PHOTOPRODUCTION OF π^0 MESONS AT HIGH ENERGIES

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Submitted to JETP editor November 15, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 1112-1114 (April, 1962)

It is shown that the pole diagram related to the decay of the π^0 meson gives a large contribution to the differential cross section for the photoproduction of π^0 mesons on protons at small angles. The forward photoproduction cross section is shown to increase as the third power of the energy of the incident photon in the laboratory frame.

As was noted by Primakoff, [1-2] the lifetime of neutral pions may be determined from experiments on photoproduction in the Coulomb field of a nucleus. The following expression was obtained for the angular distribution of the produced mesons

$$\frac{d\sigma(\theta)}{d\Omega} = Z^2 \frac{4e^2}{\mu^3\tau} \frac{kq^3}{t^2} \sin^2\theta \cdot F_1^2 \qquad (1)$$

(the notation adopted in this paper is explained below). A distinctive feature of Eq. (1) is the existence of a maximum for small angles of production of the π^0 mesons, which may be utilized for the determination of the π^0 lifetime. [3] Because of recoil effects, Primakoff's formula may not be applied to photoproduction on a nucleon at high energies.

In the present paper we discuss the analogous mechanism for the photoproduction of neutral pions on protons, related to the $\pi^0\gamma\gamma$ interaction (see Figure). It is shown that in spite of the smallness of the coupling constants in the corresponding vertices the differential cross section in the forward direction achieves a very large value.

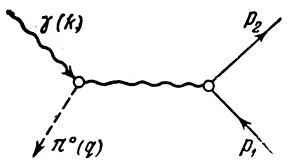
The matrix element for the diagram pictured is of the form

$$M = -i\,(2\pi)^4\delta(p_1 + k - p_2 - q)$$

$$\times \frac{e\Lambda}{2(k\omega)^{1/2}\,t} \varepsilon_{\mu\nu\sigma\rho}\, q_\nu e_\sigma k_\rho \bar{u}(p_2)\,\Gamma_\mu u(p_1),$$

$$\Gamma_\mu = [F_1(t) + F_2(t)]\,\gamma_\mu + \frac{i}{2M} F_2(t)\,(p_1 + p_2)_\mu. \qquad (2)$$

Here, and subsequently, the notation used is as follows: F_1 and F_2 are the electromagnetic form factors of the proton, Λ is the form factor of the π^0 meson, e_σ is the photon polarization vector, $\epsilon_{\mu\nu\sigma\rho}$ is the antisymmetric tensor of fourth rank, $t = (q-k)^2$ is the square of the momentum transfer, μ and M are the masses of the meson and nucleon, k, ω and E are respectively the energies of the



photon, meson, and nucleon, and W is the total energy of the colliding particles.

Equation (2) for the matrix element in the pole approximation may be obtained by choosing the $\pi^0\gamma\gamma$ interaction in the form $\Lambda\mathbf{E}\cdot\mathbf{H}\varphi$.

For the angular distribution of the π^0 mesons in the barycentric frame one may obtain the following expression

$$\frac{d\sigma(\theta)}{d\Omega} = \frac{1}{137}\frac{\Lambda^2}{16\pi}\frac{kq^3}{W^2t^2}\Big\{t\cos^2\theta\,[F_1(t) + F_2(t)]^2 + W^2\sin^2\theta\Big[2F_1^2(t) + \frac{t}{2}F_2^2(t)\Big]\Big\}. \qquad (3)$$

Here all the energy factors are expressed in units of the nucleon mass. Expressing the square of momentum transfer in the form

$$t = 2k(\omega - q) - \mu^2 + 4kq\sin^2\frac{\theta}{2} \equiv t_0 + 4kq\sin^2\frac{\theta}{2}$$

and taking into account the fact that at high energies $t_0 = \mu^4/4k^2W^2 \ll 1$, we find that the pictured diagram gives large contributions only in the region of small angles $\theta^2 \approx t_0/kq$ and, in particular, that for photoproduction in the forward direction we have at high energies

$$\frac{d\sigma(0)}{d\Omega} \approx \frac{1}{137}\frac{\Lambda^2}{4\pi}\frac{q^3k^3}{\mu^4}[F_1(t_0) + F_2(t_0)]^2 \approx 0{,}5\cdot 10^{-30}\,k^6\,\frac{\text{cm}^2}{\text{sr}}. \qquad (4)$$

In obtaining the estimate, Eq. (4), the electromagnetic form factors of the proton $F_{1,2}(t_0)$ were evaluated at $t = 0$, in view of the fact that $t_0/\mu^2 \ll 1$.

In contrast to the result of Primakoff* we have

*According to Primakoff (see[1]) the photoproduction cross section in the Coulomb field of a nucleus at the angle $\theta = 0°$ is equal to zero at all energies.

here for photoproduction forward a very fast growth of the cross section with the energy of the incident photon. In the angular distribution (3) there is also observed a maximum in the small angle region at

$$\theta^2 \approx \frac{t_0}{kq} \frac{2W^2 - kq(1+\mu_p)^2}{2W^2 + kq(1+\mu_p)^2}, \quad (5)$$

where μ_p is the anomalous part of the magnetic moment of the proton ($\mu_p = 1.79275$). The value of the cross section at maximum differs little at high energies from its value at $\theta = 0°$. (In any event there is no sharp peak in the angular distribution of the π^0 mesons, even though the differential cross section falls rapidly with increasing angle θ.)

It is necessary to have a high energy estimate of at least the interference part of the cross section before drawing definitive conclusions about the contribution of the given diagram. A rigorous estimate is impossible to make, however for the sake of comparison we give the part of the photoproduction cross section due to interference of the diagram under consideration and the remaining pole diagrams:

$$\frac{d\sigma(\theta)}{d\Omega} = \frac{1}{137} \frac{G\Lambda}{16\pi} \frac{q(qk)}{k^2 W^3 (p_2 k)} \Big\{(1+\mu_p)\Big[M(qk)^2 (F_1 + F_2) + 2W^2 k^2 \frac{q^2}{M^2} \sin^2\theta \cdot F_2\Big] - 2\mu_p k^2 W^2 q^2 \sin^2\theta (F_1 + F_2)\Big\}, \quad (6)$$

where $G^2/4\pi = g^2 \approx 15$. In particular for photoproduction forward the interference part of the cross section is of the order of $10^{-33}\, M^2/W^2$ cm^2/sterad, and at high energies cannot compete with the main effect.

I express gratitude to K. A. Ter-Martirosyan and Yu. L. Vartanyan for discussion of the results.

[1] H. Primakoff, Phys. Rev. **81**, 899 (1951).

[2] V. Glaser and R. A. Ferrell, Phys. Rev. **121**, 886 (1961).

[3] Tollestrup, Berman, Gomez, and Ruderman, Proc. 1960 Ann. Int. Conf. on High Energy Physics at Rochester, Univ. Rochester, 1961.

Translated by A. M. Bincer
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