Study of Open Charm and Open Bottom Mesons using Heavy Quark Effective Theory (HQET)

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Summary

The present thesis executes a comprehensive study of open charm and open bottom mesons. This thesis describes, the strong decay of excited open charm and open bottom mesons to the ground state mesons plus light pseudoscalar mesons within the framework of leading order approximation of heavy quark effective theory (HQET). Experimental information in the bottom sector is limited [1]. Due to large non-resonant continuum contributions, however, experimentally the broad resonance states are difficult to identify. So their masses can be calculated by exploiting the effective field theory based on heavy quark flavor symmetry [2].

The heavy quark effective theory is developed in the leading order approximation by expanding the QCD Lagrangian in the power of $1/mQ$ as,

$$\mathcal{L}_{HQET} = \mathcal{L}_0 + \frac{1}{m_Q}\mathcal{L}_1 + \frac{1}{m_Q^2}\mathcal{L}_2 + ..., \qquad (1)$$

where finite heavy quark mass corrections are applied and the heavy quark symmetry breaking terms are studied order by order. Only the first term survives at the heavy quark mass limit, and it will have the impact of interaction because the leading Lagrangian $\mathcal{L}_0 = \bar{h}_\nu(i\nu \cdot D)h_\nu$ possesses an exact spin-flavor symmetry of heavy quarks (more information can be found in Ref. [3]).

With the help of fields presented in Eqs. (1)-(7) in [4, 5], the kinetic terms of the heavy meson doublets and the field $\Sigma = \xi^2$ of light pseudoscalar mesons are define in the effective Lagrangian as [6],

$$\begin{aligned}\mathcal{L} =& iTr[\bar{H}_b\nu^\mu D_{\mu ba}H_a] + \frac{f_\pi^2}{8}Tr[\partial^\mu\Sigma\partial_\mu\Sigma^\dagger] \\ &+ Tr[\bar{S}_b(i\nu^\mu D_{\mu ba} - \delta_{ba}\Delta_S)S_a] \\ &+ Tr[\bar{T}_b^\alpha(i\nu^\mu D_{\mu ba} - \delta_{ba}\Delta_T)T_{a\alpha}] \\ &+ Tr[\bar{X}_b^\alpha(i\nu^\mu D_{\mu ba} - \delta_{ba}\Delta_X)X_{a\alpha}] \\ &+ Tr[\bar{Y}_b^{\alpha\beta}(i\nu^\mu D_{\mu ba} - \delta_{ba}\Delta_Y)Y_{a\alpha\beta}] \\ &+ Tr[\bar{Z}_b^{\alpha\beta}(i\nu^\mu D_{\mu ba} - \delta_{ba}\Delta_Z)Z_{a\alpha\beta}] \\ &+ Tr[\bar{R}_b^{\alpha\beta}(i\nu^\mu D_{\mu ba} - \delta_{ba}\Delta_R)R_{a\alpha\beta}].\end{aligned} \qquad (2)$$

Here Δ_F (with $F = S, T, X, Y, Z, R$) is the mass parameter that gives the mass splittings between excited and low-lying negative parity doublets and can write in the form of spin-average masses. The mass degeneracy between the members of spin-doublets are broken by the Lagrangian as [2],

$$\begin{aligned}\mathcal{L}_{1/m_Q} =& \frac{1}{2m_Q}\{\lambda_H Tr[\bar{H}_a\sigma^{\mu\nu}H_a\sigma_{\mu\nu}] \\ &- \lambda_S Tr[\bar{S}_a\sigma^{\mu\nu}S_a\sigma_{\mu\nu}] \\ &+ \lambda_T Tr[\bar{T}_a^\alpha\sigma^{\mu\nu}T_a^\alpha\sigma_{\mu\nu}] \\ &- \lambda_X Tr[\bar{X}_a^\alpha\sigma^{\mu\nu}X_a^\alpha\sigma_{\mu\nu}] \\ &+ \lambda_Y Tr[\bar{Y}_a^{\alpha\beta}\sigma^{\mu\nu}Y_a^{\alpha\beta}\sigma_{\mu\nu}] \\ &- \lambda_Z Tr[\bar{Z}_a^{\alpha\beta}\sigma^{\mu\nu}Z_a^{\alpha\beta}\sigma_{\mu\nu}] \\ &+ \lambda_R Tr[\bar{R}_a^{\alpha\beta}\sigma^{\mu\nu}R_a^{\alpha\beta}\sigma_{\mu\nu}]\}.\end{aligned} \qquad (3)$$

With increasing the powers of inverse heavy quark mass, the induced symmetry breaking terms will suppress. The hyperfine mass splitting between the members of the doublets is represented by the constants λ_H, λ_S, λ_T, λ_X, λ_Y, λ_Z, and λ_R.

