Mass spectra and Decay widths of dimesonic hadron molecules

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1. Introduction

In the past few years, tremendous progress has been achieved experimentally in the multiquark states, specially in the heavy quark sector. Many theoretical attempts have been made to resolved the structure of multiquark states as di-hadronic molecules. We have investigated the molecular structures of tetraquark states composed of heavy-light mesons. In the molecular framework, the masses and digamma decay widths of the meson - antimeson states are computed using the Hellmann potential.

2. Theoretical Methodology

The di-hadronic molecular system is assumed to be composed of meson and antimeson. The interaction between hadrons bound in the moleculer structure can be described by a Hellmann potential which is given by,

$$V(r) = -\frac{\alpha_s}{r} + B\frac{e^{-cr}}{r} + V_0 \tag{1}$$

Where α_s and B are the strength of coulomb and Yukawa potential, respectively. c is the screening parameter. The same form of potential has been used by A.K.Rai et al. for light sector in ref [1]. In present calculation, the input parameter are taken from ref. [2] are listed in Table I. The binding energy of the di-hadronic state is obtained by solving

TABLE I: Parameter fitted in present model.

Model parameter	Value
B	1.0
c	0.134 GeV
V_0	0.01 GeV
m_{D^0} meson	1860 MeV
$m_{D^{0*}}$ meson	2012 MeV
m_{D_s} meson	1960 MeV
$m_{D_s^*}$ meson	2112 MeV

schrödinger equation using mathematica notebook of Range-Kutta method. The mass of the di-hadronic(meson-anti meson) system is calculated as,

$$M = m_1 + m_2 + BE \tag{2}$$

Here, m_1 and m_2 are the masses of the constituent mesons and anti-mesons, BE represents the binding energy of the di-mesonic system. Further, we have also employed hyperfine interaction for $V\bar{V}$ state. To remove degeneracy the spin dependent hyperfine interactions of confined one gluon exchange potential (COGEP) is expressed respectively as, [3],

$$\langle V_{h_1-h_2}\rangle = \frac{\sigma\langle j_{h_1}j_{h_2}JM|\widehat{j_{h_1}}\widehat{j_{h_2}}|j_{h_1}j_{h_2}JM\rangle}{(E_{h_1}+m_{h_1})(E_{h_2}+m_{h_2})} \tag{3}$$

$$M_{h_1-h_2} = M + E_{hyp} \tag{4}$$

The digamma decay of the di-hadronic states are calculated using the wave function at the origin and it is given by [1],

$$\Gamma_{\gamma\gamma} = \frac{\pi\alpha^2}{m_{h_1}m_{h_2}}|\psi(0)|^2 \tag{5}$$

Where, m_{h_1} and m_{h_2} are the masses of constituent mesons.

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TABLE II: Masses of di-mesonic states and comparison of computed results with other available theoretical results (in MeV)

State	$I^G(J^{PC})$	Present	Others
D_s - $\bar{D}_s$	$0^+(0^{++})$	3917	3918.4 ± 1.9 [4]
			3927 [6]
D_s - $\bar{D}_s*$	$0^-(1^{+-})$	4069	4079 [6]
D_s - $\bar{D}_s*$	$0^-(1^{++})$	4069	$\cdots$
D_s^* - $\bar{D}_s*$	$0^+(2^{++})$	4266	4208 [6]
D_s^* - $\bar{D}_s*$	$0^-(1^{+-})$	4199	4219 [6]
D_s^* - $\bar{D}_s*$	$0^+(0^{++})$	4191	4225 [6]
D^0 - $\bar{D}^0$	$0^+(0^{++})$	3695	3729 [6]
D^0 - $\bar{D}^{0*}$	$0^-(1^{+-})$	3869	3861[5], 3875 [6]
D^0 - $\bar{D}^{0*}$	$0^-(1^{++})$	3869	3861[5],
D^{0*} - $\bar{D}^{0*}$	$0^+(2^{++})$	4071	4003[5], 3998 [6]
D^{0*} - $\bar{D}^{0*}$	$0^-(1^{+-})$	3996	4003[5], 4009 [6]
D^{0*} - $\bar{D}^{0*}$	$0^+(0^{++})$	3989	4003[5], 4015 [6]
D_s - $\bar{D}^0$	$0^+(0^{++})$	3817	$\cdots$
D_s - $\bar{D}^{0*}$	$0^-(1^{+-})$	3969	$\cdots$
D_s - $\bar{D}^{0*}$	$0^-(1^{++})$	3969	$\sim$ 3940 [4]
D_s^* - $\bar{D}^{0*}$	$0^+(2^{++})$	4168	$\sim$ 4160 [4]
D_s^* - $\bar{D}^{0*}$	$0^-(1^{+-})$	4098	$\cdots$
D_s^* - $\bar{D}^{0*}$	$0^+(0^{++})$	4090	$\cdots$

