Radially excited state masses and decay constants of $c\bar{c}$

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Introduction

The charmonia have gained considerable theoretical interest due to many new states being discovered experimentally. Many theoretical models assume the charmonium to be a regular $Q\bar{Q}$ state however the possibility of exotics is also viable. In this paper we estimate the low lying masses of the $c\bar{c}$ mesons using the gaussian wave function within a phenomenological potential model framework. Various $L = 0$ state masses and decay constants are obtained. The results are further compared with other experimental as well as theoretical model predictions.

Methodology

For the present study we employ the hamiltonian[1]

$$H = \sqrt{\mathbf{p}^2 + m_Q^2} + \sqrt{\mathbf{p}^2 + m_{\bar{Q}}^2} + V(r); \quad (1)$$

where m_i are the quark masses and potential $V(r)$ is given[2, 3] by

$$V(r) = -\frac{4}{3}\frac{\alpha_S}{r} + Ar + \left(\frac{1}{m_Q} + \frac{1}{m_{\bar{Q}}}\right) + V_0 \quad (2)$$

here α_S is the running strong coupling constant, A is a potential parameter and V_0 is a constant. We expand the hamiltonian up to order $\mathbf{p}^6$. The value of the QCD coupling constant α_S is determined as in ref [4].

In the present calculation we have employed $A = 0.18$, GeV and $m_c = 1.4$ GeV. We use variational method in which the trial wave function is a Gaussian. The position space wave function is given by

$$R_{nl}(\mu, r) = \mu^{3/2}\left(\frac{2(n-1)!}{\Gamma(n+l+1/2)}\right)^{1/2} \times (\mu r)^l e^{-\mu^2 r^2/2} L_{n-1}^{l+1/2}\left(\mu^2 r^2\right); (3)$$

and in the momentum space it is

$$R_{nl}(\mu, p) = \frac{(-1)^n}{\mu^{3/2}}\left(\frac{2(n-1)!}{\Gamma(n+l+1/2)}\right)^{1/2} \times \left(\frac{p}{\mu}\right)^l e^{-p^2/2\mu^2} L_{n-1}^{l+1/2}\left(\frac{p^2}{\mu^2}\right); (4)$$

μ is a variational parameter and L is Laguerre polynomial. The variational parameter μ is determined by making use of the virial theorem[5].

$$\langle K.E\rangle = \left\langle \frac{dV}{rdr} \right\rangle \quad (5)$$

The kinetic energy part is evaluated by making use of the wave function in momentum space whereas the potential energy part is evaluated with the help of wave function in position space. With this value of μ spin-averaged(SA) masses of $c\bar{c}$ meson are obtained by using

$$H\psi = E\psi. \quad (6)$$

The ground state spin-averaged mass is matched with the experimental spin-averaged mass in order to determine the constant V_0. Fitted value of constant $V_0 = -0.00123$ GeV. By making use of the fitted ground state parameters further radially excited state masses are obtained. The calculated values of the masses of the various S-wave states are listed in table I.

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TABLE I: S-wave masses of the $c\bar{c}$ meson(in GeV).

State	Present Work	Expt.[6]	Ref.[7]	Ref.[4]	Ref.[8]	Ref.[9]
1^1S_0	2.989	2.980	2.984	2.981	2.979	2.980
1^3S_1	3.096	3.097	3.096	3.096	3.096	3.097
2^1S_0	3.661	3.637	3.665	3.635	3.588	3.608
2^3S_1	3.684	3.686	3.692	3.686	3.686	3.686
3^1S_0	4.097		4.111	3.989	3.991	
3^3S_1	4.109	4.039	4.126	4.039	4.088	
4^1S_0	4.464		4.484	4.401		
4^3S_1	4.473	4.421	4.494	4.427		

TABLE II: Decay constants of the $c\bar{c}$ meson(in GeV).

State	f_P		f_V		
	Present	Ref.[10]	Present	Ref.[10]	Ref.[11]
1S	0.375	0.335 ± 0.075	0.383	0.416 ± 0.006	0.459 ± 0.028
2S	0.158		0.158		
3S	0.111		0.111		
4S	0.088		0.088		

Decay Constants

We compute the decay constants using the Van Royen-Weisskopff[12] formula with QCD correction[13],

$$f^2_{P/V} = \frac{12\left|\psi_{P/V}(0)\right|^2}{M_{P/V}}\left(1 - \frac{\alpha_S}{\pi}\right) \quad (7)$$

where, $\psi_{P/V}(0)$ is the wave function at the origin of the pseudoscalar or vector meson. Results are tabulated in table II

Discussion

Looking at table I we find that there is a good agreement between the estimated values for the masses obtained in the present work with experimental as well as other theoretical model predictions. However as can be seen from table II the decay constants obtained in the present model are not in good agreement with other theoretical model predictions. Further experimental results are required to better test the validity of present model.

Acknowledgments

Dr A K Rai acknowledges the financial support from Department of Science & Technology, India under the fast Track project SR/FTP/PS-152/2012.

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