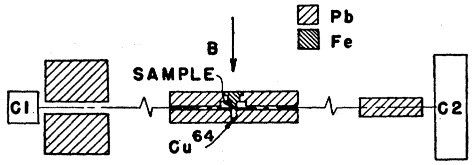

FIG. 1. Experimental arrangement.

demonstrated by the group at Illinois.[5] The purpose of the present investigation was to obtain evidence for the polarization of positive beta particles with quite a different type of experiment.

As shown in Fig. 1, positrons from a Cu^{64} source impinged on the end of a cylindrical sample 4 mm in diameter, and the two-quantum yield was detected with two NaI counters placed 180° apart and operated in coincidence. Appropriate shielding suppressed radiation from positrons annihilating anywhere but in the iron sample. The sample was mounted in a magnetic field which could be made either parallel or antiparallel to the direction of the positrons and hence to the presumed polarization.

One counter, at a distance of 290 cm, had an aperture of 9×10^{-6} steradian. The second counter, at a distance of 165 cm, was uncollimated and subtended an angle of 3×10^{-3} steradian. In order to observe the angular correlation of annihilation radiation, cylindrical lead absorbers of successively increasing diameters were inserted in front of, and coaxial with, the uncollimated counter. A measurement of the angular correlation for annihilation in copper, obtained with this technique, agreed satisfactorily with the result of Lang *et al.*[7]

A lead absorber was selected which effectively eclipsed the central cone (half-angle equals 8.5 milliradians) of the angular distribution for iron, allowing observation of the "wings" of the distribution corresponding to annihilation in the sample by electrons of high momentum. The yield so obtained was normalized to the total intensity with the absorber removed. With fields producing saturation in the iron sample, this normalized yield R was consistently higher by $(5\pm1)\%$ with the field parallel instead of antiparallel to the direction of motion of the positrons. The effect vanished when a copper sample was used. The results from one series of measurements are shown in Fig. 2. Geometrical effects were investigated by reversing the direction of the positrons and the results were not significantly different. A further check on the experimental arrangement was obtained by performing the experiment with first one half and then the other half of the large counter covered with a lead shield. In both cases the same effect was obtained. It is seen in Fig. 2 that the ratio R is higher for copper than for iron, in agreement with reference 7.

A plausible explanation of the above result may be summarized as follows: (1) Positrons emitted from a Cu^{64} source (spin change $1\rightarrow0$) are partially polarized

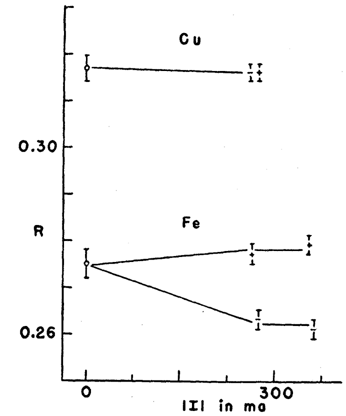

FIG. 2. Normalized coincidence rate R, as defined in the text, plotted against the magnet current. For the (+) points the magnetic field was parallel to the direction of motion of positrons. For the (−) points the field was reversed. The lines are supplied merely to aid in visualizing the data. Fe and Cu signify annihilation in the iron sample and copper sample, respectively.

parallel to their direction of motion, i.e., opposite to the direction observed for negative electrons.[5] (2) At the time of their annihilation the positrons still retain a substantial amount of this polarization. (3) Annihilation takes place predominantly in the region midway between nuclei where the d electrons mainly responsible for ferromagnetism have higher momentum than the s electrons. (4) Thus when the field is parallel (electron spin antiparallel) to the positron spin, two-quantum annihilation is enhanced in the high-momentum region of the angular correlation, and when the field is reversed it is diminished.

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Beta-Gamma Circular Polarization Correlation Measurements*

F. BOEHM AND A. H. WAPSTRA†
California Institute of Technology, Pasadena, California
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OWING to nonconservation of parity in β decay,[1] γ rays following β transitions are circularly polarized. The angular distribution of circularly polarized γ rays emitted under an angle θ with the preceding β particles is $W(\theta,\pm)=1\pm A(v/c)\cos\theta$ (+ for right-hand, − for left-hand circular polarization).[2]

We consider β transitions with spin change 0 or 1 between levels with spin j_i and j, followed by a mixed dipole-quadrupole γ radiation (mixing ratio δ) between

