# Magnetic moment of $\Xi_{bb}^{-}$ Baryon

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## Introduction

Recently, baryons containing two heavy quarks $\Xi_{cc}^{+}$ and $\Xi_{cc}^{++}$ were discovered by LHCb collaboration. Many heavy hadrons are still waiting to be discovered and the understanding of the properties of yet discovered hadrons is not complete. Therefore the study of various properties of hadrons is important task. The magnetic properties of the doubly heavy baryon encodes important information of their internal structure. The dipole magnetic moment provides important information on structure, size and shape of hadrons. We have studied the magnetic moment, transition magnetic moment and radiative M1 decay of $\Xi_{bb}^{-}$ baryon in Hypercentral constituent quark model(HCQM).

## Theoretical Framework

We have adapted the frame work of hypercentral constituent quark model(HCQM) to study the electromagnetic properties of $\Xi_{bb}^{-}$ Baryon. 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 [1]

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

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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 Eq. (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 by as in [2]

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

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

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

## Magnetic Moment and Radiative Decay of $\Xi_{bb}^{-*} \to \Xi_{bb}^{-}\gamma$ baryon

The magnetic moment of baryons are obtained in terms of its quarks spin-flavour wave function of the constituent quarks as,

$$\mu_B = \Sigma_i \langle \phi_{sf} | \mu_i | \phi_{sf} \rangle \quad (7)$$

where, $\mu_i = \frac{e_i \sigma_i}{2m_i^{eff}}$. $m_i$ the mass of $i^{th}$ quark in the three body baryon is taken as an effective mass of the constituting quarks. The radiative decay width can be expressed in terms of the radiative transition magnetic moment and photon momentum ($k$) as [3]

$$\Gamma = \frac{\alpha k^3}{M_P^2} \frac{2}{2J+1} \frac{M_{\Xi_{bb}^-}}{M_{\Xi_{bb}^{-*}}} \mu^2(\Xi_{bb}^{-*} \to \Xi_{bb}^- \gamma) \quad (8)$$

where, $J$ and $M_{\Xi_{bb}^*}$ are the spin and mass of the decaying baryon $\Xi_{bb}^*$ and $M_{\Xi_{bb}}$ is the mass of final baryon state. $k$ is the photon momentum in the center-of-mass system of decaying baryon

$$k = \frac{M^2_{\Xi_{bb}^{-*}} - M^2_{\Xi_{bb}^-}}{2M_{\Xi_{bb}^-}} \quad (9)$$

$\mu^2(B^* \to B\gamma)$ is square of the transition magnetic moment and is given as

$$\mu_{\Xi_{bb}^{-*} \to \Xi_{bb}^-} = \sum_i \left\langle \phi_{sf}^{\frac{3}{2}^+} \left| \mu_i \sigma_i \right| \phi_{sf}^{\frac{1}{2}^+} \right\rangle \quad (10)$$

$\phi_{sf}$ represent the spin flavour wave function of the quark composition for the baryon. Here, the E2 amplitudes are ignored because of spherical symmetry of S-wave baryon spatial wave function and the M1 width of the decay $\Xi_{bb}^{-*} \to \Xi_{bb}^- \gamma$ has the form of Eq. (8).

## Result and Discussion

The calculated masses of $\Xi_{bb}^-$ and $\Xi_{bb}^{-*}$ are 10.2464 and 10.2658 GeV, respectively. The obtained magnetic moment for $\Xi_{bb}^-$ is 0.2136 $\mu_N$ and $\Xi_{bb}^{-*}$ $-1.0181$ $\mu_N$. The transition magnetic moment and radiative decay are compared in Table II. The transition magnetic moment value we obtained is consistent with other approaches, showing agreement with the Ref. [7]. However, our calculated decay width is significantly lower than the values reported by other works, particularly the 0.28 keV reported by Ref. [6]. We believe that our findings will be validated by upcoming experimental and theoretical endeavors in heavy flavor physics.

TABLE I: Magnetic moments of $\Xi_{bb}^-$ for $J^P = \frac{1}{2}^+$ and $\frac{3}{2}^+$ (in $\mu_N$)

| $\mu_{\Xi_{bb}^-}$ | $\mu_{\Xi_{bb}^{-*}}$ |
|---|---|
| 0.2136 Our | -1.0181 Our |
| 0.32 [4] | -1.32 [4] |
| 0.196 [5] | -1.737 [5] |
| $0.2108 \pm 0.0003$ [7] | $-0.9809 \pm 0.0008$ [7] |

TABLE II: Transition magnetic moment (in $\mu_N$) and Radiative decay width (in KeV)

| $\mu_(\Xi_{bb}^{-*} \to \Xi_{bb}^-)$ | $\Gamma(\Xi_{bb}^{-*} \to \Xi_{bb}^- \gamma)$ |
|---|---|
| 0.7822 This work | 0.0184 This work |
| 0.73 [5] | 0.28 [6] |
| 0.428 [3] | 0.22 [3] |
| $0.7605 \pm 0.0006$ [7] | $0.102 \pm 0.005$ [7] |
| 0.643 [8] | |

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