

Half-life of the superallowed β -emitter ^{46}V

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The decay of ^{46}V was the first of the nine best-known superallowed transitions to have its Q_{EC} value measured (in 2005) with an on-line Penning trap [1]. The result differed significantly from the previously accepted result -- a longstanding reaction-based Q_{EC} value -- and shifted the ^{46}V ft value two standard deviations out of agreement with other well-known superallowed transitions. This apparent deviation from the conserved vector current (CVC) expectation raised several concerns, among them the possibility of systematic differences between reaction and Penning-trap measurements of Q values. As a result, several other measurements were performed, two with Penning-traps and one reaction based. All confirmed the new result.

In parallel with these experimental studies, the theory used in the analysis of the ^{46}V results was carefully reexamined as well and, as a result, the isospin-symmetry-breaking corrections were improved [2] by the inclusion of core orbitals in the model space used in the calculation. This improvement had the largest effect on the ^{46}V transition, but also had smaller effects on other superallowed transitions, especially on those in the $f_{7/2}$ shell. These new corrections, which were incorporated into the most recent survey of world data [3], eliminated the ^{46}V anomaly, restored the consistency with CVC and retained agreement with CKM matrix unitarity.

All these experimental and theoretical studies proceeded under the tacit assumption that the previously accepted half-life of ^{46}V was completely correct. Although there was no reason to suspect that this half-life result was in error, there had not been any reason to suspect that there was anything wrong with the now-discredited Q_{EC} value either. We have addressed this potential weakness and have made a new measurement of the ^{46}V half-life, which confirms the average of previous measurements but is a factor of two more precise than the best of them.

In that measurement, we produced ^{46}V via the $^1\text{H}(^{47}\text{Ti}, 2n)$ reaction at a primary beam energy of 32A MeV. A ^{46}V beam was obtained at the focal plane of the MARS spectrometer, from which it exited the vacuum system through a 50- μm thick Kapton window, passed through a 0.3-mm-thick BC404 scintillator and a stack of aluminum degraders, and finally stopped in the 76- μm thick aluminized Mylar tape of our fast tape-transport system. In addition to ^{46}V , there were four reaction products, ^{42}Sc ($t_{1/2} = 680.72$ ms), ^{43}Sc ($t_{1/2} = 3.891$ h), ^{44}Ti ($t_{1/2} = 60.0$ y) and ^{45}Ti ($t_{1/2} = 3.083$ h), that appeared between the extraction slits and were thus weak contaminants in the extracted ^{46}V beam. The presence of $^{44,45}\text{Ti}$ and ^{43}Sc was not problematic since their half-lives are more than four orders of magnitude longer than 423-ms ^{46}V . Our only concern was ^{42}Sc , another superallowed β -emitter with a rather similar half-life to that of ^{46}V . With the focal-plane acceptance slits of MARS set to a width of 7 mm, the total extracted beam contained 0.12% of ^{42}Sc nuclei. To minimize the effect of this small contaminant on our measurement, we carefully adjusted the distribution of implanted ^{46}V in the Mylar tape by setting the thickness of Al degraders to minimize the number of ^{42}Sc ions stopping in the tape. Finally, the composition of the beam

exiting MARS was checked on a daily basis during our half-life measurement. There were no appreciable changes observed in the extracted beam composition at any time.

After ^{46}V was collected on the tape for 0.3 or 0.5 s, the cyclotron beam was interrupted and the collected sample was moved in 180 ms to the center of a 4π proportional gas counter. Multiscaled signals from the counter were recorded for 10 s into two separate 500-channel time spectra, each corresponding to a different pre-set dominant dead-time. This “collect-move-count” cycle was repeated until high statistics were obtained. In its shielded location, the gas counter had a background rate of about 0.5 counts/s, which was 4 orders of magnitude lower than the initial count rate for each collected sample. In all, we recorded over 65 million β events from 14,422 cycles divided into 16 runs, which had various combinations of different bias voltages for the 4π proportional gas counter, discriminator thresholds, and dominant dead times.

