Magnetic Moments of Triply Heavy Baryons in Quark-Diquark Model

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Introduction

Along with the well-established triply flavoured (uuu) and strange (sss) baryons, QCD predicts similar states made up of charm quarks, the triply-charmed baryon, ccc and bottom quarks, the triply-bottom baryon, bbb. Such a state has yet to be observed experimentally. After the observation of the doubly charmed baryon by the SELEX group, it is expected that the triply heavy flavour baryonic state may be in the offing very soon. Though considerable amount of data on the properties of the singly-heavy baryons are available in literature [1–3], only sparse attention has been paid to the spectroscopy of double and triple-heavy flavour baryons, perhaps mainly due to the lack of experimental incentives.

Theoretical Framework

For QQQ baryons, we have employed the quark-diquark model with interquark potential of the coulomb plus linear potential form to study the mass and magnetic moment of baryon containing three heavy quarks.

In this case, Hamiltonian of the baryon is expressed in terms of a diquark Hamiltonian (H_{jk}) plus quark-diquark Hamiltonian ($H_{i,jk}$) as [4]

$$H = H_{jk} + H_{i,jk} \tag{1}$$

The internal motion of the diquark(jk) is described by

$$H_{jk} = \frac{p^2}{2m_{jk}} + V_{jk}(r_{jk}) \tag{2}$$

and the Hamiltonian of the relative motion of the diquark(d)- quark(i) system is described by

$$H_{i,d} = H_{i,jk} = \frac{q^2}{2m_{i,jk}} + V_{i,jk}(r_{id}) \tag{3}$$

where, (p, r_{jk}) represent the relative momenta and coordinate of the quarks within the diquark system and (q, r_{id}) is the relative momenta and coordinate of the quark-diquark system. The reduced mass of the two body systems appeared in Eqn.(2) and Eqn.(3) respectively are defined as For the present study, we have assumed colour coloumb plus linear potential for the interquark potential of Eqn.(2) as well as for the quark-diquark interaction of Eqn.(3).
Accordingly, the diquark potential can be written as,

$$V_{jk} = -\frac{2}{3}\alpha_s \frac{1}{r_{jk}} + b\ r_{jk} \tag{4}$$

and the quark-diquark potential as

$$V_{i,jk} = -\frac{4}{3}\alpha_s \frac{1}{r_{id}} + b\ r_{id} \tag{5}$$

where, r_{id} is the quark-diquark separation distance, ν is the exponent corresponding to the confining part of the potential and b is the strength of the potential, which is assumed to be same for the di-quark interaction as well as between the quark-diquark interaction. The Schrodinger equation corresponds to the

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Hamiltonian given in Eqn.(1) is numerically solved using the Runge-Kutta method. The degeneracy of the states are removed by introducing the spin dependent interaction potential given by [5].

The model parameters for the study of triple charmed baryons are strong running coupling constant(α_s) = 0.20 and quark mass parameter $m_c = 1.5\ GeV$. For other baryons, we have used (α_s) = 0.17 and $m_b = 1.5\ GeV$

Magnetic moments of QQQ baryons

We define an effective mass to the the constituting quarks within the baryons that takes care of the bound state effects including its internal motions and interactions among quarks as [3, 6]

$$m_i^{eff} = m_i \left(1 + \frac{\langle H \rangle}{\sum\limits_i m_i}\right) \tag{6}$$

For the computation of the magnetic moments, we consider the mass of bound quarks inside the baryons as its effective mass taking in to account of its binding interactions with other two quarks described by the Hamiltonian given in Eqn.(1). The effective mass for each of the constituting quark m_i^{eff} as defined in Eqn.(6).

where, $\langle H \rangle = E + \langle V_{spin} \rangle$ such that the corresponding mass of the baryon with spin angular momentum, J is given by

$$M_B^J = \sum_i m_i + \langle H \rangle_J = \sum_i m_i^{eff} \tag{7}$$

The magnetic moment of baryons are obtained in terms of the spin, charge and effective mass of the bound quarks as [3, 6]

$$\mu_B = \sum_i \langle \phi_{sf} \mid \mu_{iz} \mid \phi_{sf} \rangle \tag{8}$$

where $\mu_{iz} = \frac{e_i \sigma_{iz}}{2 m_i^{eff}}$ Using spin flavour wave function and effective masses, we compute the magnetic moments of the triple heavy flavour baryons.

TABLE I: Ground state masses (in MeV) and magnetic moments (μ_B in terms of μ_N) of triple heavy flavour baryons.

Baryons	*Masses*	Others[7]	μ_B	*Others*[8]
Ω_{ccc}^{*++}	4760	4777	1.182	1.023
Ω_{ccb}^{+}	8005	7984	0.565	0.475
Ω_{ccb}^{*+}	8027	8005	0.751	–
Ω_{bbc}^{0}	11277	11139	-0.223	-0.193
Ω_{bbc}^{*0}	11284	11163	0.285	–
Ω_{bbb}^{*-}	14370	14276	-0.196	-0.180

Using the ground state masses predicted for the triple heavy flavour (QQQ, Q ∈ c, b) baryons based on Quark-diquark approaches, we compute the effective masses of the constituting heavy quarks. The predicted magnetic moments of all the spin $J^P = \frac{1}{2}^+$ and spin $J^P = \frac{3}{2}^+$ triple heavy baryons based on quark-diquark model are listed in Table (I) and also compared with other predicted results. It is interesting to see that our results are in good agreement with the results predicted by other models.

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