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ON THE NECESSITY OF NEW MEASUREMENTS OF THE SPIN PARITY OF X° (960)-MESON

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О необходимости новых измерений спин-четности X° (960)- мезона.

Показано, что вопреки распространенному мнению на основе имеющихся экспериментальных данных нельзя утверждать, что X° (960) -мезон псевдоскалярен, спин-четность 2^{-} кажется даже несколько предпочтительней. В этом случае нонет псевдоскалярных мезонов содержал бы, в соответствии с предсказанием нарушенной $SU(6)_W$, E (1420)-мезон. Предлагается способ решить альтернативу для X° -мезона, 2^{-} или 0^{-}, путем параллельного измерения ширины распада X° на два фотона и сечения рождения X° в эффекте Примакова.

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On the Necessity of New Measurements of the Spin Parity of X^{0} (960)-Meson

It is shown that contrary to the widespread opinion, it is impossible to assert, basing on the available experimental data, that the X^{0} - meson is a pseudoscalar, the spin-parity 2^{-} seems to be even more preferable. In this case the nonet of pseudoscalar mesons would contain a E^{0} (1420)-meson according to the prediction of broken $SU(6)_W$. A method is suggested for solving the alternative 2^{-} or 0^{-} for the X^{0} -meson by measuring both the width of the two-photon X^{0}-meson decay and the X^{0} production cross section in the Primakoff effect.

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1. At present there are two mesons which may be considered to be the ninth pseudoscalar meson: $X^{o}(960)$ and E (1420)-mesons. The analysis made in [1] showns that the broken $SU(6)_W$ symmetry prefers unambiguously the E-meson. Therefore the problem as to whether the spin-particles of E- and X^{o}-mesons are determined reliably seems to be important. According to recent experimental data[2] the most probable value of the E (1420) spin-parity is just 0^-. However, further measurements are needed to make this conclusion completely reliable.

The situation is quite different in the case of the X^{o}-meson. There is a general opinion supported by the Rosenfeld Tables[3] that the pseudoscalarity of $X^{o}(960)$ meson has been firmly established. In spite of this in the present paper it is shown that the available experimental data do not allow to draw an unambiguous conclusion about the $X^{o}(960)$ spin-parity.

The methods for determining the $X^{o}(960)$ meson spin-parity are analysed in § 2. It is stressed there that the analysis of the Dalitz diagram for $X^{o} \to \eta\, 2\pi$ decay[4] in fact indicates equally to the both spin-particles 0^- and 2^- (2^- seems to be even better). The opinion, that the pseudoscalarity of X^0 is firmly established, is based[5] on another method that of the analysis of the $X^0 \to \rho\gamma \to 2\pi\gamma$ decay[6]. We show that this analysis is not correct. Even if only the simplest matrix elements are used the experimental agreement with the angular correlation $\sin^2\theta$ does not allow to distinguish the spin- parities 0^-, 1^-, 2^-. When all matrix elements are used the distribution $\sin^2\theta$ appears for all the spin-parities.

In §3 a possible method of the determination of the X^0-meson spin is suggested. By measuring independently the $X^0 \to 2\gamma$ decay width and the Primakoff's differential cross section one may distinguish between 0^- and 2^-. It turns out that for a given decay width the cross section for spin 2^- particle production is much larger (near the peak by a factor of 5) than that for spinless particle production.

The Primakoff cross section for 2^- particle production is represented in an analytic form in Appendix.

2. Let us analyse methods of the determination of the $X^0(960)$-meson spin-parity.

a) Determination of the X^0 meson parity from the decay $X^0 \to \eta\,\pi^+\pi^-$ [4].

The existence of this decay excludes completely the value 0^+. To consider other possibilities one constructs the Dalitz diagram. Since the energy releazed is low ($Q \approx 130$ MeV) the analysis is performed by means of the simplest matrix elements. (see Table IV in ref.[4]). Possible values of spin $J \leq 2$ are considered. For $J^P = 2^-$ there are two simplest matrix elements, in each of the remaining cases there is one matrix element. The forbidden configurations corresponding to these matrix elements are not expressed so clearly that it will be possible to determine the spin-parity on the basis of the density of the experimental points on the Dalitz diagram. Indeed, in ref./4/ 102 events were uniformely distributed over the whole region which allows to exclude 1^- and 2^+. Without additional analysis it is impossible to choose one of the remaining possibilities: either 0^- or 1^+ or 2^-. The additional analysis consists in the investigation of the dependence of the squared matrix elements on the η-meson energy and ion the angle θ between the relative momentum of pions and the η^0-meson momentum in the rest system of X^0. As a result of this analysis it is possible to exclude the value 1^+. However one cannot distinguish between 0^- and 2^-. Indeed (Fig.16, ref./4/), the energy behaviour of the squared matrix elements is in good agreement with $J^P=0^-$. However, in this case 2^- for a certain relationship of the contributions of the two simplest matrix elements the agreement with experiment is even better than for 0^-.

b) Determination of the X^0-meson spin-parity from the decay $X^0 \to \rho\gamma$ /6/.

