ISSN 2347-3487

Decay properties of Diquarks and exotics

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ABSTRACT

Decay and spectroscopic properties of vector and scalar diquarks have been studied. The decay widths and decay constants of scalar and vector diquarks have been estimated in the frame work of quasi particle model of diquark. The decay widths of exotic baryons like,Δ, N, θ^+ have been investigated. The investigation is important in the view of LHC era where existence of new particle (new Physics) are expected including the colored objects like diquarks. The results obtained are compared with existing theoretical and experimental works wherever available. Some interesting observations are made.

Keywords

Diquarks, Quasiparticles, Exotic particles, Decay properties.

PACS. Nos.:

14.80.-j, 14.20 Pt, 13.30.-a

Council for Innovative Research

Peer Review Research Publishing System

Journal: Journal of Advances in Physics

Vol 4, No. 2

editor@cirjap.com, japeditor@gmail.com

www.cirjap.com

INTRODUCTION

Hadron spectra in principle should be understood in the framework of QCD but the non perturbative nature of QCD has compelled to suggest a number of models which are QCD motivated. The possibility of multi-quark states have been suggested by Gell-Mann himself in his paper in addition to usual baryons and mesons. A number of particles with multiquark states have been suggested which await experimental identification [1]. The states like pentaquarks, dihadronic states,hybrid mesons need to be studied and explained. To understand the dynamics of these states clearly, study of the quark-quark interaction is inevitable. One of the important candidate for such states is diquark. Regularities of the hadron spectroscopy, partition distribution function, spin dependent structure function of hadrons hints at the existence of diquark correlation. It is not only a mathematical simplification dealing with baryon but also provide physical picture where two quarks correlate to form a single body and behave as a single object. As the results from LHC are coming up, the possibility of identification of hypothetical coloured particles seem to be highly plausible particularly in the TeV range. The possible nature of diquark correlation has been studied by a number of authors [2]. The diquark has been described as a quasi particle behaving like an independent object by Bhattacharya et al [3]. Stability of such a correlated two quark system which has been described as an independent object and which is supposed to be an important component of the hadrons structure should be studied with much attention. The stability of diquark has been studied by Tang et al [4]. They

have pointed out that the main scenario to determine the diquark lifetime is to study whether the diquark dissolve into two quarks with external disturbance. It has been believed that generally the heavy diquarks are more stable than the lighter diquarks as lighter diquarks are suggested to be dissolved easily by absorbing gluons. Bediaga et al [5] have investigated the decay constant of vector meson and axial vector diquark to estimate the baryon lifetimes with quark-diquark scheme of baryon structure. It has been suggested that the baryons can be described in the quark -diquark scheme in same way the

mesons are described as the quark-antiquark scheme. They have pointed out that such scheme of describing baryons gives accurate description of hadronic spectrum from light to heavy masses [5]. The study of decay constants of both vector and scalar diquarks are of immense importance if they are considered as a fundamental constituents of hadrons. Decay widths of baryons have been investigated by Jenkins et al [6] considering the 1/N expansion of the exotic baryons. Maris [7] has investigated the electromagnetic and decay properties of properties of pseudoscalar mesons and scalar diquark in the context of different models. Cakir et al[8] 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.

In the present work we have investigated decay constant of scalar and vector diquarks. LHC results triggered a hope for identification of coloured object along with many new particles. It is very important and interesting to suggest the theoretical models to investigate the diquark structure and dynamics and relevant properties at this conjecture. The meson as diquark -antidiquark system has been investigated by a number of authors. Maiani et al[9] have observed that the light mesons fit well in diquark-antidiquark configuration and have found that the resulting nonet obeys mass formula which respect the OZI rule to a good extent. Lichtenberg et al [10] have investigated diquark model of exotic mesons considering exotic mesons to be composed of a diquark and an antidiquark system. They have pointed out that the masses of the exotic mesons are well above the threshold for decaying into two mesons making their widths too large to observe. In the current work we have considered that the vector or scalar diquarks which are supposed to be a strong correlation between two quarks and colored object can resemble a scalar meson or a vector meson of corresponding flavour. We have estimated the decay widths and decay constants for diquarks with the same formulation of a meson as in [5]. The quasi particle model of effective mass approximation of diquark has been used. Diquark decay widths have been estimated and

compared with available results in the literature. The decay widths of exotic baryons like N,Δ and Θ+ have also been estimated. The result are found to be in very good agreement with the experimental observations.

