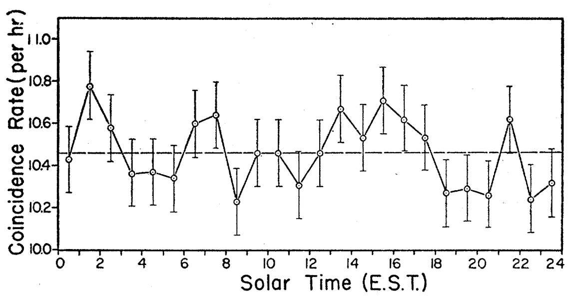

FIG. 1. Solar-time variation of cosmic rays at 1600-m water equivalent depth. Errors shown are standard errors. The horizontal line indicates the average coincidence rate per telescope.

within two standard errors the root-mean-square value of a solar diurnal effect is less than one percent for the particles observed.

In Fig. 2 the data are grouped in sidereal time intervals and plotted against local sidereal time. The local sidereal time at 0000 hours Eastern Standard Time on July 22, 1951, was taken as 19 hr 50 min. On the basis of these data the existence of a sidereal diurnal variation greater than two percent would seem highly improbable. However, the deviations of the hourly rates from the average are slightly larger than expected from a normal distribution, and the results are indecisive as to the probable existence of a sidereal diurnal effect of about one percent.

A sidereal diurnal effect of about ten percent has been reported by Sekido and collaborators[1] based on a total number of 1720 particles observed at a depth of 1400 meters H_2O equivalent. They show a peak in intensity coming at five hours and 20 minutes local sidereal time. Our data reveal no peak in intensity near this hour, and as our standard error is much smaller and our angular resolution is similar to theirs, such an effect should have been readily detectable.

Any observed anisotropy of cosmic rays depends not only on the anisotropy in the distribution of sources, but also on the deflections of the rays while crossing the space between the sources and the earth. Considerations of the energy density in cosmic rays[2] lead to the belief that they come from sources within our galaxy and are confined to the galaxy by magnetic fields. These magnetic fields would cause large and irregular changes in direction of the cosmic rays, resulting in a high degree of isotropy in the incident radiation, even if the sources are highly localized. In spite of this smearing, there should be a broad maximum in the intensity coming from the direction of any strong source. The width of the peak should be so great that the poor angular resolution of our apparatus would have little effect on it. But if curling due to magnetic fields is sufficiently strong, the departure from complete isotropy may not be observable. This has been discussed quantitatively by Cocconi,[3] who concluded from the observed isotropy of the cosmic rays of 10^{13}–10^{14} ev that the

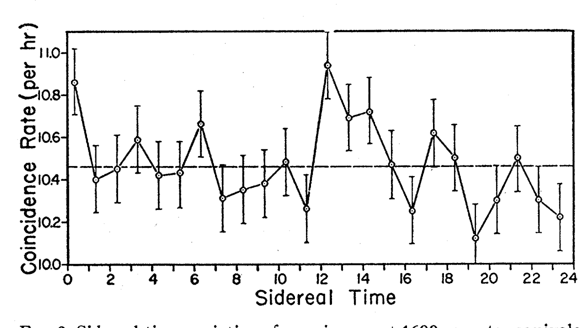

FIG. 2. Sidereal-time variation of cosmic rays at 1600-m water equivalent depth. Errors shown are standard errors. The horizontal line indicates the average coincidence rate per telescope.

galactic fields must have a strength of at least 10^{-9} gauss. Our data confirm his order of magnitude.

We are grateful to Professors G. Cocconi and K. I. Greisen for their helpful criticism and suggestions.

