Letters to the Editor

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The Angular Correlation of Scattered Annihilation Radiation*

C. S. Wu and I. Shaknov
Pupin Physics Laboratories, Columbia University, New York, New York

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As early as 1946, J. A. Wheeler[1] proposed an experiment to verify a prediction of pair theory, that the two quanta emitted in the annihilation of a positron-electron pair, with zero relative angular momentum, are polarized at right angles to each other. This suggestion involves coincidence measurements of the scattering of both the annihilation photons at various azimuths. The detailed theoretical investigations were reported by Pryce and Ward[2] and by Snyder, Pasternack, and Hornbostel.[3] The predicted maximum asymmetry ratio of coincidence counts when the two counters are at right angles to each other to coincidence counts when the counters are co-planar is as large as 2.85 and occurs at a scattering angle of $\vartheta = 82°$. Bleuler and Bradt[4] used two end-window G-M counters as detectors and observed an asymmetry ratio not inconsistent with the theory. Nevertheless, the margin of error associated with their results is so large that a detailed comparison between the theory and experiments is made rather difficult. In the meantime, Hanna[5] performed similar experiments with more efficient counter arrangements and found the asymmetry ratio observed to be consistently smaller than those predicted. Therefore, it appeared to be highly desirable to reinvestigate this problem by using more efficient detectors and more favorable conditions.

The recently developed scintillation counter has been proved to be a reliable and highly efficient gamma-ray detector. With this improved efficiency, which is around ten times that of G-M counters, there will be an increase in the coincidence counting rate of one hundred times. In our experiments, two RCA 5819 photo-multiplier tubes and two anthracene crystals $1\times1\times\frac{1}{2}$ in. were used. The efficiency for the annihilation radiation obtained with these anthracene crystals is seven to eight percent which compares favorably with the calculated value. The geometrical arrangement is schematically shown in Fig. 1.

The positron source Cu^{64} was activated by deuteron bombardment on a copper target in the Columbia cyclotron. The electroplating method was employed to separate Cu activity from other contaminations. The active Cu^{64} was packed in a small Al capsule of 8-mm diameter and 8-mm length. The annihilation radiation was collimated by a lead block $6\times6\times6$ in. with a $\frac{3}{8}$-in. channel drilled through the center of the block, such that the spread of the beam was found to be less than 3°. The aluminum scatterers were $\frac{1}{2}$ in. in diameter and 1-in. long. They were designed to absorb about 40 percent of the annihilation radiation lengthwise and to limit the multiple scattering of the radiation scattered at 90° to less than 15 percent. The crystal of the counter subtends an angle of 43° at the point in the scatterer where 20 percent of the incident radiation has been absorbed—that is, at the absorption midpoint of the scatterer. The mean scattering angle is very close to 82°, the predicted maximum of anisotropy. Under these conditions, the scattered radiation taken as the counting difference detected by the scintillation counter with and without the scatterer in place is three times the over-all background.

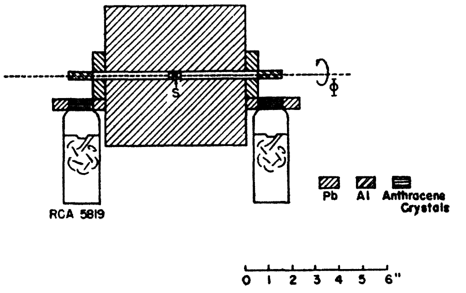

FIG. 1. Schematic diagram of experiment.

In taking the coincidence measurements, one detector was kept fixed in position, and the second detector was oriented to four different positions with azimuth differences (φ) of 0°, 90°, 180°, and 270° between the detector axis. After that, the second detector was kept fixed and the first one rotated. The total period of measurement lasted about 30 continuous hours. On account of the high coincidence rate observed (the true coincidence rates for the perpendicular position at the beginning was of the order of four per minute), the statistical deviations are much improved as compared to the results from G-M counters. The asymmetry ratio from our best run is

$$\frac{\text{Coincidence counting rate }(\perp)}{\text{Coincidence counting rate }(\parallel)} = 2.04 \pm 0.08,$$

where ±0.08 is the probable mean error. The calculated asymmetry ratio for our geometrical arrangement is 2.00. Therefore, the agreement is very satisfactory. Further work is being planned to extend the investigations to more ideal geometrical conditions.

