Decay rate of excited states of charmonium

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Introduction

Heavy quarkonia have a rich spectroscopy with many narrow states lying under the threshold of open flavour production[1]. The success of theoretical model predictions with experiments can provide important information about the quark-antiquark interactions.The decay rates of $c\bar{c}$ meson is studied in the conventional Van Royen-Weisskopf (VW)formula with and without radiative correction[2] and NRQCD formalism in terms of their short distance and long distance coefficients [1, 3]. The long distance coefficients are obtained through phenomenological potential model description of the mesons.

The mass spectrum of the $c\bar{c}$ meson is reviewed in non-relativistic phenomenological quark antiquark potential of the type $V(r) = -\frac{\alpha_c}{r} + Ar^{\nu}$, with ν varying from 0.5 to 2[1]. By incorporating the relativistic corrections of order v^4 to the heavy quarkonium decays into two photons and the vector state into lepton pairs are computed within the NRQCD formalism. It is expected that the NRQCD formalism has all the corrective contributions for the right predictions of the decay rates. NRQCD factorization expressions for the decay rates of quarkonium and decay are given by [4]

$$\begin{aligned}
&\Gamma(^1S_0 \to \gamma\gamma) \\
&= \frac{F_{\gamma\gamma}(^1S_0)}{m_Q^2}\left|<0|\chi^\dagger\psi|^1S_0>\right|^2 + \frac{G_{\gamma\gamma}(^1S_0)}{m_Q^4} \\
&Re[<^1 S_0|\psi^\dagger\chi|0><0|\chi^\dagger(-\frac{i}{2}\overrightarrow{D})^2\psi|^1S_0>] \\
&+\frac{H^1_{\gamma\gamma}(^1S_0)}{m_Q^6}[<^1 S_0|\psi^\dagger(-\frac{i}{2}\overrightarrow{D})^2\chi|0> \\
&<0|\chi^\dagger(-\frac{i}{2}\overrightarrow{D})^2\psi|^1S_0> + \frac{H^2_{\gamma\gamma}(^1S_0)}{m_Q^6} \\
&Re[<^1 S_0|\psi^\dagger\chi|0><0|\chi^\dagger(-\frac{i}{2}\overrightarrow{D})^4\psi|^1S_0>] \qquad (1)
\end{aligned}$$

$$\begin{aligned}
&\Gamma(^3S_1 \to e^+e^-) = \frac{F_{ee}(^3S_1)}{m_Q^2} \\
&\left|<0|\chi^\dagger\sigma\psi|^3S_1>\right|^2 + \frac{G_{ee}(^3S_1)}{m_Q^4} \\
&Re[<^3 S_1|\psi^\dagger\sigma\chi|0><0|\chi^\dagger\sigma(-\frac{i}{2}\overrightarrow{D})^2\psi|^3S_1>] \\
&+\frac{H^1_{ee}(^1S_0)}{m_Q^6}<^3 S_1|\psi^\dagger\sigma(-\frac{i}{2}\overrightarrow{D})^2\chi|0> \\
&<0|\chi^\dagger\sigma(-\frac{i}{2}\overrightarrow{D})^2\psi|^3S_1> + \frac{H^2_{ee}(^1S_0)}{m_Q^6} \\
&Re\left[<^3 S_1|\psi^\dagger\sigma\chi|0><0|\chi^\dagger\sigma(-\frac{i}{2}\overrightarrow{D})^4\psi|^3S_1>\right] \qquad (2)
\end{aligned}$$

The short distance coefficients F's and G's of the order of α_s^2 and α_s^3 are given by [4]

$$\begin{aligned}
&F_{\gamma\gamma}(^1S_0) = 2\pi Q^4\alpha^2\left[1 + \left(\frac{\pi^2}{4} - 5\right)C_F\frac{\alpha_s}{\pi}\right] \\
&G_{\gamma\gamma}(^1S_0) = -\frac{8\pi Q^4}{3}\alpha^2 \\
&H^1_{\gamma\gamma}(^1S_0) + H^2_{\gamma\gamma}(^1S_0) = \frac{136\pi}{45}Q^4\alpha^2 \qquad (3)
\end{aligned}$$

$$\begin{aligned}
&F_{ee}(^3S_1) = \frac{2\pi Q^2\alpha^2}{3}\{1 - 4C_F\frac{\alpha_s(m)}{\pi} + [- \\
&117.46 + 0.82n_f + \frac{140\pi^2}{27}ln(\frac{2m}{\mu_A})](\frac{\alpha_s}{\pi})^2\} \qquad (4)
\end{aligned}$$

$$G_{ee}(^3S_1) = -\frac{8\pi Q^2}{9}\alpha^2$$

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TABLE I: Decay rates (in keV) of $0^{-+} \to \gamma\,\gamma$ and the relevant correction terms of η_c meson.

