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Status of X(3860) and X(3915) as an exotic tetraquark states

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Introduction

The identification of multiquark states is a new and challenging topic in hadron physics. One can study these exotic structure by computing mass spectra and decay properties [1]. Until 2003, it was easy to understand hadron structures with the help of the quark model as it explains hadron spectra successfully and satisfactorily. In 2003, with the observation of X(3872) [2], an area of investigation for exotic states opened. Since then many unknown XYZ states, which is believed to be exotic in nature have been found and the study of the hadron physics become complicated.

Theoretical Methodology

There are various approaches to determine spectroscopical properties of conventional and exotic hadrons but phenomenological potential model is quite reliable Approach. To identify these newly observed XYZ states, we have used diquark-antidiquark approach for hidden charm tetraquark system. In the present study, we have computed the s-wave mass spectra of hidden charm tetraquark ($cq\bar{c}\bar{q}$ and $cs\bar{c}\bar{s}$) for different combination of spin of diquark and antidiquark. The non-relativistic interaction potential we have used is the Cornell potential, which consists of a central term V(r), which is just the sum of the Coulomb (vector) and linear confining (scalar) parts given by [3],

TABLE I: Fitted potential Parameters

Quark Masses (GeV/c^2)	Systems	A GeV	B GeV
$m_c = 1.55$	$c\bar{q}/cq/\bar{c}\bar{q}$	0.144	-0.44
$m_q = 0.33$	$c\bar{s}/cs/\bar{c}\bar{s}$	0.150	-0.43
m_s= 0.5	$cq\bar{c}\bar{q}$	$\frac{0.144}{4(n+1)}$	-0.44
	$cs\bar{c}\bar{s}$	$\frac{0.150}{4(n+1)}$	-0.43

$$V(r) = V_V + V_S = K_s\frac{\alpha_s}{r} + Ar + B \quad (1)$$

Where, $K_s = \frac{-4}{3}$ for $q\bar{q}$
$= \frac{-2}{3}$ for qq/$\bar{q}\bar{q}$ and α_s = Strong running coupling constant

Our goal is to compute masses of the tetraquark states in diquark-antidiquark like structure by using the same set of parameters used to compute meson spectrum. Fitted potential parameters for mesons and tetraquarks are listed in Table I. Masses of diquark (antidiquark) states are obtained by numerically solving the Schrödinger equation with the respective two body potential given by Eq.(1).

$$M_d = m_c + m_{q/s} + E_d \quad (2)$$

$$M_{\bar{d}} = m_{\bar{c}} + m_{\bar{q}/\bar{s}} + E_{\bar{d}} \quad (3)$$

Further, the same procedure is adopted to compute the binding energy of the diquark-antidiquark bound system.

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$$M_{d-\bar{d}} = m_d + m_{\bar{d}} + E_{d\bar{d}} \quad (4)$$

Here, M_d, $M_{\bar{d}}$ and $M_{d-\bar{d}}$ are the masses of diquark, antidiquark and tetraquark states. E_d, $E_{\bar{d}}$ and $E_{d\bar{d}}$ the binding energy of diquark, antidiquark and diquark-antidiquark system.

Result and Discussion

The masses of the low lying hidden charm four quarks states have been computed. Various combinations of the orbital and spin excitations have been considered to compute the masses of ground state and first radial exicted state of cq$\bar{c}\bar{q}$ and cs$\bar{c}\bar{s}$ tetraquarks. The computed mass spectra are listed in Table II and III. According to Jing Wu et al., X(3860) is observed by Belle may be $cn\bar{c}\bar{n}$ tetraquark state [4].The QSR calculation also gives an isoscalar scalar tetraquark around 3.81 GeV, which is consistent with the X(3860) [5]. Because of its broad width, the X(3860) can not considered as a pure charmonium [4]. Our Present study is also in accordance with available result, it suggests that X(3860) having $J^{PC} = 0^{++}$ is a possible $cq\bar{c}\bar{q}$ tetra quark state whose mass is 3.8513 GeV. The status of X(3915) is still not clear. The Lanzhou group suggested that the X(3915) can be assigned as a charmonium χ_{c0}(2P) [6]. It means that the X(3915) must have J^{PC}, 0^{++}, which was also confirmed by the BaBar experiment [7]. The predicted narrow decay width of the χ_{c0}(2P) is comparable with the decay width of the X(3915). However, this assignment was questioned in [8, 9]. Zhi-Yong Zhou have suggested that X(3915) is not a pure c$\bar{c}$ State [10]. V. Baru et al. have assigned the X(3915) as 2^{++} $D\bar{D}$ molecula rbound state[11]. As per our analysis, X(3915) ($J^{PC} = 0^{++}/2^{++}$) is possible $cs\bar{c}\bar{s}$ tetra quark state whose mass is 3.8954 GeV. Status of X(3915) still needs more experimental support.

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TABLE II: S wave mass of cq$\bar{c}\bar{q}$ tetraquark

S_d	L_d	$S_{\bar{d}}$	$L_{\bar{d}}$	M_d (GeV)	$M_{\bar{d}}$ (GeV)	$M_{d-\bar{d}}$ (GeV)
0	0	0	0	2.0305	2.0305	3.6541
1	0	0	0	2.1328	2.0305	3.7527
1	0	1	0	2.1328	2.1328	3.8513
0	0	0	0	2.6667	2.6667	5.0033
1	0	0	0	2.7569	2.6667	5.0917
1	0	1	0	2.7569	2.7569	5.1802

TABLE III: S wave mass of cs$\bar{c}\bar{s}$ tetraquark

S_d	L_d	$S_{\bar{d}}$	$L_{\bar{d}}$	M_d (GeV)	$M_{\bar{d}}$ (GeV)	$M_{d-\bar{d}}$ (GeV)
0	0	0	0	2.1468	2.1468	3.8954
1	0	0	0	2.2428	2.1468	3.988
1	0	1	0	2.2428	2.2428	4.0806
0	0	0	0	2.7393	2.7393	5.1485
1	0	0	0	2.8224	2.7393	5.2298
1	0	1	0	2.8224	2.8224	5.3112

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