β - γ ANGULAR CORRELATION EXPERIMENTS AND TIME-REVERSAL INVARIANCE OF THE BETA INTERACTION*.

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Curtis and Lewis[1] proposed a possible test of time-reversal invariance by measuring the transverse polarization of beta particles in a beta-gamma correlation experiment. No such polarization exists in an allowed transition; thus first forbidden transitions must be considered. The beta-gamma correlation function is of the form[1]

$$W(\vec{p}_0,\vec{k},\vec{n})=1+\tfrac{1}{2}A_2[3(\vec{p}_0\cdot\vec{k})^2-1]+F(\vec{p}_0\cdot\vec{k})(\vec{n}\cdot\vec{k}) + G(\vec{n}\cdot\vec{p}_0\times\vec{k})(\vec{p}_0\cdot\vec{k}). \quad (1)$$

$\vec{p}_0$ is a unit vector in the direction of the momentum $\vec{p}$ of the beta particle, $\vec{n}$ and $\vec{k}$ are unit vectors in the direction of the electron spin ($\vec{n}$ orthogonal to $\vec{p}$) and the gamma-ray photon, respectively. The second term gives rise to the ordinary β-γ directional correlation, the third term leads to a transverse polarization $P_{||}$ of the beta particles in the plane of $\vec{p}$ and $\vec{k}$ and the last term leads to a polarization $P_{\perp}$ perpendicular to the plane of $\vec{p}$ and $\vec{k}$. The coefficients A_2, F, and G, which are functions of p, were calculated by Curtis and Lewis,[1] neglecting the influence of the Coulomb field ($\alpha Z << 1$, $\alpha Z/pR << 1$). In this $Z \to 0$ approximation, G vanishes if the β-interaction Hamiltonian is time-reversal invariant; on the other hand, it is of appreciable magnitude if time-reversal invariance is violated. On the basis of these considerations the measurement of the beta-polarization-gamma directional correlation seemed to provide a feasible test of time-reversal invariance and the experimental investigation of the angular correlation function (1) for the first forbidden beta decay of Au^{198} was started in early 1957.

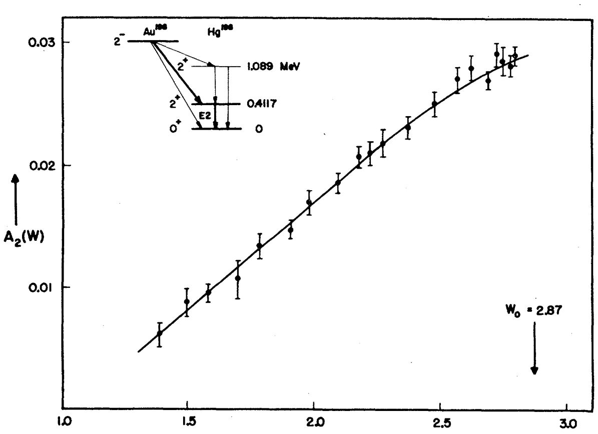

FIG. 1. Anisotropy factor $A_2(W)$ of the Au^{198} β-γ directional correlation.

Au^{198} was chosen in spite of its large Z, since it seemed the only first forbidden β emitter with decay and production features favorable to the execution of the difficult polarization-correlation experiment. The Au^{198} sources (5 $\mu g/cm^2$) were prepared by evaporation on to an aluminum foil backing (180 $\mu g/cm^2$). The beta-gamma directional correlation of Au^{198} was observed with a multichannel scintillation coincidence spectrometer.[2] The results, corrected for finite energy resolution, backscattering in the β crystal, etc., are shown in Fig. 1. The solid line represents $A_2(W)$ in the directional correlation function $W(\theta_{pk})=1+A_2P_2(\cos\theta_{pk})$.

The beta-polarization-gamma-directional correlation was investigated with the vacuum chamber shown in Fig. 2. The transverse polarization of the beta particles at $\theta_{pk}=3\pi/4$ was detected by observing the "left-right" asymmetry in a Mott scattering process on a thin gold foil (1.47 mg/cm^2). The scattering asymmetry $a(\varphi,W)$ is a function[3,4] of the scattering angle φ and of the electron energy W. In the present investigation the average values $\varphi_{Av}=120°$ and $W_{Av}=2.0$

