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LIFETIME OF THE 21.7-keV STATE IN Eu^{151}

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ABSTRACT

Using sodium iodide detectors and a time-to-height converter, the half-life of the 21.7-keV state in Eu^{151} was measured as (9.5 ± 0.5) ns. The 21.7-keV, ℓ-forbidden M1 transition is found to have a hindrance factor of 118. These results indicate that in the approach to the deformed region, the hindrance factors for the ℓ-forbidden M1 transitions from the first excited state to the ground state in Eu^{147}, Eu^{149} and Eu^{151} do not decrease monotonically, as had been previously suggested.

LIFETIME OF THE 21.7-keV STATE IN Eu^{151} *

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1. Introduction

Recently, Shirley et al. observed the Mössbauer effect of the 21.7-keV transition in Eu^{151} and were able to place a lower limit of 6.8 ns on its half-life.[1] Early attempts to measure this half-life by delayed coincidence techniques proved inconclusive.[2] During the course of this work, Berlovich et al. reported its value as 3.4 ± 0.2 ns.[3] In their investigation, the latter authors used thin stilbene crystals to detect coincidences between the K-conversion electrons from the 175-keV transition and L, M and N electrons from the 21.7-keV transition.

In this paper are presented results, obtained with the aid of NaI crystals, which differ considerably from those reported by Berlovich et al.[3]

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2. Experimental

For this study, Gd^{151} was produced by a (p,n) reaction on Eu_2O_3 (enriched in Eu^{151}), from which it was separated by the usual ion-exchange techniques.†

The decay of 140-d Gd^{151} populates the 21.7-keV level of Eu^{151}. Although many workers have investigated this decay,[3,4-7] a final decay scheme has not yet been presented. However, from a summarization of the previous work, it appears as though the scheme shown in fig. 1 is the best available at this time. Some qualitative coincidence experiments on our part were in agreement with this proposed scheme. For our purposes, we were mainly concerned with the manner in which the 21.7-keV level is populated. The excess intensity of the K x-ray and 21.7-keV transitions relative to the other transitions, suggested that the 21.7-keV level is predominantly fed by electron capture. This predominant electron-capture population of the 21.7-keV level was confirmed by photon-photon coincidence studies.

For the half-life measurements, the 21.7-keV photon was detected in a 2.54-cm dia. x 0.3-cm thick NaI (Tℓ) crystal with a 0.13-mm beryllium cover. A similar crystal was used to detect the K x-rays. A 5.1-cm dia. x 5.1-cm thick NaI (Tℓ) crystal was used to gate on the 175-and 155-keV photons. The electronics consisted of a typical fast-slow coincidence system, utilizing a time-to-height converter and a RIDL 400-channel analyzer. Measurements were performed in both 90° and 180° geometry with identical results.

<u>155, 175 keV - 21.7 keV Coincidences.</u>

One method used to measure the half-life of the 21.7-keV state was as follows: The pulses from the 5.1cm x 5.1cm scintillation spectrometer

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† The sources were kindly provided by Dr. D. A. Shirley of this department.

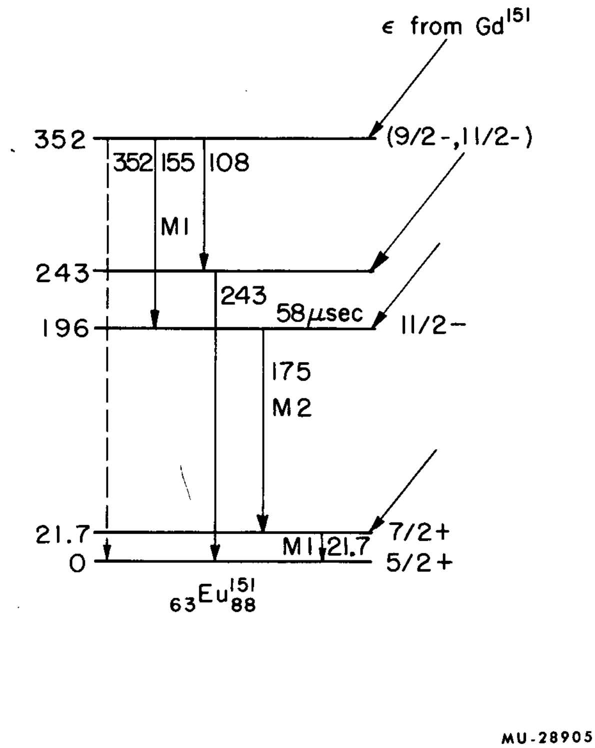

Fig. 1. Tentative decay scheme of Gd^{151}.

were fed into two single channel analyzers, one set to pass pulses with heights corresponding to the lower third of the 155 to 175 keV composite photon peak and the other set to pass pulses from the upper third. The outputs of these analyzers were put in slow coincidence with the output of a third single-channel analyzer, which gated on pulses with heights corresponding to the upper half of the 21.7-keV photon peak detected in the thin NaI crystal. The 400-channel analyzer was gated by the output of the slow coincidence circuit, and programmed to record the delay curve arising from the lower third of the 155+175 keV peak, (henceforth designated as 155-keV delay curve) in the first half of the memory, and from the upper third (henceforth designated as 175-keV delay curve) in the second half of the memory. The results are shown in fig. 2.

