

Positron Polarization in a Mirror Transition*

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The positron polarization in the mirror transition N^{13} , a predominantly Fermi transition, has been measured by detecting the circular polarization of the annihilation-in-flight quanta. The results indicate complete polarization of the positrons parallel to their momentum, showing that Fermi coupling contributes significantly to the positron polarization in the same sense as the Gamow-Teller coupling.

I. INTRODUCTION

EXPERIMENTAL studies of the longitudinal electron and positron polarization in a beta decay process provide information about the beta decay law.¹⁻³ In particular, these studies can determine the relative magnitude of the parity-conserving and parity-nonconserving couplings. In allowed transitions with spin change, that is in pure Gamow-Teller transitions, it has been found by several workers⁴⁻⁹ that the longitudinal polarization is approximately $-v/c$ for electrons and $+v/c$ for positrons. For transitions without spin change, however, where both Fermi and Gamow-Teller interactions contribute, contradictory results on the degree of longitudinal polarization has been obtained.^{7,10} A careful study of the Fermi part of the interaction seemed, therefore, desirable. This part of the beta interaction can be studied in a 0-0 transition or a mirror transition where the nuclear matrix elements are known. Among the mirror transitions N^{13} is particularly suitable because the Fermi matrix element is larger than the Gamow-Teller matrix element.¹¹ Consequently, the positron polarization will be determined mainly by the Fermi part of the transition.

We have studied the positron polarization in N^{13} by measuring the circular polarization of the high-energy annihilation-in-flight quanta. The measurements indicate that the positrons are completely polarized, from which it can be concluded that the Fermi transition as

well as the Gamow-Teller transition exhibit the maximum effect of parity nonconservation.

II. EXPERIMENTAL PROCEDURES

A suitable method for the study of positron polarization is the annihilation in flight recently discussed by Page.¹² Annihilation-in-flight photons of high energy have their spins in the direction of the initial spin of the positron.

The degree and sense of the circular polarization of photons can be measured by using the spin dependence of the Compton scattering cross section.^{13,14} We have measured the transmission of the annihilation quanta through magnetized iron. This detection method is similar to the one applied by Goldhaber *et al.*⁶

A sketch of the apparatus used is shown in Fig. 1. The annihilation-in-flight photons are produced in a carbon target surrounded by a small Lucite cover. They impinge upon a 3 inch long by $1\frac{1}{2}$ inch² Armco iron magnet which is magnetized with the help of two coils. The detector is a $1\frac{1}{2}$ -inch NaI crystal, which is located at a distance of $4\frac{1}{2}$ inches from the magnet. Lead absorbers in the amount of 1 to $1\frac{1}{2}$ inches were used to further discriminate against the 511-kev

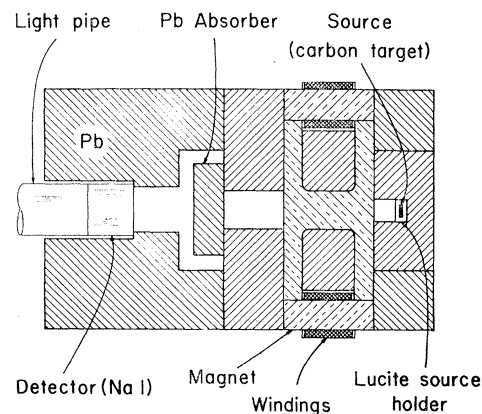


FIG. 1. Experimental arrangement for measurement of circular polarization of annihilation-in-flight photons.

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photons. Under these conditions the number of pile-up pulses in the detecting system at high energy is negligible.

The N^{13} sources were prepared by deuteron bombardment of a spectroscopically pure carbon target in the 3-Mev Van de Graaff generator with beam currents of about $20 \mu\text{a}$ at 3 Mev. Sources of 0.2 to 0.6 curie strength were measured for a period of about two half-lives, taking one-minute counts at alternate magnetic field directions in the polarization analyzer. Altogether, 20 irradiations were performed. The percent difference in counting rate for the two directions of magnetization, δ , corrected for decay, was measured at four different energies of the photons, 620 kev, 830 kev, 1040 kev, and 1140 kev. To ensure the absence of gamma-ray emitting impurities, the annihilation-in-flight spectrum was studied with a 100-channel differential analyzer. No gamma ray other than the annihilation radiation was found. Furthermore, the observed half-life in each run confirms the absence of impurity photons as well as pile-up effects.

