ζ(8.3) as a bound state of colored scalars

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The ζ (8.3) resonance is interpreted as a $1S$ level in a $\bar{\phi}\phi$ system, where ϕ is a colored scalar entity that interacts with a quark pair bu.

The ζ (8.3) resonance, which has been observed[1] in the radiative decays of the Υ meson, cannot be interpreted as either an elementary boson or a bound state of known or new quarks. We are thus probably dealing with a completely new type of matter, which is not predicted by the standard SU(3)×SU(2)×U(1) theory.

Tye and Rosenferld[2] have suggested that ζ (8.3) is a $1S$ bound state of a quark and an antiquark, both of which are *scalars*, and that the observed γ transition does not come from the Υ resonance but from the $3P$ state of the same scalar quarks, which accidentally lies very close to Υ along the mass scale and is produced along with the latter at the same energy of the e^+e^- beams (the energy spread of the beams on the DORIS installation is about 8 MeV). This hypothesis explains why the transition $\Upsilon'\to\zeta\gamma$ is not observed experimentally; the upper limit on the probability for this transition is[1] $B(\Upsilon'\to\zeta\gamma)/B(\Upsilon\to\zeta\gamma) < 0.22$ (90% CL).

In this letter we wish to propose a slightly different interpretation of the ζ (8.3) state, which does not use this assumption of an accidental precise mass degeneracy. Specifically, we consider the possibility that ζ (8.3) is the $1S$ state of a $\bar{\phi}\phi$ system (phionium), where ϕ is a scalar elementary entity that interacts (ϕ^*bu) with the b and u quarks. The ϕ thus has the quantum numbers of a diquark: a baryon charge $B_\phi = +2/3$ and an electric charge $Q_\phi = +1/3$. In terms of color, ϕ may be an antitriplet or a stet. With ordinary quarks, ϕ forms hadrons of integer charge $\phi\overline{qq}$ (and also ϕq in the case of the antitriplet). For definiteness in the specific calculations, we will consider the case of an antitriplet ϕ with the interaction

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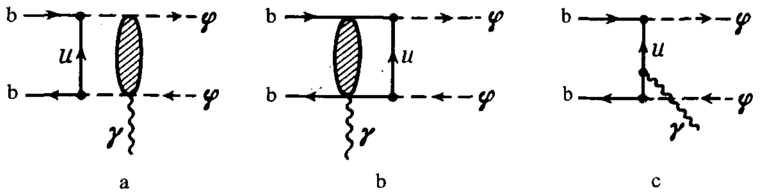

FIG. 1.

$$(h/\sqrt{2})\,\epsilon_{ijk}\,(\phi^*)^i\,(\bar{u}^{cj}(1-\gamma_5)b^k)+\ \text{c.c.} \tag{1}$$

where i, j, and k are color indices; u^c is the spinor which is the charge conjugate of u; and h is the coupling constant. [For an interaction of the type in (1), ϕ is an $SU(2)_W$ singlet.] The mass of the ϕ is slightly lower than that of the b quark.

The transition $\Upsilon\to\zeta\gamma$ results from the diagrams in Fig. 1. The hatched region is the $E1$ dipole emission of a photon by a $\bar{\phi}\phi$ or $\bar{b}b$ pair. The exchange of a u quark can be described in the nonrelativistic case (over distances for which asymptotic freedom holds) by the potential $V(r)=\alpha_h\vec{r}\vec{\gamma}/(2m_\phi r^3)$, where $\alpha_h=h^2/4\pi$. In the approximation that the γ energy, $\omega\simeq1.1$ GeV, is large in comparison with the typical level spacings in the $\bar{\phi}\phi$ and $\bar{b}b$ systems, the Green's functions which arise in diagrams 1a and 1b and which describe the propagation of these systems between the $E1$ transition and the exchange of the u quark can be replaced by numbers: $(-\omega)^{-1}$ and ω^{-1}, respectively. The width of the transition can be estimated in this approximation to be

$$\Gamma(\Upsilon\to\zeta\gamma)\simeq(8/3)\alpha_h^2\,\alpha Q_u^2\,\omega\,|<\zeta|r^{-1}|\Upsilon>|^2/m_\phi^2\ , \tag{2}$$

where $\alpha=1/137$, $Q_u=2/3$, and $\langle\zeta|r^{-1}|\Upsilon\rangle$ is the overlap integral (with a weight of r^{-1}) of the ζ and Υ wave functions. If we adopt the value $\langle r^{-1}\rangle\simeq1.5$ GeV (found from model wave functions for the Υ meson) as an estimate, we find

$$\Gamma(\Upsilon\to\zeta\gamma)\simeq(60\ \text{eV})\cdot(\alpha_h/\alpha)^2. \tag{3}$$

If one of the P levels of the phionium has a mass approximately equal to that of Υ, it will dominate the Green's function of Fig. 1a, and the transition width will be greater than estimate (3). The experimental value of the width is about[1] $160\pm35\pm85$ eV. The value of α_h can thus be estimated: $\alpha_h\lesssim1.5\,\alpha$.

