In order to compare the expressions for electron and inner bremsstrahlung polarization we quote here the result of Curtis and Lewis[2] for the longitudinal polarization[3] of electrons emitted with total energy W in an allowed beta decay:

$$P(W)=dv/(1+b/W). \quad (1)$$

The quantities d and b are combinations of coupling constants and nuclear matrix elements,[4] and we have chosen units such that $\hbar=c=m=1$.

The probability per unit time for emission of an inner bremsstrahlung photon with energy between k and $k+dk$ and with polarization $\mathbf{e}$, calculated by using the beta interaction of Lee and Yang,[4] is[5]

$$S(\mathbf{k},\mathbf{e})dkd\Omega_k=\left(\frac{e^2}{16\pi^5}\right)dkd\Omega_k\left(\frac{\xi}{k}\right)$$
$$\times[I_1+bI_2-dI_3i(\mathbf{k}\cdot\mathbf{e}\times\mathbf{e}^*)]. \quad (2)$$

The quantities I_1, I_2, and I_3 depend upon the end point energy, W_0, of the beta spectrum as well as on the photon energy k. If one introduces the quantity $x=W_0-k$ and the corresponding momentum $s=(x^2-1)^{\frac{1}{2}}$, the I's may be expressed as

$$I_1=W_0^2A(x)-W_0B(x)+C(x), \quad (3a)$$

$$I_2=2xA(x)-B(x), \quad (3b)$$

$$I_3=W_0^2A(x)-W_0B(x)+D(x), \quad (3c)$$

where

$$A(x)=\left(\frac{1}{3}x^3+\frac{1}{2}x\right)\ln(x+s)-\left(\frac{11}{18}x^2+\frac{2}{9}\right)s,$$

$$B(x)=\left(\frac{1}{2}x^4+\frac{1}{2}x^2-\frac{1}{16}\right)\ln(x+s)-\left(\frac{7}{8}x^3+\frac{1}{16}x\right)s,$$

$$C(x)=\left(\frac{7}{30}x^5-\frac{3}{16}x\right)\ln(x+s)$$
$$-\left(\frac{689}{1800}x^4-\frac{1021}{3600}x^2-\frac{4}{75}\right)s,$$

$$D(x)=\left(\frac{1}{6}x^5-\frac{1}{16}x\right)\ln(x+s)-\left(\frac{19}{72}x^4-\frac{23}{144}x^2\right)s.$$

From the expression (2), we see that the circular polarization of the inner bremsstrahlung photons is

$$P(k)=dI_3/(I_1+bI_2), \quad (4)$$

where the sign of the polarization has been chosen to be positive for left circularly polarized photons. Comparison of this expression with the expression (1) for the electron polarization shows us that, in principle, the quantities d and b can be determined equally well by measuring either the electron or photon polarization as a function of their respective energies. We might also note that if the electrons are polarized in their direction of motion then the inner bremsstrahlen will be left circularly polarized, and vice versa. As an example, in Fig. 1 the expected polarization is shown as a function of k for P^{32} ($W_0=4.335$) assuming $d=1$ and $b=0$, which would be the case if the two-component neutrino theory[6] were correct and there were no Fierz interference terms.

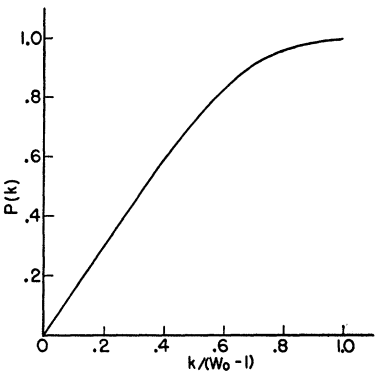

FIG. 1. Polarization of the inner bremsstrahlen from P^{32} ($W_0=4.335$) assuming $d=1$ and $b=0$. (Units are such that $\hbar=m=c=1$.)

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[1] An exception is the experiment of Goldhaber, Grodzins, and Sunyar [Phys. Rev. **106**, 826 (1957)] where the circular polarization of the outer bremsstrahlung produced by the electrons is measured. Another exception would be the measurement of Møller scattering of polarized electrons on polarized electrons.

[2] R. B. Curtis and R. R. Lewis, Phys. Rev. (to be published).

[3] Following H. A. Tolhoek, Revs. Modern Phys. **28**, 277 (1956), the polarization of a beam consisting of particles in two states 1, 2 with intensities I_1, I_2, respectively, is $P=(I_1-I_2)/(I_1+I_2)$.

[4] The quantities b and ξ are those defined by T. D. Lee and C. N. Yang, Phys. Rev. **104**, 254 (1956); the quantity d is defined in reference 2 by the equation $\xi d=|M_F|^2[C_SC_S'^*-C_VC_V'^*+\text{c.c.}]+|M_{GT}|^2[C_TC_T'^*-C_AC_A'^*+\text{c.c.}]$.

[5] In this expression the effect of the Coulomb field has been neglected. First-order Coulomb corrections are not difficult to obtain. [See R. R. Lewis and G. W. Ford, Phys. Rev. (to be published).]

[6] T. D. Lee and C. N. Yang, Phys. Rev. **105**, 1671 (1957).

