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

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We have been making precision measurements of the Internal Conversion Coefficients (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. We are now extending our series of measurements to the 65.7-keV *M*4 transition in $^{119}\mathrm{Sn}^{m}$, which has a lower Z than any case we have examined so far. This transition originates from the 293.1-day isomeric state at 89.5 keV in $^{119}\mathrm{Sn}^{m}$, which decays 100% by cascade via a 65.7-keV *M*4 and a 24-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

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

where ω_K is the fluorescence yield; N_K and N_γ 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 25-29 keV region of the *K* x-rays is not as well established as it is at higher energies, we still anticipate being able to measure the ICC to a precision of ~2%. This is sufficient precision to distinguish between the theory that ignores the atomic vacancy and the one that includes it, since the calculated ICC values differ from one another by 4.9%.

The main difficulty of this measurement comes from the large value of the 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 $^{118}\mathrm{Sn}$, ~10 mb, which we use to produce $^{119}\mathrm{Sn}^{m}$. Finally, our provider, Trace Science International, had difficulty with rolling thin tin metallic foils for us, so the best sample we received of 99%-enriched $^{118}\mathrm{Sn}$ was a foil 1 cm^2 in area and about 8 μm thick. Such a thick source led to the attenuation of K x rays being about 1.5% greater than the attenuation of 65.7-keV γ rays, a rather high value for precision work.

At a thermal neutron flux of 7.5×10^{12} n/(cm^2 s) in the Texas A&M Triga reactor, 120 hours of activation time were needed to yield a subsequent rate of 160,000 events the 65.7γ-ray peak per month of counting with our HPGe detector at 15.1 cm from cap to foil. Such a long activation time led to some unwanted effects: the thin tin foil adhered to its aluminum container, so we found it “stuck” at the bottom of the can; in addition, a corrosion process of some kind affected the surface of the foil. However, despite these impediments we were able to free the foil and use it for data acquisition with our HPGe detector.

Because of the weakness of the 65.7γ-ray, we designed and produced a Cu-Pb detector shield to reduce the counting rate in our detector from room background by a factor of about 50 compared to the normal unshielded background. Under these conditions we acquired a spectrum for 45 days.

Our impurity analysis of the acquired spectrum revealed the presence of ^{113}Sn, ^{117}Sn^{m}, and ^{125}Sb, all of which contribute at the level of a few percent to the 25-29 keV energy region where the tin K x rays appear. Two other impurities, ^{75}Se and ^{182}Ta, were seen to contribute much more strongly (20% for ^{75}Se and 30% for ^{182}Ta) to the region of the 65.7-keV γ ray. In the case of ^{182}Ta, the subtraction of the impurity presented problems because the main ^{182}Ta peak at 67.7 keV is a mixture of a strong γ ray plus three K_{β} x-rays components. For this reason we did an auxiliary experiment in which we activated a thin foil of pure ^{181}Ta to produce a pure spectrum of ^{182}Ta decay. We will use this result to provide a template for the contribution of the ^{182}Ta impurity in our ^{119}Sn^{m} data.

We also plan to activate an ^{115}In target to produce ^{116}In, which β decays to ^{116}Sn and produces γ rays and tin x rays of known relative intensity. We will use a measurement of the resulting spectrum to get an efficiency-calibration point exactly at the Sn Kx-ray energy. Also we plan to address the problem of Compton scattering affecting the Sn Kx-ray energy region by Monte Carlo simulations and by measurements with a thin silicon x-ray detector.