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The Scattering of 0.5-Mev Circularly Polarized Photons in Magnetized Iron*

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THE possibility of detecting circularly polarized photons by Compton scattering in magnetized ferromagnets has been both implied[1,2] and explicitly suggested[3] in several recent theoretical treatments. The dependence of the scattering cross section of circularly polarized (c.p.) photons upon both the sense of polarization and the polarization state of the scattering electrons is perhaps most clearly seen in the formalism adopted by Fano.[2] He describes the intensity and polarization state of an incident photon by means of a four-vector constructed from the Stoke's parameters and the scattering of this photon into another state

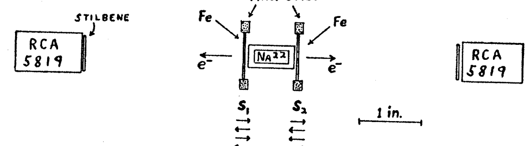

FIG. 1. Experimental arrangement.

by a 4×4 matrix which relates the Stoke's parameters of the incident and scattered radiation. In the case of unpolarized incident radiation this matrix transformation reduces to the well-known Klein-Nishina formula.

However, the intensity of c.p. incident radiation scattered at an angle θ by an electron with initial spin of direction **S** is of the form

$$\Phi(\theta)=C\{A(\theta)\pm(1-\cos\theta)(\mathbf{k}_0\cos\theta+\mathbf{k})\cdot\mathbf{S}\}, \qquad (1)$$

$$\Phi(\theta)=C\{A\mp B\mathbf{n}_0\cdot\mathbf{S}\}, \quad \text{for} \quad \theta=\pi, \qquad (2)$$

where $\mathbf{k}_0$ and $\mathbf{k}$ represent, respectively, the incident and scattered photon momenta in electron rest mass units, $\mathbf{k}_0=k_0\mathbf{n}_0$, and the upper or lower signs refer to right or left c.p. photons, respectively.

We have investigated this dependence of intensity upon **S** by observing in coincidence the forward direction Compton electrons ($\theta=\pi$) produced in magnetized Fe foils by annihilation quanta. Wheeler[4] was the first to point out that two-photon annihilation of positronium can proceed only from the singlet state (zero angular momentum). Hence, an experiment detecting coincidentally the polarization states of the annihilation photon pair must verify plane polarized photons with crossed planes or c.p. photons of opposite senses. The first possibility has been confirmed experimentally by several workers;[5,6] the second provides the c.p. photons employed in the experiment described here.

The experimental arrangement is depicted in Fig. 1. Forward direction Compton electrons from two magnetized Fe foils (0.1 g/cm²) were detected by two thin (0.5 mm) stilbene crystals covered by 0.004 g/cm² Al foil. Scintillations were recorded by a fast coincidence circuit[7] (2×10^{-8} sec resolving time), and rates were measured for each of the four possible configurations of the magnetic fields shown in Fig. 1. The photomultipliers were magnetically shielded to reduce effects incurred upon reversing the magnetic fields. After each change in the fields the single rates were carefully adjusted to the unique values employed throughout the experiment.

The thin stilbene crystals were less than 0.4 percent efficient for detection of photons but were very nearly 100 percent efficient for forward direction Compton electrons. Thus far we have not made an accurate measurement of the fraction of the singles rates which was caused by photons or by Compton electrons produced in the magnetizing coils rather than the Fe foils. However, geometrical considerations indicate that Compton electrons from the coils correspond to photons scattered at $\theta \lesssim 135°$ and, hence, for these electrons $E \lesssim 0.06$ Mev. The efficiency for their coincidence detection by the circuit employed was small relative to that for the forward direction electrons ($E \approx 0.34$ Mev). Hence, the coincidence circuit was biased strongly against detection of electrons other than those in the forward direction produced in the Fe foils.

Another possible contribution to the coincidence rate was the result of the 1.3-Mev gamma-ray following the beta-transition of Na^{22}. However, the possibility of observing these gammas in

TABLE I.[a] Observed coincidence rates.

Mag. fields S_1	S_2	Coinc. counts	Time (min)	Coinc./min	Average
←	←	12,850	425	30.23	
←	←	19,270	637	30.24	
→	→	10,866	350	30.98	
→	→	19,730	683	28.90[b]	
→	→	5227	174	30.06	
→	→	9437	316	29.90	
→	→	18,807	622	30.26	
		76,457	2524		30.29 ± 0.11
→	←	6313	220	28.70	
→	←	9472	327	28.97	
→	←	18,432	625	29.51	
←	→	20,480	694	29.60	
←	→	8877	310	28.65	
		63,574	2176		29.22 ± 0.12

