A relativistic quark model for T_{2cs}

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Introduction

Investigation of cs$\bar{c}\bar{s}$ is important because it is believed that some of charmonium-like states Y(4140) and Y(4274) would be cs$\bar{c}\bar{s}$ tetraquark states [1]. The status of these states can be predicted with the help of quark model. Thus we investigate these tetraquark states based on a relativistic quark model. For the present study we consider the tetraquark states in the hidden charm and hidden strange sector.

Theoretical Methodology

The four body system here will be treated as two two-body system such as diquark-antidiquark states being in triplet color configuration [2]. There are various confinement mechanism to study the hadronic properties. In the present study, we assume that the constituent quarks in a meson core is independently confined by an linear potential of the form,

$$V(r) = \frac{1}{2}(1+\gamma_0)(\lambda r^{1.0} + V_0) \quad (1)$$

Where λ is the strength of the confinement part of the potential. V_0 is a constant negative potential depth.

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

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

To get confined single particle energy we have solved the two component (positive and negative energy) Dirac equation. Its solution can be written as [3, 4],

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

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

and N_{nlj} is the overall normalization constant. The reduced radial part $g(r)$ and $f(r)$ of the Dirac spinor $\psi_{nlj}(r)$ are given by [3, 4],

$$\frac{d^2g(r)}{dr^2} + \left[(E_q+m_q)[E_q-m_q-V(r)] - \frac{\kappa(\kappa+1)}{r^2}\right]g(r) = 0 \quad (5)$$

and

$$\frac{d^2f(r)}{dr^2} + \left[(E_q+m_q)[E_q-m_q-V(r)] - \frac{\kappa(\kappa-1)}{r^2}\right]f(r) = 0 \quad (6)$$

On converting these equation into dimensionless form [3, 4] as,

$$\frac{d^2g(\rho)}{d\rho^2} + \left[\epsilon - \rho^{1.0} - \frac{\kappa(\kappa+1)}{\rho^2}\right]f(\rho) = 0 \quad (7)$$

$$\frac{d^2f(\rho)}{d\rho^2} + \left[\epsilon - \rho^{1.0} - \frac{\kappa(\kappa-1)}{\rho^2}\right]g(\rho) = 0 \quad (8)$$

where $\rho = \frac{r}{((E_q+m_q)\lambda)^{\frac{-1}{3}}}$ and The corresponding energy eigen value is given by[3],

$$\epsilon = (E_q - m_q - V_0)(m_q+E_q)^{\frac{1}{3}}\lambda^{\frac{-2}{3}} \quad (9)$$

Here, we incorporate additionally, the j-j coupling of confined one gluon exchange potential (COGEP) for hyperfine splliting [3],

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TABLE I: Masses of cs$\bar{c}\bar{s}$ for $L_d = 0$ and $L_{\bar{d}} = 0$ (in GeV).

S_d	L_d	$S_{\bar{d}}$	$L_{\bar{d}}$	J^{PC}	$n^{2S+1}X_J$	V_{ss}	Mass	[5]
0	0	0	0	0^{++}	1^1S_0	0	4.090	4.051
1	0	0	0	1^{+-}	1^3S_1	0	4.178	4.113
1	0	1	0	2^{++}	1^5S_2	-0.1370	4.282	4.209
				1^{+-}	1^3S_1	-0.1028	4.145	4.143
				0^{++}	1^1S_0	0.0342	4.110	4.110
0	0	0	0	0^{++}	2^1S_0	0	4.6198	⋯
1	0	0	0	1^{+-}	2^3S_1	0	4.7407	⋯
1	0	1	0	2^{++}	2^5S_2	-0.1150	4.7691	⋯
				1^{+-}	2^3S_1	-0.0862	4.6541	⋯
				0^{++}	2^1S_0	0.0287	4.6253	⋯

$$\langle V_{Q\bar{Q}}^{j_1 j_2}\rangle = \frac{\sigma\langle j_1 j_2 JM|\widehat{j_1}.\widehat{j_2}|j_1 j_2 JM\rangle}{(E_d + m_d)(E_{\bar{d}} + m_{\bar{d}})} \quad (10)$$

Whee, E_d and m_d are energy and mass of diquark and $E_{\bar{d}}$ and $m_{\bar{d}}$ are energy and mass of antidiquark.

Mass spectra of cs$\bar{c}\bar{s}$ tetra quark state

It is claimed that Heavy light diquarks can be the fundamental blocks for a rich spectrum of exotic states which cannot be fitted in the pure charmonium sector. we have calculated the mass spectra of tetraquarks with hidden charm as the bound states of two clusters Qq - $\bar{Q}\bar{q}$, (Q = c; q = s) with their spin-spin interactions included. The computed masses are tabulated in Table I.

Result and discussion

The masses of the low-lying hidden charm tetraquark are computed by using Dirac equations with a linear plus constant confinement potential. Various combinations of the orbital and spin excitations have been considered. We have predicted first excitation of cs$\bar{c}\bar{s}$. Masses for the ground state is in a good agreement with available theoretical results. From our numerical result we have predicted the status of state X(4160), Y(4274) and state X(4140) as pure cs$\bar{c}\bar{s}$ tetraquark state with J^{PC}, 1^{+-}, 2^{++} and 0^{++} respectively. The first radial excited state 2^1S_0 is predicted at 4.6198 GeV with $J^{PC} = 0^{++}$. Other radial excited states 2^1S_0, 2^1S_0 and 2^1S_0 are in accordance with some predicted tetraquark states of L. Maiani et. al [6].

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