Narrow mesons and color symmetry

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We consider the consequences of the assumption that the recently discovered narrow resonances are colored particles and the representatives of the $SU(3)$ color group octet.

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In this article we consider the consequences ensuing from the assumption that the recently discovered[1–3] narrow resonances $\psi(3105)$ and $\psi'(3695)$ are hardrons, i.e., they have strong interaction and belong to the family of colored particles.

The small width of the bosons points to the existence of a new selection rule, which forbids transitions of these resonances into known hadrons. At the present time one discusses in the main two possibilities: 1) the ψ are particles with "hidden charm," 2) the ψ are colored particles.

We make a few remarks concerning the ψ bosons within the framework of the color model,[4–6] in which the hadrons are built up of nine quarks p_i, n_i, λ_i $(i=1,2,3)$. It is assumed that the usual hadrons are singlets with respect to the $SU(3)'$ color group. If the bosons ψ and ψ' are representatives of a color octet, then their decays into ordinary hadrons should proceed mainly with photon emission. Small (~2 GeV) mass differences between the colored and white particles indicate that in this case there should take place a strongly broken $SU(9)$ symmetry,[7] so that the mesons form 81-plets, while the baryons form 84-, 165-, and 240-plets.

To classify the particles in accordance with the $SU(3)'$ group it is very important to know what interaction violates this group. We consider two variants: 1) the $SU(3)'$ group is violated only by electromagnetic and possibly weak interaction, and 2) the $SU(3)'$ group in analogy with the $SU(3)$ group is violated by some "semistrong" interaction. We shall discuss in greater detail the first variant.

If the quark charges are $p(1,1,0)$, n, $\lambda(0,0,-1)$, then it is convenient to introduce the color spin group $SU(2)'$ in the first two colors, which is not broken by the electromagnetic interaction.

The electromagnetic current is a singlet in the color spin

$$j_\alpha = e(\bar{p}_1\gamma_\alpha p_1 + \bar{p}_2\gamma_\alpha p_2 - \bar{n}_3)_\alpha n_3 - \bar{\lambda}_3\gamma_\alpha\lambda_3)$$

$$\sim j^{SU(3)}\lambda_0' + \frac{1}{\sqrt{3}}\lambda_n\lambda_8', \tag{1}$$

where

$$j^{SU(3)} = \frac{1}{2}\lambda_3 + \frac{1}{2\sqrt{3}}\lambda_8$$

is the operator of the electromagnetic current in the $SU(3)$ group (λ_i are the usual 3×3 matrices of the $SU(3)$ group).

It follows from (1) that the part of the current with change of color (the term $\lambda_0\lambda_8'$) is a singlet in the group $SU(3)$. This leads to important consequences. Thus, out of the 72 colored vector mesons, only two (ω_8 and ϕ_8 with color spin zero) can go over into a photon. We assume that

$$\begin{aligned} \psi &= \cos\alpha\,\omega_8 + \sin\alpha\,\phi_8 \\ \psi' &= -\sin\alpha\,\omega_8 + \cos\alpha\,\phi_8 \ . \end{aligned} \tag{2}$$

The symbol ω or ϕ in (2) means that the corresponding states are transformed in accordance with the $SU(3)$ group just as the ω and ϕ mesons are. The transformations of mesons of the type ω_3, ϕ_3, ρ_8^0, ρ_3^0 into a photon are forbidden in this scheme.

Nine colored mesons with zero color spin can decay into a gamma quantum and into white hadrons, namely ω_8, ϕ_8, $\rho_8^{\overset{+}{0}}$, k_8^{*+}, k_8^{*0}, and $\bar{k}{}^{*0}_8$. We note that the vector mesons should be arranged in groups of 8 particles ω_i, ϕ_i, ρ_i, k_i^* ($i=1\ldots8$). The mass splitting in each group is only the result of electromagnetic interaction, and the subgroups $8=3+4+1$ remain degenerate. Thus, the ψ-meson mass calls for the existence of seven more particles. The colored mesons that enter in the group of particles with least mass are long-lived particles. They can decay only as a result of weak interaction.

Let us discuss the properties of the decays of the ψ and ψ' mesons. Since both are isoscalar in terms of the ordinary isospin, the decay $\psi'\to\psi\pi$ is forbidden. There is therefore a noticeable probability of the decays $\psi'\to\psi\pi\pi$ and $\psi'\to\psi\eta$. If the ψ meson is the lightest of the colored mesons, then it can decay only via radiation. Writing down the $\psi\to\gamma$ transition matrix element in the form $(M_\psi^2 e/2\gamma_\psi)A_\alpha e_\alpha$, we find from the data on the $\psi\to e^+e^-$ transition width that the constant $\gamma_\psi^2/4\pi\approx2.5$, which does not differ strongly from the corresponding constants for the known vector mesons ($\gamma_\omega^2/4\pi\approx4.5$, $\gamma_\phi^2/4\pi\approx3$).

