[4] F. Cerulus and A. Martin, Phys. Lett. 8, 80 (1964).
[5] E. C. Titchmarsh, The Theory of Functions, Oxford University Press, 1939.

PRODUCTION OF PSEUDOSCALAR MESONS IN THE COULOMB FIELD OF THE NUCLEUS AND THE POSSIBILITY OF OBSERVING THE PHOTOPRODUCTION OF MESONS FROM MESONS

G. S. Iroshnikov and Yu. P. Nikitin
Moscow Engineering Physics Institute
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It is indicated in [1,2] that it is possible in principle to observe in the Coulomb field of the nucleus different photoprocesses which cannot be realized directly owing to the lack of stable meson targets. The study of such processes should be carried out in the region of small momentum transfers, when the virtual photon is close to the real one. To separate reliably the Coulomb mechanism of the reaction it is necessary to estimate the role of the strong interactions and to indicate the region of the emission angles of the secondary particles, where predominance of the Coulomb contribution at least in order of magnitude can be expected. We considered earlier [3] the reaction

$$\pi^{\pm} + Z \to \pi^{\pm} + \pi^{0} + Z \tag{1}$$

(Z - nucleus) and estimated the region of the pion emission angles in which the cross section of the process $\gamma + \pi^{\pm} \to \pi^{\pm} + \pi^{0}$ can be measured.

The present note is devoted to an analysis of reactions of more general form

$$P + Z \to P + P + Z \tag{2}$$

(P - meson from pseudoscalar octet). The corresponding experiments are performed with the aid of bubble chambers filled with heavy substances [4]. We therefore consider the concrete case of the xenon nucleus. The condition for the coherence of the action of the nucleons of the nucleus limits the momentum transfer to the nucleus to $\Delta < 1/R$ (R - dimension of nucleus). For the xenon nucleus $\Delta < 0.2\mu$ (μ - pion mass). Since most of the constants of interaction of the mesons with one another and with the nucleons are not very well known, we make extensive use of the SU(3)-symmetry predictions. In the unitary-symmetrical theory, the electromagnetic current is a component of a certain octet, and the matrix element of the process

$$\gamma + P \to P + P \tag{3}$$

is given by

$$\begin{aligned} M = \epsilon_{ik\ell m} e_i k_k k_{1\ell} k_{2m} \{ & A(s,u,t)[P_1^{\gamma}(k)\bar{P}_{\gamma}^{\delta}(k_1)\bar{P}_{\delta}^{1}(k_2) - \\ & - P_{\gamma}^{1}(k)\bar{P}_{\delta}^{\gamma}(k_1)\bar{P}_{1}^{\delta}(k_2)] + B(s,u,t)[P_{\gamma}^{1}(k)\bar{P}_{1}^{\delta}(k_1)\bar{P}_{\delta}^{\gamma}(k_2) - \\ & - P_{1}^{\gamma}(k)\bar{P}_{\delta}^{1}(k_1)\bar{P}_{\gamma}^{\delta}(k_2)] + C(s,u,t)[P_{\gamma}^{\delta}(k)\bar{P}_{\delta}^{1}(k_1)\bar{P}_{1}^{\gamma}(k_2) - \\ & - P_{\delta}^{\gamma}(k)\bar{P}_{1}^{\delta}(k_1)\bar{P}_{\gamma}^{1}(k_2)\}, \end{aligned} \tag{4}$$

where $P^\beta_\alpha(k_1)$ is the wave function of the mesons from the octet 0^-, $\bar{P}^\beta_\alpha$ is a function conjugate to P^β_α, α and β are unitary indices, k, k_1, and k_2 are the 4-momenta of the initial and final mesons, e_i is the photon polarization 4-vector, $s = (k_1 + k_2)^2$, $u = (k - k_1)^2$, and $t = (k - k_2)^2$. The functions for A, B, and C are connected with one another by crossing-symmetry relations. Since we are interested in rather small Δ^2 (when $\Delta^2 \approx 2\Delta^2_{min} = (s - m^2)^2/2E_L^2 = \Delta_0^2$, the Coulomb cross section has a maximum, m - mass of incident meson), the cross section (2) is proportional to the cross section of the process (3) [3]. The contribution of the strong interactions to the process (2) is due essentially to ω-meson exchange (more accurately, exchange of the unitary scalar 1^-), since exchange of mesons of the vector octet 1^- is forbidden by G'-parity conservation [5] and exchange of π or η mesons is suppressed because the $\pi(\eta)NN$ vertex in the pseudoscalar coupling scheme is proportional to Δ/M (M - nucleon mass). When $\Delta^2 \ll \mu^2$, the ratio of the cross sections of the Coulomb production to the contribution due to the strong interactions amounts to

$$\frac{d\sigma_i}{d\sigma_N} = \left(\frac{Z}{A}\right)^2 \frac{\alpha\,|f_{3P\gamma}|^2}{g_{\omega NN}|f_{3P\omega}|^2}\left(\frac{m_\omega}{\Delta}\right)^4, \tag{5}$$

where $\alpha = 1/137$, $f_{3P\gamma}$ and $f_{3P\omega}$ are the corresponding vertex functions, and $g_{\omega NN}$ is the square of the ωNN coupling constant. The Coulomb maximum corresponds to a secondary-meson effective mass s equal to

