Mass spectra of hidden bottom tetraquark states

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1. Introduction

Since the discovery of the X(3872) in 2003 [1], few botomonium-like XYZ states have been reported in recent years [2]. In present paper, we have computed the masses of hidden bottom tetraquarks ($bq\bar{b}\bar{q}$ where q ϵ u, d, s) in the diquark-antidiquark framework with the inclusion of spin-spin component of the one gluon exchange interaction. To get binding energy, we have solved Dirac equation using linear potential for two body interactions for tetraquark states. Here we have factorized the four body system is into three subsequent two body systems.

2. Theoretical Methodology

The interaction between the two quarks and anti-quarks is assumed to be in the form of linear potential [3],

$$V(r) = \frac{1}{2}(1+\gamma_0)(\lambda r + V_0) \tag{1}$$

The wave functions $\psi(\vec{r})$ satisfies the Dirac equation given by,

$$[\gamma^0 E_q - \vec{\gamma}.\vec{P} - m_q - V(r)]\psi_q(\vec{r}) = 0. \tag{2}$$

The solution of the Dirac equation can be written in two component (positive and negative energies in the zeroth order) form as[3, 4],

$$\psi^{(+)}_{nlj}(\vec{r}) = N_{nlj}\begin{pmatrix} ig(r)/r \\ (\sigma.\hat{r})f(r)/r \end{pmatrix}\mathcal{Y}_{ljm}(\hat{r}) \tag{3}$$

$$\psi^{(-)}_{nlj}(\vec{r}) = N_{nlj}\begin{pmatrix} i(\sigma.\hat{r})f(r)/r \\ g(r)/r \end{pmatrix}(-1)^p\mathcal{Y}_{ljm}(\hat{r}) \tag{4}$$

Where $\psi^{(+)}_{nlj}(\vec{r})$ and $\psi^{(+)}_{nlj}(\vec{r})$ are positive and negative solution of Dirac equation, $p = j + m_j - l$ and N_{nlj} is the normalization constant [3, 4] and the corresponding energy eigen value is obtained by [3],

$$\epsilon = (E_q - m_q - V_0)(m_q + E_q)^{\frac{1}{3}}\lambda^{\frac{-2}{3}} \tag{5}$$

Our goal is to compute masses of the tetra quark states in diquark-antidiquark like structure. In the approximation of one-gluon exchange the $qq/\bar{q}\bar{q}$ potential in a tetra quaek system is equal to one half of the quark-antiquark potential in a meson. i.e, $V_{qq} = \frac{1}{2}V_{q\bar{q}}$. The masses of the diquark(bq)-antidiquark ($\bar{b}\bar{q}$) system are given by [3],

$$M_d = (E_b + M_b) + (E_q + M_q) - E_{d(c.m)} \tag{6}$$

$$M_{\bar{d}} = (E_{\bar{b}} + M_{\bar{b}}) + (E_{\bar{q}} + M_{\bar{q}}) - E_{d(c.m)} \tag{7}$$

$$M_{d\bar{d}} = (E_d+M_d)+(E_{\bar{d}}+M_{\bar{d}})+E_{d\bar{d}(c.m)}+\langle V_{sd}\rangle_{d\bar{d}} \tag{8}$$

In the present paper, d and $\bar{d}$ represent diquark and antidiquark, respectively, while E_d, $E_{\bar{d}}$, $E_{d\bar{d}}$ are the energy eigenvalues of the diquark, antidiquark and diquark - antidiquark system, respectively. The spin dependent interactions of confined one gluon exchange potential (COGEP) is expressed respectively as [3, 4],

$$\langle V^{j_d j_{\bar{d}}}_{d\bar{d}}\rangle = \frac{\sigma\langle j_d j_{\bar{d}} JM|\hat{j_d}\hat{j_{\bar{d}}}|j_d j_{\bar{d}} JM\rangle}{(E_d + m_d)(E_{\bar{d}} + m_{\bar{d}})} \tag{9}$$

here, σ is j-j coupling constant.

