A βγ-CORRELATION INVESTIGATION OF THE Pr^{144} *DECAY*

V. M. LOBASHOV and V. A. NAZARENKO

Leningrad Physico-Technical Institute, Academy of Sciences, U.S.S.R.

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The correlation between the β-electron and circular polarization of the γ-quantum in the allowed Pr^{144} decay transition was investigated. From the magnitude of the correlation we can assign to the ground state Pr^{144} spin a value of 1^-, instead of the previously accepted 0^-.

THE study of β transitions is one of the basic methods of establishing the characteristics of nuclear levels. Until recently, however, the basic information was obtained from forbidden transitions: the degree of their forbiddenness, the shape of the spectra, and the magnitude of the βγ angular correlation. In a number of cases such investigations do not give unambiguous information, since the interpretation of the forbidden transitions is connected with estimates of the nuclear matrix elements by a very uncertain procedure.

The nonconservation of parity in the β decay results in a number of nonvanishing effects in the allowed transitions, the magnitude and sign of which have an appreciable dependence on the spins of the initial and final states. Then, in view of the reduction of the number of matrix elements to a maximum of two, the ambiguity in the interpretation of the results is removed.

In the present experiment, we investigated one of these effects, the correlation between the β-electron momentum and the circular polarization of the γ quantum in the Pr^{144} decay. The Pr^{144} decay has been investigated many times by various methods,[1-3] and the characteristics of the levels of the Nd^{144} daughter nucleus are well established. The adopted scheme is shown in Fig. 1.

Consideration of ft for the β transitions on the basis of the experimentally known spins and parities of the Nd^{144} levels determined from the γγ correlations allows one to assign the value 0^- or 1^- to the Pr^{144} ground state.

In[3-6] the shapes of the β-spectrum transitions and βγ angular correlations in the Pr^{144} decay were carefully investigated. The shape of the spectrum for the 2.3-Mev transition proved to be very close to the unique first forbidden transition and the value of the coefficient A_2 of the βγ angular correlation was almost a maximum. It was

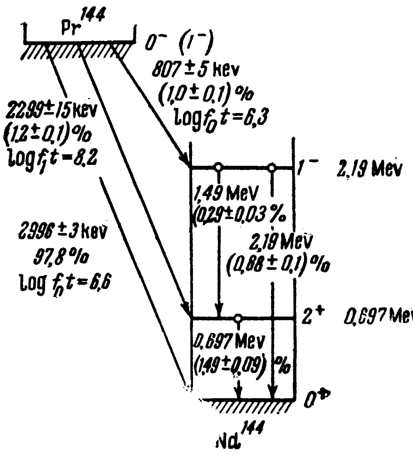

FIG. 1. Pr^{144} decay scheme. The value of the spin determined in our experiments is shown in parentheses. The relative intensities are taken from[5].

therefore concluded that the 2.3-Mev transition was a unique first forbidden transition and that the small difference in the correlation coefficient A_2 from the maximum value required for a unique transition is due to experimental errors. The ground state was therefore assigned a spin 0^-.

It should be noted that, on the basis of this value, a detailed analysis of the shape of the β spectrum of the transition between the ground states ($0^-—0^+$) was made to estimate the mixture of the pseudoscalar variant in the β interaction. In order to verify the conclusion regarding the ground-state spin, we investigated the allowed transition in the Pr^{144} decay, whose interpretation can be checked unambiguously.

We investigated the correlation between β electrons of the transition with an end-point energy of 807 kev and the circular polarization of the 2180-kev γ quanta. The experimental arrangement is shown in Fig. 2.

We detected the circular polarization by the

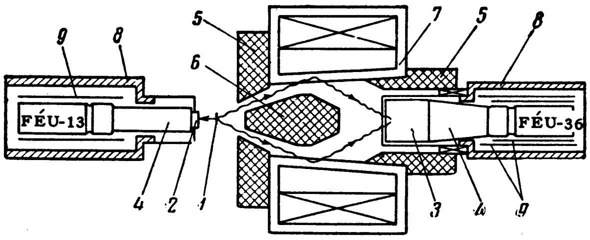

FIG. 2. Experimental arrangement: 1 – source, 2 – stilbene crystal, 3 – NaI(Tl) crystal, 4 – light guide, 5 – lead collimators, 6 – lead shield, 7 – γ-polarimeter magnet, 8 – Armco-iron housing, 9 – permalloy shields.

method of forward Compton scattering on magnetized iron, as in[7-9].

