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January 28, 1952

AT(30-1) -875

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Date: 10/20/09

Submitted to the Physical Review

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Electromagnetic Interference Effects in Charged Meson-Proton Scattering

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Bethe and Wilson¹ have recently pointed out that the sign of the scattering amplitude for meson-nucleon scattering depends on the charge of the meson and the specific meson theory employed. One is reminded of proton-proton scattering in which the interference effects between the nuclear and electromagnetic scattering were used to determine the sign of the nuclear amplitude. In the meson scattering it turns out that it is also feasible in principle to use the interference between nuclear and electromagnetic scattering by protons to determine the sign of the nuclear scattering amplitude for a given meson charge².

In order to estimate these effects one must use a given model. Although it is not expected that weak coupling theory will give a quantitatively correct account of meson interactions, it is thought that the qualitative predictions of the theory may have some interest, particularly in the non-relativistic region³. It is with this basic qualification that the interference effects are calculated to lowest order in the weak coupling approximation.

Since the present evidence strongly favors the pseudoscalar theory⁴ we restrict ourselves to this theory and consider both the direct and derivative couplings. Two Feynman diagrams are needed to calculate either process I ($\pi^+ + p \rightarrow \pi^+ + p$) or process II ($\pi^- + p \rightarrow \pi^- + p$), one for the nuclear and one for the electromagnetic scattering. The matrix elements are (primed quantities

refer to the PS(PS) theory):

$$M_I = -\frac{f^2}{\mu^2} \langle I | \left[\frac{2M(q_\mu \gamma_\mu)(q_0 \gamma_0)}{\mu^2 - 2p_0 \cdot q} + (q_\mu \gamma_\mu) \right] | F \rangle - 2e^2 \frac{\langle I | (q_\mu \gamma_\mu) | F \rangle}{(p_0 - p)^2}$$

$$M'_I = - \langle I | (q_\mu \gamma_\mu) | F \rangle \left[\frac{g^2}{\mu^2 - 2p_0 \cdot q} + \frac{2e^2}{(p_0 - p)^2} \right]$$

$$M_{II} = -\frac{f^2}{\mu^2} \langle I | \left[\frac{2M(q_\mu \gamma_\mu)(q_\nu \gamma_\nu)}{\mu^2 + 2p_0 \cdot q_0} - (q_\mu \gamma_\mu) \right] | F \rangle + 2e^2 \frac{\langle I | (q_\mu \gamma_\mu) | F \rangle}{(p_0 - p)^2}$$

$$M'_{II} = \langle I | (q_\mu \gamma_\mu) | F \rangle \left[\frac{g^2}{\mu^2 + 2p_0 \cdot q_0} + \frac{2e^2}{(p_0 - p)^2} \right]$$

The notation is that of Feynman⁵, the letters p and q referring, respectively to the proton and the meson and the subscript 0 denoting the initial state.

We note first, a feature already pointed out by Bethe and Wilson¹, that the signs of the nuclear scattering amplitudes for processes I and II, are the same for the PS(PS) theory. Therefore, if constructive interference is observed for one process (I) this theory would then predict destructive interference for the other (II). On the other hand, the PS(PV) theory behaves like the PS(PS) theory only at extremely low meson energies. At meson energies greater than approximately five to ten Mev and for reasonable angles the nuclear

amplitude changes sign for process I⁶ but does not do so for process II. Hence, under the usual experimental conditions, destructive interference should be observed for both processes I and II for the PS(PV) theory in contrast to the PS(PS) theory.

In order to demonstrate the nature of the interference effects we have calculated the differential cross section in the center of mass system for process I on the basis of the PS(PV) theory (this seems to be the more promising; see ref. 3) for three different energies of the π^+ meson in the laboratory system. The results are shown in Figs. 1 and 2 for two different coupling constants to indicate the dependence on the strength of the π meson-nucleon coupling. It is seen that a smaller coupling constant shifts the minima in the scattering cross section to higher angles. It would therefore seem possible to differentiate experimentally between the two types of coupling of the pseudoscalar theory. In any event, one should be able to obtain useful information concerning the meson-nucleon scattering amplitude by observations on the interference effects with the electromagnetic scattering.

The consideration of this problem arose from a discussion with Prof. R. E. Marshak and Mr. A. Messiah. I am indebted to Prof. Marshak for further discussion.

Footnotes

* This research supported by the A.E.C.

1 H. A. Bethe and R. R. Wilson, Phys. Rev. 83, 690 (1951).

2 These interference effects have also been considered by Dr. M. H. Johnson as a possibility of distinguishing between the various spin 0 meson theories. (Private communication from Dr. M. H. Johnson).

3 R. E. Marshak, Rev. Mod. Phys. 23, 137 (1951).

4 Clark et al, Phys. Rev. 83, 649 (1951).

5 R. P. Feynman, Phys. Rev. 76, 749 (1949).

6 At higher meson energies the sign of the nuclear scattering amplitude is determined by the second term of the nuclear matrix element, while at very low meson energies the nuclear amplitude for both processes I and II is $\sim +\frac{1}{2M}$. The change of sign of the amplitude for process I occurs at such low meson energies that it is probably not experimentally detectable due to the extremely large electromagnetic scattering in this energy region.

Captions for Figures

Fig. 1 Differential scattering cross-section in the center of mass system for the reaction $\pi^+ + p \longrightarrow \pi^+ + p$ including Electromagnetic effects for the PS(PV) theory. The π meson-nucleon coupling constant $f^2 = 1/4$. The curves are labelled according to the π meson kinetic energy in the laboratory system.

Fig. 2 Differential scattering cross-section in the center of mass system for the reaction $\pi^+ + p \longrightarrow \pi^+ + p$ including Electromagnetic effects for the PS(PV) theory. The π meson-nucleon coupling constant $f^2 = 1/2$. The curves are labelled according to the π meson kinetic energy in the laboratory system.

Fig. 2