Study of doubly heavy flavour baryons in analogy with H_2^+ ion

Alice K M [1], Keval Gandhi[2],* Tanvi Bhavsar[2],
Ajay Majethiya[3], and P.C.Vinodkumar[2]†
[1] *University of Hyderabad, Gachibowl, Hyderabad, Telangana- 500046*
[2] *Department of Physics, Sardar Patel University, Vallabh Vidyanagar-388 120, INDIA and*
[3] *Department of Physics, V.S.Patel College of Arts and Science, Billimora-396 321,INDIA*

Introduction

Doubly heavy flavour baryons (QQq) are of special interest as they can test the strong interaction from the point of view of three body forces relevant to the fundamental degrees of freedom provided by Quantum Chromo dynamics (QCD). It is observed that QQq baryon bears striking similarity with the simplest molecule (H_2^+), in the sense that both the systems are three body bound states held together by the respective interaction forces and containing two heavy particles. Recently, many new excited charmed baryons have been discovered by high energy experimental facilities world over [1–3]. Same way there exist many theoretical attempts that predicted the mass of charmed and bottom baryons containing one or more heavy flavour quarks [4, 5]. The efforts at the existing as well as upgraded experimental facilities are expected to discover many of these heavy flavor baryons that include doubly heavy flavor baryons also. So, it is very much appropriate to study them based on theoretical models.

Theoretical methodology

As H_2^+ ion (PPe- system)is bound by electromagnetic interactions of the Coulomb type the QQq baryon is bound together by the color confining force of the strong interaction. The recipe of this method is that, to solve the problem, by first determining the light quark Eigen state at fixed heavy quark positions and then taking the corresponding light quark energy as an effective potential, in conjunction with the inter heavy quark separation to describe their motion. The fundamental difference between the two systems PPe and QQq is the existence of color confinement interaction between Q-Q and Q-q quarks. Here we assume coulomb plus linear confinement form as the inter quark potential and following the same theoretical methodology applied to the study of H_2^+ ion [5, 6], we have computed the masses of QQq (Q∈ c,b and q∈ u,d,s baryon systems. A schematic representation of the coordinates to describe the 3-body $QQq-$ system is shown in figure 1.

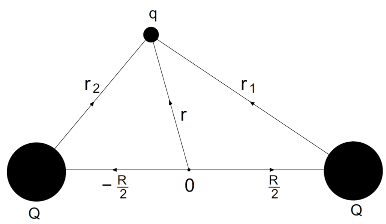

FIG. 1: A Sketch of the coordinate system adopted for the QQq system.

In the Born-Oppenheimer ansatz, the lowest Eigen state is determined at first by solving corresponding Schrödinger equation. This is exactly the same problem encountered in H_2^+, to determine the electronic ground state at fixed nuclear positions[7]. Taking the indistinguishableness of Q into account, the trial

*Electronic address: kevalgandhi25194@gmail.com
†Electronic address: p.c.vinodkumar@gmail.com

wave function can be written as

$$\varphi(R,r) = \frac{f(r_1) \pm f(r_2)}{\sqrt{2(1 \pm S(\lambda, R))}}, f(r) = \frac{\lambda^{\frac{3}{2}}}{\sqrt{\pi}} e^{-\lambda r} \quad (1)$$

The wave function φ must be either symmetric or antisymmetric upon interchange of two Q (R→-R). As it was seen in the case of H_2^+ ion, the antisymmetric configuration has higher energy level than the symmetric one. Hence the symmetric one is considered for the present study. By solving schrodinger equation we obtain the light quark energy as,

$$E(R) = \frac{\lambda^2}{2} + \frac{\lambda(\lambda+1) - C + (\lambda-2)\varepsilon + J}{(1+S)} \quad (2)$$

Where, C is interaction integral, ε is exchange integral and S is the overlap integral , all of them are functions of (λ, R). According to the variational method, the variational parameter is determined for each choices of R.

TABLE I: Predicted masses and other results of doubly heavy flavour baryons and their binding energies at different Q-Q separation distance

Baryon	Q-Q distance R (fm) (fm)	B.E (MeV)	Masses upper bound (present) (MeV)	Masses (others) (MeV)
ccu	0.857	199.58	3698.58	3673[8]
ccu	0.889	213.25	3707.25	3545[9]
ccu	0.901	220.93	3714.93	3519[10]
ccd	0.857	177.51	3683.51	3673[8]
ccd	0.889	193.58	3699.58	3545[9]
ccd	0.892	198.46	3704.46	3519[10]
ccs	0.857	235.55	3891.55	3850
ccs	0.889	254.62	3901.62	3825[8]
ccs	0.897	260.9	3916.9	3640[9]
bbu	0.857	356.54	10574.54	10219[8]
bbu	0.889	376.52	10594.52	10110[9]
bbu	0.952	415.57	10633.57	
bbd	0.857	364.65	10594.65	10219[8]
bbd	0.889	383.65	10613.65	10110[9]
bbd	0.89	388.22	10618.22	
bbs	0.88	529.77	10909.77	10374[8]
bbs	0.895	543.42	10923.42	
bbs	0.897	547.13	10927.13	

Results and discussions

The binding energy, $E(R)$ of the light quark is found to attain saturation beyond $R = 0.8 fm$ in all the choices of QQq systems. The masses computed at this saturation energy thus provides an upper bound mass of the system. These masses are tabulated in table-1 below for various choices of $Q \in c, b$ and $q \in u, d, s$. Present results are compared with other theoretical predictions.

Acknowledgments

Alice K M acknowledges Indian Academy of Science summer research project. Authors acknowledge the financial support from DST-SERB, India (research Project number: SERB/F/8749/2015-16).

References

[1] J.S.Russ, The double Charm Baryon family at SELEX, [SELEX Collaboration] (2003).
[2] R.Chistov, Charm Baryon Spectroscopy, $MEPh_I$x (2008).
[3] B Aubert et al.[BABAR collaboration], Phys. Rev. Lett. 98 122011(2007).
[4] N. Mathur, R. Lewis, and R. M. Woloshyn. Phys. Rev. D66, 014502 (2002)
[5] Ajay A. Majethiya, (Ph.D Thesis), Sardar Patel University, Gujarat (2011).
[6] Yu Jia, JHEP 10, 073 (2006).
[7] S.Flugge, Practical quantum mechanics, 2^{nd} English version,Springer-verlag,1974.
[8] D. Ebert, et al, Phys.Rev. D 54, 3619 (1996).
[9] V.V. Kiselev and A.K. Likhoded, Phys. Usp. 45, 455 (2002) (Usp.Fiz. Nauk 172, 497 (2002);arXiv:hep-ph/0103169
[10] J. M. Flynn, F. Mesia, A. S. B Tariq, Spectroscopy of Doubly- Charmed Baryons in lattice QCD [UKQCD Collaboration]