Precise measurement of α_K and α_T for the 39.8-keV *E*3 transition in ^{103}Rh: Test of internal-conversion theory

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For more than a decade, we have been testing internal-conversion theory through precise measurements of K-shell internal-conversion coefficients, α_K, for high-multipolarity transitions [1]. Our most recent measurement – the ninth – is of a 39.8-keV *E*3 transition, which de-excites the isomeric first-excited state in ^{103}Rh. Rhodium is the lowest-Z nucleus we have investigated so far.

As illustrated in Fig. 1, the isomeric $7/2^+$ state can be produced both in the β^- decay of ^{103}Ru and in the electron-capture decay of ^{103}Pd. Using sources neutron-activated at the Texas A&M TRIGA reactor, we have studied both decays.

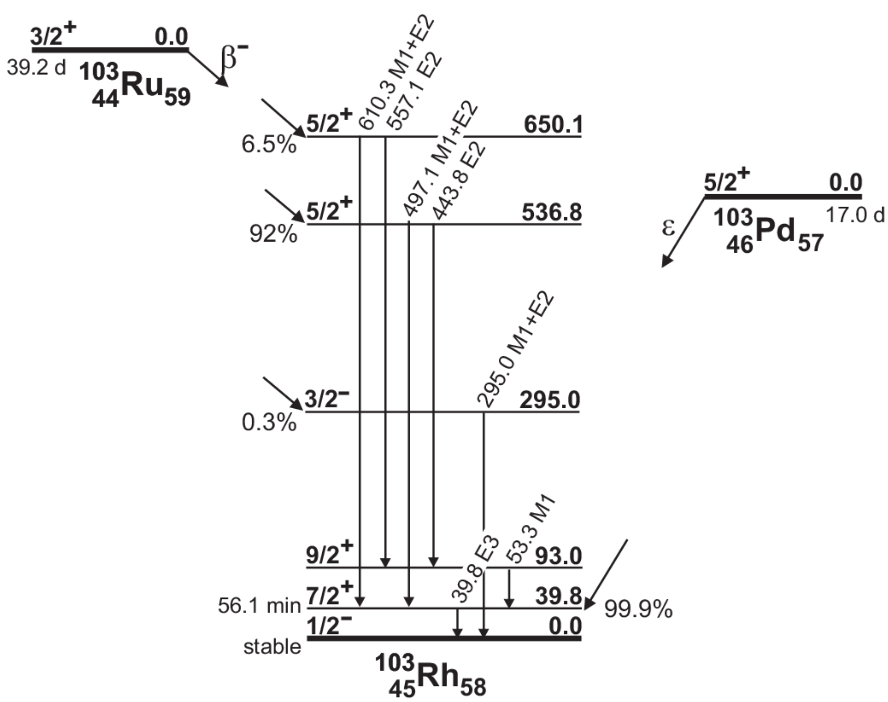

FIG. 1. Simplified decay scheme for the β- decay of ^{103}Ru and the electron-capture decay of ^{103}Pd feeding excited states in their common daughter, ^{103}Rh.

In simple cases with a single transition that can convert in the *K* shell the value of α_K is given by

$$\alpha_K = \frac{N_K}{N_\gamma} \times \frac{\varepsilon_\gamma}{\varepsilon_K} \times \frac{1}{\omega_K}, \qquad (1)$$

where ω_K is the fluorescence yield, N_K and N_γ are the total number of observed *K* x rays and γ rays, respectively; and ε_γ and ε_K are the corresponding photopeak detection efficiencies. If the 39.8-keV level is produced by the ^{103}Ru-decay route, then the decay effectively satisfies the conditions for Eq. (1), with only small corrections needed to account for conversion by the other transitions produced.

The three transitions feeding the 39.8-keV level in the decay of ^{103}Ru also yield a benefit. Because the level is not fed by β decay, the total intensity of the electromagnetic transitions populating the state must equal the total intensity of the transition depopulating it. Thus we can determine the total ICC, α_T, for the 39.8-keV level via the equation,

$$\sum_i (1+\alpha_{Ti})\frac{N_{\gamma i}}{\varepsilon_{\gamma i}} = (1+\alpha_{T39.8})\frac{N_{\gamma 39.8}}{\varepsilon_{\gamma 39.8}} \tag{2}$$

where the sum is over all transitions that populate the 39.8-keV level.

