Superallowed $0^+ \rightarrow 0^+$ Beta Decay: the Cases of ^{22}Mg and ^{30}S

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Superallowed $0^+ \rightarrow 0^+$ nuclear beta decays provide both the best test of the Conserved Vector Current (CVC) hypothesis in weak interactions and, together with the muon lifetime, the most accurate value for the up-down quark-mixing matrix element , V_{ud}, of the Cabibbo-Kobayashi-Maskawa (CKM) matrix. This matrix should be unitary, and experimental tests of that expectation constitute important tests of the Standard Model. With current world data for $0^+ \rightarrow 0^+$ nuclear beta decay [1,2] used to obtain a value for V_{ud}, and standard values [3] taken for the other required elements of the CKM matrix, the unitarity test from the sum of the squares of the elements in the first row fails to meet unity by more than twice the estimated uncertainty. This result is tantalizingly close to establishing a definitive disagreement with the Standard Model. The possibility of such an outcome is important enough to warrant a close examination of all aspects of the V_{ud} determination to establish its robustness and, if possible, to undertake new experiments to improve the precision of the unitarity result.

Careful examination [1,2] of the calculated radiative and isospin symmetry-breaking corrections applied to the data reveals no evident defects that could resolve the problem, but suspicion continues to fall on the latter, δ_C, which depends sensitively on the details of nuclear structure. If any progress is to be made in firmly establishing (or eliminating) the discrepancy with unitarity, additional experiments are required to focus on that issue. In the near future, the most promising approach appears to be in the study of $T_z = -1$ superallowed emitters with $18 \leq A \leq 38$. These nuclei are amenable to precision measurements and they cover a larger range of calculated δ_C values than the cases currently known.

As described in last year's Progress Report [4], we are preparing experiments to study these emitters, with the goal of achieving an accuracy in their measured *ft*-values of about ±0.1%. The first cases to be studied, ^{22}Mg and ^{30}S, were chosen because the calculated δ_C value for the superallowed transition from ^{22}Mg is very low, 0.35%, while that for ^{30}S is 1.2%, about a factor of two higher than for any case currently known (see fig 1). If the measured *ft*-values support this "large" calculated difference between the two cases, then the theoretical uncertainties associated with all calculated isospin symmetry-breaking corrections in this mass region can be reduced considerably.

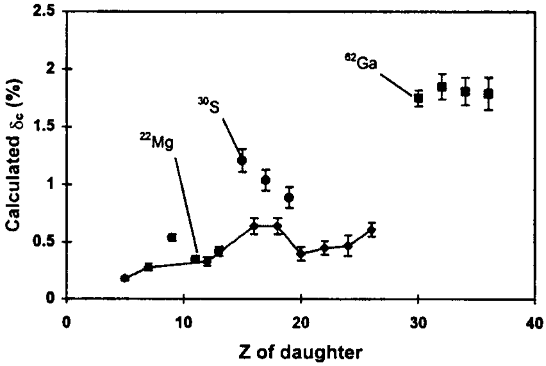

Figure 1: Calculated δ_C values plotted as a function of the Z of the daughter nucleus. The solid diamonds joined by the line represent the values of the nine well known superallowed emitters. The circles are for the $T_Z = -1$ emitters between ^{18}Ne and ^{38}Ca; while the squares are for the $T_Z = 0$ cases from ^{62}Ga to ^{74}Rb.

Since our first test run [2] with MARS established that we could produce ≥10,000 nuclei per second of 25 MeV/nucleon ^{22}Mg and ^{30}S, each with a sample purity of ≥99.6%, we have been building up the experimental equipment necessary to make precision measurements of half-lives and beta-decay branching ratios for short-lived activities ($t_{1/2} \geq 100$ ms). A fast tape-transport system has been built and commissioned [5], which is capable of moving a sample collected at the end of the MARS recoil spectrometer to a shielded counting location approximately 80 cm away in under 200 ms. The nuclei exiting MARS are degraded in energy and stopped in the 76 *μm*-thick tape after passing through a 0.3-mm-thick BC-404 scintillator disk mounted on a R329P Hamamatsu phototube, which counts each one individually. Thus, each collected sample contains a known number of atoms.

In the branching-ratio configuration at the counting location, the tape stops between two 1-mm-thick scintillator disks each mounted on a similar phototube. Behind one of these disks, in adjustable geometry, is placed a "Gamma-X" high-purity germanium detector with 70% relative efficiency. This arrangement allows us to record gamma-ray singles as well as γ-β_1-$\overline{\beta}_2$ events, in which the coincident β_1 is from the scintillator on the opposite side of the tape from the HPGe detector, and the anti-coincident $\overline{\beta}_2$ is from the scintillator on the same side. These events effectively eliminate background and spectrum distortion from betas being detected in the HPGe detector. Still under construction is a bismuth-germanate anti-Compton shield for the HPGe detector, which will be available for use when required. A dedicated data-acquisition system based on FERA electronics and KmaxNT software has also been developed [6] with the goal of reducing system dead-time to a minimum.

This gamma-ray counting system also will provide lifetime information, since each event will be tagged with the time elapsed since the last tape move. However, the high precision half-life measurement will be made with a different experimental configuration at the counting location. In this configuration the tape-transport system moves the collected sample directly into a 4π continuous gas-flow proportional counter sensitive to betas, from which signals are multiscaled [7]. This method has been used previously to measure half-lives with high precision [8].

Most components of these systems have been successfully commissioned in on-line operation with cyclotron beam. Serious data taking should begin in late summer of 1999.

References

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