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THE SU(2)×SU(2) COUPLING RULE AND A TENSOR GLUEBALL CANDIDATE

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Although the existence of glueballs has been predicted from the very beginning of QCD [1], yet this prediction is not definitely proved nor disproved. There have even been reported new states [2,3] found in radiative decay of J/ψ and, as such, have been preferably interpreted as glueballs. However, because of the lack of knowledge of basic nontrivial properties of glueball states (e.g., their decaying properties to ordinary hadrons) the troubles with their clear assignments still remain. It has been assumed [4] that glueballs, being flavour singlets, should have SU(3)-flavour symmetrical decays (without phase space corrections) into ordinary hadrons. Unfortunately, the known experimental decay data of genuine glueball candidates [2,3] do not agree with this proposition (for example, decays into pions are unexpectably suppressed experimentally), thus suggesting other possible interpretations [5,6] of the states $\iota(1440)$ and $\theta(1640)$. It should be noted here that, however, the suppression of, e.g., $\theta(1640)$ decay into pions can be achieved through the mixing between gluonic and quark states leading to the physical $f(1270)$ and $\theta(1640)$ particles [7]. Unfortunately, a more complete analysis [8] including three-body mixing between $f(1270)$, $f'(1515)$, and $\theta(1640)$ does not seem to be consistent with experiment [9].

On the other had, in our previous paper [10] we have suggested and demonstrated instead of the SU(3) coupling rule [4] another possibility, namely, an SU(2)xSU(2) mechanism for coupling of a scalar glueball to pseudoscalar Goldstone mesons. The SU(2)xxSU(2) mechanism [10] assumes that the coupling of a scalar glueball to pseudoscalar Goldstone mesons is only due to a chiral symmetry breaking quark mass term in QCD Lagrangian, i.e., in the chiral-symmetry limit glueballs do not decay to lighter pseudoscalar mesons. In the case of exact SU(2)xSU(2) symmetry the glueball decay to pions is forbidden while in the realistic world the width of such a decay is proportional to m_π^4 and thus is strongly suppressed.

The purpose of this note is to show that the SU(2)xSU(2) coupling mechanism explains reasonably well also the experimental data for decays of $\theta(1640)$ into pseudoscalar pairs [3,11]. This will be shown explicitly by constructing an effective Lagrangian describing interaction between pseudoscalar Goldstone meson pairs and a tensor flavour-independent $\theta(1640)$ particle. Such an effective interaction Lagrangian is assumed to satisfy the SU(2)xSU(2) symmetry in the limit $m_\pi^2 \to 0$, $m_K^2 \neq 0$, and thus it has the following form [12]

$$\mathcal{L}_{SB} = \mathrm{Tr}[M(W + W^{+})] , \qquad (1)$$

where M is proportional to a 3x3 real diagonal quark-mass matrix and W is any 3x3 matrix transforming as $(3,\bar{3})$ representation of the SU(3)xSU(3) chiral group and describing fields of $\theta(1640)$ and pseudoscalar octet particles. As usual, within current algebra effective Lagrangian approach the pseudoscalar Goldstone meson octet fields $\phi_i(x)$ ($i = 1, \ldots, 8$) will be represented as follows (see, e.g., [13] for more references)

$$U = f \exp\left(i \sum_{j=1}^{8} \frac{\lambda_j \phi_j}{f}\right). \qquad (2)$$

Here elements of U form $(3,\bar{3})$ representation of SU(3)xSU(3), f is the pion decay constant (f = 93 MeV) and λ's are the Gell-Mann λ matrices. The field of the tensor particle $\theta(1640)$ will be labelled as $\phi_{\mu\nu}(x)$, where $\partial^{\mu}\phi_{\mu\nu} = 0$, $g^{\mu\nu}\phi_{\mu\nu} = 0$ and $\phi_{\mu\nu}$ is symmetrical in μ, ν (see, e.g., [14]). Since $\phi_{\mu\nu}$ is flavour-independent, then besides U (eq.(2)) the following derivative terms, for example, $\phi^{\mu\nu}(\partial_\nu U)(\partial_\nu U^{+})U$, $\phi^{\mu\nu} U(\partial_\mu U^{+})(\partial_\nu U)$, $\phi^{\mu\nu}(\partial_\mu U)U^{+}(\partial_\nu U)$, etc., have $(3,\bar{3})$ chiral transformation properties, too. Thus, taking as a matrix W in eq.(1) a linear combination of the terms U, $\phi^{\mu\nu}(\partial_\mu U)(\partial_\nu U^{+})U$, etc., and using parametrization (2), one gets

$$\mathcal{L}_{\theta P\bar{P}}(x) = g\phi^{\mu\nu}(x) \sum_{i=1}^{8} m_i^2 (\partial_\mu \phi_i(x))(\partial_\nu \phi_i(x)) \qquad (3)$$

