**Nuclear-Structure Dependent Corrections to Superallowed Beta Decay**

I.S. Towner[a] and J.C. Hardy

[a] *Queen's University, Kingston, Ontario, Canada*

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 $\delta_R$ is the nucleus-dependent radiative correction, $\Delta_R^V$ a nucleus-independent radiative correction and $\delta_C$ 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 $\delta_R$, $\Delta_R^V$ and $\delta_C$ are all of order $10^{-2}$.

It is also convenient to separate $\delta_R$ into two terms:

$$\delta_R = \delta_R' + \delta_{NS}.$$

The first term, $\delta_R'$, 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 $\delta_{NS}$.

Close to major shell closures the choice of model space and effective interaction is more problematical. We adopted the following strategy. For A = 14 and 18, we use the Cohen-Kurath interaction for *p*-shell interactions, the USD for *sd*-shell interactions and the Milliner-Kurath interaction [11] for the cross-shell matrix elements. For A = 38 and 42, we proceeded similarly using the USD interaction for *sd*-shell interactions, KB3

We have re-examined the two nuclear-structure dependent corrections, $\delta_{NS}$ and $\delta_C$. Our purpose was to calculate these corrections using the same or very similar methods as before but, where possible, improving on the previous shell-model calculations (for example, see [4-6]). More importantly, we aimed to calculate $\delta_R$ and $\delta_C$ consistently using the same model approximations for each and, at the same time, assess the accuracy with which these corrections can be obtained.

The choice of an effective interaction for shell-model calculations for light nuclei whose principal configurations involve several valence nucleons away from major shell closures is easily made. There are well established interactions that give excellent fits to spectra. For A=10, we use the Cohen-Kurath [7] interaction, (8-16)POT, and for A = 22, 26, 30 and 34, we use the universal *sd*-interaction, USD, of Wildenthal [8]. For nuclei A = 46, 50 and 54, we considered two interactions: the Kuo-Brown G-matrix as modified by Poves and Zuker [9] and denoted KB3, and the *fp*-model independent interaction of Richter *et al* [10] denoted FPMI3. For nuclei A=50 and 54 it was not possible to perform an untruncated calculation in the full *fp* space; our calculations only contain $(f_{7/2})^{n-r}(p_{3/2}, f_{5/2}, p_{1/2})^r$ configurations with $r \leq 2$.

for the *pf*-shell interactions the Milliner-Kurath interaction to provide the cross-shell interactions. For practical reasons, we also restricted the number of active orbitals. For A = 38, we use the $s_{1/2}$, $d_{3/2}$ and $f_{7/2}$ orbitals; while for A = 42, we use the $d_{3/2}$, $f_{7/2}$ and $p_{3/2}$ orbitals. We also considered the interaction constructed by Warburton *et al* [12] for A = 38 and 42. Again, for practical reasons, we truncated to just the $d_{3/2}$, $f_{7/2}$ and $p_{3/2}$ orbitals and we renormalized the interaction by adjusting its centroids to obtain reasonable spectra.

**Table 1**: Adopted values for the nuclear-structure dependent corrections for superallowed beta emitters with A ≤ 54

| **Parent** | $\delta_{NS}$(%) | $\delta_C$(%) |
|---|---|---|
| **$T_Z$ = -1:** | | |
| $^{10}$C | -0.360(35) | 0.180(18) |
| $^{14}$O | -0.250(50) | 0.320(25) |
| $^{18}$Ne | -0.290(35) | 0.620(32) |
| $^{22}$Mg | -0.240(20) | 0.260(14) |
| $^{26}$Si | -0.230(20) | 0.370(14) |
| $^{30}$S | -0.190(15) | 0.925(34) |
| $^{34}$Ar | -0.185(15) | 0.680(22) |
| $^{38}$Ca | -0.180(15) | 0.785(41) |
| $^{42}$Ti | -0.240(20) | 0.770(108) |
| **$T_Z$ = 0:** | | |
| $^{26m}$Al | 0.009(20) | 0.270(14) |
| $^{34}$Cl | -0.085(15) | 0.665(25) |
| $^{38m}$K | -0.100(15) | 0.670(36) |
| $^{42}$Sc | 0.030(20) | 0.485(42) |
| $^{46}$Ti | -0.040(7) | 0.435(32) |
| $^{50}$V | -0.042(7) | 0.495(36) |
| $^{54}$Co | -0.029(7) | 0.620(38) |

Our results for the nuclear-structure dependent corrections are shown in the Table. This is the first time that a full set of consistent calculations covering all of the light (A ≤ 54) superallowed emitters. In the near future, we will extend this work to the heavier emitters (A ≥ 62) as well.

## References


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