Quark structure and radiative decays of new particles

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From data on the radiative decays of ψ we obtain the mixing parameters of heavy and light quarks in the singlet and triplet states. The results agree with expectations based on the concept of asymptotic freedom.

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It appears that the new particles (ψ particles and others related to them) consist of heavy quarks Q. They raise acutely many problems which appeared earlier in connection with the strange quarks. For example, the small widths of th new particles cannot be understood at present without the phenomenological Zweig-Iizuka rule.[1] Successive application of this rule leads to the concept of a small radius of the new particles, so that their decay is connected with quark annihilation at small distances.[2] It can be assumed that this enhances the effects due to asymptotic freedom[3] and supressing the annihilation.[4,5]

Another interesting problem is the mixing of heavy and light quarks, which s also connected with their annihilation.[6] We consider here the information hat can be extracted from the experimental data concerning the mixing parameters, and then discuss briefly the applicability of the mixing concept.

Assuming that three triplet states ω, ϕ, and ψ participate in the mixing, we an parametrize them in the form

$$\omega = (a-b)\,\omega_1 + (c-d)\omega_8 - \sin\alpha_V \cos(\phi_V - \theta_V)\psi_o\,,$$

$$\phi = -(c+d)\,\omega_1 + (a+b)\omega_8 - \sin\alpha_V \sin(\phi_V - \theta_V)\,\psi_o\,,$$

$$\psi = \sin\alpha_V \cos\phi_V\,\omega_1 + \sin\alpha_V \sin\phi_V\omega_8 + \cos\alpha_V\,\psi_o\,, \tag{1}$$

$$a = \cos^2\frac{\alpha_V}{2}\cos\theta_V, \quad b = \sin^2\frac{\alpha_V}{2}\cos(2\phi_V - \theta_V),$$

$$c = \cos^2\frac{\alpha_V}{2}\sin\theta_V\,, \quad d = \sin^2\frac{\alpha_V}{2}\sin(2\phi_V - \theta_V).$$

Here ω_1 and ω_8 are the SU_3 singlet and octet states of the pair of light quarks $\bar{q}$; ψ_0 is the $Q\bar{Q}$ state; ω, ϕ, and ψ are physical states. The angles α_V, ϕ_V, θ_V ave a simple meaning: α_V describes mixing of heavy quarks Q with light ones , ϕ_V specifies the SU structure of the $q\bar{q}$ system mixed with $Q\bar{Q}$, and θ_V determines the mixing of the light quarks. As seen from[1] the admixture of heavy uarks influences also the character of the mixing of the light quarks with one nother. This reflects a possibility of a transition of strange quarks into nontrange ones (and vice versa) via heavy quarks, for example $s\bar{s} \to Q\bar{Q} \to u\bar{u}$. As $\alpha_V \to 0$, the influence of the heavy quarks on the mixing of the light one vanishes ike $\sim\alpha_V^2$. Analogous angles (labeled P) will be introduced also for the pseudoscalar particles η, η^1, and η_0.

We shall use the data on the decays $\psi \to \pi^0\gamma, \eta\gamma, \eta'\gamma$. If it is assumed that the $\to \pi^0\gamma$ decay can proceed only via an admixture of light nonstrange quarks to , then

$$\Gamma_\psi(\pi^\circ\gamma) = \sin^2\alpha_V \cos^2(\phi_V - \theta_o)\,(k_{\psi\pi}/k_{\omega\pi})^3\Gamma_\omega(\pi^\circ\gamma), \tag{2}$$

where $\theta_0 = 36.5°$ is the ideal mixing angle; $k_{\psi\pi}$ and $k_{\omega\pi}$ are the momenta of the photon in the decays to $\pi^0\gamma$. From $\Gamma_\omega(\pi^0\gamma) = 0.87$ MeV [7] and $\Gamma_\psi(\pi^0\gamma) < 0.3$ keV [8] we have

$$\sin\alpha_V \cos(\phi_V - \theta_0) < 2.3 \times 10^{-3}. \tag{3}$$

On the other hand, if we use vector dominance, then

$$\Gamma_\psi(\pi^\circ\gamma) = \alpha\,(f_\phi^2/4\pi)^{-1}\frac{1}{3}\;\Gamma_\psi(\pi\rho) \approx 0.9\ \text{eV}, \tag{4}$$

$$\sin\alpha_V \cos(\phi_V - \theta_0) \approx 1.2 \times 10^{-4}. \tag{5}$$

If $\cos(\phi_V - \theta_0)$ were small, then the decays of ψ would proceed mainly with formation of strange particles (since the admixture to the ψ would consist mainly of strange quarks), thus contradicting the experiment. Therefore

$$\sin\alpha_V \sim 2\times 10^{-4}. \qquad ($$

An attempt to determine ϕ_V from the available data turns out to be contradictory. For example, the relation between the decays $\psi\to p\bar{p}$ and $\psi\to\Lambda\bar{\Lambda}$ agrees with $\phi_V=0$, whereas for the decays $\psi\to\pi p$ and $\psi\to kk^*$ the angle ϕ_V differs appreciably from zero.