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TABLE I: Masses of $bq\bar{b}\bar{q}$(in GeV).

state	S_d	L_d	$S_{\bar{d}}$	$L_{\bar{d}}$	J_d	$J_{\bar{d}}$	Total J	mass	[5]
1s	0	0	0	0	0	0	0	10.215	10.471
	1	0	0	0	1	0	1	10.295	10.492
	1	0	1	0	1	1	0	10.373	10.473
							1	10.374	10.494
							2	10.376	10.534
2s	0	0	0	0	0	0	0	10.912	10.917
	1	0	0	0	1	0	1	10.970	10.939
	1	0	1	0	1	1	0	11.025	10.942
							1	11.026	10.951
							2	11.028	10.969
3s	0	0	0	0	0	0	0	11.097	···
	1	0	0	0	1	0	1	11.246	···
	1	0	1	0	1	1	0	11.394	···
							1	11.395	···
							2	11.397	···

TABLE II: Masses of $bs\bar{b}\bar{s}$(in GeV).

state	S_d	L_d	$S_{\bar{d}}$	$L_{\bar{d}}$	J_d	$J_{\bar{d}}$	Total J	mass	[5]
1s	0	0	0	0	0	0	0	10.413	10.662
	1	0	0	0	1	0	1	10.525	10.682
	1	0	1	0	1	1	0	10.637	10.671
							1	10.638	10.686
							2	10.640	10.716
2s	0	0	0	0	0	0	0	11.300	11.111
	1	0	0	0	1	0	1	11.391	11.13
	1	0	1	0	1	1	0	11.482	11.133
							1	11.483	11.142
							2	11.485	11.159
3s	0	0	0	0	0	0	0	11.964	···
	1	0	0	0	1	0	1	12.031	···
	1	0	1	0	1	1	0	11.747	···
							1	11.748	···
							2	11.750	···

3. Result and discussion

In present study we have calculated the masses of tetraquarks with hidden bottom in the diquark-antidiquark picture. In our calculation, we did not introduce any new input parameters but used same set of parameters used to compute meson spectrum. Different combinations of the spin excitations have been considered. From our numerical analysis, we have predicted the status of X(10610) as a ground state of pure $bs\bar{b}\bar{s}$ tetraquark state with $J^P = 1^+$. We have also predicted first and second excitation of $bq\bar{b}\bar{q}$, $bs\bar{b}\bar{s}$ and $bq\bar{b}\bar{s}$ hidden bottom tetra quark states.

TABLE III: Masses of $bq\bar{b}\bar{s}$(in GeV).

state	S_d	L_d	$S_{\bar{d}}$	$L_{\bar{d}}$	J_d	$J_{\bar{d}}$	Total J	mass	[5]
1s	0	0	0	0	0	0	0	10.363	10.572
	1	0	0	0	1	0	1	10.475	10.593
	1	0	1	0	1	1	0	10.552	10.584
							1	10.553	10.599
							2	10.555	10.628
2s	0	0	0	0	0	0	0	11.257	11.018
	1	0	0	0	1	0	1	11.339	11.037
	1	0	1	0	1	1	0	11.393	11.041
							1	11.394	11.05
							2	11.397	11.067
3s	0	0	0	0	0	0	0	11.680	···
	1	0	0	0	1	0	1	11.747	···
	1	0	1	0	1	1	0	11.893	···
							1	11.894	···
							2	11.896	···

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References

[1] S. K. Choi et al. [Belle Collaboration], Phys. Rev. Lett. **91**, 262001 (2003)

[2] C. Patrignani et al. [Particle Data Group], Review of Particle Physics, Chin. Phys. C **40**, 100001(2016).

[3] Tanvi Bhavsar, Manan Shah and P. C. Vinodkumar,Eur. Phys. J. C **78**, 227 (2018).

[4] Manan Shah, Bhavin Patel and P. C. Vinodkumar, Phys. Rev. D **93**, 094028 (2016).

[5] D. Ebert, R. N. Faustov and V. O. Galkin, Mod.Phys.Lett.A **24**, 567-573(2009).