Mass Spectra of B, B_s Mesons using Dirac formalism with martin-like confinement potential

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Introduction

The recent observations of $B(5970)$ and $B_J^*(5732)$ by CDF Collaboration [1–3] and $B_J^*(5732)$ by DELPHI, OPAL and ALEPH collaboration [4], $B_{sJ}^*(5850)$ by OPAL collaboration [5] have created considerable interest in B and B_s meson spectroscopy. The predictions of masses of heavy-light system for low-lying states of these open beauty mesons thus become important from the point of view of understanding the behaviour of quantum chromodynamics at this hadronic scale. More over, these are open flavour beauty mesons, their decays are dominated by weak interaction processes and are free from interference due to strong interaction processes. Thus the complete understanding of the spectroscopy and decay properties of these open flavour mesons becomes very important. Though there exist theoretical predictions [6–8] for the lowlying states of B, B_s mesons,their excited state predictions in view of the new observations in the energy range 5-6 GeV become topics of current interest. Here we study the mass spectra of B and B_s mesons in a relativistic framework [9, 10].

TABLE I: Mass spectra of B ($c\bar{q}$, q = d,u) meson (in MeV).

nL	State	Present	Experiment		[7]	[8]
			Meson	Mass [1]		
1S	1^3S_1	5325.59	B^*	5325.2 ±0.4	5330	5326
	1^1S_0	5279.20	B^0	5279.58 ±0.26	5266	5280
2S	2^3S_1	5851.56			5946	5906
	2^1S_0	5820.43			5930	5890
3S	3^3S_1	6374.89		-	6396	6387
	3^1S_0	6349.38		-	6387	6379
4S	4^3S_1	6897.83		-	6773	6786
	4^1S_0	6875.23		-	6779	6781
1P	1^3P_2	5746.17	$B_2^*(5747)$	5743 ± 5	5779	5741
	1^3P_1	5736.28		-	5785	5774
	1^3P_0	5693.72	$B_0^*(5732)$	5698 ± 8 [6]	5746	5749
	1^1P_1	5726.69	$B_1(5721)$	5723.5 ± 2.0	5764	5723
2P	2^3P_2	6212.55		-	6255	6260
	2^3P_1	6202.24		-	6256	6281
	2^3P_0	6168.06		-	6225	6221
	2^1P_1	6193.39		-	6243	6209

Theoretical Framework

The quark confining interaction of meson is considered to be produced by the nonperturbative multigluon mechanism and this mechanism is unfeasible to estimate theoretically from first principles of QCD. On the other hand, there exists ample experimental support for the quark structure of hadrons. This is the origin of phenomenological models which are proposed to understand the properties of hadrons and quark dynamics at the hadronic scale. In this context for the present study, we assume that the constituent quarks inside a meson are independently confined by an average potential of the form [9]

$$V(r) = \frac{1}{2}(1+\gamma_0)(\lambda r^{0.1} + V_0) \qquad (1)$$

The two component solution of the positive and negative energy solutions of the Dirac equation can be written as

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$$\psi_A^{(+)}(\vec{r}) = N_{nlj} \begin{pmatrix} \frac{ig(r)}{r} \\ \frac{(\sigma.\hat{r})f(r)}{r} \end{pmatrix} \mathcal{Y}_{ljm}(\hat{r}) \quad (2)$$

$$\psi_B^{(-)}(\vec{r}) = N_{nlj} \begin{pmatrix} \frac{i(\sigma.\hat{r})f(r)}{r} \\ \frac{g(r)}{r} \end{pmatrix} (-1)^{j+m_j-l} \mathcal{Y}_{ljm}(\hat{r}) \quad (3)$$

Here $+/-$ represents the positive (quark) and negative (antiquark) energy states and N_{nlj} is the overall normalization constant.

The radial solutions f(r) and g(r) is obtained numerically to yield the energy eigen values. The meson radial wave function for $q\bar{q}$ combination is constructed with the respective quark and anti-quark wave functions given by Eqn. (2) and (3). The parameters are fixed to get the ground state masses of B and B_s mesons. The optimised quark mass parameters m_b, $m_{u,d}$ and m_s are 4.67 GeV, 0.003 GeV and 0.1 GeV respectively.

Results and Discussion

The predicted S-wave masses of B and B_s mesons are in very good agreement with experimental [1] results as given in Table I and II respectively. The predicted results of P-wave B meson states, 1^3P_2 (5746.17 MeV), 1^3P_0 (5693.72 MeV) and 1^1P_1 (5726.69 MeV) are in good agreement with experimental results of 5743 ± 5 MeV, 5698 ± 8 MeV and 5723.5 ± 2.0 MeV [1] respectively. We find the newly observed $B(5970)$ state as a mixed state of 2^3S_1 and 1^3D_1 with mixing angle(θ) 43°. The predicted results of P-wave B_s meson states 1^3P_2 (5841.69 MeV), 1^3P_1 (5830.90 MeV) and 1^1P_1 (5824.24 MeV) are also in good agreement with experimental results 5839.96 ± 0.2 MeV, 5853 ± 15 MeV and 5828.7 ± 0.4 MeV [1] respectively.

TABLE II: Mass spectra of B_s ($b\bar{s}$) meson (in MeV).

			Experiment			
nL	State	Present	Meson	Mass [1]	[7]	[8]
1S	1^3S_1	5415.12	B_s^*	5415.8±1.5	5417	5414
	1^1S_0	5368.38	B_s	5366.7±0.4	5355	5372
2S	2^3S_1	5944.17			6016	5992
	2^1S_0	5912.92			5998	5976
3S	3^3S_1	6468.97			6449	6475
	3^1S_0	6443.39			6441	6467
4S	4^3S_1	6992.79			6818	6879
	4^1S_0	6970.14			6812	6874
1P	1^3P_2	5841.69	$B_{s2}^*(5840)$	5839.96±0.2	5859	5842
	1^3P_1	5830.90	$B_{s1}(5850)$	5853±15	5857	5865
	1^3P_0	5782.74			5820	5833
	1^1P_1	5824.24	$B_{s1}(5830)$	5828.7±0.4	5845	5831
2P	2^3P_2	6309.69			6317	6359
	2^3P_1	6298.67			6312	6321
	2^3P_0	6258.95			6283	6318
	2^1P_1	6293.24			6306	6345

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References

[1] K.A. Olive et al. (Particle Data Group), Chin. Phys. C 38 (2014) 090001.
[2] T. Aaltonen et al. (CDF Collaboration), Phys. Rev. D 90 (2014) 012013.
[3] T. Affolder et al. (CDF Collaboration), Phys. Rev. D 64 (2001) 072002.
[4] P. Abreu et al, Phys. Lett. B 345 (1995) 598; R. Akers et al, Z. Phys. C66 (1995) 19; D. Buskulic et al, Z. Phys. C69 (1996) 393; R. Barate et al, Phys. Lett. B425 (1998) 215.
[5] R. Akers et al. (OPAL Collaboration), Z. Phys. C 66 (1995) 19.
[6] Vivek Jain, Modern Phys. Lett. A 20 (2005) 629.
[7] N. Devlani and A.K. Rai, Eur. Phys. J. A 48 (2012) 104.
[8] D. Ebert, R. Faustov, V. Galkin, Eur. Phys. J. C 66 (2010) 197.
[9] N.Barik, B. K. Dash, and M. Das, Phys. Rev. D 31, 1652 (1985).
[10] Manan Shah, Bhavin Patel and P. C. Vinodkumar, Phys. Rev. D 90 (2014) 014009.