The small value of α_V and the relatively large width of the decays $\psi\to\eta\gamma$ an $\psi\to\eta'\gamma$ [9] indicate that these decays proceed mainly via a $Q\bar{Q}$ admixture to η and η'. From the ratio[10] $\Gamma_\psi(\eta'\gamma)/\Gamma_\psi(\eta\gamma)=4\pm 2.5$ we then obtain

$$\mathrm{ctg}^2(\phi_P-\theta_P)\approx 4.8\ ; \qquad |\phi_P-\theta_P| = 24.5^\circ . \qquad ($$

If we assume that the magnetic moments μ_Q and μ_u are connected by the relati

$$\mu_Q=\mu_u\, m_u/m_Q\approx\mu_u/5\ , \qquad ($$

then

$$\Gamma_\psi(\eta\gamma)=\left[\frac{2}{3}\,\frac{1}{5}\,\sin\alpha_P\sin(\phi_P-\theta_P)\right]^2 (k_{\psi\eta}/k_{\omega\pi})^3\,\Gamma_\omega(\pi^\circ\gamma). \qquad (9$$

From $\Gamma_\psi(\eta\gamma)=95\pm 29$ eV [9] we get

$$\sin\alpha_P\approx 2.4\times 10^{-2}. \qquad (1$$

The assumption (8) is justified by the fact that it yields $\Gamma_\psi(\eta_Q\gamma)=12$ keV. This width does not contradict the experimental limitations if η_Q is identified with $X(2.8)$.

The mixing angles (6) and (10) agree qualitatively with those expected[5] on the basis of the ideas of asymptotic freedom. We note that the difference between the vector and pseudoscalar states manifests itself here even more strongly than for particles made of ordinary quarks.

The admixture of $Q\bar{Q}$ to η and η' was discussed recently by Harari.[11] The magnitude of the admixture was determined from the assumption concerning the ratio of the masses of the vector and "normal" pseudoscalar particles (without the $Q\bar{Q}$ admixture). The admixture turned out to be large and, in contrast to (10), leads to a contradiction with the observed limitations on the ψ decays. However, the method used by Harari is unreliable in many respects.

Generally speaking, the concept of mixing for heavy quarks is even more vague theoretically than for light quarks. This is connected with the appreciable increase of the mass of the new quark and is caused, mainly, by the following factors: 1) the increase of the admixture of continuous-spectrum states; 2) the appreciable difference between the spatial structures of the wave functions of the ordinary and heavy quarks in mesons.

In addition, the qualitative properties of the radiative decays of ψ can be explained as being due to direct decays of the $Q\bar{Q}$ state without mixing. In this case, the process has two stages: annihilation of the $Q\bar{Q}$ into $q\bar{q}$ and photon emission. If the heavy quarks are at a short distance and annihilate in the C-even state much more readily than in the C-odd state, then the photon is emitted mainly at the beginning, that is, from the Q quarks.[12] The final hadron system is then predominantly SU_3-singlet (or at least isosinglet). This cture determines qualitatively correctly the ratio of the channels $\eta'\gamma$, $\eta\gamma$, d $\pi^0\gamma$ in the ψ decay. It predicts also that in the $\psi \to \gamma n\pi$ decay the number of ons is in the main even [this agrees with the mixing angles (6) and (10)].

All the foregoing arguments concerning the vagueness of the mixing concept e correct to one degree or another also for the ϕ meson. However, the prop-ties of ϕ are well described just by quark mixing. It is therefore important study the applicability of this concept to ψ. It is possible to use in the veri-cation other decays and the properties of production of the new particles. he answer to the question of mixing would contribute to the understanding of ark dynamics.

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G. Zweig, Preprint CERN No. 8419/TH 412, 1964; J. Iizuka, Supplement to Prog. Theor. Phys. **37**, 1 (1966).
L. L. Frankfurt and V. A. Khoze, Preprint LIYaF No. 207, 1975.
H. D. Politzer, Phys. Rev. Lett. **26**, 1346 (1973); D. Gross and F. Wilczek, Phys. Rev. Lett. **26**, 1343 (1973).
T. Appelquist and H. D. Politzer, Phys. Rev. Lett. **34**, 43 (1975).
A. De Rujula and S. L. Glashow, Phys. Rev. Lett. **34**, 46 (1975).
Ya. B. Zel'dovich and A. D. Sakharov, Yad. Fiz. **3**, 549 (1966) [Sov. J. Nucl. Phys. **3**, 398 (1966)].
Particle. Data Group, Phys. Lett. **50B**, 1 (1974).
C. Bacci *et al.*, Nuovo Cimento Lett. **12**, 269 (1975).
B. H. Wiik, Preprint DESY 75/37.
. Heintze, Preprint DESY 75/34.
H. Harari, Phys. Lett. **60B**, 172 (1976).
R. N. Cahn and M. S. Chanowitz, Preprint LBL-3889.