Study of the state Z(4430) in tetraquark model

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Introduction

In the past decade the advancement in experimental facilities like BaBar, Belle, BESIII, CDF and LHCb etc. provided great opportunities to theorists as well as experimentalists to search new multi-quark states [1]. These multiquark states don't fit in to the conventional constituents quark composition i.e. a meson is made up of a pair of quark and antiquark and a baryon is composed of three quarks, are called Exotic States [2–4].

These exotics can be explained if the new mesons have two valence quark-antiquark pairs(tetraquarks); while the baryons contain four-quarks plus an antiquark (pentaquarks) and a mesons which contain a valence quark-antiquark pair and one or more gluons(hybrid) mesons.[5–7] For these states several theoretical explanations have been proposed as tightly bound states like in the case of hadrons or loosely bound objects like deuteron [8, 9].

The Quantum Chromo Dynamics (QCD) explains more complex multiquarks states at the same time challenges to experimentalists as well as theorists to describe the substructure of the exotic states [10, 11].

In the year 2008, Z(4430) resonance reported by Belle the experiment [12] and later confirmed by LHCb [13] having quantum number $J^{PC} = 1^{+-}$ and mass $M_Z = (4430) MeV$.

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Theoretical Approach

In the present study, we have assumed the evaluation of the tetra quark state is color less restricted state through color magnetic interaction between pair diquark-antidiqaurk $[Qq][\bar{Q}\bar{q}] = [cu][\bar{c}\bar{d}]$ [13, 14].

We have chosen system relatively heavy and constituent are diquark-antidiquark pair, therefore in the for present calculation, nonrelativistic treatment in principle can be applied.[15] We have selected the pair of diquark-antidiquark to work with them not just because they simplify the calculation but also there is a possibility of clustering between diquarks in baryons. The diquark is formed due to the gluonic interaction between two quarks or antiquarks [16, 17].

The Hamiltonian for tetra-quark model reads [18]

$$H = T_{nr} + V(r_{12}) \quad (1)$$

where T_{nr} and $V(r_{12})$ are non-relativistic Kinetic energy and interaction potential respectively. Here r_{12} is the relative separation between diquark-antidiquark pair.

The expression of non-relativistic kinetic energy term T_{nr} is given by;

$$T_{nr} = m_1 + m_2 + \frac{p^2}{2\mu} \quad (2)$$

where $m_1 = 1.638$ GeV and $m_2 = 1.65$ GeV being average masses of di-quark (anti-di-quark). The constituent quark masses of the di-quark pairs are taken from recent listing of Particle Data Group [19]. Here, P is the relative momentum of the di-quark system. The

effective interaction potential $V(r_{12})$ is the interaction between two di-quark pairs, which consists the chromo magnetic potential along with phenomenological linear confinement interaction potential.
The $V(r_{12})$ reads

$$V(r_{12}) = \frac{\alpha_s e^{\frac{-(cr_{12})^2}{2}}}{r_{12}} (\sigma_1 \cdot \sigma_2)(\lambda_1 \cdot \lambda_2) + Ar_{12}^{\nu} \quad (3)$$

here, α_s is the residual running coupling constant, c is the screen fitting parameter, the $(\sigma_1 \cdot \sigma_2)$ and $(\lambda_1 \cdot \lambda_2)$ are spin and color factor respectively. The σ and λ are usual Pauli spin matrices and Gall-Mann color matrices respectively. Whereas, A is the string tension is related to the strength in the linear confinement potential and ν is the fitting parameter. We have solved the Schrdinger equation numerically by using Mathematica code, originally developed by W. Lucha et. al. [20].

Results and Conclusion

In the present paper, we have calculated the mass of heavy-light tetraquark state with a composition of diquark-antidiquark pair [cu][$\bar{c}$ $\bar{d}$]. In general a tetraquark state should be a admixture of the two color configuration 6_c-$\overline{6_c}$ and 3_c-$\overline{3_c}$.

We have extracted the mass of the[cu][$\bar{c}$ $\bar{d}$] tetraquark state,$M_{[cu][\bar{c}\bar{d}]}$ = 4429.01 MeV by solving the Schrdinger equation numerically, which is very closed to the experimental mass reported for state Z(4430).

However for determination of the internal sub-structure of Z(4430) the decay properties are most important to reach on some conclusion.

References

[1] J. Belz et al.,Phys. Rev. Lett. **76**,3277 (1996).
[2] R. L. Jaffe and F. E. Low, Phys. Rev. D 19, 2105(1979).
[3] D.P. Rathaud and Ajay Kumar Rai, EPJ Web of Conf.**95** 05013 (2015)
[4] D.P. Rathaud and A.K. Rai, Eur. Phys. J Plus **132** 370 (2017).
[5] D.P. Rathaud and A. K. Rai, Indian J. Phys. **90**, 1299 (2016)
[6] D.P. Rathaud and A. K. Rai, AIP Conf. Proc. **1728**, 020115 (2015)
[7] D. P. Rathaud and A. K. Rai, Proc. of DAE Symp. on Nucl. Phys.,**61**, 696 (2016); Proc. of DAE Symp. on Nucl. Phys., **60**, 680 (2015); Proc. of DAE Symp. on Nucl. Phys., **59**, 630 (2014).
[8] A. K. Rai and D. P. Rathaud, Eur. Phys. J. C **75**, 462 (2015).
[9] A. K. Rai, J. N. Pandya and P. C. Vinodkumar, Indian J. Phys. **80**, 387 (2006); Nucl. Phys. A **782**, 406 (2007), Phys. Rev. C **78**, 055202 (2008).
[10] D.P. Rathaud and Ajay Kumar Rai Few-Body Syst. **60**, 37 (2019); arxiv:1706.09323[hep-ph],arxiv:1808.05815[hep-ph].
[11] Z. Shah, K. Thakkar, A.K. Rai and P.C. Vinodkumar, Chin. Phys. C **40**, 123102 (2016).
[12] S.K. Choi, Gyeonsqsang Natl. U. et al. (Belle Collaboration), Phys.Rev.Lett. **100**, 142001 (2008).
[13] Roel Aaij et al. (LHCb Collaboration), Phys.Rev.Lett. **112** 222002(2014).
[14] Z.Shah, K. Gandhi and A.K. Rai, Chin. Phys. C **43**, 024106 (2019)
[15] S. Patel, Manan Shah and P. C. Vinodkumar, Eur. Phys. J. A **50**, 131 (2014).
[16] N. Devlani et. al., Eur. Phys. J. A **48**, 104 (2012), Phys. Rev. D **84**, 074030 (2011); Eur. Phys. J A **50**, 154 (2014); Int. J. Theor. Phys. **52**, 2196 (2013).
[17] Z. Shah and A. K. Rai, Eur. Phys. J. C **77** 129 (2017); Few-Body Syst. **59**, 112 (2018); Few-Body Syst. **59**, 76 (2018).
[18] V. H. Kher, N. Devlani and A. K. Rai, Chin. Phys. C **41**, 073101 (2017); Chin. Phys. C **41**, 093101 (2018); Chin. Phys. C **42**, 083101 (2018).
[19] M. Eanabashi et al. (Particle Data Group), Phys. Rev. D **98**, 030001 (2018).
[20] W. Lucha, F. F. Schberl,Int. J. Mod. Phys. C, **10** 607 (1999).