$c\bar{c}$		Potential index ν				Expt[5]
State		0.5	1.0	1.5	2.0	
1S	Γ_0	8.17	14.65	19.97	24.297	7.2
	Γ_{0r}	5.53	9.93	13.53	16.462	± 0.7
	Γ_{NRQ}	6.08	9.39	13.142	15.60	
2S	Γ_0	1.64	3.96	6.28	8.34	1.3
	Γ_{0r}	1.11	2.68	4.25	5.65	± 0.6
	Γ_{NRQ}	2.72	8.22	15.19	22.24	
3S	Γ_0	0.74	1.99	3.32	4.54	1.21[6]
	Γ_{0r}	0.49	1.35	2.25	3.08	
	Γ_{NRQ}	1.11	4.34	9.53	14.07	

TABLE II: Decay rates (in keV) of $1^{--} \to l^+\,l^-$ and the relevant correction terms of J/ψ meson.

$c\bar{c}$		Potential index ν				Expt[5]
State		0.5	1.0	1.5	2.0	
1S	Γ_{VW}	6.13	11.05	15.16	18.55	5.55
	Γ_{rad}	5.51	9.89	13.52	16.49	± 0.14
	Γ_{NRQ}	4.97	12.39	19.04	30.03	
2S	Γ_{VW}	1.23	2.87	4.72	6.28	2.48
	Γ_{rad}	0.65	1.41	2.32	3.08	± 0.06
	Γ_{NRQ}	1.23	4.35	9.40	15.17	
3S	Γ_{VW}	0.55	1.49	2.49	3.41	0.86
	Γ_{rad}	0.27	0.73	1.22	1.67	± 0.07
	Γ_{NRQ}	0.46	2.01	5.01	9.34	

$$H^1_{ee}(^3S_1) + H^2_{ee}(^3S_1) = \frac{58\pi}{54} Q^2 \alpha^2 \quad (5)$$

details of the above equations are given in Ref[1].

Accordingly, the two photon decay width of the pseudoscalar meson is given by [1]

$$\Gamma(0^{-+} \to 2\gamma) = \Gamma_0 + \Gamma_R \quad (6)$$

Here Γ_0 is the conventional Van Royen-Weisskopf term for the $0^{-+} \to \gamma\gamma$ decays [2], where Γ_R is due to the radiative corrections for this decay which is given by

$$\Gamma_0 = \frac{12\alpha_e^2 e_Q^4}{M_P^2}\; R_P^2(0) \quad (7)$$

and

$$\Gamma_R = \frac{\alpha_s}{\pi}\left(\frac{\pi^2 - 20}{3}\right)\Gamma_0 \quad (8)$$

Similarly, the leptonic decay width of the vector meson is computed as

$$\Gamma(1^{--} \to l^+ l^-) = \Gamma_{VW} + \Gamma_{rad} \quad (9)$$

$$\Gamma_{VW} = \frac{4\alpha_e^2 e_Q^2}{M_V^2}\; R_V^2(0) \quad (10)$$

Γ_{rad}, the radiative correction is given by

$$\Gamma_{rad} = \frac{-16}{3\pi}\alpha_s\, \Gamma_{VW} \quad (11)$$

It is obvious to note that the computations of the decay rates and the radiative correction term described here require the right description of the meson state through its radial wave function at the origin, R(0) and its mass M along with other model parameters like α_s and the model quark masses.

Results and discussion

Here in this paper we have calculated the di-gamma and di-leptonic decays widths (states 1S, 2S and 3S) of $c\bar{c}$ meson using the conventional Van Royen-Weisskopf (VW)formula with and without radiative correction and NRQCD formalism. The predicted digamma width of η_c for state 1S, 2S and 3S are close to the experimental results at ν between 0.5 to 1.0. We are getting the similar trend in dileptonic widths of J/ψ also.
Details of this paper will be presented in the conference.

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