# Possibility of hidden pentaquark molecular states in the bottom sector

Smruti Patel* and P. C. Vinodkumar†
[1] *Government Science College, Songadh-394670, Veer Narmad South Gujarat University, Surat, Gujarat, INDIA and*
[2] *Department of Physics, Sardar Patel University, Vallabh Vidyanagar-388120, Gujarat, INDIA*

## Introduction

The experimental searches for the pentaquark states have a long and controversial story. Theoretical investigations of the recently discovered pentaquark states [1] provide important information on their nature and structure The non-conventional internal quark structure of these states, which are excluded neither by the naive quark model nor by QCD, puts them at the focus of increasing interests. The recent discovery of two hidden-charm resonances by the LHCb Collaboration in the has immediately attracted a lot of attention from the whole community since they could be the long-searching-for pentaquark states in the heavy flavor sector. Although their existence was predicted many decades ago by Jaffe[2], the searches on the pentaquarks ended up in positive results due to recently discovery of $P_c$ states and their properties were worked out in many theoretical studies using various formalism such as the molecule-like pentaquark states [3], the diquark-diquark-antiquark type pentaquark states [4, 5], the diquark-triquark type pentaquark states [6], re-scattering effects [7], etc.

## Phenomenology

Many theoretical works have focused on the issue of resolving the structure of pentaquark states as di-hadronic molecules or compact five quark states[2, 8]. In the pioneer paper [9], Gell-Mann indicated that the multiquark states should exist along with the simplest structures for baryons which are composed of three valence quarks and mesons which contain a quark and an antiquark. Investigations into the existence of multiquark states have begun in the early days of QCD [2, 8]. Understanding the mechanisms underlying confinement in QCD is among the most fundamental questions in hadron physics. However, little success has been achieved in understanding pentaquark states due to the non-perturbative nature of QCD at the hadronic scale. The hadron molecular considerations does simplify this difficulty by replacing interquark color interacion with a residual strong interactions between two color singlet hadrons. We study di-hadronic systems here by considering the molecular interaction between the two hadrons as the well known Yukawa type interaction V(r) and is given by

$$V(r) = \frac{-g^2}{r} e^{-kr} \tag{1}$$

Where $g$ being the coupling constant and k is the molecular interaction strength. The potential parameters employed here are taken from Ref.[10, 11]. By using Mathematica code [12] we obtained the binding energies and then computed the masses of low lying di-hadronic molecules same as done in Ref. [11].

The non-relativistic Schrödinger bound-state mass(spin average mass) of the di-hadronic system is obtained as

$$M_{cw} = m_1 + m_2 + BE \tag{2}$$

Where $m_1$ and $m_2$ are the masses of the constituent hadrons, BE represents the binding

*Electronic address: `fizix.smriti@gmail.com`
†Electronic address: `p.c.vinodkumar@gmail.com`

TABLE I: Mass spectra of meson-baryon systems in the bottom sector using Yukawa interaction (in GeV)

| System | BE | $J^P$ | $I$ | $M_{cw}$ | $E_{(j_1,j_2;J)}$ | $E_{(i_1,i_2;I)}$ | $M_{total}$ |
|---|---|---|---|---|---|---|---|
| $\Lambda_b - B$ | -0.357 | $\frac{1}{2}^-$ | $\frac{1}{2}$ | 10.540 | 0.0000 | 0.0000 | 10.540 |
| $\Lambda_b - B^*$ | -0.359 | $\frac{3}{2}^-$ | $\frac{1}{2}$ | 10.584 | 0.0007 | 0.0 | 10.585 |
| | | $\frac{1}{2}^-$ | $\frac{1}{2}$ | | -0.0015 | 0.0 | 10.583 |
| $\Sigma_b - B$ | -0.364 | $\frac{1}{2}^-$ | $\frac{3}{2}$ | 10.725 | 0.0 | 0.0007 | 10.726 |
| | | | $\frac{1}{2}$ | | 0.0 | -0.0014 | 10.724 |
| $\Sigma_b - B^*$ | -0.366 | $\frac{3}{2}^-$ | $\frac{3}{2}$ | 10.769 | 0.0007 | 0.00074 | 10.771 |
| | | | $\frac{1}{2}$ | | 0.0007 | -0.0014 | 10.768 |
| | | $\frac{1}{2}^-$ | $\frac{3}{2}$ | | -0.0014 | 0.0007 | 10.768 |
| | | | $\frac{1}{2}$ | | -0.0014 | -0.0014 | 10.766 |
| $\Sigma_b^* - B^*$ | -0.367 | $\frac{5}{2}^-$ | $\frac{3}{2}$ | 10.789 | 0.0022 | 0.0007 | 10.792 |
| | | | $\frac{1}{2}$ | | 0.0022 | -0.0014 | 10.790 |
| | | $\frac{3}{2}^-$ | $\frac{3}{2}$ | | -0.0014 | 0.0007 | 10.789 |
| | | | $\frac{1}{2}$ | | -0.0014 | -0.0014 | 10.786 |
| | | $\frac{1}{2}^-$ | $\frac{3}{2}$ | | -0.004 | 0.0007 | 10.787 |
| | | | $\frac{1}{2}$ | | -0.004 | -0.0014 | 10.784 |

energy of the di-hadronic system. Further, we have added spin and isospin contribution. Accordingly, the mass of a di-hadronic molecular state is obtained as

$$M_{Total} = M_{cw} + E_{(j_1,j_2;J)} \tag{3}$$

The hyperfine interaction is computed using the expression similar to the hyperfine interactions for quarkonia but without considering color factor which is same as in Ref. [11].

## Results and conclusion

The predicted mass spectrum of low lying pentaquark states as di-hadronic molecular states in the bottom sector is listed in Table I. There exits a $J^P = 1/2^-$ bound state $\Sigma_b - B$ with the mass of 10.726 GeV. A bound state of the main channel $\Sigma_b - \bar{B}^*$ ($J^P = 3/2^-$) with mass 10.771 GeV which can be considered as the partner of $P_c(4380)$. In the same way we can predict $\Sigma_b{}^* - \bar{B}^*$ state with $J^P = 5/2^-$ as partner of $P_c(4450)$. These partners of $P_c(4380)$ and $P_c(4450)$ are worth searching in the future experiments. These estimates may be useful for planning of future experiments and as starting point of more refined study. The predictions on the masses may shed light on experimental searches of the bottom pentaquarks.

Thus, in the absence of more experimental measurements these calculations may be considered as one of the guidelines for further experimental investigations for other predicted states within the mass range of $10.7 - 10.8$ $GeV$.

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