PHOTOPRODUCTION OF STRANGE PARTICLES ON PROTONS

V. I. MAMASAKHLISOV, S. G. MATINIAN, and M. E. PEREL' MAN

Physics Institute, Academy of Sciences, Georgian S.S.R.

Submitted to JETP editor July 27, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) 34, 195-197 (1958)

The photoproduction of strange particles on protons is considered for the case of hyperon spins of ½ and ³⁄₂. The angular distribution of K mesons is derived. Comparison of these distributions with experiment permits one to determine the parity of the (KY)-system with respect to the nucleon.

THE photoproduction of strange particles is of great interest from the point of view of the hypothesis of the "minimum electromagnetic interaction"[1] connected with the conservation of strangeness in electromagnetic processes. In addition, the investigation of the photoproduction of strange particles may lead to conclusions concerning the spin of hyperons and the parity of the (YK) system.

The aim of this work is an investigation of the photoproduction of strange particles on protons with the emission of charged K mesons:

$$\gamma + p \rightarrow \Lambda^0 + K^+ \qquad (1')$$

$$\gamma + p \rightarrow \Sigma^0 + K^+ \qquad (1'')$$

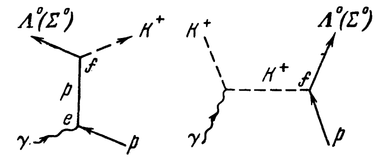
The cross sections of these processes is calculated by means of second order perturbation theory. The question of the applicability of perturbation theory to photoproduction of strange particles was considered recently by Gell-Mann,[2] who pointed out the possibility of applying weak coupling theory to the processes considered.

In accordance with experimental results,[3] we take the spin of the Λ^0-hyperon to be ½ and that of the Σ^0-hyperon to be $^3/_2$.[3,4]

It is further assumed that the proton and the Λ^0 particle obey the Dirac equation (the interaction of the electromagnetic field with the magnetic moments of the particles is neglected), while the Σ-hyperon is described by the Rarita-Schwinger equation[5] for particles with spin $^3/_2$.

Both the direct interaction of the γ-quantum with the nucleon, and its interaction with the field of the virtual K-mesons, are considered.

To the extent that we consider processes of creation of K^+ mesons and that we assume the hypothesis of the conservation of strangeness in electromagnetic interactions, the only possible diagrams of the processes are the ones shown below in the figure.



a b

Carrying out the standard calculation, we obtain in the center-of-mass system (c.m.s.) the following expression for the angular distribution of K^+-mesons produced in reaction (1′) ($\hbar = c = 1$):

$$\frac{d\sigma}{d\omega} = \frac{e^2 f^2}{32\pi^2} \frac{q}{\varphi^4 \omega^3} \Big\{ mM(m^2 + \omega\varphi) + a\varphi\big(M(m^2 - \omega^2) - \omega^2 q \cos\theta\big) + \frac{2q^2\varphi^2}{(\varphi - M)^2 (1 - v\cos\theta)^2} \big[mM + a\big(M\sqrt{m^2 + \omega^2}\big) - \omega q \cos\theta\big] \sin^2\theta \Big\}, \qquad (2)$$

$$\varphi = \omega + \sqrt{\omega^2 + m^2}, \quad q = \sqrt{(\varphi - M)^2 - \mu^2}.$$

Here v and q are the velocity and the momentum of the K meson in the c.m.s., ω is the energy of the incident γ-quanta, f is the coupling constant of the fields of the nucleons, hyperons and K mesons. The factor a is equal to +1 of to −1 depending upon whether the (hyperon − K^+ meson) system has the same parity as the proton or the opposite parity.

The calculation shows that the interaction of γ-quanta with the field of the virtual K^+ mesons gives an appreciably smaller contribution to the cross section than the direct interaction of a γ-quantum with a proton. From this it follows that if the ($\Lambda^0 K^+$) system has the same parity as the proton, the angular distribution of the K^+ mesons will be shifted in the c.m.s. towards the larger angles; for a parity of the $(\Lambda^0 K^+)$ system opposite to the parity of the proton, the opposite is true.

For a 1-Bev γ-quantum (in the laboratory system) the order of magnitude of the total cross section of reaction (1′) is $f^2 \times 2 \times 10^{-32}$ cm^2.

Let us now consider the production of Σ-hyperons [reaction (1″)]. We proceed from the Rarita-Schwinger equation[5] for particles of spin $3/2$

$$(\gamma_k \partial/\partial x_k + M)\Psi_i = 0 \quad (i, k = 1, 2, 3, 4), \tag{3}$$

where Ψ_i is a spin vector with the combined transformation properties of a four-vector and a Dirac bispinor. Ψ_i obeys the added conditions:

$$\partial\Psi_i/\partial x_i = 0, \quad \gamma_i \Psi_i = 0,$$

which lead to the fact that a direct interaction of the fields cannot be constructed. The only field couplings possible are those including the boson derivatives

$$H = (F/M)(\overline{\Psi}_i^{\Sigma}\Psi^N)\,\partial\varphi_K^+/\partial x_i + \text{complex conjugate},$$
$$H = (F/M^2)(\overline{\Psi}_i^{\Sigma}\gamma_m\Psi^N)\,\partial^2\varphi_K^+/\partial x_i \partial x_m + \text{complex conjugate}. \tag{4}$$

Starting with the first interaction in (4), and using, for the spin- the projection operator of the Rarita-Schwinger equation in the form[6]

$$\Lambda_{il} = \sum_s \Psi_l^s \Psi_i^{s+} = \delta_{il} + \frac{2}{3M^2} p_i p_l - \frac{1}{3iM}(p_i\gamma_l - p_l\gamma_i) - \frac{1}{3}\gamma_i\gamma_l \tag{5}$$

(p_i is a four-momentum) in the summation of the Σ^0-hyperon over the spin projections in the final state, we find that the angular distribution of K^+-mesons formed in reaction (1″) does not depend on the parity of the $(\Sigma^0 K^+)$ system (relative to the proton). Further, the angular dependence of the cross section enters only in the term described by diagram b in Fig. 1. As in the previous case, the term corresponding to this diagram gives a small contribution to the cross section and can be neglected. Therefore the observed angular distribution must be isotropic in the c.m.s.

The total cross section of reaction (1″) has the form

$$\sigma = \frac{e^2}{6\pi}\left(\frac{F}{M}\right)^2 \frac{qmM(\varphi\omega + m^2)}{\omega^3\varphi^4} \times \left[5 + 10\frac{\varphi}{M} + 14\left(\frac{\varphi}{M}\right)^2 - 6\left(\frac{\varphi}{M}\right)^3 + \left(\frac{\varphi}{M}\right)^4\right]. \tag{6}$$

provided the square of the mass of the K meson is neglected in comparison with the square of the mass of the Σ hyperon.

Comparison of the obtained results with experiment will help decide the question of the parity of the $(\Lambda^0 K^+)$ system relative to the proton. Let us mention further that if an isotropic distribution of K^+ mesons formed in reaction (1″) will be observed experimentally, then it may serve as an argument in favor of spin $3/2$ for the Σ hyperon.

Naturally, one must bear in mind at the same time that the results discussed above are obtained on the basis of perturbation theory, the applicability of which to the processes studied requires further investigation.

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Translated by Fay Ajzenberg-Selove
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