Study of 1F doublet $(3^+, 4^+)$ for Bottom spectra using HQET

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Introduction

Mesons carrying one heavy quark (Q=c,b) and one light quark (q=u,d,s) act as the hydrogen atom of hadron physics and provides a good platform to study non-perturbative QCD. In the last decade, meson spectroscopy has undergone the discovery of many new mesons like $D_2^*(3000)$, $B_J(5970)$, $B_J(5840)$ etc. These newly observed higher excited charm and bottom states observed by LHCb, CDF, D0, CLEO, BaBar collaborations stimulates the interest of theorists to check the authenticity of the theoretically available models for these upcoming data. It also motivates the theorists to fill the void in the spectrum. So in the same context, we use heavy quark effective theory (HQET) to explore the heavy quark flavor symmetry property to predict the masses and strong decay properties of experimentally missing $1F_{7/2}$ bottom states B_3, B_4^*, B_{S3} and B_{S4}^*. The comparison of our result with other theoretically available data also help in checking the validity of this symmetry for higher excited states.

Framework

In the $m_Q \to \infty$ limit, light quarks have total angular momentum j_q with $j_q = s_q + L$ where s_q is the spin of the light quark and L is its orbital angular momentum. Therefore the resultant angular momentum J for each heavy-light meson is J = $j_q + s_Q$. The quantum numbers s_Q and j_q are separately conserved thus, for a given L, the states will be grouped into doublets characterized by the angular momentum of the light quark. For the F-wave states with L=3 the two doublets are represented as $(2^+, 3^+)$ and $(3^+, 4^+)$. The effective field R for $(3^+, 4^+)$ doublet is given as

$$R_a^{\mu\nu\rho} = \frac{1+\not{v}}{2}\{P_{4a}^{*\mu\nu\rho\sigma}\gamma_5\gamma_\sigma - P_{3a}^{\alpha\beta\tau}\sqrt{\frac{7}{4}} [g_\alpha^\mu g_\beta^\nu g_\tau^\rho - \frac{g_\beta^\nu g_\tau^\rho \gamma_\alpha(\gamma^\mu - v^\mu)}{7} - \frac{g_\alpha^\mu g_\tau^\rho \gamma_\beta(\gamma^\nu - v^\nu)}{7} - \frac{g_\alpha^\mu g_\beta^\nu \gamma_\tau(\gamma^\rho - v^\rho)}{7}]\} \quad (1)$$

where a = u, d, s is the flavor index and v is the meson four velocity. Heavy quark symmetry preserve the property, that the mass splittings among the different doublets are independent of the heavy quark flavor. To use this property, we define two mass splitting parameters Δ_F and λ_F [5]. Δ_F is defined as the spin average mass splittings between the higher mass doublet $(3^+, 4^+)$ and the lowest lying doublet $(0^-, 1^-)$ with $\Delta_F = \overline{M}_F - \overline{M}_H$. Here $\overline{M}_H = (3M_{P_1^*} + M_{P_0})/4$ and $\overline{M}_F = (9M_{P_4^*} + 7M_{P_3})/16$. And the other parameter λ_F is defined as the hyperfine splitting within the members of the doublet $(3^+, 4^+)$ where $\lambda_F = \frac{7}{32}(M_{P_4^*}^2 - M_{P_3}^2)$. According to flavor symmetry these parameters Δ_F and λ_F are the same regardless of the heavy quark flavor (Q=c,b). When considering the heavy-light meson decays of $(3^+, 4^+)$ to $(0^-, 1^-)$ with the emission of a light pseudoscalar meson, the strong decay width formulas are given as

$$\Gamma(3^+ \to 1^-) = C_M \frac{36 g_{RH}^2}{35\pi f_\pi^2 \Lambda^6} \frac{M_f}{M_i}[p_M^9]$$
$$\Gamma(4^+ \to 1^-) = C_M \frac{4 g_{RH}^2}{7\pi f_\pi^2 \Lambda^6} \frac{M_f}{M_i}[p_M^9]$$
$$\Gamma(4^+ \to 0^-) = C_M \frac{16 g_{RH}^2}{35\pi f_\pi^2 \Lambda^6} \frac{M_f}{M_i}[p_M^9] \quad (2)$$

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where g_R is the coupling constant. p_M and m_M are the final momentum and mass of the light pseudo-scalar meson.

