Masses of $\Sigma_c\Sigma_c$ and $\Sigma_b\Sigma_b$ di-baryonic states

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Introduction

Physicists have been fascinated by hadrons with unusual quantum numbers and multiquarks ever since the quark models and quantum chromodynamics (QCD) were developed. In the last two decades, various charmonium like XYZ states, P_c states, $Z_c(3900)^+$ and the double charm T_c^{++} state have been reported experimentally[1]. These new search create the interest in studying the exotic hadron spectroscopy. The theoretical article suggest the various possible exotic states, such as glueballs, hybrids, tetraquark, pentaquark, hexaquark and molecules [2–10].

The baryons are made up of three quarks and we have calculated the properties of singly heavy Σ baryon system in our precious study [11]. We investigate the possible $\Sigma_c\Sigma_c$ and $\Sigma_b\Sigma_b$ di-baronic molecule in the open charm and open bottom sector In the present study,. Here, we have approximated the interaction potential of the di-baryon as a s-wave One Boson Exchange Potential plus screen Yukawa like potential. We predict the masses of $\Sigma_c\Sigma_c$ and $\Sigma_b\Sigma_b$ molecule in its relative s-wavestate.

Methodology

The variational scheme is used for the calculation of mass spectra of the di-hadronic systems by using the hydrogen like trial wave function. For s wave mass spectra, One Boson Exchange(OBE) plus screen Yukawa-like potential are used. The Hamiltonian of di-hadronic molecule is given by [2, 3]

$$H = \sqrt{P^2 + m_d^2} + \sqrt{P^2 + m_b^2} + V_{hh}(r_{db}) \quad (1)$$

m_d and m_b are the masses of constituents and P is the relative momentum of two hadrons and $V_{hh}(r_{db})$ is the inter-hadronic interaction potential. To incorporate the relativistic effect, we have included corrections to the potential and expand the kinetic energy term of Hamiltonian up to O(P^6). The binomial expansion of kinetic energy term is given by [2],

$$K.E. = \frac{P^2}{2}\left(\frac{1}{m_d} + \frac{1}{m_b}\right) - \frac{P^2}{8}\left(\frac{1}{m_d^3} + \frac{1}{m_b^3}\right) + \frac{P^2}{16}\left(\frac{1}{m_d^5} + \frac{1}{m_b^5}\right) + O(P^6) \quad (2)$$

The di-hadronic interaction potential is given by,

$$V_{hh}(r_{db}) = V_{OBE}(r_{db}) + V_Y(r_{db}) \quad (3)$$

the term $V_Y(r_{db})$ is screen Yukawa-like potential and V_{OBE} is the s-wave One Boson Exchange (OBE) potential.

The screen Yukawa-like potential expressed as

$$V_Y = -\frac{k_{mol}}{r_{db}} e^{\frac{-c^2 r_{db}^2}{2}} \quad (4)$$

here, c is a screen fitting parameter of the potential while K_{mol} is the residual running coupling constant.The net s-wave OBE potential with finite size effect can be expressed as

$$V_{OBE} = V_{ps}(r_{db})_F + V_s(r_{db})_F + V_v(r_{db})_F \quad (5)$$

Results and disscussion

In this work, we attempt to systematically inspect the most promising single flavored dibaryon bound states $\Sigma\Sigma$. We study the binding energy and spatial configuration of $\Sigma_c\Sigma_c$ and $\Sigma_b\Sigma_b$ states with quark combination *uuddcc* and *uuddbb* respectively.

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The similar study has been performed in different appraoches such as, the asymptotic interation method (AIM) [12], quark delocalization color screening model [13], the dispersion relation technique [14], one boson exchange model [15]. Our obtained masses are compared with other predition in Table 1. We have calculated the system with the values of Isospoin I=1, $J^P = \frac{1}{2}^+$, charge Q=0.

TABLE I: The ground state masses of $\Sigma_c\Sigma_c$ and $\Sigma_b\Sigma_b$ hexaquark states (in GeV)

System	Mass	[12]	[13]	[14]	[15]
Σ_c Σ_c	4.907	4.754	4.925	4.420	4.906
Σ_b Σ_b	11.626	11.460	11.618	11.518	

We can observe that the masses are in accordance with other theoretical predictions very well for both di-baryonic molecule. The study may help future experiments to identify di-baryonic states. We can also calculate the another ground state masses with $J^P = \frac{3}{2}^+$ of $\Sigma\Sigma$ system. The same methodology can also be applied for other heaxaquark system, such as, $\Lambda\Lambda$, $\Xi\Xi$ and $\Omega\Omega$.

References

[1] R.L. Workman et al. (Particle Data Group), Prog. Theor. Exp. Phys. **2022**, 083C01 (2022).

[2] D. P. Rathaud, A. K. Rai, Eur. Phys. J. Plus **132(8)**, 370 (2017).

[3] A. K. Rai et al., Eur. Phys. J. C **75**, 462 (2015).

[4] D. P. Rathaud, A. K. Rai, Indian J. Phy. **90** 1299 (2016).

[5] D. P. Rathaud, A. K. Rai, Few body syst. **60**, 1-12 (2019); Proc. of Sci. Hadron 2017, 244 (2018).

[6] A. K. Rai et al., Indian J. Phys. **80 (4)**, 387-392 (2006)

[7] A. K. Rai et al.,Nucl. Phys. A **782 (1-4)**, 406-409 (2007).

[8] R. Tiwari et al., Indian J. Phys. **97**, 943 (2023)

[9] R. Tiwari et al., Eur. Phys. J. A **57**, 1-11 (2021).

[10] R. Tiwari et al., Few body Syst. **64** 20 (2023).

[11] Z. Shah et. al; Eur. Phys. J. A 52 (10), 313 (2016); Chin. Phys. C **40 (12)**, 123102 (2016); Nucl. Phys. A 965, 57-73 (2017).

[12] N.Shiri et al., arXiv:2305.02716 (2023)

[13] Z. Xia et al., Phy. Rev. C **105**, 025201 (2022)

[14] S. M. Gerasyuta et al., Int. J. Mod. Phy. E. **21**, 1250058 (2012).

[15] Xi-Zhe Ling et al., Eur. Phy. J. C. **81**(12), 1090 (2021).