Figure 2 shows a typical differential channel photon spectrum of N^{13} . Curve (a) is the experimentally observed uncorrected pulse distribution. Curve (b) shows the same distribution after correcting for detector sensitivity and absorption in the analyzer. The theoretical annihilation-in-flight spectrum is given in curve (c). The procedure for obtaining this curve is discussed below. The deviations at lower energies are presumably due to forward scattered quanta of originally higher energy.

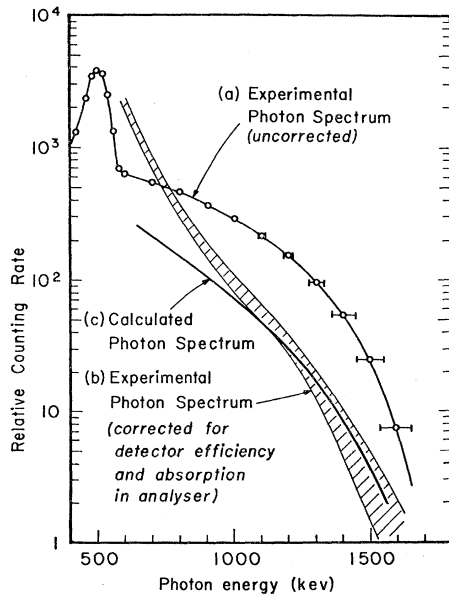


FIG. 2. Photon spectrum from 2-quantum annihilation-in-flight of N^{13} positrons in carbon. The intensity scales are arbitrary. Curves (b) and (c) are normalized at 1200 kev.

III. CALIBRATION

In order to determine the N^{13} positron polarization from the measured effect, one has to calculate the degree of photon polarization for the annihilation-in-flight quanta as a function of the positron polarization. In the experimental arrangement which has been used the positron source is mostly surrounded by carbon. The positrons therefore annihilate isotropically in this material. The number of right (+) or left (-) circular polarized annihilation quanta of energy k is then given by the expression

$$W_{\pm}(k) = \int_{E_{\min}(k)}^{E_0} dE' \left\{ \frac{1}{2} \left(1 \pm \alpha \frac{v}{c} \right) \omega_{+}(E', k) + \frac{1}{2} \left(1 \mp \alpha \frac{v}{c} \right) \omega_{-}(E', k) \right\} N(E'), \quad (1)$$

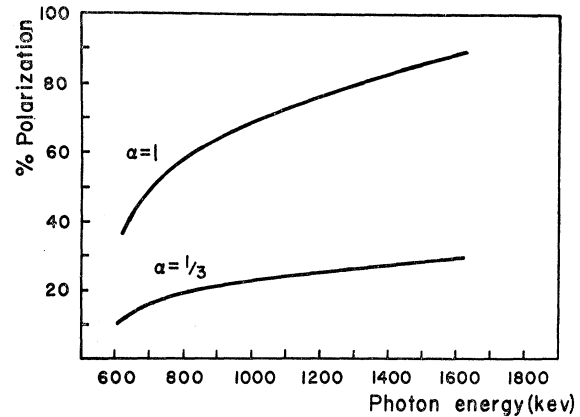


FIG. 3. Calculated polarization of γ quanta from annihilation-in-flight of N^{13} positrons in carbon. A positron polarization $P = +\alpha v/c$ is assumed and curves are shown for $\alpha = +1$ and $\alpha = +\frac{1}{3}$.

where

$$\omega_{\pm}(E', k) = 2n_0 Z \int_{E_{\min}(k)}^{E'} dE \frac{\sigma_{\pm}(E, k)}{(-dE/dx)},$$

n_0 = carbon atoms per unit volume, and Z = charge number = 6. Here $N(E')$ represents the N^{13} positron spectrum with a maximum energy, $E_0 = 1200$ kev. dE/dx gives the energy loss per path length in carbon and $E_{\min}(k)$ denotes the minimum positron energy required to produce a γ quantum of energy k . The cross section for the two-quantum annihilation at energy E yielding a right or left circular quantum k is denoted by $\sigma_{\pm}(E, k)$ and can be derived from the formulas given by Page.¹² The degree of positron polarization is written as $\alpha v/c$ (v/c to be taken at energy E') where v is the positron velocity. A numerical integration of Eq. (1) gives the theoretical γ spectrum presented in Fig. 2.

