Masses and Decays of excited bottom mesons

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Introduction

Recently significant progress has been achieved in studying the spectroscopy of mesons with one heavy quark (Q = c, b) and one light quark (q = u, d, s). Several new excited states $D_0^*(3000)$, $D'_1(3000)$, $D_2(2740)$, $D_3^*(2760)$ and $D_{S3}^*(2860)$ are discovered in charm spectra [1]. But there is very limited information on the spectra of excited bottom mesons. Only the ground state S-waves and a few of the J^P = 3/2 P-waves (1^+, 2^+) are presently well established. The theoretical tools available to determine the properties of excited states in heavy-light systems are heavy quark effective theory (HQET), QCD sum rules, $^3P_0$ model, QCD lattice etc. In this paper we study the unknown $(\tilde{B}_0^*,\ \tilde{B}_1')$ P-wave for n=2 and (B_2, B_3*) D wave for n=1 B and B_S meson states in the framework of heavy quark effective theory and calculated their masses and strong decay widths.

Framework:

In the infinite heavy quark mass limit, the system of heavy-light $Q\bar{q}$ can be classified in doublets defined as n L s_l J_P where n is radial quantum number, $s_l = s_q + l$ is the total angular momentum of light degree of freedom and $J = s_l + s_Q$ is the total momentum of the system. For n = 1, L=0 (S wave), doublet corresponds to s_l =1/2 consisting of two states having spin-parity J^P (0^- , 1^-) represented by (P, P*). Similarly for L=2 (P-wave) there are two doublets, one for s_l =1/2 and second one for s_l =3/2 representing J^P states as (0^+, 1^+) and (1^+, 2^+) respectively. Symbolically these states are notated as (P_0*, P'_1) and (P_1, P_2*) respectively. For n=2, these states are replaced by a tilde (∼) on them e.g. $\tilde{P}, \widetilde{P^*}$. The negative parity ground doublet is represented by H_a field where a=1, 2, 3 for u, d, s. Similarly the excited positive parity doublets are represented by S_a and T_a fields. These fields are used to form an effective lagrangian which is invariant under both the heavy quark spin-flavour and light quark chiral transformations. Spin-averaged masses of the doublets are represented by the mass parameters Δ_F (with F = S, T, X, Y) which is given as $\Delta_F = \bar{M}_F - \bar{M}_H$ i.e. the mass splitting's between the higher mas doublets described by F and the lowest lying doublet described by H field, where

$$\bar{M}_H = \frac{3M_{P^*}+M_P}{4}$$

$$\bar{M}_S = \frac{3M_{P_1'}+M_{P_0^*}}{4}$$

$$\bar{M}_Y = \frac{7M_{P_3^*}+5M_{P_2}}{12}$$

The mass degeneracy between the members of the meson doublets is broken by the terms which involve $\lambda_H, \lambda_S, \lambda_T, \lambda_X, \lambda_Y$ constants given as

$$\lambda_H = \frac{1}{8}\left[M_{P^*}^2 - M_P^2\right]$$

$$\lambda_S = \frac{1}{8}\left[M_{P_1'}^2 - M_{P_0^*}^2\right]$$

$$\lambda_Y = \frac{5}{24}\left[M_{P_3^*}^2 - M_{P_2}^2\right]$$

In the heavy quark limit, information on the bottom mesons can be predicted by exploiting the data available on charm meson masses, decays and couplings. Hence, due to heavy quark symmetry in charm and bottom sectors, we obtain the equalities $\Delta_F^{(c)} = \Delta_F^{(b)}$ and $\lambda_F^{(c)} = \lambda_F^{(b)}$ for $F = \tilde{H}, S, T, X, Y$. In this paper, we use these two equalities and the experimentally available information on charm meson states, to predict the corresponding data of the unknown bottom mesons. Strange masses are predicted on the basis of the fact that, the effect of the strange quark is to shift the mass of a given state by the same amount in the fundamental mode n=1 and for n = 2 radial excitation doublet [2], i.e.

$$M_{D_s} - M_{D^0} = M_{\tilde{D}_s} - M_{\tilde{D}^0} \qquad (1)$$

Using the known masses of the fundamental P wave bottom mesons, the masses for radial quantum number n = 2 can be calculated. These predicted masses are then used to calculate their strong decay widths for F→HM, with M being the light pseudo-scalar mesons (π, η, K). Strong interactions are very important to study the heavy hadrons in the non-perturbative regime and are studied by their decay to light- pseudo scalar mesons. Strong decay width formulae's are derived using the lagrangian interaction term [2]. It can be seen in Ref. [2] that, the decay width depends on the initial and final meson mass, coupling constants, pion decay constant (f_π = 120MeV), chiral symmetry breaking scale (Λ = 1GeV), light pseudo-scalar masses and momentums. For n=1 the couplings are notated as g_{SH}, g_{TH} etc, and for coupling between n=2 and n=1 they will be replaced by $\widetilde{g_{SH}}$, $\widetilde{g_{TH}}$ etc.