We wish to express our appreciation to Professors J. R. Dunning, W. W. Havens, Jr., and L. J. Rainwater for their constant interest and encouragement. We also wish to thank the cyclotron group for preparing the Cu^{64} source and the U. S. AEC which aided materially in the performance of this research.

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[1] J. A. Wheeler, Ann. New York Acad. Sci. **48**, 219 (1946).
[2] M. H. L. Pryce and J. C. Ward, Nature **160**, 435 (1947).
[3] Snyder, Pasternack, and Hornbostel, Phys. Rev. **63**, 440 (1948).
[4] E. Bleuler and H. L. Bradt, Phys. Rev. **73**, 1398 (1948).
[5] R. C. Hanna, Nature **162**, 332 (1948).

The Optical Detection of Radiofrequency Resonance

M. H. L. Pryce
Clarendon Laboratory, Oxford, England

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In a recent paper under this title, Bitter[1] discusses the effect of a radiofrequency field on the optical Zeemann effect. He illustrates the question by treating an atomic system whose ground state is ^2S, making optical transitions to a ^2P state. The atoms are in a steady magnetic field H_z on which is superposed a rotating radiofrequency field H_0, in the xy plane, of angular frequency ω. According to Bitter, when there is a resonance between ω and $\omega_0 = g\mu_0 H_z/h$, the precession frequency of the spin moment in the ^2S ground state, certain observable changes happen to the Zeeman effect.

Such an effect certainly occurs, but Bitter's discussion is incorrect, and it is very doubtful if the effect could be observed in practice. Bitter calculates the frequencies of the Zeemann lines by means of a *mean energy* of the ground level in the presence of the radiofrequency field. This is a fallacious argument. The fre-

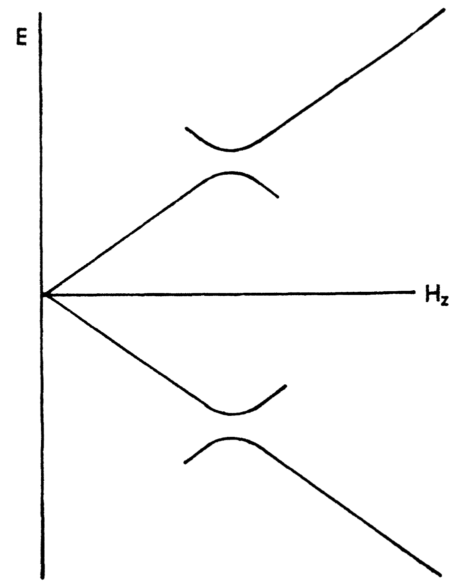

FIG. 1. Effective energy of ground level $J=\frac{1}{2}$ in the presence of a radiofrequency field.

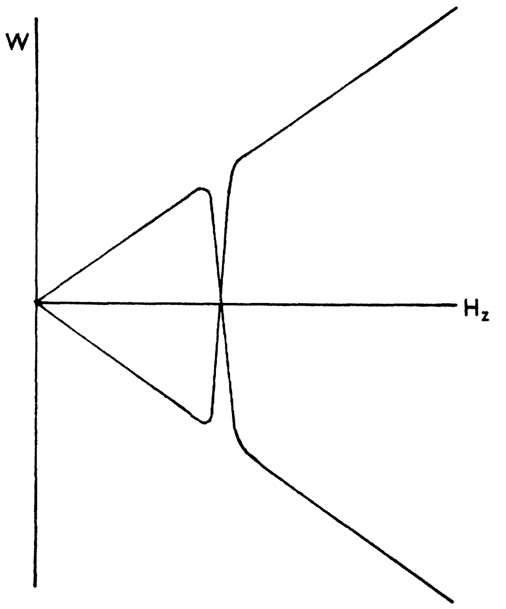

FIG. 2. Mean energy according to Bitter.

quencies are those which are associated with the non-vanishing matrix elements of electric dipole moment coupling ground and excited states, which are simply calculated from the time-dependent wave functions quoted by Bitter. These frequencies are such as would occur if the ground level had energies

$$E=\pm\tfrac{1}{2}\hbar\omega\pm\tfrac{1}{2}[\hbar^2(\omega_0-\omega)^2+(g\mu_0H_0)^2]^{\frac{1}{2}}. \tag{1}$$

