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Circular Polarization Measurements in Eu^{154}†

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The circular polarization of the 1.28-MeV gamma ray following the beta decay in Eu^{154} was measured by means of the transmission method. The anisotropy coefficient A was found to be $A=-0.21\pm0.07$ which gives the $M2$ to $E1$ multipolarity admixture as $\delta=-0.07\pm0.08$ (standard deviations). This together with other information implies the K value for the 1.4-MeV level in Gd^{154} is $K=1$.

I. INTRODUCTION

SEVERAL authors[1-3] have developed the expression for the angular distribution of right or left circularly polarized photons as a function of $\theta_{\beta,\gamma}$, the angle between the direction of the beta and gamma rays. The probability that a gamma ray with right ($p=1$) circular polarization or left ($p=-1$) circular polarization is emitted at an angle $\theta_{\beta\gamma}$ with respect to the preceding beta ray is conveniently written as

$$W(\theta_{\beta\gamma},p)=\frac{1}{2}\left(1+pA^{\pm}\frac{v}{c}\cos\theta_{\beta\gamma}\right).$$

The term v/c is the ratio of the velocity of the beta ray which precedes the gamma to velocity of light. The coefficient $A^{\pm}$ is designated the "anisotropy coefficient" and is written

$$A^{\pm}=\frac{\sum_{\lambda\lambda'}\delta_\lambda\delta_{\lambda'}F_1(\lambda\lambda' I_{ff}I_f)}{1+0.684y^2}\left\{\frac{\pm0.289}{[I_f(I_f+1)]^{1/2}}\times[I_f(I_f+1)-I_i(I_i+1)+2]-0.95y\right\}. \quad (1)$$

Here λ and λ' refer to the multipolarity of the gamma-ray transition. The I_i, I_f, and I_{ff} are the spins of the initial, intermediate, and final states, respectively. The F_1's are the gamma-gamma correlation coefficients and are given in Ref. 1. The ($\pm$) refers to $\beta^{\pm}$ emission and y is the ratio of the Fermi matrix element to the Gamow-Teller matrix element. This expression shows that, in general, even if the spin and parity of all three states is known, the measurement of the circular polarization of the gamma rays following beta decay depends upon two other parameters, namely the multipolarity admixture δ and the nuclear parameter y. In the case of the 0.57-MeV beta transition in Eu^{154}, it is clear that $y=0$ for this unique Gamow-Teller transition.

II. METHOD OF ANALYSIS

The decay scheme of Eu^{154} is shown in Fig. 1. The method used to analyze the degree of circular polarization of the 1.28-MeV gamma ray is the transmission through magnetized iron which was first suggested by Lundby.[4] This method was chosen over the forward scattering method described by Schopper[5] because of the superior gamma-ray energy resolution possible with the transmission method. The main difficulty with the transmission method is that the counting rates are small. However, due to the presence of competing gamma radiation in Eu^{154}, it was felt that the improved energy resolution outweighed the disadvantage of the long counting times required (~20 days).

The difference in the beta-gamma coincidence rates for opposite directions of the magnetic field was measured.[6] The standard fast-slow coincidence arrangement

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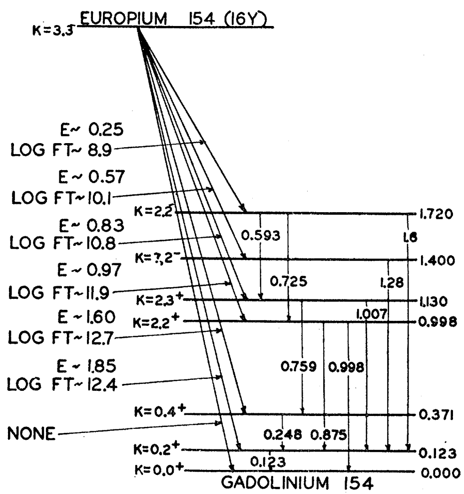

FIG. 1. Europium-154 decay scheme. The 1.4-MeV level of gadolinium-154 is of interest due to the uncertainty of the K value for this level and the abnormally high $\log ft$ ($\simeq$10.1) for the beta decay to this level.

was used with a ratio of the true to accidental coincidence rates of approximately four. Typical counting rates were 60×10^4 beta/min, 8×10^3 gamma/min, and 15 to 30 coincidences/min. The coincidence circuit resolving time was 22 nsec.

