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J/Ψ DECAYS, QUARK-GLUON MIXING IN LIGHT MESONS AND THE GLUEBALL INTERPRETATION OF L(1440), Θ(1720) AND S*(980)- MESONS

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Շ.Ս. ԵՐԵՄՅԱՆ, Ա.Է. ՆԱԶԱՐՅԱՆ

J/Ψ ՏՐՈՀՈՒՄՆԵՐԸ, ՔՎԱՐԿ-ԳԼՈՒՈՆԱՅԻՆ ԽԱՌՆՈՒՄԸ ԹԵԹԵՎ ՄԵԶՈՆՆԵՐՈՒՄ ԵՎ ι/1440/, θ/1720/ ԵՎ S^*/980/ ՄԵԶՈՆՆԵՐԻ ԳԼՈՒԲՈԼԱՅԻՆ ՄԵԿՆՈՒԹՅՈՒՆԸ

Ենթադրելով գլուոնային բաղադրիչի առկայությունը փսևդոսկալյար, սկալյար և թենզորական մեզոններում, ստացված են այդ մասնիկների մուլտիպլետների խառնման անկյունները: Ցույց է տրված, որ ստացված արդյունքները կախված չեն խառնման մատրիցի տեսքից: Քննարկված են մոդելի երկու տարբերակ: Պարզվում է, որ ι/1440/, θ/1720/ և S^*/980/ մեզոնները հանդիսանում են գլուբոլների բավականաչափ իրական թեկնածուներ: 0^-, 2^+ և 0^+ մեզոնների երկմասնիկյա տրոհման գոյություն ունեցող բոլոր փորձնական տվյալները վերարտադրված են մոդելի սահմաններում և բացի այդ, այդ տեսակի տրոհումների համար արված են բավականին մեծ թվով կանխագուշակումներ:

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Sh.S.EREMYAN, A.E. NAZARYAN

J/Ψ DECAYS, QUARK-GLUON MIXING IN LIGHT MESONS AND THE GLUEBALL INTERPRETATION OF ι(1440), θ(1720) AND S*(980)-MESONS

The mixing angles for pseudoscalar, tensor and scalar meson multiplets are obtained in assumption on existence of a glueball component. The results are shown to be independent on the kind of the mixing matrix. It turned out that ι(1440), θ(1720) and S*(980) mesons are quite real candidates for glueballs. All the available experimental data on two-particle decays of 0^-, 2^+ and 0^+-mesons are described and predictions for a large of such decays are given.

Yerevan Physics Institute

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Ш.С.ЕРЕМЯН, А.Э.НАЗАРЯН

РАСПАДЫ J/Ψ, КВАРК-ГЛЮОННОЕ СМЕШИВАНИЕ В ЛЕГКИХ МЕЗОНАХ И ГЛЮБОЛЬНАЯ ИНТЕРПРЕТАЦИЯ $\iota(1440)$, $\theta(1720)$ и $S^*(980)$ - МЕЗОНОВ

В предположении о существовании глюбольной компоненты, получены углы смешивания для мультиплетов псевдоскалярных, тензорных и скалярных мезонов. Показано, что результаты не зависят от вида матрицы смешивания. Рассмотрены два разных варианта модели. Оказалось, что $\iota(1440)$, $\theta(1720)$ и $S^*(980)$-мезоны являются вполне реальными кандидатами в глюболы. Описаны все существующие экспериментальные данные по двухчастичным распадам 0^-, 2^+ и 0^+ -мезонов, и даны предсказания по большому количеству таких распадов.

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1. Introduction

In the framework of QCD gluons, interacting with each other, may produce bound states - glueballs. Such particles are considered to have properties making them to be very like the usual mesons (i.e. composed of quark-antiquark pairs). It makes their interpretation and the search for them very difficult.

Stricly speaking, in the search for and interpretation of such states we can only follow the OZI phenomenological rule. There is suggested to search for glueballs in processes inhibitted by this rule, but not experimentally suppressed, for instance, $\pi^- p \to \varphi\varphi n$. Radiative decays of J/Ψ are considered to be another source of positive, C-even glueballs (it will be further shown that in some cases it is not so). In these decays the OZI rule again plays an important role.

The study of the mixing effects between $q\bar{q}$ and the glueball components in usual hadrons [1-6] is another possibility for the investigation of properties of gluon states. Really, in the general case the glueball states can annihilate into a $q\bar{q}$ pair which leads to mixing of pure glueballs with neutral isoscalar hadrons composed of $q\bar{q}$ pairs. And if there really exist glueballs of masses $\sim 1 \div 2$ GeV, then they must essentially change the standard schemes of $\eta - \eta'$ or $f - f'$ mixing.

The candidates for pure glueballs are usually considered to satisfy the following set of features [6]:

1. The glueball must have no place in a usual $q\bar{q}$ nonet.
2. Flavour symmetric decays, i.e. equal coupling to u, d

and s quarks.

3. Copious production in glue-inhanced channels like radiative J/Ψ decays.

4. The glueballs must not be produced in $\gamma\gamma$ -scattering.

5. Their production in hadron scattering is suppressed.

At present there is no particle-candidate for a glueball satisfying all five requirements at once. For instance, $\iota(1440)$ and $\theta(1720)$ are well produced in J/Ψ decays, while G(1590) and f_2 (2050) - in hadron interactions.

In our paper it is shown that all five glueball criteria are really satisfied for the pure glueball component of the meson and all breakings of these criteria take place only due to quark--gluon mixing. The quark-antiquark-pair admixture strongly violates all the criteria except for the first one. That is to say, there are no ideally pure glueballs in nature, but there are more or less mixed among each other quark-antiquark and glueball states which produce real hadrons , the usual $q\bar{q}$ nonets turn into new ten-particle sets. Dubious for glueballs become particle sets containing three isoscalar states which do not strongly differ from each other by their masses (200-300 MeV). There are considered three meson families in this work: P - the sector of pseudoscalar mesons 0^{-+}, π , K , $\eta(550)$, $\eta'(958)$ and $\iota(1440)$; T - the sector of tensor mesons 2^{++} - $A_2(1320)$, K(1430), f(1270), f'(1525) and $\theta(1720)$; S - the sector of scalar mesons 0^{++} - S(980), $\varkappa$ (1350), $S^*(975)$, ε (1300) and $S^{*\prime}(1720)$.

It was obtained that $\iota(1440)$ and $\theta(1720)$ contained a very high admixture of $\geqslant$ 80%. In the sector S the $S^{*\prime}(975)$-meson is a very good candidate for a glueball which contains more than 60% of glueball component.

The scheme of mixing of $|N\rangle$, $|S\rangle$ and $|G\rangle$ states comprised of normal and strange quarkonia and the ideal glueball $|G\rangle$,is given in section 2. It is shown that in the general case of a three-dimensional basis the problem becomes independent on a certain type of mixing matrix and is totally determined by Euler's angles α , β and γ of rotation in a three-dimensional space.

Two mass matrices are considered: Rosner's [4] and Kawai's [5] in cases with square-law and linear mixing formulae. It is shown that the answer is independent on the choice of the mixing model.

In section 3 the decays $J/\Psi \to \gamma A$ are considered, where A is a particle belonging to one of the sectors P,T or S. The width of this decay is shown to be independent not only on the glueball Z_A fraction weight in the A particle, but also on the other signs of x_A and y_A quarkonium pair weights in that particle. Just this effect breaks the third property of the ideal glueball.

In section 4 the amplitudes of decays into two pseudosaclars, two γ-quanta, those of decays $P \to V\gamma$ are given, where V are the vector mesons ρ , ω , φ .

In section 5 the processes $J/\Psi \to VA$ are considered.

Sections 6,7,8 are devoted to the analysis of the results obtained for the P,T and S sectors, respectively.

2. The Scheme of Mixing

Like in refs. [1-3], we shall deal with the ideal basis containing the normal $|N\rangle = 1/\sqrt{2}\,|u\bar{u}+d\bar{d}\rangle$, strange $|S\rangle = |s\bar{s}\rangle$ quarkonia and glueball state vectors. The physical state $|A\rangle$ is their linear combination

$$|A\rangle = x_A|N\rangle + y_A|S\rangle + z_A|G\rangle \qquad (1)$$

where

$$x_A^2 + y_A^2 + z_A^2 = 1 \qquad (2)$$

x,y and z are the weights of the corresponding states in the hadron A. All the observed properties are totally determined by these values. A glueball admixture in the physical state is possible only if $z^2 = 1-x^2-y^2 > 0$. Further we shall call a glueball a particle for which $z^2 \geqslant 0.5$, regardless whether the given particle is strongly or weakly coupled with the gluon current.