To determine the X^0-meson spin-parity it was suggested/6/ to measure the correlation between the ρ-meson polarization (i.e. the relative momentum of π^+ and π^- from the ρ-decay) and the direction of the photon momentum k in the rest system of X^0-meson. The matrix elements and the corresponding correlations are given in the Table. All matrix elements both the simplest ($\sim g$) ones and those of the highest degree in $k(\sim f)$ are represented there.

Note that in ref./6/ even some simplest matrix elements were omitted, the authors did not notice the simplest matrix elements $k_i(e\rho)$ and $e_i(k\times\rho)_j + e_j(k\times\rho)_i + \frac{2}{3}\delta_{ij}([e\times k]\rho)$ for 1^- and 2^-, respectively. The conclusion, that the X^0-meson spin-parity is 0^-, fol-

Table 1.

J^P	The matrix element	$M^2(\theta)$
0^-	$g\,\mathbf{k}\cdot\mathbf{e}\times\boldsymbol{\rho}$	$g^2\sin^2\theta$
1^+	$g\,\mathbf{e}\times\boldsymbol{\rho} + f\,\mathbf{k}\,(\mathbf{k}\cdot[\mathbf{e}\times\boldsymbol{\rho}])$	$g^2(1+\cos^2\theta) + k^2(f^2k^2 + 2fg)\sin^2\theta$
1^-	$g_1\boldsymbol{\rho}\times[\mathbf{k}\times\mathbf{e}] + g_2\mathbf{k}(\mathbf{e}\boldsymbol{\rho})$	$g_1^2(1+\cos^2\theta) + (g_2^2 + 12g_1g_2)\sin^2\theta$
2^+	$g[e_i\rho_j + e_j\rho_i - \frac{2}{3}\delta_{ij}(e\rho)] + f_1[k_ik_j - \frac{1}{3}\delta_{ij}k^2](e\rho)$ $+ f_2[k_ie_j + k_je_i] - (k\rho)$	$g^2(1+\frac{1}{6}\sin^2\theta) + \frac{1}{6}k^2(f_1^2k^2 - 2gf_1)\sin^2\theta$ $+ k^2(k^2f_2^2 + 2gf_2)\cos^2\theta$
2^-	$g_1[\rho_i(k\times e)_j + \rho_j(k\times e)_i - \frac{2}{3}\delta_{ij}(\rho[k\times e])] +$ $+ g_2[e_i(k\times\rho)_j + e_j(k\times\rho)_i - \frac{2}{3}\delta_{ij}(e[k\times\rho])] +$ $+ f[k_ik_j - \frac{1}{3}\delta_{ij}k^2](k\,[e\times\rho])$	$g_1^2(1+\frac{1}{6}\sin^2\theta) +$ $+[\frac{1}{6}f^2k^4 + \frac{7}{6}g_2^2 + \frac{5}{3}g_1g_2 -$ $-\frac{1}{3}(g_1 - g_2)fk^2]\sin^2\theta$

lowed from the fact that the experimental data (40 events) imitate the distribution $\sin^2\theta$. However, as is seen from the Table, this conclusion is not reliable since even in the case of only simplest elements, $\sin^2\theta$ appears for 1^- and 2^-, too. Besides, at an energy release of about 200 MeV there are no grounds to disregard other matrix elements and then all values of J^P are possible. Therefore this method is simple inconsistent.

Thus, we conclude that the available experimental data do not allow to establish unambiguously the $X^0(960)$ meson spin-parity. The most probable values of its J^P are 0^- and 2^-.

3. Now let us discuss a possible method for determining the X^0-meson spin. This method is based on the study of the two processes: the radiative decay $X^0 \to 2\gamma$ and the Primakoff process (Fig.1).

