Mass Spectroscopy of fully heavy $[cc][\bar{c}\bar{c}]$ tetraquark in diquark-antidiquark formalism

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Introduction

Exotic hadrons are the systems which consist of more than three quarks, they do not fit into ordinary quark-antiquark(meson) or three quark(baryon) system. The hypothetical existence of exotic hadrons were proposed by Gell-Mann and Zweig in 1964[1, 2]. In recent years, the field of exotic hadrons have been seen considerable growth due to the available experimental facilities such as Belle, BaBar, BES3, CLEO, LHCb etc.[3–6], recently tetraquark state X(6900) which contain all heavy quarks ($cc\bar{c}\bar{c}$) was discovered experimentally at LHCb[7]. However the quantum numbers J^{PC} have yet to be confirmed. The discovery of this experimental state created a new window and provide opportunities and challanges to theorists as well as experimentalist to study the spectroscopy of these novel and complicated states. The research work on tetraquark containing all charm quarks has been published by Iwsaki in 1975[8], this discovery of the tetraquark state containg all heavy quark created a huge interest theoretically as well as experimentally. It motivates us to study the static and dynamic properties of all charm tetraquarks.

Theoretical Approach

For the study of fully heavy tetraquark $cc\bar{c}\bar{c}$ (as a bound state of diquark-antidiquark), we have employed a non-relativistic Hamiltonian given by

$$H = \frac{p^2}{2m} + V(r) \qquad (1)$$

where r is the distance between diquark and antidiquark, p is the relative momentum of each diquark (or antidiquark), $m = \frac{m_d m_{\bar{d}}}{m_d + m_{\bar{d}}}$ represents the reduced mass of the system; where m_d (m_{cc}) and $m_{\bar{d}}$ ($m_{\bar{c}\bar{c}}$) are the masses of diquark and antidiquark and V(r) is the diquark-antidiquark general power law potential with colour coloumb term given by[9]

$$V(r) = k_s \frac{\alpha_s}{r} + br^{\nu} \qquad (2)$$

where α_s is the QCD running coupling constant, k_s is color factor related to the color structure of the system, b is string tension, ν is the general power varying from 0.1 to 2.0 for the present study. To solve the Schrodinger equation we have considered the hydrogenic radial wave function for the (n,l) state. So the mass-spectra of fully heavy tetraquark $T_{[cc][\bar{c}\bar{c}]}$ have been obtained by

$$M([cc][\bar{c}\bar{c}]) = m_{cc} + m_{\bar{c}\bar{c}} + E_{[cc][\bar{c}\bar{c}]} + \langle V_{sd} \rangle \quad (3)$$

where $\langle V_{sd} \rangle$ is spin-dependent interaction potential such as spin-spin (V_{SS}), spin-orbit (V_{LS}) and tensor (V_T) which are included for the better understanding of the splitting between states with different quantum numbers.

Results, summary and conclusion

In the framework of non-relativistic quark model, the mass spectra of all charm tetraquark ($[cc][\bar{c}\bar{c}]$) is investigated using coulomb plus power potential. For different

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power index ν, potential model parameter b is fitted to get the experimental ground state of $cc\bar{c}\bar{c}$. Fitted potential model parameters for tetraquark system are shown in table 1.

TABLE I: Model parameters

	M_{SA} (GeV)	α_s (GeV)	σ
$cc\bar{c}\bar{c}$	6.118	0.35	2.991

Our predicted S state and P state masses of fully charm tetraquark for potential index ν varying from 0.1 to 2.0 are shown in table 2 and 3. Our theoretical predictions of S-wave and P-wave masses of fully heavy tetraquark at potential index $\nu = 1$ are found to be in good accordance with the experimental values as well as other available theoretical predictions.

TABLE II: S-wave masses of tetraquark $cc\bar{c}\bar{c}$

state	power index(ν)	potential parameter(b) ($GeV^{\nu+1}$)	0^{++} n^1S_0 (GeV)	2^{++} n^5S_2 (GeV)
1s	0.1	0.273	6.048	6.152
	0.5	0.223	6.007	6.173
	1.0	0.174	5.966	6.194
	1.5	0.133	5.937	6.209
	2.0	0.099	5.920	6.219
	[11]		5.939	6.079
	[12]		5.966	6.193
2s	0.1	0.273	6.268	6.288
	0.5	0.223	6.399	6.459
	1.0	0.174	6.542	6.647
	1.5	0.133	6.659	6.792
	2.0	0.099	6.753	6.903
	[11]		6.642	6.676
3s	0.1	0.273	6.321	6.330
	0.5	0.223	6.575	6.608
	1.0	0.174	6.899	6.953
	1.5	0.133	7.191	7.256
	2.0	0.099	7.432	7.506
	[11]		7.017	7.032

TABLE III: P-wave masses of tetraquark $cc\bar{c}\bar{c}$

state	power index (ν)	0^{-+} n^3P_0 (GeV)	1^{-+} n^3P_1 (GeV)	2^{-+} n^3P_2 (GeV)	1^{--} n^5P_1 (GeV)	3^{--} n^5P_3 (GeV)
1p	0.1	6.270	6.273	6.277	6.268	6.280
	0.5	6.380	6.393	6.409	6.373	6.420
	1.0	6.476	6.507	6.545	6.463	6.570
	1.5	6.541	6.589	6.648	6.522	6.690
	2.0	6.591	6.652	6.728	6.567	6.782
	[11]	6.460	6.554	6.587	6.459	6.623
	[12]	6.398	6.494	6.539	6.508	6.653
2p	0.1	6.321	6.323	6.326	6.320	6.327
	0.5	6.552	6.566	6.583	6.546	6.596
	1.0	6.807	6.851	6.907	6.791	6.950
	1.5	6.997	7.085	7.198	6.969	7.285
	2.0	7.150	7.277	7.441	7.109	7.567
	[11]	6.851	6.926	6.951	6.849	6.982

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