The implantation profiles of ^{46}V and ^{42}Sc as determined by a combination of measurement (for ^{46}V) and calculation (for ^{42}Sc) are shown in Fig. 1. Although it is too small to be visible in the figure, our detailed scan of ^{46}V activity versus degrader thickness showed evidence of a very weak tail, amounting to $\sim 1\%$ of the total, extending to the left of the depth distribution. We take this result to be a good gauge of the upper limit for how many ^{42}Sc nuclei could have been retained in the collection tape. With this approach we can then conclude that the $^{42}\text{Sc}/^{46}\text{V}$ ratio in the collected samples was less than 0.0015 %.

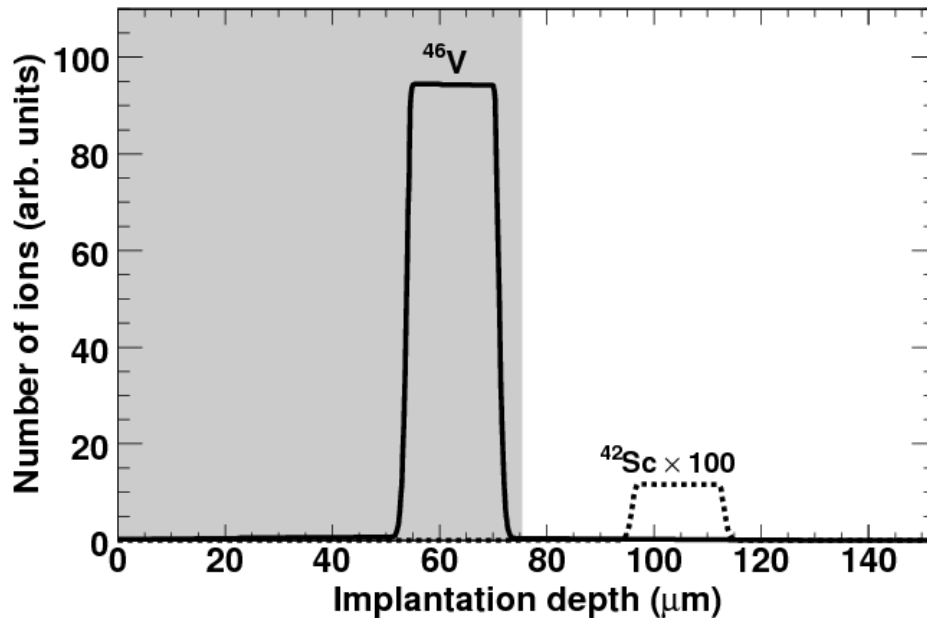


FIG. 1. The implantation profiles of ^{46}V (solid line) and ^{42}Sc (dashed line) in and beyond the Mylar tape, under the conditions applying to our half-life measurements. The beams enter from the left. The shaded region corresponds to the actual thickness of our collection tape: all ions within the shaded region are collected in our sample; all others are not.

We also used a second independent method to search for any evidence of ^{42}Sc activity by examining the recorded time-decay spectra. We fitted each spectrum from the 16 individual runs with a

function including two exponentials, one each for the decays of ^{46}V and ^{42}Sc , together with a constant background. In the first fit, we set the initial $^{42}\text{Sc}/^{46}\text{V}$ ratio of intensities to the 0.0015% value just obtained; set the half-life of ^{42}Sc to its world-average value, 680.72 ms [3]; and extracted a half-life for ^{46}V . Then we refitted the same 16 spectra with the initial $^{42}\text{Sc}/^{46}\text{V}$ ratio as the adjustable parameter. In this case, the half-life of ^{42}Sc was again set to its world-average value but the ^{46}V half-life was fixed at a range of values around the average value obtained from the first fit. We found that the $^{42}\text{Sc}/^{46}\text{V}$ ratio obtained from the fits was very insensitive to the half-life used for ^{46}V , and that, in all cases, the ratio was less than 0.01%. In arriving at the final half-life for ^{46}V and its uncertainty, we have adopted a very conservative range for the $^{42}\text{Sc}/^{46}\text{V}$ ratio, taking the value to be 0.006(6)%.

