Tests of internal-conversion theory with precise γ- and x-ray spectroscopy: the case of $^{119}Sn^m$

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In the past year we continued the study of the internal conversion coefficient (ICC) of the 65.7-keV *M*4 transition in $^{119}Sn^m$, which we described in last year's annual report. This is the latest in a series of precision measurements of the ICCs of high-multipolarity transitions to establish the accuracy of calculated ICCs and, in particular, to discriminate between the theoretical prescriptions used to deal with the atomic vacancy left by the emitted electron. The $^{119}Sn^m$ case has a lower Z than any case we have examined so far. The transition originates from the 293.1-day isomeric state at 89.5 keV in $^{119}Sn^m$, which decays 100% by cascade via a 65.7-keV *M*4 and a 23.9-keV *M*1/*E*2 transition. Since the latter cannot convert in the *K* shell, the *K* x rays in the measured photon spectrum from this decay scheme are exclusively from the *M*4 transition. Consequently, the *K* conversion coefficient for the *M*4 transition can be determined from the equation

$$\alpha_K \omega_K = \frac{N_K}{N_\gamma} \cdot \frac{\varepsilon_\gamma}{\varepsilon_K} \tag{1}$$

where ω_K is the fluorescence yield; N_K and $N\gamma$ are the total numbers of observed *K* x rays and 65.7-keV γ rays, respectively; and ε_K and ε_γ are the corresponding detector efficiencies. This is our standard method for making such measurements and, although our detector efficiency in the 23-29 keV region of the tin *K* x-rays is not as well established as it is at higher energies, we still anticipate being able to measure the ICC to high enough precision to distinguish between the theory that ignores the atomic vacancy and the one that includes it. The two calculated ICC values differ from one another by about 5%.

The main difficulty of this measurement comes from the large value of the total ICC, ~5000, which means that the γ-ray component of the 65.7-keV transition is extremely weak and difficult to detect. This difficulty is further increased by the small cross section for thermal-neutron capture on ^{118}Sn, ~10 mb, which we use to produce $^{119}Sn^m$. Also, as noted in last year's report, two impurity activities, ^{75}Se and ^{182}Ta, contribute quite strongly to the region of the 65.7-keV γ ray peak. In the case of ^{182}Ta, the subtraction of the impurity presents problems since the main ^{182}Ta γ-ray peak at 67.7 keV is unresolved from three tantalum K_β x-ray components, whose total strength relative to that of the γ ray depends critically on possibly unreliable published data.

To resolve this latter difficulty, we activated a thin foil of pure ^{181}Ta to produce a clean spectrum of ^{182}Ta decay. From the observed spectrum we planned to extract a template for the ^{182}Ta peak structure, which we could use to subtract the ^{182}Ta impurity from our primary $^{119}Sn^m$ spectrum. Unfortunately the spectrum of ^{182}Ta was affected by fluorescence *K* x rays from the tantalum, so the template itself required some correction. The template ratios extracted from both $^{119}Sn^m$ and ^{182}Ta spectra were in agreement and we used their average value for the final correction. In the end we determined that impurities accounted for 40.3(10) % of the 65.7-keV γ ray – 26.6(8) % from ^{182}Ta and 13.7(6) % from ^{75}Se.

We also addressed the problem of precise efficiency calibration for the 23-29-keV interval, where the tin *K* x rays and the 23.9-keV *M*1/*E*2 γ ray from ^{119}Sn^{m} decay are located. We produced samples of 54-minute ^{116}In^{m} by activating samples of about 1-mg of 99%-enriched ^{115}In oxide (In_2O_3) as a thin powder layer between two thin Mylar foils. Two separate activations were made in the Triga reactor of Texas A&M University, one for 10 s and the other 40 s, at a flux of 7.5×10^{12} n/(cm^{2}s). The nucleus ^{116}In^{m} β-decays to states in ^{116}Sn, which subsequently decay by γ-ray transitions that partially convert and thus produce tin x rays. Since the strong transitions are all of relatively high energy and low multipolarity their α_K values can be unambiguously calculated, so the intensity of the K x rays can be calculated relative to that of the γ rays in the observed spectrum. Applying Eq. (1) to this situation where we know α_K, we can deduce ε_K, the detection efficiency at 25.8-keV, which is the weighted average energy of Sn *K* x rays.

Although scattered photons have little effect on higher energy photo-peaks, at energies as low as 25 keV they make significant contributions to the peaks themselves. The amount depends strongly on the particular geometry of the experiment. For this reason, we measured the first ^{116}In source on our usual detector table, while for the second source there was a deep gap between the source and the detector. In both cases the distance between source and detector was 151 mm, the distance for which our detector is well calibrated (at higher energies). This distance was measured precisely and maintained by means of a laser-based device. The first of these two set-ups favored scattering, while the second one was essentially scattering-free. Indeed, there was a significant difference between the two results. Gratifyingly, the ε_K experimentally determined with the second scattering-free set-up was found to agree exactly with the Cyltran Monte-Carlo calculation for our detector.

Our analysis also revealed an unexpected impurity in the ^{116}In^{m} decay spectrum: namely indium *K* x rays coming from the (n,n’) population of a 4.5-hour, 336-keV isomeric state in ^{115}In. While we have never before encountered any significant (n,n’) population in our series of neutron-activation experiments at the Texas A&M Triga reactor, we convincingly identified this one by the energy and measured half-life of its 336-keV γ ray. We later confirmed that at the activation location in the reactor there is indeed an unavoidable fast neutron flux component that can account for population of the 336-keV ^{115}In isomeric state.

Finally by applying all corrections to the 65.7-keV transition from ^{119}Sn^{m}, we get the preliminary result α_K(exp) = 1607(60). This can be compared to the calculated ‘no-hole’ value of α_K(calc) = 1544 and ‘with-hole’ value of α_K(calc) = 1618, which accounts for the hole using the “frozen orbital” method. Our previous α_K measurements on heavier nuclei have all favored the latter calculations. In this case, our preliminary result shows the same preference but the high uncertainty so far precludes a definitive statement. We plan next to consolidate our measured result and, if possible, reduce its uncertainty.