β-γ CIRCULAR POLARIZATION CORRELATION OF Sb^{124}

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The first forbidden $3^- - 2^+$ transition of Sb^{124} with an end-point energy of 2.3 Mev is of special interest as it exhibits a considerable deviation from an allowed spectrum and a large β-γ anisotropy which cannot be explained by an accidental cancellation of matrix elements as in the decay of RaE. The classical experiments (ft value, shape, β-γ anisotropy) alone do not allow one to determine the 4 matrix elements $\int \vec{r}$, $\int i\vec{\sigma}\times\vec{r}$, $\int i\vec{\alpha}$, and B_{ij} which can contribute to a $\Delta I = \pm 1$, yes transition. It will be shown that a unique determination of these quantities can be achieved by measuring the β-γ circular polarization correlation. The set of matrix elements derived from the experimental results is in agreement with the "modified B_{ij} approximation" requiring B_{ij} matrix elements much larger than all the others. The transition of Sb^{124} investigated here is the first uniquely established example of the "selection rule effect" which has been discussed by several authors.[1,2]

The experimental setup was very similar to that used in previous measurements of the circular polarization of γ rays following allowed β decay.[3] Compton forward scattering from a magnetized iron cylinder was used to detect the γ polarization which is given by $P_\gamma = \omega(v/c)\cos\theta$, where v and c are the velocity of the electrons and of light, respectively, θ is the angle between electron and γ momentum, and ω is the symmetry coefficient.[4] For allowed transitions ω is only a function of the matrix elements and the spins whereas in forbidden transitions it depends also on the total electron energy W (measured in units of m_0c^2) and θ. As ω changes considerably if θ is varied, the instrumental angular spread must be kept as low as possible. To achieve this, three quarters of the scattering magnet was filled with lead, although the coincidence counting rate is decreased appreciably by this procedure. As in addition only a small region of the β spectrum can be used (a second β spectrum starts at $W_0 = 4.1$), about two months of continuous data collecting were required for one measurement in order to get sufficient statistical accuracy.

The experimental results are presented in Table I. Measurements were performed at two different angles and for two energy ranges. The upper range extending from $W=3.8$ to $W=5.5$ ($\bar{W}=4.3$) contains only a very small contribution from the second β spectrum, whereas in the lower energy range ($W=3.0$ to $W=3.8$) the coincidence rate due to the low-energy branch amounts to about 30%. As the details of this second transition are not known, it is difficult to infer quantitative results from the measurements at the lower β energy. They show, however, qualitatively that ω does not depend strongly on the β energy. On the other hand, ω changes rapidly with θ. Therefore the most accurate determination of the matrix elements will be achieved if measurements at different angles but at a fixed energy are used rather than by taking advantage of the energy dependence.

Table I. Experimental results for $\langle \omega \cos\theta \rangle_{av}$.

$\bar{W}$	4.3	3.2
$\bar{\theta} = 126°$	0.226 ± 0.046	0.190 ± 0.060
$\bar{\theta} = 160°$	-0.107 ± 0.035	-0.094 ± 0.043

The equations relating the observed quantities ω and ϵ (the β-γ directional correlation coefficient) to the matrix elements are rather complicated[1,2] but a solution can be found easily in the following way. The difference $W_{\beta\gamma}(160°)\omega(160°) - W_{\beta\gamma}(126°)\omega(126°)$ depends only on one combination of matrix elements i.e., $2x - u$. From the experiments at $\bar{W}=4.3$, one deduces $2x - u = 0 \pm 0.19$. Assuming that $2x = u$ is rigorously valid, one can eliminate x from all equations, leaving the two parameters $\zeta_1 = Y + (u-x)W_0/3$ and u. In a $\zeta_1 - u$ plane each experimental value determines a conic section (Fig. 1). The intersections of the curves for $\omega(\theta=160°)$ and $\omega(\theta=126°)$ give two sets of solutions but only one is consistent with the β-γ anisotropy.[5]

Within the experimental errors the three curves intersect at one point proving that $2x = u$ is a good approximation.[6] A better intersection than shown in Fig. 1 can be achieved by putting $2x - u = +0.1$ although this change is still within the experimental uncertainties. It may be pointed out that all these calculations were performed by aver-