The decays of $X^0(960)$ meson into two photons have not been observed yet. According to the theorem about the classification of the two-photon states [7,8] their presence will exclude unambiguously spin 1. However, even the measurement of the photon polarization does not allow to distinguish between 0^- and 2^- we are interested in, since the photon spin density matrices are identical in both these cases (see Appendix, (A1) and (A4)).

When, however, $X^0 \to 2\gamma$ decay will be established and the inverse process, photoproduction of the X^0-meson in the Coulomb field (the Primakoff's effect[9-12]) will be observed then the measurement of the $X^0 \to 2\gamma$ decay width and that of the differential cross section of the Primakoff's effect will allow to distinguish between 0^- and 2^-. These cross sections depend on the photon energy and the production angle as follows (see Appendix): in the case 0^-, the differential cross section for production of 0^- particle is

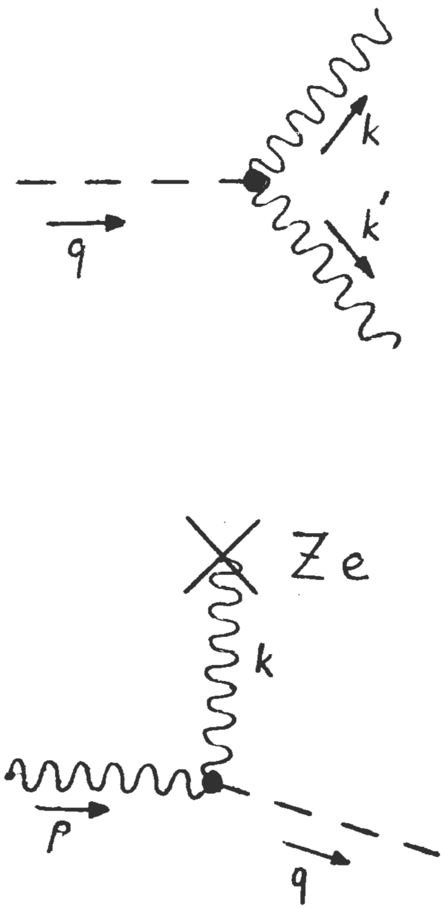


Fig.1.

$$\frac{d\sigma}{d\Omega}\frac{m^3}{\Gamma_{\gamma\gamma}}\frac{1}{\alpha Z^2|F(k)|^2} = 8\,\frac{v^3\sin^2\theta}{[(1-v)^2+2v(1-\cos\theta)]^2} \equiv f_0$$

