CIRCULAR POLARIZATION OF THE γ RAYS ACCOMPANYING THE β DECAY OF Nd^{147}

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The asymmetry coefficient for $\beta\gamma$ correlation was determined by measuring the degree of circular polarization of 530-kev γ rays accompanying the β decay of Nd^{147} and found to be $A = -0.093 \pm 0.15$. This value is consistent with a spin of $7/2$ for the state of Pm^{147} in question and for a mixed E2 + M1 transition, with an amplitude ratio E2/M1 equal to $+1.75 \pm 0.15$.

INTRODUCTION

ONE of the consequences of parity nonconservation in β decay is that the γ rays emitted by excited nuclei after β decay are circularly polarized. The first measurements of γ-ray circular polarization were done to check the nonconservation of parity.[1,2] At the present time, the fundamental principles involved in the nonconservation of parity in β decay have been established.[3] Measurements of the degree of circular polarization of γ rays can be used to establish quantum numbers for nuclear levels, the multipolarity of radiative transitions, and nuclear matrix elements for β transitions. The theory is sufficiently detailed[4,5] that experimental results can be interpreted from this point of view. There have been only a few papers published[6,7] on measurements of circular polarization for spectroscopic purposes.

In this paper we report on measurements of $\beta\gamma$ correlation and circular polarization of the 530-kev γ rays accompanying the β decay of Nd^{147}. Nd^{147} has been also studied by Bishop et al.[8] using a low temperature technique, but the results obtained did not allow firm conclusions to be drawn.

MEASUREMENT PROCEDURE

In general, the measurements were made using conventional techniques. The γ-ray circular polarization was detected by using the cross section of forward Compton scattering from polarized electrons. The scattering cylinder was made of a magnetic material with induction $B = 2.2 \times 10^4$ gauss in a field H = 15 oersted. The mean scattering angle for the γ rays was $\sim 55°$. To minimize the magnetic field at the photomultiplier (FÉU-13) we used a 15 cm light pipe. The electrons were detected by an anthracene crystal 2 mm thick; a threshold could be set to discriminate against electrons having small values of v/c. The γ rays reflected from the scatterer were detected by a NaI(Tl) crystal having dimensions 40×40 mm^2. The γ-ray pulses were passed through a single channel analyzer with variable window. This selected the pulses due to γ rays of the desired energy. $\beta\gamma$ coincidences were selected with a resolving time of $\tau = 3 \times 10^{-8}$ sec, the total (i.e., sum of true and accidental coincidences) and accidental coincidence rates being recorded simultaneously.[9] We measured the quantity

$$\varepsilon = 2[N_{\beta\gamma}(\uparrow) - N_{\beta\gamma}(\downarrow)]/[N_{\beta\gamma}(\uparrow) + N_{\beta\gamma}(\downarrow)],$$

where $N_{\beta\gamma}(\downarrow)$ is the $\beta\gamma$ coincidence rate when the magnetic field in the scatterer was directed away from the source, and $N_{\beta\gamma}(\uparrow)$ was the coincidence rate with the magnetic field directed to the source. The direction of the magnetic field was changed every 10 minutes. The effect on the mean counting rate in the various channels was not greater than 0.05%. From the value of ϵ we calculated the asymmetry coefficient A for $\beta\gamma$ correlation with circularly polarized γ rays. To test the apparatus, measurements were made on Co^{60} and Na^{22}. The results are shown in the table. The experimental values of A agree both with theory and also with the results of other authors. From the measurements on Co^{60} and Na^{22} we concluded that there were no instrumental asymmetries.

MEASUREMENTS ON Nd^{147}

In the measurements on Nd^{147}, coincidences were recorded between 530-kev γ rays and elec-

	ε, %	A	
		experiment	theory
Co^{60}	+1.44±0.27	−0.34±0.06	−0.33
Na^{22}	−1.45±0.32	+0.30±0.07	+0.33
Nd^{147}	+0.21±0.34	−0.093±0.15	−0.21

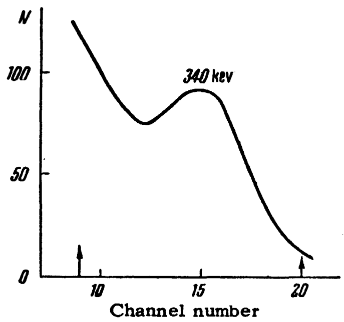

FIG. 1. Spectrum of scattered γ rays from Nd^{147} (the arrows show the window of the discriminator).

