The Roper resonance as a spin partner of the nucleon in a chiral quark-diquark model

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It is known that the basic theory for quarks are the quantum chromodynamics (QCD). Although the hadron physics, the dynamics of mesons and baryons, should be described from QCD, non-perturbative properties of QCD make it difficult and there are still many unsolved problems.

The understanding of the Roper resonance, which has the quantum number $(1/2)^+$ and the mass 1440 MeV, is one of such problems. There were some approaches to describe the Roper resonance[1].

In this brief report, we study the masses of ground state nucleons by using a chiral quark-diquark model. In this quark-diquark picture, we need to introduce two types of diquarks in the point of view of the chiral symmetry; one is Lorentz scalar iso-scalar diquark and the other is axial-vector iso-vector diquark[2]. In this work, we employ the two channel interaction rather than the one channel one, which was suggested by Nagata[3] *et al*,

$$\mathcal{L}_{qD} = G_1 \bar{\chi} D^\dagger D \chi + v(\bar{\chi} D^\dagger \gamma^\mu \gamma^5 D_\mu \chi + \bar{\chi}\gamma^\mu\gamma^5 D_\mu^\dagger D\chi) + G_2 \bar{\chi}\gamma^\mu\gamma^5 D_\mu^\dagger D_\nu \gamma^\nu \gamma^5 \chi \ , \tag{1}$$

where χ, D and $\vec{D}_\mu$ are the constituent quark, scalar- diquark and axial-vector diquark fields, G_1 and G_2 are the coupling constants for the quark and scalar diquark, and for the quark and axial-vector diquark. The coupling constant v causes the mixing between the scalar and axial-vector diquark component in the nucleon wave-functions. Using this two channel interactions, we obtain two nucleon states as bound states of a quark and diquark. After some algebra, one finds

$$\mathcal{L} = \bar{N}_1(\not{p} - M_1)N_1 + \bar{N}_2(\not{p} - M_2)N_2. \tag{2}$$

N_1 is the state in which the scalar diquark component of the nucleons is dominant, on the other hand N_2 is the axial-vector diquark dominant state. The two states transform as

$$N_{1,2} \to h(x) N_{1,2} \ , \tag{3}$$

where $h(x)$ is a local transformation under the group local $SU(2)_V$. Note that the two state transform independently. Fig.1 shows the masses M_1 and M_2 as functions of v for an appropriate parameter set. One found that M_1 is 940 MeV and M_2 is 1440 MeV when $v \sim 25$ GeV^{-1} and the mass difference $M_2 - M_1 = 400 \sim 500$ MeV. The mass difference is basically from the mass difference $M_A - M_S$. In quark diquark models, the masses of two diquarks are related to $M_A - M_S = 2(M_\Delta - M_N) \sim 550$ MeV. If we identify the lowest state with the physical nucleon, then M_2 becomes about 1500 MeV. We suggest that the Roper resonance is the simple three quark state as an spin partner of the ground state nucleon.

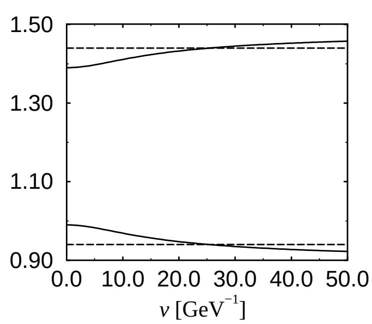

Figure 1: The mixing interaction v dependence of the masses M_1 and M_2. The solid lines represent M_1 (bottom) and M_2 (top). The dashed horizontal lines represent the experimental values of the nucleon (bottom) and Roper resonance (top). The parameter sets, the masses of the quark m_q=390 MeV, scalar diquark M_S=650 MeV and axial-vector diquark M_A=1050 MeV, are used.

References

[1] A. Hosaka and H. Toki, *Quarks, Baryons and Chiral Symmetry*, World Scientific (2001), and references therein.

[2] L. J. Abu-Raddad, A. Hosaka, D. Ebert and H. Toki, Phys. Rev. C **66** (2002) 025206.

[3] K. Nagata, A. Hosaka and L. J. Abu-Raddad, hep-ph/0404312.