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QUARK-GLUON MIXING IN PSEUDOSCALAR AND TENSOR MESONS

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ԹՎԱՑՅԱԼ-ՍԿԱԼՅԱՐ ԵՎ ԹԵՆԶՈՐԱՅԻՆ ՄԵԶՈՆՆԵՐՈՒՄ ՔՎԱՐԿ-ԳԼՅՈՒՈՆԱՅԻՆ ԽԱՌՆՈՒՅԹ

Բերվում է քվարկ-հակաքվարկային և գլյուոնային վիճակների մոդելը η, η', ι/1440/ թվացյալ-սկալյար և f, f', Θ/1690/ թենզորային մեզոններում: Այդ մասերի մասնակցությամբ նկարագրված և կանխատեսված են 68 մասնիկների տրոհումները: Ցույց է տրված, որ ι/1440/ 80% կազմված է գլյուոնից, իսկ Θ/1690/ մաքուր գլյուոնային վիճակ է: Ստացված է նույնպես, որ քվարկ-գլյուոնային և գլյուոն-գլյուոնային կապի ծայրակետերը թվացյալ-սկալյար բաժնում ավելի ուժեղ են թենզորայինի համեմատությամբ:

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Sh.S. EREMYAN, A.E. NAZARYAN

QUARK- GLUON MIXING IN PSEUDOSCALAR AND TENSOR MESONS

A mixing model of quark-antiquark and gluonium states in η, η', $\iota(1440)$ pseudoscalar and f, f', $\theta(1690)$ tensor mesons is considered. Description of and predictions for 68 two-particle decays with these particles taking part in them are obtained. It is shown that $\iota(1440)$ by 85% consists of gluonium and $\theta(1690)$ is a pure gluonic state. The quark-gluon and gluon-gluon couplings in the pseudoscalar sector are obtained to be stronger as compared to the corresponding ones in the tensor case.

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КВАРК-ГЛЮОННОЕ СМЕШИВАНИЕ В ПСЕВДОСКАЛЯРНЫХ И ТЕНЗОРНЫХ МЕЗОНАХ

Рассмотрена модель смешивания кварк-антикварковых и глюонных состояний в η , η' , $\iota(1440)$ псевдоскалярных и f , f', $\theta(1690)$ тензорных мезонах. Получено описание и предсказания для 68-х двухчастичных распадов с участием этих частиц. Показано, что $\iota(1440)$ на 80% состоит из глюония, а $\theta(1690)$ является чистым глюонным состоянием. Также получено, что кварк-глюонные и глюон-глюонные вершины связи в псевдоскалярном секторе сильнее по сравнению с соответствующими вершинами в тензорном случае.

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1. Introduction

The discovery of $\iota(1440)$ ($J^{PC}=0^{-+}$)[1,2] and $\theta(1690)$ ($J^{PC}=2^{++}$) [3] mesons puts a question: are these particles radially excited quark-antiquark or gluonic states - glueballs? Various authors have considered the possibility of interpretation of $\iota(1440)$ meson as a radial excitation of a quark-antiquark system [4-6] . The basic disadventage of this approach is the large width $\Gamma(\iota\to\gamma\gamma)$ and too small width $\Gamma(J/\Psi\to\iota\gamma)$.

In the QCD framework gluons interacting with each other can form bound states - glueballs. In general, such gluonic states can annihilate into quark-antiquark pairs, that is why there must be mixing of pure gluonic states with neutral iso - scalar mesons. In particular, both candidates for gluonic states, $\iota(1440)$ and $\theta(1690)$ must have a quark-antiquark mixture, i.e. they must be glukonia. Such probability has been considered by various authors (see Refs [7-13]).

In present paper we suppose that there a mixing of quark-antiquark and gluonic states takes place in the η, η', $\iota(1440)$

pseudoscalar and f, f, $\Theta(1690)$ tensor mesons. All the available experimental data on two-particle decays with these particles, taking part in them, and also a Regge description of reactions $\pi^- p \to \eta(\eta')n$ [7] are used to determine the parameters of mixing.

The obtained data show that in the η meson the normal and strange quarks are almost equally mixed and practically there is no gluon contribution. There appears a little gluonic mixture in the η' meson, and $\iota(1440)$ already by 85% consists of gluonium with a slight admixture of normal and strange quarks.

In tensor mesons, on the contrary, we have a set of practically pure states: f meson is a pure normal state, f' meson- a pure $s\bar{s}$ state and $\Theta(1690)$ - a pure gluonic state. So, there is an ideal mixing in the sector of tensor mesons.

Constants of annihilation of two gluons into quark-antiquark pairs are also calculated in this work. It turned out, that these couplings are of the same order in 0^- case and are quite large ~ 500 MeV and in case of 2^+ mesons the gluon-normal state couplings are ~ 100 MeV, and the gluon-strange quark ones are ~ 200 MeV. This explains why there is a strong mixing in case with 0^- mesons, while in case with 2^+ ones there is practically no mixing (since transition of normal quarks into strange ones and vice versa is very difficult).

The obtained parameters allow to describe a very large number of processes (in the paper the widths of 68 decays with 0^- and 2^+ mesons participating in them are calculated and predicted).

In chapter 2 description of the model is given and the number of free parameters is considered. There remains only two free parameters for pseudoscalar mesons and four - for tensor mesons.

In chapter 3 formulae are presented by which the widths of decays of 0^- and 2^+ mesons are calculated in a nonplanar approximation.

