Masses of P and D wave $c\bar{b}$ states in relativistic model

Antony Prakash Monteiro[1],* Manjunath Bhat[1], K. B. Vijaya Kumar[2], and Bhavyashri[3]
[1] *P.G Department of Physics, St Philomena College, Darbe, Puttur-574202,INDIA*
[2] *Deptartment Physics, Mangalore University, Mangalagangothri P.O., Mangalore - 574199, INDIA and*
[3] *Department of Physics,ACS College of Engineering,Bangalore*

Introduction

The B_c meson is a double heavy quark-antiquark bound state and carries flavours explicitly and provides a good platform for a systematic study of heavy quark dynamics. B_c mesons are predicted by the quark model to be members of the $J^P = 0^-$ pseudo scalar ground state multiplet [1]. The first successful observation of B_c meson was made by CDF collaboration in 1998 from run I at TEVATRON through the semileptonic decay channel $B_c \to J/\Psi + l^+ + \bar{\nu}_l$ [2]. They measured the mass of B_c to be $m_{B_c} = 6.40 \pm 0.39 \pm 0.13$ GeV and the life time $\tau_{B_c} = 0.46^{+0.18}_{-0.16} \pm 0.03$ ps. The more precise measurement of mass of B_c i.e.,$m_{B_c} = 6275.6 \pm 2.9(\text{stat}) \pm 5(\text{syst})$ MeV/c^2 was done by the CDF collaboration through the exclusive non-leptonic decay $B_c \to J/\Psi\pi^+$[3]. The results of the CDF collaboration was confirmed by the observations made by the D0 collaboration [3] at TEVATRON. The LHCb has reported several new observations on B_c decays recently. More experimental data on B_c meson are expected to come in near future from LHCb and TEVATRON.

Theory

We investigate properties of $c\bar{b}$ states using confined one gluon exchange potential in the frame work of relativistic harmonic model (RHM) [4]. The Hamiltonian used has the confinement potential and a two body confined one gluon exchange potential(COGEP) [5–8].

In RHM, quarks in a hadron are confined through action of a Lorentz scalar plus a vector harmonic oscillator potential [9, 10]

$$V_{CONF}(r) = \frac{1}{2}(1+\gamma_0)A^2r^2 + M \quad (1)$$

where γ_0 is the Dirac matrix, M is a constant mass and α^2 is the confinement strength.

The central part of the COGEP is

$$V^{cent}_{COGEP}(\vec{r}) = \frac{\alpha_s N^4}{4}\lambda_i \cdot \lambda_j \left[D_0(\vec{r}) + \frac{1}{(E+M)^2}\left[4\pi\delta^3(\vec{r}) - c^4r^2D_1(\vec{r})\right]\left[1 - \frac{2}{3}\vec{\sigma}_i \cdot \vec{\sigma}_j\right]\right] \quad (2)$$

where $D_0(r)$ and $D_1(r)$ are the propagators given by

$$D_0(r) = \frac{\Gamma_{1/2}}{4\pi^{3/2}}c(cr)^{-3/2}W_{1/2;-1/4}(c^2r^2) \quad (3)$$

$$D_1(r) = \frac{\Gamma_{1/2}}{4\pi^{3/2}}c(cr)^{-3/2}W_{0;-1/4}(c^2r^2) \quad (4)$$

where $\Gamma_{1/2} = \sqrt{\pi}$, W's are Whittaker functions and $c(\text{fm}^{-1})$ is a constant parameter which gives the range of propagation of gluons and is fitted in the CCM to obtain the glue-ball spectra and r is the distance from the confinement center.

The spin orbit part of COGEP is

$$V^{LS}_{12} = \frac{\alpha_s}{4}\frac{N^4}{(E+M)^2}\frac{\lambda_1 \cdot \lambda_2}{2r} \times \Big[[r \times (\hat{P}_1 - \hat{P}_2)\cdot(\sigma_1+\sigma_2)] (D_0'(r) + 2D_1'(r)) + [r \times (\hat{P}_1 + \hat{P}_2)\cdot(\sigma_1-\sigma_2)] (D_0'(r) - D_1'(r))] \quad (5)$$

The spin orbit term has been split into the symmetric $(\sigma_1+\sigma_2)$ and anti symmetric $(\sigma_1 - \sigma_2)$ spin orbit terms.