Everywhere we shall disregard the little admixture of $c\bar{c}$ in the states considered, and also the admixture of radial excitations, though they may be essential in the pseudoscalar and scalar sectors. Let the physical states contain three isoscalar particles A,B and C. Then there must be a unitary matrix U transforming the ideal basis into physical ones $|A\rangle$, $|B\rangle$, $|C\rangle$, i.e. $U\hat{M}U^{-1}$ must be a diagonal matrix with diagonal units A,B,C (here and after we shall use the letter of the given meson to denote its mass square or simply the masses in case of a square or a linear matrix, respectively). $\hat{M}$ denotes the mass matrix. In the most general case of three-dimensional ideal basis the matrix of mixing is written as

$$\hat{M} = \begin{pmatrix} a_1 & a & b \\ a & a_2 & c \\ b & c & a_3 \end{pmatrix} \qquad (3)$$

where a corresponds to the transition $|N\rangle \to |S\rangle$, b - to the $|N\rangle \to |G\rangle$ and c - to $|S\rangle \to |G\rangle$. The units a_1, a_2 and a_3 correspond to the masses of N,S and G with account of mixing admixture. The state vectors $|A\rangle$, $|B\rangle$ and $|C\rangle$ are the eigenvectors of the matrix (3) with eigenvalues A,B and C.

The matrix U is written as

$$U = \begin{pmatrix} x_A & y_A & z_A \\ x_B & y_B & z_B \\ x_C & y_C & z_C \end{pmatrix} . \qquad (4)$$

Here the weights x_i, y_i and z_i are physically observed values.

More usual are the following denotations:

$$|A\rangle = a_{11}|A_8\rangle + a_{12}|A_1\rangle + a_{13}|g_o\rangle ,$$
$$|B\rangle = a_{21}|A_8\rangle + a_{22}|A_1\rangle + a_{23}|g_o\rangle , \qquad (5)$$
$$|C\rangle = a_{31}|A_8\rangle + a_{32}|A_1\rangle + a_{33}|g_o\rangle ,$$

where the singlet $|A_1\rangle = \frac{1}{\sqrt{3}}|u\bar{u} + d\bar{d} + s\bar{s}\rangle$ state and the octet $|A_8\rangle = \frac{1}{\sqrt{6}}|u\bar{u} + d\bar{d} - 2s\bar{s}\rangle$ one are introduced and, moreover, the existence of a pure glueball singlet state $|g_0\rangle$ is postulated.

The coefficients a_{ij} are the units of Euler's matrix for rotations in the three-dimensional space

$$a_{11} = \cos\alpha\cos\gamma - \sin\alpha\cos\beta\sin\gamma ; \quad a_{12} = \sin\alpha\cos\gamma + \cos\alpha \times$$
$$\times \cos\beta\sin\gamma ; \quad a_{13} = \sin\beta\sin\gamma ; \quad a_{21} = -\cos\alpha\sin\gamma - \sin\alpha\cos\beta\cos\gamma ;$$
$$a_{22} = -\sin\alpha\sin\gamma + \cos\alpha\cos\beta\cos\gamma ; \quad a_{23} = \sin\beta\cos\gamma ; \qquad (6)$$
$$a_{31} = \sin\alpha\sin\beta ; \quad a_{32} = -\cos\alpha\sin\beta ; \quad a_{33} = \cos\beta .$$

At $\beta = \gamma = 0$ this scheme is reduced to a conventional singlet-octet mixing. The observed values x_i, y_i and z_i are expressed through three mixing angles α, β and γ as follows:

$$\sqrt{3}x_A = a_{11} + \sqrt{2}a_{12} ; \quad \sqrt{3}y_A = -\sqrt{2}a_{11} + a_{12} ; \quad z_A = a_{13} ;$$
$$\sqrt{3}x_B = a_{21} + \sqrt{2}a_{22} ; \quad \sqrt{3}y_B = -\sqrt{2}a_{21} + a_{22} ; \quad z_B = a_{23} ; \qquad (7)$$
$$\sqrt{3}x_C = a_{31} + \sqrt{2}a_{32} ; \quad \sqrt{3}y_C = -\sqrt{2}a_{31} + a_{32} ; \quad z_C = a_{33} ;$$

Hence, it is possible to estimate x_i, y_i and z_i by the experimentally found mixing angles α, β and γ. That is to say, the problem becomes practically a model-independent one.

The theoretical arbitrariness consists in the following assumptions: first, the basis is limitted by only three ideal states $|N\rangle$, $|S\rangle$ and $|G\rangle$; second, the choice of the particles A,B and C itself is arbitrary. The validity of the choice must be confirmed or refuted by experiment.

The units of the mixing matrix $\hat{M}$ are directly connected with x_i, y_i and z_i and with the observed masses of A,B,C as follows:

$$a_1 = Ax_A^2 + Bx_B^2 + Cx_c^2 ; \qquad a = Ax_A y_A + Bx_B y_B + Cx_c y_c ;$$
$$a_2 = Ay_A^2 + By_B^2 + Cy_c^2 ; \qquad b = Ax_A z_A + Bx_B z_B + Cx_c z_c ; \qquad (8)$$
$$a_3 = Az_A^2 + Bz_B^2 + Cz_c^2 ; \qquad c = Ay_A z_A + By_B z_B + Cy_c z_c .$$

Here,e.g., $A = m_A^2$ in case of a quadratic mass matrix, and $A = m_A$ in case of a linear one.

Regardless of the kind of the mixing matrix, in case of exact SU(3)-symmetry the value of $\nu = \sqrt{2}\,c/b = 1$. The deviation of ν from unity indicates to the degree of SU(3) breaking. At $\nu = 1$ we obtain the following relation between the particle masses and the angles α , β , γ

$$\cos\beta = \frac{(B-A)\,\mathrm{ctg}\,\alpha\,\sin 2\gamma}{C - A\sin^2\gamma - B\cos^2\gamma} .$$

It was a matter of much dispute in literature whether what mass matrix, a linear or a quadratic one, breaks the SU(3)-symmetry weaker (see,e.g., refs [4,5] . That is why we considered both possible variants here and got convinced that both of them brought to the same breaking).

Having the numerical values of the units of the general mixing matrix $\hat{M}$, one may give its units already in more detail, and adopt a certain mixing model.

Among all possible models most reasonable seem to be Rosner's [4] and Kawai's [5] matrices which will just be considered here.

$$\hat{M}_R = \begin{pmatrix} N+2\tau & \sqrt{2}\tau\nu & \sqrt{2}\sigma \\ \sqrt{2}\tau\nu & S+\tau\nu^2 & \sigma\nu \\ \sqrt{2}\sigma & \sigma\nu & G \end{pmatrix} \tag{9}$$

is Rosner's mixing matrix, and

$$\hat{M}_K = \begin{pmatrix} N+2\lambda_N^2 & \sqrt{2}\lambda_N\lambda_S & \sqrt{2}\lambda_N\lambda_G \\ \sqrt{2}\lambda_N\lambda_S & S+\lambda_S^2 & \lambda_S\lambda_G \\ \sqrt{2}\lambda_N\lambda_G & \lambda_S\lambda_G & G_K+\lambda_G^2 \end{pmatrix} \tag{10}$$

is Kawai's mixing matrix. The units of these matrices are connected with the matrix (3) by simple relations

$$\begin{aligned} \lambda_N^2 &= \tau = ab/2c \,, & \lambda_S^2 &= ac/b \\ \sigma &= b/\sqrt{2} \,, & \lambda_G^2 &= bc/a \\ \nu &= \sqrt{2}\,c/d \,, & G_K &= a_3 - \lambda_G^2 \end{aligned} \tag{11}$$

These values may be plotted as shown in fig.1 . Each matrix has its advantages and drawbacks which will be considered elsewhere. The common drawback of the whole approach is, that the mixing parameters a,b and c are considered independent on the energy, i.e. we admit the model of orthogonal mixing. Such a model works well in the case when the masses of A,B and C are close to each other or when their widths are relatively small. The account of the dependence of a, b and c on the energy makes the problem much complicated and model-dependent, that is why we shall restrict ourselves to the orthogonal mixing for the present.

