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WILSON-PEIERLS AMBIGUITY IN HIGH-ENERGY PHOTOPRODUCTION

J. J. Sakurai

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WILSON-PEIERLS AMBIGUITY IN HIGH-ENERGY PHOTOPRODUCTION

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Recent experiments at Cornell University and at the California Institute of Technology have revealed the presence of a second peak in photoproduction of a single pion.[1] It has been suggested by R. R. Wilson that this peak corresponds to a resonance in an excited isobaric state of the proton with $T = \frac{1}{2}$ and $J = \frac{3}{2}$.[2] The parity of the isobaric state was originally assigned by him to be even so that the isobar decays into a p-wave pion and a nucleon. However, in a more recent letter R. F. Peierls has pointed out that the π^+ production can be more readily understood in terms of a resonance in a $T = \frac{1}{2}$, $J = \frac{3}{2}$ state with <u>odd</u> parity,[3] which means that the proposed isobar has a symmetry property required of a nucleon plus a d-wave pion. Arguments based on the angular distribution of the π^+ production are not very conclusive, since there are many nonresonant states which are expected to be important for photoproduction of <u>charged</u> pions. The purpose of this letter is to point out that there exists a very definite possibility of resolving this $p_{3/2}$ <u>vs.</u> $d_{3/2}$ ambiguity by measuring the polarization of the recoil proton in the reaction

$$\gamma + p \rightarrow p + \pi^0 , \tag{1}$$

and that such an experiment is indeed feasible.

Let us recall that the $p_{3/2}$ state of the pion-nucleon system can be reached from the magnetic dipole channel of the γp system and the $d_{3/2}$

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* On leave of absence from the University of Chicago.

state from the electric dipole channel. We construct the production matrix M for Eq. (1) under the assumption that only these two channels contribute, since other nonresonant states are expected to be relatively unimportant for photoproduction of neutral pions provided that either of the resonance models is correct.[4] We have[5]

$$M = A\left[2\hat{q}\cdot(\hat{k}\times\hat{\varepsilon}) - i(\sigma\cdot\hat{k}\hat{q}\cdot\hat{\varepsilon} - \sigma\cdot\hat{\varepsilon}\hat{q}\cdot\hat{k})\right] + iB(3\sigma\cdot\hat{q}\hat{\varepsilon}\cdot\hat{q} - \sigma\cdot\varepsilon), \tag{2}$$

where $\hat{\varepsilon}$, $\hat{k}$ and $\hat{q}$ are unit vectors along the photon polarization, the photon momentum, and the pion momentum respectively, and A and B are the transition amplitudes for $M1 \rightarrow p_{3/2}$ and for $E1 \rightarrow d_{3/2}$ respectively. In Wilson's $p_{3/2}$ model B is 0 and $|A|^2$ is essentially proportional to the total π^0 production cross section at all energies up to $E_\gamma = 800$ Mev. In Peierls's $d_{3/2}$ model A is dominant in the first resonance region ($E_\gamma \approx 320$ Mev), both A and B contribute in the transition region (450 Mev $< E_\gamma <$ 600 Mev), and B is dominant in the second resonance region ($E_\gamma \approx 700$ Mev). From Eq. (2) we obtain the angular distribution

$$I(\theta) \sim (|A|^2 + |B|^2)(1 + \frac{3}{2}\sin^2\theta) - 2\mathrm{Re}\,(AB^*)\cos\theta. \tag{3}$$

From the experimental point of view the most striking feature of Reaction (1) is that the π^0 angular distribution is forward-backward symmetric in the entire region up to 800 Mev and is consistent with the $1 + \frac{3}{2}\sin^2\theta$ distribution. Hence unless one has

$$2\,\mathrm{Re}\,(AB^*) \approx 0 \tag{4}$$

at all energies Peierls's model is untenable—a point already noted by Peierls himself. Note that Peierls's model implies that A and B are about 90° out of phase in the transition region where we know both A and B contribute substantially.

