# Diquark Approach to Calculating the Mass and Stability of $H_{cc}$-Dibaryon

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**Abstract**— Diquarks may play an important role in hadronic physics particularly near the phase transitions ( chiral , deconfinement points ), current lattice QCD determinations of baryon charge distributions do not support the concept of substantial u - d scalar diquark clustering as an appropriate description of the internal structure of nucleon. Thus vector diquarks are more favorable. By using of vector diquark ideas in the chiral limit diquark correlations in the relativistic region and imposing HF interactionsbetween quarks in a vector diquark we calculated the mass of $H_{cc}$dibaryon, also by using of tunneling method we simultaneously calculated its decaywidth.

**Keywords –** Dibaryon,Diquark,Decay Width,Hcc - Dibaryon, Lattice QCD, Lattice QCD,Quark Mass.

## 1 INTRODUCTION

THEORETICALLY, QCD is believed to be the underlying theory of strong interactions which has three fundamental properties asymptotic freedom, color confinement, approximate chiral symmetry and its spontaneous breaking. In high energy level QCD has been tested up to 0.01 level. The behavior of QCD in the low-energy is nonperturbative and the SU (3) color group structure is non-abelian. However besides conventional mesons and baryons.QCD itself does not exclude the existence of the nonconventional states such as glueballs ( gg, ggg, ….) hybrid mesons (qqg ), and other multiquark states (qqqq, qqqqq ).

Do other multiquark hadrons exist 4q, 6q, 7q? Is there an upper limit for N? Study of these issues will deepen our understanding of the low energy sector of QCD. It is very difficult to calculate the whole hadrons' spectrum from first principles in QCD. Under such a circumstance various models which are QCD- based or incorporate some important properties of QCD were proposed to explain the hadron spectrum and other low-energy properties [1].

In1977 abound six-quarkstate(uuddss),theH -dibaryon, was predicted in a bag-modelcalculation by Jaffe[2].This state is the lowest SU(3)flavor singlet state with spin zero, strangeness -2and$J^P = 0^+$. In the last twenty years many attempts to verifythe existenceand stability of this particle were under taken by means of various methods. Perturbative calculations included spin dependent q-q arising from one gluon exchange (OGE) [2, 3],Instanton induced interactions and Goldstone boson exchange (GBE)interactions [4]. One of the great open problems of intermediate energy physics is the question of existence or nonexistence of dibaryons. Early theoretical models based on SU (3)and SU (6) symmetries [5, 6] and on Regge theory [4, 5] suggest that dibaryonsshould exist. There is QCD-based models predict dibaryons with strangeness S = 0, -1, and -2 and invariant masses range between 2 and3 GeV [9,10,11,12,13,14,15,16,17,18,19]. The masses and

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Widths of the expected6-quark states differ considerably for these models. But it seems that all QCDinspired models predict dibaryons and none forbids them. Until now, about 30 years after the first predictions of the S = -2 H-dibaryon by Jaffe [9] this questionis still open. The theory of quantum chromodynamics imposes no specific limitationon the number of quarks composing hadrons other than that they form color singlet states. Although only qqq and q bar states have beenobserved, other combinations can form color singlets. Jaffe hasproposed that a six-quark state uuddss may have sufficient color-magnetic binding to be stable against strong decay. Such a state, which Jaffenamed H-,Dibaryon would decay weakly, and the resultant long lifetime wouldallow the possibility of observing such particles in neutral beams.

Theoretical estimates of itsdecay width have varied widely, ranging from a deeplybound state with 2.10 GeV/ to a slightly unbound state with nearthe threshold, 2.23 GeV/. Allexperimental efforts failed so far to identify dibaryons. A possible reason could be that the experimental resolutions and the statistical accuracieswere not sufficient. In this context it should be mentioned that the search for S = 0 and S = -2 dibaryons has been most intense whereas S = -1 dibaryons havereceived less attention, although the lowest lying S = -1 dibaryon states are expectedto be very narrow.In our previous paper we concentrated on H-Dibaryon, but here we deal with $H_{CC}$-Dibaryon, composed of uuddcc quarks.

## 2 DIQUARK APPROACH

We consider $H_{CC}$dibaryon which composed of uuddcc, three vector ud - ud - ccdiquarks, each of which is a color antitriplet and is symmetric in flavor and spin and orbital space, this leads to a six - quark state whichis color singlet, we ignore the Pauli principle for quarks in different diquarksin the limit that diquarks are pointlike, but two quarks in each diquark satisfy this principle.Now by using of diquark ideas in the chiral limit diquark correlationsin the relativistic region and imposing HF interactions between quarksin a diquark, we led to introducing a conventionalHamiltonian fig.1.

$$H(H) = T(H) + V^{CS}(H) \quad (1)$$

In which T(H) is Kinetic energy between two vector ud diquarks and $V^{CS}$(H) is the attractive q-q color-spin potential.

