Orbitally excitation of Λ_b^0 baryon

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Introduction

Experimentally, the ground state properties (mass, decay width, life time etc.) of the Λ_b^0 baryon are established very well in past few years see Refs. [1–4]. The LHCb Collaboration [5] observed that the two new resonance peaks with a mass differences, 292.60 ± 0.12(stat) ± 0.04(syst) MeV/c^2 and 300.40 ± 0.08(stat) ± 0.04(syst) MeV/c^2, with respect to ground state Λ_b^0 baryon. They found to be a first orbital excited state of Λ_b^0 baryon of total spin 1/2 and 3/2 and the Particle Data Group's (PDG) [6] naming them as a $\Lambda_{b^{*0}(5912)}$ and $\Lambda_{b^{*0}(5920)}$ respectively. At present, an experimental observations of the Λ_b^0 baryon are rare. The running experiment LHCb [7–9] will expecting to give more informations regarding to this baryon in the upcoming years.

Capstick and Isgur have been first predict the orbital excited states of Λ_b^0 baryon in the relativistic quark model [10] and the predicted masses of the first orbital excited were exactly matched with the later experimental observations of Ref. [5]. Up to now, there are many theoretical the phenomenological approaches have been studied the radial as well as the orbital excited states of singly bottom heavy flavor baryons. Relativistic quark-diquark picture by D. Ebert et al. [11], lattice QCD (Quantum Chromodynamics) study [12], QCD sum rule [13], non-relativistic constituent quark model [14], mass spectra from the Regge like formula [15] and many more.

In this present study, we want to calculate the radial and the orbital excited states of Λ_b^0 baryon. For that we employ the non-relativistic approach of the constitute quark model with a screened potential as used as a scalar confinement potential. The spin-dependent part of the potential is incorporated to see the splitting in mass spectra.

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Theoretical Framework

It is complicated to study the dynamics of a system containing three quarks. The Jacobi coordinates ($\vec{\rho}$ and $\vec{\lambda}$) are introduced [16],

$$\vec{\rho} = \frac{\vec{r_1} - \vec{r_2}}{\sqrt{2}} \quad and \quad \vec{\lambda} = \frac{\vec{r_1} + \vec{r_2} - 2\vec{r_3}}{\sqrt{6}}; \tag{1}$$

to see the relativistic motion three quarks inside the hadrons. The Hamiltonian for a three body system is,

$$H = \frac{P^2}{2m} + V(x); \tag{2}$$

where P^2 is the conjugate moment and m is the reduced mass of Jacobi coordinates [17]. Here, $x = (\vec{\rho}, \vec{\lambda})$ is the hypercentral coordinate written in a six-dimensional space. In this work, the color coulomb plus screened potential is used as a long range spin-independent interaction potential [18, 19]. And, the spin-spin $V_{SS}(x)$, spin-orbit $V_{\gamma S}(x)$ and the spin-tensor $V_T(x)$ interactions are taking into the consideration as a spin-dependent potential $V_{SD}(x)$ for the calculations of orbital excitations (for details see Refs. [20, 21]). Hence,

$$V(x) = -\frac{2}{3}\frac{\alpha_s}{x} + a\left(\frac{1 - e^{-\mu x}}{\mu}\right) + V_{SD}, \tag{3}$$

where,

$$V_{SD}(x) = V_{SS}(x)(\vec{S_\rho} \cdot \vec{S_\lambda}) + V_{\gamma S}(x)(\vec{L} \cdot \vec{S}) + V_T(x)\left[S^2 - \frac{3(\vec{S} \cdot \vec{x})(\vec{S} \cdot \vec{x})}{x^2}\right]. \tag{4}$$

Here, 2/3 is color factor. The $\alpha_s(x)$ is the strong running coupling constant given by,

$$\alpha_s = \frac{\alpha_s(\mu_0)}{1 + \left(\frac{33-2n_f}{12\pi}\right)\alpha_s(\mu_0)ln\left(\frac{q^2}{\mu_0^2}\right)}. \quad (5)$$