For the analogous transition $\Upsilon'\to\zeta\gamma$, the overlap integral must be much smaller because of the alternating sign of the wave function of the $2S$ state (Υ'). Estimates based on model wave functions yield a suppression factor of 0.1–0.2 in the probability. It is to achieve this suppression that we need the exchange of a light quark, which gives rise to a long-range effect.

Let us examine some of the consequences of interaction (1). The exchange of the ϕ in the t channel gives rise to a contribution to the decay $\Upsilon\to\bar{u}u$; part of the amplitude interferes destructively with the analogous electromagnetic amplitude. The width of this decay can be estimated from

$$B(\Upsilon\to\bar{u}u)=3\left[\left(\frac{\alpha_h}{\alpha}-\frac{2}{3}\right)^2+\left(\frac{\alpha_h}{\alpha}\right)^2\right]B(\Upsilon\to\mu^+\mu^-)\lesssim25\%. \tag{4}$$

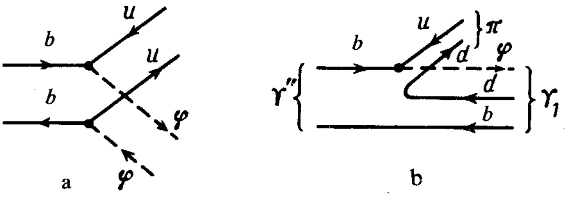

FIG. 2.

Experimentally, an anomalous contribution of this type to the decay into $\bar{u}u$ could be detected from an increase in the yield of an even number of π mesons at the Υ resonance, which would be greater by a factor of 2–2.5 than the resonant increase in the electromagnetic amplitude (larger, for example, than the increase in the $\mu^+\mu^-$ yield). This additional contribution to the decay into $\bar{u}u$ would reduce the estimated width $\Gamma(\Upsilon\to 3g)$ by a factor of about 1.5. A conversion[3] from $\Gamma(\Upsilon\to 3g)$ to $\Gamma(\psi\to 3g)$ based on the asymptotic-freedom formula for α_s results in a quantitative agreement with the experimental data.

Hadron transitions from the $\bar{b}b$ levels to levels of phionium must also result from the process in Fig. 2a. For transitions from the ${}^3S_1$ levels, the quantum numbers of the $\bar{u}u$ pair must correspond to vector and axial mesons with $I = 0$ and $I = 1$. The relative probabilities for the decays $\Upsilon\to(\rho, \omega, \pi) + \zeta$ and $\Upsilon'\to(\rho, \omega, \pi) + \zeta'$ might be 0.1–1%.

The mass of the ground state of the three-particle system $(\phi\bar{b}\bar{q})$, where $q = u$ or d, must be approximately equal to the masses of Υ' and Υ''. Figure 2b describes the transition from Υ'' to this state, accompanied by the emission of a pion. If the mass of this state is approximately 10.25 GeV, it might play the role of the isovector resonance Υ_1 which has been suggested[4] to explain the observed spectrum of $\pi\pi$ invariant masses in the decay $\Upsilon''\to\Upsilon\pi\pi$. (According to Ref. 4, the actual transition $\Upsilon''\to\Upsilon_1\pi$ does not go kinematically, but the pole corresponding to Υ_1 dominates the decay $\Upsilon''\to\Upsilon\pi\pi$ because of the proximity to the physical region.)

The assumption of the existence of a colored elementary scalar ϕ with an interaction as in (1), runs the risk of contradicting experimental data. In the first place, $\bar{\phi}\phi$ pairs should be produced in e^+e^- annihilation. If the ϕ decays sufficiently rapidly ($\tau_\phi \lesssim 10^{-12}$ s), the manifestation of this production would be a contribution to R: $\delta R = 1/12$. This value is apparently not ruled out the experimental data.

Second, we should consider the decays of the b and ϕ hadrons in the presence of interaction (1). The most dangerous situation arises in the decay $B^- = (b\bar{u})\to(\phi\bar{u}\bar{u}) + \gamma$ [some other possible channels are $B^-\to(\phi\bar{u}\bar{u}) + \pi^0$, $B^-\to(\phi d) + \bar{p}$]. If this decay is not to occur, the hadron $(\phi\bar{q}\bar{q})$ would have to be heavier than the B meson; in this case, we would, on the contrary, have the rapid decay $(\phi\bar{q}\bar{q})\to B + \gamma$. If ϕ is a colored sextet, we would resolve the question of the decays of the ϕ hadrons, since $(\phi\bar{q}\bar{q})$ are the lightest hadrons. In the case of an antitriplet ϕ, the lightest ϕ hadron (ϕq) might decay through a virtual b quark. In this case we would have $\tau_\phi \simeq 10^2\text{–}10^3\,\tau_B$, which, at $\tau_B \simeq 10^{-12}$ s, would contradict data from searches for heavy, long-lived particles in e^+e^- annihilation.[5] This danger can be avoided if ϕ also has an interaction with the du or su channel that is weak enough ($\lesssim 10^{-3}\,\alpha_h$) to avoid a reduction in τ_B. Finally, we do not rule out the possibility that the experimental[6] lifetime of 10^{-12} s pertains to ϕ hadrons, rather than b hadrons (since the latter have not been identified) and that we would have $\tau_B \simeq 10^{-14}$–10^{-15} s.

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