## Title

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## Authors

Soinski, A.J.
Karlsson, E.
Shirley, D.A.

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# University of California

# Ernest O. Lawrence Radiation Laboratory

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# SPINS AND ATTENUATION COEFFICIENTS OF THE 86.5- AND 105.3-keV STATES IN $^{155}$Gd

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# SPINS AND ATTENUATION COEFFICIENTS OF THE 86.5- AND 105.3-keV STATES IN $^{155}$Gd[*]

A. J. Soinski, E. Karlsson,[†] and D. A. Shirley

Department of Chemistry and
Lawrence Radiation Laboratory
University of California
Berkeley, California

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## ABSTRACT

Nuclear orientation was used to determine the spins of the 86.5- and 105.3-keV states in $^{155}$Gd as 5/2 and 3/2 respectively. Derived values for the attenuation coefficients showed that the orientation is strongly perturbed in the 86.5-keV state.

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[†] Summer visitor, 1967. Permanent
Address: University of Uppsala, Institute of Physics, Uppsala, Sweden.

Despite several experimental investigations[1-8)], the spins of the 86.5- and 105.3-keV states in $^{155}$Gd had not been established with certainty. The two states have been of interest in interpreting the nuclear structure of deformed $^{155}$Gd[9)]. The E1 nature of the transitions from these states to the 3/2- ground state of $^{155}$Gd[10)], together with the log ft values for the beta decay of $^{155}$Eu[11)], establish both states as having positive parity and spins of 3/2 or 5/2. There have been no definite spin assignments until now, however, especially for the 86.5-keV state. In this letter we report measurements of angular distributions of these two $\gamma$ rays following the decay of oriented $^{155}$Eu. By invoking straightforward angular-momentum theory, we used these data to make unequivocal spin assignments of 5/2 for the 86.5-keV state and 3/2 for the 105.3-keV state. In addition, we have derived values for the attenuation coefficients $G_2$ for both $\gamma$ rays. These values, $G_2(86.5) = 0.26(8)$ for the decay through the 6.3 nsec[12)], 86.5-keV state and $G_2(105.3) = 0.80(9)$ for the decay through the 1.14 nsec, 105.3-keV state consitute the first evidence for perturbation effects associated with electronic rearrangements during the first few nanoseconds after the $\beta$-decay of oriented nuclei.

$^{155}$Eu was oriented in the neodymium ethylsufate (NES) lattice into which $Eu^{3+}$ grows substitutionally. The angular distribution of $\gamma$ rays following the decay of oriented europium nuclei in NES is given by

$$W(\theta) = 1 + g_2 G_2 B_2 U_2 F_2 P_2(\cos\theta) + \ldots \tag{1}$$

with higher rank terms being undetectably small for the low degree of orientation achieved. Here $g_2$ is a solid-angle factor, $B_2$ is the nuclear orientation tensor given by

$$B_2 = (2I+1)^{1/2} \sum_M (-1) \begin{pmatrix} I & I & 2 \\ M & -M & 0 \end{pmatrix} a(M) \qquad (2)$$

where $a(M)$ is the fractional population of substate $M$, and $U_2$ is an angular-momentum reorientation coefficient. The other terms are familiar from angular correlation theory. The spin Hamiltonian governing orientation is pure quadrupolar, i.e., $\mathcal{H} = [3eQq/4I(2I-1)][M^2 - 1/3\ I(I+1)]$; and for low degrees of orientation we have

$$B_2 \cong (P/3kT)[1/5\ I(I+1)(2I-1)(2I+3)]^{1/2} \quad . \qquad (3)$$

We have used $^{154}$Eu in the same sample as a nuclear thermometer. Its nuclear orientation characteristics have been studied extensively$^{13)}$, and $B_2^{(154)}(T)$ was obtained from the angular distribution of the 1277-keV $\gamma$ ray following the decay of $^{154}$Eu. From the above equations we find $B_2^{(155)} = (1/2)(14/3)^{1/2} (Q_{155}/Q_{154})B_2^{(154)}$ where $B_2^{(154)}$ is known to be positive.