for the interaction between $\theta(1640)$ and pseudoscalar pair particles P, $\bar{P}$. Here g is some unknown coupling constant and m_i's ($i = 1, \ldots, 8$) are masses of the pseudoscalar octet members. The interaction between $\theta(1640)$ and pseudoscalar pairs characterized by eq.(3) is the only non-trivial and independent one coming from the general effective quark mass term (1) and thus representing the SU(2)xSU(2) coupling mechanism. From eq.(3) one easily finds the $\theta(1640) \to P\bar{P}$ ($P\bar{P} = \pi^{+}\pi^{-}$, $K^{+}K^{-}$, etc.) decay amplitude *

$$T_{\theta \to P\bar{P}} = -g\, m_P^2\, h_{\mu\nu}(p,\lambda)\,[p_1^{\mu} p_2^{\nu} + p_1^{\nu} p_2^{\mu}] , \qquad (4)$$

where p, p_1, and p_2 ($p = p_1 + p_2$) are 4-momenta of $\theta(1640)$, P and $\bar{P}$ mesons, respectively, while $h_{\mu\nu}(p,\lambda)$ satisfies [14]

* The states are normalized as $<p|p'> = (2\pi)^3\, 2\omega_p\, \delta^{(3)}(p - p')$, while $T_{\theta \to P\bar{P}}$ is defined as $<P(p_1)\bar{P}(p_2)|S|\theta(p,\lambda)> = \delta_{if} + i(2\pi)^4 \delta^{(4)}(p_1 + p_2 - p)\, T_{\theta \to P\bar{P}}$.

$$\sum_{\lambda=1}^{5} h_{\mu\nu}(\lambda) h_{\rho\sigma}(\lambda) = \frac{1}{2} P_{\mu\rho} P_{\nu\sigma} + \frac{1}{2} P_{\mu\sigma} P_{\nu\rho} - \frac{1}{3} P_{\mu\nu} P_{\rho\sigma} , \qquad (5)$$

and $P_{\mu\nu} = g_{\mu\nu} - \frac{P_\mu P_\nu}{m_\theta^2}$.

From eq.(4) and after averaging over $\theta(1640)$ spin states by using eq.(5) we get the following partial decay width relations

$$\Gamma_{\theta \to \pi^{+}\pi^{-}} = 2\Gamma_{\theta \to \pi^{\circ}\pi^{\circ}} = C\, m_\pi^4 \left(1 - \frac{4m_\pi^2}{m_\theta^2}\right)^{5/2} ,$$

$$\Gamma_{\theta \to K^{+}K^{-}} = \Gamma_{\theta \to K^{\circ}\bar{K}^{\circ}} = C\, m_K^4 \left(1 - \frac{4m_K^2}{m_\theta^2}\right)^{5/2} , \qquad (6)$$

$$\Gamma_{\theta \to \eta\eta} = \frac{1}{2} C\, m_\eta^4 \left(1 - \frac{4m_\eta^2}{m_\theta^2}\right)^{5/2} ,$$

where an overall unknown constant C depends only on g and m_θ. We see from eqs.(6) that the decay of $\theta(1640)$ to pions is naturally suppressed due to smallness of the pion mass. Eqs.(6) give (for $m_\theta = 1.64$ GeV) $\Gamma_{\theta \to \pi\pi} / \Gamma_{\theta \to \eta\eta} \ll 1$ and $\Gamma_{\theta \to K\bar{K}} / \Gamma_{\theta \to \eta\eta} = 3.7$ in a remarkable agreement with existing experimental data [3,11]. This shows that the coupling of $\theta(1640)$ to pseudoscalar Goldstone mesons could better be realized by the SU(2)xSU(2) mechanism than by the SU(3) one. The SU(3) coupling pattern is realized only in the exact SU(3) limit ($m_\pi = m_K = m_\eta$), however, because of the smallness of pion mass the real world seems to prefer the SU(2)xSU(2) coupling rule.

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Ланик Й. E2-84-331
SU(2)xSU(2) правило связи
и тензорный глюбольный кандидат

Показано, что SU(2)xSU(2) механизм для связи тензорного глюбольного кандидата $\theta(1640)$ с псевдоскалярными голдстоновскими мезонами находится в замечательном согласии с существующими экспериментальными данными.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Lánik J. E2-84-331
The SU(2)xSU(2) Coupling Rule
and a Tensor Glueball Candidate

It is shown that the SU(2)xSU(2) mechanism for coupling of $\theta(1640)$ tensor glueball candidate to pseudoscalar Goldstone mesons is in a remarkable agreement with existing experimental data.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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