Thus from the π^0 angular distribution we cannot decide between Wilson's model with $B = 0$ and Peierls's model with $Re(AB^*) \approx 0$,[6] and it would be nice if we could directly test Peierls's hypothesis that $|2\,Im(AB^*)|$ is almost as large as $|A|^2 + |B|^2$ in the transition region where $|A| \approx |B|$. We now note that the polarization of the recoil proton is given by

$$P(\theta) \equiv \frac{(\uparrow) - (\downarrow)}{(\uparrow) + (\downarrow)}$$

$$= 4\,Im(AB^*)\sin\theta \Big/ \left[\left(|A|^2 + |B|^2\right)\left(1 + \frac{3}{2}\sin^2\theta\right) - 2\,Re(AB^*)\cos\theta\right], \qquad (5)$$

where $(\uparrow)$ and $(\downarrow)$ refer to the respective probabilities for observing the proton with spin up and spin down relative to the production plane whose normal is given by $\hat{k} \times \hat{q}$. Quantitatively Peierls's model implies that with A and B 90° out of phase the polarization is as large as 80% in the angular region $40^\circ < \theta_{cm} < 140^\circ$ at about $E_\gamma = 550$ Mev (or, more precisely speaking, at that energy where $|A| = |B|$), as shown in Fig. 1. Fortunately this polarization is rather insensitive to variations in the relative phase of A and B; even if the relative phase is 60° (which would probably give too much forward-backward asymmetry to be consistent with the angular-distribution measurements) the polarization can be still as large as 70% in the broad angular region shown in Fig. 1.

The recoil proton in Reaction (1) has a substantial laboratory-system kinetic energy in the major part of the region of our interest. Specifically at $E_\gamma = 550$ Mev, $\theta_{cm} = 55^\circ$ the proton kinetic energy is 215 Mev. As is well known, a polarized proton beam can be analyzed by a scattering from complex nuclei. In fact the situation here is extremely favorable: For 220-Mev polarized protons the analyzing power of proton-carbon scattering is essentially 100%

at optimum angles, so that at such angles the observed right-left asymmetry in the subsequent p-C scattering is the proton polarization itself.[7] With only a few hundred events a statistically significant result can be obtained, and in spite of a low expected counting rate such an experiment is feasible.

In view of this large asymmetry expected from Peierls's model and no asymmetry expected from Wilson's model, we believe that the Wilson-Peierls ambiguity can be resolved in this manner. Should the proposed experiment indeed show a large proton polarization in the transition region (i.e. between the first and second peak), such a polarization would be a very striking confirmation of Peierls's model. Of course the possibility exists that neither Peierls's model nor Wilson's model is correct. We expect that most other models[8] are likely to give a proton polarization substantially smaller than 80%. The energy and angular dependence of the proton polarization will throw further light on the nature of the second peak.

The investigation discussed here was sparked by stimulating conversations the author had with Dr. Oreste Piccioni. Thanks are also due to Drs. M. J. Moravcsik and T. J. Ypsilantis for helpful discussions.

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FOOTNOTES

1 De Wire, Jackson, and Littauer, Phys. Rev. 110, 1208 (1958);
P. C. Stein and K. C. Rogers, Phys. Rev. 110, 1209 (1958);
Heinberg, McClelland, Turkot, Wilson, Woodward and Zipoy, Phys. Rev. 110, 1211 (1958);
F. P. Dixon and R. L. Walker, Phys. Rev. Letters 1, 142 (1958).

2 R. R. Wilson, Phys. Rev. 110, 1212 (1958).

3 R. F. Peierls, (to be published).

4 In Wilson's model, however, the neglect of the $E2 \rightarrow p_{3/2}$ transition in the second resonance region may not be justified on *a priori* theoretical grounds.

5 For the construction of the production matrix see, e.g., M. J. Moravcsik, p. 15-16, *Selected Topics in Low-Energy Pion Physics* BNL-459 (T-100) (Associated Universities, 1957).

