Charmonium phenomenology and $L=0$ trigluonia

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(Received 26 December 1990)

Several charmonium decays which cannot be understood in a perturbative QCD scheme are considered and the possible role of glueballs in these decays is studied. In particular the decays of the η_c in two vector mesons and in $p\bar{p}$ might receive a strong contribution from a trigluon 0^{-+} state with a mass close to that of the η_c. Experimental data on the decays of the η'_c could confirm the existence of such a state.

Bound states of gluons, called glueballs, are implied by quantum chromodynamics, as has been known for a rather long time. In spite of this, no experimental identification of any of these states has yet taken place, although many candidates exist. In this paper we wish to point out that the presence of some trigluon states with a mass around 3 GeV/c^2 could affect the decays of various charmonium states and could in fact explain some of their features otherwise not understood.

The existence of one such trigluonium has already been advocated earlier [1–4]. We recall that the presence of a vector glueball with a mass some 80 MeV/c^2 smaller than the J/ψ mass was suggested some years ago [3] in order to explain the relatively large branching ratio of the J/ψ in a vector and a pseudoscalar meson [5]:

$$B(J/\psi\to\rho\pi)=(1.28\pm0.10)\times10^{-2}\,,\qquad B(J/\psi\to K^*\bar{K})=(3.8\pm0.7)\times10^{-3}\,. \tag{1}$$

Such decays are forbidden, in a perturbative QCD quark scheme, by the hadron-helicity conservation theorem [6]. Given the existence of a glueball with a mass close to that of the J/ψ, instead, these decays would proceed by the sequence $J/\psi\to$glueball $1^{--}\to VP$. In this case the QCD helicity conservation theorem, built on the assumption of a pointlike interaction among the constituents, is violated because of the large transverse size of the gluonium state. For other vector charmonium state decays, this contribution would be much smaller due to a larger mass difference with the 1^{--} trigluonium. A confirmation comes from the large suppression for the analogous decays of $\psi'\to VP$ [3,5]:

$$B(\psi'\to\rho\pi)<8.3\times10^{-5}\,,\qquad B(\psi'\to K^*\bar{K})<1.79\times10^{-5}\,. \tag{2}$$

Actually, the estimate of the mass difference between the J/ψ and the supposed gluonium state was based on the experimental, unexpectedly small, bounds

$$\frac{B(\psi'\to\rho\pi)}{B(J/\psi\to\rho\pi)}<0.006 \tag{3}$$

and

$$\frac{B(\psi'\to K^*\bar{K})}{B(J/\psi\to K^*\bar{K})}<0.005\,, \tag{4}$$

the so-called J/ψ $(\psi')\to\rho\pi,K^*\bar{K}$ puzzle [3]. Glueballs, of course, could not explain the isospin-nonconserving decay $J/\psi\to\omega\pi$, which has been observed [5]; its decay rate, however, is sensibly smaller than the $J/\psi\to\rho\pi$ one.

A rather similar situation encounters in the decays of the η_c in two vector mesons $(\rho\rho,K^*\bar{K}^*,\phi\phi)$ and in $p\bar{p}$. These decays, again, are forbidden by the perturbative QCD scheme and helicity conservation [6–8]: such a scheme, in fact, would naturally give final particles with opposite helicities, in contradiction, for the above cases, with parity and angular momentum conservation. However, these processes are actually observed to occur with relatively large branching ratios [5]:

$$\begin{aligned}&B(\eta_c\to\rho\rho)=(2.6\pm0.9)\times10^{-2}\,,\\&B(\eta_c\to K^*\bar{K}^*)=(9\pm5)\times10^{-3}\,,\\&B(\eta_c\to\phi\phi)=(3.4\pm1.2)\times10^{-3}\,,\\&B(\eta_c\to p\bar{p})=(1.04\pm0.19)\times10^{-3}\,.\end{aligned} \tag{5}$$

A nonzero decay width for $\eta_c\to p\bar{p}$ can actually be obtained when diquark contributions in the proton structure are taken into account [8]. Even so, however, model calculations show that, when all parameters are fixed, the theoretical result turns out to be much smaller than the actual data [9]. Analogously, quark mass corrections to the perturbative QCD computations of the decays $\eta_c\to VV$ have been shown not to help at all, in that the theoretical predictions keep giving a zero result [10].