$n_f = 4$ gives the number of active quark flavored contributing effectively in a quark-gloun loops and the quantity $(33 - 2n_f)$ is must be greater than zero, so n_f is never larger than six. We used $\alpha_s(\mu_0 = 1GeV) = 0.6$ and set the constituent quarks masses are: $m_u = 0.338$ GeV, $m_d = 0.350$ GeV and $m_b = 4.670$ GeV are consider for the $\Lambda_b^0(udb)$ baryon. The screening factor $\mu = 0.07$. The six-dimensional hyperradial Schrödinger equation is solve numerically in the Mathematica notebook [22].

Results

TABLE I: Radial and orbital excited states masses of Λ_b^0 baryon (in GeV)

State	This work	PDG [6]	Ref. [11]
$1^2S_{\frac{1}{2}}$	5.619	5.620	5.620
$2^2S_{\frac{1}{2}}$	6.011		6.089
$3^2S_{\frac{1}{2}}$	6.341		6.455
$1^2P_{\frac{1}{2}}$	5.960	5.912	5.930
$1^2P_{\frac{3}{2}}$	5.958	5.920	5.942
$1^2D_{\frac{3}{2}}$	6.192		6.190
$1^2D_{\frac{5}{2}}$	6.188		6.196

The ground state mass of the Λ_b^0 baryon is fix from PDG-2018 [6] and generate their masses of radial ($2S$ and $3S$) as well as orbital ($1P$ and $1D$) excited states. Our results are listed in Table I and compare with the predictions of Ref. [11]. For the $2S$, $3S$ and $1P$-wave our results are smaller to Ref. [11] and for the $1D$-wave they are in well agreement. So we will extending this scheme to calculate mass spectra of isotriplet Σ_c baryons.

References

[1] R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. **119**, 062001 (2017).

[2] R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. **112**, 202001 (2014).

[3] T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. D **89**, 072014 (2014).

[4] G. Aad *et al.* (ATLAS Collaboration), Phys. Rev. D **87**, 032002 (2013).

[5] R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. **109**, 172003 (2012).

[6] M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D **98**, 030001 (2018) and 2019 update.

[7] L. Capriotti, J. Phys. Conf. Ser. **1137**, 012004 (2019).

[8] A. Piucci, J. Phys. Conf. Ser. **878**, 012012 (2017).

[9] W. Barter, Mod. Phys. Lett. A **38**, 1630044 (2016).

[10] S. Capstick and N. Isgur, Phys. Rev. D **34**, 2809 (1986).

[11] D. Ebert, R. N. Faustov and V. O. Galkin, Phys. Rev. D **84**, 014025 (2011).

[12] Z. S. Brown, W. Detmold, S. Meinel and K. Orginos, Phys. Rev. D **90**, 094507 (2014).

[13] Q. Mao, H.X. Chen, W. Chen, A. Hosaka, X. Liu and S.L. Zhu, Phys. Rev. D **92**, 114007 (2015).

[14] K. Thakkar, Z. Shah, A.K. Rai and P.C. Vinodkumar, Nucl. Phys. A **965**, 57 (2017).

[15] K. Chen, Y. Dong, X. Liu, Q.-F. Lü and T. Matsuki, Eur. Phys. J. C **78**, 20 (2018).

[16] J.-M. Richard, Phys. Rep. **212**, 1 (1992).

[17] M.M. Giannini and E. Santopinto, Chin. J. Phys. **53**, 020301 (2015).

[18] J.-Z. Wang, D.-Y. Chen, X. Liu and T. Matsuki, Phys. Rev. D **99**, 114003 (2019).

[19] B.-Q. Li and K.-T. Chao, Phys. Rev. D **79**, 094004 (2009).

[20] M.B. Voloshin, Prog. Part. Nucl. Phys. **61**, 455 (2008).

[21] S. Bethke, Eur. Phys. J. C **64**, 689 (2009).

[22] W. Lucha and F. Schoberls, Int. J. Mod. Phys. C **10**, 607 (1999).