TABLE III: Digamma decaay width of meson-anti-meson molecule (in keV)

State	$I^G(J^{PC})$	Present ($\Gamma_{\gamma\gamma)}$ (in keV)
D_s - $\bar{D}_s$	$0^+(0^{++})$	4.7300
D_s - $\bar{D}_s*$	$0^-(1^{+-})$	4.3900
D_s - $\bar{D}_s*$	$0^-(1^{++})$	4.3900
D_s^* - $\bar{D}_s*$	$0^+(2^{++})$	4.0741
D_s^* - $\bar{D}_s*$	$0^-(1^{+-})$	4.0741
D_s^* - $\bar{D}_s*$	$0^+(0^{++})$	4.0741
D^0 - $\bar{D}^0$	$0^+(0^{++})$	5.2528
D^0 - $\bar{D}^{0*}$	$0^-(1^{+-})$	4.8560
D^0 - $\bar{D}^{0*}$	$0^-(1^{++})$	4.8560
D^{0*} - $\bar{D}^{0*}$	$0^+(2^{++})$	4.4891
D^{0*} - $\bar{D}^{0*}$	$0^-(1^{+-})$	4.4891
D^{0*} - $\bar{D}^{0*}$	$0^+(0^{++})$	4.4891
D_s - $\bar{D}^0$	$0^+(0^{++})$	4.9848
D_s - $\bar{D}^{0*}$	$0^-(1^{+-})$	4.626
D_s - $\bar{D}^{0*}$	$0^-(1^{++})$	4.626
D_s^* - $\bar{D}^{0*}$	$0^+(2^{++})$	4.2765
D_s^* - $\bar{D}^{0*}$	$0^-(1^{+-})$	4.2765
D_s^* - $\bar{D}^{0*}$	$0^+(0^{++})$	4.2765

3. Result and discussion

Using the Hellmann potential, we have solved the Schrödinger equation to compute the binding energy, masses, and digamma decay widths for di-hadronic states. We have used different combinations of di-hadronic states like $P\bar{P}$, $P\bar{V}$ and $V\bar{V}$ - states to calculate the possible molecular structure of heavy-light mesons. The digamma decay width is evaluated using the wave function at the origin. Our calculated masses and decay widths are tabulated in Tables II and III respectively. Zhi-Hui Wang et al have studied the strong decays of X(3940) and X(4160) [7]. According to them, X(3940) is a possible $\eta_c(3S)$ state. Additionally, they have also suggests that X(4160)is difficult to consider it as $\eta_c(4S)$ state [7]. According to present analysis, the state X(3940) is a possible D_s - $\bar{D}^{0*}$ state having $I^G(J^{PC}) = 0^-(1^{+-})/0^-(1^{++})$. Present calculation also suggests that X(4160) state is a possible D_s^* - $\bar{D}^{0*}$ molecular tetraquark state. The possible $I^G(J^{PC})$ for X(4160) state is $0^+(2^{++})$ and the computed digamma decay width is 4.2765 keV. However, the experimental identification of the (J^{PC}) values for X(3940) and X(4160) states are still an open question. The state X(3915) having $I^G(J^{PC})$ $= 0^+(0/2^{++})$ is an possible candidate of D_s - $\bar{D}_s$ molecular state. As it's $\gamma\gamma$ decay has been observed but not identified experimentally, we have computed the $\Gamma_{\gamma\gamma}$ as 4.7300 keV. The molecular structure of exotic tetra quark state could be tested only by the future quantitative experimental observations and the radiative J/ψ decay.

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