We fitted the data from each of the 16 runs separately, incorporating three components: ^{46}V , ^{42}Sc and a constant background. The half-life of ^{42}Sc was fixed at its known value of 680.72 ms [3] and the initial activity of ^{42}Sc relative to ^{46}V was set at 0.006%. Since each run was obtained with a different combination of detection settings, we could use the individually fitted half-lives of ^{46}V to test for any systematic dependence on those settings. As displayed in Fig. 2, the half-life results showed no

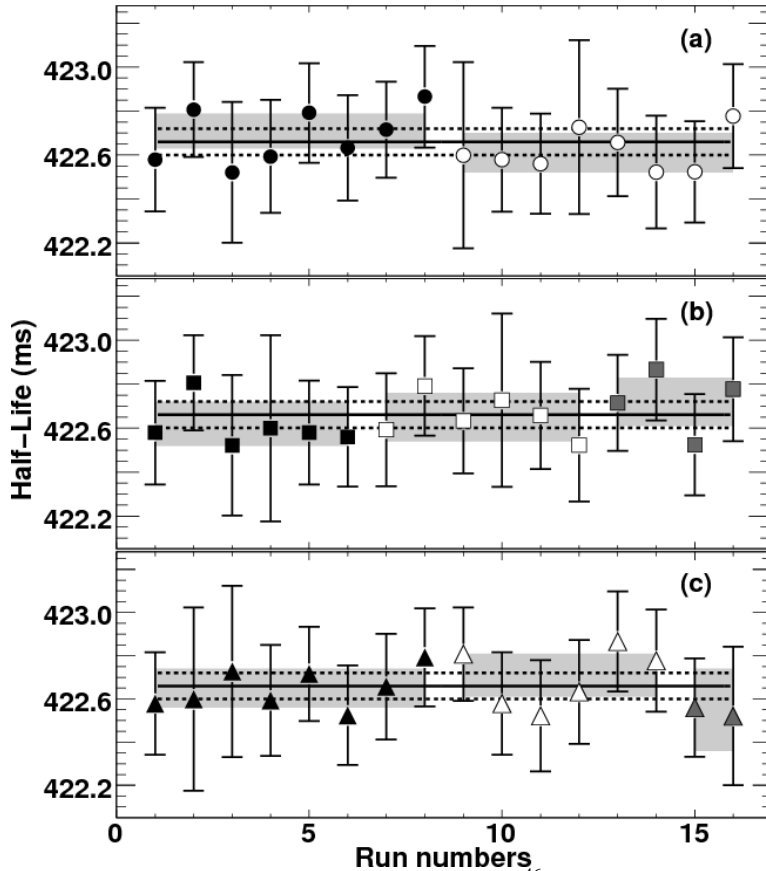


FIG. 2. Test for possible systematic bias in the ^{46}V half-life measurement due to three different detection parameters: (a) two detector biases, 2650V/2750V, represented by black/open circles; (b) three discriminator settings, 150 mV/200 mV/250 mV, represented by black/open/grey squares; (c) three imposed dead times, 4 μs /6 μs /8 μs , represented by black/open/grey triangles. Note that the runs have been grouped differently in each part of the figure. In all cases, the grey bands represent the $\pm\sigma$ limits of the average for a given condition. The average value for the half-life is 422.66(6) ms (statistical uncertainty only) with $\chi^2/\text{ndf} = 3.3/15$. The average value for all the runs appears as the solid line, with dashed lines as uncertainty limits.

systematic dependence on detector bias voltage, discriminator threshold setting, or the dominant dead time we imposed in the electronics, the average half-life yielding a remarkably low value for the normalized χ^2 of 0.2. With this degree of consistency in the data, we can be confident that any systematic dependence on detection parameters must be negligible with respect to our quoted statistical uncertainty.

Our final result for the half-life of ^{46}V is 422.66(6) ms. The quoted uncertainty includes provision for uncertainty in the $^{42}\text{Sc}/^{46}\text{V}$ ratio. This result is a factor of two more precise than the best previous result [4], with which it is completely consistent. If our half-life value is combined with previous measurements of the same quantity, it yields a new world average of 422.62(05) ms. This is statistically consistent with the previous world average [3] but is more than a factor of two more precise. Evidently, the important experimental components of the ^{46}V superallowed transition -- its half-life and Q_{EC} value -- have now been satisfactorily confirmed and improved. The Ft value for this transition is certainly not anomalous at the 0.08% level of precision currently quoted on that quantity.

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