Spectroscopy of hidden flavour tetraquark state

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1. Introduction

In a constituent quark model picture [1], which was first proposed by Murray Gell-Mann in 1964 [2], a significant number of conventional hadrons, baryons (qqq), and mesons ($q\bar{q}$) are described accurately. Since the early days of the quark model, the idea of exotic multiquark hadrons with valence quark and anti-quark contents other than the conventional hadrons are also discussed. A number of various collaborations, including BABAR, Belle, BES, CDF, CLEO-c, LHCb, etc., have seen several exotic states due to years of experimental work in high-energy physics.

The existence of a bound state in fully charmed and hidden-bottom tetraquarks has been the subject of several quark model-based studies, some of which deserve citation, including [3–5]. Furthermore, studies using quark models have provided information on potential stable or narrow states in the $bb\bar{b}\bar{c}$ and $bc\bar{b}\bar{c}$ sectors [6, 7]. The characteristics of color-magnetic and Coulomb interactions, as well as various colour configurations inside the fully-heavy tetraquark states, were examined in reference [10] using various models. Additionally, a chiral effective field theory investigation [11] successfully identified the charmonium- and bottomonium-like $Z_c(3900)$, $Z_c(4020)$, $Z_b(10610)$, and $Z_b(10650)$ states as the $D^*\bar{D}^*$ and $B^*\bar{B}^*$ molecular resonances, respectively [8, 9].

It would be highly helpful to study the confinement dynamics and to challenge alternative methods to QCD if fully-heavy tetraquark bound states or resonances could be identified in experiments. With well-identified real or virtual quarkonia in the final state, the double hidden-flavor configurations may be more accessible to most detectors. While a J/ψ trigger remains an effective tool in experimental settings, it should not become an addiction that hampers explorations of the flavour space, since many intriguing problems involve open flavour states such as $bb\bar{c}\bar{c}$. The investigation of the mass spectra of the hidden flavour tetraquark state $[bc][\bar{b}\bar{c}]$, in the framework of a non-relativistic diquark-antidiquark model, is the major focus of this article.

2. Theoretical Formalism

Tetraquarks $[QQ'\bar{Q}\bar{Q}']$ (Q=b, Q'=c)are composed of a diquark $[QQ']$ and an antidiquark $[\bar{Q}\bar{Q}']$ in colour antitriplet $\bar{\mathbf{3}}$ and triplet $\mathbf{3}$ configurations respectively, which are held together by colour forces [12, 13]. Both the diquark $[QQ]$ and the antidiquark $[\bar{Q}\bar{Q}']$ are comprised of two quarks (antiquarks) in antitriplet (triplet) colour states.

We have utilized the cornell-like potential $V_{C+L}(r)$, which consists of a coulomb term governing gluonic interaction and a linear term governing quark confinement [12].

$$V_{C+L}(r) = \frac{k_s \alpha_s}{r} + br + V^1(r) \qquad (1)$$

The central potential also includes the non-perturbative form of relativistic mass correction term $V^1(r)$ which is not yet known, but leading order perturbation theory yields term;

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

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where $C_F = \frac{4}{3}$ and $C_A = 3$ are the Casimir charges of the fundamental and the adjoint representation respectively [14]. The spin-spin interaction is included pertubatively in the central potential [12], which gives;

$$V_{SS}(r) = C_{SS}(r) S_1 \cdot S_2, \qquad (3)$$

The mass-spectra of $[bc\bar{b}\bar{c}]$ tetraquark states have been calculated by;

$$M_{bc\bar{b}\bar{c}} = m_{bc} + m_{\bar{b}\bar{c}} + E_{[bc][\bar{b}\bar{c}]} + \langle V^1(r) \rangle \qquad (4)$$

Results and Discussion

We have determined the ground state masses of all heavy tetraquarks with hidden charm and bottom that are made of the heavy diquark and antidiquark, each of which contains two heavy quarks and antiquarks respectively. The masses of low-lying S-wave $M_{bc\bar{b}\bar{c}}$ states are anticipated to be in the range of 12-13 GeV [3, 10, 15] , in the current study, the masses are also found to be in this range. The masses of ground states are 200-300 MeV below than two meson thresholds like $B_c^{\pm} B_c^{\pm}$, $B_c^{\pm} B_c^{*\pm}$ and $B_c^{*\pm} B_c^{*\pm}$. The large attractive strength of coulombic term shows the dominance of gluonic interaction particularly in 1S wave which increases the binding energy of these states. When compared to the exotic charmonium-like and bottomonium-like states, the exotic $QQ'\bar{Q}\bar{Q}'$ states that solely contain heavy quarks (Q = b, Q'=c) are of particular interest. This is because their nature can be identified more readily. They ought to compose the vast majority of compact tetraquarks. In point of fact, a molecular conformation is quite improbable. In spite of the fact that these tetraquark states have not yet been observed in experimentation, currently it is time to carry out a systematic investigation of the mass spectrum of the $bc\bar{b}\bar{c}$ tetraquark system. This investigation may provide essential information that can be applied to further experimental investigation.

TABLE I: The mass-spectra of S-wave tetraquark state $bc\bar{b}\bar{c}$. Parameters are taken from recent updated PDG [16]. M_{Th} corresponds to threshold mass.

$N^{2S+1}L_J$	J^{PC}	$M_{bc\bar{b}\bar{c}}$	M_{Th}	Threshold
1^1S_0	0^{++}	12286	12548	$B_c^{\pm} B_c^{\pm}$
1^3S_1	1^{+-}	12311	12608	$B_c^{\pm} B_c^{*\pm}$
1^5S_2	2^{++}	12362	12666	$B_c^{*\pm} B_c^{*\pm}$
2^1S_0	0^{++}	12994	-	-
2^3S_1	1^{+-}	13001	-	-
2^5S_2	2^{++}	13011	-	-

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