Investigating the mass spectra of all charm tetraquark

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Introduction

Since the discovery of the first tetraquark candidate, experimental state $X(3872)$, in 2003, a new arena of high energy physics has opened up. Following the success of the constituent quark model, a variety of unconventional states that do not match the model have not only been empirically found but also theoretically predicted. [1–9]. The most prevalent hypotheses for these unconventional resonances include hadronic molecules, tetraquarks, pentaquarks, and hybrids, among others. [3–5].

So far more than 15 candidates for tetraquark state have experimentally been observed and most of them consist of atleast one charm quark resonance. The unexpected finding of all charm tetraquark resonance X (6900) in 2020 inspired researchers to explore for its bottom equivalent, all bottom tetraquark resonance [10].

The objective of this article is to investigate the mass spectra of all-charm tetraquark states $[cc][\bar{c}\bar{c}]$, also known as T_{4c}, in a potential model with coulumbic plus quadratic quark confinement form. In our previous studies, the well known Cornell Potential has been employed and several tetraquarks have been calulated [11–13] .

Theoretical Framework

A bound state of four quark resonances in the form of a pair of diquark $[QQ]$ and antidiquark $[\bar{Q}\bar{Q}]$ bound together by color forces in a color neutral state is considered as a general description of a tetraquark state. A set of two quarks or two anti-quarks interact with each other using the gluonic exchange form a bound state namely, diquark and antidiquark.

We have utilized the coulumb plus quadratic potential $V_{C+Q}(r)$, which consists of a gluonic interaction described by coulombic term. At the same time the quark confinement is determined using a quadratic term. The quadratic confinement potential is comparable to the harmonic oscillator potential, although the exact nature of the confinement process in Quantum Chromodynamics is still unknown.

$$V_{C+Q}(r) = \frac{k_s \alpha_s}{r} + br^2 \quad (1)$$

Non-perturbative form of relativistic mass correction is incorporated using term $V^1(r)$ [14–17], given by

$$V^1(r) = -\frac{C_F C_A}{4}\frac{\alpha_s^2}{(r)^2} \quad (2)$$

where C_F and C_A are the Casimir charges of the fundamental and the adjoint representation respectively [14]. The spin-dependent interaction is included pertubatively in the central potential [7], which gives;

$$V_{SD}(r) = V_{SS}(r) + V_{LS}(r) + V_T(r) \quad (3)$$

The fine structure of any given state is depicted by the spin-orbit term, V_{LS} and the tensor term V_T. Similarly, the spin-spin interaction term, V_{SS} accounts for the hyper-fine splitting [18]. The mass-spectra of diquark $[cc]$ antidiquark $[\bar{c}\bar{c}]$ and tetraquarks states T_{4b} have been calculated by;

$$M_{(cc)} = 2M_c + E_{(cc)} + \langle V^1(r)\rangle \quad (4)$$

$$M_{(\bar{c}\bar{c})} = 2M_{\bar{c}} + E_{(\bar{c}\bar{c})} + \langle V^1(r)\rangle \quad (5)$$

$$M_{cc\bar{c}\bar{c}} = m_{cc} + m_{\bar{c}\bar{c}} + E_{[cc][\bar{c}\bar{c}]} + \langle V^1(r)\rangle \quad (6)$$

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Results and Discussion

The mass spectra of S-Wave and P-Wave T_{4c} states are calculated, in the current study, and are compared with the two-meson threshold and other theoretical model.

TABLE I: The mass-spectra of S-wave and P-Wave all charm tetraquarks. Parameters are taken from recent updated PDG [19].

State	J^{PC}	Mass	[11]	M_{Th}	Threshold
$^0S_1$	0^{++}	5955.77	5939	5967.80	$\eta_c\eta_c$
$^3S_1$	1^{+-}	5962.04	5986	6080	$\eta_c J/\psi$
$^5S_2$	2^{++}	5975.17	6079	6193.8	$J/\psi J/\psi$
$^1P_1$	1^{--}	6448.33	6553	-	-
$^3P_0$	0^{-+}	6351.04	6460	6398.61	$\eta_c\chi_{c0}$
$^3P_1$	1^{-+}	6443.17	6554	6494.57	$\eta_c\chi_{c1}$
$^3P_2$	2^{-+}	6478.17	6587	6540.07	$\eta_c\chi_{c2}$
$^5P_1$	0^{--}	6341.19	6459	6509.27	$\eta_c h_c$
$^5P_2$	1^{--}	6459.23	6577	6607.57	$J/\psi\chi_{c1}$
$^5P_3$	3^{--}	6511.62	6623	6653.07	$J/\psi\chi_{c2}$

The mass spectra of all charm tetraquarks have been calculated in this study using the zeroth order potenial in the form of coulombic plus quadratic term. The masses of the All charm tetraquark are compared to various theoretical models [11] and the two meson threshold. The ground state tetraquark is only a few MeV below the two meson threshold, and subsequent states do not diverge far from it. The computed masses show comparable results to other models and will contribute to future experimental and theoretical research of tetraquarks and other exotic hadrons.

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