In chapter 4 the obtained results are discussed.

2. Mixing Model

As in Ref. [7] , we also shall operate with an ideal basis containing state vectors of normal $|N\rangle = \frac{1}{\sqrt{2}}|u\bar{u} + d\bar{d}\rangle$, strange $|S\rangle = |s\bar{s}\rangle$ quarkonia states and of gluonic state $|G\rangle$. Physical states $|\Psi\rangle$ are their linear combination.

$$|\Psi\rangle = x_\Psi |N\rangle + y_\Psi |S\rangle + z_\Psi |G\rangle , \qquad (1)$$

where

$$\Psi = \eta, \eta', \iota \qquad \text{or} \qquad \Psi = f, f', \theta$$

The reason for quark-gluon mixing in QCD is the quark-antiquark system annihilation into gluons(in the lowest order of perturbation theory the annihilation terms for pseudoscalar and tensor mesons consists of two gluons). Consequently, in the quadratic mass matrix of isoscalar mesons there must be added members which correspond to that annihilation [7-10, 12] . So,there are six free parameters for each case (pseudoscalar, tensor) in the model: the masses of ideal states m_N , m_S , m_G and the annihilation parameters λ_N , λ_S , λ_G . Weights of ideal states $|N\rangle$, $|S\rangle$, $|G\rangle$ in physical states $|\Psi\rangle - x_\Psi, y_\Psi, z_\Psi$ are functions of these parameters. The physical states must satisfy the equation on eigenvalues [7], and hence, one obtained three equations expressing the annihilation parame - ters via the mass of ideal and physical states:

$$
\begin{aligned}
2\lambda^2_{Na} = &\left[m^2_{Na} m^2_{Sa}(m^2_{Sa} - m^2_{Na}) + m^2_{Na} m^2_{Ga}(m^2_{Na} - m^2_{Ga}) + m^2_{Sa} m^2_{Ga}(m^2_{Ga} - \right.\\
&\left. - m^2_{Sa})\right]^{-1} \left[m^4_{Na}(m^2_{\eta,f} + m^2_{\eta',f'} + m^2_{\iota,\theta} - m^2_{Na}) + m^2_{\eta,f} m^2_{\eta',f'} m^2_{\iota,\theta} - \right.\\
&\left. - m^2_{Na}(m^2_{\eta,f} m^2_{\eta',f'} + m^2_{\eta,f} m^2_{\iota,\theta} + m^2_{\eta',f'} m^2_{\iota,\theta})\right] \cdot (m^2_{Ga} - m^2_{Sa}) ,\\
\lambda^2_{Sa} = &\left[m^2_{Na}(m^2_{Ga} - m^2_{Sa})\right]^{-1} \left[m^2_{\eta,f} m^2_{\eta',f'} m^2_{\iota,\theta} - m^2_{Na} m^2_{Sa} m^2_{Ga} - \right.\\
&\left. - m^2_{Na} m^2_{Sa} \textstyle\sum_a - 2\lambda^2_{Na} m^2_{Sa}(m^2_{Sa} - m^2_{Na})\right] ,\\
\lambda^2_{Ga} = &\textstyle\sum_a - 2\lambda^2_{Na} - \lambda^2_{Sa} ,
\end{aligned}
\qquad (2)
$$

where $\sum_a = m^2_{\eta,f} + m^2_{\eta',f'} + m^2_{\iota,\theta} - m^2_{Na} - m^2_{Sa} - m^2_{Ga}$,

the index a indicates pseudoscalar and tensor sectors. Taking into account, that in the pseudoscalar sector the state $|N\rangle$ is an orthogonal partner of π^0 , one may suppose that $m^2_N = m^2_{\pi^0}$ and similarly, using the Gell-Mann-Okubo mass formula, $m^2_S = 2m^2_K - m^2_\pi$. Thus, there remains only one free parameter in the pseudoscalar sector, through which the mixing parameters x_Ψ, y_Ψ, z_Ψ are expressed ($\Psi = \eta, \eta', \iota$) . To check up these assumptions, various experimental data processing variants have been considered: in one of them m_N , m_S , m_G have been considered as free parameters, in another - only m_G has been. The obtained results $m_N = 0.1349 \pm 0.0004$ GeV, $m_s = 0.6874 \pm 0.0004$ GeV (see Table 1) well agree with the m_{π^0} mass and with the Gell-Mann-Okubo mass formula and shows to validity of assumptions.

In case of tensor mesons A_2 meson is the orthogonal partner of the ideal state $|N\rangle$, though the mass of $A_2(1320)$ meson is larger than that of $f(1270)$, which does not allow to use the equation $m_N = m_{A_2}$. So, in the tensor sector there remain three free parameters: m_N, m_S, m_G, their values being found from the comparison with the experimental data and given in Table 1. The obtained value of m_S indicates to the fact that in this case the mass formula of Gell-Mann-Okubo is well satisfied (from Gell-Mann-Okubo formula we have $m_S = 1.525$ GeV; the fit makes 1.521 ± 0.002 GeV). Aside from these mixing parameters, it is necessary to insert in the theory another parameter [8] for the correct regard for all effects. The value of this parameter is determined from the comparison with the experiment and is given in Table 1. The parameter ξ differentiates between the couplings of normal and strange quarks with photons.

