$N - \Delta$ and $\Delta - \Delta$ Di-baryonic Molecular Systems

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Introduction

Experimental facilities world wide like BES, Belle, BaBar, CLEO provides the new data in the field of hadron physics especially in the light quark sector [1, 2]. Baryons and Mesons are made up of quarks and antiquarks.

Some newly observed states needs explanation as these states could have more complicated structures like tetraquark, pentaquark, hexaquark or molecular states and could not explained in $q\bar{q}$ and qqq pattern estimated by standard model. Such states are known as Exotic states.

The QCD describe more complex multiquark states and gives opportunities and challenges to theorists as well as experimentalists to explain the internal structure of these novel exotic states [2]. Over the time, theorists comes with different models for explanation of these exotic states[1–11]. Recently, $d^*(2380)$ resonance reported with $I\,(J)^P = 0\,(3)^+$, could be potential candidate of hexaquark states [7]. The mass of $d^*(2380)$ has reported 2461.87 MeV. If this state carried molecular structure then it required binding energy near about 80 MeV which is in contrast with loosely bound deuteron. Our aim is to study the mass spectra of Di-baryonic molecular systems.

Theoretical Approach

In phenomenological study, the potential model has been proved as successful tool in both relativistic and non-relativistic regime [2, 5, 6, 8, 9]. The Potential models are either motivated by QCD or inspired by experimental facts. The Yukawa like potential is used here to calculate the masses and binding energy of the Di-baryonic states, as suggested and used in ref.[2]. We have used the mathematica code for solving Schrödinger equation numerically, originally devloped by W. Lucha et. al. [3]. The behavior of the interquark potential at short range is known to have 1/r dependence. Perturbative QCD does not give hint of intrinsically non-perturbative phenomena such as color confinement [4].

The model governed by Hamiltonian, is essentially a potential approach which is composed of two parts: a kinetic energy and potential energy [5, 6].

$$H = T + V \quad (1)$$

The expression of non-relativistic is given by

$$T = T_{nr} = m_1 + m_2 + \frac{p^2}{2\mu} \quad (2)$$

Where $\mu = \frac{m_1 m_2}{m_1+m_2}$ is the reduced mass of the system, m_1 and m_2 being constituent masses of baryons and p, the relative momentum of Di-baryonic system.

$V(r)$ is the Di-baryonic interaction potential, namely

$$V(r) = \frac{A}{r}\exp\left[\frac{-c^2x^2}{2}\right](S_1\cdot S_2)(I_1\cdot I_2) \quad (3)$$

where A is the residual strength like running coupling constant and c is the fitting parameter of the potential. The parameter values are $A = 0.3$ and $c = 1.5385\frac{GeV}{c^2}$. Masses and quantum number of the baryons are taken from PDG [10]; $M_N = 1440MeV$ ($I\,(J)^P = \frac{1}{2}\left(\frac{1}{2}\right)^+$) and $M_\Delta = 1232MeV$ ($I\,(J)^P = \frac{3}{2}\left(\frac{3}{2}\right)^+$). Here, $(S_1\cdot S_2)$ and $(I_1\cdot I_2)$ are spin and isospin factor respectively.

$$(S_1\cdot S_2)(I_1\cdot I_2) = 4[S(S+1)-3/2]*[I(I+1)-3/2] \quad (4)$$

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TABLE I: Mass spectra of $N-\Delta$
A = Allowed F = Forbidden

S	I	$S_1.S_2$	$I_1.I_2$	B.E.(in MeV)	Mass(in MeV)	
1	1	-3	-5	29.9999	2702	F
2	1	3	-5	-1.30452	2670.7	A
1	2	-5	3	-1.30452	2670.7	F
2	2	3	3	7.77335	2679.7	F

TABLE II: Mass spectra of $\Delta-\Delta$

S	I	$S_1.S_2$	$I_1.I_2$	B.E.(in MeV)	Mass (in MeV)	
0	0	-15	-15	35.0649	2499.06	F
3	0	9	-15	-2.1288	2461.87	A
0	3	-15	9	-2.1288	2461.87	F
3	3	9	9	29.999	2494	F

A is residual strength like running coupling constant and can be estimated by [2, 8, 9]

$$A = \frac{4\pi}{\left(11-\frac{2n_f}{3}\right)\ln\left(\frac{m_l^2+m_2^2}{\lambda^2}\right)} \quad (5)$$

Results and Conclusion

We have found the bound state in $N-\Delta$ and $\Delta-\Delta$ molecular system, and results are tabulated in Table-I & II. We have found state in $N-\Delta$ molecular system for (I,S) = (2,1), B.E. is about -1.30 MeV. Whereas, we have found bound state in $\Delta-\Delta$ state for (I,S) = (0,3), B.E. is about -2.12 MeV. These results shows probability of very near threshold deuteron-like molecular systems.

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