Mass Measurements and Superallowed Beta Decay

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The recent CPT Penning-trap measurement of the Q_{EC} value for the superallowed decay of ^{46}V [1] disagreed significantly with the previously accepted value [2], a survey result principally based on a 30-year-old (^{3}He,t) Q-value measurement by Vonach et al. [3]. Since this result reduced the consistency among the $\mathcal{F}t$ values for the nine most precisely characterized T=1 superallowed beta emitters, it raised the possibility of a systematic discrepancy between *on-line* Penning-trap measurements and the reaction-based measurements upon which Q_{EC} values depended in the past.

We have carefully re-analyzed (n,γ) and (p,γ) reaction measurements in the $24 \leq A \leq 28$ mass region, and compared the results to very precise *off-line* Penning-trap measurements of the stable nuclei ^{24}Mg, ^{26}Mg and ^{28}Si [4]. Since the Penning-trap results are quoted to 13, 32 and 1.9 eV, respectively, we consider them to be free of systematic problems at the ~100 eV level, which concerns us here. From our comparison, we conclude that if any systematic differences exist between *off-line* Penning-trap and individual (n,γ) measurements, they must be less than 100eV. For (p,γ) reactions the limit is not so small: in that case, we conclude that any systematic differences must be less than 200 eV.

Based on well-founded (n,γ) and (p,γ) reactions, we then established two values for the mass excess of ^{26}Al, -12210.27(11) keV and -12210.21(22) keV. The first value does not include any provision for possible systematic effects in the reaction measurements on which it is based; the second value includes such provisions. We proposed that these two values together provide a critical standard for reaction-based results, against which a future on-line Penning-trap mass measurement could be compared. If the Penning-trap result were to lie within the limits of our first value (the one uncorrected for possible systematic effects), then one could be reasonably confident that actual systematic effects are below the upper limits we set; in that case Penning-trap measurements, when they proliferate, could simply be averaged in with the earlier reaction-based results. If the Penning-trap result were to lie outside the limits of our first value but inside the limits of our second value (adjusted for systematics), then one must suspect that reaction measurements in general might suffer from undiagnosed systematic effects; wherever their quoted uncertainties are in the few-hundred-eV region, they would need to be increased accordingly.

Finally, if the Penning-trap result were to lie outside the range of even our systematics-adjusted result, then that could be a sign of serious systematic difficulties, which could call into question all reaction-based measurements of superallowed transition energies or, conversely, could cast doubt on the precision of on-line Penning-trap measurements of radioactive isotopes. This would require serious and urgent attention, particularly in the evaluation of superallowed beta decay and its associated weak-interaction tests.

Since this work was published [4], we have measured the mass of ^{26}Al with the JYFLTRAP Penning-trap facility at the University of Jyväskylä cyclotron facility [5]. This is the first time it has been measured with a Penning trap. Our result, -12209.95(16) keV, does not differ significantly from either of the values we offer as a test; however, it certainly agrees more nearly with the systematics-adjusted value. We cannot therefore exclude systematic differences of up to ~100 eV between reaction-based and *on-line* trap measurements but anything significantly greater is ruled out. This conclusion is further supported by our Penning-trap Q_{EC}-value measurement for ^{42}Sc [5], which agrees well with the most precise previous result obtained from (n,γ) and (p,γ) reaction Q values [2].

We conclude that new Penning-trap Q_{EC} -value measurements, when they appear, can safely be averaged on an equal footing with previous reaction-based results. To date, on-line Penning-trap results are being quoted with uncertainties comparable to the best of the earlier measurements, so no large changes should be expected in the resultant averages. Evidently the discrepancy found in the case of ^{46}V was due simply to a 30-year-old experimental mistake, not to some widespread systematic problem.

[1] G. Savard, F. Buchinger, J.A. Clark, J.E. Crawford, S. Gulick, J.C. Hardy, A.A. Hecht, J.K.P. Lee, A.F. Levand, N.D. Scielzo, H. Sharma, I Tanihata, A.C.C. Villari and Y. Wang, Phys. Rev. Lett. **95**, 102501 (2005).

[2] J.C. Hardy and I.S. Towner, Phys. Rev. C **71**, 055501 (2005).

[3] H. Vonach *et al.*, Nucl. Phys. **A278**, 189 (1977).

[4] J.C. Hardy, I.S. Towner and G. Savard, Int. J. Mass Spec. **251**, 95 (2006).

[5] T. Eronen, V. Elomaa, U. Hager, J. Hakala, A. Jokinen, A. Kankainen, I. Moore, H. Penttilä, S. Rahaman, A. Saastamoinen, T. Sonoda, J. Äystő, J.C. Hardy and V. Kolhinen, (to be published).