3. Two-Particle Decays

To determine the mixing parameters and interprete $\iota(1440)$ and $\theta(1690)$ mesons we have considered the following classes of two-particle decays in which, because of not full knowledge in the dynamics, the theoretical formulae are written for ratios of decay widths

1. $0^- \to \gamma\gamma$.

$$\frac{\Gamma(\psi \to \gamma\gamma)}{\Gamma(\pi^0 \to \gamma\gamma)} = \frac{1}{9}\left(\frac{m_\psi}{m_\pi}\right)^3 (5X_\psi + \sqrt{2}\,\xi\, y_\psi)^2, \qquad (3)$$

where $\psi = \eta, \eta', \iota$.

2. $0^- \to 1^-\gamma$, $1^- \to 0^-\gamma$.

$$\frac{\Gamma(\eta' \to \omega\gamma)}{\Gamma(\omega \to \pi^0\gamma)} = \frac{1}{3}\left(\frac{m_{\eta'}^2 - m_\omega^2}{m_\omega^2 - m_\pi^2} \cdot \frac{m_\omega}{m_{\eta'}}\right)^3 X_{\eta'}^2, \qquad (4)$$

$$\frac{\Gamma(\varphi \to \eta\gamma)}{\Gamma(\omega \to \pi^0\gamma)} = \frac{4}{9}\mu^2\left(\frac{m_\varphi^2 - m_\eta^2}{m_\omega^2 - m_\pi^2} \quad \frac{m_\omega}{m_\varphi}\right)^3 y_\eta^2 \,, \tag{5}$$

$$\frac{\Gamma(J/\Psi \to \eta'\gamma)}{\Gamma(J/\Psi \to \eta\gamma)} = \left(\frac{m_{J/\Psi}^2 - m_{\eta'}^2}{m_{J/\Psi}^2 - m_\eta^2}\right)^3 \left(\frac{G_{\eta'}}{G_\eta}\right)^2 , \tag{6}$$

where $G_{\eta,\eta',\iota} = \sqrt{2}\,\lambda_N x_{\eta,\eta',\iota} + \lambda_S y_{\eta,\eta',\iota} + \lambda_G z_{\eta,\eta',\iota}$, parameter μ , proportional to the factor m_u/m_s [9], indicates that the strange quark has a smaller magnetic momentum than d quark has. Similar formulae are obtained for decays $\eta'(\iota) \to \rho\gamma$, $\iota \to \omega(\varphi)\gamma$, $\rho(\omega) \to \eta\gamma$, $J/\Psi \to \iota\gamma$, $\Psi'(3685) \to \eta(\eta',\iota)\gamma$.

3. $2^+ \to 0^-0^-$.

$$\frac{\Gamma(A_2 \to \pi\eta'(\iota))}{\Gamma(A_2 \to \pi\eta)} = \left(\frac{p_{\eta'(\iota)}}{p_\eta}\right)^5 \left(\frac{x_{\eta'(\iota)} + \sqrt{2}\,\lambda_N z_{\eta'(\iota)}}{x_\eta + \sqrt{2}\,\lambda_N z_\eta}\right)^2 . \tag{7}$$

4. $2^+ \to \gamma\gamma$.

$$\frac{\Gamma(f \to \gamma\gamma)}{\Gamma(A_2 \to \gamma\gamma)} \simeq \frac{25}{9}\left(x_f + \frac{\sqrt{2}}{5}\xi\, y_f\right)^2 , \tag{8}$$

the same way for decays $f' \to \gamma\gamma$, $\theta \to \gamma\gamma$.

5. $2^+ \to 0^-0^-$.

$$\frac{\Gamma(f' \to \pi\pi)}{\Gamma(f \to \pi\pi)} = \frac{m_f}{m_{f'}}\left(\frac{p_{f'}}{p_f}\right)^5 \left(\frac{x_{f'} + \sqrt{2}\,\lambda_N z_{f'}}{x_f + \sqrt{2}\,\lambda_N z_f}\right)^2 , \tag{9}$$

$$\frac{\Gamma(f \to \bar{K}K)}{\Gamma(f \to \pi\pi)} = \frac{1}{3}\left(\frac{p'}{p}\right)^5 \left(\frac{x_f + \sqrt{2}\,y_f + \sqrt{2}(\lambda_N + \lambda_s) z_f}{x_f + \sqrt{2}\,\lambda_N z_f}\right)^2 , \tag{10}$$

$$\frac{\Gamma(\theta \to \eta\eta)}{\Gamma(\theta \to \pi\pi)} = \frac{1}{3}\left(\frac{p_\eta}{p_\pi}\right)^5 \frac{\left[x_\eta^2(x_\theta + \sqrt{2}\lambda_N z_\theta) + y_\eta^2\sqrt{2}(y_\theta + \lambda_s z_\theta) + \sqrt{2}\lambda_G z_\eta^2 z_\theta\right]^2}{(x_\theta + \sqrt{2}\,\lambda_N z_\theta)^2} , \tag{11}$$

the same for decays $\theta \to \pi\pi$, $\theta \to \bar{K}K$, $f' \to \bar{K}K$, $f \to \eta\eta$, $f' \to \eta\eta$, $f' \to \eta'\eta$, $\theta \to \eta'\eta$.