The angular-momentum factors $U_2F_2$ have different signs for E1 decays through 3/2+ and 5/2+ states, but their magnitudes depend on the spin of $^{155}$Eu (which we take as 5/2) and, in the case of the decay through the 5/2+ state, on the Fermi to Gamow-Teller ratio in the allowed beta decay (Table 1). Clearly a positive $U_2F_2$ indicates spin 5/2 while a negative $U_2F_2$ requires a spin of 3/2. We found $G_2B_2U_2F_2(86.5) = +0.014(3)$ and $G_2B_2U_2F_2(105.3) = -0.041(4)$ at $T = 0.011$°K. If $Q_{155}/Q_{154} > 0$ and $G_2 > 0$ for both states (both very good assumptions, then $B_2^{(155)} > 0$ and $I(86.5) = 5/2$ and $I(105.3) = 3/2$. Although these spin assignments are opposite to those given by Nathan and Nilsson$^{14)}$, they are predicted if the [651]3/2+, [642]5/2+ and [660]1/2+ Nilsson orbitals are Coriolis coupled$^{9)}$. Moreover, trends in the energies of Nilsson orbitals in neighboring odd-neutron nuclei indicate that the [651]3/2+ and [642]5/2+ orbitals are close-lying at neutron number 91[8].

Having determined the spins, we can now make a more quantitative interpretation of the data. Of particular interest is the time-dependence of $G_2$ in intermediate states following beta decay of oriented nuclei. In metals it is now known that higher oxidation states produced in beta decay are reduced in $< 1$ nsec and that subsequent attenuation occurs in times of the order of $T_1$ (i.e., microseconds to milliseconds). In ionic crystals, on the other hand, relatively little is known. Earlier experiments in this laboratory had indicated that substantial attenuation could occur in a few nsec, but not in $< 1$ nsec. The $^{155}$Gd results are thus of special interest because we might expect substantial attenuation in the 6.3 nsec, 86.5-keV level but little attenuation in the 1.1 nsec, 105.3-keV level. Using $Q = Q_0\ I(2I-1)/(I+1)(2I+3)$, and assuming $Q_0(154) \cong Q_0(155)$, we can compare our results with theory to obtain $G_2(86.5) = 0.26(8)$ and $G_2(105.3) = 0.80(9)$, in excellent confirmation of these expectations. If we have made a systematic error in the analysis and if $G_2(105.3)$ is as large as 1, the derived value of $G_2(86.5)$ would be 0.33(10). None of the proposed theoretical models for intermediate state reorientation of nuclei[15-17] can account for the strong attenuation in the 86.5-keV level. Daniels and Misra[17] assumed that the initial and intermediate states have the same electronic configuration. However, if the $Eu^{3+}$ configuration were retained, reorientation would not occur. The opposite assumption, namely that the electronic equilibrium state of $Gd^{3+}$ is attained in a time much less than the nuclear lifetime, cannot explain our data either. Therefore we infer that randon stepwise electronic recovery occurs, leading to time-dependent perturbations.

Table 1

Summary of results

| Spin Sequence | | $U_2F_2$ | |
|---|---|---|---|
| 5/2 + (Gamow-Teller $\beta^-$) | 3/2 + (E1) 3/2- | -0.2994 | |
| 5/2 + (Fermi $\beta^-$) | 5/2 + (E1) 3/2- | +0.3742 | +0.310(64) |
| 5/2 + (Gamow-Teller $\beta^-$) | 5/2 + (E1) 3/2- | +0.2458 | |

| Gamma Ray Energy | $G_2B_2U_2F_2$ at 0.011°K | $G_2$ (If $B_2^{(155)} = 0.174(13)$) |
|---|---|---|
| 86.5 keV | +0.014(3) | (+)0.26(8) |
| 105.3 keV | -0.041(4) | (+)0.80(9) |

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## Figure Captions

Fig. 1. Partial decay scheme of $^{155}$Gd adapted from ref. 11.

Fig. 2. Upper section. Summation of cold counts at 0.011°K following sixteen adiabatic demagnetizations.

Lower section. Difference between the total cold counts (oriented nuclei) and the total warm counts (nuclei randomly oriented) for the same series of demagnetizations. The spin assignments $I(86.5) = 5/2$ and $I(105.3) = 3/2$ depend on the signs of this difference at these energies.