QUASI PARTICLE MODEL FOR DIQUARK

Recently we have suggested a model[11] in which two quarks are assumed to be correlated to form a low energy configuration, forming a diquark and behaves like a quasi particle in an analogy with an electron behaving as a quasi particle in the crystal lattice. It is well known that a quasi particle is a low-lying excited state whose motion is modified by the interactions within the system. An electron in a crystal is subjected to two types of forces, namely, the effect of the crystal field (∇V) and an external force (F) which accelerates the electron [12]. Under the influence of these two forces, an electron in a crystal behaves like a quasi particle having velocity v whose effective mass m^* reflects the inertia of electrons which are already in a crystal field so that:

$$m^* \frac{dv}{dt} = F \quad \text{......................................(1)}$$

The bare electrons (with normal mass) are affected by the lattice force $-\nabla V$ (where V is the periodic potential) and the external force F so that:

$$m \frac{dv}{dt} = F - \frac{dV}{dx} \quad \text{......................................(2)}$$

Hence the ratio of the normal mass (m) to the effective mass ($m*$) can be expressed as [12]:

$$m/m^{*} = 1 - \frac{1}{F}[\frac{\delta V}{\delta x}]$$
....................................(3)

An elementary particle in vacuum may be suggested to be in a situation exactly resembling that of an electron in a crystal [12]. We have proposed a similar type of picture for the diquark [*ud*]0 as a quasi particle inside a hadron. We have assumed that the diquark is an independent body which is under the influence of two types of forces. One is due to the background meson cloud which is represented by potential V =−(2/3)α_S/r , α_s being the strong coupling constant, and this potential resembles the crystal field on a crystal electron. On the other

hand for the external force we have considered an average force F = -ar, where a is a suitable constant, which is of confinement type. It has been assumed that under the influence of these two types of interactions the diquark behaves like

a quasi particle (colour anisymmetric), a low lying elementary excited state simulating many body interaction and its mass gets modified. The ratio of the constituent mass and the effective mass of the diquark (m*D*) can be expressed by using the same formalism as in equation (3) and is obtained as:

$$\frac{m_q + m_{q\prime}}{m_D} = 1 + \frac{\alpha}{2ar^3}$$
....(4)

Here *mq +mq_* represents the normal constituent mass of the diquark and M_d is the effective mass of the diquark, α=2

3α_s, α_s = 0.58 [13]and the strength parameter a = 0.02 GeV^3 [14], *V* being the average value of the one gluon exchange type of potential. 'r' is the radius parameter of the diquark. To calculate the effective mass of the diquark from the above expression we need the radius parameter r of the diquark. The radii of scalar and vector *rud* diquark has been taken from Nagata [15] whereas *rus* has been taken from Maris [7] for both scalar and vector configurations. The radii of scalar diquarks [cs],[uc],[bs], [cc],[bb] and vector diquark systems [us], [cs], [uc/dc] [cc]and [bb] have been used from Castro et al [16]. We have estimated masses of scalar and vector diquarks in the quasi particle approach and used for the subsequent

analysis.

Decay widths of scalar (Γ_S) and vector (Γ_V) diquarks decaying into quark pairs have been derived from the baryon number conserving Lagrangian [17] and can be expressed as:

$$\Gamma_S = C_F \frac{F_s.g_2^2 M_D}{16\pi}$$
...............................(5)

$$\Gamma_V = C_F \frac{F_s.g_2^2 M_D}{24\pi}$$
................................(6)

where $g_2{}^2 = 4\pi\alpha$, C_F is color factor,α is coupling constant. We have estimated the decay widths and decay constants of scalar and vector diquarks with α =0.01 using the above expressions. Results are displayed in Table-I along with the diquark mass obtained in the effective mass approximation. Variation of decay widths with diquark mass has been displayed in Fig-1. Cakir et al [8] have investigated the decay widths of heavy diquarks with mass starting from 700 GeV. They have obtained Γ_S = 8.75GeV and Γ_V = 5.83GeV. The present work shows that decay widths are in the range 14 MeV to 174 MeV for scalar diquark and 13 to 114 MeV for vector diquarks. The ratio of decay widths of scalar and vector diquarks have been computed. The ratios are found to be ~1.49 for heavy sector whereas for light diquarks the ratios are found to be ~1.2 except charmed diquark where ratio is found to be ~ 1. Van Royen Wiesskopff formula for decay constant of pseudoscalar scalar and vector meson can be expressed as [18]:

$$f_{S/V} = 2\sqrt{3}|\psi(o)|/\sqrt{M_{S/V}}$$
...........................(7)

We have used the above expression for the decay constant for mesons to compute the decay constant of scalar and vector diquarks by replacing the meson masses as in [5] by the masses of the diquarks of different flavours as estimated by us in quasi particle approach. We have used the statistical model wave function [19] for a hadron for diquarks. It may be mentioned that the wave function derived in the context of statistical model [19] contains radius parameter only. We have used this wave function for diquark to compute the decay constants with the input of the radius of the corresponding diquarks.The statistical model wave function for ground state runs as [19];

$$|\phi(r)|^2 = \frac{315}{64\pi r_B^3}$$ ....(8)

where R*B* is the radius parameter of the corresponding hadron. With the input of diquark radius and mass of the diquarks estimated in quasi particle model the decay constants have been estimated using the expressions (7). The ratios of decay constant of scalar to vector diquarks have been computed and results are displayed in Table-II. It is interesting to observe that the ratios are observed to be 2.4 for the light sector whereas it almost unity for the heavy sector indicating the fact that the decay constants are same for both heavy scalar and vector diquarks.

