Electric properties of the nucleon and Roper resonance in a chiral quark-diquark model

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The Roper resonance $N(1440)$ is of prime interest in low-energy baryon spectroscopy because of its small excitation energy. Recently, we have proposed an alternative description of the Roper resonance as a bound state of a quark and a diquark [1]. Therein correlations between quarks, which are referred to as diquark correlations, play an important role in violating the spin-flavor symmetry.

In diquark models, the nucleon is described by using two types of quark-diquark bound states; one is a bound state of a quark and a scalar diquark and the other is that of a quark and an axial-vector diquark. Two kinds of the nucleon-states can be described as linear combinations of those quark-diquark bound states. In Ref. [1], we investigated the masses of those nucleon-states by using the chiral quark-diquark model. We showed that the those nucleon-states are naturally identified with the nucleon and Roper resonance. Therein the mass difference between the nucleon and Roper resonance is mostly generated by the mass difference between the scalar and axial-vector diquarks, which also cause the mass difference between the nucleon and $\Delta(1232)$. Hence the Roper resonance is not a radial excitation, rather a spin-partner of the nucleon in the sense that it has different diquark components of different spins.

One of the important feature is that the appearance of the Roper resonance results from the violation of the spin-flavor $SU(4)_{SF}$ symmetry. As we have explained, the mass difference between the scalar and axial-vector diquark, which is a major cause of the excitation energy of the Roper resonance, is generated by the same mechanism as the mass difference between the nucleon and Δ. The $N-\Delta$ mass difference is generated by the violation of $SU(4)_{SF}$. Therefore the excitation energy of the Roper is caused by the violation of $SU(4)_{SF}$. Indeed we showed [1] that the wave-function of the Roper resonance corresponds to a forbidden state in $SU(4)_{SF}$ quark models.

Based on Ref. [1], we investigate the electromagnetic form factors of the nucleon and Roper resonance, where we included the intrinsic structure of the diquarks. The results are shown in Table. 1.

Table 1: The charge Q, magnetic moment μ and charge radius $\langle r^2\rangle$ of p, n, p^* and n^*. The values in the bracket are the experimental values. We employ the diquark size 0.5 and 0.8 [fm] for the scalar and axial-vector diquarks.

	p	n	p^*	n^*
Q	1	0	1	0
$\mu(\kappa=0)$	1.5(2.79)	$-0.73(-1.91)$	0.82	-0.172
$\mu(\kappa=2)$	1.6(2.79)	$-0.76(-1.91)$	2.1	-0.61
$\langle r^2\rangle_E^{1/2}$ [fm]	0.75(0.86)	-	0.84	-
$\langle r^2\rangle_E$ [fm^2]	-	$-0.074(-0.12)$	-	0.046

We obtain smaller values of the proton and neutron magnetic moments. It is caused by the fact that the chiral quark-diquark model is based on the NJL model. In the NJL model, Mineo et al. showed that with the inclusion of the pion the experimental values of the magnetic moments can be obtained.

We obtain reasonable values of the charge radii of the proton and neutron, with using the diquark sizes 0.5 and 0.8 [fm] for the scalar and axial-vector diquarks. The charge radii of the Roper resonance are 0.86 [fm] and 0.046 [fm^2] for the proton (p^*) and neutron (n^*) components. The size of n^* is sensitive to the diquark sizes. In conventional picture of the collective excitation of the Roper resonance, the charge radii of the Roper resonance are larger than those of the nucleon both for the proton and neutron component. In the quark-diquark picture, the Roper resonance is a spin-partner of the nucleon with the different spin component. In this case the nucleon and Roper resonance, in zeroth order approximation, have almost the same sizes.

References

[1] K. Nagata and A. Hosaka, J. Phys. G **32** (2006) 777.
[2] H. Mineo, W. Bentz, N. Ishii and K. Yazaki, Nucl. Phys. A **703** (2002) 785.