Tests of internal-conversion theory with precise γ- and x-ray spectroscopy: The case of ^{125m}Te

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Internal conversion is an important component of most nuclear decay schemes. In order to balance decay schemes correctly, one needs to know the internal conversion contribution to each transition as expressed by its internal conversion coefficient (ICC). Nevertheless, ICCs are only rarely measured; instead they are taken from tabulations. As a result, calculated ICCs are essential input to every decay scheme, except those for the lightest nuclei. Unfortunately, over the decades, tabulated ICC values have differed significantly from one calculation to another by a few percent. Although for many applications such differences can be tolerated, transitions used in critical calibrations require very precise and accurate ICC values, precision that has simply been impossible to guarantee at the one-percent level or below.

In order to correct for this deficiency one can only seek guidance from measured ICCs that have sufficient precision to distinguish among the various calculations. However, as recently as about a decade ago, when a survey of measured ICCs was made by Raman et al. [1], there were only five published ICC values with precision of the order of ±1%, not enough to make any definitive conclusion possible. At that time, one aspect of the ICC calculations remained a particular concern. The final-state electron wave function must be calculated in a field that adequately represents the remaining atom. But should that representation include the atomic vacancy created by the conversion process? Some calculations included it and some did not.

Thus the problem of measuring ICCs at the ±1% precision level became critical and, with our very precisely efficiency-calibrated HPGe detector [2], we found ourselves in a position to be able to address it. Consequently, over the past decade we have been measuring a series of ICCs [3] covering a wide range of atomic numbers, $50 \leq Z \leq 78$. So far, all these results have indicated that the atomic vacancy should be taken into account in the calculations. The most recent case, the 109.3-keV $M4$ transition depopulating ^{125m}Te, is reported here. We selected it because previous measurements of its α_K value disagreed with theory, whether or not the vacancy was accounted for.

The total intensity of an electromagnetic transition is split between γ-ray emission and electron conversion, which can take place in several atomic shells and subshells, and is followed by the corresponding x rays. If only K-shell conversion is considered, then one can use the following formula to determine the K-shell conversion coefficient, α_K:

$$ {}_K \quad {}_K = \frac{N_K}{N} \quad \frac{}{{}_K} , \tag{1}$$

where ω_K is the fluorescence yield, which we take from Ref. [4]; N_K and N_γ are the respective peak areas of the K x rays and the γ ray; and ε_K and ε_γ are the corresponding detector absolute efficiencies.

The transition of interest here is the 109.3-keV, *M4* transition in ^{125}Te, which depopulates the 144.8-keV, 57.4-day isomeric state. The measurement is complicated by the fact that the *M*4 transition is followed by a 35.5-keV, *M1+E2* transition to the stable ground state. (The *E2* admixture, δ = 0.031(3) is small.) With a large value of $\alpha_K(35.5) = 11.64$[*], the *K* x rays from the conversion of the 35.5-keV transition constitute about 60% of the total strength of the tellurium *K* x-ray peaks in the spectrum. Thus, to achieve precision on the strength of K x rays attributable to the 109.3-keV transition, which is required to apply Eq. (1), a very precise detector efficiency is required at 35.5 keV γ-ray energy, as well as at 109.3 keV and at 28.0 keV, the weighted average energy of the tellurium *K* x rays.

Our detection efficiency for the 109.3-keV γ ray is known to within ±0.15% relative precision but, as described in Ref. [2], the original detector calibration was only established with that precision at energies above 50 keV. Accordingly, a special investigation was required to determine efficiency values below 50 keV, a task made especially difficult by the scattered radiation that becomes increasingly difficult to distinguish from the total-energy peak as the γ-ray energy decreases [3]. We obtained efficiencies at two different energies. The first, at 22.6 keV, was obtained with a standard ^{109}Cd source, which produces an 88-keV γ ray and 22.6-keV silver *K* x rays. The second, at 34.1 keV, came from the decay of locally made ^{139}Ba, which yields 165.9-keV γ rays and 34.1-keV lanthanum *K* x rays. For both sources the relative intensities of their γ and x rays are well known so this allowed the low energy data to be connected to the higher-energy data, for which our detector efficiencies were well established. We quote the efficiencies at the lower energies with an uncertainty of ±1%.

A ^{125m}Te radioactive source was prepared from 99.9%-enriched ^{124}Te, which was in the form of a thin disk 0.5 μm thick and 17 mm in diameter electroplated on a 10-μm thick pure Al backing. The source was activated by thermal neutrons for 24 h at the Nuclear Science Center TRIGA reactor of Texas A&M University to produce a very pure ^{125m}Te radioactive source, which we measured for several days. The spectra were carefully searched for impurities but no major impurities were detected.

Because of the contribution from the 35.5-keV transition to the x-ray peak, our result, $\alpha_K(109.3) = 187.2(58)$, is rather less precise than in our previous measurements but it is quite sufficient to refute the previous measurements, 166(9) and 166(11), and confirm the theoretical ICC calculation. Furthermore, it clearly shows a preference for the theory that includes the vacancy, which yields $\alpha_K = 186$, over the calculation that ignores the vacancy, which yields $\alpha_K = 179$ but the experimental uncertainty prevents that discrimination from being conclusive.

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[*] Average value calculated with the interpolator code BrIcc (http://bricc.anu.edu.au) of 11.68 (including vacancy, "frozen orbital" approach) and 11.60 (excluding vacancy).

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