Mass spectrum and decay width for excited ($n = 2$) $D-$wave Bottom meson family

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Introduction

Mesonic system carrying one heavy quark ($m_Q \gg \Lambda_{QCD}$) and one anti-light quark ($m_q \ll \Lambda_{QCD}$) provides unique opportunity to study low energy QCD physics where Λ_{QCD} is non perturbartive scale of 1 GeV. In recent decades, meson spectroscopy have flourished theoretically as well as experimentally. Many new candidates like $D_J^*(3000)$, $D_J(3000)$, $D_1^*(2680)$, $D_{so}(2590)^+$, $B_J(5840)$, $B_{s1}(5830)$, $B_{s2}^*(5840)$, $B_S^0(6108.8)$, $B_S^0(6114)$, $B_S^0(6158)$[1–3] observed by experimental facilities LHCb, $D\emptyset$, BABAR, BESIII collaborations enriched meson spectrum. These upcoming data stimulates curiosity of theorists to test reliability of available theoretical models. So, in same context, using available data on charm mesons and applying heavy quark symmetry parameters, we predict the masses and decay widths for experimentally missing D-wave bottom mesons.

Framework

In heavy quark limit ($m_Q \to \infty$), total angular momentum of light quark $j_q = s_q + l$ decouples from spin of heavy quark s_Q. Here $s_q = 1/2$ is spin of light quark and l =orbital angular momentum of light quark. So, total angular momentum of mesons is $J = j_q + s_Q$ and parity $P = (-1)^{l+1}$. The quantum number s_Q and j_q are individually conserved. For given value of l, meson are classified into doublets described by total angular momentum J. For $D-$wave state, $l = 2$, two doublets are given as $(1^-, 2^-)$ and $(2^-, 3^-)$. The effective fields describing these doublets are

$$X_a^{\mu} = \frac{1+\not{v}}{2}\{P_{2a}^{\mu\nu}\gamma_5\gamma_\nu - P_{1a\nu}^{*}\sqrt{\frac{3}{2}}\left[g^{\mu\nu} - \frac{\gamma_\nu(\gamma^\mu + v^\mu)}{3}\right]\} \quad (1)$$

$$Y_a^{\mu\nu} = \frac{1+\not{v}}{2}\left\{P_{3a}^{*\mu\nu\sigma}\gamma_\sigma - P_{2a}^{\alpha\beta}\sqrt{\frac{5}{3}}\gamma_5\left[g_\alpha^\mu g_\beta^\nu - \frac{g_\beta^\nu\gamma_\alpha(\gamma^\mu - v^\mu)}{5} - \frac{g_\alpha^\mu\gamma_\beta(\gamma^\nu - v^\nu)}{5}\right]\right\} \quad (2)$$

where a is light quark flavour index and v is heavy quark four velocity. In HQET(Heavy quark effective theory) framework, mass splitting parameters Δ_F, λ_F are independent of flavour of heavy quark due to heavy quark symmetry [4]. Mass parameter Δ_F is defined as spin averaged mass difference between higher states and ground state doublet. Another mass parameter λ_F is defined as hyperfine splitting between spin partners of each doublets. For D-wave these parameters are described as: $\overline{M}_X = (5m_{X^*}^Q + 3m_X^Q)/8$, $\overline{M}_Y = (7m_{Y^*}^Q + 5m_Y^Q)/12$, $\lambda_X = \frac{3}{16}(M_{P_2}^2 - M_{P_1^*}^2)$, $\lambda_Y = \frac{3}{16}(M_{P_3}^2 - M_{P_2^{*'}}^2)$ Beauty of heavy quark symmetry implies: $\Delta_F^{(c)} = \Delta_F^{(b)}$, $\lambda_F^{(c)} = \lambda_F^{(b)}$. Using above mentioned flavour symmetry parameters and available charm meson masses for $n = 2$, we estimate masses for $n = 2$ $D-$wave bottom meson. When considering decays of excited D-wave mesons to ground state, strong decay width expressions are: $(1^-, 2^-) \to (0^-, 1^-) + M$

$$\Gamma(1^- \to 0^-) = C_M\frac{4g_{XH}^2}{9\pi f_\pi^2\Lambda^2}\frac{M_f}{M_i}[p_M^3(m_M^2 + p_M^2)] \quad (3)$$

$$\Gamma(1^- \to 1^-) = C_M\frac{2g_{XH}^2}{9\pi f_\pi^2\Lambda^2}\frac{M_f}{M_i}[p_M^3(m_M^2 + p_M^2)] \quad (4)$$

$$\Gamma(2^- \to 1^-) = C_M\frac{2g_{XH}^2}{3\pi f_\pi^2\Lambda^2}\frac{M_f}{M_i}[p_M^3(m_M^2 + p_M^2)] \quad (5)$$

