

One of us (A.S.) hopes to return to the electromagnetic case.

¹ A. Storruste and H. Wergeland, Kgl. N. V. Selsk. Forh. (1948) (in print).

² Stratton, Morse, Chu, and Hutner, *Elliptic Cylinder and Spheroidal Wave Functions* (1941).

³ E. A. Hylleraas, Zeits. f. Physik 71, 739 (1931).

Correlation between the States of Polarization of the Two Quanta of Annihilation Radiation*

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IT has been pointed out by J. A. Wheeler¹ that according to pair theory the planes of polarization of the two quanta originating in the annihilation of a positron should be perpendicular to each other. This correlation is the equivalent of angular momentum conservation in the process of annihilation of an electron pair with relative velocity zero in the singlet state. The azimuthal variation of intensity of the simultaneous Compton scattering of the two quanta, resulting from this correlation between their respective states of polarization, has been calculated by Pryce and Ward² and by Snyder, Pasternack, and Hornbostel.³ An experimental verification has been attempted with the aid of the arrangement shown in Fig. 1.

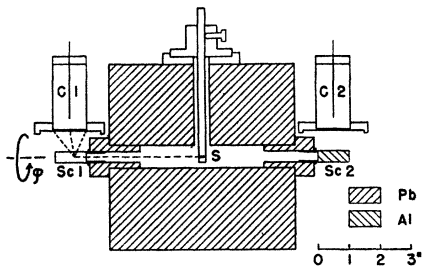


FIG. 1. Coincidence measurement of Compton scattering.

The annihilation radiation of the source S (Cu^{64} , prepared by deuteron irradiation of copper in the Purdue cyclotron) is collimated by a $\frac{3}{8}$ -in. channel in the lead block. The quanta are scattered by cylindrical aluminum scatterers Sc and detected with bell-shaped Geiger counters with lead cathodes. Coincidences were measured for azimuth differences (φ) of 0° , 90° , 180° , and 270° between the counter axes. In order to eliminate all asymmetries both counters were rotated in turn. As a result of absorption in the scatterer the mean scattering angle is slightly less than 90° , near the theoretical maximum of anisotropy calculated for a scattering angle of 82° . Taking into account the finite

TABLE I.

Average single counts without scatterers	3000/min.
Average single counts with scatterers	5370/min.
Chance coincidences ($T = 1.2 \cdot 10^{-7}$ sec.)	0.117/min.
Genuine coincidences C_{\perp}	0.152/min.
Genuine coincidences C_{\parallel}	0.073/min.
Asymmetry ratio C_{\perp}/C_{\parallel}	2.1 ± 0.64

solid angle subtended by the counters, a ratio $C_{\perp}/C_{\parallel} \approx 1.7$ is expected for the coincidence rates at $\varphi = 90^\circ$ (C_{\perp}) and $\varphi = 180^\circ$ (C_{\parallel}). Four different runs were made with different sources consistently showing $C_{\perp} > C_{\parallel}$. Data for a characteristic run of 16 hours are given in Table I.

The observed average asymmetry ratio for all runs is

$$C_{\perp}/C_{\parallel} = 1.94 \pm 0.37.$$

The indicated error is the statistical mean standard deviation. The theoretical prediction is therefore confirmed by this experiment.

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¹ J. A. Wheeler, Ann. N. Y. Acad. Sci. 48, 219 (1946).

² M. H. L. Pryce and J. C. Ward, Nature 160, 435 (1947).

³ H. S. Snyder, S. Pasternack, and J. Hornbostel, Phys. Rev. 63, 440 (1943).

Piezoelectric or Electrostrictive Effect in Barium Titanate Ceramics

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IN a recent Letter to the Editor,¹ Matthias and Von Hippel have discussed the resonances obtained in a piece of multicrystalline barium titanate ceramic and have called the effect a "quadratic" piezoelectric effect. While the term used is to some extent a matter of definition, it appears worth while to point out that the effect in the titanate ceramic does not conform to the original definition of a "quadratic" piezoelectric effect, but is, on the other hand, the analog of a magnetostrictive effect in a ferromagnetic material.

According to Mueller,² a "quadratic" piezoelectric effect is one following the same equations as an electrostrictive effect but depending on a strain caused by a spontaneous polarization or an applied field acting on the piezoelectric constant. The discovery³ that a shear vibration can be set up when an a.c. field is applied at right angles to a d.c. polarization and the quantitative check between the value of this constant and the radial and thickness constants show that the effect cannot be a "quadratic" piezoelectric effect. This follows from the fact that the only type of symmetry that the ceramic can have in the presence of an applied field is that known as transverse isotropy. For this case the $c = Z$ axis lies along the direction of the field, and the properties in any direction perpendicular to the field are independent of direction. The effect of this symmetry is to reduce the constants to the terms $d_{31} = d_{32}$, d_{33} , $d_{15} = d_{24}$, and there is no necessary relationship between d_{15} and d_{31} and d_{32} .

On the other hand, if the effect is regarded as a second-order electrostrictive effect, it was shown in a previous paper⁴ that the stress strain and electric relations are given by the tensor equations (when other second-order effects are neglected)

$$\begin{aligned} S_{ij} &= T_{kl} s_{ijkl} P + \delta_n [g_{ijn} + Q_{ijn} \delta_0], \\ E_m &= -T_{kl} [g_{mkl} + 2Q_{klmn} \delta_n] + \delta_n [4\pi \beta_{mn} T], \end{aligned} \quad (1)$$