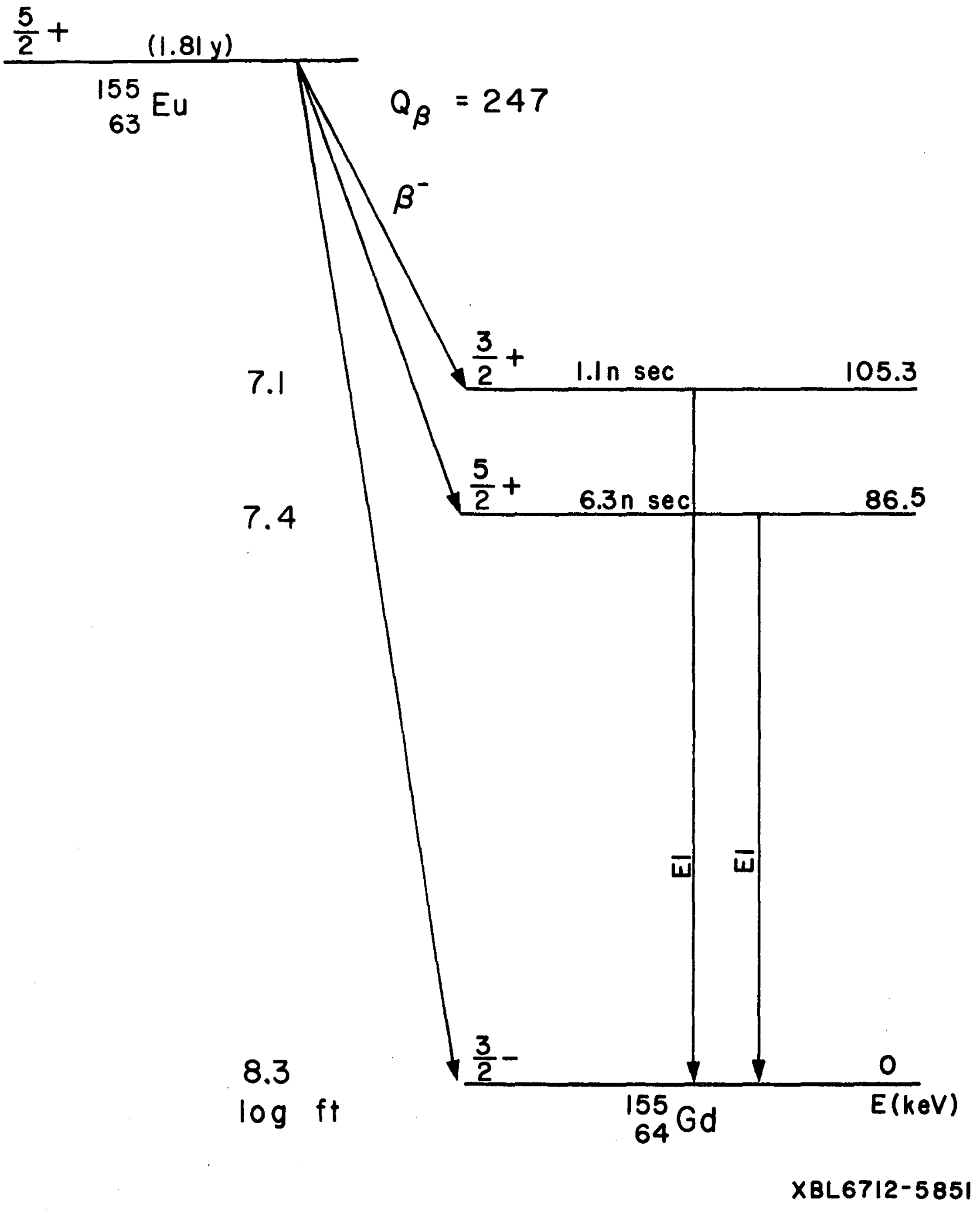
5/2 +
(1.81 y)
155 63 Eu
Q_β = 247
β⁻
3/2 +
1.1n sec
105.3
7.1
5/2 +
6.3n sec
86.5
7.4
E1
E1
3/2 −
0
8.3
log ft
155 64 Gd
E(keV)
XBL6712-5851