6. $1^- \to 2^+\gamma$

$$\frac{\Gamma(J/\Psi \to f'(\theta)\gamma)}{\Gamma(J/\Psi \to f\gamma)} = \left(\frac{\alpha_s(f',\theta)}{\alpha_s(f)}\right)^4 \frac{M_{J/\Psi}^2 - M_{f',\theta}^2}{M_{J/\Psi}^2 - M_f^2}\left(\frac{M_{f',\theta}}{M_f}\right)^3 \left(\frac{G_{f',\theta}}{G_f}\right)^2 \frac{1 + a_{f',\theta}^2 + b_{f',\theta}^2}{1 + a_f^2 + b_f^2} , \tag{12}$$

where $G_{f,f',\theta} = \sqrt{2}\lambda_N x_{f,f',\theta} + \lambda_S y_{f,f',\theta} + \lambda_G z_{f,f',\theta}$. λ_N , λ_S , λ_G are the annihilation parameters of tensors in the formulae (9-12). In the sixth class processes the decay products can be produced with an orbital momentum of ℓ =0,2,4 consequently, these processes are determined by three amplitudes. The values a, b in the formula (12) stand for these amplitudes and are determined experimentally in Ref. [14], $\alpha_s(Q^2) = 12\pi/(27\ln Q^2/\Lambda)$, Λ = 96 MeV, α_f =0.27, $\alpha_{f'}$ = 0.253, α_θ = 0.243.

Beside the decays, the ratio of differential cross sections of processes $\pi^- p \to \eta(\eta')n$ obtained in Ref. [7], have been considered. In our representation this ratio has the form:

$$R_{\eta'(\iota)/\eta} = \frac{x_{\eta'(\iota)} + \sqrt{2}\lambda_N z_{\eta'(\iota)}}{x_\eta + \sqrt{2}\lambda_N z_\eta} . \qquad (13)$$

7. $1^- \to 1^- 0^-$ $(J/\Psi - 1^- 0^-)$.

$$\frac{\Gamma(J/\Psi \to \omega\eta)}{\Gamma(J/\Psi \to \rho^0\pi^0)} = \left(\frac{P_\omega}{P_\rho}\right)^3 \left(\frac{x_\eta(1+e_N)+\sqrt{2}\,\xi G_\eta}{1+e_N}\right)^2 , \qquad (14)$$

$$\frac{\Gamma(J/\Psi \to \varphi\eta)}{\Gamma(J/\Psi \to \rho^0\pi^0)} = \left(\frac{P_\varphi}{P_\rho}\right)^3 \left(\frac{R(y_\eta+\xi G_\eta)-2\mu e_N y_\eta}{1+e_N}\right)^2 , \qquad (15)$$

$$\frac{\Gamma(J/\Psi \to K^{*+}K^-)}{\Gamma(J/\Psi \to \rho^0\pi^0)} = \frac{1}{3}\left(\frac{P_K}{P_\rho}\right)^3 \left(\frac{1+R+e_N(2-\mu)}{1+e_N}\right)^2 , \qquad (16)$$

$$\frac{\Gamma(J/\Psi \to K^{*0}\bar{K}^0)}{\Gamma(J/\Psi \to \rho^0\pi^0)} = \frac{1}{3}\left(\frac{P_K}{P_\rho}\right)^3 \left(\frac{1+R-e_N(1+\mu)}{1+e_N}\right)^2 , \qquad (17)$$

$$\frac{\Gamma(J/\Psi \to \rho^0\eta)}{\Gamma(J/\Psi \to \rho^0\pi^0)} = 3\left(\frac{P_{\rho\eta}}{P_\rho}\right)^3 \left(\frac{e_N x_\eta}{1+e_N}\right)^2 , \qquad (18)$$

$$\frac{\Gamma(J/\Psi \to \omega\pi^0)}{\Gamma(J/\Psi \to \rho^0\pi^0)} = 3\left(\frac{e_N}{1+e_N}\right)^2 , \qquad (19)$$

the same for decays of J/ψ into $\varphi_\iota, \varphi_{\eta'}$ and of $\psi'(3685)$ into the corresponding end products.

8. $1^- \to 1^- 2^+$ $(J/\psi \to 1^- 2^+)$

For this kind of decays the formulae coincide with $J/\psi \to 1^- 0^-$ with due regard for substitutions $\pi \to A_2$, $\eta \to f$, $\eta' \to f'$, $\iota \to \theta$ with weights x, y, z correspondingly.

The considered first six types of decays, as seen from the formulae (3-12), are determined by contributions of planar and nonplanar diagrams, which are due to two-gluon annihilation of the $q\bar{q}$ system, consequently, are fully determined by parameters described in chapter 2 and from the comparison of experimental data [14-24]. And the classes 7,8 differ by quite new three types of diagrams [25,26] shown in Fig.1. For the account of these diagrams one is to introduce new phenomenological parameters: $R = \lambda_S^V / \lambda_N^V$ allowing for the difference between the annihilation of $\bar{s}s$ pair into three gluons and the annihilation of $\bar{u}u$, $\bar{d}d$ systems; e_N is a parameter corresponding to the decay of J/ψ through a virtual photon, Fig.1c; ζ is a parameter corresponding to the difference between the diagrams of three-gluon annihilation, Fig.1a, and doubly disconnected ones, Fig.1b. These parameters, obtained from the comparison with the experimental data [15,25,26], allow to predict 13 more decay widths (see Table 5). Note, that these processes have not been considered at determination of the model parameters m_N, m_S, m_c, ξ and they are a good test for the obtained quark-gluon structures of pseudoscalar and tensor mesons, as the quark composition of vector mesons is determined quite well.

