Diquark and Baryon Masses in Composite Fermion Approach

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Aim of the work

- Baryons described as diquark-quark system. The Composite Fermion (CF) Model of diquark has been employed to obtain diquark mass.

- The masses of the light **(Λ^o,Σ^-,Ξ^-,Ω^-)**, heavy **(Λ_c^+,Σ_c^+,Ξ_c^o,Ω_c^o** and **Λ_b^o,Σ_b^0,Ξ_b^o,Ω_b^-)**, doubly heavy **(Ξ_{cc}^{++},Ξ_{cc}^+,Ξ_{cb}^0,Ξ_{cb}^+,Ξ_{bb}^0,Ξ_{bb}^-,Ω_{cc}^+,Ω_{cb}^o,$\Omega_{b\bar{b}}$)** and triply heavy **(Ω_{ccc},Ω_{ccb},Ω_{cbb},Ω_{bbb})** baryons have been computed for $J^p = 1/2^+$ and $3/2^+$ in the Composite Fermion (CF) approach of diquark.

- The results are compared with the experimental findings and other theoretical works.

The Diquark

- At low energies the quark dynamics can be revisited in the light of new results of baryon and exotics spectroscopy.
- The regularities in hadron spectroscopy , parton distribution function , spin dependent structure function of hadrons, etc hint at the existence of diquark correlation[1]. In QCD both the gluon exchange interaction and Instanton Induced Interaction [2] 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. Diquark has been assumed to be a fundamental entity behaving like an independent body inside the baryon simulating many body interactions.
- The exact nature of the diquark correlation is under extensive study.

Ref: [1] A.S.Castro et al.,Z. Phys. **C 57**(1997) 315 ; D.B. Lichtenberg et al., Z. Phys. **C 17** (1983) 57; E.V.Shuryak , Nucl. Phys. **B 50** (1982) 93; T. Schafer et al., Rev. Mod. Phys. **70** (1998) 323.

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The Quasiparticle and The Composite Fermion (C-F) Model

- Quasiparticles are the particles like entities, arising in some system of interacting particles. It's a low lying excited state representing the properties of the system.
- Composite Fermion (CF) is the bound state of an electron and an even number of quantised vortices originally envisioned in the context of the Fractional Quantum Hall Effect [FQHE] [3]. It is described in gauge invariant way in the system of gauge interaction of two dimensional electron gas in high magnetic field [4]. CF can have fractional charges and their spin is frozen. CFs are described as the stable quasi particles in the system.
- In analogy with this we have suggested a CF model for the diquark where it is described as Composite Fermion in presence of chromomagnetic nature of the vacuum.
- With CF [5] model for diquark the masses of diquarks for different flavors are computed.
- Light and heavy baryon masses have been estimated .

Ref: [3] J.K.Jain ; Physics Today April 2000, 39.
[4] B.I.Helperin et al., Phys. Rev.**B 47** (1993) 7312.
[5] A.Raghavchari et al., arXiv:cond.matt./9707055.

The Composite Fermion (C-F) Model

- Starting from Hamiltonian of composite fermion (cut off Λ) the quasi particle mass in a gauge invariant system can be obtained as [5]

$$\frac{1}{m^*} = \frac{1}{m}\left(1 + \frac{\Lambda^4}{2p_F^4}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

- where m* is the effective mass of quasiparticle , m is the constituent particle mass.

- Applying the CF picture for diquarks , the effective mass of diquark runs as:

$$\frac{1}{m_D^*} = \frac{1}{m_{q_1} + m_{q_2}}\left(1 + \frac{\Lambda^4}{2p_F^4}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where m_D^* is the effective mass of the diquark; m_{q_1}, m_{q_2} are the constituent masses of quark flavours constituting the diquark. 'Λ' = 0.573 Gev for light sector [6] and 0.6533 GeV for heavy sector [7] . The Fermi momentum (p_F) of the diquark obtained from [8 ,9] (with radii of diquarks from existing literature)

The diquark masses obtained from (2) furnished in Table-I.

Ref:[6]S.Pepin et al; arXiv:hep-ph/9912475(1999) [7] M.Huang; arXiv:hep-ph/0207008(2002).
[8] A.Bhattacharya et al., Int. J. Mod. Phys. **A 15** (2003) 2053.
[9] A.Bhattacharya et al., Eur. Phys. J. **C 2** (1998) 671.

The Diquark as a Quasi Particle

- The expression for baryon mass runs as:

$$M_B = m_q + m_D^* + E_{BE} + E_S \ldots\ldots\ldots\ldots\ldots(3)$$

- The binding energy (E_{BE}) of the quark-diquark has been estimated by considering a harmonic type of potential between quark-diquark like

$$V(r) = ar^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where 'a' is the interaction parameter and its value is taken as 0.02 GeV ^3 for triply heavy sector [10] and a=0.06GeV^3 for light and heavy sector [11].

- The spin term E_S runs as,

$$E_s = \frac{8}{9}\frac{\alpha_s}{m_q m_D}\overrightarrow{S_q}\cdot\overrightarrow{S_D}|\Psi(0)|^2 \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

the strong interaction constant 'α_s' = 0.59 from [12]. S_q the spin of the quark, S_D is the spin of diquark.

- The masses are computed using expression (3) and displayed in Table- II,III,IV,V and VI.

Ref: [10] B.Chakrabarti et al.,Act. Phys. Pol. **B 41** (2010) 97.

[11] M.Hirano et al., Prog. Theo. Phys. **45** (1971) 645.