Flavor symmetry states that the mass splitting Δ_F between doublets and the mass splitting λ_F between spin-partners in doublets are unaffected by heavy quark flavor, *i.e.*

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$$\Delta_F^{(c)} = \Delta_F^{(b)} \qquad \lambda_F^{(c)} = \lambda_F^{(b)}, \qquad (4)$$

where c and b represent the charm and bottom quarks, respectively. The masses of open-charm mesons can use to predict the masses of open-bottom mesons in this case.

The effective heavy meson chiral Lagrangians (defined in Eqs. (9)-(17) in [4, 5]) determine the expressions of strong decays of heavy-light mesons to a member of the lowest-lying heavy-light spin doublet plus light pseudoscalar mesons (π, η, and K),

$$\Gamma = \frac{1}{2J+1} \sum \frac{\vec{P}_{\mathcal{P}}}{8\pi P_a^2} |\mathcal{M}|^2; \qquad (5)$$

where $|\vec{P}_{\mathcal{P}}| = \frac{\lambda^{1/2}(M_{P_a}^2, M_{P_b}^2, M_{\mathcal{P}}^2)}{2M_{P_a}}$ for the two-body strong decay $P_a \to P_b + \mathcal{P}$, with the triangular function; $\lambda(M_{P_a}^2, M_{P_b}^2, M_{\mathcal{P}}^2) = M_{P_a}^4 + M_{P_b}^4 + M_{\mathcal{P}}^4 - 2M_{P_a}^2 M_{P_b}^2 - 2M_{P_a}^2 M_{\mathcal{P}}^2 - 2M_{P_b}^2 M_{\mathcal{P}}^2$. J is the total angular momentum of initial state of meson and $\mathcal{M}$ gives the scattering amplitude.

For $D_3^*(2750)$ as 1^3D_3, the two-body strong decays $D_3^*(2750) \to D\pi, D^*\pi$; having the π mesons three momenta $\vec{P}_\pi = 749$ and 648 MeV, respectively. The decay widths

$$\Gamma(D_3^*(2750) \to D\pi, D^*\pi) \propto \vec{P}_\pi^7, \qquad (6)$$

where $\vec{P}_\pi^7 = 1.3 \times 10^{20}$ and 4.8×10^{19} MeV^7 in the decays to the final states $D\pi$ and $D^*\pi$, respectively. A small difference in $\vec{P}_\pi$ can lead to a large difference in $\vec{P}_\pi^7$, so we have to take into account the heavy quark symmetry-breaking corrections and chiral symmetry-breaking corrections so as to make robust predictions [7]. The higher-order corrections for spin and flavor violation of the order $\mathcal{O}(\frac{1}{m_Q})$ are not taking into consideration to avoid introducing new unknown coupling constants. We expect that the corrections would not be larger than (or as large as) the leading order contributions. At the hadronic level, the $\frac{1}{m_Q}$ corrections can be crudely estimated to be of the order $\vec{P}_\pi/M_D* \approx$ 0.15-0.30.

We obtain the explicit expression of decay widths in the form of a square of the strong coupling constants [4, 5]. We hope that the results from the LHCb, BESIII, and the next experimental facility $\overline{\text{P}}$ANDA will fit these strong couplings in the near future. The ratios among the decay widths are independent of the couplings and confronted directly with the experimental measurements. That can be used to confirm or reject the quantum number assignments of experimentally observed excited heavy-light flavored mesons. Additionally, our spin-parity assignment of experimentally observed open-charm mesons are allows to construct the Regge trajectories in (M^2, J) and (M^2, n_r) planes, where n_r is the radial principal quantum number, and M^2 is the square of the meson mass [8]. We fix the slope and the intercept of each Regge line and estimate the masses of higher excited open-charm mesons lying on the Regge lines. Their ratio of the strong decay rates may guide future experimental studies to find them in fundamental decay modes.

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