[a] Difference = 1.07 ± 0.23; percent difference = 3.5 ± 0.75 percent.
[b] At the end of this run the single counting rate of one counter failed to repeat. Hence, this low rate is not included in the computation of the average coincidence rate for the first field configuration. Subsequent data confirmed previous coincidence rates for this configuration. If one includes this run, the observed difference is 2.6 ± 0.07 percent.

coincidence with an annihilation quantum was small since the 1.3-Mev gammas are of spherical directional symmetry while the relative direction of an annihilation pair is π-radians. This argument is supported experimentally by previous work.[6]

The collected data from 12 independent runs and the difference in coincidence rates for the indicated field configurations are presented in Table I. From Eq. (2) and the knowledge that a coincident photon pair are left and right or right and left circularly polarized, one deduces for the expected coincidence rates for $\theta_1 = \theta_2 = \pi$

$$\Phi_1\Phi_2 = C^2(A^2+B^2), \quad \text{for} \quad \begin{cases} \rightarrow \ \rightarrow \\ \leftarrow \ \leftarrow \end{cases},$$

$$\Phi_1\Phi_2 = C^2(A^2-B^2), \quad \text{for} \quad \begin{cases} \rightarrow \ \leftarrow \\ \leftarrow \ \rightarrow \end{cases}.$$

After substituting appropriate values for k_0, k, etc., and taking into account that only 2.2 of the 26 orbital electrons in Fe are polarized, one finds for the expected difference 0.9 percent. The expected difference has also been computed for $k_0 \gtrsim 1.5$ by Halpern,[3] whose result predicts a 2 percent difference in a coincidence experiment of this kind.

The somewhat greater observed difference, 3.5±0.8 percent, may be a discrimination by the coincidence circuit against the detection of K and L shell (unpolarized) Compton electrons. It is known[8] that orbital binding changes the intensity of the scattered radiation and gives rise to a coherent (unshifted) scattering in addition to Compton scattering. We have been unable to find a computation of this effect for high energy photons scattered in Fe. This possibility is being investigated further.

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Phenomena Associated with Negative μ-Mesons Stopped in Photographic Emulsions*

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ELECTRON sensitive Ilford G-5 plates of 400-micron thickness were exposed behind absorbers in the 145-Mev negative π-meson beam from the University of Chicago cyclotron. The geometry of the exposures is shown in Fig. 1. A fraction of the π-mesons decay in flight before entering the Cu absorbers. The μ-mesons from the decay of the π-mesons in the forward direction have an additional range of about one inch in Cu compared to the range of the π-mesons. The additional range of the μ-mesons makes it possible to separate the μ-mesons from the π-mesons.

Meson tracks were studied which entered the emulsions within 45° of the direction of the π-meson beam and which stopped in the emulsion further than 30 microns from the surfaces. A total of 1008 meson endings was studied. In 8 cases it is difficult to determine the phenomena associated with the mesons. In 6 cases a track of an electron of a few hundred kev is associated with each meson. The electron tracks are due either to decay electrons or to electrons which were ejected in the process of capture of the mesons. In 2 cases the mesons either produced one-prong stars or were scattered through a large angle near the end of the tracks. In 32 cases the mesons produced stars of one or more prongs of length greater than 10 microns. The prong distribution of these stars and the prong distribution of negative π-meson stars[1] are given in Table I. The prong distribution of the 32-meson stars indicate that nearly all of these stars are due to negative μ-mesons rather than negative π-mesons. No protons of energy greater than 30 Mev were observed from any of the stars. One of the stopped mesons ejected a single proton of 20 Mev. It seems probable that the event is due to a negative π-meson. It is possible that a portion of the 2- and 3-prong stars were produced by negative π-mesons. However, the various energies of the charged particles from the 2- and 3-prong stars are considerably lower than the energies of the charged particles from negative π-meson

TABLE I. Prong distribution of μ^- and π^- meson stars.

	Number of prongs of the star 1	2	3	4	5
No. of μ^- meson stars of N prongs	27	4	1	···	···
Percentage of μ^- mesons which produced N-prong stars	2.6	0.5	0.1	···	···
Percentage of π^- mesons which produced N-prong stars	21	27	15	7.8	1.8