$\gamma\gamma$ and gg decay of heavy pseudoscalar quarkonia

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Introduction

The study of heavy quarkonium systems has played an important role in the development of quantum chromodynamics (QCD). There are different models in literature which describes the quarkonium spectra. The prediction of mass spectrum in accordance with the experimental results doesn't guarantee the validity of the model for describing hadronic interactions. This is because different potentials have been proposed which reproduce the same spectra. Therefore using the model, one must be able to calculate other observables like the radiative decay widths, the leptonic decay widths, the charge radii, etc. The leptonic decay widths are a probe of the compactness of the quarkonium system and provide important information complementary to level spacings. The decay of a heavy quark-antiquark pair into final states involving leptons, photons and light quarks can provide useful information on the strong coupling constant (α_s) [1, 2]. Heavy quarkonium decays provide a deeper insight on the exact nature of the interquark forces and decay mechanisms. In the present work we have calculated the two-photon and the two-gluon decay widths of ground state pseudoscalar quarkonia $\eta_c(1S)$ and $\eta_b(1S)$. The annihilation of a heavy quark-antiquark pair into final states consisting of leptons, photons and light quarks can provide useful information on the strong coupling constant $\alpha_s(\mu)$, where μ is a renormalization scale [1].

The Model

The $^1S_0$, $^3P_0$ and $^3P_2$ levels of charmonium and the upsilon system can decay into two photons. These same states can also decay

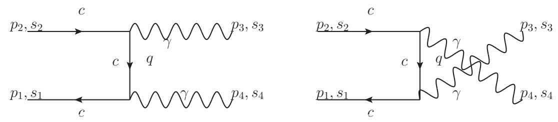

FIG. 1: Two-photon decay

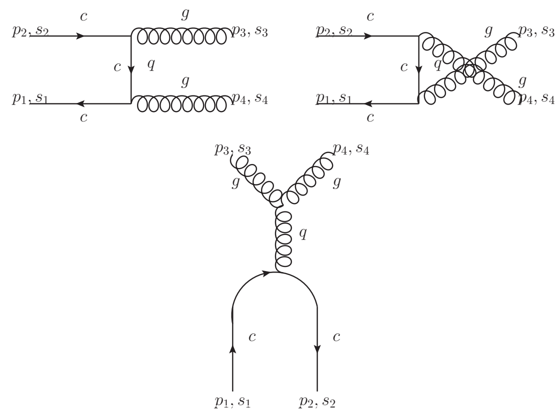

FIG. 2: Two-gluon decay

into two gluons, which accounts for a substantial portion of the hadronic decays for states below the c$\bar{c}$ or b$\bar{b}$ threshold [3]. The Feynman diagrams for two photon decay and two gluon deay are as shown in fig. 1 and fig. 2 respectively.

The width for two-photon decay can be derived using fig. 1. The width is given by:

$$\Gamma_{\gamma\gamma} = \frac{12\pi e_q^4 \alpha^2}{m_q^2} |\psi(0)|^2 \left(1 - \frac{3.4\alpha_s}{\pi}\right), \quad (1)$$

where e_q is the quark charge ($e_q = 2/3$ for c and -1/3 for b), α is the QED coupling constant, m_q is the quark mass and $|\psi(0)|$ is the meson wave function calculated at the origin. The term in the parenthesis is the first order QCD correction factor [1].

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The decay width for two-gluon decay (fig. 2) is given by:

$$\Gamma_{gg} = \frac{8\pi\alpha_s^2}{3m_q^2}|\psi(0)|^2 \times CF, \qquad (2)$$

where e_q is the quark charge ($e_q = 2/3$ for c and -1/3 for b), α_s is the QCD coupling constant, m_q is the quark mass and $|\psi(0)|$ is the meson wave function calculated at the origin. CF is the first order QCD correction factor. It is given by [1]: $(1 + 4.8\alpha_s/\pi)$ for η_c and $(1 + 4.4\alpha_s/\pi)$ for η_b.

The mass of the quarks m_q, α_s and the quarkonium wave function are fixed from the quarkonium spectrum. For obtaining the quarkonium spectrum we employed the relativistic harmonic model (RHM) [4]. The quark-antiquark interaction potential is given by the confined one gluon exchange potential (COGEP) [5]. The $q\bar{q}$ wave function for each meson state is expressed in terms of oscillator wave functions corresponding to the center of mass (CM) and relative coordinates. The oscillator quantum number for the CM wavefunctions are restricted to $N_{CM} = 0$. The Hilbert space of relative wavefunctions is truncated at radial quantum number $n = 5$. The Hamiltonian matrix is constructed in the basis states of $|N_{CM} = 0, L_{CM} = 0; n\ {}^{2S+1}L_J >$ and diagonalised. The diagonal values give the masses of the ground and radially excited states.

Results and discussions

The masses of the ground and excited states of the pseudoscalar mesons η_c and η_b after diagonalisation in harmonic oscillator basis are listed in Table II in comparison with experiment [6]. Expressing the meson state by harmonic oscillator wave function, the two-photon and the two-gluon decay widths are calculated using Eq.(1) and Eq.(2). The results are listed in Table II in comparison with experimental and other theoretical values. For charmonium there is a reasonable agreement with the experimental results. The two-photon decay rates for the upsilon system have not been measured.

TABLE I: Pseudoscalar Mass Spectrum(in MeV)

Meson	**Mass**	**PDG[6]**	**[7]**
$\eta_c(1S)$	2980	2980	3000
$\eta_c(2S)$	3391	3637	3670
$\eta_b(1S)$	9455	9391	9410
$\eta_c(2S)$	9858		10000

TABLE II: DecayWidths

Decay	**Present**	**Exp.**	**[3]**
$\eta_c \to \gamma\gamma$	3.61 keV	7.2 keV	3.48 keV
$\eta_b \to \gamma\gamma$	0.08 keV		0.32 keV
$\eta_c \to gg$	5.06 MeV	26.7 MeV	10.57 MeV
$\eta_b \to gg$	1.85 MeV		12.39 MeV

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