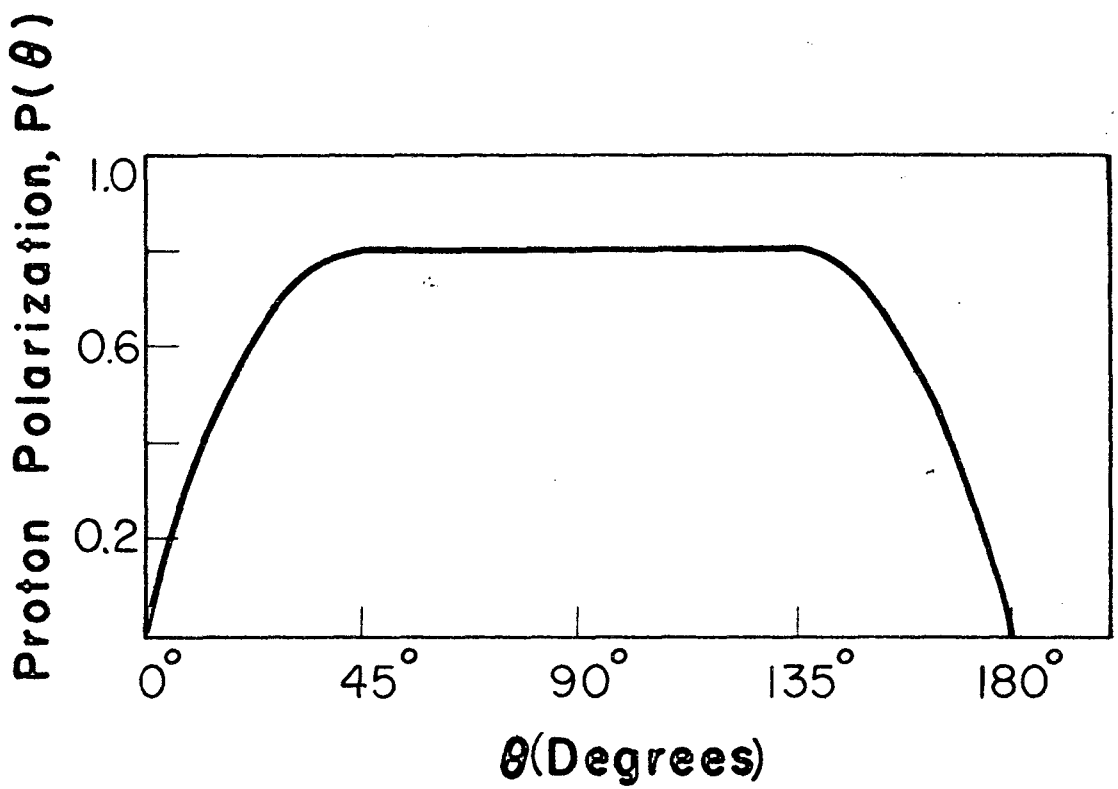
6 In principle we can resolve the ambiguity by using a polarized γ-ray beam. The A term gives $1 + 3 \sin^2 \theta \sin^2 \phi$, whereas the B term gives $1 + 3 \sin^2 \theta \cos^2 \phi$, where ϕ is the angle between $\hat{\varepsilon}$ and $\hat{q}$. However, the possibility of obtaining a polarized γ-ray beam at 700 Mev seems to be rather remote at present.

7 See, e.g., E. M. Haffner, Phys. Rev. 111, 297 (1958).

8 Cf. remarks by R. L. Walker and M. Gell-Mann, *Proceedings of the Eighth Annual Conference on High Energy Nuclear Physics* (CERN, Geneva, 1958; to be published).

FIGURE CAPTION

Fig. 1. Expected proton polarization for Reaction (1) in Peierls's model in the energy region where the $p_{3/2}$ state and the $d_{3/2}$ state contribute equally under the assumption that the $p_{3/2}$ amplitude and the $d_{3/2}$ amplitude are 90° out of phase.



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