The situation might seem to be simpler for the decay of ^{103}Pd since it populates the 39.8 keV state uniquely. There is a complication, however, because electron-capture decay gives rise to *K* x rays in similar numbers to the subsequent internal conversion. From this decay, we can establish a relationship between α_K and α_T as follows:

$$\alpha_K + (1+\alpha_T)P_{ec,K} = \frac{N_K}{N_\gamma}\times\frac{\varepsilon_\gamma}{\varepsilon_K}\times\frac{1}{\omega_K} \tag{3}$$

Where $P_{ec,k}$ is the probability per parent decay for electron capture out of the atomic *K* shell.

We recorded sequential ~12-hour decay spectra, later added together for each source. In total, ^{103}Ru decay was recorded for 41 days spread over 3 months; ^{103}Pd decay was recorded for 21 days spread over 2 months. Careful attention was paid to detector efficiency and to corrections for small impurities, attenuation in the sample, fluorescence and the Lorentzian x-ray peak shapes (see [2] for details).

From the combined ^{103}Ru and ^{103}Pd decay data we obtained α_K = 141.1(23) and α_T = 1428(13) for the 39.8-keV transition. In Table 1 these results are compared with Dirac-Fock calculations, with and without the *K*-shell vacancy, and with and without a small contribution from *M*4 into this predominantly *E*3 transition. Our results strongly disagree with the calculations that ignore the vacancy, which is consistent with the conclusion drawn from our series of measurements on high-multipolarity transitions in nuclei with higher *Z*. However, our results disagree with the vacancy-included results as well, albeit by a smaller amount. This latter disagreement disappears entirely if we assume a 0.04% *M*4 admixture (δ=0.02), which is allowed by the upper limit set in the only existing prior study of the mixing ratio [3].

Table I. Comparison of the measured α_K and α_T values for the 39.752(6)-keV *E*3 transition in ^{103}Rh with calculated values based on two different theoretical models, one that ignores the *K*-shell vacancy and one that deals with it in the "frozen orbital" approximation. Shown are the percentage deviations Δ from the experimental values calculated as (experiment-theory)/theory. Calculated values are given, both for a pure *E*3 transition and for an *E*3+*M*4 transition with a mixing ratio of ö=0.02.

Model	**α_K**	**Δ(%)**	**α_T**	**Δ(%)**
Experiment	141.1(23)		1428(13)	
Theory:				
(a) Pure *E*3				
No vacancy	127.5(1)	+10.7(18)	1388(2)	+2.9(9)
Vacancy, FO	135.3(1)	+4.3(17)	1404(1)	+1.7(9)
(b) *E*3+*M*4 δ=0.02				
No vacancy	131.3(1)	+7.5(18)	1410(2)	+1.3(9)
Vacancy, FO	139.4(1)	+1.2(17)	1426(2)	+0.1(9)

Finally, if we take the position that the need for the vacancy to be included in ICC calculations has already been proven by our previous eight measurements, then we can use these calculations to determine the mixing ratio that best fits the data for α_K and α_T. Doing so, we determine the mixing ratio for the 39.8-keV transition to be δ = 0.023(5). It appears that this is the first transition ever observed with mixed E3 + M4 character and a definitively non-zero mixing ratio.

[1] J.C. Hardy *et al*., Progress in Research, Cyclotron Institute Texas A&M University (2018-2019) p. I-9.

[2] N. Nica, J.C. Hardy, V.E. Iacob, V. Horvat, H.I. Park, T.A. Werke, K.J. Glennon, C.M. Folden III, V.I. Sabla, J.B. Bryant, and X.K. James, Phys. Rev. C **98**, 054321 (2018).

[3] H. Pettersson, S. Antman, and Y. Grunditz, Z. Phys. **233**, 260 (1970); **235**, 485(E) (1970).