3. Decays

The main difference between Kawai's matrix and that of Rosner is that the interaction in $\hat{M}_K$ is factorized and there exist two types of gluons - constituent gluons and interaction-transferring ones. For example, the transition $|N\rangle \to |S\rangle$ takes place as follows: at first the N-quarks annihilate into interaction-transferring gluons which in their turn produce $s\bar{s}$ pairs. λ_G is the vertex of the glueball transition into interaction-transferring gluons. These vertices are shown in fig.1 . The vertices λ_i themselves are expressed in terms of masses of ideal and physical states as follows:

$$2\lambda_N^2 = \frac{(A-N)(B-N)(C-N)}{(G_K-N)(S-N)}$$
$$\lambda_S^2 = \frac{(A-S)(B-S)(C-S)}{(G_K-S)(N-S)} \qquad (12)$$
$$\lambda_G^2 = \frac{(A-G_K)(B-G_K)(C-G_K)}{(S-G_K)(G_K-N)}$$

The main advantage of Kawai's matrix is that all the parameters of λ_i have explicit physical meaning and can be further used to describe, for instance, the decays

$$\Gamma(J/\Psi \to \gamma A) \sim [\sqrt{2}\lambda_N x_A + \lambda_S y_A + \lambda_G z_A]^2 \qquad (13)$$

The main drawback of this matrix is that $\lambda_G = 0$ for the pure glueball state with $z = 1$, i.e. it cannot be produced in processes of $J/\Psi \to \gamma A$ type and cannot decay in strong interactions. Besides, the factorization characteristic imposes severe conditions on the values of N,S and G_K which cannot always be met.

Rosner's matrix is devoid of these drawbacks, but we regret that its parameters τ and σ cannot be further used to describe the values observed. To describe processes $J/\Psi \to \gamma A$ it is necessary to introduce two new parameters a_R and b_R which connect the perturbative gluons with the quarks and glueballs, respectively. They are shown in fig.2 .

The decays $J/\Psi \to \gamma A$ will be considered according to a conventional scheme shown in fig.3 . So, the width of $J/\Psi \to \gamma A$ is expressed as

$$\Gamma(J/\Psi \to \gamma A) \approx [G(A)]^2 , \tag{14}$$

where

$$G(A) = a_R(\sqrt{2}\, x_A + \nu y_A) + b_R z_A \tag{15}$$

In the case with Kawai's matrix one must substitute a_R by λ_N and b_R by λ_G . Formulae for the decays $J/\Psi \to \gamma A$ in different sectors are presented in refs. [2,3]. It is seen from (15), that the width of $J/\Psi \to \gamma A$ depends on the values and relative signs of the weights x, y, z and on the parameters a_R and b_R . At small z and large x and y the width will essentially depend on the relative signs of x and y. We shall forestall and say, that it is just because of this effect that $\Gamma(J/\Psi \to \gamma\eta) < \Gamma(J/\Psi \to \gamma\eta')$ and not because of small glueball admixture in η' . For the pure glueball $z \approx 1$ the width of this decay will also be completely determined by the value of b_R . For the real case, when x and y are not so small, their relative signs begin to play an essential part. For instance, if x and y have the same signs and z another, then $\Gamma(J/\Psi \to \gamma A)$ may appear to be a very small value even if $z \sim 0.9$, i.e.

though the glueball component is strongly connected with the gluon current and is large, nevertheless the destructive interference with quark components can lead to a small width of $J/\Psi \to \gamma A$. Such effect exists in the sector of scalar mesons.

4. Decay Amplitudes

Decays into standard particles can take place only from the quark-containing states. The weight of the final quark states in hadron is determined by the values of x and y . In Rosner's matrix there exists direct transition of the glueball into a $q\bar{q}$ state which may as well decay into two particles. In Kawai's matrix there is no such transition, but there exist transitions via interaction-transferring gluons instead. With account of all these transitions, the production amplitudes of final quark states have the form

$$A_N = X_A + \sqrt{2}\left(\tau Z_A + \varkappa G(A)\right), \qquad (16)$$

$$A_S = y_A + \nu\left(\tau Z_A + \varkappa G(A)\right)$$

for nonstrange and strange quarkonia, respectively. The physical meaning of the value of τ becomes clear from fig.4 . $\varkappa$ and τ are new unknown parameters which must be determined in comparison with the experiment. They show the degree of OZI rule breaking. In case of Kawai's matrix $\tau = 0$.

All the decay widths are expressed in terms of A_N and A_S.

$$\Gamma(A \to \pi\pi) \sim A_N^2 \,,$$
$$\Gamma(A \to \bar{K}K) \sim (A_N + \sqrt{2} A_S)^2 \,, \qquad (17)$$
$$\Gamma(A \to \gamma\gamma) \sim (A_N + \frac{\sqrt{2}}{5} \xi A_S)^2$$

The parameter ξ accounts for the difference of the nonstrange and strange quarkonia coupling with photons [5], and is determined from the comparison with the experiment. The widths of all necessary decays are more detailly given in refs. [1-3].

Decays into $\eta\eta$ and $\eta\eta'$ look somewhat more complex owing to the presence of glueball components in η and η' .

$$\Gamma(A \to \eta\eta') \sim [A_N \eta_N \eta'_N + \sqrt{2} A_S \eta_S \eta'_S + \sqrt{2} \chi G(A) G(\eta) G(\eta')]^2 \qquad (18)$$

where the third term corresponds to the diagram shown in fig. 5 . The new parameter χ must be determined from the comparison with the experiment. The amplitudes A_N and A_S stand for x and y , but unlike them they do not comply with the orthonormality condition (2), i.e.

$$A_N^2 + A_S^2 + Z_A^2 \neq 1 \qquad (19)$$

The extent of deviation of this sum from unity shows to what extent the our chosen three-dimensional basis is a complete one. If deviation from unity is higher, it means that we omitted some important contribution into the mixing matrix, e.g., four--quark states or radial excitations. Comparison with the experiment shows that the OZI breaking parameters τ and $\ae$ appear to be very small and are determined with very large errors $\sim$ 100%. That is to say, the sum (19) is equal to 1 with a very good accuracy, and the basis chosen by us is a complete one with a good accuracy and there is no need to introduce new states.

5. Decays $J/\Psi \to VA$

The processes $J/\Psi \to VA$ are good tests for finding of the quark content of isoscalar mesons. These decays in the main order of perturbation theory are described by the sum of four diagrams shown in fig.6 [7]. The main contribution makes the diagram in fig.6 a). In this case the quark content of the vector meson uniquely determines that of the meson A. The contributions of the diagrams 6 b) and c) are essentially smaller, but they make the main contribution in those cases when the quark content of V and A do not coincide.

In our denotations the contribution of the diagram 6 a) has the form

$$\sim A_N V_N + \nu_V A_S V_S . \qquad (20)$$

The sum of contributions from 6 b) and c) parametrize as

$$\sim \zeta G(A) G(V) . \qquad (21)$$

The virtual photon exchange contribution shown in fig.6 d) write as

$$\sim e_N (A_N V_N - 2\mu A_S V_S) \qquad (22)$$

where $\mu = m_u / m_s$. New unknown parameters ν_V, ζ and e_N are introduced here, which must be determined from the experiment. ν_V is the analogue of the value of ν determined in eq.(11) for the sector of vector mesons: at the exact SU(3) symmetry $\nu_V = 1$. The parameter ζ corresponds to the sum of the diagrams b) and c). The parameter ℓ_N corresponds to the coupling of J/Ψ with $q\bar{q}$-pairs via virtual photon. These parameters are universal for all the sectors P, T and S.

The comparison with the experiment yields the following values for these parameters:

$$\nu_V = 0.867 \pm 0.041$$
$$\zeta = -0.219 \pm 0.048 \qquad (23)$$
$$\ell_N = 0.118 \pm 0.011 \ .$$

It appears, that if assumed that $\nu_V = 1$, $\zeta = \ell_N = 0$, then the results will not be strongly changed and there will be good agreement with the experiment.

Formulae for the widths of certain decays in different sectors are presented in refs.[2,3] .

