Nuclear-Structure Dependent Corrections to Superallowed Beta Decay

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Critical components of any test of CKM unitarity via superallowed beta decay [1] are the small calculated correction terms, some of which depend on the nuclear structure of the states involved in the decay. The expression [2, 3] for the corrected $\mathcal{F}t$ value is

$$\mathcal{F}t = ft(1+\delta_R)(1-\delta_C) = K/[2\, G_F^2\, V_{ud}^2(1+\Delta_R^V)],$$

where δ_R is the nucleus-dependent radiative correction,. Δ_R^V a nucleus-independent radiative correction, and δ_C an isospin-symmetry breaking correction; K is a numerical constant, G_F the fundamental weak-interaction coupling constant, and V_{ud} the up-down quark-mixing matrix element of the Cabibbo-Kobayash-Maskawa (CKM) matrix. The three correction terms δ_R, Δ_R^V, and δ_C are all of order 10^{-2}.

It is also convenient to separate δ_R into two terms:

$$\delta_R = \delta_R' + \delta\ .$$

The first term, δ_R', is a function of the positron's energy and the charge of the daughter nucleus, Z, and therefore depends on the particular nuclear decay, but it is independent of nuclear structure. It can be calculated from standard QED. Somewhat smaller but nuclear-structure dependent is the correction δ_{NS}.

In the last progress report [4] we reported on a re-examination of the two nuclear-structure dependent corrections, δ_{NS} and δ_C, for all T_Z = -1 superallowed emitters with A$\leq$ 42 and T_Z = 0 ones with A $\leq$54. We calculated new values for δ_R and δ_C in a consistent approach, using the same model approximations for each and, at the same time, assessing the accuracy with which these corrections can be obtained. Here we report on an extension of this work to the heavy superallowed emitters with $62 \leq A \leq 74$.

For ^{62}Ga and its daughter ^{62}Zn we employed a ^{56}Ni closed $f_{7/2}$ shell and placed six nucleons in the other three *p,f* orbitals: $p_{3/2}$, $f_{5/2}$ and $p_{1/2}$. This is the same model space as that used by Koops and Glaudemans [5] in their study of the nickel and copper isotopes using a modified surface-delta interaction (MSDI). This interaction produces very acceptable spectra for zinc and gallium nuclei as well. We also considered as a residual interaction the Kuo-Brown G-matrix [6] as modified by Poves [7] and called KB3G. It did not produce satisfactory spectra within our model space and we did not pursue it further.

We used the same MSDI interaction and ^{56}Ni core to compute the spectra of the T_Z = +1 even-even nuclei ^{66}Ge and ^{70}Se, the daughters of the superallowed emitters ^{66}As and ^{70}Br. We found very acceptable agreement with experimental data, and used this interaction to calculate the charge dependent corrections for these decays too.

The decay of ^{74}Rb presented considerably greater difficulties. The MSDI interaction with the ($p_{3/2}$, $f_{5/2}$, $p_{1/2}$) model space produces approximately the right density of natural-parity states – the only states available in this model space – for A = 74, but the state-by-state correspondence with experiment is not good. Furthermore, a more obvious defect is that the experimental spectrum does include unnatural parity states. Evidently, the influence of the $1g_{9/2}$, $2d_{5/2}$, and possibly the $1g_{7/2}$ orbitals is quite strong at the end of the *p*, *f* shell. To examine the influence of the intruder orbitals, we calculated the charge-dependent corrections with three different model spaces: 1) the ($p_{3/2}$, $f_{5/2}$, $p_{1/2}$) space already described; 2) a ^{64}Ge core with model space $(f_{5/2}, p_{1/2}, g_{9/2})^{10}$ with the off-diagonal matrix elements between the *p*, *f* orbitals and the *g* orbitals multiplied by 0.15; and 3) a space of $(p_{3/2}, f_{5/2}, p_{1/2})^n + (p_{3/2})^8(f_{5/2}, p_{1/2})^{(n-10)} (g_{9/2}, d_{5/2}, g_{7/2})^2$, where n = A-56, for the natural parity states and of $(p_{3/2}, f_{5/2}, p_{1/2})^{(n-1)}(g_{9/2}, d_{5/2}, g_{7/2})^1 + (p_{3/2})^8(f_{5/2}, p_{1/2})^{(n-11)} (g_{9/2}, d_{5/2}, g_{7/2})^3$ for the unnatural parity ones. In the latter case, we multiplied all $< 0\hbar\omega|V|2\hbar\omega >$ matrix elements by 0.2, in order to place the first-excited 0^+ state in ^{74}Kr at 0.5 MeV, its experimental location. We calculated the charge-dependent corrections in all three model spaces and then used the spread in the results to determine our quoted uncertainty.

The charge-dependent corrections for ^{62}Ga, ^{66}As, ^{70}Br and ^{74}Rb were calculated with the techniques we have used before [3]. In particular, in calculating δ_{NS} we have used a known quenching factor [7] for the axial-vector coupling constant at the beginning of the *p*, *f* shell and then scaled it as $A^{1/3}$ for the heavier nuclei. Our results are shown in Table I. Together with our previous results for the lighter superallowed emitters, this completes a consistent set of calculations for all superallowed transitions likely to be measured with precision in the foreseeable future.

Table I: Adopted values for the nuclear-structure dependent corrections for superallowed beta emitters with $62 \le A \le 74$.

Parent	δ_{NS}(%)	δ_C(%)
$T_Z = 0$:		
^{62}Ga	-0.040(20)	1.380(16)
^{66}As	-0.050(20)	1.400(16)
^{70}Br	-0.060(20)	1.350(20)
^{74}Rb	-0.065(20)	1.430(40)

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