Radiative decays of $Q\bar{Q}$ mesons

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Introduction

The decay rates of quarkonia are quite important to study due to huge amount of high precession data acquired using number of experimental facilities worldwide. New states and production mechanisms, new decays and transitions have been identified and even larger data samples are expected to come from the BES-III upgraded experiment, while the B factories and the Fermilab Tevatron will continue to supply valuable data for few years [1]. New facilities like the LHC experiments at CERN, Panda at GSI etc. will offer greater challenges and opportunities in this field [1, 2, 3].

The experimental detection of heavier mesons with heavy flavour combinations have opened up a vast data bank for the hadronic decays into various channels. For example, the production of noncharmed hadrons in the decays of $c\bar{c}$ states like ψ, η_c, χ is radiative (e.g. $\psi \to \gamma \to$ hadrons). A hadronic transition or decay between quarkonium levels can be understood as a two-step process in which gluons first are emitted from the heavy quarks annihilating each other and then recombine into light hadrons. Perturbative QCD is not directly applicable because the energy available to the light hadrons is small and the emitted gluons are soft. Nevertheless, the final quarkonium state is small compared to the system of light hadrons and moves nonrelativistically in the rest frame of the decaying quarkonium state.

Radiative decays

The decay rates of the mesons are factorized into a short-distance part that is related to the annihilation rate of the heavy quark and antiquark and a long-distance part containing all nonperturbative effects of the QCD. The short-distance factor calculated in terms of the running coupling constant $\alpha(M)$ of QCD is evaluated at the scale of the heavy-quark mass M, while the long-distance factor is expressed in terms of the meson's nonrelativistic wave function, or its derivatives, evaluated at origin. The di-gamma decay of $^1S_0$ state using the conventional Van-Royen Weisskopf formula [4]

$$\Gamma_0 = \frac{12\alpha_e^2 e_Q^4}{M_P^2}\, R_P^2(0) \qquad (1)$$

as well as using the NRQCD formalism have been computed. The NRQCD factorization expressions for the decay rates are given by [5]

$$\begin{aligned}\Gamma(^1S_0 \to \gamma\gamma) \;=\; & \frac{2Imf_{\gamma\gamma}(^1S_0)}{m_Q^2}\left|\langle 0|\chi^\dagger\psi|^1S_0\rangle\right|^2 \\ & +\frac{2Img_{\gamma\gamma}(^1S_0)}{m_Q^4} \\ & \times Re\left[\langle ^1S_0|\psi^\dagger\chi|0\rangle\right. \\ & \left.\langle 0|\chi^\dagger(-\frac{i}{2}\overrightarrow{D})^2\psi|^1S_0\rangle\right] \\ & +O(v^4\Gamma) \qquad (2)\end{aligned}$$

The Vacuum saturation allows the matrix elements of some four fermion operators to be expressed in terms of the regularized wave-

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function parameters given by [5]

$$\langle {}^1S_0|\mathcal{O}({}^1S_0)|{}^1S_0\rangle \;=\; \frac{3}{2\pi}|R_{{}^1S_0}(0)|^2 \times[1+O(v^4)] \qquad (3)$$

$$\langle {}^1S_0|\mathcal{P}_1({}^1S_0)|{}^1S_0\rangle \;=\; -\frac{3}{2\pi}|\overline{R^*_{cw}}\ \overline{\nabla^2 R_{cw}}| \times[1+O(v^4)] \qquad (4)$$

$$\Gamma({}^1S_0\to\gamma\gamma) \;=\; \frac{2Imf_{\gamma\gamma}({}^1S_0)}{\pi\ m_Q^2}\,|R_{{}^1S_0}|^2 - \frac{N_c\ Img_{\gamma\gamma}({}^1S_0)}{\pi m_Q^4} \times Re(\overline{R_s^*}\ \overline{\nabla^2 R_s}) + O(v^4\Gamma) \qquad (5)$$

TABLE I: $0^{-+}\to\gamma\gamma$ (in keV) of $c\bar{c}$ and $b\bar{b}$ mesons.

			Γ_0	Γ_{NRQCD}	$\Gamma_{Expt.}$ [12]
$c\bar{c}$	ERHM [6]		7.67	3.401	
	BT [7]		11.19	5.165	$7.0^{+\ 1.0}_{-\ 0.9}$
	PL(Martin) [8]		13.81	6.054	
	Log [9]		11.26	5.364	
	Cornell [10]		20.09	8.614	
	CPP_ν [11]ν	=0.5	8.173	2.213	
		=1.0	14.649	5.513	
		=1.5	19.971	7.889	
		=2.0	24.297	9.920	
$b\bar{b}$	ERHM [6]		0.440	0.207	
	BT [7]		0.569	0.278	
	PL(Martin) [8]		0.408	0.195	0.364 [5]
	Log [9]		0.437	0.211	0.490 [13]
	Cornell [10]		1.258	0.597	
	CPP_ν [11]ν	=0.5	0.345	0.163	
		=1.0	0.529	0.251	
		=1.5	0.683	0.324	
		=2.0	0.811	0.385	

The short distance coefficients f's and g's computed in the order of α^2 as [5]

$$Imf_{\gamma\gamma}({}^1S_0) = \pi Q^4\alpha^2 \qquad (6)$$

$$Img_{\gamma\gamma}({}^1S_0) = -\frac{4\pi Q^4}{3}\alpha^2 \qquad (7)$$

Where $C_F = (N_c^2-1)/(2N_c) = 4/3$.

The decay rates are computed using conventional Van-Royen Weisskopf formula for Γ_0 as well as using NRQCD expressions.

Conclusion

We have computed the radiative decay rates of the charmonia and bottomonia systems using spectroscopic parameters obtained from different potential models within the NRQCD formalism. As the non-perturbative aspect of the interaction has already been taken into account in the confinement schemes of quarks and gluons, the residual one gluon exchange effects employed in this study are treated perturbatively.

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