6. Pseudoscalar Mesons

In the sector P Euler's angles α , β , γ are determined from the fit of the whole set of experimental data available at present. The obtained values for the angles of mixing are presented in Table 1. The experiments on the decays of $P \to \gamma\gamma$ [8,9] , $V \to P\gamma$ [8] and those on production of $\pi^- p \to \eta(\eta')n$ [1] appeared to be decisive in the procedure of fitting. The obtained quark content of η , η' and $\iota(1440)$ is given in Table 1. It turned out that $|N\rangle$ and $|S\rangle$ make almost equal contributions to η and η' mesons, the latter having a small admixture of the $|G\rangle$ state. In $\iota(1440)$ there is a large glueball component with a small admixture of $|N\rangle$ and $|S\rangle$ states.

By the formulae (8) there were determined the units of the mixing matrix from which by means of the formulae (11) the units of Rosner's and Kawai's matrices were calculated in the quadratic and linear cases. All these values are presented in Table 1. The parameter of the SU(3) breaking in the pseudoscalar ν_p in case of quadratic mass matrix is equal to 0.85 ± 0.09 and in case of a linear one - to 0.73 ± 0.12. Besides, the Gell--Mann-Okubo (GMO) quadratic formula gives 0.47 GeV^2 for the mass square of the $s\bar{s}$-state, which is in good agreement with the calculated value of $m_s^2 = 0.48 \pm 0.05$ GeV^2. The linear GMO formula gives 0.86 GeV, and the calculated value of $m_s = 0.68 \pm 0.04$ GeV. That is to say, one may conclude that in the sector P the quadratic mass matrix acts better. Besides, since $\nu_p \approx 1$, one may say that the pseudoscalar glueball annihilates into a quark--antiquark pair independent on the quark flavour, i.e. the second property for the glueballs is kept.

The parameters a_R and b_R have been determined from the decays $J/\Psi \to \gamma P$. It turned out that a_R is with a good accuracy equal to λ_N, and $b_R > \lambda_G$. Hence, we hereinafter assume $a_R = \lambda_N$ and fit the ratio b_R / a_R. In the P-sector we obtain

$$b_R / a_R = 1.05 \pm 0.12 , \qquad \xi = 0.69 \pm 0.08 \qquad (24)$$

We have also tried to find the contribution of diagrams breaking the OZI rule, i.e. calculate the parameters τ_p and $\varkappa_p$, determined in eq.(16). It turned out that

$$\tau_p = -0.046 \pm 0.037 ; \qquad \varkappa = -0.028 \pm 0.026 \qquad (25)$$

hence, we can simply put $\tau_p = \varkappa = 0$, the results not being practically changed. Since in determining the parameters τ and $\varkappa$ the main contribution make the diagrams in fig.7 , then one may apparently conclude that the vertices of glueball annihilation to four-quark states in fig.7 are small.

The results of comparison of the experimental data with theoretical predictions are presented in Table 2. It is seen that all the data available are quite well described by a model which has four parameters: α_-, β, γ and b_R/a_R. The total χ^2 over the whole experimental massive is equal to 19 over 22 experimental points and four parameters.

In ref.[2] it was shown that all these data can be well described in Kawai's matrix model with one free parameter.

One may conclude that the available experimental data on the decays of pseudoscalar mesons are in good agreement with each other other and with the model proposed.

The chosen by us ideal basis is in quite good agreement with reality and there is no need in introducing new terms, e.g., such as $c\bar{c}$, radial excitations, hybrid or four-quark states.

From the results of the analysis one can unambiguously conclude that $\iota(1440)$ is a very good candidate for a glueball. We hope that the further experiments will affirm our predictions.

We regret that the ratio

$$\frac{d\sigma/dt\ (\pi^- p \to \iota(1440) n)}{d\sigma/dt\ (\pi^- p \to \eta n)} = 0.081 \pm 0.02$$

is obtained very small. It will make the search for $\iota(1440)$ very difficult in hadron interactions.

Some words about $J/\Psi \to \gamma P$. The width of $J/\Psi \to \gamma\eta$ is obtained small not due to the small glueball contamination in the η-meson, but due to the destructive interference of X_η and Y_η. The width of $J/\Psi \to \gamma\eta'$ is obtained to be large due to the constructive interference of $x_{\eta'}$ and $y_{\eta'}$, and not due to the still small contribution of $|G\rangle$ to η'. The width of $J/\Psi \to \gamma\ \iota(1440)$ is obtained to be large, first, due to large z_ι and second, due to the fact that x_ι, y_ι and z_ι have the same sign. Since $b_R/a_R \approx 1$, the gluon current, the source of which is the decay $J/\Psi \to \gamma P$, is equally well coupled with both glueballs and quark-antiquark pairs. After all the necessary values of free parameters were determined, we fitted the processes $J/\Psi \to VP$. For these decays we had nine experimental points [7] to determine the three unknown parameters ν_V, ζ, ℓ_N. Their obtained values are presented in eqs.(23) As expected, it turned out that $\nu_V \approx 1$, and ζ and ℓ_N were quite small. If fixed that $\nu_V = 1$ and $\zeta = \ell_N = 0$, then the results will unessentially differ from those given in Table 3.

Total: in the pseudoscalar sector there are described 31 processes at four free parameters: angles of mixing α, β and γ and the constant of transition of the gluon current into a glueball - b_R. All the other parameters are not of principal character and they only slightly improve the description. Hence, one can without detriment take $\xi = \nu_V = 1$ and $\tau = \text{\ae} = \zeta = \ell_N = 0$, the basic results not being practically changed.

7. Tensor mesons

In the sector T the angles of mixing α_T, β_T and γ_T have been determined from the fit of the whole set of experimental data. The obtained values are presented in Table 4. Decisive for the fitting procedure appeared to be the data from $T \to PP$ decays [8]. The lack of data on the weights of $\Gamma(f' \to K\bar{K})$

and $\Gamma(\theta \to K\bar{K})$ sharply complicates the matters. It leads to ambiguity in determining $\Gamma(J/\Psi \to \gamma f')$ and $\Gamma(J/\Psi \to \gamma\theta)$.

The calculated values of x, y and z (quark content of f, f' and θ) are presented in Table 4. Ibidem the units of the mixing matrix and the parameters of Rosner's and Kawai's matrices in the quadratic and linear cases are given. It is seen from Table 4 that there is almost ideal mixing in the sector of tensor mesons: f(1270) is almost a pure $|N\rangle$ -state, f'(1525) is a pure $|S\rangle$ -state with a slight admixture of $|G\rangle$, and θ(1720) is a pure $|G\rangle$ -state with slight admixtures of $|S\rangle$ and $|N\rangle$ -states. The admixture of $s\bar{s}$-quarks in θ(1720) is 2.4 times larger than that of $u\bar{u}$- and $d\bar{d}$ quarks, this explaining why $\theta \to K\bar{K}$ dominates over $\theta \to \pi\pi$.

The fact that there is ideal mixing in the T-sector affects that all the mixing parameters τ, σ, λ_i in the T-sector are essentially smaller than in the sector of pseudoscalar mesons where there is no ideal mixing.

In the tensor sector the SU(3)-symmetry breaking parameter $\nu_T = 1.39 \pm 0.09$ in case of quadratic matrix of mixing, and $\nu_T = 1.28 \pm 0.08$ in case of a linear one. The GMO quadratic formula gives $m_s^2 = 2.33$ GeV^2 for the mass of the $s\bar{s}$-state, the fit gives $m_s^2 = 2.31 \pm 0.03$ GeV^2. The GMO linear formula gives $m_s = 1.56$ GeV and the fit gives $m_s = 1.52 \pm 0.01$ GeV. We obtain 1.39 ± 0.01 GeV for the mass of the K^{**}-meson in both cases, i.e. both variants act equally well in the T-sector, the degree of the SU(3)-symmetry breaking not exceeding the standard level.

From the decays $J/\Psi \to \gamma T$ [6,10] the following ratio has been found:

$$b_R/a_R = 1.64 \pm 0.18 \quad (26)$$

The OZI-breaking parameters are found to be

$$\tau = -0.017 \pm 0.015; \quad \varkappa = 0.003 \pm 0.034; \quad \chi = 2.5 \pm 1.9 \quad (27)$$

They turned out quite small values and were determined with large errors. The parameter χ is a large one in itself, but it is multiplied by a small value of $G(T) \cdot G(\eta) \cdot G(\eta')$. Hence, one can assume all these parameters to be equal to zero without prejudice to description of experimental data.