and in case of 2^- we have

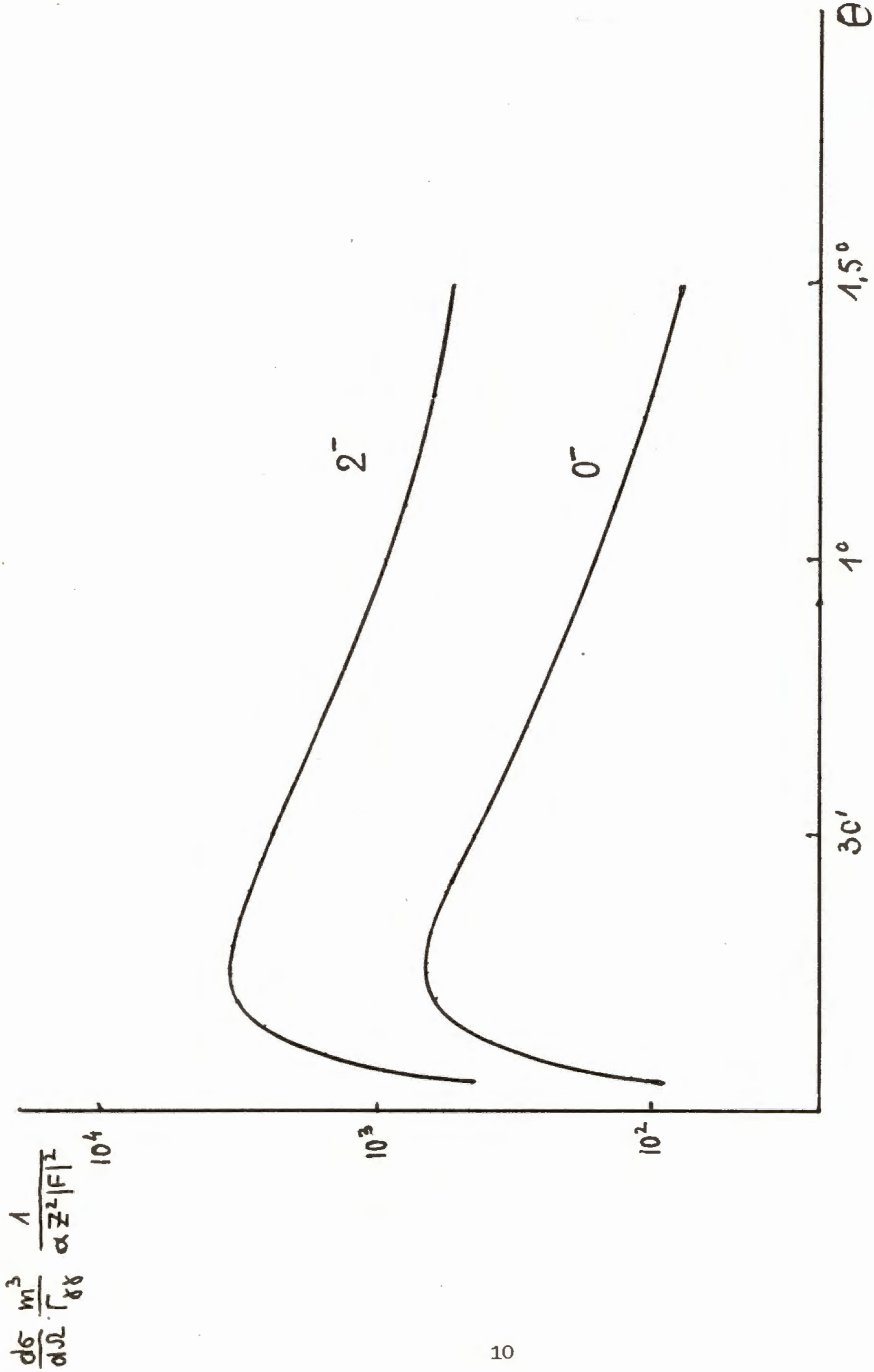
$$\frac{d\sigma}{d\Omega}\frac{m^3}{\Gamma_{\gamma\gamma}}\frac{1}{\alpha Z^2|F(k)|^2} = 640\left(\frac{E_\gamma}{m}\right)^8\frac{v^3\sin^2\theta\,(1-v\cos\theta)^4}{[(1-v)^2+2v(1-\cos\theta)]^2} \equiv f_2\,,$$

where m is the X^0 meson mass, $\Gamma_{\gamma\gamma}$ is the $X^0\to 2\gamma$ decay width, Ze is the nucleus charge, $F(k)$ is the electric form factor of the nucleus, E_γ is the photon energy , v is the X^0-meson velocity, θ is the angle between the momentum of an incident photon and the momentum of X^0 meson.

The angular dependence of the function f_0 (for large E_γ) is well known /9-12/: f_0 vanishes at $\theta = 0$, at $\theta \approx \frac{m^2}{2E_\gamma^2}$ function f_0 reaches its maximum $(f_0)_{max} \approx (\frac{E_\gamma}{m})^4$, for large angles f_0 decreases rapidly (Fig.2),. The angular behaviour of f_2 is similar to that of f_0 since the position of the peak is determined by the expression in the denominator which is identical both for f_0 and f_2 . For large angles f_2 decreases slowly than f_0 (Fig.2). The ratio near the peak is independent of the photon energy and is equal to:

$$\frac{f_2}{f_0} \approx 80\left(\frac{E_\gamma}{m}\right)^8(1-v\cos\theta)^4 \approx 80\left(\frac{E_\gamma}{m}\right)^8\left[1-\left(1-\frac{1}{2}\frac{m^2}{E_\gamma^2}..\right)\left(1-\frac{1}{2}\frac{m^4}{4E_\gamma^4}+\dots\right)\right]$$

$$\approx 5+O\left(\left(\frac{m}{E_\gamma}\right)^8\right).$$



$\frac{d\sigma}{d\Omega} \cdot \frac{m^3}{\Gamma_{\gamma\gamma}} \cdot \frac{1}{\alpha Z^2 |F|^2}$
10^4
10^3
10^2
2^-
0^-
30'
1°
1,5°
θ

Fig.2.

Thus, for a given $\Gamma_{\gamma\gamma}$ the angular cross section for the spin 2^- particle production is larger (near the peak by a factor of 5) than that for the spinless particle production. Therefore the knowledge of the cross section and the decay width allow, in principle, to distinguish between spins 0^- and 2^-.