The decay width of a baryon decaying into a pseudoscalar meson and a baryon in the context of $1/N_c$ expansion runs as [6]:

$$\Gamma_B = \frac{g_a^2 p_f^2}{3\pi f^2}$$ ....(9)

where *pf* is the Fermi momentum of the corresponding pseudoscalar meson, g_A is the coupling normalized to the axial coupling of constituent quark and ~ 0.75. To estimate the decay widths we need the fermi momentum of the corresponding meson. In our previous works [19,20] we have studied the the fermi momentum of the mesons in the frame work of the statistical model and investigated the CP violating parameters. We have obtained a relation between the Fermi momentum, decay constant and the mass of a meson 19,20 such that;

$$p_f^3 = \frac{3\pi^2}{24} f^2 M_m$$ ....(10)

Substituting the meson mass by the mass of the diquark of same flavour the decay widths of N →N *η*, Δ → N *π* and Θ → KN. Results obtained is displayed in Table-II along with experimental values [21,24]. Estimated decay widths show very good agreement with experimental predictions. It may be mentioned here that the meson mass as diquark in effective mass approximation reproduces the decay widths very well.

DISCUSSION

In the current work we have investigated the decay widths and decay constants of diquarks of different flavors in the context of effective mass approximation suggested by us. Decay widths are estimated and it has been observed that the ratios of decay widths of scalar to vector diquarks are more than one for all diquarks. It is interesting to observe that for heavy sector the ratios are found to be ~ 1.5 whereas for light diquarks the ratios are slightly less ~ 1.2 indicating the fact that the stability of vector diquark is more than the vector diquarks. Similar observation is made by Cakir [8] for heavy diquarks having masses over 700GeV. Considering the fact that the meson masses can be replaced by the masses of the diquarks of corresponding flavours as in [5], decay constants for both vector and scalar diquarks have been estimated using Van Royen Weisskof formaula replacing the mass of the mesons by corresponding diquarks mass estimated in the context of quasi particle model. The results obtained shows a number of remarkable feature. The ratios of decay constants

fs/fv are found to be ~ 1 for heavy sector which agrees closely with QCD calculation of ratio of mesons decay constants [22]. It may be pointed out here that the radius of the diquarks are not known. Maris [7] has investigated the electromagnetic properties of diquarks using Bethe Salpeter equation and has observed that [ud] diquark radius is 8 percent larger than the corresponding scalar meson. In the current investigation the radius of the diquarks have been used from the works of different authors [7,15]. The vector diquark radius are supposed to be more than the scalar one. Bediaga [5]et al have investigated the decay constants of [ud], [sd], [cd] vector diquarks and obtained the values as f_{ud}, f_{sd}, f_{cd} 208 MeV, 212 MeV and 181 MeV respectively with the input of vector diquark masses from Lichtenberg et al [10]. The QCD sum rule calculation yields $f_D^*/f_D \sim f_k^*/f_k$. We have observed that the ratio of scalar to vector diquark decay constants are same for the light flavoured diquarks and it is 2.4 whereas for other flavours the ratios are approximately equal to unity. Exotic baryons are not only light but they have also very narrow decay widths.The narrow decay widths have been studied in different models [23]. Hong et al [24] have suggested that the small decay width is largely due to a large tunnelling of suppression of quark between two diquarks. The decay widths of exotic baryons decaying into a nucleon and a pseudoscalar meson,estimated considering mesons resembling diquarks in effective mass approximation in the current work are found to be in very good agreement with the experimental values.

It may be mentioned that the exotic particles are light and diquark is a promising candidate for the structure of exotics. Exact nature of the diquark is yet to be settled. The comparison of diquark properties with that of meson may throw some light on the understanding of the structure and dynamics of the diquark. We have investigated the problem in the context of the quasi particle model of diquark and it appears that the stability of vector diquark is more than scalar one for same flavor whereas the light diquarks are found to be more stable than heavier one. It would be interesting to point out here that in the context of discussing the stability of diquarks Tang et al [4] have observed that heavy diquarks are less stable than the light-light or heavy - light diquarks under external disturbances using QCD sum rules whereas it is generally believed that diquarks composed of two heavy quarks are more stable. We have observed in our work that light diquarks are more stable.

