A relativistic approach for triply heavy flavour baryon

Tanvi Bhavsar[1],* Manan Shah[2],† and P.C.Vinodkumar[1]‡
[1]*Department of Physics, Sardar Patel University, Vallabh Vidyanagar-388 120, INDIA and*
[2]*P. D. Patel Institute of Applied Sciences, CHARUSAT, Changa-388 421, INDIA*

1. Introduction

The heavy flavor hadrons are very useful to understand QCD interactions and quark structure. After the experimental observation of the doubly charmed baryons [2], one may expect to fill the space of missing baryon family i.e., baryons composed of all heavy quarks. One of the basic properties of these lowest lying baryons is their masses, which are computed using relativistic formalism.

2. Theoretical Methodology

To study QQQ baryon, we have employed the quark-diquark approach and the interaction between the two quarks forming a diquark is assumed to be in the form of linear potential. The form of the model potential is expressed as [3],

$$V(r) = \frac{1}{2}(1+\gamma_0)(\lambda r^{1.0} + V_0) \qquad (1)$$

To get binding energy for QQQ system we have solved the two component (positive and negative energy) Dirac equation. As we require binding energy of quarks, we have used only positive energy solution of Dirac equation [3, 4],

$$\psi_{nlj}(r) = \begin{pmatrix} \psi^{(+)}_{nlj} \\ \psi^{(-)}_{nlj} \end{pmatrix} \qquad (2)$$

where

$$\psi^{(+)}_{nlj}(\vec{r}) = N_{nlj}\begin{pmatrix} ig(r)/r \\ (\sigma.\hat{r})f(r)/r \end{pmatrix}\mathcal{Y}_{ljm}(\hat{r}) \qquad (3)$$

The energy eigen value is obtained from,,

$$\epsilon = (E_q - m_q - V_0)(m_q + E_q)^{\frac{1}{3}}\lambda^{\frac{-2}{3}} \qquad (4)$$

For the quark-quark interaction in a diquark, the potential between the two quarks, $V_{QQ} = \frac{1}{2}V_{Q\bar{Q}}$ [5]. The diquark masses and the baryon mass are written as,

$$M_d = 2(E_Q + M_Q) - E_{d(c.m)} \qquad (5)$$

$$M_{dQ} = 3(E_Q + M_Q) - E_{dQ(c.m)} \qquad (6)$$

Here, 'd' and 'Q' represent diquark and heavy quark respectively, while E_d and E_{dQ} are the energy eigenvalues of the diquark and diquark - quark system respectively. In the present calculation we have also incorporated spin spin interaction to get hyperfine splitting. The j-j coupling of confined one gluon exchange potential (COGEP) is given by, [4]

$$\langle V^{j_d j_Q}_{baryon}\rangle = \frac{\sigma\langle j_d j_Q JM|\widehat{j_d}.\widehat{j_Q}|j_d j_Q JM\rangle}{(E_d + m_d)(E_Q + m_Q)} \qquad (7)$$

3. Result and discussion

We use relativistic Dirac formalism to estimate masses of the lowest-lying bcc, ccc, bbb and bbc states. The computed masses for QQQ baryons arr listed in Table I. The model parameters for the study of triple heavy baryons are $m_c = 1.27$ GeV and $m_b = 4.67$ GeV and coupling constants σ for cc and bb diquarks are 0.025 GeV^3 and 0.25 GeV^3. Our

*Electronic address: tanvibhavsar1992@yahoo.com
†Electronic address: mnshah09@gmail.com
‡Electronic address: p.c.vinodkumar@gmail.com

TABLE I: Triple heavy baryon masses(in MeV).

Baryon	Spin	Our	[6]	[7]
Ω_{ccc}^{++}	3/2	4703	4736	4978
Ω_{ccb}^{*+}	3/2	7963	8099	8358
Ω_{bbc}^{*0}	3/2	11265	11394	11609
Ω_{bbb}^{-}	3/2	14214	14370	15118
Ω_{ccb}^{+}	1/2	7895	8089	8229
Ω_{bbc}^{0}	1/2	11176	11354	11738

predicted masses for these states are lower than those made by B. Patel et al. [6] and Z. Ghalenovi et al. [7] but still compatible with the known mass inequalities in QCD. There exists one inequality, which relates the masses of baryons and mesons [8, 9], which originates from the fact that the diquark potential in a baryon is half of the quark-antiquark potential [10],

For instance in the triple charm baryonic case,

$$M_{\Omega_{ccc}} \geq \frac{3M_{J/\psi}}{2} \tag{8}$$

and similarly for triple beauty baryon,

$$M_{\Omega_{bbb}} \geq \frac{3M_{\Upsilon}}{2} \tag{9}$$

Our calculated masses for J/ψ, Υ Ω_{ccc}^{++} and Ω_{bbb}^{-} are 3097 MeV, 9461 MeV, 4541 MeV and 14172 MeV respectively. for single flavour baroyn case this inequality holds true. For mixed flavour baryons this inequality becomes,

$$M_{\Omega_{ccb}} \geq \frac{M_{J/\psi}}{2} + M_{B_c} \tag{10}$$

$$M_{\Omega_{bbc}} \geq \frac{M_{\Upsilon}}{2} + M_{B_c} \tag{11}$$

From our analysis we found that above inequality also holds for ccb and bbc baryons. The disparity observed in our mass predictions

TABLE II: The computed ground state masses of heavy flvour mesons(in MeV).

Meson	M_v Vector mass	M_p Pseudoscalr mass
Υ meson	9461	9390
J/ψ meson	3097	2983
B_c meson	6339	6272

with other theoretical predictions can only be resolved with the experimental confirmation of these states. We look forward to the experimental support to our predictions, from different future heavy flavour high luminosity experiments like LHCb, B factories(BARBAR and BELLE) and CLEO.

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