Due to the large mass of the X^0-meson the cross section for the Primakoff process should be measured apparently at high energies, $E_\gamma \approx 10$ GeV.

4. The final conclusions of the analysis performed are the following:

a) At present the $X^0(960)$ meson spin-parity has not been firmly established yet contrary to the widespreed belief that X^0 is a pseudoscalar.

b) The most probable values for the X^0-meson spin-parity are 0^- and 2^-.

c) In order to distinguish between these values it is suggested to measure the $X^0 \to 2\gamma$ decay width and the Primakoff cross section.

In conclusion we make some remarks about the place of X^0-meson in the elementary particle classification. If the X^0-meson spin-parity is 2^- then there arises the problem of its partners in the nonet of $SU(3)$. Candidates for filling other places in the multiplet with $J^P = 2^-$ should be looked for among resonances the spin-parity of which has not been established yet unambiguously, for example /3/ $B(1220)$, $K(1320)$ and so on. If the X^0-meson spin-parity turns out to be 0^- then we shall have ten pseudoscalar mesons $\pi, K, \bar{K}, \eta, E, X^0$. This situation will be interesting and not clear for many reasons: it is not clear by what the ninth meson differs form the tenth one, in quark model there are only nine 0^- mesons, etc. Therefore we stress once again the importance of experiments on unambiguous determination of the spin-parity both for X° and E -mesons.

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Appendix

Primakoff's Effect

0: The matrix elements of the $0^{-} \to 2\gamma$ decay (Fig.1) is of the form

$$M = G_0 \phi(q) \epsilon_{\mu\nu\lambda\sigma} e_{\mu}(k) e'_{\nu}(k') k_{\lambda} k'_{\sigma} , \qquad (A.1)$$

where ϕ describes the 0^{-} particle. In the rest system of a decaying particle with mass m

$$d\Gamma_{\gamma\gamma} = \frac{(2\pi)^4}{2} \frac{1}{2m} \sum_{\substack{\text{over}\\ \text{spins of}\\ \text{photons}}} |M|^2 \frac{d^3k}{(2\pi)^2 2k_0} \frac{d^3k'}{(2\pi)^3 2k'_0} \delta(m - k_0 - k'_0) \delta^3(k + k').$$

Then /8-11/ the width is

$$\Gamma_{\gamma\gamma} = \frac{m^3}{64\pi} G_0^2 . \qquad (A.2)$$

In the case of the inverse process (Fig.1) the S -matrix element is

$$\frac{i\, 2\pi G_0}{\sqrt{2 p_0 2 q_0}} \delta(k_0) Ze F(k) \frac{q(p \times e)}{k^2} .$$

and taking into accout (A.2) we get the angular cross section /8-11/

$$\frac{d\sigma}{d\Omega} = 8\alpha Z^2 |F(k)|^2 \frac{\Gamma_{\gamma\gamma}}{m^3} \frac{v^3 \sin^2\theta}{[(1-v)^2 + 2v(1-\cos\theta)]^2} . \tag{A.3}$$

2^-: Matrix element of the $2^- \to 2\gamma$ decay (Fig.1) is

$$M = G_2 T_{\mu\nu} k_\mu k_\nu \epsilon_{\alpha\beta\gamma\delta} k_\alpha k'_\beta e_\gamma e'_\delta , \tag{A.4}$$

where $T_{\mu\nu}$ describes the spin 2^- particle . For the width of the decay into two photon we get

$$\Gamma_{\gamma\gamma} = \frac{1}{120} \frac{m^7}{64\pi} G_2^2 . \tag{A.5}$$

The S -matrix element for the Primakoff's process is

$$- \frac{i2\pi \ G_2}{\sqrt{2p_0^2 q_0}} \delta(k_0) Ze F(k) T_{\mu\nu} \ p_\mu p_\nu \frac{q[p \times e]}{k^2}$$

and for the angular cross section we obtain

$$\frac{d\sigma}{d\Omega} = 640\alpha Z^2 |F(k)|^2 \frac{\Gamma_{\gamma\gamma}}{m^3} \left(\frac{E_\gamma}{m}\right)^8 \frac{v^3 \sin^2\theta (1-v\cos\theta)^4}{[(1-v)^2 + 2v(1-\cos\theta)]^2} , \tag{A.6}$$

where $E_\gamma = p_0$ is the photon energy.

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