Diquark and Baryon Masses in Composite Fermion Approach

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A model for diquark has been suggested describing it as a Composite Fermion. The masses of the light [Λ^0, Σ^-, Ξ^-, Ω^-], heavy [Λ_c^+, Σ_c^+, Ξ_c^0, Ω_c^- and Λ_b^0, Σ_b^0, Ξ_b^0, Ω_b^-], doubly heavy [Ξ_{cc}^{++}, Ξ_{cc}^+, Ξ_{cb}^+, Ξ_{cb}^0, Ξ_{bb}^0, Ξ_{bb}^-, Ω_{cc}^+, Ω_{cb}^0, Ω_{bb}^-] and triply heavy [Ω_{ccc}, Ω_{ccb}, Ω_{bbc}, Ω_{bbb}] baryons have been studied for J$^P = \frac{1}{2}^+$ and $\frac{3}{2}^+$ states. The results are found to be in good agreement with available experimental data and other theoretical works.

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At low energies the quark dynamics can be revisited in the light of new results of baryon and exotics spectroscopy. The regularities in hadons spectroscopy, parton distribution function, spin dependent structure function of hadrons etc hint at the existence of diquark correlation. In QCD both the gluon exchange interaction and Instanton Induced Interaction favour the spin singlet and colour anti-symmetric diquark combination. A deeply bound diquark system is one of the most important candidate for describing the baryonic and exotic system. The exact nature of the diquark correlation is under extensive study. In the present work diquarks have been described in the frame work of Composite Fermion (CF) model of quasi particle in an analogy with the electrons in strong magnetic field. The masses of the light, single heavy, doubly heavy and triply heavy baryons have been studied for J$^P = \frac{1}{2}^+$ and $\frac{3}{2}^+$ states considering the diquark-quark configuration with the suggested CF model of diquark. It has been suggested that the CFs can be described in gauge invariant way in the system of gauge interaction like the two dimensional electron gas in high magnetic field where electrons can be described as Composite Fermions [1]. This in turn may form Fermi liquid like state near the Fermi surface. CFs can have fractional charges and their spin is frozen. Such CFs are described as the stable quasi particles in the system. In the context of degenerate electron gas Raghavchari et al [2] have studied the quasi particle mass which is fully gauge invariant and can be expressed as a response function of the system. It has been observed that the strongly interacting particles sometimes behave like weekly coupled system and form a system of particles of new kind. The quasi particle behaviour of electron in a crystal is an example of such system. The electron in the lattice changes in behaviour and exists as an independent object. In the present work we have applied the idea of CF model describing a diquark as a composite fermion and have computed the masses of diquarks considering Fermi momentum (p_f) as cut off parameter.

Starting from the Hamiltonian of a CF with a momentum cut off λ the expression for the quasi particle mass in gauge invariant system can be obtained as [2] (with potential V=0):

$$\frac{1}{m^*} = \frac{1}{m}(1 + \frac{\Lambda^4}{2p_F^4}) \tag{1}$$

where m^* is the effective mass of the CF, m be the mass of each component, (p_f) is the Fermi momentum of CF and Λ is the cut off parameter. We have applied this CF picture for diquarks and computed the effective mass of diquarks. The Fermi momentum of corresponding diquarks have been estimated using the work of Bhattacharya et al [3, 4]. Considering baryon as a system of a quark and a diquark, under the influence of suitable binding energy and spin interaction the mass of heavy or light baryons can be expressed as :

$$M_B = m_q + m_D^* + E_{BE} + E_S \tag{2}$$

where m_q is quark mass, m_D^* is the diquark mass and E_{BE} is the binding energy of the quark-diquark corresponding to the potential expressed as V(r)= ar^2, where 'a' is the interaction parameter and 'r' is the baryon radius. We have used the wave function from the Statistical Model [3, 4] and the spin interaction term is expressed as :

$$E_S = \frac{8}{9}\frac{\alpha_S}{m_q m_D}\vec{S}_q \cdot \vec{S}_D |\psi(0)|^2 \tag{3}$$

where the symbols have their usual meanings. The masses of the respective baryons have been estimated by using the relation (2) and displayed in Tables 1 to 5. We have obtained very good results for Λ^0,but higher results for Σ^- and lower values for Ξ^- and Ω^-. For Σ_c^+, Λ_b^0 and Ω_c^- there is a very good agreement between our results and experimentalfindings [5, 6]. For Ξ_{cc}^{++} our proposed mass [3.5308 GeV for J^P = $\frac{1}{2}^+$] agrees reasonably with experimental value 3.5189 ± 0.0009 GeV. For doubly heavy and triply heavy Ω sectors the results have been compared with other theoretical works and there is a reasonable agreement. However it may be pointed out that the most uncertainty comes from the radii parameters which is not exactly known.

CF model is found to be quiet successful in reproducing the masses of the baryons over a wide range. Diquark in presence of chromo magnetic QCD vacuum may behave like a CF as an electron in strong magnetic field. The diquark as CF may throw some light on the understanding of structure and dynamics of the baryons.

