Regge Trajectories of triply heavy baryons

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Abstract. Ωccc, Ωbbb, Ωbcc and Ωccb baryons are considerable theoretical interest in a baryonic analogue of heavy quarkonium because of the color-singlet bound state of three heavy quark (c,b) combination inside. Regge trajectories are concerned with the mass spectrum of the particles so that the present study exhibits the regge trajectories obtained from excited states of four experimentally unknown triply heavy Ω baryons. The trajectories are plotted in (n, M²) and (J, M²) planes which are helpful to determine the unknown quantum number and J² values. The calculations have computed in Hypercentral Constituent Quark Model with hyper coulomb plus linear potential.

1. Introduction
The three heavy quarks (c,b) united and generate the system called triply heavy baryons. The well-known light baryon Ω contains the three strange quark combination. While these lights quarks are replaced by the heavy quarks the four new baryons are generated: Ωccc, Ωbbb, Ωbcc and Ωccb [1]. The baryons with three same heavy quarks are spin symmetrical states and thus, the ground states and radial excited states of Ωccc and Ωbbb baryons are determined only with J² = 3/2. Whereas, the rest two baryons; mixed combination of c and b can have these states with J² = 1/2, 3/2 [2]. Any experimental evidence of these states have not evicted yet. Although, many authors have studied theoretically the mass spectra of triply heavy baryons using different approaches [3–8, 10–12]. In this paper, we have used the masses of Ωccc, Ωbcc and Ωccb baryons to construct the regge trajectories after the brief introduction and short discussion of our model.

The Hypercentral Constituent Quark Model(hCQM) is used to generate the mass spectra of triply heavy baryons in this paper. The model has successfully determined the ground states and excited states of singly, doubly, some of the triply heavy baryons in charm and bottom sector in our previous work [2,13–17].

The Hamiltonian of the three-quark system is taken as

\[ H = \frac{p^2}{2m} + V(x) \]  \hspace{1cm} (1)

The hyper radius \( x = \sqrt{\rho^2 + \lambda^2} \) and \( \rho \) and \( \lambda \) are the Jacobi co-ordinates [18–20]. \( m = \frac{2m_qm_A}{m_q + m_A} \) is the reduced mass and \( x \) is the six dimensional radial hyper central coordinate of the three body system. The quark masses taken in calculations are \( m_c = 1.275 \) and \( m_b = 4.67 \) (in GeV).
The hypercentral potential $V(x)$ is the hyper color coulomb plus linear potential with first order correction $[21]$. It also contains the spin-dependant part.

$$V(x) = V^0(x) + \left( \frac{1}{m_p} + \frac{1}{m_\lambda} \right) V^{(1)}(x) + V_{SD}(x)$$  \hspace{1cm} (2)

The first order correction $V^{(1)}(x)$ has already been used to obtain the mass spectra of heavy baryons, heavy-light mesons and exotic states $[2, 14–16, 22–24]$. The detail description of Eqn. (2) can be found in Ref. [14] and the refs. therein.

2. Regge Trajectories

Tullio Regge had introduced the topic of Regge trajectories to the hadron physics $[25]$. The dynamical origin of regge trajectories are reviewed in different model of hadron spectroscopy broadly. The Regge trajectories are related by the mass and the spin of a hadrons $[26]$.

The mass spectra are calculated for 1S-5S, 1P-5P, 1D-4D and 1F-2F states of triply heavy $\Omega_{ccc}$, $\Omega_{bcc}$ and $\Omega_{ccb}$ baryons. These generated masses are used to plot the regge trajectories in two different planes figures (12). Figure (1) shows the graph using the masses of triply charm baryon, whereas figure (2) shows the graph using the masses of two charm-bottom triply heavy baryons.

![Figure 1. Regge trajectories of $\Omega_{ccc}$ baryon in (n, $M^2$) (a) and (J, $M^2$) (b) planes $[2]$.](image)

Regge trajectories are related with the baryon masses(M), Isospin(I), principal quantum number(n) and total angular momentum(J). The relations are:

$$n = \beta M^2 + \beta_0 \hspace{1cm} \& \hspace{1cm} J = \alpha M^2 + \alpha_0$$  \hspace{1cm} (3)

where, $\beta, \alpha$ are slopes and $\beta_0, \alpha_0$ are intercepts. With the help of slopes and intercepts one can identify the state with the $J^P$ value.

The regge trajectories are plotted in (n, $M^2$) and (J, $M^2$) planes. In ($M^2 \to n$) graphs, the S, P, D and F states are plotted with $J^P$ values $1^+, \frac{1}{2}^+, \frac{3}{2}^+$ and $\frac{7}{2}^-$, in ($M^2 \to J$) graphs, $\Omega_{ccc}$ is plotted for unnatural parities and $\Omega_{bcc}$ are plotted for natural parities. These graphs show the linearity between the states in same plane.
3. Conclusion

All three triply heavy baryons are experimentally unknown. Thus, the motive of these studies are identifying the states with particular $J^P$ values. The trajectories are useful in that and the slope and intercepts of the graphs will also identify the principal quantum number of the state. These trajectories are still effective in determining spin and parity of discovered hadrons.

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