Influence of Strong Magnetic Field on Depolarization of Muons*

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THE decay positrons from cyclotron-beam muons have the angular distribution $(1+a\cos\theta)$.[1–3] The strongest asymmetry which has been observed is $a=-0.25\pm0.01$ and occurs when μ^+ are stopped in such substances as carbon, aluminum, copper, and bromoform.[1–3] Other materials give a values ranging from

0 to -0.25. With counter techniques, Ilford $G5$ nuclear-emulsion targets give $a=-0.12\pm0.2$ or $(50\pm8)\%$ of the maximum value.[1,2] The $\mu-e$ angular distribution can also be measured directly in the emulsion using scanning techniques. The weighted mean of all such scanning measurements is $a=-0.12\pm0.015$ as compiled at the recent Rochester conference.[4] This 50% depolarization must be due in some way to the effect of the local magnetic fields produced by neighboring electrons. For example, if the muon experiences a local field of 6.3×10^4 gauss (the classical field of a Bohr magneton at a distance of one Bohr radius) for a time 10^{-10} sec, it will precess 31°. This effect could be reduced by causing the neighboring electrons to precess faster than 10^{10} revolutions per second. An external magnetic field of 10 kilogauss causes a free electron to precess at a rate 2.8×10^{10} revolutions per second. The reduction of depolarization by such a technique can be calculated exactly for the case of one electron bound to the μ^+ in a $1S$ state (muonium). With no external magnetic field the formation of muonium gives a 50% depolarization, while in a field of 9000 gauss, muonium formation would give rise to only a 1.5% depolarization. Quantitatively the fraction of depolarization due to munoium formation in an external magnetic field H is $0.5/(1+x^2)$ where $x=e\hbar H/(mc\Delta E)$. ΔE is the $1S$ hyperfine splitting of muonium and m is the reduced mass of the electron-muon system.

Using the magnetic resonance setup of Garwin, Lederman, and Sachs, we applied a field of 9 ± 1 kilogauss along the beam direction to a small stack of $G5$ nuclear emulsion in which μ^+ mesons from the 85-Mev Nevis π^+ beam were stopped. The plates were area scanned for μ endings. All muons were traced back more than 650 microns in order to eliminate any contributions from $\pi-\mu-e$ decays. Out of a total of 3009 μ^+ endings, only 5 had doubtful or "missing" secondaries. From this and other checks, we conclude that the data are free from forward-backward selection bias. We found 1315 decay positrons in the forward hemisphere, and 1689 in the backward hemisphere. This gives a result $a=-0.249\pm0.036$ which is 3.6 standard deviations away from the zero-field value of $a=-0.12$. This result indicates that the application of an external magnetic field along the spin direction reduces the amount of depolarization and improves nuclear emulsion as a tool for experiments involving muons.

We thank Dr. Garwin, Dr. Lederman, and Dr. Sachs for suggesting the experiment and for helping with the exposure.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission and by a National Science Foundation research grant.

[1] Berley, Coffin, Garwin, Lederman, and Weinrich, Bull. Am. Phys. Soc. Sec. II, 2, 204 (1957), and private communication.

[2] Swanson, Campbell, Garwin, Sens, Telegdi, Wright, and Yovanovitch, Bull. Am. Phys. Soc. Ser. II, 2, 205 (1957), and private communication.

[3] Cassels, O'Keeffe, Rigby, Wetherell, and Wormald (to be published).

[4] *Proceedings of the Seventh Annual Rochester Conference on High-Energy Physics*, (Interscience Publishers, Inc., New York, 1957). In the lumping of data, we have assumed that cosmic-ray pions are the same as pions produced in the laboratory.

Small-Angle Photoproduction of Positive Mesons from Hydrogen*

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THE angular distributions of photomesons produced in hydrogen have previously been measured adequately only in a range of angles from 40° to 180° c.m.[1,2] A recent paper by Moravcsik[3] points out that in such a restricted angular range it is quite possible to analyze the angular distributions by a polynomial including terms up to $\cos^2\theta$, representing S- and P-wave production only. However, the basic Chew-Low theory of photoproduction contains a term of the form $[\boldsymbol{\varepsilon}\cdot\mathbf{q}\boldsymbol{\sigma}\cdot(\mathbf{K}-\mathbf{q})]/[q_0K-\mathbf{q}\cdot\mathbf{K}]$, where $\mathbf{K}$ and $\boldsymbol{\varepsilon}$ are the photon momentum and polarization, $\mathbf{q}$ and q_0 the momentum and energy of the meson, and $\boldsymbol{\sigma}$ the nucleon spin.[4] This term arises from the interaction of the meson current with the incident photon and, because of the denominator, mixes in higher angular-momentum states. The effect of this term should be most noticeable in the shape of the distribution at forward angles and in forward-backward asymmetry.

In this experiment we have measured the relative angular distributions for the yield of positive pions produced by (260 ± 5)-Mev gamma rays. Figure 1 shows the experimental arrangement. The target is a 2-inch liquid hydrogen vessel with thin Mylar walls (0.015 in.). The mesons were detected by their characteristic $\pi-\mu$ decay in a six-counter telescope whose complexity was dictated by the need to cope with the heavy electron and γ-ray background. Mesons are par-

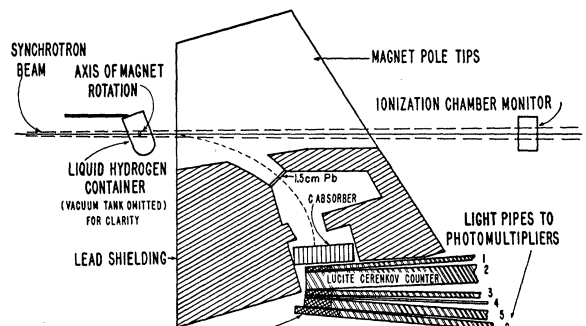

FIG. 1. Experimental arrangement.