INFN

41th International Conference on High Energy Physics

ICHEP 2022 BOLOGNA

Study of the heavy bottom baryons in a potential model

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Abstract

The bottom heavy baryons are studied in the framework of a nonrelativistic quark model. We use the hypercentral approach to solve the six-dimentional Schrödinger equation of the baryons. Introducing a potential model, the ground state masses and magnetic moments of the Λ_b,Σ_b, Ξ_{bc}, Ξ_{bb} heavy baryons are calculated. We investigate the semileptonic decay widths of the Λ_b bottom baryon. Our results are in agreement with the available experimental data and those of other works.

The model

We consider the baryons as a bound state of three quarks in the hypercenteral approach. To describe the baryon containing three quarks, we use the Jacobi coordinates

$$\rho = \frac{1}{\sqrt{2}}(r_1 - r_2), \quad \lambda = \frac{1}{\sqrt{6}}(r_1 + r_2 - 2r_3),$$

and

$$m_\rho = \frac{2m_1m_2}{m_1+m_2}; \quad m_\lambda = \frac{3m_3(m_1+m_2)}{2(m_1+m_2+m_3)}$$

One can introduce the hyperspherical coordinates:

$$x = \sqrt{\vec{\rho}^2 + \vec{\lambda}^2}, \quad \xi = \tan^{-1}(\frac{\rho}{\lambda})$$

Therefore the Hamiltonian will be

$$H = \frac{p_\rho^2}{2m_\rho} + \frac{p_\lambda^2}{2m_\lambda} + V(\rho,\lambda) = \frac{p^2}{2m} + V(x)$$

The three-body Schrodinger equation in the hypercentral model is obtained as

$$\left[\frac{d^2}{dx^2} + \frac{5}{x}\frac{d}{dx} - \frac{\gamma(\gamma+1)}{x^2}\right]\psi_\gamma(x) = -2m\left[E_\gamma - V(x)\right]\psi_\gamma(x)$$

Where $\psi(x)$, E_γ , x and L are the wave function, energy eigenvalues, distance between two particles, and angular quantum number respectively. m is the reduced mass and x is the hyerradious and definded in terms of the Jacobi coordinates:

$$m = \frac{2m_\rho m_\lambda}{m_\rho + m_\lambda},$$

and potential V(x) is definded as follows

$$V(x) = ax - \frac{c}{x}$$

Where the coefficients of the confining and color-coulombic parts, a and c, are constant. The hyperfine interactions are considered as perturbation. We assume the wave function to be in the form of

$$\psi_\gamma = x^{5/2}\varphi_\gamma$$

to simplify the Schrodinger equation and then solve the equation numerically. For details see Ref. [1].

By using the obtained eigenenergies E_γ, eigenfunctions and also the perturbative hyperfine energy E_{hyp}, the mass of the baryon is obtained as a summation of the quark masses and the energies

$$M = \mathrm{m1+m2+m3} + E_\gamma + E_{hyp}$$

Our results for the ground state baryon masses are as follows

$\Lambda_c = 2259MeV, \Sigma_c = 2471MeV, \Lambda_b = 5639MeV, \Sigma_b = 5859MeV, \Xi_b = 5858MeV, \Omega_b = 5917MeV\ , \Xi_{bc} = 6989MeV, , \Xi_{bb} = 10369MeV.$

We compared our results for the some of the baryon masses with other results in table 1.

Table 1: Masses of the bottom baryons (in MeV).

State	Prediction	Exp [5]	[6]	[7]
Σ_b	5859	5813	5808	5823
Λ_b	5639	5620	5620	5618
State	Prediction	[8]	[9]	[10]
Ξ_{bc}	6989	6933	6928	7020
Ξ_{bb}	10369	10202	10198	10340

The magnetic moments are computed as

$$\mu_B = \sum_i < \phi_{sf}|\mu_i\sigma_i|\phi_{sf} >$$

where $|\phi_{sf}>$ is the spin-flavour wave function of the quark and μ_i is the magnetic moment of ith quark.

Table 2: Spin-flavour wave functions of Σ_b and Λ_b baryons and its magnetic moment in terms of t constituent quarks magnetic moments.