4. Discussion

The obtained values of the model parameters m_N, m_S, m_G for tensor and m_G for pseudoscalar mesons are given in Table 1. Ibidem the values of annihilation parameters λ_N , λ_S , λ_G (remember, that they are free parameters of the model and, as seen from the Eq.(2), are mass functions of ideal and physical states) and the values of weights x , y , z of ideal states $|N\rangle$, $|S\rangle$, $|G\rangle$ are given, correspondingly.

The annihilation parameters λ_N , λ_S , λ_G , as phenomenological ones, have a physical meaning of effective vertices of quark-gluon and gluon-gluon interactions and their determination from the comparison with the experimental data is very valuable because it allows to avoid the difficulties in the perturbation theory in the QCD framework. The fact that these parameters are different in pseudoscalar and tensor mesons, indicates to their dependence on the spin - parity of the $q\bar{q}$ system at its annihilation into two gluons due to which, apparently, is the strong mixing of pseudoscalar mesons in contrast to tensor ones which are mixed almost ideally. The comparison of the weights x , y , z , which are functions of annihilation parameters, shows that in the η meson the gluon admixture is very little in contrast to normal and strange quarks whose contributions are almost equal. The η' meson is a very strongly mixed particle ($\sim$36% of normal, $\sim$48% strange quarks and $\sim$16% of gluonium). The $\iota(1440)$ mainly ($\sim$85%) consists of gluonium. The f meson consists of only normal quarks, f'- only of strange quarks($\sim$5% of gluonium), and $\theta(1690)$ is a pure gluonium state with a slight ($\sim 0.5\%$) admixture of strange quarks.

In Table 2 experimental data [15,22] and theory predictions for decays with pseudoscalar mesons are presented. Different experimental data [15,22] have been used to determine the values of free parameters. It turned out, that all of them gave the same result, but with different extent of errors, i.e. all the experimental data are self-consistent except for the width of decay $\omega \to \eta \gamma$, the experimental value of which [15] is evidently underestimated. In Table 2 results with the least errors are presented. The processing of all experimental data results in them. While, the processing of data on decays only with η and η' mesons shows that one can predict (unaware of $\iota(1440)$, supposing mixing between $|N\rangle, |S\rangle$ and $|G\rangle$ states only) the mass of $m_\iota = 1.438 \pm 0.05$ MeV and the true values of widths of partial decays of that particle. It means that all the other admixtures are negligible.

In Table 3 experimental data [14-16], [22-24] and theory predictions for decays with tensor mesons are presented. Here too, different experimental data have been considered to determine the free parameters of the model. All the variants yield the same values of these parameters, though the extent of errors is different. The least errors are at the full fit. Just this variant is presented in the Table. Estimations of widths of $\theta \to \pi\pi$, $\theta \to \bar{K}K$ decays are obtained from Ref.[22] with the assumption that the observed partial decays of $\theta(1690)$ on the installation MARK III are the only ones.

In one of the variants, at determination of the values of parameters m_G and m_θ at a fixed m_N and m_S, the experimental data have been processed without $\theta(1690)$. The value of m_θ = = 1.696 ± 0.1 MeV (showing that their possible admixtures are little) means that the available data allow to predict the mass of θ meson, and the obtained partial widths $\Gamma(\theta \to \pi\pi)$ and $\Gamma(\theta \to \bar{K}K)$ well agree to the values given in Table 3.

The obtained information on weights of $|N\rangle$, $|S\rangle$ and $|G\rangle$ ideal states in η, η', $\iota(1440)$ and f, f', $\theta(1690)$ mesons allows to consider processes $J/\Psi \to V + P$ and $J/\Psi \to V + T$. However, three new types of diagrams determine these processes and are shown in Fig.1. Consequently, three new parameters R, e_N, ζ are to be introduced into the theory (it should be noted, that due to little contribution of diagrams in Figs.1b, c, making ~10% of the total contribution, if one regards for diagrams in Fig. 1a only, and ignoring decays with φ, K, K^* mesons, one can do without additional parameters). The values of these parameters have been determined by comparison with the experimental data [15,25,26] and are given in table 4.

Three different variants have been considered and hence, three different sets of values for them are obtained. In the first variant the contribution of doubly disconnected diagrams (Fig.1b) is neglected. In the second and the third variants the contribution of all three diagrams have been taken into account. The difference in them is, that in the third variant all the experimental data have been processed to determine the parameters, while in the second one the width of $J/\Psi \to \omega\eta'$ has not been taken into account. The comparison of parameters obtained in different variants indicates to insensitivity of R and e_N to different sets of experimental data, i.e. contributions from doubly disconnected diagrams are small. Parameter ξ will be considered below.

Experimental values [15,25,26] and theory predictions for widths of $J/\Psi \to V+P$ and $J/\Psi \to V+T$ are presented in Table 5. Their analysis shows that the experimental values of widths of decays $J/\Psi \to K^* \bar{K}$, taken from the MARK III collaboration data, are in better agreement with all the other data than the values from Ref. [15]. The width of decay $J/\Psi \to \omega \eta'$ is very sensitive to ξ. That is why in the second variant this process has not taken part in the fitting procedure. If the measurement of the width $\Gamma(J/\Psi \to \omega \eta') = 0.02 \pm 0.01$ keV is correct, then $\xi = -0.254$ and the theory predictions brought in the third variant are realized. Otherwise the second variant must be fulfilled.

Thus, the analysis made shows, that $\iota(1440)$ and $\theta(1690)$ mesons are almost pure gluonic states. Quark-gluon and gluon-gluon pseudoscalar couplings are stronger as compared with the corresponding ones in the tensor case.