The fitted results of description of and predictions for the experimental data are presented in Table 5. New data are mainly taken from ref.[6] . It is seen that the agreement with the available data is rather a good one. Instead of experimental data for $f'(1525)$ and $\theta(1720)$ the results from the analysis of ref. [11] are presented which unexpectedly well agree to our predictions [2] (these values did not take part in the fit). Owing to the fact that the experiment gives mainly the products of branchings, in Table 6 these products are presented together with the predictions for the processes $J/\Psi \to VT$.

It is seen that the data on the processes with $\theta(1720)$ allow two possible variants of solution: with a large width of $\theta \to K\bar{K}$ and a small one of $\Gamma(J/\Psi \to \gamma\theta)$ and vice versa. The same can be said about processes including $f'(1525)$. In the case with $\theta(1720)$ we obtain some mean values for $\Gamma(\theta \to K\bar{K})$ and $\Gamma(J/\Psi \to \gamma\theta)$. At the same time it appears that the presented widths cover $(47 \pm 31)\%$ of the full width of $\theta(1720)$. The rest must be provided by multiparticle decays or by decays of the type $\rho\rho$, $\omega\omega$ or $K^*\bar{K}^*$. The existing experimental.

restrictions on these widths are not at variance with our results.

Although the contribution of the $|G\rangle$ -state to $f'(1525)$ is small, it plays an important role. If $z_{f'} = 0$ is taken, it will bring to the fact that the width of $f' \to K\bar{K}$ will be 1.5 times larger than the experimental full width of $f'(1525)$ and consequently, the width of $f' \to \gamma\gamma$ too will be enlarged.

The predictions for the processes $J/\Psi \to VT$ are presented in Table 6. The parameters ν_V, ζ and ℓ_N are taken the same as in the pseudoscalar sector (23). The obtained predictions may vary within 2-3 times when the spin structure of these decays described by five helicity amplitudes is correctly taken into account.

It seems to us that the obtained results quite convincingly testify to the fact, that $\theta(1720)$ is a glueball with a slight admixture of strange and nonstrange quarks.

Total: in the tensor sector there are given predictions for and descriptions of 46 processes at four free parameters. The total χ^2 is equal to 27 over 18 experimental points taking part in the fitting procedure.

8. Scalar Mesons

The experimental situation in the sector of scalar mesons was thoroughly considered in our work [3] . In [3] , in the model of Kawai's mass matrix, the experimental data were analyzed, and it was shown that the particles $S^*(975)$, $\varepsilon(1300)$ and $S^{*'}(1730)$ can be reduced to one multiplet. In the present work the experimental data have been processed in terms of the angles of mixing when $\zeta = \varkappa = 0$. The obtained results are given in Table 7. The basic statements of ref. [3] are entirely confirmed. There is ideal mixing in the S-sector: $S^*(975)$ is a glueball, $\varepsilon(1300)$ consists of nonstrange quarks, $S^{*'}(1730)$ consists of strange quarks.

There is rather large quark component in $S^*(975)$ - $\gtrsim 40\%$. The decays of $S^* \to \pi\pi$ and $K\bar{K}$ take place due to that component. The strong coupling of S^* with the $K\bar{K}$ channel is due to the large contribution of the $s\bar{s}$-component. Since $\zeta = \varkappa = 0$, then the glueball component makes no contribution to these decays. By this property the $|G\rangle$ -component strongly differs from the possible admixture of four-quark components. In four-quark models (see [12]) the strong coupling with the $K\bar{K}$ channel is owing to the existence of already ready K-mesons in S^*. In our model the small width of S^* is due to the large glueball contribution to that particle (the glueballs do not decay to anything). This contribution by ~ 5 times narrows its width. The same can be said about $S^{*'}(1730)$. The small glueball admixture narrows its width 1.5 times. In consequence, for the full widths of scalar mesons we obtain

$$\Gamma^{tot}(S^*)/\Gamma^{tot}(\delta) = 0.45 \pm 0.09$$

$$\Gamma^{tot}(\varepsilon)/\Gamma^{tot}(\delta) = 3.7 \pm 0.6 \qquad (28)$$

$$\Gamma^{tot}(S^{*'})/\Gamma^{tot}(\delta) = 3.1 \pm 0.5$$

All these values essentially depend on the real full width of $\delta(983)$; at $\Gamma^{tot}(\delta) = 80 \pm 10$ MeV we obtain $\Gamma^{tot}(S^*) = 36 \pm 6$ MeV, $\Gamma^{tot}(\varepsilon) = 298 \pm 24$ MeV, $\Gamma^{tot}(S^*) = 251 \pm 26$ MeV.

In contrast to the P and T-sectors, there takes place a strong breaking of SU(3)-symmetry in the S-sector. In both quadratic and linear mass matrices the GMO mass formula is violated by $\sim 15\%$ and besides, the SU(3)-breaking parameter is large - $\nu = 3.4 \pm 0.2$. Here different suppositions are possible. We may have no complete information about the S-sector. If there existed two more scalar particles within the mass range of ~ 1 GeV, then there would be no SU(3) breaking and the particles $\varepsilon(1300)$, G(1590) and $S^{*'}(1730)$ would enter another multiplet of radially excited mesons, but then one would have to postulate the existence of an isovector particle of mass ~ 1300 MeV and of a strange meson. In ref. [15] there is a hint of possible existence of a light multiplet of scalar particles: $\varepsilon(900)$ with decays to $\pi\pi$, $S_1(988) \rightarrow K^0\bar{K}^0$ and $S_2(991)$ having the same coupling constant as $\pi\pi$ and $K\bar{K}$ channels do (a candidate for a glueball). $\varepsilon'(1430)$ is suggested instead of $\varepsilon(1300)$. But the absence of isovector and strange particles in that multiplet makes its existence doubtfull.

We think that that breaking of the SU(3)-symmetry is due to purely experimental reasons - poor knowledge of masses of particles in the multiplet. The calculations show that some increase in the mass of ε and decrease in the mass of $S^{*'}$ lead to the fact that ν is decreased down to two. The variation of the S^* mass can make this value still less.

It is usually assumed [12] that $S^*(975)$ and $\delta(980)$ are four-quark states, therefore they cannot enter our multiplet. But in this case too, it is necessary to postulate the existence of two nonets of scalar mesons having explicitly exotic properties. The comparison with the experimental data and the predictions for different processes with scalar mesons participating in them are given in Tables 8 and 9. The scanty experimental data available are quite well described in our model. The only apparent discrepancy here is the smallness of the radiative decay $J/\Psi \to \gamma S^*$. Really, there was obtained a rather severe restriction on $BR(J/\Psi \to S^*\gamma) \cdot BR(S^* \to \pi\pi)$ ($< 7\ 10^{-5}$, 90% C.L.) by MARK III group [10]. If the value of $BR(S^* \to \pi\pi)$ be taken from Table 8, one obtains $\Gamma(J/\Psi \to \gamma S^*) < 5$ eV, which must be compared with $\Gamma(J/\Psi \to \gamma\eta') = 263 \pm 46$ eV. Let us consider this in more detail. As it has been shown in section 3, the width of $J/\Psi \to \gamma S^*$ can be written as

$$\Gamma(J/\Psi \to \gamma S^*) = g^2_{\Psi\gamma S} P_s^3 [a_R(\sqrt{2} x_{S^*} + y_{S^*}) + b_R z_{S^*}]^2 \qquad (29)$$

In the scalar sector $S^*(975)$ is the lightest particle in its multiplet. It can be shown that this fact unambiguously fixes the relative signs of the weights x_s, y_s and z_s. They were obtained to be: $x_{S^*} = 0.24 \pm 0.02$; $y_{S^*} = 0.50 \pm 0.04$; $z_{S^*} = -0.83 \pm 0.02$, i.e. there distructive interference takes place in (29) and because of this the width $\Gamma(J/\Psi \to \gamma S^*)$ may seem to be a small one. If assumed that a_R and b_R are the same in the scalar and pseudoscalar sectors (though, in reality, they are most likely smaller) and take, that $g^2_{\Psi\gamma S} = g^2_{\Psi\gamma P} = 0.27 \pm 0.03$, one obtains $\Gamma(J/\Psi \to \gamma S^*) = 0.15 \pm 0.93$ eV, which is essentially smaller than the experimental restriction. In Table 8 the widths of radiative decays into ε and $S^{*\prime}$, obtained in this assumption, are presented. That is to say, although the glueball component of $S^*(975)$ is strongly coupled with the gluon current, the source of which is the radiative decay of J/Ψ, yet the effect of destructive interference with quark components weaker coupled with the gluon current leads to the fact that the whole particle becomes one weaker coupled with the gluon current.