To fix the geometry, the beam of incident and scattered γ quanta passed through lead collimators. The scattering-magnet core was made of Armco iron. The measured flux density inside it was 22 000 gauss, which corresponds to saturation (21 000 gauss). The mean scattering angle was 45°. The scattered γ quanta were detected by a 70×70 mm NaI(Tl) crystal coupled to a light guide 100 mm long with an FÉU-13 photomultiplier. In order to decrease the influence of the magnetic field, the photomultiplier was enclosed in an Armco-iron housing 1 cm thick and a double permalloy shield. Moreover, a compensation winding was used. All this reduced the influence of the magnetic field to $\sim 0.08\%$ in amplitude.

The β electrons were detected by a stilbene crystal coupled to a light guide with an FÉU-36 photomultiplier. The photomultiplier was also shielded by 1 cm of Armco iron and 1 mm of permalloy.

The photomultiplier output was connected to a fast-slow coincidence circuit with a resolving time of $\tau = 5 \times 10^{-9}$ sec. The efficiency of the circuit was $\sim 95\%$. The transition had an intensity of 1% and was superimposed on a β spectrum with an end-point energy of 3 Mev. In order to provide a reasonable coincidence counting rate, we used a 10^6 sec^{-1} gate on the β channel. Of course, with such a gate the usual method of pulse amplitude selection in which the pulse from the FÉU dynode is fed directly to a slow differential discriminator cannot be used. We therefore used time preselection triggered by a pulse from the fast coincidence circuit.

The selection circuit was designed on the principle of an ordinary diode coincidence circuit and had a resolving time of 7×10^{-8} sec. Such a circuit passed linearly pulses 5×10^{-8} sec wide and 20 volts in amplitude with a pedestal of ~ 0.8 volts. The fast selecting pulse (7×10^{-8} sec) underwent preselection from the pulse of the differential discriminator connected in the β channel. After the selecting circuit, the pulse, which was passed linearly through the β channel, was fed to the slow differential discriminator and then to the counting circuit. With such an arrangement the superposition of pulses was reduced to a value no greater than 5%.

The limits of discrimination were set so that electrons of energy from 300 to 800 kev were selected.

To eliminate the effect of the gate on the operation of the FÉU, the three final dynodes of the FÉU were connected to a separate power supply.

In the measurements, the coincidence counting rate was 0.5 pulse/sec with a random coincidence background of 20%. In order to improve the stability, the temperature of the preamplifier was maintained constant by an automatic arrangement. The direction of magnetization was reversed automatically every 3.5 min.

The choice of the energy interval of the scattered γ quanta involved some special problems, since γ quanta of 2180 and 1480 kev with relative intensities 5.6 : 2.3 coincided with the 807-kev β transition. The spin decreases by one in the 2180-kev γ transition and increases by one in the 1480-kev transition. Therefore the circular polarization of these γ quanta was of opposite sign. Of course, the presence of the 1480-kev γ transition should decrease the correlation coefficient.

As a result of Compton scattering, the γ lines were greatly broadened, and one can therefore expect a certain overlapping of the 2180- and 1480-kev γ lines.

In order to estimate the contribution of the 1480-kev line we performed a special experiment. The β detector was replaced by a 70×50 mm NaI(Tl) crystal and we measured the spectrum of scattered γ quanta in coincidence with the 695-kev line. The coincidence and singles spectra of the scattered γ quanta are shown in Fig. 3. The chosen limits of discrimination in the γ channel are indicated by arrows. With this discrimination the contribution of the 1480-kev line was $\sim 5\%$. As a source we used, without a carrier, Ce^{144} whose daughter product is Pr^{144}. The source was prepared by the drop method on a terylene base $\sim 4\mu$ thick. Its density was about 100 $\mu g/cm^2$. The source activity was about 1 mC.

The results of the measurements were calculated, as usual, in the form

$$\Delta = 2(I_1 - I_2)/(I_1 + I_2), \qquad I_{1,2} = R_{\text{coinc}} / R_\gamma \theta_\beta.$$

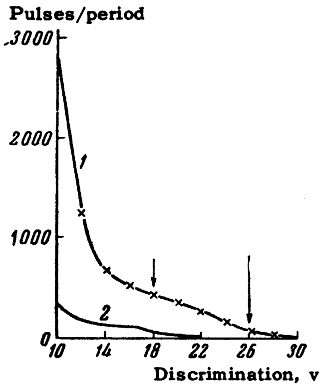

FIG. 3. Spectra of scattered γ quanta in coincidence with the 807-kev β spectrum (curve 1) and with the 695-kev γ line (curve 2). The scale on the ordinate axis corresponds to the same efficiency of the other coincidence channel (β or γ). The arrows indicate the limits of discrimination.