The tensor part of the COGEP is,

$$V^{TEN}_{12}(r) = -\frac{\alpha_s}{4}\frac{N^4}{(E+M)^2}\lambda_1 \cdot \lambda_2 \times \left[\frac{D_1''(r)}{3} - \frac{D_1'(r)}{3r}\right]S_{12} \quad (6)$$

*Electronic address: aprakashmonteiro@gmail.com

where

$$S_{12} = [3(\sigma_1 \cdot \hat{r})(\sigma_2 \cdot \hat{r}) - \sigma_1 \cdot \sigma_2] \quad (7)$$

TABLE I: B_c **meson mass spectrum (in GeV).**

State $n\ ^{2S+1}L_J$	This work	Ref. [11]	Ref. [1]	Ref.[12]
$1\ ^3P_0$	6.646	6.680	6.700	6.699
$1P1$	6.663	6.730	6.730	6.734
$1P1'$	6.696	6.740	6.736	6.749
$1\ ^3P_2$	6.700	6.760	6.747	6.762
$1\ ^3D_1$	6.941	7.010	7.012	7.072
$1D2$	6.945	7.020	7.012	7.077
$1D2'$	6.960	7.030	7.009	7.079
$1\ ^3D_3$	6.962	7.040	7.005	7.081
$2\ ^3P_0$	7.103	7.100	7.108	7.091
$2P1$	7.120	7.140	7.135	7.126
$2P1'$	7.140	7.150	7.142	7.145
$2\ ^3P_2$	7.147	7.160	7.153	7.156
$3\ ^3S_1$	7.316	7.280	7.235	

Results and Conclusion

The six parameters in our model are the mass of charm quark M_c, the mass of beauty quark M_b, the harmonic oscillator size parameter b, the confinement strength A^2, the CCM parameter c and the quark-gluon coupling constant α_s. We use the following set of parameter values.
$M_c = 1.552$ GeV; $M_b = 4.880$ GeV;
$b = 0.25$ fm; $\alpha_s = 0.3$; $A^2 = 780$ MeV fm^{-2};
$c = 1.74$ fm^{-1}
The calculated masses of the $c\bar{b}$ states after diagonalization are listed in Table I. Our calculated mass value for $B_c(1S)$ is 6277.99 MeV and for $B_c^*(1\text{S})$ is 6341.09 MeV. $B_c^*(1\text{S})$ is heavier than $B_c(1\text{S})$ by 63.1 MeV. This difference is justified by calculating the $^3S_1 - ^1S_0$ splitting of the ground state which is given by

$$M(^3S_1) - M(^1S_0) = \frac{32\pi\alpha_s|\psi(0)|^2}{9m_c m_b} \quad (8)$$

The mass of first radial excitation $B_c(2\text{S})$ is 6861.2 MeV which is heavier than $B_c(1\text{S})$ by 583.21 MeV. This value agrees with the experimental value of $B_c(2\text{S})$ 6842±4±5 [13]. The difference between the $B_c^*(2\text{S})$ and $B_c^*(1\text{S})$ masses turns out to be 520.11 MeV. Our prediction for masses of orbitally excited $c\bar{b}$ states are in good agreement with the other model calculations.

The complete spectrum of $c\bar{b}$ states has been calculated in a relativistic quark model. The ground state mass of $c\bar{b}$ state calculated in our model matches the experimental data. When the results for $c\bar{b}$ state mass spectrum are compared with the previous calculations, it is found that the predictions for the mass spectrum agree within a few MeV. The differences between the predictions in most cases do not exceed 30 MeV and the higher orbitally excited states are 50-80 MeV heavier in our model.

Acknowledgments

One of the authors (APM) is grateful to BRNS, DAE, India for granting the project and JRF (37(3)/14/21/2014BRNS).

References

[1] E. J. Eichten and C. Quigg, Phys. Rev. D **49**, 5845 (1994)
[2] F. Abe *et al.* (CDF Collaboration) Phys. Rev. D **58**, 112004 (1998)
[3] K. Olive et al., Chinese Physics C **38**, 090001 (2014).
[4] S. B. Khadkikar and S. K. Gupta, Phys. Lett. B **124**, 523 (1983).
[5] P. C. Vinod Kumar, K. B. Vijaya Kumar and S. B. Kadkikar, Pramana J. Phys. **39**, 47 (1992).
[6] S. B. Khadkikar and K. B. Vijaya Kumar, Phys. Lett. B **254**, 320 (1991).
[7] K. B. Vijaya Kumar and S. B. Khadkikar, Nucl. Phys. A **556**, 396 (1993).
[8] K. B. Vijaya Kumar, A. K. Rath and S. B. Khadkikar, Pramana J. Phys. **48**, 997 (1997).
[9] K. B. Vijaya Kumar, B. Hanumaiah, and S. Pepin, Eur. Phys. J. **A19**, 247 (2004).
[10] K. B. Vijaya Kumar, Bhavyashri, Yong-Ling Ma, and A. P. Monteiro, Int. J. Mod. Phys. A **22**, 4209 (2009).
[11] J. Zeng, J. W. Van Orden and W. Roberts, Phys. Rev. D **52**, 5229(1995).
[12] D. Ebert, R. N. Faustov and V. O. Galkin, Phys. Rev. D **67**, 014027(2003)
[13] G. Aad *et al.* ((ATLAS Collaboration)), Phys. Rev. Lett. **113**, 212004 (2014).