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Results

Table I : Diquark Radius, Fermi momentum (p_f) and Diquark Mass:

Diquark Content [qq]	Fermi-momentum Computed (GeV)		Diquark-mass Computed (GeV)	
	Scalar	Vector	Scalar	Vector
[ud]	0.5820	0.713	0.4898	0.5957
[us]	0.4706	0.5669	0.4287	0.5913
[ss]	0.6438	0.6048	0.822	0.7698
[uc]	0.5185	0.6624	0.9158	1.4052
[sc]	0.5281	0.7266	1.0363	1.6958
[ub]	0.6481	0.7085	3.568	4.0775
[sb]	0.6956	0.7889	4.0244	4.5258
[cc]	0.9902	1.0185	3.124	3.1531
[bc]	1.1809	1.1834	6.4575	6.4599
[bb]	1.6297	1.6629	9.9712	9.9811

Results

Table II: Mass Spectrum (J^p= 1/2$^+$ and 3/2$^+$) of the Light Baryons:

Baryon	Baryon mass (GeV) Our-work for $J^p = 1/2^+$	Expt.[13,14]	Baryon mass (GeV) Our-work for $J^p = 3/2^+$	Expt.[13,14]
Λ^o	1.1188	1.1156± 0.000006	1.3086	--------
Σ^-	1.3295	1.1974± 0.00004	1.449	1.387± 0.0005
Ξ^-	1.2137	1.3217± 0.00007	1.3948	1.535± 0.0006
Ω^-	1.551	-------	1.5200	1.672± 0.00029

Results

Table III: Mass Spectrum (J^p= 1/2$^+$ and 3/2$^+$) of the Heavy Baryons:

Baryon	Baryon mass (GeV) Our-work for J^p = 1/2$^+$	Expt.[13,14]	Baryon mass (Gev) Our-work for J^p = 3/2$^+$	Expt.[13,14]
Λ_c^+	2.9377	2.2864±0.00014	3.04477	------
Λ_b^o	5.5891	5.6202±0.0016	5.7168	------
Σ_c^+	2.4577	2.4529±0.0004	2.5690	2.518
Σ_b^o	5.5751	5.808	5.7169	5.829
Ξ_c^o	2.2687	2.4708+0.00034 - 0.0008	2.4464	2.646
Ξ_b^o	5.5069	5.7924±0.003	5.7201	------
Ω_c^o	2.6724	2.6952±0.0017	2.63122	2.768
Ω_b^-	5.9631	6.165±0.023	5.9176	------

Results

Table IV: Mass Spectrum ($J^p = 1/2^+$ and $3/2^+$) of the Doubly Heavy Ξ Baryons:

Baryon	Baryon mass (GeV) for $J^p = 1/2^+$			Baryon mass (GeV) for $J^p = 3/2^+$		
	Ours	Expt.	Others	Ours	Expt.	Others
Ξ_{cc}^{++}	3.9496	------	3.579;3.730 3.480	3.9807	----	3.708;3.800 3.610
Ξ_{cc}^{+}	3.5308	3.5189± 0.0009 [13,14]	3.584;3.755 3.480	3.6222	---	3.713;3.828 3.610
Ξ_{cb}^{0}	6.9065	------	6.95; 7.01	6.9205	----	7.02 7.10
Ξ_{cb}^{+}	7.2534	------	6.965±0.09	7.2569	----	7.06±0.09
Ξ_{bb}^{0}	10.6764	------	10.339;10.114 10.093	10.6873	-----	10.468;10.165 10.330
Ξ_{bb}^{-}	10.5389	-------	10.23;10.344 10.30	10.551	-----	10.28;10.473 10.34

Results

Table V: Mass Spectrum (J^p = 1/2$^+$ and 3/2$^+$) of the Doubly Heavy Ω Baryons:

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

Results

Table VI: Mass Spectrum (J^p = 1/2$^+$ and 3/2$^+$) of the Triply Heavy Ω Baryons:

Baryon	Baryon mass (GeV) Our-work for J^p = 1/2 +	Baryon mass (GeV) Other-works for J^p = 1/2 +	Baryon mass (GeV) Our-work for J^p = 3/2 +	Baryon mass (GeV) Other-works for J^p = 3/2 +
Ωccc	4.8508	-------- --------	4.8916	4.803;4.925 4.9(0.25)
Ωccb	8.355	8.229;8.018 --------	8.3575	8.358;8.025 8.200
Ωcbb	11.695	11.280;11.609 --------	11.6974	11.287;11.48 11.738
Ωbbb	15.0329	-------- --------	15.0449	15.118;14.760 14.7(0.3)

Conclusions

- The mass of Λ^o (1.1188 GeV) for $J^p = 1/2^+$ is in very good agreement with experimental findings (1.1156 GeV).

- For Σ_c^+, Λ_b^o, Ω_b^- reasonably good agreement have been obtained.

- The mass of Ξ_{cc}^+ (3.5308 GeV) for $J^p = 1/2^+$ agrees very well with the experimental value (3.5189 ± 0.0009 GeV).

- It may be pointed out that some uncertainty may come from the radii of the baryons and diquarks which are not exactly known and have a substantial contribution in determining the fermi momentum and the binding energy of baryons.

- In present investigation it has been observed that the CF description of diquark is quiet successful in reproducing the masses of baryons and may not be far from the reality. The diquark as CF may throw some new light on the understanding of structure and dynamics of baryons.

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