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Table 1

m_K, ξ Model Parameters. Annihilation Parameters λ_K and Weights x, y, z in 0^- and 2^+ Mesons. m_K and λ_K are in GeV

	Pseudoscalars	Tensors
m_N	0.1349±0.0004	1.2692±0.0018
m_S	0.6874±0.0017	1.5150±0.0042
m_G	1.3181±0.0268	1.6508±0.0062
ξ	0.4542±0.1217	0.5170±0.1298
λ_N	0.5785±0.0106	0.08269±0.01603
λ_S	0.4606±0.0115	0.1955±0.0383
λ_G	0.4269±0.0326	0.3354±0.0299
	η(549)	f(1270)
x	0.7302±0.0026	0.9991±0.0005
y	-0.6790±0.0020	-0.02930±0.0112
z	-0.07508±0.0074	-0.03068±0.00512
	η'(958)	f'(1525)
x	-0.6174±0.0124	-02512±0.00995
y	-0.7030±0.0095	-0.9913±0.0033
z	.3529±0.0405	0.1288±0.0237
	ι(1440)	θ(1690)
x	-0.2924±0.0327	-0.03419±0.00675
y	-0.2114±0.0250	-0.1279±0.0232
z	-0.9326±0.0159	-0.9912±0.0032

Table 2

Comparison with the Experimental Data and Predictions for

Pseudoscalar Mesons

No	Processes	Experiment	Theory
1	$\Gamma(\pi^0 \to \gamma\gamma)$ eV	7.33 ± 0.20	-
2	$\Gamma(\eta \to \gamma\gamma)$ keV	0.56 ± 0.040 0.53 ± 0.08	0.566 ± 0.043
3	$\Gamma(\eta' \to \gamma\gamma)$ keV	4.2 ± 0.9 5.51 ± 1.1	3.64 ± 0.32
4	$\Gamma(\iota \to \gamma\gamma)$ keV	$< \begin{cases} 2.2 \\ 2.0 \end{cases}$	2.53 ± 0.56
5	$\Gamma(A_2 \to \eta\pi)$ MeV	16.0 ± 1.5	-
6	$\Gamma(A_2 \to \eta'\pi)$ MeV	< 2.2	0.502 ± 0.050
7	$R\, \eta'/\eta$	0.758 ± 0.096	0.845 ± 0.014
8	$R\, \iota/\eta$	?	0.400 ± 0.045
9	$\Gamma(\omega \to \pi^0\gamma)$ keV	861 ± 56	-
10	$\Gamma(\rho \to \eta\gamma)$ keV	55.4 ± 14	56.49 ± 3.69

Continued Table 2.

No	Processes	Experiment	Theory
11	$\Gamma(\omega \to \eta\gamma)$ keV	2.97±1.3	7.33±0.48
12	$\Gamma(\varphi \to \eta\gamma)$ keV	54.86±3.04 50.6 ±8.6	62.82±4.10
13	$\Gamma(\eta' \to \rho\gamma)$ keV	66±10 87±16	88.32±6.74
14	$\Gamma(\eta' \to \omega\gamma)$ keV	6.1±1.4 8.1±2	8.011±0.611
15	$\Gamma(\varphi \to \eta'\gamma)$ keV	?	0.309±0.022
16	$\Gamma(\iota \to \rho\gamma)$ keV	1400±600	550.6±128.2
17	$\Gamma(\iota \to \omega\gamma)$ keV	?	58.6 ±13.6
18	$\Gamma(\iota \to \varphi\gamma)$ keV	?	17.89±4.38
19	$\Gamma(J/\psi \to \eta\gamma)$ keV	0.0542±0.0096	-
20	$\Gamma(J/\psi \to \eta'\gamma)$ keV	0.296± 0.071 0.23 ±0.05	0.318±0.57
21	$\Gamma(J/\psi \to \iota\gamma)$ keV	0.378±0.12	0.243±0.071
22	$\Gamma(\psi' \to \eta'\gamma)/\Gamma(\psi' \to \eta\gamma)$	?	6.25±0.21
23	$\frac{\Gamma(\psi' \to \iota\gamma)}{\Gamma(\psi' \to \eta\gamma)}$	?	5.51±1.27

Table 3

Comparison with Experimental Data and Predictions for

Tensor Mesons

No	Process	BR		Γ	
		Experiment	Theory	Experiment	Theory
24	$A_2 \to \gamma\gamma$			1.14±0.46KeV	-
25	$f \to \gamma\gamma$	(1.5±0.2) 10^{-5}	(1.49±0.62) 10^{-5}	2.65±0.12 KeV 2.67±0.47	2.645±1.067
26	$f' \to \gamma\gamma$	(2.1±1.3) 10^{-6}	(2.73±0.52) 10^{-6}	0.15±0.09 KeV 0.77±0.18	0.191±0.0024
27	$\theta \to \gamma\gamma$	?	(2.35±0.92) 10^{-7}	?	0.0305±0.011KeV
28	$f \to \pi\pi$	0.843±0.012	-	150±17 MeV	-
29	$f' \to \pi\pi$	?	0.117±0.021	?	0.114±0.0987MeV
30	$\theta \to \pi\pi$	?	0.0858±0.0367	≲ 10.7±4.8MeV	10.887±4.46
31	$f \to \bar{K}K$	0.029±0.004	0.0272±0.0045	5.16±0.68MeV	4.845±0.583
32	$f' \to \bar{K}K$	dominant	0.791±0.145	≲ 70±17.2MeV	55.35± 6.36
33	$\theta \to \bar{K}K$	?	0.184±0.083	≲ 42.9±17MeV	23.89±10.1
34	$\frac{\theta \to \pi\pi}{\theta \to \bar{K}K}$	0.25±0.15	0.455±0.072	0.25 ±0.15	0.455±0.072