The γ -polarization resulting from Eq. (1) is plotted in Fig. 3 for the case $\alpha=1$, i.e., for $+v/c$ polarization, and for $\alpha=1/3$. In these cases the γ polarization is such that the photon advances as a right-handed screw.

The efficiency of the magnetic analyzer in determining the degree of γ polarization has been calculated by using the spin-dependent part of the total Compton cross section.^{13,14} The effective length of fully saturated iron is estimated to be $2\frac{3}{8}$ inches. The expected percent difference in counting rate, δ , for alternate magnetic field directions in the iron is the product of this efficiency with the calculated polarization of Fig. 3 and is given in Fig. 4.

An attempt was made to check the efficiency of the analyzer experimentally using the bremsstrahlung photons produced in lead by the β rays of a 150 *mC* and 500 *mC* P^{32} source. The P^{32} electrons are polarized to a degree $-v/c$, as has been found by several workers,^{4,7} and the bremsstrahlung photons should therefore have a circular polarization of similar magnitude and sign. The experimental points obtained with our geometry follow, as expected, the calculated efficiency curve except for a region around 1 Mev where the experimental points are approximately 30% lower. The calibration curve in Fig. 4 can therefore be considered as an upper limit and perhaps should be somewhat lower near 1 Mev.

RESULTS AND DISCUSSION

The results of the present experiments on N^{13} are plotted in Fig. 4. The errors are statistical errors. The size of the effect and the energy dependence indicate a polarization of positrons of the amount $(0.93 \pm 0.20)v/c$ with the spin pointing in the same direction as the momentum vector.

N^{13} is a well-analyzed mirror transition. From an analysis of the ft values it has been concluded that the ratio of the square of Gamow-Teller and Fermi matrix elements is 0.40.¹¹ Our result shows clearly that the Fermi part of this transition contributes significantly to the positron polarization in the same sense as the Gamow-Teller transition. If only the Gamow-Teller part of the transition contributed to the polarization, one would expect the points to follow approximately the curve for $\alpha=1/3$. In fact, our result is consistent with the largest possible polarization and indicates, therefore, a positron polarization $+v/c$ for pure Fermi transitions.

This result is in contradiction with the small electron polarization values found in Au^{198} , Sc^{46} , and Ga^{66} ,^{7,10} but is in agreement with recent measurements by

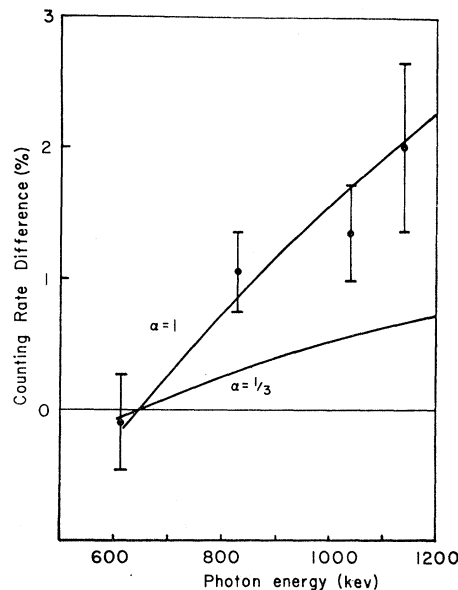


FIG. 4. Comparison of N^{13} experimental points and theoretical curves for a positron polarization of $+v/c$ and $+1/3 v/c$.

Deutsch *et al.*¹⁵ who find a large polarization for the 0-0 transitions in Ga^{66} and Cl^{34} .§

Assuming that the polarization is exactly v/c ,³ as seems likely from the present experiment, one can conclude that the following relations for the scalar and vector coupling constants hold¹⁶:

$$C_S' = -C_S \quad \text{and} \quad C_V' = C_V.$$

If the two-component neutrino theory is valid, it follows from this result that the β -coupling contains either S and T , or V and A interactions.

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§ Recent measurements by Benczer, Koller, Schwarzschild, Vise, and Wu [Phys. Rev. (to be published)] and by Cavanagh, Turner Coleman, Gard, and Ridley (to be published) give a large electron polarization for the forbidden transition in Au^{198} .

¹⁶ This is in disagreement with the predictions by M. Goepfert Mayer and V. L. Telegdi [Phys. Rev. **107**, 1446 (1957)] and by M. A. Preston, Can. J. Phys. (to be published).