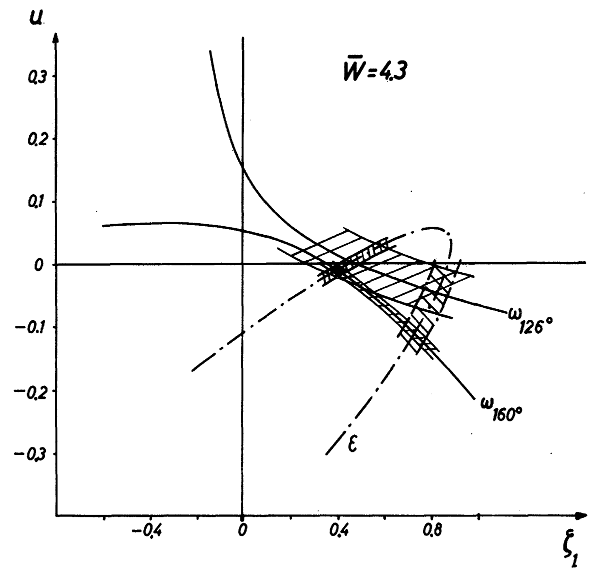

FIG. 1. Graphic determination of the parameters u and ζ_1 from the measured quantities $\omega_{160°}$, $\omega_{126°}$, and ϵ.

aging over the finite sizes of source, β counter, and scattering magnet and over the energy and by taking into account Coulomb corrections. A complete description of these calculations and of the experimental details will be given elsewhere.

In conclusion the following ratios of matrix elements (compared to the standard matrix element B_{ij}) can be inferred:

$$Y = 0.42 \pm 0.1,$$

$$u = -0.01 \pm 0.02,$$

$$x = 0.05 \pm 0.05.$$

The absolute value of B_{ij} can be derived from the ft value by taking into account the results for Y, u, and x and is found to be $|B_{ij}|^2 = (8.0 \pm 0.8) \times 10^{-10}\ \text{sec}^{-1}$. Thus all matrix elements are known. It turns out that the B_{ij} matrix element is much larger than the momentum-type matrix elements $\int \vec{r}$ and $\int i\vec{\sigma} \times \vec{r}$ and is of the same order of magnitude as the relativistic matrix element $\int i\vec{\alpha}$. Moreover it is found that $\int i\vec{\alpha}$ is in phase with B_{ij}. The unusual enhancement of B_{ij} can be explained by the "selection rule effect" as discussed by Morita and Morita[1] and by Kotani.[2]

The results obtained here can be illustrated by comparing them with some special cases investigated by Kotani.[2] In Fig. 2, $\omega \cos\theta$ is plotted as a function of $\cos\theta$. Curve I corresponds to a

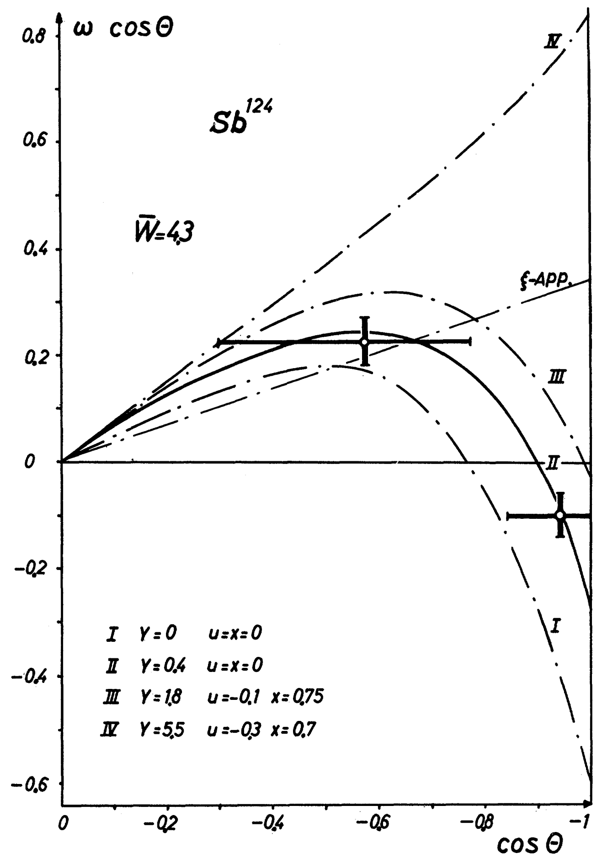

FIG. 2. Comparison of experimental and theoretical values of $\omega \cos\theta$. Curve I: "unique" transition (only B_{ij} contributes). Curve II: modified B_{ij} approximation. Curve III: intermediate case. Curve IV: cancellation of matrix elements.

