Spectroscopic Properties of Heavy Baryons

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Introduction

There have been several bottom baryon decay channels observed at experimental facilities in worldwide and a significant quantity of information on heavy baryons has been collected. And Partcle Data Group (PDG) also established the singly bottom states [1].

A study of heavy baryon spectroscopy is fascinating and essential. Heavy baryons allow us to study light and heavy quark interactions. QCD interactions between heavy-light and heavy-heavy baryons may be understood through the investigation of heavy baryon characteristics. Heavy baryons are studied using the Hypercentral Constituent Quark Model (hCQM) [3]. The model makes three-quark dynamics easier to grasp. The non-relativistic perturbative technique was used by incorporating screened potential as a restricting term. The Schr̈dinger equation may be solved numerically to determine the mass value of a baryonic condition.

Many experimental facilities are detecting heavy-flavored baryons. Various experimental groups report many heavy baryon results. Daily ground and low-lying conditions of heavy baryons are recorded. To establish the detected particle's J^p value and quantum number, a thorough grasp of QCD and hadron spectroscopy is required.

Model

The Hypercentral Constituent Quark Model (hCQM) has been described as the underlying framework for this study. The component quarks provide the foundation for hCQM, which is based on the standard model. Primary quantum numbers of baryons can be described in terms of their constituent quarks, which are effective degrees of freedom, although with variation in QCD, quarks can gain mass and even size.

When considering a three-body system from a hypercentral perspective, the underlying purpose is straightforward. The non-relativistic Schrödinger equation in six dimensions is solved by rewriting two relative coordinates ($\vec{\rho}$ and $\vec{\lambda}$) as a single six-dimensional vector. Three-body interactions are handled efficiently by converting them in two-body interaction in terms of ρ and λ.
An expression of the Hamiltonian for a three-body system reduced to one body is written in the form of Jacobi coordinates as [2],

$$H = -\frac{\hbar^2}{2m}\left(\frac{\partial^2}{\partial x^2} + \frac{5}{x}\frac{\partial}{\partial x} + \frac{L^2(\Omega)}{x^2}\right) + V(x) \quad (1)$$

where, x is the six-dimensional hypercentral coordinate, $x = (\vec{\rho}, \vec{\lambda})$. $L^2(\Omega) = L^2(\Omega_\rho, \Omega_\lambda, \xi)$ is the quadratic Casimir operator of the six-dimensional rotational group $\mathcal{O}(6)$.

The hyperradial Schrödinger equation corresponds to the three quark hyperradial wave function can be written as [2],

$$\left[\frac{d^2}{dx^2} + \frac{5}{x}\frac{d}{dx} - \frac{\gamma(\gamma+4)}{x^2}\right]\Psi_\gamma(x) = -2m[E - V(x)]\Psi_\gamma(x) \quad (2)$$

The exact solution of the QCD equation is very complex, so one has to rely on conventional quark models. The six-dimensional hyperradial Schrödinger equation corresponds to the above Hamiltonian reduces to

$$\left[-\frac{1}{2m}\frac{d^2}{dx^2} + \frac{\frac{15}{4} + \gamma(\gamma+4)}{2mx^2} + V(x)\right]\phi(x) = E\phi(x) \quad (3)$$

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The Schrödinger equation is solved in Mathematica Notebook [4].

Results

The mass spectra are obtained for singly, doubly and triply heavy baryons for 1S-5S, 1P-4P, 1D-4D and 1F-2F [5–11]. The obtained results which are matching with experimentally observed resonance are listed in Table I.

TABLE I: Experimentally observed states, width and assigned J^P values

Resonance	Exp. Mass (MeV)	Our results (MeV)	assigned J^P value
$\Lambda_b(6070)^0$	6072.3 ± 2.9	6067	$\frac{1}{2}^+$ (2S)
$\Sigma_b(6097)^+$	6095.8 ± 1.7	6098	$\frac{3}{2}^-$ (1P)
$\Sigma_b(6097)^-$	$6098.0 \pm 1.7 \pm 0.5$	6098	$\frac{3}{2}^-$ (1P)
$\Xi_b(6100)^-$	6100.3 ± 0.2	6135	$\frac{3}{2}^-$ (1P)
$\Xi_b^(6227)'^-$	6227.9 ± 0.9	6232	$\frac{3}{2}^-$ (1P)
$\Xi_b(6327)^-$	$6327.3^{+0.23}_{-0.21}$	6243	$\frac{3}{2}^+$ (1D)
$\Xi_b(6333)^-$	$6333.3^{+0.17}_{-0.18}$	6240	$\frac{5}{2}^+$ (1D)
$\Omega_b(6316)^-$	6315.6 ± 0.6	6341	$\frac{3}{2}^-$ (1P)
$\Omega_b(6330)^-$	6330.3 ± 0.6	6344	$\frac{1}{2}^-$ (1P)
$\Omega_b(6340)^-$	6339.7 ± 0.6	6339	$\frac{3}{2}^-$ (1P)
$\Omega_b(6350)^-$	6349.8 ± 0.6	6343	$\frac{5}{2}^-$ (1P)

Conclusion

By employing screening potential as a confining potential with color-Coulomb potential, the Hypercentral Constituent Quark Model (hCQM) is used to predict the mass spectra of the radial and orbital states of heavy baryons. Following that, the results are compared with other theoretical predictions. Our results are quite consistent with them. In the future, it may be possible to determine the quantum numbers of novel resonances that have been experimentally discovered using the masses that have been counted in this research as reliable proof. The spin-parity value has been defined to the newly discovered experimental states. The electromagnetic and decay properties are also investigated.

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