Generalized Weinberg sum rule and estimate of the decay widths of new neutral vector mesons into lepton-antilepton pairs

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The use of the generalized Weinberg sum rule makes it possible to obtain an estimate for the widths of the decays of new neutral vector mesons, predicted by the three-triplet symmetrical quark model of the hadrons, into lepton-antilepton pairs. The value obtained for the width of the decay of the new ω_m meson is $9^{+3}_{-1.5}$ keV and is in satisfactory agreement with the experimental data for the recently discovered $\Psi(3105)$ mesons. Predictions are made for other ρ_m and ϕ_m neutral vector mesons.

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The discovery of a new narrow high-lying meson resonance $\Psi(3105)$[1-3] has raised the question whether this resonance is an intermediate boson responsible for weak interaction, or whether it is a vector meson and constitutes a new class of particles whose strong interaction with ordinary hadrons is significantly suppressed. We shall dwell on the second approach and consider the predictions with respect to the production of new vector mesons in collision of electron positron colliding beams. Our reasoning will be based on the three-triplet symmetrical quark model of hadrons, which was investigated by one of us[4] and is a further development of the three-triplet model of Bogolyubov *et al.*[5] Many of the conclusions that follow can be, however, easily applied to other composite models, particularly models with "charmed" quarks.

In the symmetrical three-triplet model the charges of the quarks are assumed to be integers, and the main assumption is that the physical states are simultaneously also eigenstates of the electric charge and vectors of irreducible representations of the group S_3 of the permutations of the numbers of the quark triplets. Thus, in this model there is realized an $SU(3)\times S_3$ symmetry of the hadronic state, in contrast to the $SU(3)\times SU(3)'$ symmetry considered by Han and Nambu. As a consequence of the foregoing requirement, the only allowed states are those with quark numbers that are multiples of three, and with an arbitrary number of quark-antiquark states. The states forbidden are the single-quark and diquark states,[4] which are allowed in other models.[6] The allowed states are determined by the type of Young symmetry and by the internal quantum numbers, the isospin and the hypercharge. In this scheme, the usual mesons and baryons correspond to quark-antiquark and three-quark states belonging to symmetrical and antisymmetrical representations of the S_3 group, respectively. At the same time, new meson and baryon states, corresponding to other types of symmetry, are possible. In particular, besides the usual nonet of the vector mesons, the existence of two other nonets of vector mesons is possible, with the same values of the isospin and strangeness, but corresponding to two basis vectors of the mixed representation of the group S_3. We shall dwell here on the properties of the new neutral vector mesons, which in analogy with the usual ones we shall designate by the symbols ρ_m^0, ω_m, and ϕ_m (m stands for "mixed"). The mass splitting of the ordinary mesons from the new ones is due to their belonging to different irreducible representations of the permutation group S_3, and as shown by experiment, should be quite appreciable. On the other hand, the breaming of the S_3 symmetry is assumed to be of electromagnetic origin. Therefore the transitions of the new particles into ordinary ones and vice versa are either due to their electromagnetic interactions, or to satisfaction of the rules for associative production.

In the model considered here, the electromagnetic current is a sum of a "symmetric" current and a "mixed" current

$$J_\mu^{e.m.} = J_\mu^{sym} + J_\mu^{mixed'} + J_\mu^{mixed''}, \tag{1}$$

where

$$J_\mu^{sym} = J_\mu^{(1)} + > J_\mu^{(2)} + J_\mu^{(3)}, \tag{2}$$

$$J_\mu^{mixed'} = -\frac{2}{\sqrt{6}}\left[2\cos\theta J_\mu^{(1)} - (\cos\theta + \sqrt{3}\sin\theta)J_\mu^{(2)} - (\cos\theta - \sqrt{3}\sin\theta)J_\mu^{(3)}\right]\cos\theta, \tag{3}$$

$$J_\mu^{mixed''} = -\frac{2}{\sqrt{6}}\left[2\sin\theta J_\mu^{(1)} + (\sqrt{3}\cos\theta - \sin\theta)J_\mu^{(2)} - (\sqrt{3}\cos\theta + \sin\theta)J_\mu^{(3)}\right]\sin\theta. \tag{4}$$

