Masses and magnetic moment of doubly heavy baryons

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Introduction

Doubly heavy baryons are composed of two heavy quarks (b and/or c) and one light quark (u, d or s). There have been many theoretical attempts to compute masses of these states [1]. Experimental observation of such heavy resonances are expected from the facilities such as LHCb and Bell II. We employ the extended relativistic harmonic confinement model (ERHM) to compute the masses of doubly heavy baryons. The magnetic moments of heavy flavour baryons are also computed using the spin-flavour wave functions of the constituent quarks and their effective masses within the baryon.

Theoretical framework

In the relativistic harmonic confinement model (RHM) with scalar plus vector potential for the quark confinement, coloured quarks in a hadron are confined through the action of a Lorentz scalar plus a vector harmonic oscillator type of potential. The RHM has been extended to accommodate multiquark states from lighter to heavier flavour sectors with unequal quark masses [2]. The mass of baryon in the N energy eigenstate and J spin state can be computed as [2, 3]

$$M_N^J = \sum_{i=1}^{3} \epsilon_N(q_i)_{conf} + \sum_{i<j=1}^{3} \epsilon(q_i, q_j)_{coul} + \sum_{i<j=1}^{3} \epsilon_N^J(q_i, q_j)_{S.D.} \quad (1)$$

First term is confinement energy of the constituent quarks inside the baryon; second term is the residual colour coulomb interaction between confined quarks and the third term corresponds to the spin-dependent interactions. The colour coulomb interaction energy is computed using the residual coulomb potential $V_{coul}(q_i q_j) = \frac{k\alpha_s(\mu)}{\omega_n r}$. Where ω_n is the state dependent colour dielectric coefficient [2]. It is also the measure of confinement strength through the non- perturbative contributions to the confinement scale at the respective threshold energy of the quark- antiquark excitations.

The wave function for the baryons are constructed through the single particle wave function but with the three particle size parameters [2, 3]. The spin averaged mass of the doubly heavy baryons are obtained using the model parameters $k = 0.37$, confinement parameter $A = 2166$ MeV$^{3/2}$, quark masses $m_u = 240$ MeV, $m_d = 243$ MeV, $m_s = 450$ MeV, $m_c = 1275$ MeV, $m_b = 4660$ MeV. The octet and decuplet masses are computed by considering the residual two body chromomagnetic interaction through the spin dependent term of confined one gluon exchange potential perturbatively.

Magnetic Moment

Considering the mass of bound quark inside the baryon as effective mass, the magnetic moment is computed using [4]

$$m_i^{eff} = m_i \left(1 + \frac{\langle H \rangle}{\sum_i m_i}\right) \quad (2)$$

such that the mass of the bayron is

$$M_B = \sum_{i}^{3} m_i^{eff} \quad (3)$$

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TABLE I: Masses of doubly heavy baryons in MeV

Baryon	quark content	present	[4]	[5]	[6]	[7]	[8]
Ξ_{cc}^{++}	ccu	3542	3439	3612	3620	3532	
Ξ_{cc}^{*++}	ccu	3677	3516	3706	3727	3623	
Ξ_{cc}^{+}	ccd	3544	3440	3605	3620	3537	3520
Ξ_{cc}^{*+}	ccd	3677	3518	3685	3727	3629	
Ω_{cc}^{+}	ccs	3644	3479	3702	3778	3667	
Ω_{cc}^{*+}	ccs	3717	3559	3783	3872	3758	
Ξ_{bc}^{+}	bcu	6928	6834	6919	6933	6988	
Ξ_{bc}^{*+}	bcu	6990	6865	6986	6980	7083	
Ξ_{bc}^{0}	bcd	6929	6838	6820	6933	–	
Ξ_{bc}^{*0}	bcd	6990	6870	—-	6980	–	
Ω_{bc}^{0}	bcs	7012	6893	6986	7088	7103	
Ω_{bc}^{*0}	bcs	7045	6936	7046	7130	7200	
Ξ_{bb}^{0}	bbu	10257	10114	10197	10202	10344	
Ξ_{bb}^{*0}	bbu	10289	10165	10236	10237	10431	
Ξ_{bb}^{-}	bbd	10257	10117	10197	10202	–	
Ξ_{bb}^{*-}	bbd	10289	10170	10236	10237	–	
Ω_{bb}^{-}	bbs	10333	10164	10260	10359	10397	
Ω_{bb}^{*-}	bbs	10350	10236	10297	10389	10495	