Table 3

Continued

No	Process	BR Experiment	BR Theory	Γ Experiment	Γ Theory
35	$J/\psi \to f\gamma$	$(1.35\pm0.11)\ 10^{-3}$	-	0.085 ± 0.023 KeV	-
36	$J/\psi \to f'\gamma$	$(0.60\pm0.11)\ 10^{-3}$	$(0.968\pm0.376)10^{-3}$	$\lesssim 0.05\pm0.026$	0.061 ± 0.022 KeV
37	$J/\psi \to \theta\gamma$	$(1.3\pm0.2)\ 10^{-3}$	$(4.76\pm2.49)\ 10^{-3}$	>0.184 KeV	0.299 ± 0.151
38	$f \to \eta\eta$	< 0.02	0.0028 ± 0.0005	?	0.494 ± 0.058 MeV
39	$f' \to \eta\eta$	0.32 ± 0.16	0.115 ± 0.023	22.4 ± 14.4MeV	8.08 ± 1.09
40	$f' \to \eta\eta'$	?	$(5.71\pm1.12)\ 10^{-5}$	?	0.004 ± 0.00054 MeV
41	$\theta \to \eta\eta$	?	0.0296 ± 0.0134	?	3.85 ± 1.64 MeV
42	$\theta \to \eta\eta'$	?	$(4.23\pm2.25)\ 10^{-4}$	?	10.055 ± 0.028MeV

	Experiment	Theory
$BR(J/\psi \to f'\gamma) \cdot BR(f' \to \bar{K}K)$	$(6.0\pm2.6)\ 10^{-4}$	$(7.69\pm2.49)\ 10^{-4}$
$BR(J/\psi \to \theta\gamma) \cdot BR(\theta \to \pi\pi)$	$(2.4\pm0.9)\ 10^{-4}$	$(3.76\pm1.19)\ 10^{-4}$
$BR(J/\psi \to \theta\gamma) \cdot BR(\theta \to \bar{K}K)$	$(9.6\pm3.0)\ 10^{-4}$	$(7.50\pm2.75)\ 10^{-4}$
$BR(J/\psi \to \theta\gamma) \cdot BR(\theta \to \eta\eta)$	$(3.8\pm1.6)\ 10^{-4}$	$(1.30\pm0.47)\ 10^{-4}$

Table 4

Parameters of Processes $J/\Psi \to VP$ and $J/\Psi \to VT$

	1	2	3
R	0.7889±0.0759	0.8075±0.0803	0.8090±0.0794
e_N	0.120±0.0170	0.1208±0.0170	0.1197±0.0170
ζ	0	-0.08505±0.1351	-0.2585±0.0733

1. With regard for the diagrams a and c , Fig.1 .
2. With regard for all diagrams in Fig.1, but for the experiment on $\Gamma(J/\Psi \to \omega\eta')$.
3. With regard for all diagrams in Fig.1 .

Table 5

Comparison with Experimental Data and Predictions for

Processes $J/\Psi \to VP$ and $J/\Psi \to VT$

No	$J/\Psi \to VP$	BR(x 10^{-3})	Fit with reg. for diagrams c & a, Fig.1	Fit of all diagrams in Fig.1, Except for No46	Full fit
43	$\to \rho\pi$	13.3 ± 1.8	-	-	-
44	$\to \omega\eta$	1.9 ± 0.5	2.1 ± 0.3	1.95 ± 0.36	1.7 ± 0.3
45	$\to \varphi\eta$	0.68 ± 0.15	0.49 ± 0.13	0.57 ± 0.18	0.66 ± 0.17
46	$\to \omega\eta'$	0.41 ± 0.16	1.16 ± 0.16	0.90 ± 0.40	0.48 ± 0.16
47	$\to \varphi\eta'$	0.37 ± 0.12	0.39 ± 0.10	0.33 ± 0.13	0.20 ± 0.07
48	$\to \omega\iota$	?	0.14 ± 0.02	0.078 ± 0.092	0.0046 ± 0.012
49	$\to \varphi\iota$	?	0.017 ± 0.004	0.0072 ± 0.013	~ 0
50	$\to K^{*+}K^{-}$ + c.c.	6.8 ± 1 5.1 ± 0.6	7.6 ± 1.2	7.8 ± 1.2	7.8 ± 1.2
51	$\to K^{*0}\bar{K}^{0}$ + c.c.	2.7 ± 0.6 4.1 ± 0.6	5.0 ± 0.8	5.2 ± 0.8	5.2 ± 0.8