The 155-keV delay curve predominantly arises from prompt coincidences between the 155-keV photon and that portion of the K x-ray distribution that underlies the upper half of the 21.7-keV photon peak. If one considers this curve as representing the "prompt" curve, then the half life of the 21.7-keV state can be determined from the slope of the 175-keV delay curve. The latter yields a value

$$T_{1/2} = 9.8 \text{ ns.}$$

It should be noted that the 155-keV delay curve has not been corrected for contributions from other cascades. Analysis has shown that the 175-keV delay curve contains less that $\approx$ 20% prompt coincidences, assuming the 155-keV delay curve represents the "prompt" spectrum.

In view of the large discrepancy between our value for the half-life of the 21.7-keV state in the Eu^{151} and that reported by Berlovich et al.,[3] we have analyzed the data shown in fig. 2 by the centroid shift method.[8] Since we have not "purified" either the 155-keV "prompt" curve, or the 175-keV

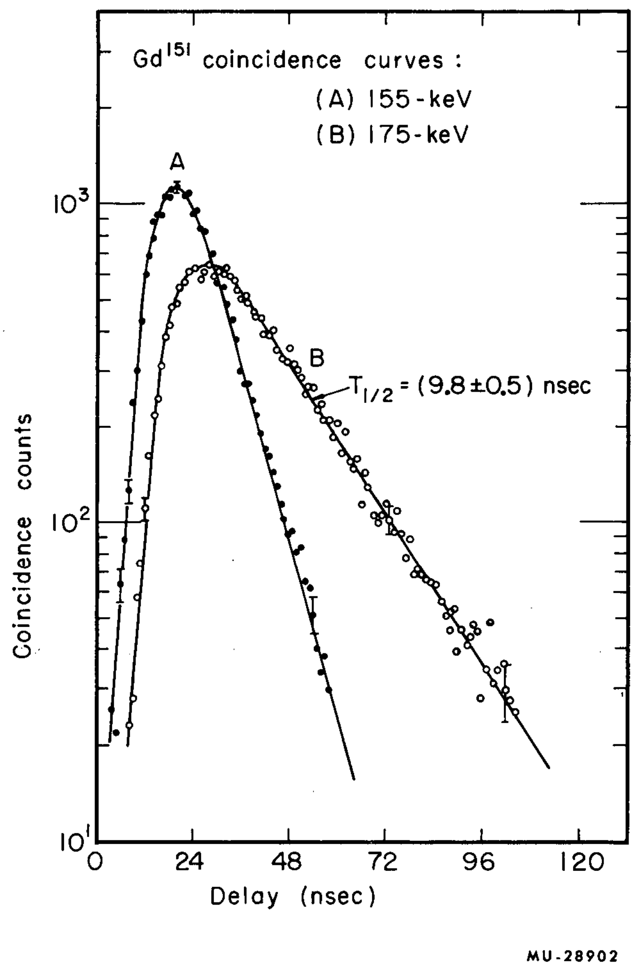

Fig. 2. Gadolinium-151 coincidence curves: (A) 155-21.7 keV "prompt" curve, (B) 175-21.7 keV delay curve. Chances have been subtracted.

delay curve, we consider such an analysis only valid to determine a lower limit for the half-life of the 21.7-keV state in Eu^{151}. Of course, this also includes the assumption that the lifetime of the 352-keV level is short enough so that it in itself does not influence the results of such an analysis. The value so obtained was

$$T_{1/2} \geq 6.8 \text{ ns}.$$

K X-ray — 21.7 keV Coincidences.

Two thin NaI crystals were used to measure the delay curve arising from coincidences between K x-rays and 21.7-keV photons. The single channel analyzers were set to gate on the upper halves of the K x-ray and 21.7-keV photon peaks, respectively. Curve A in fig. 3 shows the K x-ray-21.7 keV delay curve so obtained. Curve B in this figure represents the "prompt" curve obtained by inserting a 0.038-mm gold absorber between the source and the detector used to select the 21.7-keV photon, which selectively absorbed the 21.7-keV photon relative to the K x-ray. From the slope of the K x-ray-21.7 keV delay curve we obtain

$$T_{1/2} = 9.2 \text{ ns},$$

for the half-life of the 21.7-keV state. Treatment of the data shown in fig. 3 by the centroid shift method yielded

$$T_{1/2} \geq 6.8 \text{ ns}.$$

The discrepancy between the half-life determinations by the slope method and the centroid shift method was believed to be caused by the presence of prompt coincidences in the K x-ray - 21.7 keV delay curve. To investigate this possibility, as well as to check that the circuitry was functioning properly, we narrowed the window of the analyzer used to detect the 21.7-keV photon and recorded a number of delay curves with the threshold varied over an energy range from 10 to 35 keV. With the threshold set at 35 keV, the

