The expected properties of the η'_c meson

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The properties of the η'_c meson, the pseudoscalar analog of the $\psi'(3.7)$ resonance, is considered in the charmonium model.

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Searches for radiative decays of the $\psi(3.1)$ resonance have led recently[1,2] to observation of the decay

$$\psi \to \eta_c + \gamma, \quad \eta_c \to 2\gamma$$

where the particle η_c has a mass ~ 2.8 GeV.

It appears that η_c is the pseudoscalar analog of ψ, the ground $^1S_0$ state of $c\bar{c}$ quarks (para-charmonium). Let us see that properties should be possessed by the first radially excited state of paracharmonium η'_c (the pseudoscalar analog of $\psi'(3.7)$).

We estimate the expected mass of the η'_c meson within the framework of the nonrelativistic model[3] of charmonium

$$\frac{m_{\psi'} - m_{\eta'_c}}{m_\psi - m_{\eta_c}} \approx \frac{|\Psi'(0)|^2}{|\Psi(0)|^2},$$

where $\Psi(\Psi')$ are the wave functions of the ground (first excited) state of charmonium. This relation implies that the splitting of the $^3S_1$ and $^1S_0$ levels of charmonium is proportional to the product of gluon "magnetic moments" of the c and $\bar{c}$ quarks by the quark density as $r \to 0$. Recognizing that within the framework of the model we have

$$\frac{\Gamma(\psi' \to e^+e^-)}{\Gamma(\psi \to e^+e^-)} \approx \frac{|\Psi'(0)|^2 m_\psi^2}{|\Psi(0)|^2 m_{\psi'}^2},$$

and using the values[4] $m_\psi = 3.1$ GeV, $m_{\psi'} = 3.7$ GeV, $\Gamma(\psi \to e^+e^-) = 5$ keV, $\Gamma(\psi' \to e^+e^-) = 2$ keV, and[1,2] $m_{\eta_c} = 2.8$ GeV, we obtain $m_{\eta'_c} \sim 3.5$ GeV. At this mass, the η'_c meson turns out to be in the immediate vicinity of the charmonium P levels that are produced in radiative decays of the ψ' meson.[1,2,5] It is thus not excluded that some of the decays of the states with $m \sim 3.4$—3.5 GeV belong to η'_c.

Let us estimate the probability of the ψ'-meson radiative decay leading to the formation of η'_c. In the nonrelativistic magnetic-dipole transition approximation we have

$$M(\psi' \to \eta'_c \gamma) \approx M(\psi \to \eta_c \gamma) .$$

However, taking the kinematic factors into account, we get

$$\frac{\Gamma(\psi'\to\eta_c'\gamma)}{\Gamma(\psi\to\eta_c\gamma)}=\frac{(m_{\psi'}^2-m_{\eta_c'}^2)^3 m_\psi^3}{(m_\psi^2-m_{\eta_c}^2)^3 m_{\psi'}^3}\approx 0.3.$$

The width $\Gamma(\psi\to\eta_c\gamma)$ has so far not been measured in experiment. If we assume tentatively $B(\psi\to\eta_c\gamma)\sim 10\%$, then

$$B(\psi'\to\eta_c'\gamma)\sim 0.3\cdot 0.1(\Gamma_{tot}(\psi)/\Gamma_{tot}(\psi'))\sim 10^{-2},$$

which is at the level of the observed[5] photon-hadron cascades

$$\psi'\to\gamma X(3.5) \to 4\pi,\ 6\pi.$$

The expected total width of η_c', just as the width of η_c should be of the order of several MeV. The main channel of η_c' decay should be hadronic. In particular, we note the 2ρ, 2ω, 2ϕ, $k^*\bar{k}^*$, and $p\bar{p}$ channels, and especially the $\eta_c'\to\eta_c 2\pi$ decays. Inasmuch as in the analogous $\psi'\to\psi 2\pi$ decays the pions are emitted isotropically, it can be assumed that the spin degrees of freedom do not play any role and consequently the corresponding amplitudes are equal to

$$M(\eta_c'\to\eta_c 2\pi)=M(\psi'\to\psi 2\pi).$$

The dependence of these amplitudes on the invariant mass q^2 of the two pions is determined[6] mainly by the Adler self-consistency condition. Assuming that

$$M\sim(q^2/\mu_0^2)-1,$$

where $\mu_0\sim m_\pi$, which agrees[6] with the observed[7] mass spectrum of the dipions in the $\psi'\to\psi 2\pi$ decay, and using the width[4] $\Gamma(\psi'\to\psi\pi^+\pi^-)=70$ keV, we obtain $\Gamma(\eta_c'\to\eta_c\pi^+\pi^-)=300$ keV (at $m_{\eta_c'}=3.5$ GeV).

As to the radiative decays of η_c', the decay $\eta_c'\to\psi\gamma$ is forbidden in the considered nonrelativistic approximation:

$$M(\eta_c'\to\psi\gamma)=M(\psi'\to\eta_c\gamma)=0.$$

In additions, a rough estimate yields

$$B(\eta_c'\to\gamma+\text{hadrons})=B(\eta_c\to\gamma+\text{hadrons})$$

$$B(\eta_c'\to 2\gamma)=B(\eta_c\to 2\gamma).$$

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