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$$(2^-,3^-) \rightarrow (0^-,1^-)+M$$

$$\Gamma(2^- \rightarrow 1^-) = C_M \frac{4g_{YH}^2}{15\pi f_\pi^2 \Lambda^4} \frac{M_f}{M_i} [p_M^7] \quad (6)$$

$$\Gamma(3^- \rightarrow 0^-) = C_M \frac{4g_{YH}^2}{35\pi f_\pi^2 \Lambda^4} \frac{M_f}{M_i} [p_M^7] \quad (7)$$

$$\Gamma(3^- \rightarrow 1^-) = C_M \frac{16g_{YH}^2}{105\pi f_\pi^2 \Lambda^4} \frac{M_f}{M_i} [p_M^7] \quad (8)$$

Numerical Analysis

To study the dynamics of heavy-light $B-$mesons, masses are the most fundamental property to be studied. So, we have calculated masses for $n = 2$ $D-$wave bottom mesons. The preliminary step is to determine average masses $\overline{M_F}$, then calculate symmetry parameters Δ_F, λ_F for input values mentioned in Table 1. Now using

TABLE I: Input values used in this work [5]. All values are in units of MeV.

State	J^P	$c\bar{q}$	$c\bar{s}$	$b\bar{q}$	$b\bar{s}$
2^1S_0	0^-	2581	2643	-	-
2^3S_1	1^-	3110	3193	-	-
2^3D_1	1^-	3231	3306	-	-
2^1D_2	2^-	3248	3323	-	-
2^3D_2	2^-	3212	3298	-	-
2^3D_3	3^-	3226	3311	-	-
2^1S_0	0^-	-	-	5904	5984
2^3S_1	1^-	-	-	5933	6012

heavy quark symmetry $\Delta_F^{(c)} = \Delta_F^{(b)}$, $\lambda_F^{(c)} = \lambda_F^{(b)}$ and inputs mentioned in Table I, we computed masses for $n = 2$ $D-$wave bottom meson. The results are listed in Table II. Our computed masses are compared with different theoretical models in Table II, and our results are in good agreement with theoretical models. Using these predicted masses, we calculated strong decay width from excited($n = 2$) to ground state only in terms of coupling constants for non strange $D-$wave bottom mesons. Values of these decay widths are $\Gamma_{B(2^3D_1)} = 20.45\ \tilde{\tilde{g}}_{XH}$, $\Gamma_{B(2^1D_2)} = 18.72\ \tilde{\tilde{g}}_{XH}$, $\Gamma_{B(2^3D_2)} = 4634.91\ \tilde{\tilde{g}}_{YH}$, $\Gamma_{B(2^3D_3)} = 7312.51\ \tilde{\tilde{g}}_{YH}$.

TABLE II: Predicted masses for radially excited bottom mesons

J^P	Masses of n=2 Bottom Mesons (MeV)					
	Non-Strange			Strange		
$(n^{2S+1}L_J)$	calculated	[6]	[7]	calculated	[6]	[7]
$1^-(2^3D_1)$	6534.61	6542	6475	6606.61	6629	6542
$2^-(2^1D_2)$	6543.02	6534	6486	6615.02	6625	6536
$2^-(2^3D_2)$	6504.00	6554	6450	6578.00	6651	6542
$3^-(2^3D_3)$	6556.57	6528	6460	6629.57	6637	6534

Conclusion

Using HQET and applying flavor symmetry with available data of higher charm states, we calculate masses and decay width for $n = 2$ $D-$wave bottom mesons. These decay widths are written with their respective coupling constants. The masses are compared with different theoretical models and data found to be in good agreement. This theory seems to be reliable to confirm higher excited state masses. Theoretical decay widths may help us to constraint these coupling constants $\tilde{\tilde{g}}_{XH}$, $\tilde{\tilde{g}}_{YH}$. The estimated masses and decay widths may get confirmation through further experimental investigations.

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