$*$ indicates $J^P = \frac{3}{2}^+$ state

TABLE II: Magnetic moments in μ_N

Baryon	present	[4]	[5]	RQM [11]	NRQM [11]	[9]
Ξ_{cc}^{++}	-0.169	-0.137	-0.208	-0.130	-0.010	
Ξ_{cc}^{*++}	2.72	2.749	2.670	–	–	2.59
Ξ_{cc}^{+}	0.853	0.859	0.785	0.720	0.740	
Ξ_{cc}^{*+}	-0.23	-0.168	-0.311	–	–	-0.20
Ω_{cc}^{+}	0.74	0.783	0.635	0.670	0.670	
Ω_{cc}^{*+}	0.16	0.121	0.139	–	–	0.12
Ξ_{bc}^{+}	-0.52	-0.400	-0.475	-0.120	-0.290	-0.387
Ξ_{bc}^{*+}	2.68	2.052	2.27	–	–	2.011
Ξ_{bc}^{0}	0.63	0.476	0.518	0.420	0.460	0.499
Ξ_{bc}^{*0}	-0.76	-0.567	-0.712	–	–	-0.551
Ω_{bc}^{0}	0.49	0.396	0.368	0.450	0.390	0.399
Ω_{bc}^{*0}	-0.32	-0.316	-0.261	–	–	-0.279
Ξ_{bb}^{0}	-0.89	-0.656	-0.742	-0.530	-0.580	-0.665
Ξ_{bb}^{*0}	2.30	1.576	1.870	–	–	1.596
Ξ_{bb}^{-}	0.32	0.190	0.251	0.180	0.189	0.208
Ξ_{bb}^{*-}	-1.32	-0.951	-1.11	–	–	-0.984
Ω_{bb}^{-}	0.16	0.109	0.101	0.040	0.100	0.111
Ω_{bb}^{*-}	-0.86	-0.711	-0.662	–	–	-0.703

$*$ indicates $J^P = \frac{3}{2}^+$ state

Here the magnetic moment is obtained in terms of its constituent quarks as

$$\mu_B = \sum_i \langle \phi_{sf} | \mu_i \vec{\sigma_i} | \phi_{sf} \rangle \quad (4)$$

where $\mu_i = e_i/2m_i^{eff}$. e_i and σ_i shows the charge and spin of the quark constituting the baryonic state and $|\phi_{sf}\rangle$ represents the spin flavor wave function of the respective baryonic state. [10].

Results and Discussion

We have employed ERHM to compute masses of baryons double heavy quarks. The computed mass spectra is found to be matching with available results from other theoretical approaches and are listed with them in table I. The magnetic moments are computed without introducing any extra parameters or correction to the wave function and are found in agreement with other theoretical calculations. It is observed that presence of b quark in the baryons raises the magnitude of the magnetic moments by a factor. This suggests that inclusion of some relativistic corrections and use of other suggested approaches for computation of magnetic moments may improve the results.

Acknowledgments

This work is supported by the University Grants Commission of India under Major Research Project F.No.42-775/2013(SR)

References

[1] Y. L. Ma and M. Harada, Phys. Lett. B **754**, 125 (2016) and references there in.

[2] P C Vinodkumar *et al.*, Eur. J. Phys. A **4**, 83 (1999).

[3] J. N. Pandya and P. C. Vinodkumar, Pramana J. Phys. **57**, 821 (2001).

[4] B Patel *et al.*, J. Phys. G:Nucl. Part. Phys **35**, 065001 (2008).

[5] C. Albertus *et al.*, Eur. Phys. J. A. **31**, 691 (2007).

[6] D Ebert *et al.*, Phys. Rev. D **66**, 014008 (2002).

[7] Z. Ghalenovi *et al.*, Mod. Phys. Lett. A, **29**, 1450106 (2014).

[8] K.A. Olive *et al.* (Particle Data Group), Chin. Phys. C, **38**, 090001 (2014).

[9] R. Dhir and R. C. Verma, Eur. Phys. J. A **42**, 243 (2009); R. Dhir *et al.*, Phys. Rev. D **88**, 094002 (2013).

[10] Yu A Simonov *et al.*, Phys. Rev. D **65**, 094013 (2002).

[11] A Faessler *et al.*, Phys. Rev. D **73**, 094013 (2006).