mass of the sought particle is of the order of the muon mass.

3. In conclusion, it should be noted that the advanced considerations should be regarded so far only as a hypothesis, since there are no other data confirming them at present.

[1] A. Einstein, The Meaning of Relativity (Russian translation), IIL, 1955.
[2] J. Burbidge and M. Burbidge, Quasars (Russian translation), Mir, 1969 (Postscript of the translation editor).
[3] Ya.B. Zel'dovich and I.D. Novikov, Relyativistskaya astrofizika (Relativistic Astrophysics), Nauka, 1967.
[4] Ya.B. Zel'dovich, ZhETF Pis. Red. 6, 772 (1967) [JETP Lett. 6, 236 (1967)].
[5] I.D. Novikov, Zemlya i Vselennaya (Earth and Universe), No. 5, 1969.

POSSIBILITY OF DETERMINING THE SPIN AND PARITY OF THE X^0 (960) MESON IN ELECTROMAGNETIC INTERACTIONS

A.N. Zaslavskii and V.A. Khoze

Submitted 3 May 1971
ZhETF Pis. Red. 13, No. 12, 706 - 710 (20 June 1971)

1. The spin and parity of the X^0 (960) meson have not yet been firmly established [1, 2]. The available skimpy experimental data can be reconciled equally well with the hypotheses 2^- and 0^- for the X^0 (960) meson, with 2^- being the preferable hypothesis [3]. An analysis of the decays $X^0 \to \eta 2\pi$, $X^0 \to \rho^0\gamma$, and $X^0 \to 2\gamma$ does not make it possible to distinguish between the hypotheses 0^- and 2^-, owing to the lack of clearly pronounced forbiddennesses. In this connection, it becomes important to study the mechanism of production of X^0 (960) in different reactions in strong and electromagnetic interactions.

We analyze in this paper processes of electromagnetic production of the X^0 (960) meson, in order to establish its spin and parity.

2. Photoproduction of X^0 (960) on a nucleus with spin 0. An interesting possibility of determining the spin of the X^0 meson is contained in the reaction[1]

$$\gamma + \mathrm{He} \to \mathrm{He} + X^0(960). \tag{1}$$

The choice of helium is dictated both by the zero spin of the nucleus, and by the absence of closely-lying exciting states. In the reaction $\gamma + \mathrm{He} \to \mathrm{He} + X^0$ (960) there exists an entire aggregate of effects leading to conclusions concerning the spin and parity of X^0 and based on the fact that the spin of the helium nucleus is zero. For the alternative 0^-, the differential cross section of the reaction (1) depends strongly on the angle of production of X^0, and vanishes like $\sin^2\theta$ as $\theta \to 0°$. For the hypothesis $J^P(X^0) = 2$, the simplest angular distribution does not vanish at $\theta = 0°$ (180°).

The dependence of the differential cross section of the process $\gamma + \mathrm{He} \to \mathrm{He} + X^0$ on the polarization of the initial photon for $J^P(X^0) = 0^-$ is strongly *pronounced*

[1] At the present time there are experimental data on the photoproduction of X^0 (960) on protons [4]. The maximum $\sigma \sim 1.5$ μV is reached at $E_\gamma \sim$ (1.6 - 1.7) GeV.

$$\frac{d\sigma_\xi}{d\Omega} = \frac{d\sigma_0}{d\Omega}(1+\xi), \quad (2)$$

where ξ is the Stokes parameter of the photon and characterizes the degree of linear polarization of the photon along a normal to the reaction plane, and $d\sigma_0/d\Omega$ is the differential cross section of the process with unpolarized γ quanta. A deviation from this relation is incompatible with the pseudoscalar character of the X^0 meson. Interest attaches also to threshold effects, which are different for both hypotheses (the threshold behavior of the cross section is $\sim|\vec{q}|^3$ and $\sim|\vec{q}|$ in the cases 0^- and 2^-, respectively). In addition, near the threshold the cross section for the alternative 2^- does not depend on the polarization of the γ quantum.

In the case of the hypothesis 0^-, the Coulomb photoproduction can imitate fully the spin 2^- for the X^0 meson [2]. Therefore an investigation of the reaction $\gamma + He \to He + X^0$ (960) must be carried out in a region where Coulomb photoproduction is negligible [5][2)].

