Search for Evidence of Parity Nonconservation in π^+-Meson Production by Polarized Protons*

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A search was made for evidence of parity nonconservation in π^+-meson production in aluminum. Mesons of mean energy 40 Mev were produced at 92° by 209-Mev polarized protons, and the numbers of mesons emitted parallel and antiparallel to the polarization direction were compared. No significant asymmetry was found, indicating that the parity-mixing coefficient $F^2 \leq 2\times10^{-3}$.

ALTHOUGH it is generally assumed that parity is conserved in strong interactions, the upper bound on the parity-mixing coefficient for nuclear interactions is based on relatively few experiments. The original estimate of Lee and Yang[1] was based on asymmetry measurements in scattering of polarized protons in the plane containing the polarization vector. If the nucleon-nucleon (or nucleon-nucleus) interaction did not conserve parity, one would expect an asymmetry given by

$$\epsilon = F\langle\boldsymbol{\sigma}\rangle\cdot\mathbf{k},$$

where $\langle\boldsymbol{\sigma}\rangle$ is the polarization vector, of magnitude equal to the degree of polarization P, and $\mathbf{k}$ is the propagation vector of the scattered nucleon in the center-of-mass system. We have reviewed the evidence on this point, and find that the best measurement of this type is apparently included in the original polarization experiment of Oxley, Cartwright, and Rouvina[2]; the asymmetry in "up-down" scattering of transversely polarized protons from hydrogen was found to be ≤ 0.02, leading to an upper bound for F^2 of about 10^{-2}. The experiment of Chamberlain *et al.*[3] cited by Lee and Yang was very insensitive to possible parity mixing, principally because of the small center-of-mass scattering angle, and results in setting an upper bound of $F^2 \leq 3\times10^{-2}$, rather than the value 10^{-4} quoted by Lee and Yang.[1]

With regard to parity mixing in many-nucleon systems, one may look for evidence of transitions forbidden by parity conservation. Tanner[4] has recently shown in such an experiment that in the ground states of O^{16} and He^4, and the corresponding compound Ne^{20} state, the amount of parity mixing is probably less than 2×10^{-4}. Since this sets an upper bound to F^2 of 4×10^{-8}, this result is by far the most precise one available at present.

We have looked for evidence of parity nonconservation in the production of π^+ mesons by polarized protons in aluminum. Although meson production is thought to be very closely related to other forms of nuclear interactions, the result may be of interest in that the experiment deals directly with the elementary Yukawa reaction.

METHOD

It is well known that π^+ mesons produced in nucleon-nucleon encounters at energies not much above threshold are emitted primarily in p waves, presumably because of the conservation of parity. If parity were not rigorously conserved, π^+ mesons could also be produced in s waves,[5] resulting in an asymmetry in the production cross section given by the formula above, where $\mathbf{k}$ is now the propagation vector of the meson. In a search for a term of this type, we have measured the cross section for meson production in aluminum at about 90° to the incident beam direction, in the plane containing the polarization vector. The protons had an energy of 209±6 Mev, and were 89% polarized in the vertical direction. We therefore looked for an "up-down" asymmetry.

APPARATUS AND PROCEDURE

The apparatus and procedure used in this experiment were almost identical to those described in the previous paper,[6] which dealt with measurements of the cross section and "right-left" asymmetry in meson production. We list below the points of departure from the previously described method:

(1) Before aligning an optical telescope along the beam center line, we investigated the proton beam distribution along a vertical line at the target position. The distribution was found to be uniform over a range of more than 4 inches in height; since the beam was to be collimated by $1\frac{1}{2}$-inch slits, we felt certain that no geometrical asymmetries would result from nonuniform illumination of the target.

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[1] T. D. Lee and C. N. Yang, Phys. Rev. **104**, 254 (1956). We do not include the estimate based on the absence of an electric dipole moment for the neutron, since this fact was later found to be irrelevant [L. Landau, Nuclear Phys. **3**, 127 (1957)].

[2] Oxley, Cartwright, and Rouvina, Phys. Rev. **93**, 806 (1954). In deducing the bound on F^2, we assume the beam polarization to be about 32% (C. L. Oxley, private communication, June, 1958). The center-of-mass scattering angle was about 54°.

[3] Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis, Phys. Rev. **93**, 1430 (1954). We assume the beam polarization to be 70%, and the center-of-mass scattering angle to be about 17°.

[4] N. Tanner, Phys. Rev. **107**, 1203 (1957).

[5] Such s-wave production, in contrast to the parity-conserving type, is independent of nuclear recoil effects, and in fact would occur even in the case of an infinitely heavy target.

[6] Heer, Roberts, and Tinlot, Phys. Rev. **111**, 640 (1958), preceding paper.

(2) The slits were made by boring $1\frac{1}{2}$-inch holes in brass plates 2 inches thick. The axes of the holes were aligned along the optical center line with an accuracy of better than 0.01 inch by means of centered cross hairs.

(3) The meson detector and meson-producing target were mounted in a rigid assembly which could be rotated about a horizontal axis. This axis was also accurately aligned by the use of cross hairs. In this geometry, the angle between the proton beam center line and the axis of the detector was fixed at 90°; the effective angle for meson detection was $92°\pm 10°$, as in the previous experiment. The detector was placed for equal integrated beam intensities in the "up" and "down" positions.

(4) The target was aluminum 0.911 $g\text{-}cm^{-2}$ thick, and the meson absorber was set to select mesons of energies 38.0–42.8 Mev.

RESULTS AND DISCUSSION

The result obtained after about 80 hours of taking data is as follows:

$$\epsilon = 0.014 \pm 0.037.$$

This indicates a small (but not significant) excess of mesons emitted downward. Taking into account the degree of polarization (0.89) and assuming the center-of-mass system to be essentially at rest in the laboratory frame, we deduce that

$$F^2 \leq 2\times 10^{-3}.$$

We did not believe it worthwhile to attempt to reduce this upper bound without a considerably more careful study of possible systematic errors. It is, however, not out of the question to design an experiment to detect an asymmetry of less than 1%, so that it may be possible to reduce this limit by another order of magnitude.

It may be noted that this measurement is closely related to the search of Garwin *et al.*[7] for circular polarization of the photons from π^0 decay, since the π decay is presumed to proceed mainly through the channel $\pi^0 \rightarrow p + \bar{p}$, which is a form of the Yukawa reaction in a virtual state. Their result was also negative: $F^2 \leq 8\times 10^{-3}$. As in all such experiments, a negative result may of course be caused by accidental cancellation of the interference term between the parity-conserving and parity-nonconserving parts of the Hamiltonian; however, this is considered very unlikely. We therefore conclude that these experiments are consistent with the usual picture of the emission of spin-zero π^+ mesons in a Yukawa reaction.

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[7] Garwin, Gidal, Lederman, and Weinrich, Phys. Rev. **108**, 1589 (1957).