In conclusion we express our gratitude to K.G. Boreskov and A.B. Kaidalov for long and fruitfull discussions.

Table 1

The parameters of the sector of pseudoscalar mesons

1. Angles of mixing (in degrees)

$\alpha_P = 3.3 \pm 1.2$; $\beta_P = 160.9 \pm 2.4$; $\gamma_P = -12.6 \pm 0.7$

2. The quark content of η, η' and $\iota(1440)$

	$\eta(550)$	$\eta'(958)$	$\iota(1440)$
x	0.769 ± 0.012	-0.586 ± 0.017	-0.256 ± 0.032
y	-0.635 ± 0.015	-0.745 ± 0.015	-0.204 ± 0.026
z	-0.0711 ± 0.0087	0.319 ± 0.040	-0.927 ± 0.078

3. Units of the mixing matrix (3)

	quadratic	linear
a_1	0.628 ± 0.026	0.747 ± 0.013
a_2	0.717 ± 0.016	0.813 ± 0.009
a_3	1.947 ± 0.031	1.386 ± 0.013
a	0.361 ± 0.015	0.225 ± 0.007
b	0.313 ± 0.034	0.139 ± 0.015
c	0.195 ± 0.022	0.074 ± 0.009

4. The masses of ideal states

	quadratic	linear
N	0.0485 ± 0.12	0.328 ± 0.081
S	0.492 ± 0.053	0.692 ± 0.029
G_K	1.778 ± 0.059	1.340 ± 0.021

5. The parameters of Rosner's matrix (10)

	quadratic	linear
τ	0.290 ± 0.048	0.210 ± 0.034
σ	0.221 ± 0.024	0.0982 ± 0.011
ν	0.881 ± 0.046	0.758 ± 0.046

6. The parameters of Kawai's matrix (11)

	quadratic	linear
λ_N	0.538 ± 0.044	0.458 ± 0.075
λ_S	0.474 ± 0.039	0.347 ± 0.028
λ_G	0.411 ± 0.082	0.215 ± 0.017

7. The coupling constants

$g^2_{P\gamma\gamma} = 2.67 \pm 0.07$ $g^2_{\psi\gamma P} = 0.268 \pm 0.028$

$g^2_{V\gamma P} = 15257.8 \pm 706.0$

$g^2_{\psi VP} = 1.11 \pm 0.046$

Table 2

Comparison with the experimental data and predictions for pseudoscalar mesons

No.	Process	Experiment (keV)	Theory
1	$\Gamma(\pi^0 \to \gamma\gamma)$	$(7.3 \pm 0.2 \pm 0.1)10^{-3}$	$(7.4 \pm 0.2)10^{-3}$
2	$\Gamma(\eta \to \gamma\gamma)$	0.56 ± 0.04	0.54 ± 0.04
3	$\Gamma(\eta' \to \gamma\gamma)$	4.50 ± 0.40	4.2 ± 0.3
4	$\Gamma(\iota \to \gamma\gamma)$	< 2.2	2.3 ± 0.6
5	$\Gamma(\omega \to \pi^0\gamma)$	853 ± 56	837.2 ± 38.7
6	$\Gamma(\rho^0 \to \eta\gamma)$	55 ± 14	60.9 ± 3.4
7	$\Gamma(\omega \to \eta\gamma)$	3.2 ± 2.5	7.9 ± 0.4
8	$\Gamma(\varphi \to \eta\gamma)$	54.9 ± 4.5	53.4 ± 3.5
9	$\Gamma(\eta' \to \rho^0\gamma)$	72 ± 10	77.2 ± 5.6
10	$\Gamma(\eta' \to \omega\gamma)$	6.5 ± 1.5	7.2 ± 0.5
11	$\Gamma(\varphi \to \eta'\gamma)$	?	0.35 ± 0.02
12	$\Gamma(\iota \to \rho^0\gamma)$	?	408.4 ± 102.2
13	$\Gamma(\iota \to \omega\gamma)$	?	43.3 ± 10.9
14	$\Gamma(\iota \to \varphi\gamma)$	?	16.2 ± 4.2
15	$\Gamma(J/\psi \to \gamma\eta)$	0.054 ± 0.009	0.053 ± 0.01
16	$\Gamma(J/\psi \to \gamma\eta')$	0.263 ± 0.046	0.276 ± 0.060
17	$\Gamma(J/\psi \to \gamma\iota)$	0.41 ± 0.09	0.41 ± 0.12
18	$\frac{d\sigma/dt\,(\pi^- p \to \eta' n)}{d\sigma/dt\,(\pi^- p \to \eta n)}$	0.62 ± 0.11	0.58 ± 0.03
19	$\frac{d\sigma/dt\,(\pi^- p \to \iota n)}{d\sigma/dt\,(\pi^- p \to \eta n)}$	?	0.11 ± 0.02
20	$\frac{\Gamma(\psi' \to \gamma\eta')}{\Gamma(\psi' \to \gamma\eta)}$	?	5.4 ± 0.7
21	$\frac{\Gamma(\psi' \to \gamma\iota)}{\Gamma(\psi' \to \gamma\eta)}$	?	9.5 ± 2.0

Table 3

Comparison with the experimental data and predictions for the processes $J/\Psi \to VP$

No.	Process VP	$BR(J/\Psi \to VP)\ 10^{-3}$ Experiment	Theory
22	$\rho\pi$	12.7±0.9	12.6±0.6
23	$\omega\eta$	1.9±0.4	1.8±0.1
24	$\varphi\eta$	0.67±0.08	0.68±0.08
25	$\omega\eta'$	0.40±0.11	0.46±0.1
26	$\varphi\eta'$	0.37±0.06	0.32±0.05
27	ω L(1440)	?	0.0014±0.0056
28	φ L(1440)	?	0.0020±0.0035
29	$K^+K^{*\mp}$ c.c.	6.8±1.0	8.4±0.5
30	$K^0\bar{K}^{*0}$ + c.c.	6.26±0.61	5.9±0.4
31	$\rho^0\eta$	0.18±0.04	0.20±0.04
32	$\rho^0\eta'$	< 0.1	0.09±0.02
33	ρ^0 L(1440)	?	0.01±0.003
34	$\omega\pi^0$	0.67±0.13	0.38±0.06

Table 4

The parameters of the sector of tensor mesons

1. Angles of mixing (in degrees)

$\alpha_T = 28.8 \pm 1.6$; $\beta_T = 155.1 \pm 1.6$; $\gamma_T = -22.2 \pm 1.8$

2. The quark content of f(1270), f'(1525), O(1720)

	f(1270)	f'(1525)	O(1720)
x	0.983 ± 0.002	-0.027 ± 0.019	-0.184 ± 0.012
y	-0.097 ± 0.018	-0.921 ± 0.011	-0.379 ± 0.025
z	-0.159 ± 0.012	0.390 ± 0.025	-0.907 ± 0.012

3. Units of the mixing matrix (3)

	quadratic	linear
a_1	1.664 ± 0.005	1.288 ± 0.002
a_2	2.390 ± 0.010	1.545 ± 0.003
a_3	2.717 ± 0.012	1.646 ± 0.004
a	0.101 ± 0.014	0.035 ± 0.005
b	0.193 ± 0.012	0.065 ± 0.004
c	0.160 ± 0.009	0.049 ± 0.003

4. The masses of ideal states

	quadratic	linear
N	1.542 ± 0.025	1.242 ± 0.094
S	2.306 ± 0.023	1.519 ± 0.007
G_K	2.413 ± 0.061	1.553 ± 0.019

5. The parameters of Rosner's matrix

	quadratic	linear
τ	0.061 ± 0.01	0.023 ± 0.004
σ	0.136 ± 0.009	0.046 ± 0.003
ν	1.172 ± 0.093	1.072 ± 0.086

6. The parameters of Kawai's matrix

	quadratic	linear
λ_N	0.247 ± 0.040	0.151 ± 0.013
λ_S	0.290 ± 0.023	0.162 ± 0.013
λ_G	0.551 ± 0.045	0.305 ± 0.085