3. Production of X^0 (960) mesons in reactions with colliding e^+e^- beams. At the present time experiments are being planned [7] on the production of X^0 (960) mesons with colliding e^+e^- beams in the reactions $e^+e^- \to X^0\rho^0$ ($X^0\gamma$). A study of such processes is of interest also from the point of view of determining the spin and parity of X^0 (960).

a) $e^+e^- \to X^0\rho^0$.

The differential cross section of the two-particle annihilation of the e^+e^- pair in the c.m.s. is written in the one-photon approximation in the form

$$\frac{d\sigma}{d\Omega} \sim A(\Delta^2)(1+\cos^2\theta) + B(\Delta^2)\sin^2\theta, \quad (3)$$

where $\Delta^2 = 4E^2$, E is the energy of the electron in c.m.s., and θ is the angle between the momenta of the initial and final particles. If X^0 (960) is pseudoscalar, then B = 0 for the process (a) and we have for the differential cross section

$$\frac{d\sigma_{0^-}}{d\Omega} \sim A(\Delta^2)(1+\cos^2\theta). \quad (4)$$

The amplitude of the reaction $e^+e^- \to X^0\rho^0$ for $J^P(X^0) = 2^-$ depends on four form factors [5]. Near the threshold ($|\vec{q}|^2/m_X^2) \ll 1$, where $\vec{q}$ is the momentum of the final ρ^0 meson in the c.m.s.), the differential cross section is determined only by two amplitudes and is given by (3) with

$$A = |q|^2\left\{2 + 5\left[\left|\frac{\bar{m}_x}{m_x + m_\rho} C + 1\right|^2 + \frac{m_x^2}{(m_x+m_\rho)^2}\left|C\right|^2\right]\right\}, \quad (5)$$

$$B = 6|q|^2,$$

[2)] The photoproduction of pseudoscalar mesons on helium was considered in detail by Tsarev [6].

where C is the mixing parameter for the two amplitudes that give the main contribution to the $X^0 \to \rho^0\gamma$ decay. It is precisely this energy region which is of real interst, since $d\sigma/d\Omega$ decreases rapidly with increasing energy. At C = -1, good agreement is obtained between the 2^- hypothesis and the experimental data on the decay $X^0 \to \rho^0\gamma$ [3], and then we have

$$\frac{d\sigma}{d\Omega} \sim |\,q\,|^2 (7.2 + \sin^2\theta). \tag{6}$$

A comparison of formulas (4), (5), and (6) leads to the conclusion that the behavior of the differential cross section of the reaction $e^+e^- \to X^0\rho^0$ near the threshold makes it possible to distinguish between the hypotheses 0^- and 2^- for the X^0 meson.

b) $e^+e^- \to X^0\gamma$.

In the case when $J^P(X^0) = 0^-$, the differential cross section of the reaction $e^+e^- \to X^0\gamma$ is the same as for the reaction $e^+e^- \to X^0\rho^0$ and is given by formula (4). The amplitude of the reaction (b) depends on three form factors if $J^P(X^0) = 2^-$ [5]. Near the threshold, in the region of the ϕ resonance, where the cross sections are indeed large, it is possible to omit from the differential cross section the terms of order $|\vec{q}|/m_X \sim 0.06$. With the indicated accuracy, the angular distribution is determined only by one form factor and is given by

$$\frac{d\sigma_{2^-}}{d\Omega} \sim (14 - \sin^2\theta). \tag{7}$$

Investigation of the differential cross section of the process $e^+e^- \to X^0\gamma$ near the threshold makes it thus possible to determine the spin of the X^0 meson.

4. The decay $X^0 \to \rho^0 e^+e^-$. It can be shown that owing to the small energy release, the value of the conversion coefficient

$$\left(k = \frac{\Gamma(X^0 \to \rho^0 e^+e^-)}{\Gamma(X^0 \to \rho^0\gamma)} = \frac{a}{3\pi}\left[2\ln\frac{m_x - m_\rho}{m_e} - 3.4\right] \sim \frac{1}{150}\right)$$

and the Dalitz plot for the decay $X^0 \to \rho^0 e^+e^-$ cannot be used to establish the spin of the X^0 meson, since the conversion coefficient and the distribution on the Dalitz plot coincide with good accuracy for $J^P(X^0) = 0^-$ and 2^-.

