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METHOD FOR MEASURING INTERNAL CONVERSION COEFFICIENTS USING A
BENT-CRYSTAL GAMMA-RAY MONOCHROMATOR AND A MAGNETIC ELECTRON SPECTROMETER*

E. N. Hatch, G. W. Eakins, G. C. Nelson, and R. E. McAdams
Institute for Atomic Research and Department of Physics
Iowa State University, Ames, Iowa (USA)

MASTER

A direct method for experimentally determining internal conversion coefficients has been studied with the hope of achieving accuracy of 5 per cent or better for many nuclear transitions of interest. In this method the relative intensities of internal conversion lines from a radioactive source are determined with a magnetic electron spectrometer. The relative intensities of the gamma rays from the same source are then determined by a least-squares analysis of the NaI pulse-height spectrum using monochromatic response functions obtained with a bent-crystal gamma-ray diffraction monochromator, as has been described previously^{1,2}). Relative internal conversion coefficients are then obtained by taking the ratio of the conversion line intensities to the gamma-ray relative intensities. In order to normalize the relative internal conversion coefficients, a $\text{Te}^{123\text{m}}$ source is mixed with the source to be measured, and the experimentally measured Te^{123} 159-keV internal conversion coefficient is used for the normalization standard. To illustrate this method, internal conversion coefficients of the Yb^{170} 84-keV transition have been determined.

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For measuring the Yb^{170} 84-keV coefficients, a radioactive source was prepared by evaporation in vacuum of Tm^{170} onto 1/4 mil aluminized mylar. The electron spectrum showing the internal conversion lines of the Yb^{170} 84-keV transition along with conversion lines from the Tm^{171} contamination, as recorded at a momentum resolution of 1 per cent in an intermediate-image magnetic spectrometer, is shown in slide 1. A second source prepared with $\text{Te}^{123\text{m}}$ was obtained by neutron irradiation of a sample of enriched Te^{120} but containing all Te isotopes in the MTR at Arco, Idaho. The Te^{123} was then separated from the other Te isotopes in the Ames Laboratory electromagnetic isotope separator³⁾. The electron spectrum from the separated $\text{Te}^{123\text{m}}$ source is shown in slide 2. From this spectrum, assuming the 89-keV transition is 100 per cent internally converted, the K- and L-shell conversion coefficients of the Te^{123} 159-keV transition can be easily determined using the relation

$$\alpha_{K,L}^{(159)} = \frac{e_{K,L}^{(159)}}{e_K^{(89)} + e_L^{(89)} + e_{M+N+\dots}^{(89)} - e_K^{(159)} - e_L^{(159)} - e_{M+N+\dots}^{(159)}}$$

where the $e_X^{(E)}$ are the relative intensities of the conversion lines for transitions of energy E. The results for conversion coefficients of the Te^{123} 159-keV transition are shown in Table 1. The total conversion coefficient for the 89-keV transition is $\alpha_T \approx 1200$ from the theoretical values^{5,6)}. This value would add an uncertainty in the 159-keV coefficients of the order of 0.1 per cent.

A third source was then prepared for the electron spectrometer by first evaporating $\text{Te}^{123\text{m}}$ on 1/4 mil aluminized mylar, and subsequently evaporating Tm^{170} source material over the $\text{Te}^{123\text{m}}$. The $\text{Te}^{123\text{m}}$ was obtained

by irradiating enriched Te^{122} in the same irradiation with the Te^{120} previously mentioned. The electron spectrum obtained from this "mixed" source is shown in slide 3.

For determining the internal conversion coefficients of the Yb^{170} 84-keV transition, the relative intensities of conversion lines of the Te^{123} 159-keV K transition and the Yb^{170} 84-keV L transition were measured with the mixed source. The same source was then placed on the focal circle of the bent-crystal diffraction spectrometer at the point V as shown in slide 4. The gamma-ray pulse-height spectrum was obtained by exposing this source directly to the NaI detector of the spectrometer with the bent diffraction crystal removed. Examples of NaI pulse-height spectra obtained for the $\text{Te}^{123\text{m}}$ and for Tm^{170} sources recorded individually are shown in slide 5. The NaI pulse-height spectrum of the source of the $\text{Te}^{123\text{m}}$ - Tm^{170} mixture placed on the bent-crystal spectrometer focal circle is shown in slide 6.