We wish to suggest here that this situation can once more be attributed to the presence of a trigluonium pseudoscalar state with a mass not far from the η_c mass.

The $L=0$ trigluonia may have quantum numbers $J^{PC}=0^{-+}$, 1^{--}, 3^{--}; in QCD, generally, antiparallel spin states have masses lower than parallel spin ones (for instance, the $^1S_0$ and the $^1P_1$ meson masses are respectively lower than those of the $^3S_1$ and of the $^3P_1$ mesons: similarly, in the baryon sector, $M_N < M_\Delta$, etc.). Thus, if a 1^{--} trigluonium is found near the J/ψ, it is utterly plausible that a 0^{-+} trigluonium should be found near the $1\,^1S_0$ $c\bar{c}$ state (the η_c) and that they should mix. No data on η_c' decays in VV or $p\bar{p}$ are available yet (but they should in the rather near future). For this reason we are not yet in measure to evaluate the mass difference between the η_c and the hypothetical 0^{-+} glueball. We can, however, give some rough estimates if we make some assumptions. For instance, if this gluonium state has a mass within about 60 MeV/c^2 from the η_c, the following branching ratio bounds hold:

$$\begin{aligned} &B(\eta_c' \to \rho\rho) \lesssim 3.2\times 10^{-5} , \\ &B(\eta_c' \to K^*\bar{K}^*) \lesssim 1.1\times 10^{-5} , \\ &B(\eta_c' \to \phi\phi) \lesssim 4.2\times 10^{-6} , \\ &B(\eta_c' \to p\bar{p}) \lesssim 1.3\times 10^{-6} , \\ &B(\eta_c' \to \omega\omega) < 3.8\times 10^{-6} . \end{aligned} \tag{6}$$

The above bounds have been calculated from the present data on η_c branching ratios with the same relation used in [3]:

$$\frac{B(\eta_c' \to VV)}{B(\eta_c \to VV)} = \frac{B(\eta_c' \to h)}{B(\eta_c \to h)} \frac{(M_{\eta_c} - M_G)^2 + \Gamma_G^2/4}{(M_{\eta_c'} - M_G)^2 + \Gamma_G^2/4} , \tag{7}$$

where h denotes all unforbidden hadronic channels and we assume [5]

$$\frac{B(\eta_c' \to h)}{B(\eta_c \to h)} \simeq \frac{B(\psi' \to h)}{B(J/\psi \to h)} \simeq 0.128 . \tag{8}$$

Such an assumption is rather plausible given that $M_{\eta_c'} - M_{\eta_c} \simeq M_{\psi'} - M_{J/\psi}$.

In this scheme also the 3^{--} trigluon state should not be much above 3 GeV/c^2; say around 3.1–3.2 GeV/c^2, if $M_{3^{--}} - M_{1^{--}} \simeq M_{1^{--}} - M_{0^{-+}}$. It could be an interesting decay channel of the $^3D_3$ charmonium state.

It is important to stress that all these glueball states should be within reach. For instance, they could be searched for in ψ' decays (into $K^*\bar{K}\pi\pi$, $\rho\pi\pi\pi$, $K^*\bar{K}\eta$, $\rho\pi\eta$ for the vector state [3], into $\gamma\rho\rho$, $\gamma K^*\bar{K}^*$, $\gamma\phi\phi$ for the pseudoscalar one) and in $p\bar{p}$ scattering around $\sqrt{s} \simeq 3$ GeV.

Of course, the trouble is that they could be rather wide resonances, very difficult to detect experimentally in a direct way. We may, therefore, have to face the possibility that, for the time being, the best evidence of their existence may remain indirect; i.e., may come from anomalies such as the dissimilar decays of similar particles [the J/ψ and ψ' decays into VP or the η_c and η_c' decays into VV, should the limits (6) be roughly correct].

Qualitative as the above arguments are, the elusiveness of glueballs deserves that the decays of charmonium states be analyzed along the lines suggested in this paper in the hope that some light may be shed on the existence and the properties of trigluonia.

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