"unique" decay (B_{ij} contributes only) and curve IV to a cancellation of matrix elements as in the decay of RaE. Another curve shows the "ξ approximation" which is valid in most first forbidden decays. The experimental results clearly exclude all these possibilities and are reproduced only by the "modified B_{ij} approximation" which requires large B_{ij} but $Y \neq 0$.

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[1] M. Morita and R. S. Morita, Phys. Rev. 109, 2048

(1958).

[2]T. Kotani, Phys. Rev. 114, 795 (1959).

[3]H. Schopper, Phil. Mag. 2, 710 (1957); and Nuclear Instr. 3, 158 (1958).

[4]The notation of Kotani[2] is used throughout this paper.

[5]We are greatly obliged to Professor R. M. Steffen for enabling us to use his results prior to publication and for helpful discussions. According to his measurements $\epsilon(p^2/W)^{-1} = -0.09 \pm 0.001$ at $W = 4.3$.

[6]A similar curve could be derived from the shape factor $C(W)$. However, we did not add this curve as C is not known with reliability.

CIRCULAR POLARIZATION OF INTERNAL BREMSSTRAHLUNG ACCOMPANYING β DECAY

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As a consequence of parity nonconservation in weak interactions the particles emitted in β decay possess definite helicities. This is true even for second order processes. In a previous paper[1] it was shown that the photons emitted together with electrons and neutrinos are circularly polarized. For the K capture of A^{37} complete polarization (with positive helicity) was found[2] for the internal bremsstrahlung. The circular polarization of photons with negative helicity accompanying the β decay of Y^{90}, however, showed some deviations from the theoretical expectation.[1] This might be explained by systematic experimental errors or by the circumstance that the decay of Y^{90} is unique forbidden whereas the theory has been developed for allowed transitions only. In order to clarify the situation, the circular polarization of internal bremsstrahlung for different types of β transitions (allowed, first forbidden, unique forbidden) was investigated and all corrections were determined as accurately as possible.

The experimental setup was very similar to that used previously.[1] Compton forward scattering from magnetized iron was used to measure the circular polarization. The inner diameter of the scattering magnet (18 cm) and, at the same time, the length of the central lead absorber (14 cm) were increased in order to achieve a more effective absorption of the direct radiation. The electrons were stopped in paraffin so that the contribution from external bremsstrahlung was kept low. No correction was applied as this influence is negligible compared to statistical errors.

The difficulties in measuring the circular polarization of internal bremsstrahlung are twofold. The yield is very small ($\sim 10^{-3}$ photon/β decay) and thin sources must be used to avoid external bremsstrahlung produced in the source. This requires long counting times in order to get sufficient statistical accuracy. Secondly the spectrum of the bremsstrahlung drops very rapidly with increasing quantum energy. This circumstance, peculiar to bremsstrahlung, makes some corrections much more important than in other experiments. For example, the scattered photons degraded in energy have to compete with the direct radiation which penetrates the central lead absorber and has higher energy and hence a larger primary intensity.

In calculating the γ polarization from the measured change in counting rate (produced by reversing the magnetization), corrections were applied (a) for the elastic scattering of γ rays from the iron cylinder, (b) for Compton scattering from the copper of the magnetization coil, and (c) for photons penetrating the central lead absorber. These corrections are small for low photon energies but amount to about 30% at 1.5 Mev. Apart from these corrections the calculations were performed in the usual way.[3]

In order to avoid the production of external bremsstrahlung the sources and their backings had to be thin. Hostaphan foils (2 mg/cm^2) were used as backings. The sources were thinner than 2 mg/cm^2 and possessed activities of a few mC. A special procedure had to be used to prepare RaE sources.[4] RaE was deposited on Ni foils from RaD solution. As together with RaE some RaF which has a weak γ transition is deposited, a further separation was necessary. This was achieved by evaporating the RaE in a hydrogen stream and condensing it on cooled Al foils (~ 10 mg/cm^2) used as target backings in this case. Due to the short half-life of RaE, several sources had to be produced.

The experimental results for the three decays