Composite Fermion Approach to Diquark and Heavy-Light Baryon Masses

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Introduction :

The role of diquark in baryon spectroscopy have been discussed by number of authors [1–3]. The diquark is supposed to be a fundamental candidate for the structure and interaction of the heavy baryons and exotics. The New LHC data opens up immense possibility of identifying a numbers new particles which would need to describe. Baryon in the framework of diquark-quark system describes the dynamics and interaction of the baryons to a considerable extent particularly for heavy baryons. Cakir et al[4] have investigated the resonant production of first generation scalar and vector diquarks in LHC collider and observed that LHC collider predicts a larger value of cross section. They have emphasized that the diquarks with different mass range could be investigated in LHC with suitable values of α. A number of models have been suggested for diquarks [5,6]. The diquark has been described as a quasi particle behaving like an independent entity by Bhattacharya et al[7]. It has been suggested that the diquark as can be described in gauge invariant way in the system of gauge interaction like two dimensional electron gas in high magnetic field where electrons can be described as composite Fermions(CF)[8]. This in turn may form Fermi liquid like state near the Fermi surface. Composite fermion can have fractional charges and their spin is frozen. Such CFs are described as the stable quasi particles in the system. Raghavchari et al [9] have studied the quasi particle mass which is fully gauge invariant and can be expressed as response function of the system. In the present work we have applied the idea for diquark describing it as a composite fermion as in the work of Raghavchari et al [9] and have computed the masses of diquarks. We have computed the masses of heavy-light baryon for both charm and bottom sector. A good agreement with the experimental results are obtained.

Composite fermion model of Diquarks and Baryon masses:

In a fermi liquid, the low lying excitations may be described as stable quasi particle and quasi-hole excitation. These low energy eigen states can be labeled as occupation configuration n_k. Such a state is smoothly connected to the corresponding state of the free fermi system by adiabatically turning of interactions. The energy of such states can be evaluated by Hellman-Feynman theorem [14].The energy deference between ground state and the excited state is related to the quasiparticle effective mass. Starting from the Hamiltonian of a composite fermion with a momentum cut off Λ the expression for the quasi particle mass in a gauge invariant system can be obtained as: [9] (with potential V=0)

$$1/m^* = 1/m(1+\Lambda^4/2k_F^4) \qquad \text{---------(1)}$$

where m* is the effective mass of the CF , m is the mass of each component, k_F is the fermi momentum of the CF and Λ is a cut off parameter.We have applied The CF picture for the diquarks and the effective mass of diquark m_D* has been expressed as:

$$1/m^*_D = \{1/(mq_1 + mq_2)\}.\,(1+\Lambda^4/2k_F^4) \quad \text{--(2)}$$

where m^*_D is the mass of the diquark, m_{q1} , m_{q2} are the constituent masses of the corresponding quark flavours constituing the diquark. The fermi momentum of the corresponding diquark has been estimated using the work of Bhattacharya et al[10,11]. In this work a relation between the fermi momentum and the radius of a meson has been derived in the frame work of the statistical model [10,11]. We have used Fermi momentum of meson (consists of same flavour as that of diquark) as the fermi momentum of the corresponding diquark in CF picture which in turn describes the meson. We have considered heavy baryons as a system of a heavy quark and a diquark,consisting of light flavours. With a suitable binding energy between the heavy quark and the diquark, the mass of heavy baryon can be expressed as:

$M_B = m_q + m_D^* + E_{BE}$ ---------(3)

where m_q is the heavy quark mass, m^*_D is diquark mass and E_{BE} is binding energy of the quark-diquark and has been expressed as $E_{BE} = < \psi|V\ |\psi >$. The potential has been expressed as: $V= br_B$ where b is the interaction parameter and r_B is the baryon radius. To estimate the binding energy we have used the wave function from the statistical model. We have come across an expression for the probability density of the baryons and the expression for $|\psi(r)|^2$ for a baryon after normalization is obtained as,

$|\psi(r)|^2 = 314/64r_B^{9/2}\ (r_B - r)^{3/2}\Theta(r_B - r)$ -----(4)

where r_B is the radius parameter of the baryon and Θ is the usual step function. We have estimated the masses of the heavy light baryons using the expression (3). The results are displayed in Table-I and Table-II for charm and bottom sector respectively and are compared with the experimental findings [12]. In the present work the masses of the heavy-light baryons Λ^+_c, Σ^+_c,Ξ^0_c, Ω^0_c and Λ^+_b,Σ^+_b, Ξ^0_b, Ω^-_b have been computed using cut off Λ as 0.25 GeV [13], interaction parameter b=0.3 GeV^2 as in Lucha et al [14] for charm sector whereas for bottom sector we have used b=1GeV^2 from the work of Liang et al [15]. The radii parameter of the baryons have been used from Brac et al [16]. We have obtained very good agreement with the experimental results for the charm sector except Σ^+_c where difference is ~160MeV whereas for the bottom sector we have obtained little bit lower value for Σ^+_b and Ω^-_b. However it may be pointed out that the most uncertainty comes from the radii parameters which is not exactly known.

Results:

Table-I :

Masses of the Heavy-light Baryons (Charm sector (J^P=1/2$^+$) in GeV

Λ^+_c i)Theory ii)Expt	Σ^+_c i)Theory ii)Expt	Ξ^0_c i)Theory ii)Expt	Ω^0_c i)Theory ii)Expt
i)2.272 ii) 2.286	i)2.292 ii)2.452	i)2.464 ii)2.471	i)2.636 ii)2.695+/-0.0017

Table II:

Masses of the Heavy-light Baryon (Bottom sector (J^P=1/2$^+$)) in GeV

Λ^+_b i)Theory ii)Expt	Σ^+_b, i)Theoy ii)Expt	Ξ^0_b i)Theory ii)Expt	Ω^-_b i)Theory ii)Expt
i)5.496 ii)5.620	i)5.551 ii)5.807	i) 5.707 ii) 5.7924 +/- 0.003	i).5.91 ii) 6.165+-0.0023

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