$L = 0$ spectra of Ξ_{cc}^{++} baryon in relativistic Dirac formalism with independent quark model

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Introduction

The LHCb Collaboration [1, 2] confirmed the existence of double heavy baryon $\Xi_{cc}^{++}(ccu)$ baryon with a mass of 3621.40 ± 0.78 MeV and lifetime 0.256 ± 0.014 ps shows an significant development in heavy hadron physics. At present, there is no other experimental data has been observed for such hadrons. It is possible that future analyses at LHC and the forthcoming experiments like PANDA at FAIR could be able to detect the production and decays of doubly heavy baryons. Here, The mass spectra of radially excited states of doubly heavy baryons are calculated under a mean field confinement of Martin-like potential with a parametric centre of weight mass correction in an independent quark model with Dirac relativistic formalism.

Methodology

To study the heavy baryons, we have used Martin-like potential for quark confinement in relativistic approach. The form of the model potential is expressed as,

$$V(r) = \frac{1}{2}(1+\gamma_0)(\lambda r^{0.1} + V_0) \qquad (1)$$

Here, λ is the potential strength and V_0 is the potential parameter.

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The wave function $\Psi(\vec{r})$ satisfies the Dirac equation given by

$$[\gamma^0 E_q - \vec{\gamma}.\vec{P} - m_q - V(r)]\Psi(\vec{r}) = 0 \qquad (2)$$

To obtain the binding energy of the quark (+ve energy) and the anti-quark (-ve energy) we have solved the Dirac equation. The solution of Dirac equation can be written in two component form as [2] but here for baryons we require only the positive energy solution as given by [3];

$$\Psi_{nlj}(\vec{r}) = \begin{pmatrix} \Psi_A \\ \Psi_B \end{pmatrix} \qquad (3)$$

where

$$\Psi_A^{(+)}(\vec{r}) = N_{nlj} \begin{pmatrix} \frac{ig(r)}{r} \\ \frac{(\sigma.\hat{r})f(r)}{r} \end{pmatrix} Y_{ljm}(\hat{r}) \qquad (4)$$

and N_{nlj} is the overall normalization constant.

The spin-average mass of a baryon (having quark structure QQq) in this formalism can be written as

$$M_{SA}^{Qqq} = E_Q^D + 2E_q^D - E_{CM}, \qquad (5)$$

where, E_Q^D and E_q^D represents the Dirac energy of Q and q quarks respectively and E_{CM} is the parametric centre of mass correction.

The spin degeneracy can be removed by considering the spin-spin $(j \cdot j)$ interactions as

$$\langle V^{jj}_{QQq}(r)\rangle = \sum_{i=1,i<k}^{i,k=3} \frac{\sigma\langle j_i j_k JM|\widehat{j_i}\widehat{j_k}|j_i j_k JM\rangle}{(E_{q_i}+m_{q_i})(E_{q_k}+m_{q_k})}, \quad (6)$$

where, σ is the $j-j$ coupling constant.

The fitted values for potential parameters, $j-j$ coupling constant and parametric centre of mass correction are $\lambda = 1.150\ GeV^{1.1}$, $V_0 = -0.960\ GeV$, $\sigma = 0.159\ GeV^3$ and $E_{CM} = 0.129\ GeV$ respectively.

The computed S-wave masses ($L = 0$) are given in **TABLE I** along with the available experimental data [6] and other theoretical predictions [7], [8] and [9].

TABLE I : S state of Ξ_{cc}^{++} in GeV

$n^{2S+1}S_J$	Our mass	Exp.[6]	[7]	[8]	[9]
$1^2S_{\frac{1}{2}}$	3.636	3.621	3.581	3.547	3.685
$1^4S_{\frac{3}{2}}$	3.715	-	3.726	3.719	3.754
$2^2S_{\frac{1}{2}}$	3.959	-	3.925	4.183	4.079
$2^4S_{\frac{3}{2}}$	4.022	-	3.988	4.282	4.114
$3^2S_{\frac{1}{2}}$	4.145	-	4.241	4.640	4.159
$3^4S_{\frac{3}{2}}$	4.202	-	4.234	4.719	4.131
$4^2S_{\frac{1}{2}}$	4.278	-	4.535	-	-
$4^4S_{\frac{3}{2}}$	4.331	-	4.466	-	-
$5^2S_{\frac{1}{2}}$	4.399	-	4.821	-	-
$5^4S_{\frac{3}{2}}$	4.422	-	4.687	-	-

Result and Conclusion

We have predicted the ground state masses of the doubly heavy baryons as well as radial excitation of baryon using the optimized fitted potential parameters which are found to be in good agreement with available experimental results as well as other theoretical predicted data. For predicting $(\frac{3}{2}^+)$ and $(\frac{1}{2}^+)$ states, we have incorporated the $j-j$ coupling. In this study, the ground state masses for $1^2S_{\frac{1}{2}}$ $3.636 GeV$ is in good agreement with the available experimental mass $3.621 GeV$.

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