In this expression all four combinations of the ± signs are to be taken. The appearance of four effective energy values, instead of two, can be understood in terms of the possibility of the emission or absorption of one quantum or no quantum by the radiofrequency field. The intensities of the lines are obtained from the intensities in the absence of radiofrequency field, by multiplying by a factor

$$\frac{1}{2}\left[1\pm\frac{\hbar(\omega_0-\omega)}{[\hbar^2(\omega_0-\omega)^2+(g\mu_0H_0)^2]^{\frac{1}{2}}}\right], \tag{2}$$

the sign being + if the two signs are equal in Eq. (1) and − if unequal.

Equation (1) for the effective energy should be contrasted with Bitter's result for the mean energy,

$$\begin{aligned}W&=\pm\tfrac{1}{2}g\mu_0H_z\left[\frac{\delta+H_0/H_z}{(1+\delta^2)^{\frac{1}{2}}}\right]\\&\equiv\pm\tfrac{1}{2}\hbar\omega_0\left[\frac{\hbar(\omega-\omega_0)+g\mu_0H_0^2/H_z}{[\hbar^2(\omega_0-\omega)^2+(g\mu_0H_0)^2]^{\frac{1}{2}}}\right].\end{aligned} \tag{3}$$

The two expressions are plotted in Figs. 1 and 2.

The intensity factors (2) are such that the intensity becomes very small when the energy deviates appreciably from the straight lines of Fig. 1. The changes of frequency associated with an appreciable intensity are therefore smaller than predicted by Bitter, namely, of order $\frac{1}{2}g\mu_0H_0/h$ instead of $\frac{1}{2}g\mu_0H_z/h$. Their detection will probably be rather difficult, as the mean position of the two components into which each Zeemann line is split weighted with their intensities, coincides with the position without radiofrequency field. The splitting would therefore have to be nearly resolved to detect significant changes in the polarization distribution on the Zeemann pattern.

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[1] F. Bitter, Phys. Rev. 76, 833 (1949).

The Beta-Spectrum of Ca^{45}*

P. MACKLIN, L. FELDMAN, L. LIDOFSKY, AND C. S. WU
Pupin Physics Laboratories, Columbia University,
New York, New York
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CALCIUM^{45} was first produced in the cyclotron by bombarding calcium with deuterons or neutrons. The radioactivity consists of a soft beta-radiation of long half-life (152 days).

The upper energy of the Ca^{45} beta-spectrum is listed in Seaborg and Perlman[1] as 0.260 or 0.21 Mev by the aluminum absorption method and 0.25 Mev by spectrometer measurement. The details of the spectrometer measurement are unfortunately not available since they appear in the Plutonium Project Reports. The most recent value reported, 0.22 Mev,[2] was obtained by absorption methods.

Recently, we received a shipment of Ca^{45} from the Isotopes Division of the AEC at Oak Ridge of specific activity around 2 μc/mg which is sufficiently high for investigation of the upper energy region of its beta-spectrum in our spectrometer. Several sources with approximate average thicknesses varying from 200–450 μg/cm^2 were prepared on collodion backings of 12–14 μg/cm^2. The spectrum was investigated in the Columbia magnetic solenoidal spectrometer, using a counter with a collodion window of about 40 μg/cm^2 thickness and with three percent resolution (full

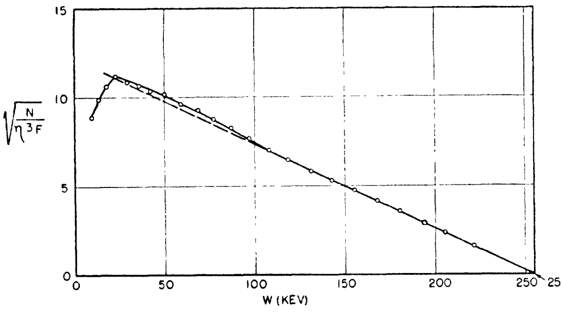

FIG. 1. Fermi plot of Ca^{45} beta-spectrum.