Properties of Λ_b Baryon

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Introduction

The investigation into baryons that incorporate heavy quarks containing (c/b) have great interest, primarily the abundant data reported by various experimental facilities like LHCb, CDF, BABAR, CMS, SELEX and others [1, 2]. The spectrum of baryons with a single quark is remarkable in advancing our comprehension of QCD. This is because the presence of heavy quark within the baryon provided us insights into dynamics of quark interaction.

Λ_b is the lightest of the bottom baryon family, exhibits a singlet state attributed to its isospin 0 [3]. The two relatively narrow states namely $\Lambda_b(5912)$ and $\Lambda_b(5920)$ were initially detected through the decay of exited into the final state $\Lambda_b\pi^+\pi^-$ by LHCb [1] experiment. And assignment of spin-parity J^P value $\frac{1}{2}^-$ and $\frac{3}{2}^-$ of 1P states, similarly $\Lambda_b(6146)$ and $\Lambda_b(6152)$ have been observed and assign spin-parity J^P value $\frac{3}{2}^+$ and $\frac{5}{2}^+$ of 1D states respectively by LHCb collaboration.

The mass spectra of baryons containing single bottom quark have been examined by using various methods such as QCD sum rules,[4, 5] Regge phenomenology,[6, 7] relativistic flux tube model[8] etc. We have conducted a comparative analysis of mass spectra for both the ground and excited states of Λ_b using our calculations, and we have contrasted our results with those obtained through different theoretical methods.

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Theoretical Model

The non-relativistic approach known as the Hypercentral Constituent Quark Model(hCQM) has been utilized to provide insights into the interaction among constituent quarks within bottom baryons that do not contain strange quark [9–13]. Since a baryon consists of three quarks, we employed Jacobi coordinates to describe the dynamics of this three-body system.The model itself implies that the potential to be selected must be hypercentral, meaning it should solely depend on the hyper-radius, denoted as x [14, 15, 22]. In this context, a combination of the coulomb term, a confining potential, and a spin-dependent interaction V_{SD} incorporating effects like spin-orbit interactions, spin-spin interactions, and tensor terms [17].

$$V(x) = -\frac{\tau}{x} + \alpha x \tag{1}$$

In this context, τ is defined as $\frac{2}{3}$ the running coupling constant denoted by α_s. We performed first order $O(\frac{1}{m})$ correction in the spin-dependent section, but this was unable to resolve spin-splitting in the proper order. As a result, we conducted a second order $O(\frac{1}{m^2})$[18–20] correction in the spin-orbit and spin-tensor terms,which resolved mass hierarchy.

$$V^1(x) = -C_F C_A \frac{\alpha_s^2}{4x^2} \tag{2}$$

In this scenario, C_F is set at 4/3, and C_A is equal to 3. These values correspond to the Casimir elements associated with the fundamental and adjoint representations in the context of SU(3). The Hamiltonian is given as

$$H = \frac{P^2}{2m} + V(x) + V_{SD}(x) + \frac{1}{m}V^1(x) + \frac{1}{m^2}V^2(x) \tag{3}$$

Results and Discussion

TABLE I: Resonance masses of Λ_b and results from few other models

State	J^P	M_{theo}	M_{exp}	[21]	[16]	[23]	[24]
1S	$\frac{1}{2}^+$	5619	5619	5618	5621	5620	5620
2S	$\frac{1}{2}^+$	6054	6072	6153	6026	6089	6026
3S	$\frac{1}{2}^+$	6361		6467	6380	6455	6406
1P	$\frac{1}{2}^-$	5927	5920	5938	6000	5930	
	$\frac{3}{2}^-$	5937		5939	5988	5942	5924
1D	$\frac{3}{2}^+$	6182	6146	6211	6233	6190	
	$\frac{5}{2}^+$	6194	6152		6213	6196	6213

The mass calculations for the radial and orbital states within singly bottom baryons without strange quarks have been performed within the frame work of Hypercentral Constituent Quark Model.
We have conducted mass spectra calculations for different states of Λ_b baryon, such as 1S-3S, 1P and 1D states which is presented in table 1. Our predicted 1S state is consistent with experimental and other theoretical approaches, we assign spin-parity $J^P{=}\frac{1}{2}^+$. The predicted masses of our 2S and 3S states exhibit a slight variation of approximately 20 MeV when compared to both experimental data and other theoretical models. The orbitally excited states 1P and 1D are in agreement with other models, with only a slight variation of a few MeV.

Conclusion

In our current study, we have employed the Hypercentral Constituent Quark Model (hCQM) framework to compute the radial and orbitally excited states of the Λ_b baryon. Furthermore, we have incorporated higher-order corrections, specifically first and second-order corrections in terms of mass, while considering spin-dependent factors. These adjustments have allowed us to establish the correct order of mass hierarchy as we move from lower excited states to higher excited states. In general we predicted mass spectra of Λ_b baryon and compared with other approaches and accordingly assign spin-parity.

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