Decay modes and coupling constants for D^*_{s1} (2700) and D_{sJ} (2860)

P. Gupta[1]*, A. Upadhyay[2]
[1,2] School of Physics and Material Science, Thapar University Patiala 147004, Punjab, INDIA
*E.Mail: pallavigupta@thapar.edu,

Introduction

Many experiments like LHCb, D0, KEK, SLAC etc have been working to find the states fitting the spectroscopy of heavy-light mesons. Recently LHCb has discovered many new non-strange states like D^*_J (2650), D^*_J (2760), D_J (2580) , D_J (2740), D_J $(3000)^0$, D^*_J $(3000)^+$ [1]. Strange charm states like D_{SJ} (2860), discovered by BABAR collaboration [2], D_{SJ}(2710) discovered by Belle and BABAR collaboration[2,3], D_{SJ}(3040) by BABAR collaboration[4] have been also added to the list. Theoretically these states are being studied by various models like heavy quark effective theory (HQET), QCD sum rules, $^3P_0$ model, QCD lattice. By these theories D_s(2710) has been assigned the spin –parity state as n=2 $J^P=1^-$ and D_s(2860) as mixture of n=1 $J^P=3^-$ and n=3 $J^P=1^-$ states. This assignment is done by studying their properties like decay channels, coupling constants, masses etc. Decays can be strong, Radiative, semi-leptonic. In this paper we will be studying the two body strong decays of strange charm states D_s(2700), D(2860) using the HQET and then assign the values of the coupling constants.

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 $J^P = s_l + s_Q$ is the total momentum of the system. For n=1, L=0(S-wave), doublet corresponds to $s_l=1/2$ consist of two states having spin-parity J^P $(0^-, 1^-)$represented by (P,P*). Similarly for L=2 (P-wave) there are two doublets for $s_l=1/2$ and $s_l=3/2$ representing J^P states as $(0^+,1^+)$ (P_0^*, P'_1) and $(1^+, 2^+)$ (P_1,P_2^*)respectively. The negative and positive parity doublets can be respectively described by the fields Ha, Sa, T_a^μ, a=u,d,s being a light flavour index. The properties of hadrons with a heavy quark coupled with light degrees of freedom can be explained on the basis of symmetries occurring in heavy-light quark system. Theories related to two symmetries, chiral symmetry for light quarks u, d, s in the zero mass limit and heavy quark spin and flavor symmetry for heavy quarks c and b in the infinite mass limit can be exploited to explain a system with one heavy quark and other light one. Heavy light mesons can be studied by implementing both the chiral symmetry and heavy quark spin and flavor symmetry in the form of an effective Lagrangian. Effective Lagrangian here is formulated using the HQET approach which describes the interplay between the chiral symmetry and heavy quark symmetry in the form of low energy gradients with heavy and light fields as operators. For Heavy-light system, heavy quark doublets are represented by effective fields and the octet of light pseudo Goldstone bosons are grouped in a single field. At the leading order, heavy meson chiral lagrangian L_H, L_Y is written as

$$L_H = g_H Tr\left\{\overline{H_a} H_b \gamma_\mu \gamma_5 A^\mu_{ba}\right\}$$

$$L_Y = \frac{1}{\Lambda^2} Tr\{\overline{H_a} Y_b^{\mu\nu} [k_1^Y \left\{D_\mu, D_\nu\right\} A_\lambda + k_2^Y \left(D_\mu D_\lambda A_\nu + D_\nu D_\lambda A_\mu\right)]_{ba} \gamma^\lambda \gamma_5\} + h.c.$$

Similarly, there are other fields also such as L_s,L_T etc which include scalars, axial-vectors and tensor terms[5].

Here decay channels DK,D*K, Ds η , Ds* η of D_s(2700) and D_s(2860)[6] are analysed and coupling constants is calculated. The masses of the final product ground state $(0^-,1^-)$ are computed by heavy hadron chiral perturbation theory for one loop case[7].Coupling constant weights the interaction of the interacting heavy-light meson doublet with the light pseudo-scalar mesons. We also find the branching ratio R defined as

$$R = \frac{B\left(D_{sJ} \to D^* K\right)}{B\left(D_{sJ} \to DK\right)}$$

for all the three cases. This ratio does not include the effect of coupling as coupling constant cancels out in this ratio.

Calculations

Using the heavy meson chiral lagrangian, strong decay widths for D(2700) and D_s(2860) to the final states $D^{(*)}\pi$, $D^{(*)}\eta$ and $D_s^{(*)}K$,[5] is

$$\Gamma(1^- \to 1^-) = c_P \frac{g_H^2 M_f p_f^3}{3\pi f_\pi^2 M_i}$$

$$\Gamma(1^- \to 0^-) = c_P \frac{g_H^2 M_f p_f^3}{6\pi f_\pi^2 M_i}$$

$$\Gamma(3^- \to 1^-) = c_P \frac{16 g_Y^2 M_f p_f^7}{105\pi f_\pi^2 \Lambda^4 M_i}$$

$$\Gamma(3^- \to 0^-) = c_P \frac{4 g_Y^2 M_f p_f^7}{35\pi f_\pi^2 \Lambda^4 M_i}$$

Where g_H, g_Y are the coupling constants, M_f , M_i are the final and initial masses, p_f is the final momentum of the pseudo-scalar mesons, Λ is the chiral symmetry breaking scale taken to be Λ=1GeV and f_π is the pion decay constant =130 MeV. Decay width formulae for n=1,2,3..heavy mesons with same heavy flavor and parity would remain same except for the coupling constants.

Decay of D(2700) can be listed as

Meson	n J^P	channel	Width (MeV)
D(2700)	2 1^-	DK	51.92
		D*K	44.26
		Ds η	7.73
		Ds* η	2.1
		D* K_0*	22.8[6]
		total	128.86

Table 1: Partial decay width in MeV for the D^*_{s1} (2700) state.

Comparing it with experimental value 125MeV[7], it gives coupling constant g'_{hh}= 0.25.

Decay of D^*_{s1}(2860) can be listed as

Meson	n J^P	channel	Width (MeV)
D(2860)	3 1^-	DK	46.95
		D*K	55.45
		Ds η	9.63
		Ds* η	8.69
		D* K_0*	7.15[6]
		DK*	37.10[6]
		total	164.99

Table 2: Partial decay width in MeV for the D^*_{s1} (2860) state.

Comparing it with its experimental value 159MeV[7], calculated coupling constant g''_{hh}= 0.18.

Decay of D^*_{s3} (2860) can be listed as

Meson	n J^P	channel	Width (MeV)
D(2860)	1 3^-	DK	23.3
		D*K	3.15
		Ds η	0.91
		Ds* η	0.002
		D* K_0*	16.16[6]
		DK*	2.81[6]
		total	46.36

Table 3: Partial decay width in MeV for the D^*_{s3} (2860) state.

Comparing with its experimental value 53MeV[7] coupling constant g_{xh}=0.71 is obtained.

R (D_s)	Calculated	Experimentally
R D^*_{s1} (2700)	0.8	0.91
R D^*_{s1}(2860)	1.18	1.10
R D^*_{s3}(2860)	0.26	0.68

Table 4: Compares the R value for the states

Conclusions:

HH*X*PT can be justified as masses calculated using this approach gives ratio comparable to the experimental values[8]. Moreover the calculated coupling constant g'_{hh}=0.25, g''=0.18 and g_{xh}=0.71 can be used to obtain the decays and masses for other newly observed states can provide justified theory to be compared to future experimental data.

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