Table 5

Continued

52	$\to \rho^0 \eta$	0.17 ± 0.06	0.22 ± 0.06	0.22 ± 0.06	0.22 ± 0.06
53	$\to \rho^0 \eta'$	< 0.1	0.12 ± 0.04	0.12 ± 0.04	0.12 ± 0.03
54	$\to \rho^0 \iota$	?	0.015 ± 0.004	0.015 ± 0.004	0.015 ± 0.004
55	$\to \omega \pi$	0.67 ± 0.17	0.46 ± 0.13	0.46 ± 0.13	0.45 ± 0.13
56	$J/\psi \to VT$ $\to \rho A_2$	8.4 ± 4.5	-	-	-
57	$\to \omega f$	2.3 ± 0.8	3.0 ± 1.6	2.98 ± 1.60	2.89 ± 1.55
58	$\to \varphi f$	< 0.37	$(2.9 \pm 1.7)\ 10^{-4}$	$(5.6 \pm 5.9)\ 10^{-4}$	0.0013 ± 0.0008
59	$\to \omega f'$	< 0.16	$(1.4 \pm 0.7)\ 10^{-4}$	$< 9.9\ 10^{-5}$	$< 4.1\ 10^{-4}$
60	$\to \varphi f'$	0.37 ± 0.13	0.23 ± 0.13	0.24 ± 0.14	0.24 ± 0.14
61	$\to \omega \theta$	?	0.0025 ± 0.0013	< 0.0026	0.019 ± 0.018
62	$\to \varphi \theta$	?	0.0062 ± 0.0036	0.0035 ± 0.0044	$< 8.2\ 10^{-4}$
63	$\to K^{**+} K^{*-}$ + c.c.	?	3.3 ± 1.8	3.3 ± 1.8	3.3 ± 1.8
64	$\to K^{**0} \bar{K}^{*0}$ + c.c.	6.7 ± 2.6	2.2 ± 1.2	2.2 ± 1.2	2.2 ± 1.2
65	$\to \rho^0 f$	?	0.32 ± 0.19	0.32 ± 0.19	0.32 ± 0.19
66	$\to \rho^0 f'$	?	$(1.5 \pm 0.8)\ 10^{-5}$	$(1.5 \pm 0.8)\ 10^{5}$	$(1.4 \pm 0.8)\ 10^{-5}$
67	$\to \rho^0 \theta$	?	$(2.7 \pm 1.6)\ 10^{-4}$	$(2.7 \pm 1.6)\ 10^{-4}$	$(2.7 \pm 1.6)\ 10^{-4}$
68	$\to \omega A_2^0$	?	0.28 ± 0.17	0.28 ± 0.17	0.28 ± 0.17

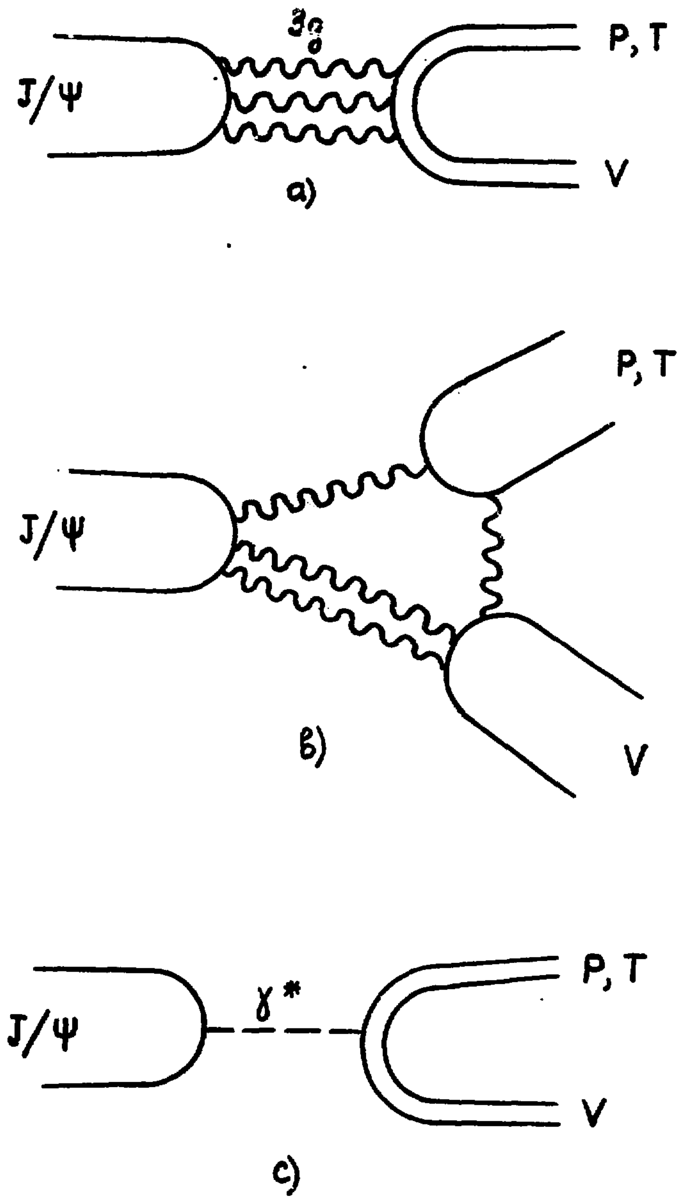

Fig. 1 The main contributions to processes $J/\Psi \to V + P$

$J/\Psi \to V + T$

a) three-gluonic processes,

b) doubly disconnected processes,

c) single-photon annihilation.

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Ш.С.ЕРЕМЯН, А.Э.НАЗАРЯН
КВАРК-ГЛЮОННОЕ СМЕШИВАНИЕ В ПСЕВДОСКАЛЯРНЫХ И ТЕНЗОРНЫХ МЕЗОНАХ
(на английском языке, перевод Г.А.Папяна)

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