for the nuclei with 62#A#74, our calculations indicate that the Gamow-Teller branching fraction is substantially larger, ranging from 0.3% in ^{62}Ga to 1.6% in ^{70}Br, and certainly cannot be ignored. Furthermore, it is also important to recognize that these are accumulated branching fractions, the sum of many individual branches. The largest single (non-superallowed) branch calculated in each case is about one-third of the total: 0.1% to the sixth 1^+ state in ^{62}Zn; 0.2% to the third 1^+ state in ^{66}Ge; 1% to the third 1^+ state in ^{70}Se; and 0.3% to the fifth 1^+ state in ^{74}Kr. The remaining two-thirds of the Gamow-Teller strength in each decay is spread over a large number of states: for example, in the case of ^{74}Rb decay, there are 20 transitions with individual branching ratios above 0.005%. To date, none of the 1^+ daughter states has even been located and, in most cases, the ∃-decay branches feeding them will be below normal detection sensitivity for such exotic nuclei.

There is clear experimental support for these predictions of complexity. First, the observed decays of ^{62}Ga [3] and ^{74}Rb [4] show evidence for the population of states in their daughters that could not be fed directly by allowed ∃-decay but must have been populated by unobserved (transitions from weakly fed states at higher excitation. Second, multiple Gamow-Teller transitions of the type we describe have been observed [12] in the decays of odd-odd 0^+ nuclei with N□Z in this mass region: ^{64}Ga, ^{66}Ga and ^{78}Rb. All three exhibit complex decays with a minimum of 9, 12 and 23 significant Gamow-Teller transitions respectively, which populate 1^+ states in their daughters. All three have Q_{EC} values that are *lower* than the N=Z nuclei listed in Table I and the measured log*ft*-values are between 5 and 8, quite comparable to those calculated for the latter.

These results clearly indicate that if superallowed ∃-decay *ft*-values are to be determined for A#62 nuclei with a precision better than, say, 0.5 %, then new techniques will have to be developed to incorporate the effects of many weak Gamow-Teller transitions. Total absorption spectrometry has the potential to accomplish this goal, but whether it can do so with sufficient precision is an unanswered question. For these heavy nuclei to become useful in testing $*_C$ calculations, the development of such new techniques will have to become a priority.

References

[1] J. C. Hardy *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2001-2002), p. I-21.

[2] M. Sanchez-Vega *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2001-2002), p. I-24.

[3] C. A. Gagliardi *et al., Progress in Research*, Cyclotron Institute, Texas A&M University (2000-2001), p. I-36.

[4] J. C. Hardy *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2001-2002), p. I-35.

[5] J. C. Hardy *et al.*, Phys. Lett. **B71**, 307 (1977); Phys. Lett. **B136**, 331 (1984).

[6] T. T. S. Kuo and G. E. Brown, Nucl. Phys. **85,** 40 (1966).

[7] A. Poves and A. P. Zuker, Phys. Reports **70**, 235 (1981).

[8] W. A. Richter *et al.*, Nucl. Phys. **A523**, 325 (1991).

[9] J. E. Koops and P. W. M. Glaudemans, Z. Phys. **A20**, 181 (1977).

[10] E. Hagberg *et al.*, Phys. Rev. Lett. **73**, 396 (1994).

[11] I. S. Towner and J. C. Hardy in *Proceedings of the Fifth International WEIN Symposium: Physics Beyond the Standard Model*, eds. P. Herczeg, *et al.*, World Scientific (1999), p. 338-359.

[12] National Nuclear Data Center, http://www.nndc.bnl.gov.