Heavy Quark Effective Theory For Mesons

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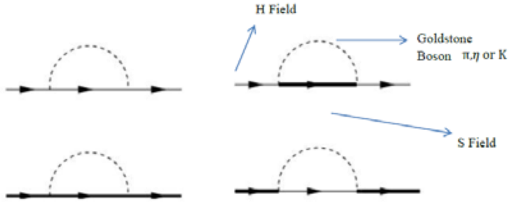
Introduction

We are interested in the Mesons with one heavy quarks and one light anti-quark out of up, down or strange quark. Such systems are of much interest because in such systems we encounter new symmetries which are not present even in the original theory (QCD). Such symmetries have been exploited to formulate a theory that describes the low energy interactions among the heavy mesons. We studied the masses of even and odd parity charmed mesons within the framework of heavy quark effective theory and the chiral perturbation theory.

Spin and Flavor Symmetries

In heavy-light systems the light quarks are bound to the heavy quark with soft gluons which do not have sufficient energy to probe the heavy quark. Compton wavelength, of heavy quark$(\lambda_Q \propto 1/m_Q)$ is very-very small as $m_Q \to \infty$. Light quark can probe only distances much greater than m_Q an hence cannot feel spin and flavor of the heavy quark [1].Here is the origin of new symmetries called spin and flavor symmetries. We can use these symmetries to relate the properties of various mesons differing in spin or flavor or both. If in a meson, with bottom quark as heavy quark,bottom is replaced by a charm quark with same or different spin, then resulting meson will have similar properties. When bottom quark is changing into charm quark spontaneous symmetry is broken and Goldstone Boson (Π, η or K-meson) are exchanged between the fields representing the mesons shown in the Fig. below:



Effective Lagrangian and Mass Formula

Interaction between various mesonic states is seen through the interaction of fields. Ground state mesons i.e. vector and pseudo scalar mesonic states are represented by a single field H, while excited states i.e. scalar and axial vector mesonic states are represented by another single field S. Then we can have three types of basic interactions namely H-H, S-S or H-S interaction. To study these dynamics an effective Lagrangian [2] is formulated making the use of above symmetries in which effects of heavy quark fields are integrated out partly as they do not affect the dynamics to much extent due to above symmetries. Mass formula is then used for ground state $J^P = 0^-\&1^-$ and first excited state $J^P = 0^+\&1^+$charmed mesons up to one loop chiral corrections [3]. The masses are depending on a number of factors, some of which are symmetry breaking ($\Delta_H, \Delta_s, \Delta_H^\sigma, \Delta_H^{(a)}$, $\Delta_S^\sigma, \Delta_S^{(a)}$) and others are symmetry conserving parameters $(\sigma_s, \sigma_H, a_s$ and $a_H)$. The values of some parameters are poorly known or unknown & hence their contributions are absorbed in the other parameters. With resulting eight equations, we tried to fit the masses by varying the parameters to sufficient ranges to get the better central values for the masses of the charmed mesons which are ambiguous at various experiments. Similar work has been done in some research papers [4]

Results

We worked at the energy range ∼ 1 GeV. The masses of up and down quarks are taken to be equal and ∼ 4 MeV, while the mass of strange quark is taken to be ∼ 90 MeV.

The values of various parameters giving better values of masses are

$g = 0.01, g' = 0.01, h = 0.05, \delta_H = 4,$
$\delta_S = 432, \ \Delta_H = 14, \ \Delta_S = 128, \ a_H = 1.1, \ a_S = 0.21, \Delta_H^a = -0.04, \Delta_S^a = 0.14.$

The comparison of calculated masses in our work and the values of masses at experiments is shown in the table 1.

We also studied the variation of mass splittings and spin splittings w.r.t. various symmetry conserving and symmetry breaking parameters graphically, varying a particular parameter keeping all other parameters fixed and watching the variation in splitting values. One such plot showing large variation in the mass splittings with the variation in symmetry conserving parameter a_H is shown in Fig. 1. The terms proportional to a_H results in $SU(3)_V$ violating mass splittings amongst the vector mesons. From these type of graphs we get an idea about the possible ranges of the parameters to be considered while calculations. After analyzing the graphs, a constrain fit has been applied to get appropriate values of the splittings. The parameter set satisfying these splitting values is

$g = 0.01, \ g' = 0.01, \ h = 0.01, \ \delta_H = 4, \ \delta_S = 432, \Delta_H = 144, \ \Delta_S = 126, \ a_H = 1.1, \ a_S = 0.2, \ \Delta_H^a = -0.03, \Delta_S^a = 0.14.$

The calculated mass splittings are :

$D_s^* - D_u^*(1^- - 1^-)$ = 94.04MeV

$D_s - D_u(0^- - 0^-)$ = 96.58MeV

$D_s^* - D_u^*(1^+ - 1^+)$ =20.33MeV

$D_s - D_u(0^+ - 0^+)$ =8.12MeV

Similarly spin splittings have also been calculated and the results are in good agreement with the experimental values.

Mesonic state	Experimental masses	Calculated masses
$D^{0,+}$	1867.21	1867.04
$D_s^{\pm}$	1968.47±0.33	1967.74
D_0^0	2318±29	2314.09
D_{s0}^+	2317.8±0.6	2314.55
$D^{*0,+}$	2008.60	2017.24
D_s^{*+}	2112.1	2109.50
D_1^0	2438±31	2433.52
D_{s1}^+	2459.5±0.6	2456.29

Table 1: Experimental Vs. calculated masses

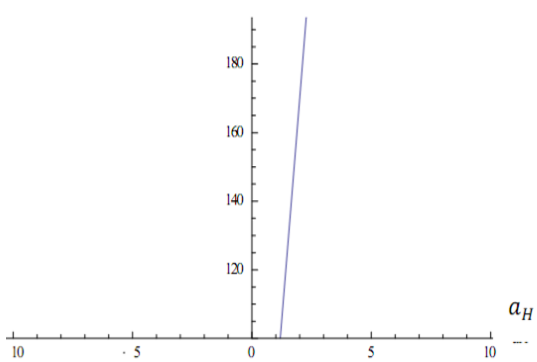


Fig. 1 Variation in mass splitting with a_H

Conclusion

We calculated the values for the mass, mass splittings and spin splitting by setting the range for the poorly known parameter that are responsible for symmetry breaking or conserving. The results almost matches with the experimental data and also gives the masses for the ambiguous states non strange $J^P = 1^+$ states. Despite above approximations, the HQET works better for matching the experimental values within small experimental error.

References

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