Radiative M1 decay of Ω_{bb}^{-} Baryon

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Introduction

Only two doubly heavy baryons(DHB) have been observed experimentally: Ξ_{cc}^{++} and Ξ_{cc}^{+} both being doubly charmed. Doubly bottom and bottom-charmed baryons are yet to be observed experimentally. Studying baryons with two heavy quarks is interesting because examining the electromagnetic properties of two heavy quarks coupled to a light quark provides insight into the dynamics that govern internal interactions in baryons with heavy quarks. The radiative decays can also be useful in the determination of the quantum numbers of parity states, as well as for understanding their internal structures.Electromagnetic properties of such baryons have been studied within various different approaches: The bag model[1, 2], Quark model [3], the potential model[4], chiral perturbation theory[5] and many others. We have adapted Hypercentral Constituent Quark Model(HCQM) to calculate the radiative decay width of Ω_{bb}^{-}, which is the heaviest of all the DHB.

Theoretical Framework

The kinetic energy operator in HCQM can be written as

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

The six-dimensional hyperradial *Schrödinger* equation can be written as [6]

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

where $\psi_{\nu\gamma}(x)$ is the hyper-radial wave function. In this study, we have consider the hypercentral potential V(x) as the hyper Coulomb plus linear potential given by

$$V(x) = \frac{\tau}{x} + \beta x + V_0 + V_{spin}(x) \quad (3)$$

The fourth term of equation Eqn. (3) represents the spin-dependent part of the three-body interaction, and is taken as

$$V_{spin}(x) = -\frac{A}{4}\alpha_s \frac{e^{-\frac{x}{x_0}}}{x x_0^2}\sum_{i<j}\frac{\overrightarrow{\sigma_i}\cdot\overrightarrow{\sigma_j}}{6m_i m_j}\overrightarrow{\lambda_i}\cdot\overrightarrow{\lambda_j} \quad (4)$$

where $\overrightarrow{\sigma_i}\cdot\overrightarrow{\sigma_j}$ are the spin operator, $\overrightarrow{\lambda_i}\cdot\overrightarrow{\lambda_j}$ are the color operator. The trial radial wave function is given as in [7]

$$\psi_{\nu\gamma} = \left[\frac{(\nu-\gamma)!(2g)^6}{(2\nu+5)(\nu+\gamma+4)!}\right]^{\frac{1}{2}} (2gx)^{\gamma}\times e^{-gx}L_{\nu-\gamma}^{2\gamma+4}(2gx) \quad (5)$$

The baryon masses are determined by the sum of the model quark masses, kinetic energy and potential energy

$$M_B = \sum_i m_i + \langle H\rangle \quad (6)$$

Radiative Decay of $\Omega_{bb}^{-*} \to \Omega_{bb}^{-}\gamma$ baryon

The radiative decay width can be expressed in terms of the radiative transition magnetic moment and photon momentum (k) as [1]

$$\Gamma = \frac{\alpha k^3}{M_P^2}\frac{2}{2J+1}\frac{M_{\Omega_{bb}^-}}{M_{\Omega_{bb}^{-*}}}\mu^2(\Omega_{bb}^{-*}\to\Omega_{bb}^{-}\gamma) \quad (7)$$

where $\alpha = \frac{1}{137}$, M_P is mass of proton = 0.938 GeV. Here, J and $M_{\Omega_{bb}^{-*}}$ are the spin and mass

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TABLE I: Transition magnetic moment and Radiative decay width for $\Omega_{bb}^{-*} \rightarrow \Omega_{bb}^{-}\gamma$

μ (in μ_N)	Γ (in keV)
0.5342 This work	0.0078 This work
0.307 [1]	0.011 [1]
0.478 [2]	0.051 ± 0.018 [9]
0.48 [8]	0.0426 ± 0.0018 [10]
0.4906 ± 0.0014 [10]	0.0226 ± 0.0045 [11]

of the decaying baryon Ω_{bb}^{-*} and $M_{\Omega_{bb}^{-}}$ is the mass of final baryon state. k is the photon momentum in the center-of-mass system of decaying baryon. Here, we have ignored the E2 amplitudes because of the spherical symmetry of S-wave baryon spatial wave function and the M1 width of the decay $\Omega_{bb}^{-*} \rightarrow \Omega_{bb}^{-}\gamma$ has the form of Eq. (7).

Result and Discussion

The calculated masses of Ω_{bb}^{-*} is 10.3281 GeV and Ω_{bb}^{-} is 10.3093 GeV. The calculated transition magnetic moment and radiative decay widths for $\Omega_{bb}^{-*} \rightarrow \Omega_{bb}^{-}$ are 0.5342 μ_N and 0.0078 keV, respectively. The comparison with other theoretical predictions are shown in Table I. Our finding of transition magnetic moment exhibit variability across different models. Notably, our transition magnetic moment is closest to the result reported by [10]. The radiative decay width we obtained is lower compared to most other studies, Ref [9] reported a much higher value. These differences highlight the sensitivity of the $\Omega_{bb}^{-*} \rightarrow \Omega_{bb}^{-}$ transition properties to the theoretical models and methods used.

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