To search for negative parity Y states in a non-relativistic Approach

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Introduction

In the past decades, a series of charmoniumlike states with $J^{PC} = 1^{--}$, so-called Y states, were observed in e^+e^- annihilation experiments [1, 2]. Besides these states, a numerous new Y states exotic hadrons were discovered experimentally following the developments in the high-energy experiments and the accumulation of the precise data in the low energy exclusive measurements i.e. at B-factories and CLEO and BESIII experiments[3].

The interpretations of these new states have initiated considerable amount of theoretical work, especially due to the their mysterious internal structure.Up to now, the internal structure of these Y states are unclear and many theoretical models, such as hybrid charmonium, tetraquark or hadronic molecule, are proposed to interpret their natures, but none of them are conclusive [4, 5]. Such states present a challenge for theoretical description of tetraquark systems, and a better understanding of the internal workings of these and similar, yet unobserved, resonances may provide new insights into the strong dynamics of multiquark systems.

Phenomenology

There are many methods to estimate the mass of a hadron, among which phenomenological potential model is a fairly reliable one, specially for exotic hadrons. In this paper we shall take a different path and investigate different ways in which the experimental data can be reproduced. Non-relativistic interaction potential we have used here is the Cornell potential consists of a central term V(r) which is being just a sum of the Coulomb(vector) and linear confining(scalar) parts given by

$$V(r) = V_V + V_S = k_s \frac{\alpha_s}{r} + \sigma r \tag{1}$$

$$\begin{aligned} k_s &= -4/3 \quad for \quad q\bar{q} \\ &= -2/3 \quad for \quad qq \quad or \quad \bar{q}\bar{q} \end{aligned} \tag{2}$$

The model parameters we have used in the present study are same as in refs[6, 7]. The constituent quark masses employed here are taken from Particle Data Group [8].

By using Mathematica code [9] we obtained the binding energies and then computed the masses of different degenerate n$^{2S+1}L_J$ low-lying tetraquark states by including spin dependent part of the usual one gluon exchange potential same as done in Ref. [6]. The non-relativistic Schrödinger bound-state mass(spin average mass) of the four quark state system is obtained as

$$M_{cw} = m_1 + m_2 + BE \tag{3}$$

Where m$_1$ and m$_2$ are the masses of the constituent diquarks and antidiquarks, BE represents the binding energy of the four quark system. For the mass of diquarks and antiquarks, the same approach has been adopted. Further, we have added spin and isospin contribution. Accordingly, the mass of a four quark state is obtained as

$$M_{Total} = M_{cw} + < V_{SD} > \tag{4}$$

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TABLE I: The mass spectra of $Qs\bar{s}\bar{s}$ states for quark content $cs\bar{s}\bar{s}$ (In GeV).

Diquark content	S	L	J	M_{cw}	V_{SS}	V_{LS}	V_T	M_J
$S\bar{A}$	1	0	1	3.681	0.0	0.0	0.0	3.681
	1	1	0	4.138	0.0	-0.033	-0.14	3.964
			1		0.0	-0.016	0.035	4.157
			2		0.0	0.016		4.120
$A\bar{A}$	0	0	0	3.695	-0.128	0.0	0.0	3.566
	1	0	1		-0.064	0.0	0.0	3.630
	2	0	2		0.064	0.0	0.0	3.759
	0	1	1	4.151	-0.011	0.0	-0.117	4.023
	1	1	0	4.151	-0.0057	-0.05	-0.362	3.878
			1		-0.0057	-0.016	0.128	4.071
			2		-0.0057	0.033	-0.187	4.034
	2	1	1	3.695	0.0057	-0.050	-0.362	3.744
			2		0.0057	-0.016	0.128	4.269
			3		0.0057	0.033	-0.187	4.003

where pertabative interaction $< V_{SD} >$ is incorporated through one gluon exchange potential.

Results and conclusion

In the present work, we perform a systematical investigation of the mass spectra of the low lying open charm-strange tetraquark states as diquark−diantiquark ($Qs - \bar{s}\bar{s}$) with various combinations of the orbital and spin excitations which are listed in table 1. The authors of Ref[7, 10] have considered only spin interactions between diquarks and antidiquarks. Thus, this ignorance of the spin-orbit interactions have contributed to the differences between the present results and those of the Refs[7, 10]. We have predicted some of the states with its parity quantum number which and they are in good agreement with the experimental results. Many of these states require further experimental support. Their underlying nature is still unknown and considerable experimental and theoretical work remains to be done before a satisfying understanding of these states will be achieved. Finally, we believe that future high luminosity experiments will be able to shed more light in the understanding of the these exotic states.

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