However, a study of the correlation between the relative momentum of the pions from the decay of the ρ^0 meson and the momenta of the e^+e^- pair in the rest system of the ρ^0 meson make it possible to distinguish between the hypotheses 0^- and 2^-. For the 0^- alternative, the dependence of the distribution of the decay π mesons on the emission angle is clearly pronounced

$$W(\theta, \phi, \gamma) = \left[\frac{\Delta^2}{2} - 2\sin^2\theta\sin^2\phi\, p^2_{e^+}\right]\sin^2\gamma, \tag{8}$$

where θ is the angle between the direction of the momenta of the positron (p_{e^+}) and of the X^0 meson ($\vec{K}$) in the rest system of ρ^0, γ is the angle between the momenta of $X^0(\vec{K})$ and $\pi^+(\vec{q})$ in this system, ϕ is the angle between the planes $(\vec{k}, \vec{p}_{e^+})$ and $(\vec{k}, \vec{q})$, and $\Delta^2 = (\vec{p}_{e^+} + \vec{p}_{e^-})^2$.

If $J^P(X^0) = 2^-$, then the angular distribution $W(\theta, \phi, \gamma)$ depends little on the angles γ and ϕ. Thus, a study of the distribution $W(\theta, \phi, \gamma)$ makes it possible to determine the spin of the X^0 meson if the number of events is sufficiently large.

The dependence on the polarization of the γ quantum in the $X^0 \to \rho^0\gamma$ decay is different for the alternatives 2^- and 0^-. This fact could be used to determine the spin of X^0 were it possible to measure the polarization of the fast γ quantum. The possibility of determining the spin of X^0 is inherent also in the reaction $\gamma + p \to p + X^0$ on a polarized target.

A detailed analysis of the foregoing questions will be presented in an extensive article.

One can hope that accumulation of experimental data will make it possible to answer the important question of the quantum numbers of X^0 (960) meson in the nearest future.

The authors are sincerely grateful to V.I. Ogievetskii for suggesting the problem and for numerous discussions, to I.G. Aznauryan, S.B. Gerasimov, K.A. Ispiryan, S.G. Matinyan, and R.M. Ryndin and particularly to B.N. Valuev for useful discussions.

[1] Particle Data Group. Phys. Lett. 33B, 1 (1970).
[2] A.N. Zaslavskii, V.I. Ogievetskii, and W. Tybor, ZhETF Pis. Red. 6, 604 (1967) [JETP Lett. 6, 106 (1967)]; Yad. Fiz. 9, 852 (1969) [Sov. J. Nucl. Phys. 9, 498 (1969)].
[3] V.I. Ogievetsky, W. Tybor, and A.N. Zaslavsky, Preprint JINR, E2-5627, 1971, Dubna.
[4] Aachen - Berlin - Bonn - Hamburg - Munchen - Heidelberg Collaboration Phys. Rev. 175, 1669 (1968).
[5] V.A. Khoze and. A.N. Zaslavsky, Preprint YPI, 1971, Yerevan.
[6] V.A. Tsarev, Yad. Fiz. 10, 367 (1969) [Sov. J. Nucl. Phys. 10, 211 (1970)].
[7] W. Ash et al., Preprint LNF-69/6 (1969).

POSSIBILITY OF MULTIPLY-VALUED EQUILIBRIUM DISTRIBUTION OF THE CARRIERS IN MANY-VALLEY SEMICONDUCTORS

V.A. Kochelap, V.I. Pipa, V.N. Piskovoi, and V.N. Sokolov
Semiconductor Institute, Ukrainian Academy of Sciences
Submitted 3 May 1971
ZhETF Pis. Red. 13, No. 12, 710 - 713 (20 June 1971)

We consider in this article, in the deformation-potential model, the effect exerted by a homogeneous deformation of the lattice, due to the free carriers, on the equilibrium distribution of the electrons over the equivalent valleys. If the concentration of the free carriers exceeds a certain critical value, then this deformation, which increases the elastic energy of the lattice, leads to a general lowering of the thermodynamic potential, connected with the decrease of the energy of the carriers in some of the valleys. As a result, the equilibrium distribution becomes multiply-valued[1)], i.e., there

[1)] The possibility of multiply-valued intervalley redistribution in a different situation (the multiply-valued Sasaki effect) was predicted in [1].