$$s = \sqrt{2}\Delta_0 E_L + m^2. \tag{6}$$

We require that the Coulomb cross section exceed the nuclear cross section by one order of magnitude in the region of the Coulomb maximum. Since the eternal structure of the $3\pi\gamma$ and the $3\pi\omega$ vertices is the same, we should get the equality $f_{3\pi\gamma}f_{\pi\rho\omega} = f_{3\pi\omega}f_{\pi\rho\gamma}$; the values of $f_{3\pi\omega}$ [6], $g_{\omega NN}$ [7], and $f_{\pi\rho\gamma}f_{\pi\rho\omega}$ [8] can be taken from the experimental data on the decays and NN interactions, recognizing that the ratio

$$\beta = \frac{|f_{3P\gamma}|^2}{g_{\omega NN}|f_{3P\omega}|^2}$$

remains of the same order of magnitude also for the other region of kinematic variables (this assumption is not very important in view of the weak dependence of the result on β). Making extensive use of the connection between the different constants, which follows from SU(3) symmetry (e.g., $f_{K^*\to K\gamma} = f_{\rho\to\pi\gamma}$), it is possible to obtain estimates for the values of β. We note that the cross sections of the processes (2) vanish in the forward direction, are symmetrical with respect to the secondary-particle emission angles in their c.m.s., and have a maximum at $\theta_c = \pi/2$ (at least for the p-wave) owing to the properties of the matrix element (4). We introduce an angle θ_L for which the Coulomb cross section is maximal in the l.s. and an angle φ_L, which is the maximum secondary-emission angle in the l.s. at a given s. Then the estimates show that the Coulomb mechanism of the reactions (2) dominates over the nuclear mechanism when $\Delta \lesssim (0.08 - 0.10)\mu$. In the region of the Coulomb maximum ($\Delta \simeq \Delta_0$), at a specified primary-meson energy E_L, we can determine the corresponding region of variation of s and calculate the angles θ_L and φ_L. For the process $\pi^{\pm} \to \pi^{\pm}\pi^0$ in the field of the nucleus, $E_L \simeq (10 - 70)$ GeV, θ_L changes from 2.5 to 1°, $\varphi_L \simeq 4°$, and $11\ \mu^2 \leq s \leq 71\ \mu^2$; at 40 GeV, the minimum scattering angles of the γ quanta from the π^0 meson lie in the interval $1.15° \leq \chi_L \leq 14.5°$. For the reaction $K^{\pm} \to K^{\pm}\pi^0$ we have $\theta_L^{\pi^0} \simeq 2.5 - 1°$, $\varphi_L^{\pi^0} \approx 4.5°$, $\varphi_L^{K^{\pm}} \approx 1.25°$, $\theta_L^{K^{\pm}} \approx 1°$, and $25\ \mu^2 \leq s \leq 45\ \mu^2$. For the reaction $K^{\pm} \to K^0(\bar{K}^0) + \pi^{\pm}$ we have $\theta_L^{\pi^{\pm}} \approx 1.5 - 1.0°$, $\varphi_L^{\pi^{\pm}} \approx 2 - 3°$, $\theta_L^{K^0} \approx 0.75°$, $\varphi_L^{K^0} \approx 0.75 - 1°$, $25\ \mu^2 \leq s\ 45\ \mu^2$, and $(15 \leq E_L \leq 40)$ GeV. For the reaction $\pi^{\pm} \to K^{\pm} + \bar{K}^0(K^0)$ the threshold (at $\Delta \simeq \Delta_0$) lies too far in terms of energy, $E_L \gtrsim 60$ GeV. For the reaction $\pi^{\pm} \to \pi^{\pm} + \eta$ the results are approximately the same as for the reaction $K^{\pm} \to K^{\pm}\pi^0$. The angles θ_L and φ_L ($E_L \gtrsim 10$ GeV) depend little on the inaccurate parameter β ($\varphi_L \sim \beta^{1/4}$ and $\theta_L \sim \beta^{1/8}$); therefore the foregoing estimates are sufficiently reasonable to stimulate the organization of suitable experiments.

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[1] I. Ya. Pomeranchuk and I. M. Shmushkevich, Nucl. Phys. 23, 452 (1961).
[2] M. L. Good and W. D. Walker, Phys. Rev. 120, 1857 (1960).
[3] G. S. Iroshnikov and Yu. P. Nikitin, Yad. Fiz. 7, 616 (1968) [Sov. J. Nucl. Phys. 7, (1968) in press].
[4] B. V. Barmin, Yu. S. Krestnikov, E. V. Kuznetsov, A. G. Meshkovskii, Yu. P. Nikitin, and V. A. Shebanov, Zh. Eksp. Teor. Fiz. 43, 1223 (1962) and 44, 748 (1963) [Sov. Phys.-JETP 16, 871 (1963) and 17, 505 (1963)].
[5] Nguyen Van Hieu, Lektsii po teorii unitarnoi simmetrii elementarnykh chastits (Lectures on the Theory of Unitary Symmetry of Elementary Particles), Atomizdat, 1967.
[6] V. M. Shekhter, Resonance States of Elementary Particles, Itogi nauki (Science Summaries), VINITI, 1965.
[7] G. Kopp and P. Soding, Phys. Lett. 23, 494 (1966).
[8] W. Alles and D. Boccaletti, Nuovo Cimento 27, 306 (1963); M. Gell-Mann, D. Sharp, and W. C. Wagner, Phys. Rev. Lett. 8, 261 (1962).

E R R A T U M

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On page 179, line 13 from the bottom, correct "... v_v - to the experimental values" to read "... v_v - to the extremal values."