It is more difficult to understand the small value of the ratio $\Gamma_{\psi\to\text{all}}/\Gamma_{\psi\to e^+e^-}=16$. It would be natural to expect a value $1/\alpha$ for this ratio. The ψ meson could decay into a γ quantum and white particles with zero isospin and positive G parity, e.g., into $\pi\pi\gamma$, $\eta\gamma$, $\rho\rho\gamma$, etc. We present an estimate of the decay to the $\pi\pi\gamma$ channel. We write down the matrix element in the form

$$M_{\psi\to\pi\pi\gamma} = eL^2 F^{\psi}_{\mu\nu} F^{\gamma}_{\mu\nu} \ , \tag{3}$$

where $F_{\mu\nu}=k_\mu A_\nu - A_\mu k_\nu$, and L is a quantity of dimension $1/M$. We obtain $\Gamma_{\psi\to\pi\pi\gamma}=\alpha L^4 M_\psi^5/2^7 3\pi^2$. If $L\sim1/M_\psi$ (as is the case when this quantity is estimated in the vector dominance model using the chain $\psi\to\psi'\pi\pi\to\psi\pi\pi$), then $\Gamma_{\psi\to\pi\pi\gamma}\sim8$ keV. Taking the other channels into account in similar fashion, we can obtain the value $\Gamma_\psi\approx100$ keV. It is important here, however, that the values of L in all the matrix elements should be $\sim1/M_\psi$.

The ratio of the electronic widths of the ψ and ψ' mesons makes it possible, in principle, to determine the mixing angle in (2)

$$\frac{\Gamma_{\psi\to e^+e^-}}{\Gamma_{\psi'\to e^+e^-}} = \frac{M_\psi}{M_{\psi'}}\,\mathrm{tg}^2(\alpha+\beta), \quad \text{where} \quad \mathrm{tg}\,\beta=\sqrt{2}\ . \tag{4}$$

If ψ and ψ' are analogous to the ω and ϕ meson, respectively (i.e., $\alpha\approx0$), then $\Gamma_{\psi\to e^+e^-}/\Gamma_{\psi'\to e^+e^-}\approx1.7$, which does not contradict the experimental data. The new colored particles can be produced when hadrons collide either associatively (e.g., $pp\to\psi pB$, where B is a colored baryon with mass 3 to 4 GeV), or jointly with the γ quantum (the latter can take place only for the aforementioned nine mesons with zero color spin). The cross sections for the production of hadronic systems with large mass decreases rapidly with increasing m. This explains the small value of the cross section for the production of a ψ boson in NN collisions.

In photoproduction at high energies, the ψ and ψ' bosons could be produced without any additional hindrances. The experimental observation of ψ-boson photo-production makes it possible to estimate with the aid of vector dominance the cross section of the $\psi N\to\psi N$ elastic scattering

$$\sigma_{\psi N\to\psi N} = \frac{4}{\alpha}\left(\frac{\gamma_\psi^2}{4\pi}\right)^2\sigma_{\gamma N\to\psi N}\ . \tag{5}$$

If $\sigma_{\gamma N\to\psi N}\approx20$ mb, then $\sigma_{\psi N\to\psi N}\approx3\times10^{-2}$ mb.

In a number of papers[4,8–10] they obtained mass formulas with which to calculate the average particle mass for different representations of the color group

$$m = n\left(m_0 - \frac{8}{3}U\right) + 2C(N)U\ , \tag{6}$$

where n is the number of quarks of which the particle is made up, m_0 is the quark mass, U is the average potentials between the quarks, and $C(N)$ is the quadratic Casimir operator of the $SU(3)'$ group: $C(1)=0$, $C(3)=4/3$, $C(8)=3$.

Assuming that the average mass of vector mesons is ~0.8 GeV in the singlet representation of the $SU(3)'$ group and ~3.4 GeV in the octet group, we find for the quark mass a value ≈1.7 GeV. Since the white pseudoscalar mesons are lighter than the white vector mesons, the average effective potential for the pseudo-scalar particles is somewhat larger than for the vector particles. It follows therefore that the masses of the colored pseudoscalar mesons should be larger than the masses of the colored vector mesons.

The relatively light quarks (and diquarks with $M\approx2$ GeV) could decay into ordinary white hyperons and mesons as a result of the weak interaction. The search for these particles is of great interest.

In conclusion, let us dwell on the variant with broken $SU(3)'$ symmetry, in which the subgroup $SU(2)'$, in analogy with the isotopic group, is broken by the electromagnetic interaction. As the color analog of strangeness we can choose the baryon charge. Assigning to the quarks charges $p(0,1,1)$, n, $\lambda(-1,0,0)$ we find that the electromagnetic current has a symmetrical form: $j\sim j^{SU(3)}\lambda'_0-\lambda_0 j^{SU(3)'}$. Four mesons ($\phi_3,\phi_8,\omega_3,\omega_8$) can go over into a photon, and with lower probability also ρ_8 (owing to the mixing with ρ_0). If the breaking of the $SU(3)'$ group is strong enough, then the mesons with subscript 8 will be shifted in mass relative to the mesons with subscript 3, and can have a relatively larger width, $\Gamma_8 \gg \Gamma_3$. Then the ψ and ψ' bosons must be set in correspondence with orthogonal combinations of ω_3 and ϕ_3, of which the lightest can decay only as a result of the electromagnetic interaction. If the breaking is relatively weak, then the masses and widths of the 3 and 8 mesons may turn out to be close. The existence of vector mesons that are almost degenerate in mass in the region of the ψ and ψ' resonances could lead to strong interference effects in the region of the maxima.

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