Here R_{coinc} is the coincidence counting rate, R_γ is the counting rate of the γ channel, θ_β is the correction for the influence of the magnetic field on the β channel, which, in this case, is 0.05%. The subscripts 1 and 2 refer to different directions of the γ-polarimeter magnetization. As a result of the measurements we obtain the value $\Delta = +(2.3 \pm 0.5)\%$ (the error represents the statistical standard deviation). From this we obtain the correlation coefficient with allowance for the random coincidence background, geometry, and mixture of the 1480-kev γ line:

$$A_1 = +0.43 \pm 0.09.$$

Since the electron energy was > 300 kev, the corrections for the source thickness were negligible. The scattering of the β electrons in air could also be neglected.

The correlation coefficient for the allowed transitions has been calculated by a number of authors.[10-11] The general form of the correlation, as is known, is

$$W(\theta) = 1 + A_1 \frac{v}{c} \cos\theta.$$

In the case of pure multipolarity of the γ quanta, we have for the A—V variant and conservation of combined parity

$$A_1 = \frac{j_1(j_1+1) - j_2(j_2+1) + I(I+1)}{2I(I+1)\sqrt{j_1(j_1+1)}} \times \left[\frac{2\lambda}{1+\lambda^2} + \frac{j_1(j_1+1) - j_0(j_0+1) + 2}{2\sqrt{j_1(j_1+1)}} \frac{1}{1+\lambda^2}\right]$$

$$\left(\lambda = -\frac{|C_V|\, M_F}{|C_A|\, M_{GT}}\right)$$

where j_0 and j_1 are the angular momenta of the initial and final states in the β transition, j_2 is the angular momentum of the final level of the γ transition, I is the multipolarity of the γ quanta, M_F, M_{GT} are the Fermi and Gamow-Teller matrix elements, C_A and C_V are the axial-vector and vector variants of the β interaction. Different combinations of the level spins and the correlation coefficients corresponding to them are shown in the table. It is seen that the first and third cases do not agree with the experimental value. In the second case, the value of A_1 depends on λ. This dependence is shown in Fig. 4. The shaded region indicates the limits of the experimental value of the correlation coefficient. Unfortunately, theoretical estimates of λ have not been made; however, the obtained value is not surprising, since in many jj transitions the Fermi matrix element proves to be small.

Case no.	Transition	$A_{theor.}$	$A_{exptl.}$
1	$0^- \xrightarrow{\beta} 1^- \xrightarrow{\gamma} 0^+$	$+1,00$	
2	$1^- \xrightarrow{\beta} 1^- \xrightarrow{\gamma} 0^+$	$+\frac{1}{2}\,\frac{2\sqrt{2}\,\lambda+1}{1+\lambda^2}$	$+0.43\pm0.09$
3	$2^- \xrightarrow{\beta} 1^- \xrightarrow{\gamma} 0^+$	$-1/2$	

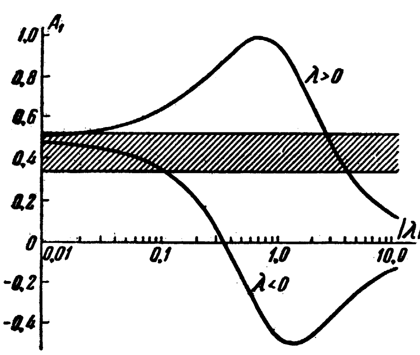

FIG. 4. Dependence of the value of the correlation coefficient on λ. The shaded region indicates the limits of the experimental value of the correlation coefficient.

Hence the obtained result indicates that the Pr^{144} ground state should be assigned a spin 1^-. The value 0^- adopted earlier cannot be reconciled with experiment.

It should be mentioned that Hickok et al[6] noted that, on the basis of the shell model, the ground state should be assigned a spin 1^-. Subsequent investigators,[3-5] however, did not consider this value to be in agreement with experiment and therefore concluded that there is a disagreement with the shell model which required special explanation.

It should also be noted that since the transition between the ground states is a $1^- \rightarrow 0^+$ transition, the earlier attempts to determine the mixture of the pseudoscalar interaction from the shape of the spectrum are without justification.

From the above it can be concluded that the investigation of forbidden β transitions cannot, in a number of cases, give unambiguous information; therefore, wherever possible, the described method for the investigation of allowed transitions should be used in view of the simple interpretation of the results.

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