Numerical Analysis

To study the behavior of the heavy-light mesons for their spectroscopy, masses are the most important property to be studied, so we start our calculations by predicting the bottom masses for the higher excited 1F $(3^+, 4^+)$ doublet. For this we use the fact that mass slitting parameters Δ_F and λ_F are independent of the heavy quark flavor. Exploring these parameters for the theoretically available charm masses $M(D_3)$=3103.75MeV ,$M(D_4^*)$=3119.75MeV, $M(D_{S3})$=3206MeV and $M(D_{S4}^*)$=3219.25MeV[1, 2], corresponding bottom mesons are obtained which are tabulated in Table I. To check the validity of these parameters, we have also compared the masses of our result with the masses predicted by various other models.

TABLE I: Predicted masses of 1F bottom mesons in MeV.

B_3		B_4^*		
Non-strange	Strange	Non-strange	Strange	
6450.50	6536.39	6458.21	6543.20	Our
6391	6468	6380	6475	[1]
6220	6332	6226	6337	[2]
6358	6425	6364	6432	[3]
6393	6422	6243	6319	[4]

Now we use these calculated bottom masses to study some other properties like strong decay widths and branching ratios for these states. The strong decay width of $(3^+, 4^+)$ doublet decaying to ground state doublet $(0^-, 1^-)$ with the emission of light pseudoscalar mesons are tabulated in Table II and Table III corresponding to non-strange and strange bottom mesons respectively. As these decays are in terms of the experimental unknown coupling constant g_R, so we define the branching ratio with respect to $B^{*+}\pi^-$ and $B^{*0}K^0$ for non-strange and strange states respectively. These ratios are more effective than the total decay width values, as these ratios gives result independent of the coupling constants g_R, thus making the predictions model independent.

Conclusion

We use HQET to check the effectiveness of heavy quark flavor symmetry property for the 1F doublet by predicting the $1F_{7/2}$ bottom state masses. The predicted non-strange bottom masses are only deviated by 1.9%. A similar pattern is observed for strange state masses where the deviations are below 2.1%. This shows that this heavy flavor symmetry property is valid even for the higher excited states. Strong decays of these states concludes that $B^*\pi^+$, $B^+\pi^-$, $B^{*0}K^{*0}$ and B^+K^- decay modes are suitable for the experimental search for these missing non-strange and strange 1F bottom mesons doublets $(3^+, 4^+)$.

TABLE II: Decay width for non-strange bottom mesons in GeV.

Decay	B_3		B_4^*	
channel	Decay Width	Ratio	Decay Width	Ratio
$B^*\pi^+$	$19.13g_R^2$	1	$11.14g_R^2$	1
$B^*\pi^0$	$9.610g_R^2$	0.50	$5.60g_R^2$	0.50
$B^*\eta$	$1.00g_R^2$	0.05	$0.59g_R^2$	0.05
B_s^*K	$3.25g_R^2$	0.16	$1.96g_R^2$	0.17
$B^0\pi^0$	-	-	$6.14g_R^2$	0.55
$B^+\pi^-$	-	-	$12.24g_R^2$	1.09
$B^0\eta$	-	-	$0.72g_R^2$	0.06
B_sK	-	-	$2.53g_R^2$	0.22
Total	$33.00g_R^2$	-	$40.95g_R^2$	-

TABLE III: Decay width for strange bottom mesons in GeV.

Decay	B_3		B_4^*	
channel	Decay Width	Ratio	Decay Width	Ratio
B^0K^0	-	-	$10.63g_R^2$	0.13
B^+K^-	-	-	$10.77g_R^2$	1.15
$B_s\pi^0$	-	-	$6.17g_R^2$	0.65
$B_s\eta$	-	-	$1.47g_R^2$	0.15
$B^{*0}K^0$	$15.97g_R^2$	1	$9.35g_R^2$	1
$B^{*+}K^-$	$16.20g_R^2$	1.01	$9.49g_R^2$	1.01
$B_s^*\pi^0$	$9.38g_R^2$	0.58	$5.47g_R^2$	0.58
$B_s^*\eta$	$2.18g_R^2$	0.13	$1.28g_R^2$	0.13
Total	$43.74g_R^2$	-	$54.66g_R^2$	-

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