Θ^+ Excited states and Decay width

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Introduction:

Diakonov et al.[1] theoretically proposed the low mass(1530MeV) and decay width (Γ<15MeV) of the exotic baryon in the framework of chiral soliton model and denoted the exotic baryon a Θ^+ pentaquark in the year 1997. In the year 2003 LEPS Collaboration[2] reported the first experimental evidence of a sharp baryon resonance peak at 1540±10MeV with a decay width Γ <25MeV, and in the same year SHAPHIR Collaboration[3] has detected a resonance peak at 1540±4±2MeV with same decay width. ZEUS collaboration [4] reported that experimental existence of pentaquark suggesting the mass to be 1521.5±1.5MeV with Γ=6.1±1.6MeV whereas CLASS Collaboration [5] suggested a value to be 1555±10MeV and Γ <26MeV. Recently Iwasaki and Takagi [6] have studied the higher energy states and decay width of pentaquark with the use of WKB approximation in the context of flux tube model.

In the current work the mass splitting and the decay width of pentaquark (Θ^+) have been investigated in the framework of flux tube model considering the diquark-diquark-antiquark picture of Θ^+. Quasi particle model have been employed to obtain diquark mass and the statistical model wave function have been used to evaluate the whole computation.

Quasi Particle Model of Diquark :

We have suggested a quasi particle model [7] for diquark where two quark are assumed to be correlated to form a low energy configuration forming a diqaurk and behaving like a quasi particle in an analogy with the electron behaving as a quasi particle in crystal lattice and the motion of the quasi particle get modified by the interactions within the system. It have been assumed that diquark is a fundamental entity behaving like independent body which is under two types of forces. One is short range interaction(due to Background meson cloud) of asymptotic freedom like and other is long range interaction (external force of harmonic oscillator type) of confinement type. Therefore the total interaction potential (V_{ij}) can be expressed as,

$V_{ij} = -\alpha/r + ar^2$, where the symbols have the same meaning as in reference[4].The effective mass of diquark(m_D) in the background of the quark field gets modified in the quasi particle approximation as it happens also in the crystal lattice[8]. The constituent quark mass (m_q) and the diquark mass ratio is,

$\{(m_q+ m_q)/ m_D\}=1+\{\alpha/(2ar^3)\}$ ………………..(1)

where 'r' is the radius of the diquark.

The mass of scalar diquark[ud] have been computed(506MeV) [7].

Formulation :

The Hamiltonian for the pentaquark system can be written as:

$\langle H\rangle = \langle p^2/2\mu\rangle + \langle V\rangle$ ………………………(2)

Where, μ is the reduced mass of pentaquark and 'p'the momentum of the system is equal to the gradient of the wave function '$\Psi(r)$'. The average potential energy (linear potential V=ar) is of the form,

$\langle V\rangle = \int V(r) |\Psi(r)|^2 d\tau$ …………(3)

In the context of statistical model [9] we have derived an expression for the wave function as:

$|\Psi(r,\theta,\Phi)|^2 = C (r_0-r)^{3/2}\theta(r_0-r) |Y_{l,m}(\theta,\Phi)|^2$

where $C=(315/64\pi r_0^{9/2})$ …………(4)

Where r_0 is the radius of the corresponding hadron and $\theta(r_0-r)$ is the step function. The Hamiltonian have been computed for higher value of angular momentum states and the result are displayed in table-1.

The probability(w) of decay in unit time can be written like [6],

$\Gamma=\int w\upsilon(r)|\Psi(r,\theta,\Phi)|^2 d\tau$ ………………………(5)

Where, $\upsilon(r)$ (=σr) represents the volume of the string, σ is the area of the tube in the rest frame of the string. Decay widths for higher angular momentum have been computed using the wave function as in equation-4.

The orbital excitation of Θ^+ can be expressed by the Regge Trajectory which runs as:

$M^2=\alpha$ J and $\alpha=1/(2\pi\nu)$ where 'α' is the regge slope and 'ν' is the string tension of the flux tube. The Regge trajectory have been shown in Fig-1.

Results:

Figure-1 The Regge Trajectory for pentaquark(Θ^+)

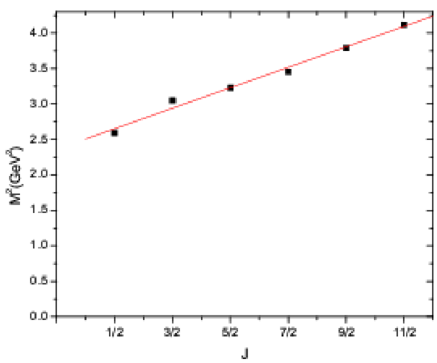

Table-1: Higher angular momentum states of Pentaquark.

Total angular momentum 'J'	Mass(GeV)	Decay width (MeV)
1/2	1.610	8.8
3/2	1.746	9.35
5/2	1.797	12.21
7/2	1.859	14.63
9/2	1.947	16.17
11/2	2.030	17.71

Table-2: Regge slope and string tension of pentaquark(Θ^+)

Particle	Regge slope(GeV^2)	String tension (GeV^{-2})
Θ^+	0.29	0.55

Discussions:

In this present work we have studied the ground state mass as well as the higher angular momentum states of pentaquark(Θ^+) taking into consideration the diquark-diquark-antiquark configuration of pentaquark. It have been found that the mass of pentaquark (for J=1/2 state) we have obtained (1610MeV) is 50 MeV higher than the experimentally predicted value by LEPS Collaboration[2], whereas many theoretical conjecture and also some experiments suggest some other values higher and lower than the LEPS result. The ground state decay width that we have computed(Γ=8.8MeV) is close to the result of DIANA collaboration[10] ($\Gamma<9$MeV). Since LEPS Collaboration reported the existence, several group confirm the state[3,4,5] whereas a number of experiment gives null result. The next generation of experiments have been taken by JLAB,CLAS for further search. It may be pointed out that the rising Regge trajectories are consistent with the experimental findings. Bisht et al.[11] have investigated the Regge Trajectories for hadrons in detail and have observed that most of the trajectory show non-linearity with 'α' varying from 0.314 to 1.581 GeV^2 and the string tension is found to vary from 0.0142 GeV^{-2} to 1.137GeV^{-2} .

References:

[1] D Diakonov et al., Z.Phys. **A359** 305 (1997)
[2] T Nakano et al.,LEPS Collaboration, Phys.Rev.Lett. **91** 012002 (2003)
[3] J Barth et al.,Phys.Lett.**B 572** 127 (2003)
[4] S Chekanov et al.,ZEUS Collaboration, Phys.Lett **B 591** 7 (2004)
[5]V Kubarovsky et al., CLASS Collaboration Phys.Rev. Lett. **92** 032001 (2004); Phys.Rev.Lett. **92** 049902 (2004)
[6] M Iwasaki and F Takagi,Phys.Rev **D 77** 054020 (2008)
[7] A Bhattacharya et al.,Int.J.Theor.Phys. **51** 206 (2011)
[8] A Haug,Theor.Solid State Physics,Vol-**I**(Pergamon Press,Oxford) p-100(1975)
[9] A Bhattacharya et al., Nucl. Phys. **B 142** 13 (2005); B.Chakrabarti et al., Int.J.Mod.Phys. **A 44** 5575 (1989)
[10]V Barmin et al., DIANA Collaboration Phys.At.Nucl. **66** 1715 (2003); Yad.Fiz. **66** 1763 (2003).
[11] S Bisht et al., J Theor.Phys.**7** 299 (2010)