Calculations:

Charm states $D_0^*(3000)$, $D'_1(3000)$, $D_2(2740)$, $D_3^*(2760)$ and $D_{S3}^*(2860)$ predicted by LHCb [1] are confirmed to be $2P_{1/2}(0^+)$, $2P_{1/2}(1^+)$, $1D_{5/2}$ (2^-), $1D_{5/2}$ (3^-) and 1 $D_{S\ 5/2}$ (3^-) respectively. Using these charm states and the equalities discussed above, the corresponding predicted bottom mesons are listed in Table 1. Again, using equation 1 and the 1P charm masses (D_0*, D'_1) and (D_{0s}*, D'_{1s}) [6], excited strange charm masses are obtained for n=2 S-field, which are then inserted in the two equalities to obtain the strange 2P (S-field) masses for bottom mesons. Mass of D_{s2} is used as 2931 MeV [4]. Theoretical mass of this D_{s2} state is greater than the experimental mass of its spin partner state D_{s3}^* (2860). Masses predicted in our work are compared with the masses predicted by other theoretical models.

State n LJ^P	Our Work (MeV)	[3] (MeV)	[4] (MeV)	[5] (MeV)
2 P(0^+)	6335.99	6213	6221	6163
2 P(1^+)	6318.84	6228	6281	6175
1 D(2^-)	6086.96	6095	6103	5985
1 D(3^-)	6097.84	6106	6091	5993
$2P_S(0^+)$	6282.37	6279	6318	6264
$2P_S(1^+)$	6318.44	6296	6345	6292
$1D_S(2^-)$	6235.82	6169	6189	6095
$1D_S(3^-)$	6203.10	6179	6191	6103

Table 1: Predicted masses of bottom mesons.

These masses are then used to calculate their strong decays through pseudo-scalar mesons. Since the strong couplings are same for both charm and bottom mesons. The average for the coupling's $\widetilde{g}_{sh}$ obtained from the decay width of D_0^*(3000) and D'_1(3000), and coupling g_{yh} obtained from decay of D_2(2740) and D_3*(2760) states comes out to be $\widetilde{g}_{sh} = 0.12$ and $g_{yh} = 0.37$. Using these couplings, decay width for the bottom mesons are listed in Table 2.

n LJ^P	Decay widths (MeV)			
	Non-Strange		Strange	
	Decay channel	Decay width (MeV)	Decay channel	Decay width (MeV)
2P(0^+) $\tilde{B}_0^*$	$B^0\pi^0$	51.03	$B_s\pi^0$	35.14
	$B^+\pi^-$	102.02	$B_s\eta$	39.94
	$B^0\eta$	15.32	B^+K^-	81.13
	B_sK^0	73.74	B^0K^0	80.98
	Total	242.12	Total	237.19
2 P(1^+) $\tilde{B}_1'$	$B^{*0}\pi^0$	43.57	$B_s^*\pi^0$	38.95
	$B^{*+}\pi^-$	87.11	$B_s^*\eta$	45.05
	$B^{*0}\eta$	12.82	$B^{*0}K^0$	89.67
	$B_s^*K^0$	68.01	$B^{*+}K^-$	89.81
	Total	211.52	Total	263.49
1 D(2^-) B_2	$B^0\pi^0$	25.45	$B_s\pi^0$	41.98
	$B^+\pi^-$	50.74	$B_s\eta$	7.72
	$B^0\eta$	0.73	B^+K^-	52.70
	B_sK^0	1.53	B^0K^0	51.48
	Total	78.47	Total	153.90
1 D(3^-) B_3*	$B^0\pi^0$	17.49	$B_s\pi^0$	20.40
	$B^+\pi^-$	34.86	$B_s\eta$	4.16
	$B^0\eta$	0.79	B^+K^-	15.97
	B_sK^0	2.11	B^0K^0	25.01
	$B^{*0}\pi^0$	15.85	$B_s^*\pi^0$	18.29
	$B^{*+}\pi^-$	31.88	$B_s^*\eta$	2.64
	$B^{*0}\eta$	0.51	$B^{*0}K^0$	20.75
	$B_s^*K^0$	1.12	$B^{*+}K^-$	21.30
	Total	104.64	Total	111.53

Table 2: Decay width of the predicted bottom states

Conclusion:

Comparison in Table 1 shows the masses obtained by our work, are within the range of 30-100 MeV with respect to the masses predicted by the other theoretical models. The width of $\tilde{B}_0^*$ and its strange partner $\tilde{B}_{S0}^*$ comes out to be 242 MeV and 237 MeV respectively, depicting them to be broad state. $B^+\pi^-$ is seen to be the dominating mode for $\tilde{B}_0^*$ and B^+K^- for the $\tilde{B}_{S0}^*$. Similar results are shown for the other bottom mesons $\tilde{B}_1', B_2, B_3^*, \tilde{B}_{S1}', B_{S2}, B_{S3}^*$ in Table 2. Apart from decay to H fields, these states also decay to X and Y fields, but the value of decay width for these decay channels is very small, so it can be neglected. In this paper, we computed masses and decay widths of $(\tilde{B}_0^*, \tilde{B}_1')$ and (B_2, B_3*) bottom states, which are expected to be useful for experimentalists in future.

References

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