7. The coupling constants

$g^2_{T\gamma\gamma} = 0.390 \pm 0.019$

$g^2_{TPP} = 318.15 \pm 9.76$

$g^2_{\psi\gamma T} = 391.0 \pm 35.32$

$g^2_{\psi VT} = 0.669 \pm 0.101$

Table 5

Comparison with the experimental data and predictions for tensor mesons

No.	Process	Experiment (keV)	Theory
1.	$\Gamma(A_2 \to \gamma\gamma)$	0.87 ± 0.12	1.01 ± 0.05
2.	$\Gamma(f \to \gamma\gamma)$	2.70 ± 0.14	2.62 ± 0.15
3.	$\Gamma(f' \to \gamma\gamma)$	?	0.14 ± 0.05
4.	$\Gamma(\theta \to \gamma\gamma)$	?	0.29 ± 0.07
5.	$BR(f \to \pi\pi)$	0.843 ± 0.012	0.83 ± 0.10
6.	$BR(f \to K\bar{K})$	0.029 ± 0.004	0.026 ± 0.002
7.	$BR(f \to \eta\eta)$	0.0031 ± 0.0008	0.0042 ± 0.0008
8.	$BR(f' \to \pi\pi)$	0.017 ± 0.012	0.022 ± 0.015
9.	$BR(f' \to \bar{K}K)$	0.76 ± 0.07	0.84 ± 0.09
10.	$BR(f' \to \eta\eta)$	0.29 ± 0.04	0.14 ± 0.02
11.	$BR(f' \to \eta\eta')$	?	$(5.2 \pm 0.5)\ 10^{-5}$
12.	$BR(\theta \to \pi\pi)$	$0.039^{+0.002}_{-0.024}$	0.123 ± 0.033
13.	$BR(\theta \to \bar{K}K)$	$0.38^{+0.09}_{-0.19}$	0.346 ± 0.072
14.	$BR(\theta \to \eta\eta)$	$0.18^{+0.03}_{-0.13}$	0.066 ± 0.038
15.	$BR(\theta \to \eta\eta')$	?	$(5.26 \pm 1.58)\ 10^{-4}$
16.	$BR(A_2 \to \eta\pi)$	0.145 ± 0.012	0.145 ± 0.008
17.	$BR(A_2 \to \eta'\pi)$	< 0.02	0.0045 ± 0.0002
18.	$BR(A_2 \to \bar{K}K)$	0.049 ± 0.008	0.068 ± 0.004
19.	$BR(K^{**} \to K\pi)$	0.45 ± 0.027	0.44 ± 0.02
		$BR(J/\Psi \to \gamma T) \cdot 10^{-3}$	
20.	f	1.60 ± 0.21	1.63 ± 0.38
21.	f'	?	0.28 ± 0.09
22.	θ	?	2.3 ± 0.6

Table 6

Comparison with the experimental data and predictions for the data containing the products of the widths of

23	$\Gamma(f' \to \gamma\gamma) \times BR(f' \to \bar{K}K)$	0.107±0.025 keV	0.11±0.04
24	$\Gamma(\theta \to \gamma\gamma) \times BR(\theta \to \bar{K}K)$	< 0.1 keV	0.099±0.031
		$BR \times BR \times 10^{-4}$	
25	$BR(J/\Psi \to \gamma f)\, BR(f \to \pi\pi)$	13.5±1.8	13.5±2.7
26	$BR(J/\Psi \to \gamma\theta)\, BR(\theta \to \bar{K}K)$	9.6±1.4	8.2±2.8
27	$BR(J/\Psi \to \gamma\theta)\, BR(\theta \to \pi\pi)$	2.0±0.4	2.9±1.1
28	$BR(J/\Psi \to \gamma\theta)\, BR(\theta \to \eta\eta)$	2.6±1.1	1.5±1.0
29	$BR(J/\Psi \to \gamma\theta)\, BR(\theta \to \eta\eta')$	< 2.1	0.012±0.003
30	$BR(J/\Psi \to \gamma f')\, BR(f' \to \bar{K}K)$	1.6±0.5	2.4±0.9
31	$BR(J/\Psi \to \gamma f')\, BR(f' \to \eta\eta)$	1.9±0.9	0.44±0.19
32	$BR(J/\Psi \to \gamma f')\, BR(f' \to \pi\pi)$	≲ 0.7	0.07±0.06
		Decays $J/\Psi \to VT$	
		$BR(J/\Psi \to VT) \times 10^{-3}$	
33	ρA_2	11.8±3.2	12.6±2.2
34	ωf	2.3±0.8	3.1±0.6
35	φf	< 0.37	0.04±0.02
36	$\omega f'$	< 0.16	0.07±0.02
37	$\varphi f'$	?	0.7±0.2
38	$\omega\theta$	?	1.5±1.7
39	$\varphi\theta$	?	0.8±0.3
40	$K^{*+}K^{**-}$ + c.c.	?	11.0±2.0
41	$K^{*o}\bar{K}^{**o}$ + c.c.	6.7±2.6	9.2±2.4
42	$\rho^{o} f$	?	0.04±0.07
43	$\rho^{o} f'$	?	(1.5±2.8) 10^{-4}
44	$\rho^{o}\theta$	?	0.002±0.004
45	ωA_2	?	0.1±0.2
46	$BR(J/\Psi \to \varphi f')\, BR(f' \to K\bar{K})$	0.47±0.04	2.3±0.8

Table 7

The parameters of the sector of scalar mesons

1. Angles of mixing (in degrees)

$\alpha_s = 37.3 \pm 1.6$; $\beta_s = 122.7 \pm 2.6$; $\gamma_s = -85.4 \pm 1.5$

2. The quark content of $S^*(975)$, (1300), $S^{*\prime}(1730)$

	$S^*(975)$	$\varepsilon(1300)$	$S^{*\prime}(1730)$
x	0.238±0.017	0.938±0.0048	-0.252±0.025
y	0.490±0.037	-0.340±0.016	-0.803±0.023
z	-0.839±0.028	0.068±0.022	-0.540±0.038

3. Units of the mixing matrix (3)

	quadratic	linear
a_1	1.96±0.02	1.395±0.007
a_2	2.30±0.07	1.49±0.03
a_3	1.52±0.08	1.19±0.03
a	0.070±0.034	0.011±0.012
b	0.329±0.012	0.126±0.005
c	0.818±0.037	0.306± 0.014

4. The masses of ideal states

	quadratic	linear
N	1.93±0.03	1.39±0.01
S	2.14±0.14	1.46±0.05
G_K	- 2.3±2.0	-2.3±3.8

5. The parameters of Rosner's matrix

τ	0.014±0.007	0.002±0.003
σ	0.232±0.009	0.089±0.003
ν	3.52±0.20	3.42±0.20

6. The parameters of Kawai's matrix

λ_N	0.118±0.028	0.048±0.026
λ_S	0.419±0.010	0.164±0.089
λ_G	1.95±0.46	1.85±1.01

7. The coupling constants

$$g^2_{S\gamma\gamma} = 0.27 \pm 0.18$$

$$g^2_{SPP} = 619.5 \pm 10.2$$

$$g^2_{\psi VS} = 0.424 \pm 0.137$$

Table 8

Comparison with the experimental data and predictions for scalar mesons

No.	Process	Experiment	Theory
1	$\Gamma(\delta \to \gamma\gamma)$	0.29 ± 0.19	- keV
2	$\Gamma(S^* \to \gamma\gamma)$	< 1.12	0.12 ± 0.08 keV
3	$\Gamma(\varepsilon \to \gamma\gamma)$	?	1.6 ± 1.1 keV
4	$\Gamma(S^{*\prime} \to \gamma\gamma)$	?	0.98 ± 0.65 keV
5	$BR(\delta \to \eta\pi)$	0.92 ± 0.25	0.65 ± 0.02
6	$BR(\delta \to K\bar{K})$	0.65 ± 0.32	0.35 ± 0.01
7	$BR(S^* \to \pi\pi)$	0.78 ± 0.03	0.71 ± 0.14
8	$BR(S^* \to \bar{K}K)$	0.22 ± 0.03	0.29 ± 0.06
9	$BR(\varepsilon \to \pi\pi)$	~ 0.9	0.88 ± 0.03
10	$BR(\varepsilon \to \bar{K}K)$	~ 0.1	0.072 ± 0.01
11	$BR(\varepsilon \to \eta\eta)$	≈ 0.025	0.025 ± 0.004
12	$BR(\varepsilon \to \eta\eta')$	?	0.021 ± 0.003
13	$BR(S^{*\prime} \to \pi\pi)$	?	0.062 ± 0.013
14	$BR(S^{*\prime} \to \bar{K}K)$	dominant	0.74 ± 0.084
15	$BR(S^{*\prime} \to \eta\eta)$	?	0.18 ± 0.03
16	$BR(S^{*\prime} \to \eta\eta')$	?	0.017 ± 0.003
17	$\Gamma(J/\Psi \to \gamma S^*)$	< 0.005 keV	$(4.4 \pm 16.4)10^{-4}$
18	$\Gamma(J/\Psi \to \gamma\varepsilon)$	?	0.19 ± 0.01 keV
19	$\Gamma(J/\Psi \to \gamma S^{*\prime})$	?	0.33 ± 0.01 keV
20	$\Gamma(L \to \delta\pi)$	?	21 ± 10 MeV