The decay widths of exotic baryons are reproduced very well with the effective mass approximation. With the results coming from LHC a new unexplored domain of particles are expected. One of such particle is coloured diquarks. It may decay into two light quarks, two top quarks or a top and light quark [25]. Arik et al [17] have investigated the resonance production of first generation of vector diquarks at LHC and have suggested the possibility of identifying vector diquark with mass around 9TEV. and 4TeV. It has been suggested that the results would throw some light on the prediction for colour sextet Higgs field. Possibility of diquark structure of Higgs have also been probed by some authors [26]. Hence it is extremely important to study diquark properties at this conjecture of particle physics research. We have estimated mass, decay widths, decay constants of diquarks using the masses of diquarks estimated in the effective mass approximation. The results of decay widths of exotic particles are in very good agreement with experiments. It is pertinent to note that replacing the meson mass by corresponding diquark mass yields the results very well and may be attributed to the reality of meson description of diquark. It may be mentioned that recently there is suggestion of describing exotic meson structure in the frame work of diquark-antidiquark configurations to reproduce the spectroscopic and decay properties of exotic mesons [27]. However,the properties of diquarks awaits experimental verification and excepted in near future. Further study on the diquark structure of meson would be done in our future works.

ACKMOWLEDGEMENT

Authors are Thankful to University Grants Commission (UGC), New Delhi,India for financial assistance.

Table-1. Diquark masses and decay widths.

***Diquark Content*[*qq*]**	***Diquark Mass(GeV)***		***Decay width(GeV)***		***Decay width ratio***
	scalar	***vector***	***scalar*** Γ_s	***vector*** Γ_v	Γ_s/Γ_v
$[ud]$	0.441	0.624	0.0168	0.0138	1.212
$[us], [ds]$	0.659	0.835	0.0220	0.0186	1.186
$[cs]$	2.12	2.13	0.0708	0.0473	1.496
$[uc], [dc]$	1.98	1.99	0.0661	0.0442	1.4955
$[ub]$	5.14	5.15	0.1716	0.1143	1.4996
$[bs]$	5.21	5.22	0.174	0.1159	1.5012
$[cc]$	0.9613	1.3656	0.0321	0.0303	1.0603
$[bb]$	3.565	3.426	0.1188	0.0761	1.561

Table-2. Diquark decay constants.

Quark content	**Radius (fm)**		F_s/f_v
	Scalar	**vector**	
$[ud]$	0.5	0.8	2.405
$[us], [ds]$	0.6	1.006	2.442
$[cs]$	0.767	0.785	1.034
$[uc], [dc]$	0.835	0.861	1.049
$[ub]$	0.797	0.805	1.023
$[bs]$	0.717	0.723	1.011
$[cc]$	0.576	0.579	1.2
$[bb]$	0.350	0.343	0.954

Table-3. Decay width of N ,Δ ,θ⁺ in MeV.

Particle	Decay width (MeV) Present	Expt.
$N(N \to N\eta)$	70.80	$70 - 90[21]$
$\Delta(\Delta \to N\pi)$	32.50	$35 - 90[21]$
$\Theta^+(\Theta^+ \to KN)$	2.55	$1.7 - 4.8[24]$

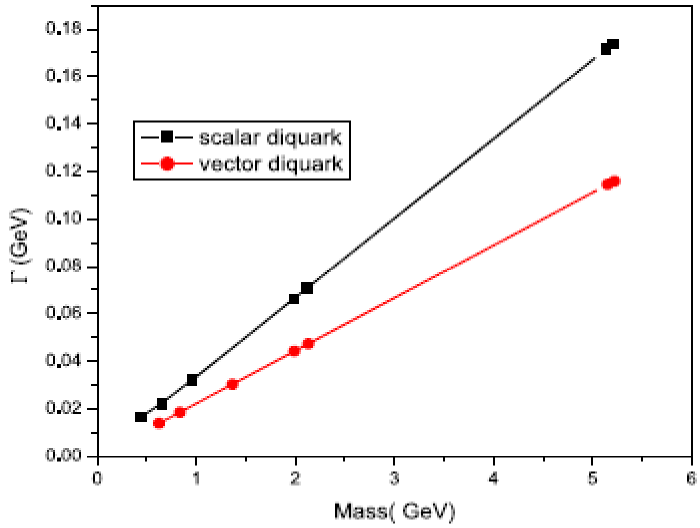

Fig 1: Scalar and vector diquark decay width as a function of diquark masses

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