In these expressions, the superscripts in the parenthesis indicate the numbers of the quark triplets, and the angle θ is determined by the breaking of the S_3 symmetry. In our case it is electromagnetic in character, and in the zeroth approximation we have $\theta = 0$.[4] The symmetrical current (2) has the usual unitary structure, and therefore the electromagnetic properties of the ordinary mesons and baryons remain unchanged. The mixed currents (3) and (4) turn out to be unitary singlets. In the one-photon approximation, the annihilation of an electron and positron can therefore lead to the formation of new ω_m and ϕ_m mesons, but cannot lead to formation of the ρ_m^0 mesons. Further, if it is assumed that the ω_m and ϕ_m mesons consist, as the ordinary ones, mainly of nonstrange and strange quarks, respectively, then we obtain for the widths of the decays of these mesons into lepton pairs the relation

$$\Gamma(\omega_m \to e^+e^-) : \Gamma(\phi_m \to e^+e^-) = 2 : 1. \tag{5}$$

As indicated above, within the framework of the considered model there should take place a doublet splitting of the mesons, including that of each of the new ω_m and ϕ_m mesons. But in the zeroth approximation ($\theta = 0$) one of the doublet components has a zero width for decay into a lepton-antilepton pair, and is therefore not produced in a collision of electron-positron beams.

To estimate the absolute values of the widths, we use the generalized Weinberg sum rules. We assume that the spectral densities corresponding to the symmetrical and mixed electromagnetic currents are asymptotically equal[4]

$$\lim_{k_\mu \to \infty} (\Delta^{mixed}_{\mu\nu}(k) - \Delta^{sym}_{\mu\nu}(k)) = 0 . \tag{6}$$

From the condition (6) we obtain by the usual technique[7] a sum rule for the total cross section for annihilation of a lepton pair into hadronic symmetric and mixed states

$$\int_0^\infty s\, ds\, \sigma_{tot}(e^+e^- \to (\text{hadrons})_{\text{sym}} = \int_0^\infty s\, ds\, \sigma_{tot}(e^+e^- \to (\text{hadrons})_{\text{mixed}}). \tag{7}$$

We shall assume that this rule can be replaced by a finite sum rule, assuming that the contributions from the continuous spectrum of the hadrons to the left and right sides of (7) are approximately equal above the threshold of hadron production in the mixed state. Then, separating only the low-lying resonances, we obtain

$$m_\rho \Gamma(\rho \to e^+e^-) + m_\omega \Gamma(\omega \to e^+e^-) + m_\phi \Gamma(\phi \to e^+e^-) + \frac{1}{12\pi^2} \int_{m_\phi^2}^{m^2_{mixed}} s\, ds$$
$$\times\, \sigma_{tot}(e^+e^- \to \text{hadrons}) = m_{\omega_m} \Gamma(\omega_m \to e^+e^-) + m_{\phi_m} \Gamma(\phi_m \to e^+e^-).$$

Using the data on the cross section for annihilation into hadrons[8] and assuming that $m_{\omega_m} \approx m_{\phi_m} \approx 3$ GeV, we obtain the estimate

$$\Gamma(\omega_m \to e^+e^-) = 2\Gamma(\phi_m \to e^+e^-) = 9^{+3}_{-1.5} \text{ keV}. \tag{9}$$

We note that the main contribution (~85%) to the uncertainty is made by the integral over the continuous spectrum. The obtained value (9) is in satisfactory agreement with the value ~5 keV obtained from a preliminary reduction of the experimental data[1] for the recently discovered $\Psi(3105)$ meson.

Just when this work was completed, we learned of the discovery, in a colliding-beam setup, of one more meson $\Psi(3695)$, which is produced with approximately the same probability as the $\Psi(3105)$ meson. It is natural to identify these mesons with the ϕ_m and ω_m mesons considered above, respectively. This would make possible the decay $\Psi(3695) \to \Psi(3105) + 2\pi$, which has apparently been observed. Within the framework of the considered model, there should exist also neutral and charged new ρ_m mesons, and the decay $\Psi(3695) \to \rho_m(?) + \pi$ should be observed. The existence or nonexistence of charged states of the Ψ meson would be a critical test of not only the present model, but also of many other hadron models. We note also that owing to the known duality rules in quark models, the production of the $\Psi(3695)$ meson in proton-proton collisions, as the analog of the ϕ meson, would be appreciably decreased in comparison with the production of the $\Psi(3105)$ meson, and this appears likewise to be confirmed by experiment.[9] We note, however, that our last remarks are only preliminary.

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