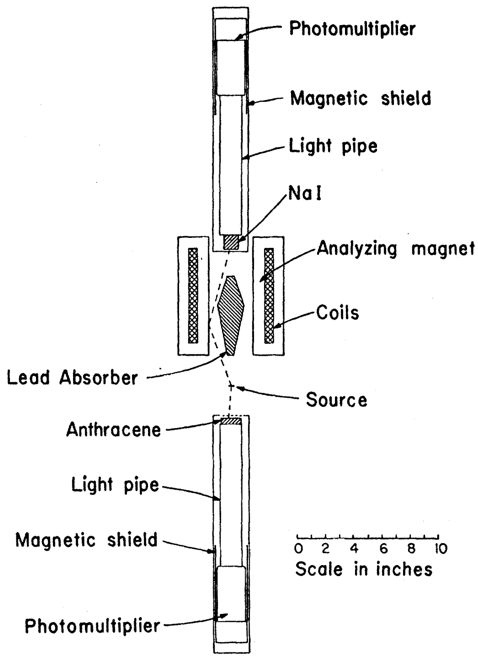

FIG. 1. Experimental arrangement for measuring $\beta-\gamma$ circular polarization correlations.

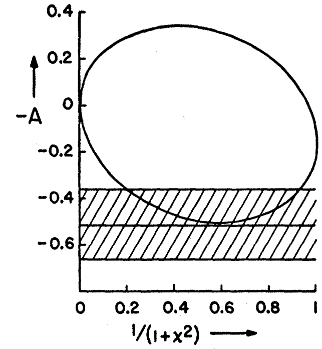

FIG. 2. Correlation coefficient A in Au^{198} as a function of the fraction of β interaction with spin change, $1/(1+x^2)$. The experimental value is indicated.

levels with spins j and j_f. A is then given by the following formula, derived from the work by Alder, Stech, and Winther[2] who also give a table of the coefficients F_1:

$$A=\frac{2}{3}\left(\frac{F_1(1,1,j_f,j)+\delta F_1(1,2,j_f,j)+\delta^2 F_1(2,2,j_f,j)}{1+\delta^2}\right)\times\left(\frac{F_1(1,1,j_i,j)+xF_1(1,0,j_i,j)}{1+x^2}\right),$$

in which $x=C_S|\int\beta|/C_T|\int\beta\boldsymbol{\sigma}|$ for allowed transitions, and

$$x=\left\{C_P\left|\int\beta\gamma_5\right|+C_T\xi\left|\int\frac{\beta}{i}\boldsymbol{\sigma}\cdot\mathbf{r}\right|\right\}\Big/\times\left\{C_S\xi\left|\int i\beta\mathbf{r}\right|+C_T\left|\int\beta\boldsymbol{\alpha}\right|+C_T\xi\left|\int\beta\boldsymbol{\sigma}\times\mathbf{r}\right|\right\}$$

for first forbidden transitions.[3]

Circular polarization can be studied experimentally by utilizing the polarization dependence of the Compton scattering cross section.[4] We have designed a polarization-analyzer magnet consisting of a hollow Armco iron cylinder which can be magnetized with help of a coil (Fig. 1). The γ rays emitted from a radioactive source are scattered at an angle of approximately 52° on the inside of this cylinder. A lead absorber suppresses the direct γ rays. Gamma rays are measured with a NaI crystal, electrons with an anthracene crystal. Light pipes between crystals and photomultipliers and magnetic shields eliminate the influence of the magnetic field on the detectors. The % differences in single β and γ counting rates with opposite saturated magnetizations in the analyzer were negligible: (0.02 ± 0.005)% for β rays and (0.005 ± 0.04)% for γ rays.

Coincidences between β particles and scattered γ rays were measured with a fast-slow coincidence circuit having a resolving time of 0.03 μsec. In order to correct for fluctuations in fast-coincidence resolving time and discriminator settings, the following precautions were taken. Successive measurements (usually of 40-min duration) were made with alternate magnetic field directions; every run consisted of about 10 measurements in either field direction. Care was taken that corrections for accidental coincidences were not larger than ~15%. The coincidence counting rates were divided by the product of the single counting rates before further analysis.

In our geometry, the efficiency of the analyzer, defined as the percentage difference in counting rate for different directions of the (saturated) magnetic field for completely circularly polarized γ rays of energy $k(m_0c^2)$ is computed to be[5] (with an estimated accuracy of 15%)

$$\epsilon=2.90k(1+0.13k)/(1+0.36k+0.09k^2).$$

For $\beta-\gamma$ angular correlation this efficiency has to be multiplied by the cosine of the average angle between β and γ radiations (148°).

Partly as a check to this formula, we have measured the bremsstrahlung of β particles of Tm^{170}. According to theory[2] and experiment,[6,7] these β particles are polarized in the direction of their motion. According to the two-component neutrino theory[1] the degree of polarization is approximately $-v/c$ ($\simeq -0.92$ for the highest energy electrons in Tm^{170}). McVoy[8] computed that completely polarized electrons of about 900 kev would give rise to bremsstrahlung circularly polarized to a degree of 85% near the high energy of this bremsstrahlung spectrum. We found a difference of (2.4 ± 0.4) % in the single counting rates near the high-energy end of the Compton scattered bremsstrahlung spectrum for opposite magnetic field directions. This yields an efficiency of $(3.1\pm0.4)\%$, compatible with the value $\epsilon=3.3\%$ computed with the formula given above. Reversely, the experimental result together with the computed efficiency can be considered as a check on the v/c law for the polarization of electrons emitted in β decay.