The source geometry is given in Fig. 2. If $h^{\pm}$ represents the coincidence rate with ($\pm$) directions of magnetization, and if the entire difference in coincidence rates is due to a change in the Compton cross section, then it can be shown that

$$\frac{h^+-h^-}{h^++h^-}=A\ \tanh(-nt\sigma_h\nu)\left\langle\frac{v}{c}\right\rangle\langle\cos\theta_{\beta\gamma}\rangle, \qquad (2)$$

where σ_h=polarization-dependent part of Compton cross section, n=number of iron atoms per unit volume, t=thickness of iron analyzer=15 cm, ν=number of polarized electrons per atom at saturation, $\langle v/c\rangle$=average of the ratio of the velocity of the beta particles accepted into the beta discriminator window to the velocity of light, $\langle\cos\theta_{\beta\gamma}\rangle$=the $\cos\theta_{\beta\gamma}$ averaged over the beta and gamma detector solid angles and the finite extension of the source, and A=anisotropy coefficient given in Eq. (1).

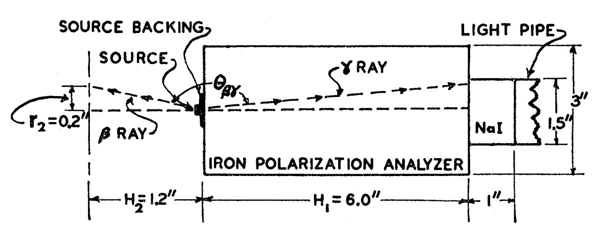

FIG. 2. Source geometry to analyze the degree of circular polarization of the gamma ray following beta decay using the transmission method.

The expressions $\langle v/c\rangle$ and $\langle\cos\theta_{\beta\gamma}\rangle$ are easily calculated; however, the term $\tanh(-nt\sigma_h\nu)$ is difficult to evaluate due to the incomplete magnetization at the ends of the iron analyzer. This, of course, results in an uncertainty concerning the number of polarized electrons in the iron. The difficulty can be overcome because $(nt\sigma_h\nu)$ can be experimentally determined[7] by measuring gamma singles rate $(N_\gamma{}^+)$ with plus direction of magnetization and then the gamma singles rate $(N_\gamma{}^0)$ with the iron analyzer demagnetized. Under these conditions then

$$(N_\gamma{}^+-N_\gamma)^0/N_\gamma{}^0\approx\tfrac{1}{2}(nt\sigma_h\nu)^2.$$

The experimentally determined value $(nt\sigma_h\nu)$, along with $\langle v/c\rangle$ and $\langle\cos\theta_{\beta\gamma}\rangle$ is then used to evaluate the anisotropy coefficient A.

III. SOURCE

The Eu^{154} was produced by Oak Ridge National Laboratory by thermal neutron irradiation of 99% enriched Eu^{153} in the oxide form. The EuO_3 was dissolved in HCl and deposited on 1-mg/cm^2 Mylar backing which was treated with insulin before the deposition. The source extended to about 4 mm diam.

IV. RESULTS

The beta-gamma coincidence rates for ($\pm$) magnetizations were used to evaluate $(h^+-h^-)/(h^++h^-)$ of Eq. (2). The results were corrected for the accidental coincidences, scattering from the source and detector holder, dead-time losses, solid-angle effects (as well as finite extension of the source), systematic instrumental errors, and nonuniformity of magnetic field existing in the iron absorber due to fringing effects. No gamma-gamma coincidence correction was necessary as the beta detector was a solid-state detector which is insensitive to gamma radiation. In addition, the absolute anisotropy coefficient was obtained for Co^{60} as a calibration standard. The result for Co^{60} was $A=-0.34\pm0.09$. This result compares favorably with the well-known value of $A=-\frac{1}{3}$ for Co^{60}.