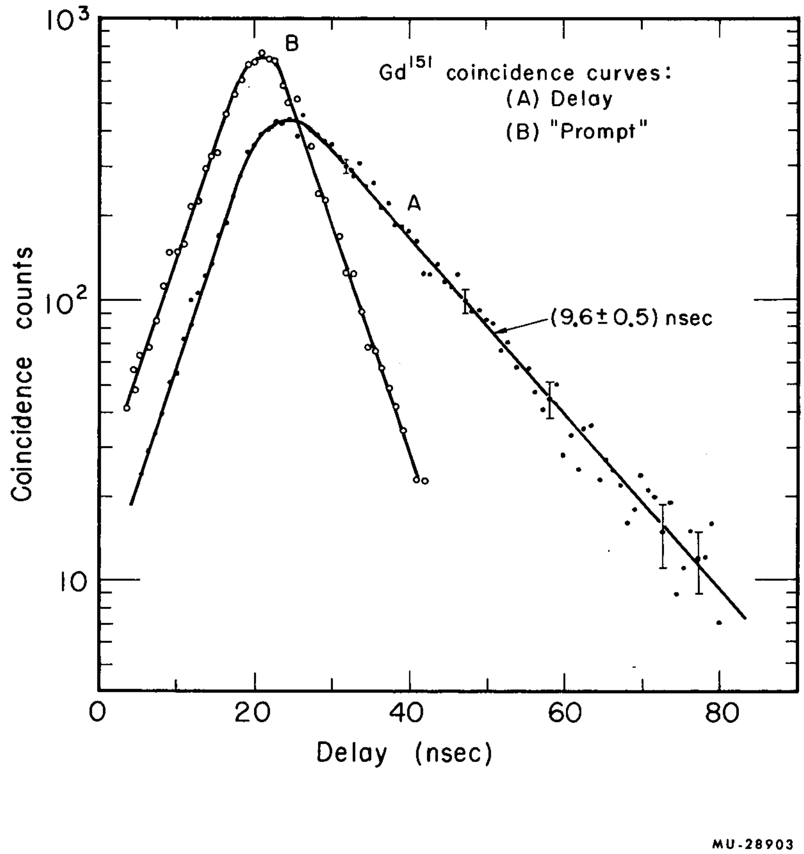

Fig. 3. Gadolinium-151 coincidence curves: (A) K x-ray-21.7 keV delay curve, (B) "prompt" curve obtained by inserting a 0.038-mm gold absorber before detector used to select the 21.7-keV photon.

delay curve was similar to that shown by curve B in fig. 3. When the threshold was lowered so as to gate on 21.7-keV photons, the result was similar to curve A in fig. 3. As the threshold was further reduced, the slope of the delay curve corresponded to 9.5 ns, but the peak began to show the type of structure expected to result from a composite prompt and delay curve. When the threshold was set at 10 keV, the delay curve again resembled the "prompt" curve (curve B in fig. 3), except the slopes were slightly smaller (i.e., longer fall off).

We conclude from these results that our measured delay curves contain a component due to prompt coincidences, and that the half-life of the 21.7-keV state in Eu^{151} can be determined from their slopes. From a number of least-square fits to same, our best value for this half-life is

$$T_{1/2} = 9.5 \pm 0.5 \text{ ns}.$$

3. Conclusions

The large discrepancy between our value ($T_{1/2} = 9.5 \pm 0.5$ ns) and that reported by Berlovich et al.[3] ($T_{1/2} = 3.4 \pm 0.2$ ns) for the half-life of the 21.7-keV state in Eu^{151} is not understood. However, our results are in good agreement with the lower limit of 6.8 ns set by Shirley et al.[1] on the basis of their Mössbauer scattering experiments.

The half-life determined in this work and the total conversion coefficient ($\alpha_T = 29.1$)[9] for the 21.7-keV transition allows one to calculate its absolute transition probability as $T_{exp} = 2.42 \times 10^6$ sec^{-1}. A comparison to that calculated by the Moskowski single particle formula[10] shows that this ℓ-forbidden M1 transition is hindered by a factor of 118. Utilizing the data given in table 1 of the paper by Berlovich et al.[3] for the analogous

ℓ-forbidden M1 transitions in Eu^{147} (229.5 keV) and Eu^{149} (150 keV), and recalculating their hindrance factors, we obtain values of 107 and 71, respectively. The hindrance factor for the transition in Eu^{151} is larger than those for the transitions in Eu^{147} and Eu^{149}, which appears to contradict the conclusion drawn by Berlovich et al.[3] that the hindrance factor for these M1 transitions decreases monotonically when approaching the deformation region (i.e., $N > 88$).

4. Acknowledgements

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