We have made $\beta-\gamma$ coincidence measurements with Co^{60}. The difference in coincidence counting rates (corrected as described in the foregoing) with opposite field directions was $(0.92\pm0.19)\%$. This value is the average of 9 runs with different sources and under slightly different conditions. This result, together with the fact that in the average $v/c=0.69$ for the electrons selected by the β discriminator, leads to a value $A=-0.40\pm0.09$, in agreement with the theoretical[1,2] value, -0.33.

Recently we were informed that Schopper[9] had made experiments in a very similar arrangement. His result for Co^{60} is $A=-0.41\pm0.07$.

A measurement of A may be used to obtain data about nuclear spins. We have applied this method to Au^{198} and Hg^{203}. Au^{198} is essentially a simple first forbidden 960-kev β transition to a 2^+ 411-kev excited state followed by a single $E2$ γ ray to a 0^+ ground state. The Au^{198} ground state was first thought to have a spin 3,[10] but later measurements indicate a spin 2.[11,12] Hg^{203} has a first-forbidden 210-kev β transition to a $\frac{3}{2}^+$ 279-kev excited state followed by a mixed $M1-E2$ γ ray $(\delta=1.45)$[13] to a $\frac{1}{2}^+$ ground state. The spin of the Hg^{203} ground state is unknown. The very low intensity of the ground-state transition[14] is most easily explained by assuming a spin $\frac{5}{2}$.

The measurements were made with the arrangement described in the preceding letter. For Au^{198} a coincidence counting rate difference of $(0.71\pm0.17)\%$ was found, corresponding to a value $A=+0.52\pm0.16$. This result excludes a spin 3 for the Au^{198} ground state, which should have yielded $A=-0.32$. Figure 2 gives A as a function of the mixing parameter x for a spin 2. Our experiment indicates that the spin changes direction in roughly $\frac{2}{3}$ of the Au^{198} decays. The sign of x is negative.

The measurements on Hg^{203} are more difficult, due to the lower energy of both β and γ rays. Preliminary measurements yielded a coincidence counting rate difference of $(0.07\pm0.24)\%$, corresponding to a value, $A=+0.10\pm0.30$. The precision is not sufficient to exclude a spin $\frac{5}{2}$ for Hg^{203}, which would give $A=-0.21$; our result, however, agrees better with a spin $\frac{3}{2}$.

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Possible Existence of a Heavy Neutral Meson*

YOICHIRO NAMBU
The Enrico Fermi Institute for Nuclear Studies, The University of Chicago, Chicago, Illinois
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IN an attempt to account for the charge distributions of the proton and the neutron as indicated by the electron scattering experiments,[1] we would like to consider the possibility that there may be a heavy neutral meson which can contribute to the form factor of the nucleon. We assume that this meson, ρ^0, is a vector field with isotopic spin zero and a mass two to three times that of the ordinary pion, coupled strongly to the nucleon field. An isolated ρ^0 would decay through virtual nucleon pair formation according to the following schemes:

(a) $\rho^0\to\pi^0+\gamma,\quad 2\pi^0+\gamma,\quad \pi^++\pi^-+\gamma;$
(b) $\rho^0\to e^++e_-,\quad \mu^++\mu^-;$
(c) $\rho^0\to\pi^++\pi^-.$

The process (a) would have a decay probability roughly of the order of $P_a\sim(\mu c^2/\hbar)(G^2/\hbar c)(e^2/\hbar c)(\mu/M)^2$, where G is the nuclear coupling constant, μ and M the ρ^0 and the nucleon masses, respectively. For the process (b), the probability would be $P_b\sim(\mu c^2/\hbar)(G^2/\hbar c)(e^2/\hbar c)^2\times(\mu/M)^2$. The process (c) is a forbidden transition, so that it can take place only in violation of the isotopic spin conservation, with a decay rate comparable to that for (b).

Now the process (b) gives rise to a short-range interaction between a nucleon and an electron (or a muon) by exchange of a ρ^0. This will contribute a form factor $F'(k^2)\sim Gg/(\mu^2+k^2)$ to the electron-nucleon scattering, where g is the effective ρ^0-electron coupling, $g^2/\hbar c\sim(G^2/\hbar c)(e^2/\hbar c)^2(\mu/M)^2$. Since ρ^0 is an isotopic scalar, F' has the same sign for both proton and neutron, whereas the corresponding form factor F