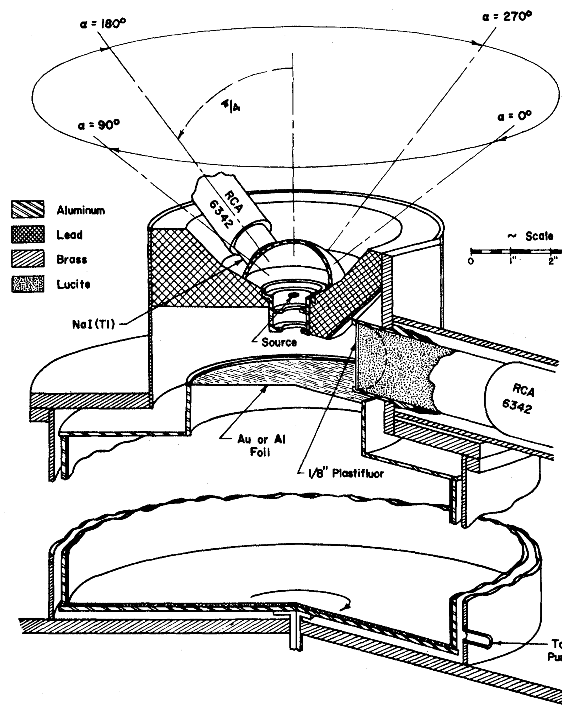

FIG. 2. Vacuum chamber for the measurement of the transverse polarization of β particles in a β-γ correlation experiment.

Table I. Transverse polarization of the Au^{198} β particles (p=1.7, θ_{pk}=3π/4).

Experiment	Scatterer	$\Delta(\alpha)$	Polarization at $\theta_{pk}=3\pi/4$
Polarization parallel to to $\vec{p}$-$\vec{k}$ plane (α = 90°)	Au Al	-0.0030 ± 0.0011 +0.0020 ± 0.0011	$P_{\parallel}$ = + 0.013 ± 0.006
Polarization perpendicular to $\vec{p}$-$\vec{k}$ plane (α = 0)	Au	-0.0035 ± 0.0015	$P_{\perp}$ = + 0.003 ± 0.013

(p = 1.7) were selected. The measurements were performed by alternating the Au scattering foil with an Al foil whose thickness was chosen to give approximately the same (very small) probability for plural scattering as the Au foil. The position of the gamma detector axis, which is given by the angle α between the source-γ-counter plane and the source-β-detector plane (compare Fig. 2), was changed every 15 minutes and the relative difference $\Delta(\alpha)=[N(\alpha)-N(\alpha+180°)]/[N(\alpha)+N(\alpha+180°)]$ of the β-coincidence rates N recorded. $P_{\perp}$ was determined from observing $\Delta(0)$, and $P_{||}$ was extracted from the measurement of $\Delta(90°)$. The results of 450 days of continuous measurement are summarized in Table I. The considerably larger error of $P_{\perp}$ as compared to the one of $P_{||}$ is a result of the fact that the counter arrangement is less symmetric in the $P_{\perp}$ position (α=0) so that more corrections must be considered. Using the data of Fig. 1 and Table I, the final experimental result for the complete beta-polarization-gamma-directional correlation of Au^{198} for p = 1.7 is

$$\begin{aligned} W(\vec{p}_0,\vec{k},\vec{n}) = 1 &+ (0.0088\pm0.0004)[3(\vec{p}_0\cdot\vec{k})^2-1] \\ &-(0.026\pm0.012)(\vec{p}_0\cdot\vec{k})(\vec{n}\cdot\vec{k}) \\ &-(0.006\pm0.026)(\vec{n}\times\vec{p}_0\cdot\vec{k})(\vec{p}_0\cdot\vec{k}) \end{aligned} \quad (2)$$

While this investigation was in progress, Iben[5] and Kotani[6] have shown that even for low Z the coefficients A_2, F, and G in Eq. (1) are very different from the Z = 0 approximation of Curtis and Lewis. In fact the time-reversal testing terms in G are, in general, largely dominated by contributions which are independent of time-reversal invariance. Consequently the mere presence or absence of the G term does not allow one to draw any conclusions concerning time-reversal invariance. Only a careful measurement of the energy dependence of G (i.e., of $P_{\perp}$) could possibly allow a separation of the time-reversal dependent contributions and thus could give information on time-reversal invariance. Such an experiment seems to be beyond the possibilities of present experimental techniques.

In the high Z approximation ($\xi = \alpha Z/2R \gg 1$; for Au^{198}, ξ = 15) a definite relationship[5] exists between the coefficients A_2, F, and G:

$$A_2 : F : G = \tfrac{2}{5}p : (-1)^r : \tfrac{3}{4}\alpha Z. \quad (3)$$

The exponent r depends on the choice of the coupling constants in the beta-interaction Hamiltonian. For the V-A coupling r = 1, for the S-T coupling r = 0. On the basis of Eq. (3), the results of the β-γ directional correlation of Fig. 1 allow one to predict the values of F and G. For p = 1.7 one obtains $F=(-1)^r(0.016\pm0.001)$, G = $+0.007\pm0.001$, respectively. The negative sign of the experimental value of F=-0.026 ± 0.012 favors very strongly r = 1 and thus gives further evidence of the predominance of the V-A coupling in beta decay.

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