Baryon	*Baryon*	*mass(GeV)*	*Baryon*	*mass(GeV)*
	Our − work	*Expt.*[5, 6]	*Our − work*	*Expt.*[5, 6]
	$J^p = \frac{1}{2}^+$	$J^p = \frac{1}{2}^+$	$J^p = \frac{3}{2}^+$	$J^p = \frac{3}{2}^+$
Λ^0	1.1188	1.1156	1.3086	–
Σ^-	1.3295	1.1974	1.449	1.387
Ξ^-	1.2137	1.3217	1.3948	1.535
Ω^-	1.551	–	1.5200	1.672

Table 1: Mass Spectrum (J^p=$\frac{1}{2}^+$ and $\frac{3}{2}^+$) of Light baryons

$Baryon$	$Baryon$	$mass(GeV)$	$Baryon$	$mass(GeV)$
	$Our-work$	$Expt.$[5, 6]	$Our-work$	$Expt.$[5, 6]
	$J^p=\frac{1}{2}^+$	$J^p=\frac{1}{2}^+$	$J^p=\frac{3}{2}^+$	$J^p=\frac{3}{2}^+$
Λ_c^+	2.9377	2.2864 ± 0.00014	3.04477	–
Λ_b^0	5.5891	5.6202 ± 0.0016	5.7168	–
Σ_c^+	2.4577	2.4529 ± 0.0004	2.5690	2.518
Σ_b^0	5.5751	5.808	5.7169	5.829
Ξ_c^0	2.2687	$2.4708^{+0.00034}_{-0.0008}$	2.4464	2.646
Ξ_b^0	5.5069	5.7924 ± 0.003	5.7201	–
Ω_c^0	2.6724	2.6952 ± 0.0017	2.63122	2.768
Ω_b^-	5.9631	6.165 ± 0.023	5.9176	–

Table 2: Mass Spectrum (J^p=$\frac{1}{2}^+$ and $\frac{3}{2}^+$) of Heavy baryons

$Baryon$	$Baryon$	$mass$	(GeV)	$Baryon$	$mass$	(GeV)
	for	$J^p=$	$\frac{1}{2}^+$	for	$J^p=$	$\frac{3}{2}^+$
	$Ours$	$Expt.$[5, 6]	$Others$	$Ours$	$Expt.$	$Others$
Ξ_{cc}^{++}	3.9496	–	3.579	3.9807	–	3.708
			3.730			3.800
			3.480			3.610
Ξ_{cc}^+	3.5308	3.5189	3.584	3.6222	–	3.713
		± 0.0009	3.755			3.828
			3.480			3.610
Ξ_{cb}^0	6.9065	–	6.95	6.9205	–	7.02
			7.01			7.10
Ξ_{cb}^+	7.2534	–	6.965	7.2569	–	7.06
			± 0.09			± 0.09
Ξ_{bb}^0	10.6764	–	10.339	10.6873	–	10.468
			10.114			10.165
			10.093			10.330
Ξ_{bb}^-	10.5389	–	10.23	10.551	–	10.28
			10.344			10.473
			10.30			10.34

Table 3: Mass Spectrum (J^p=$\frac{1}{2}^+$ and $\frac{3}{2}^+$) of the Doubly Heavy Ξ baryon

$Baryon$	$Baryon$	$mass(GeV)$	$Baryon$	$mass(GeV)$
	$Our-work$	$Other-works$	$Our-work$	$Other-works$
	$J^p=\frac{1}{2}^+$	$J^p=\frac{1}{2}^+$	$J^p=\frac{3}{2}^+$	$J^p=\frac{3}{2}^+$
Ω_{cc}^+	3.6843	3.74 ± 0.07	3.8590	3.82 ± 0.08
		3.76		3.89
		3.718		3.847
Ω_{cb}^0	7.0225	7.045 ± 0.09	7.0769	7.12 ± 0.09
		7.05		7.11
		7.05		7.13
Ω_{bb}^-	10.6455	10.37 ± 0.1	10.6581	10.40 ± 0.1
		10.32		10.36
		10.34		10.38

Table 4: Mass Spectrum (J^p=$\frac{1}{2}^+$ and $\frac{3}{2}^+$) of the Doubly Heavy Ω baryon

$Baryon$	$Baryon$	$mass(GeV)$	$Baryon$	$mass(GeV)$
	$Our-work$	$Other-works$	$Our-work$	$Other-work$
	$J^p=\frac{1}{2}^+$	$J^p=\frac{1}{2}^+$	$J^p=\frac{3}{2}^+$	$J^p=\frac{3}{2}^+$
Ω_{ccc}	4.8508	–	4, 8916	4.803
		–		4.925
		–		4.9(0.25)
Ω_{ccb}	8.355	8.229	8.3575	8.358
		8.018		8.025
		–		8.200
Ω_{bbc}	11.695	11.280	11.6974	11.287
		–		11.48
		11.609		11.738
Ω_{bbb}	15.0329	–	15.0449	15.118
		–		14.760
		–		14.7(0.3)

Table 5: Mass Spectrum (J^p=$\frac{1}{2}^+$ and $\frac{3}{2}^+$) of the Triply Heavy baryons

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