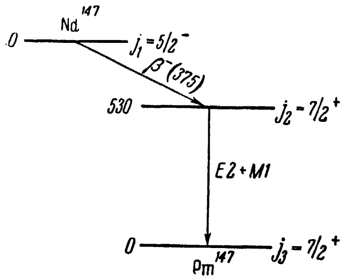

FIG. 2. Decay scheme for the transition $Nd^{147} \rightarrow Pm^{147}$.

trons of the β spectrum having an upper limit of 375 kev. The threshold in the β channel was set at 140 kev, which corresponds to a mean value $\bar{v}/c = 0.71$. Figure 1 shows the spectrum of pulses from the NaI(Tl) crystal. These pulses are due to scattered γ rays. The diffuse photopeak corresponds to an energy of 340 kev and is due to γ rays with initial energy 530 kev. The arrows on Fig. 1 indicate the part of the spectrum selected by the single-channel analyzer. About one coincidence was counted per second, true and accidental coincidences being approximately equally probable. The result of the measurement is given in the table, together with its mean square error. One possible source of systematic error is that the part of the γ-ray spectrum measured may have contained γ quanta due to other transitions. The correction for this is not greater than one fifth the mean square error.

The β transition in Nd^{147} is a first-forbidden one. For Nd^{147}, Z = 60. According to Gaponov, the β transition should be of the Coulomb type, i.e., the β spectrum should have the allowed shape and the angular distribution of the γ rays about the direction in which the electron is emitted should be isotropic. As a test, we made some measurements of $\beta\gamma$ correlation without looking at the circular polarization of the γ rays. The angular distribution obtained was isotropic to 0.5%, which confirms that the β decay is of the Coulomb type. Hence the formulae in reference 5 may be used to interpret our results.

DISCUSSION

According to Gaponov,[5] the asymmetry coefficient A for Coulomb type β transitions depends on the angular momenta of the initial nucleus (j_1) and of the final nucleus both in its excited state (j_2) and in its ground state (j_3). The value of A depends also on the multipolarity of the radiative transition. For $j_1 = j_2$ the matrix elements for the β decay must also be known.

Using a paramagnetic resonance technique, Kadzic et al. have measured the spin of the ground state of Nd^{147} to be $j_1 = {}^5/_2$.[10] From optical spectroscopy, Klinkenburg and Tomkins have found the spin of the ground state of Pm^{147} to be $j_3 = {}^7/_2$.[11]

Bishop et al.[8] have established that the 530-kev radiative transition in Pm^{147} has a mixed multipolarity E2 + M1 (see Fig. 2). However, in analyzing their data, they used spins $j_1 = {}^9/_2$ and $j_3 = {}^5/_2$, in contradiction with the results of references 10 and 11. We reviewed the analysis given by Bishop et al.,[8] and found that if the spin j_2 were assumed to be ${}^5/_2$, it would be very difficult to fit the experimental data, no matter what ratio δ were assumed for the amplitudes of the electric quadrupole and magnetic dipole radiations (E2/M1). On the other hand, the assumption $j_2 = {}^7/_2$ gave good agreement with the data for two values of $\delta : \delta_1 = +1.75 \pm 0.15$ and $\delta_2 = -1.02 \pm 0.13$. The spin assignment $j_2 = {}^9/_2$ is not excluded by this data, but does imply a unique β transition and an anisotropy in the $\beta\gamma$ correlation (summed over circular polarizations) and so is ruled out by our results.

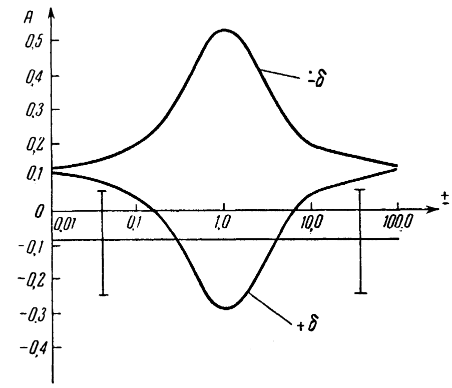

FIG. 3. The asymmetry coefficient A in $\beta\gamma$ correlation with circularly-polarized γ rays as a function of δ, the amplitude ratio E2/M1.

Figure 3 shows the asymmetry coefficient A as a function of the amplitude ratio δ for $j_2 = {}^7/_2$.[5] Our experimental result for A agrees with $j_2 = {}^7/_2$ if δ is taken with a plus sign. We conclude that the excited state in Pm^{147} at 530 kev must have spin $j_2 = {}^7/_2$, and the amplitude ratio E2/M1 for the radiative transition to the ground state must be $\delta = +1.75 \pm 0.15$.

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