Fig. 1

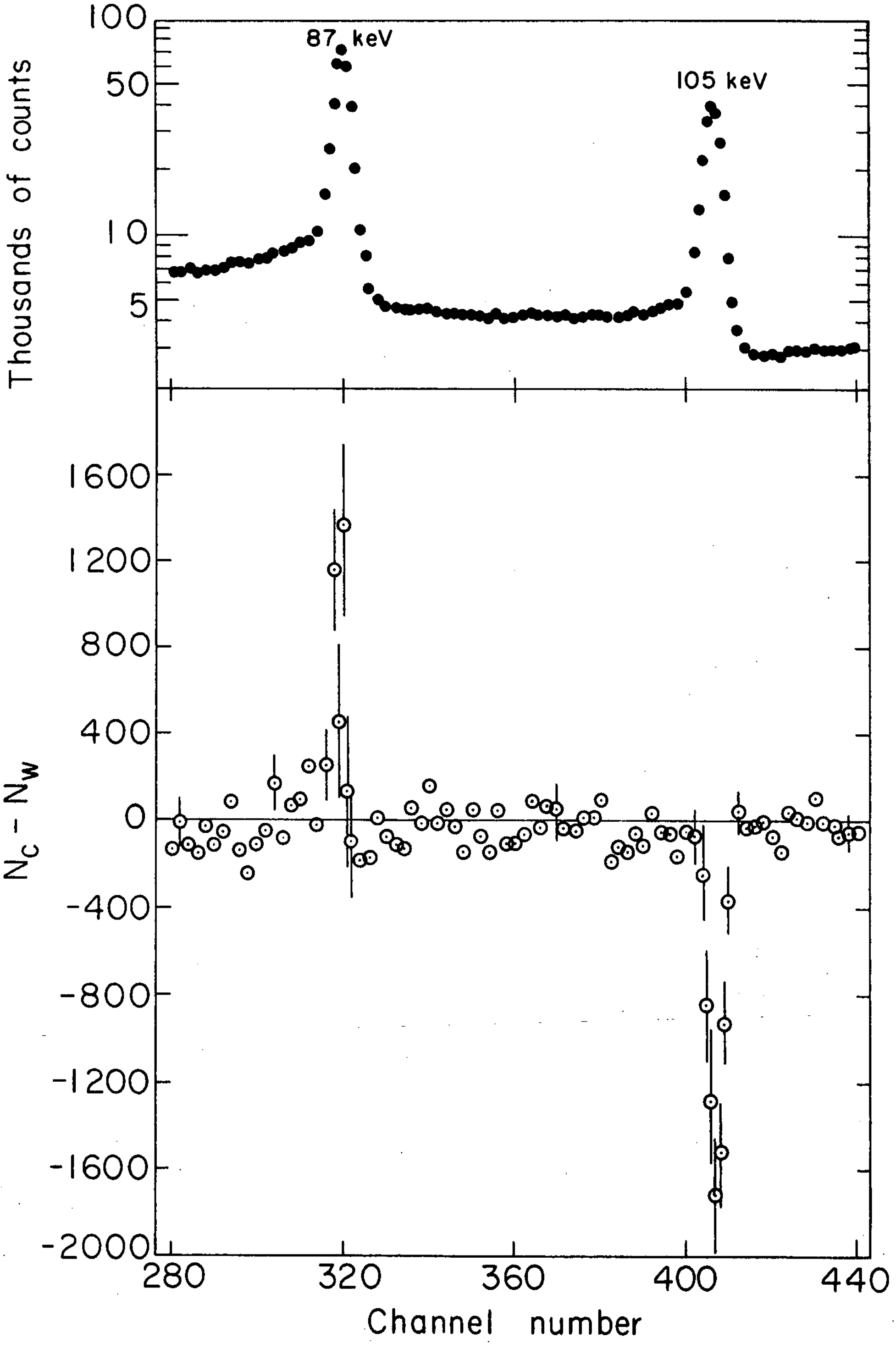
Thousands of counts
100
50
10
5
87 keV
105 keV
$N_C - N_W$
1600
1200
800
400
0
-400
-800
-1200
-1600
-2000
280
320
360
400
440
Channel number
XBL6712-5913

Fig. 2