Table 9

Comparison with the experimental data and prediction for the processes $J/\Psi \to VS$

No.	Process	$BR(J/\Psi \to VS) \cdot 10^{-3}$ Experiment	Theory
21	$J/\Psi \to \rho\delta$	< 0.74	2 ± 1
22	ωS^*	0.12 ± 0.03	0.12 ± 0.03
23	φS^*	0.32 ± 0.10	0.19 ± 0.05
24	$\omega\varepsilon$	?	1.0 ± 0.2
25	$\varphi\varepsilon$	?	0.16 ± 0.04
26	$\omega S^{*\prime}$	?	< 0.002
27	$\varphi S^{*\prime}$	?	0.12 ± 0.03
28	$æ^+ K^{*-}$ + c.c.	?	2.7 ± 0.6
29	$æ^0 \bar{K}^{*0}$ + c.c.	?	1.9 ± 0.4
30	$\rho^0 S^*$	?	0.012 ± 0.003
31	$\rho^0 \varepsilon$	?	0.15 ± 0.04
32	$\rho^0 S^{*\prime}$	?	0.009 ± 0.006
33	$\omega\delta^0$	?	0.20 ± 0.04
34	$BR(J/\Psi \to \omega S^*)/BR(J/\Psi \to \varphi S^*)$	0.38 ± 0.15	0.64 ± 0.12
35	$BR(J/\Psi \to \rho\delta) \cdot BR(\delta \to \eta\pi) \cdot 10^{-3}$	< 4.4	3.9 ± 1.0
36	$BR(J/\Psi \to \omega S^*) \cdot BR(S^* \to \pi\pi) \cdot 10^{-3}$	$0.095 \pm 0.01 \pm 0.022$	0.087 ± 0.030
37	$BR(J/\Psi \to \varphi S^*) \cdot BR(S^* \to \pi\pi) \cdot 10^{-3}$	0.25 ± 0.07	0.13 ± 0.05

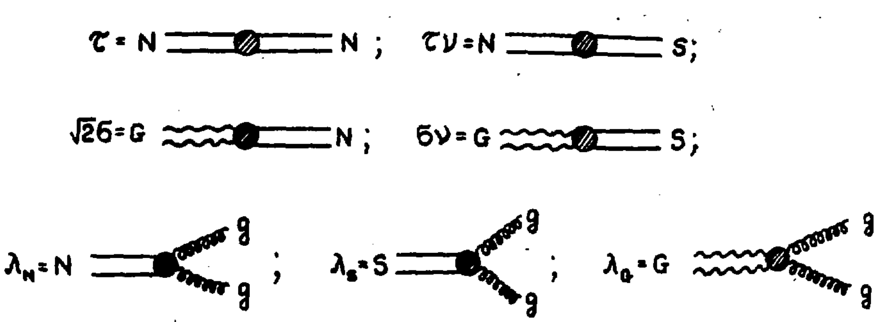


Fig.1

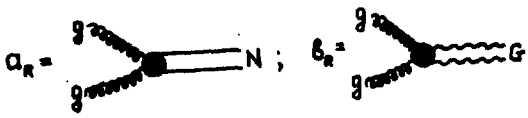


Fig.2

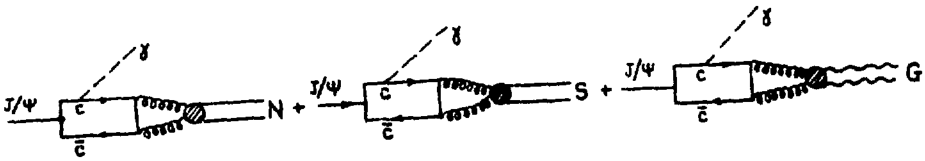
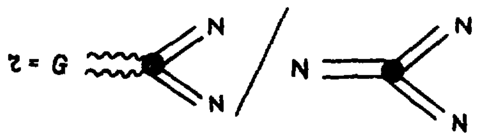


Fig.3



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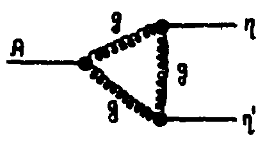

Fig.5

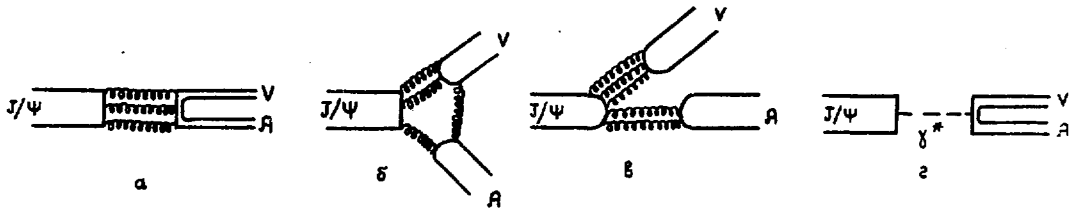

Fig.6

Fig.7

Figure Captions

Fig.1 Units of the mixing matrix. The wavy lines correspond to the constituent gluons, the spiral ones - to the interaction-transferring gluons.

Fig.2 Constants of coupling of interaction-transferring gluons with quarks and glueballs.

Fig.3 The scheme of $J/\Psi \to \gamma A$.

Fig.4 (no caption)

Fig.5 (no caption)

Fig.6 The main contributions into the amplitude of $J/\Psi \to VA$

References

1. Еремян Ш.С., Назарян А.Э. Процессы с рождениями и распадами, содержащие псевдоскалярные глюонии. ЯФ, 1986, т.43, вып.5, с.1303-1312.
2. Еремян Ш.С. Назарян А.Э. Кварк-глюонное смешивание в псевдоскалярных и тензорных мезонах. ЯФ, 1987, т.45, вып.6, с.1758-1768.
3. Еремян Ш.С., Назарян А.Э. Кварк-глюонное смешивание в скалярных мезонах. Препринт ЕФИ-930(81)-86.
4. Rosner J.L. Quark content of neutral mesons. Phys.Rev.D, 1983, vol.27, No. 5, p.1101-1108.
5. Kawai E. A large mixing effect on η , η' and ι . Phys. Lett.B, 1983, vol.124, No. 3,4 , p.262-264.
6. Cooper S. Spectroscopy of light and heavy quarks. SLAC-PUB--4139, T/E, 1986.
7. Perries J. Physics at the J/Ψ and the status of glueballs. SLAC-PUB-3436, T/E, 1984.
8. Particle Data Group. Phys.Lett.B, 1986, vol.170.
9. Aihara H., Alston-Garnjost M., Avery R.E. et al. Experimental Limit on $\iota \to \gamma\gamma$ and the Interpretation of the Iota as a Glueball. Phys.Rev.Lett., 1986, vol.57, No.1, p.51-54.
10. Einsweiler K.F. Radiative decays of the $\Psi(3097)$ to two meson final states. SLAC-REPORT-272, 1984.
11. Longacre R.S., Etkin A., Foley K.J. et al. A measurement of $\pi^- p \to K^0_S K^0_S$ at 22 GeV/c and a systematic study of the 2^{++}. Phys.Lett.B, 1986, vol.177, No.2, p.223-227.

12.Ачасов Н.Н., Девянин С.А., Шестаков Г.Н. Проблема скалярных мезонов. УФН, 1984, т.124, вып.3, с.361-395.

13. Albrow M. CERN Lightest Glueball? CERN Courier, vol.27, p.16-18, 1987.

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