In order to obtain the relative intensities of the Te^{123} 159-keV gamma ray and the Yb^{170} 84-keV gamma ray in the mixed source, the monochromatic response functions for these two gamma rays along with those for the $\text{Yb } K_{\alpha}$ and $\text{Yb } K_{\beta}$ x-rays were determined using separately $\text{Te}^{123\text{m}}$ and Tm^{170} line sources in the bent-crystal spectrometer. In order to obtain the response functions, the bent-crystal spectrometer was set at the Bragg angle corresponding to these lines so that after diffraction, photons of only one energy were incident on the NaI crystal at each setting. The pulse-height spectrum for each Bragg angle setting was then recorded in a 400-channel pulse-height analyzer. The response functions obtained in this way are shown in slide 7. When the computer analysis of the relative intensities was obtained, it was apparent that there was a 19% contribution

to the peak containing the 84-keV photopeak on the low energy side in the pulse-height spectrum from the mixed source. This peak had an energy corresponding to the Pb K x-rays, and apparently arises in the Pb collimator and shielding of the spectrometer.

When the relative intensities of the Te^{123} 159-keV and Yb^{170} 84-keV gamma rays were obtained, corrections were made for the bremsstrahlung background distribution from the Tm^{170} beta particles, for the energy dependence of the absorption in the air path, the absorption in the aluminum cover of the NaI crystal, and the efficiency of the NaI detector.

The L conversion coefficient for the Yb^{170} 84-keV transition was then obtained from the ratios of the electron line intensities $[e_x^{(E)}]$ and the gamma-ray intensities $[\gamma^{(E)}]$ from the mixed Tm^{170} - Te^{123m} source using the formula:

$$\alpha_L^{84} = \frac{\gamma^{159}}{\gamma^{84}} \cdot \alpha_K^{159} \cdot \frac{e_L^{84}}{e_K^{159}}.$$

The K and M+N+... conversion coefficients for the Yb^{170} 84-keV transition were then obtained from the determined α_L^{84} and the K:L:M+N+... electron ratios from the separate Tm^{170} source. The Yb^{170} 84-keV coefficients obtained in this way are:

$$\alpha_K = 1.47 \pm 0.09, \alpha_L = 4.11 \pm 0.21, \alpha_{M+N+\dots} = 1.38 \pm 0.08$$

The value for the K conversion coefficient of the Yb^{170} 84-keV transition is compared with theoretical values of Rose⁵⁾ and Sliv and Band⁶⁾ and with some other recent experimental determinations⁷⁻¹⁰⁾ in Table 2.

The errors in the determination of the Yb^{170} 84-keV coefficients resulted principally from the electron intensities due to uncertainties

in the background, from back scattering and absorption in the source.

At higher energies where these effects are not so pronounced, conversion line relative intensities can be determined in many cases with uncertainties of 2 to 3 per cent. Similarly, the gamma-ray relative intensities in many cases can be determined with uncertainties of the order of 2 to 3 per cent. Therefore, it is estimated that it is possible to obtain experimentally measured internal conversion coefficients with this method with accuracies within 5 per cent.

REFERENCES AND FOOTNOTES

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TABLE 1 159-keV Transition in Te^{123}

	Present Result	Previous Measurement ⁴⁾
α_K	0.170 ± 0.004 K:L=7.4 ± 0.2	0.165 ± 0.005 K:L=6.6 ± 0.3
α_L	0.0229 ± 0.0009	
$\alpha_{M+N+\dots}$	0.0050 ± 0.0005	

TABLE 2 84 keV Transition in Yb^{170}

	α_K (Experimental)	α_K (Theoretical)
Present Result	1.47 ± 0.09	
Dingus and Talbert ⁷⁾	1.48 ± 0.05	Rose ⁵⁾ 1.33
Huotari ⁸⁾	1.46 ± 0.05 - 0.03	Sliv and Band ⁶⁾ 1.36
Jansen <u>et al.</u> ⁹⁾	1.57 ± 0.10 - 0.15	
Thosar <u>et al.</u> ¹⁰⁾	1.31 ± 0.08	