Coupled channel effects in $c\bar{b}$ spectra

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Introduction

The calculation of hadron loop effects gained special importance after the discovery of the narrow charm-strange mesons $D_{s0}(2317)^+$ and $D_{s1}(2460)^+$, since the loops are often cited as a possible reason for the surprisingly low masses of these mesons. The second-order virtual processes ($A \to BC \to A$) give rise to mass shifts of the bare hadron states, and contribute continuum components to the physical hadron state vectors. A careful estimate of these mass shifts is of great interest, since they are neglected in quark potential models. Studies on heavy quarkonium spectroscopy have been stimulated greatly in recent years by the discovery of B_c meson and many other hidden charm states, the so-called XYZ mesons. The QCD-inspired potential models, such as the Cornell model, one gluon exchange potential(OGEP) model and confined one gluon exchange potential(COGEP) are successful in predictions of $c\bar{b}$,charmonium and bottomonium spectra below the open flavor thresholds.

Current QCD inspired potential models generally neglect the hadron loop effects (continuum couplings). These couplings lead to two body strong decays of the meson above threshold and below threshold they give rise to mass shifts of the bare meson states.

Coupled channel effects

In the coupled channel model, the full hadronic state is given by [1–3]

$$|\psi\rangle = |A\rangle + \sum_{BC} |BC\rangle \tag{1}$$

where we have considered open flaovour strong decay $A \to BC$. Here A, B, C denote mesons.

The wave function $|\psi\rangle$ obeys the equation

$$H|\psi\rangle = M|\psi\rangle \tag{2}$$

The Hamiltonian H for this combined system consists of a valence Hamiltonian H_0 and an interaction Hamiltonian H_I which couples the valence and continuum sectors.

$$H = H_0 + H_I \tag{3}$$

where

$$H_I = g \int d^3x \bar{\psi}\psi \tag{4}$$

The matrix element of the valence-continuum coupling Hamiltonian is given by [2, 3]

$$\langle BC|H_I|A\rangle = h_{fi}\delta(\vec{P}_A - \vec{P}_B - \vec{P}_C) \tag{5}$$

where h_{fi} is the decay amplitude.

The mass shift of hadron A due to its continuum coupling to BC can be expressed in terms of partial wave amplitude $\mathcal{M}_{LS}$ [1, 3]

$$\Delta M_A^{(BC)} = \int_0^\infty dp \frac{p^2}{E_B + E_C - M_A - i\epsilon} \int d\Omega_p |h_{fi}(p)|^2 = \int_0^\infty dp \frac{p^2}{E_B + E_C - M_A - i\epsilon} \sum_{LS} |\mathcal{M}_{LS}|^2$$

$$\Delta M_A^{(BC)} = \mathcal{P} \int_0^\infty dp \frac{p^2}{E_B + E_C - M_A} \sum_{LS} |\mathcal{M}_{LS}|^2 + i\pi \left(\frac{p * E_B * E_C}{M_A} \sum_{LS} |\mathcal{M}_{LS}|^2 \right) |_{E_B+E_C=M_A} \tag{6}$$

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The decay amplitude h_{fi} can be combined with relativistic phase space to give the differential decay rate, which is

$$\frac{d\Gamma_{A\to BC}}{d\Omega} = 2\pi P \frac{E_B E_C}{M_A} |h_f i|^2 \quad (7)$$

where in the rest frame of A, we have $\vec{P}_A = 0$ and $P = |\vec{P}_B| = |\vec{P}_C|$.

The total decay rate is given by [1, 3]

$$\Gamma_{A\to BC} = 2\pi P \frac{E_B E_C}{M_A} \sum_{LS} |\mathcal{M}_L S|^2 \quad (8)$$

Results and conclusion

We evaluate the mass shifts due to BD,B_sD_s, B^0D^0, B^*D, $B_s^*D_s$, B^*D^* and $B_s^*D_s^*$ loops (with M_B = 5279.26 MeV, M_{B_s} = 5366.77 MeV, M_{B^0} = 5279.58 MeV, M_{B^*} = 5324.6 MeV, $M_{B_s^*}$ = 5415.4 MeV, M_D = 1869.61 MeV, M_{D_s} = 1968.30 MeV, M_{D_0} = 1864.84 MeV, M_{D^*} = 2006.96 MeV and $M_{D_s^*}$ = 2112.1).

We have calculated the meson loop effects on the masses of 1S, 2S, 1P, 2P and 1D $c\bar{b}$ states. We present the calculated mass shifts in table I and II. The mass shifts calculated due to these loop effects are found to be very large.

TABLE I: **Mass shifts (in MeV).**

Bare cb State $n\ ^{2S+1}L_J$	BD	B_sD_s	B_0D_0	Total
$1\ ^1S_0$	0	0	0	0
$1\ ^3S_1$	-2.046	-1.805	-2.052	-5.903
$1\ ^3P_0$	-57.922	-57.406	-57.946	-173.274
$1\ ^1P_1$	0	0	0	0
$1\ ^3P_1$	0	0	0	0
$1\ ^3P_2$	-40.618	-40.314	-40.632	-121.564
$2\ ^1S_0$	0	0	0	0
$2\ ^3S_1$	-0.546	-0.476	-0.548	-1.57
$1\ ^3D_1$	-30.675	-30.312	-30.682	-91.669
$1\ ^1D_2$	0	0	0	0
$1\ ^3D_2$	0	0	0	0
$1\ ^3D_3$	-40.753	-40.359	-40.772	-121.884
$2\ ^3P_0$	-148.72	-146.395	-148.828	-443.943
$2\ ^1P_1$	0	0	0	0
$2\ ^3P_1$	0	0	0	0
$2\ ^3P_2$	-79.114	-77.890	-79.171	-236.175

TABLE II: **Mass shifts (in MeV).**

Bare cb State $n\ ^{2S+1}L_J$	B^*D	$B_s^*D_s$	B^*D^*	$B_s^*D_s^*$	Total
$1\ ^1S_0$	-5.661	-5.033	-10.434	-9.328	-30.456
$1\ ^3S_1$	-3.955	-3.496	-7.293	-6.488	-27.135
$1\ ^3P_0$	0	0	-19.088	-18.932	-38.02
$1\ ^1P_1$	-18.49	-18.393	-37.603	-37.901	-112.387
$1\ ^3P_1$	-38.390	-38.049	0	0	-76.439
$1\ ^3P_2$	0	0	0	0	0
$2\ ^1S_0$	-1.547	-1.361	-2.837	-2.523	-8.268
$2\ ^3S_1$	-1.929	-1.711	-1.049	-0.920	-5.609
$1\ ^3D_1$	-15.326	-15.146	-3.077	-3.044	-36.593
$1\ ^1D_2$	-3.147	-3.111	-27.643	-27.49	-61.45
$1\ ^3D_2$	-27.214	-27.552	-69.486	-68.957	-193.209
$1\ ^3D_3$	-54.308	-53.783	-20.835	-20.606	-149.532
$2\ ^3P_0$	0	0	-48.589	-47.903	-96.492
$2\ ^1P_1$	-25.081	-24.744	-49.343	-48.741	-147.909
$2\ ^3P_1$	-98.623	-97.088	0	0	-195.711
$2\ ^3P_2$	0	0	0	0	0

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