Baryon	Spin-flavour wave function	μ_B
Σ_b^+	$\frac{1}{\sqrt{18}}[2u\uparrow b\downarrow u\uparrow +2u\uparrow u\uparrow b\downarrow +2b\downarrow u\uparrow u\uparrow -u\uparrow u\downarrow b\uparrow - u\uparrow b\uparrow u\downarrow -u\downarrow b\uparrow u\uparrow -b\uparrow u\downarrow u\uparrow -b\uparrow u\uparrow u\downarrow -u\downarrow u\uparrow b\uparrow]$	$\frac{4}{3}\mu_u - \frac{1}{3}\mu_b$
Σ_b^0	$\frac{-1}{6}[u\uparrow d\downarrow b\uparrow +d\uparrow u\downarrow b\uparrow +b\uparrow d\downarrow u\uparrow +b\uparrow u\downarrow d\uparrow -2u\uparrow b\downarrow d\uparrow -2d\uparrow b\downarrow u\uparrow +u\downarrow d\uparrow b\uparrow +d\downarrow u\uparrow b\uparrow -2b\downarrow d\uparrow u\uparrow -2b\downarrow u\uparrow d\uparrow +u\downarrow b\uparrow d\uparrow +d\downarrow b\uparrow u\uparrow -2u\uparrow d\uparrow b\downarrow -2d\uparrow u\uparrow b\downarrow +b\uparrow d\uparrow u\downarrow +b\uparrow u\uparrow d\downarrow +u\uparrow b\uparrow d\downarrow +d\uparrow b\uparrow u\downarrow]$	$\frac{2}{3}\mu_d + \frac{2}{3}\mu_d - \frac{1}{3}\mu_b$
Σ_b^-	$\frac{1}{\sqrt{18}}[2d\uparrow b\downarrow d\uparrow +2d\uparrow d\uparrow b\downarrow +2b\downarrow d\uparrow d\uparrow -d\uparrow d\downarrow b\uparrow - d\uparrow b\uparrow d\downarrow -d\downarrow b\uparrow d\uparrow -b\uparrow d\downarrow d\uparrow -b\uparrow d\uparrow d\downarrow -d\downarrow d\uparrow b\uparrow]$	$\frac{4}{3}\mu_d - \frac{1}{3}\mu_b$
Λ_b^0	$\frac{\sqrt{3}}{6}[u\downarrow d\uparrow b\uparrow -d\downarrow u\uparrow b\uparrow +u\downarrow b\uparrow d\uparrow -d\downarrow b\uparrow u\uparrow -u\uparrow d\downarrow b\uparrow +d\uparrow u\downarrow b\uparrow -b\uparrow d\downarrow u\uparrow +b\uparrow u\downarrow d\uparrow +b\uparrow d\uparrow u\downarrow -b\uparrow u\uparrow d\downarrow -u\uparrow b\uparrow u\downarrow +d\uparrow b\uparrow u\downarrow]$	μ_b

The magnetic moments of the bottom baryon are obtained as

$\Lambda_b = -0.06\mu_N$, ${\Sigma_b}^+ = 2.45\ \mu_N$, ${\Sigma_b}^0 = 0.62\ \mu_N$, ${\Sigma_b}^- =$-1.00 μ_N, ${\Xi_{bb}}^0 = -2.00\ \mu_N$

Semileptonic transition of Λ_b baryon

In the heavy-quark limit, all the form factors describing the semileptonic decays are proportional to the universal function $\xi(\omega)$ known as the Isgur-Wise (IW) function.

$$F_1 = G_1 = \xi$$
$$F_2 = G_2 = F_3 = G_3 = 0$$

To consider the $\Lambda_b \to \Lambda_c$ we use the following form of the IW function obtained by Jenkins, Manohar and Wise:

$$\xi(\omega) = 0.99\exp[-1.3(\omega - 1)]$$

The differential decay width has the form

$$\frac{d\Gamma}{d\omega} = \frac{2}{3}m_{\Lambda_c}^4 m_{\Lambda_b} A\xi^2(\omega)\sqrt{\omega^2 - 1}[3\omega(\eta + \eta^{-1}) - 2 - 4\omega^2]$$

Where $\eta = \frac{m_{\Lambda_b}}{m_{\Lambda_c}}$ and $A = G_F^2/(2\pi)^3|V_{cb}|^2 B(\Lambda_c \to ab)$.

$B(\Lambda_c \to ab)$ is the branching ratio for the decay $\Lambda_c \to a + b$ through which Λ_c is detected. For the considered universal function $\xi(\omega)$ we get the slope as

$$\rho^2 = \frac{d\xi(\omega)}{d\omega}|_{\omega=1} = 1.28$$

The decay width can be calculated as

$$\Gamma = \int_{\omega=1}^{\omega_{max}} \frac{2}{3}m_{\Lambda_c}^4 m_{\Lambda_b} A\xi^2(\omega)\sqrt{\omega^2 - 1}[3\omega(\eta + \eta^{-1}) - 2 - 4\omega^2]\, d\omega$$

where ω max is defined as

$$\omega_{max} = \frac{m_{\Lambda_b}^2 + m_{\Lambda_c}^2}{2m_{\Lambda_b}m_{\Lambda_c}}$$

using the obtained baryon masses we get

$$\Gamma = 8.87B \times 10^{10}\ s^{-1}$$

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