Molecular like states in charmonium sector

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Introduction

The spectroscopy of the exotic states have created lots of interest from past decade due to continuous measurements from world wide experimental facilities like Belle, BESIII etc. [1–3]. The exposure of hadronic molecule in charmonium sector is interesting because no exotic states still identified as a hadronic molecule. In the case of heavy quark system, the small kinetic term raise more possibilities for formation of molecule [4]. There are many authors used the non-relativistic quark model to study the exotic states [5].

Theoretical framework

The molecular like structure of four quark state (meson-antimeson) is like deuterium, bound state of the two nucleons, the binding mechanism involves boson exchange. We use the relativistic correction to the kinetic energy term, as we have used for the study of heavy-light flavor mesons [6]. The di-mesonic hamiltonian is,

$$H = \sqrt{P^2 + m_{h1}^2} + \sqrt{P^2 + m_{h2}^2} + V(r) \quad (1)$$

where m_{h1} and m_{h2} are masses of mesons, P is the relative momentum of two mesons and V(r) is the molecular interaction potential of the di-mesonic system. In present calculation, the potential consists of the confined one gluon exchange interaction and one pion interaction potential as long range and short range interaction respectively.

$$V(r) = -\frac{k_{mol}}{r} e^{-\frac{c^2 r^2}{2}} + V_\pi(r) + V_{SD}(r) \quad (2)$$

where k_{mol} is the residual strength of the strong interaction coupling and C is the effective color screening parameter of the confined gluon. The one pion exchange potential and spin-dependent interaction potential takes the form,

$$V_\pi(r) = \frac{1}{3}\frac{g^2{}_8}{4\pi}\left(\frac{m_\pi^2}{4m_i m_j}\right) f_i \cdot f_j \; \sigma_i \cdot \sigma_j \times \left(\frac{e^{-m_\pi r_{ij}}}{r_{ij}} - \left(\frac{\Lambda_\pi}{m_\pi}\right)^2 \frac{e^{-\Lambda_\pi r_{ij}}}{r_{ij}}\right) \quad (3)$$

$$V_{SD}(r) = \frac{8}{9}\frac{K_{mol}}{m_{h1} m_{h2}} S_1 \cdot S_2 |\psi|^2 \quad (4)$$

the parameter used in pion exchange is from ref [5]. We have used the variational method for finding the lowest energy eigenstates. The hydrogenic trial wave function is used for present study. We fix color screening parameter C= 0.170 GeV and experimental masses of the mesons are taken from [3].

Results and Discussion

Using the relativistic correction to the kinetic energy term, we have calculated the masses and the binding energy of the some molecular states from charmonium sector. We have identified the states X(3823), X(3872), X(3915), Y(4008) and $Z_1(4050)$ as a $D - D_s$, $D - D^*$, $D_s - D_s$, $D^* - D^*$ and $D_s - D_s^*$ molecular states respectively. The J^{PC} values with isospin and G-parity are also assign as per ref [8]. The J^{PC} for X(3823) experimentally is still unclear, our predictions suggest as isospin $\frac{1}{2}$ and J^{PC} 0^{++}. The state X(3872) recently has assigned J^{PC} as 1^{++} which is not matching with our suggestion as $0^-(1^{+-})$ / $1^+(1^{+-})$ where as the mass and binding energy are in good agreement with experimental data. We have identified X(3915) with

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TABLE I: Masses and binding energy of di-mesonic states

System (h_1-h_2)	J^{PG}	m_1 (GeV)	m_2 (GeV)	μ (GeV)	R(0) $(GeV^{\frac{3}{2}})$	B.E. (MeV)	Mass (GeV)	Expt. mass (GeV)
$D-D$	0^+ (0^{++})	1.8696	1.8696	0.2297	0.0778	-5.776	3.7334	
$D-D$	1^- (0^{++})	1.8696	1.8696	0.2297	0.0778	-5.776	3.7334	
$D-D_s$	$\frac{1}{2}$ (0^{++})	1.8696	1.9685	0.2286	0.0772	-15.95	3.8324	3.823±0.0019 [1]
$D-D^*$	0^- (1^{+-})	1.8696	2.0069	0.2281	0.0770	-5.600	3.8710	3.8716±0.0001 [3]
$D-D^*$	1^+ (1^{+-})	1.8696	2.0069	0.2281	0.0770	-5.600	3.8710	3.8716±0.0001 [3]
D_s-D_s	$(0^+)(0^{++})$	1.9685	1.9685	0.2292	0.0776	-5.692	3.9312	3.9175±0.0027 [1, 9]
D_s-D^*	$\frac{1}{2}(1^{+-})$	1.9685	2.0069	0.2288	0.0774	-5.644	3.9698	
$D-D_s^*$	$\frac{1}{2}(1^{+-})$	1.8696	2.1123	0.2271	0.0765	-5.345	3.9765	
D^*-D^*	0^+ (0^{++})	2.0069	2.0069	0.2290	0.0775	-5.658	4.0083	$4.008^{\pm 0.0026}_{\pm 0.0037}$ [1, 3, 5]
	1^- (0^{++})	2.0069	2.0069	0.2290	0.0775	-5.658	4.0083	
D^*-D^*	0^- (1^{+-})	2.0069	2.0069	0.2290	0.0775	-5.060	4.0089	
	$1^+(1^{+-})$	2.0069	2.0069	0.2290	0.0775	-5.060	4.0089	
D^*-D^*	0^+ (2^{++})	2.0069	2.0069	0.2290	0.0775	-4.470	4.0094	
	1^- (2^{++})	2.0069	2.0069	0.2290	0.0775	-4.470	4.0094	
$D_s-D_s^*$	$0^-(1^{+-})$	1.9685	2.1123	0.2276	0.0768	-5.519	4.0752	4.051±0.014 [1, 7]
$D^*-D_s^*$	$\frac{1}{2}(0^{++})$	2.0069	2.1123	0.2144	0.0702	-5.458	4.1138	
$D^*-D_s^*$	$\frac{1}{2}$ (1^{+-})	2.0069	2.1123	0.2144	0.0702	-5.000	4.1142	
$D^*-D_s^*$	$\frac{1}{2}$ (2^{++})	2.0069	2.1123	0.2144	0.0702	-4.540	4.1147	

quantum numbers $0^+(0^{++})$ and is in agreement with Youchang et. al. [9]. The status of Y(4008) is uncertain, we suggest $I^G(J^{PC})$ for Y(4008) having six possibilities as molecular state [3], see table 1. We predicts the $Z_1(4050)$ as molecular state with $0^-(1^{+-})$ quantum numbers.

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