In a manner similar to the Co^{60} measurements, the experimental value of the anisotropy coefficient for Eu^{154} was found to be $A_{\rm exp}=-0.21\pm0.07$, and from Eq. (1), the multipolarity admixture $\delta_{\rm exp}=-0.07\pm0.08$.

V. DISCUSSION

Since Gd^{154} is definitely in the vibrational-rotational excitation region, it is reasonable to expect that the nucleons are performing some kind of collective motion. If the 1.4-MeV state is collective in origin, an assignment of the K value can be made. The 1.4-MeV level has been measured by Baba and Bhattacherjee[8] to be

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$I=2^-$. Therefore, the gamma-ray transition to the $K=0$, $I=2^+$, $E=0.123$-MeV state could be electric dipole plus magnetic quadrupole.

Now, the dependence of the anisotropy coefficient on the multipolarity admixture δ is not single valued. The experimental result of $A=-0.21\pm0.07$ is consistent with a value of $\delta>1$ or with a value of $\delta\ll1$. Baba and Bhattacherjee were able to establish the $E1$ character of the 1.28-MeV gamma transition. Hence, the large value of δ can be excluded.

The assignment $K=0$ to the 1.4-MeV state can be eliminated due to symmetry conditions. It is further noted that the assignment $K=2$ to the 1.4-MeV state would leave the electric dipole K forbidden while the magnetic quadrupole is allowed. The result is that the $E1$ transition would be retarded which would permit a large admixture of $M2$ into the transition. This has been observed in a similar gamma transition of the 1189-keV level in W^{182} with a 40% $M2$ admixture.[9]

However, the assignment of $K=1$ to the 1.4-MeV level would greatly reduce the $M2$ admixture with the result that $M2/E1$ should be less than unity by several orders of magnitude.

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We note the experimental $M2/E1$ admixture gives the $M2$ intensity as 2% or less and consistent with zero which implies the K value is $K=1$. In addition the abnormally large $\log ft=10.1$ could be explained by a $K=1$ assignment to the 1.4-MeV level. Since the ground state of Eu^{154} is a $K=3$ state, the beta decay to the 1.4-MeV level would be a second-order K forbidden transition and thus would be greatly retarded. Also, the $K=2$ assignment is not indicated by the ratio of the ft values for the beta transitions to the 1.72-MeV level and the 1.4-MeV level. A $K=2$ assignment to 1.4-MeV level would give this ratio a value of around one while the experimentally observed ratio is $\sim$0.07. On the basis of the above discussions a tentative assignment of $K=1$ is given to the 1.4-MeV level.

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Fluctuations in the Partial Radiation Widths of U^{239}†

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The Argonne fast chopper has been used to measure the distribution of the sum of the intensities of transitions having energies between 3.8 and 4.2 MeV in the neutron-capture spectra of 12 neutron resonances of U^{238}. The pulse-height spectra were observed in a large (8×6 in.) NaI(Tl) scintillator. The partial radiation widths exhibit large fluctuations. If the observed distribution is characterized by a number ν of degrees of freedom, as in the theoretical treatment by Porter and Thomas, a value of $\nu=5.8\pm2.3$ is obtained. This is in contrast to the previously reported results which range from 11 to 90 and is consistent with the predictions of the simple statistical model for the distribution of the sum of four uncorrelated partial radiation widths.

I. INTRODUCTION

THE study of the statistical properties of partial radiation widths for nuclei excited by neutron capture has been of central interest in slow-neutron spectroscopy for the last four years. From the various experiments[1–4] on a wide range of nuclei, with one exception clear and consistent conclusions have been obtained. The distribution that governs the partial radiation widths for transitions from resonances of a given spin and parity to a definite final state is characterized by large fluctuations about a mean value; widths with values less than the mean predominate. It has been customary to analyze experimental data in terms of the family of χ^2 distributions with ν degrees of freedom, as proposed by Porter and Thomas.[5] The Porter-Thomas distribution, which is in good agreement with data on reduced neutron widths corresponds

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