Superallowed $0^+!0^+$ Beta Decay

J. C. Hardy, V. E. Iacob, M. Sanchez-Vega, A. Azhari, C. A. Gagliardi, J. Giovinazzo$^a$, E. Mayes, R. G. Neilson, L. Trachte, R. E. Tribble, D. K. Willis and Y. M. Xiao

$^a$ Centre d’Etudes Nucléaires de Bordeaux-Gradignan, IN2P3/CNRS, France

At present, the most exacting test of the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix is provided by nuclear beta decay. Precise measurements of beta-decay transitions between analog $0^+$ states are used to determine $G_V$, the vector coupling constant; this, in turn, yields $V_{ud}$, the up-down element of the CKM matrix. To date, the $ft$-values for nine $0^+\to 0^+$ transitions have been determined to a precision of $\sim 0.1\%$ or better; this spans a wide range of nuclear masses from $^{10}\text{C}$, the lightest parent, to $^{54}\text{Co}$, the heaviest. As anticipated by the Conserved Vector Current hypothesis, CVC, all nine yield consistent values for $G_V$, but the value of $V_{ud}$ derived from their average yields a more provocative result. The unitarity test of the CKM matrix fails by more than two standard deviations: $\nuiz V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.9968 \pm 0.0014$. This result would have far-reaching consequences if it were to be confirmed with improved statistical definition.

We are already well advanced on an experimental and theoretical program aimed at reducing the uncertainty of the unitarity test by improving our knowledge of $\ast_C$. The experimental components of the program currently comprise the determination of $ft$-values for the superallowed beta decays of $^{22}\text{Mg}$ ($t_{1/2} = 3.9\text{ s}$), $^{30}\text{S}$ (1.2 s) and $^{34}\text{Ar}$ (0.8 s); and the observation of non-analog $0^+\to 0^+$ transitions from $^{62}\text{Ga}$ (0.1 s), and $^{74}\text{Rb}$ (0.06 s). The $^{74}\text{Rb}$ decay experiments are being undertaken with the new ISAC facility at TRIUMF; the others are taking place at Texas A&M, where we use the MARS spectrometer and the fast tape-transport system. The mass measurements required for precise determination of each $Q_{EC}$-value will be undertaken with the Canadian Penning Trap at the Atlas facility at Argonne. All five cases are additional to the nine already well-known superallowed transitions. Each has been selected because its calculated $\ast_C$ value is either particularly high (1-2\%) or particularly low (<0.3\%). If experiments confirm these extreme transition-to-transition differences, then the uncertainty in all $\ast_C$ values will be reduced accordingly.

Our initial emphasis is on the three lighter cases, $^{22}\text{Mg}$, $^{30}\text{S}$ and $^{34}\text{Ar}$. These nuclides share the same nuclear shell-model space as the nine currently contributing to the unitarity test and, particularly in the $sd$-shell, that model is extremely successful in calculating a wide range of nuclear properties. Thus, any discrepancies observed between theory and experiment for
these cases would directly reflect on the $\ast_c$ values now being used in the extraction of $V_{ud}$. None of these decays has previously been accessible to precise $ft$-value measurements since each parent decays by several beta transitions of comparable strength and the branching ratio for the superallowed transition must be determined from photo-peak intensities in the spectrum of beta-delayed gamma-rays. To be useful in the present context, these intensities are required to a precision approaching 0.1% over energy ranges from 70 to 1300, 670 to 2350 and 460 to 3130 keV, for $^{22}\text{Mg}$, $^{30}\text{S}$ and $^{34}\text{Ar}$, respectively. This is a very demanding requirement never previously achieved!

In subsequent reports we describe our measurement of branching ratios in the decay of $^{22}\text{Mg}$ [2], and of the half-life for the same nucleus [3]. Following that is a description of our first investigation into the $^{34}\text{Ar}$ decay [4]. These branching-ratio measurements, in which we record extremely clean beta-coincident gamma-ray spectra from pure source samples, have only become possible as a result of our success in efficiency-calibrating a HPGe detector to sub-percent precision with a combination of source measurements and Monte Carlo calculations [5]. As a further control on precision, we have also determined that beta-gamma angular correlations can have no significant affect on our results[6].

The short-term goals in our studies of the decays of the heavier N=Z nuclei, $^{62}\text{Ga}$ [7] and $^{74}\text{Rb}$ [8], are necessarily more modest. The $Q_{EC}$-values for such exotic nuclei are unlikely to be known with sufficient precision to determine a useful $ft$-value for some years to come. However, a less-precise measure of the $ft$-value for the non-analog $0^+$-to-$0^+$ transition to the lowest excited $0^+$ state in their daughters is definitely feasible. Such a transition can only occur through the effects of charge-dependent mixing, effects that also determine $\ast_c$. The measured $ft$-value will provide a valuable constraint on $\ast_c$.

Finally, with I.S. Towner on the theoretical side, we have undertaken a new, complete and consistent set of calculations for the nuclear-dependent parts of the radiative and charge corrections. It is these calculations which will ultimately be tested by our experiments and, if verified, will be used to determine an improved value of $V_{ud}$. The initial results of these calculations appear in a subsequent report [9] as well.

References