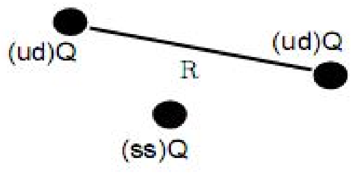


Fig.1.$H_{CC}$-Dibaryon which composed of uu-dd-cc three vector diquarks.

We have for T (H)

$$T(H) = \nabla^2(R)/2m \quad (2)$$

And for the potential energy $V^{CS}$ (H)

$$V^{CS}(H) \sim (\lambda^a{}_1 \lambda^a{}_2)(s_1 s_2) \quad (3)$$

Where $\lambda^a{}_i$ ,$S_i$ denote SU (3) color(flavor) and SU(2) spin generators for spin dependent q-q interactions in three vector diquarks respectively. The orbital wave function for two ud (Q) vector diquarks is

$$\psi_m = N[aRY1m(R) \exp -a^2R^2/2] \quad (4)$$

We calculated the masses of three vector diquarksusing color - spin interactions as hyperfine HF interaction between quarks in a vectordiquark and ignored flavor – spin interactions. Thus for the vector diquark mass we have

$$M(ud) = m(u) + m(d) + V^{CS(ud)} \quad (5)$$

$$M(ss) = m(s) + m(s) + V^{cs}{}_{(CC)} \quad (6)$$

And for $H_{CC}$-Dibaryon mass we have

$$M(H) = M(ud) + M(ud) + M(cc) + T(H). \quad (7)$$

If we take over the results and consider a T (H) = 1367 MeV Kinetic energy as the binding energy for two ud (Q) vector diquarks in the $H_{cc}$-Dibaryon the mass of it would be equal to the sum of the $X_U$ and N massesconsidering the following decay process .

$$H \rightarrow X_U + N \quad (8)$$

Since the diquark masses ( e.x, vector or tensor, .... ) are smaller thanthe constituents, they are stable against decay near mass shell, in such a configuration, the diquarks are nearby and "tunneling "of one of thequarks between the two diquarks may take place.We suppose that Decay widths of$H_{CC}$-Dibaryon in the mentioned decay process Eq (8), is due to tunnelingof one of the quarks between the two vector diquarks.Thus in the decay process $H \rightarrow X_U + N$ , a (d) quark tunnels from a diquarkud to the other diquark to form a nucleon (udd) N and an off-shell (u) quark which forms $X_U$ with the other diquark.We calculated the decay width of this process

$$\Gamma_H \simeq 5.0e^{-2S_0}(g^2 g^2{}_A / 8\pi f_k{}^2)|\psi(0)| \quad (9)$$

Which we have used WKB approximation for the tunneling amplitude. We have

$$\Delta E = (m(u) + m(d) - M(ud)) \quad (10)$$

The ψ (0) is the 1S wave function of quark – diquark at the origin and can be written as

$$\Psi(0) = (1/2\sqrt{\pi})(2/a_0{}^{2/3}) \quad (11)$$

Where$a_0$ is the Bohr radius of the quark-diquark bound state and we have

$$a_0 \sim (2MB)^{1/2} \quad (12)$$

Where M = 250 MeV is the reduced mass and B is the binding energy of the quark – diquark bound state.According to our model the Kinetic energy

$$T(H) = \nabla^2(R)/2m = 3a^2/4m \sim 1367 \text{ MeV} \quad (13)$$

Which leads to a = 773 and then

$$r_0 = \langle R \rangle = (5/2\, a^2)^{1/2} = 0.002 \quad (14)$$

g = 3.03,$g_A$ = 0.75 from the quark model and M (ud) = 520 MeV for the vector diquarkmass in our model.

Inserting this values intoEq(9) we find

$\Gamma_H$ = 52 MeV.

## 3 CONCLUSIONS

With the assumption that $H_{CC}$ -Dibaryon decays into $X_U$ and N by tunnelingof one d quark to (ud) diquark, we calculated its decay width 52 MeV. Thus the $H_{CC}$-Dibaryon which is constructed by vector diquarks is unstable. There is other channels for H- Dibaryon decay for example into two baryon and one can estimate the decay width for them using this method. Our theoretical results on the mass and width of $H_{CC}$ are in good agreementwith many experimental results and one can use our vector diquark approach for calculating the mass and width of other multiquark states.

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