The Structure of the Nuclear Force in a Chiral Quark-Diquark Model

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One of the main interests of nuclear and hadron physics is to understand the hadron dynamics from the quark level. Especially, the chiral symmetry plays an important role to connect the hadron physics and QCD.

Recently, Abu-Raddad *et al* derived a chiral meson-baryon Lagrangian using the path-integral method of hadronization for the chiral quark-diquark model[1]. One of advantages of the method is to describe mesons and baryons as composites of quarks and diquarks with incorporating the underlying symmetries. Using the chiral and gauge symmetric Lagrangian, physical quantities such as the nucleon mass, magnetic moments and axial couplings were studied. In this report, we make a progress report on the calculation of the Nuclear force [2].

In the quark-diquark model[1], we obtain two types of interactions for nuclear force; one is one-boson exchange potential, the other quark or diquark exchange diagrams (Fig. 1). In

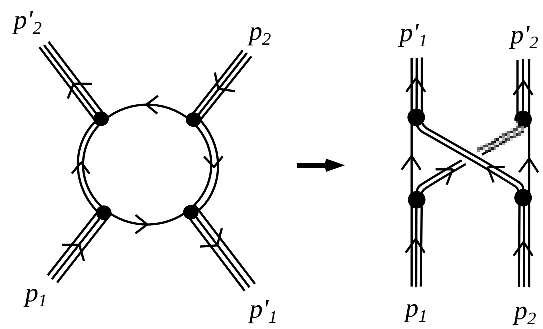

Figure 1: Quark or diquark exchange diagrams. Single, double and triple lines are quarks, diquarks and nucleons. Blobs denote contact interactions. When the flows of arrows of two nucleons in initial (final) states, the quark-diquark loop diagrams (right) becomes the diquark (or quark) exchange diagrams (right).

this work, we neglect axial vector diquarks as a first steps. We deal with this diagrams in the center-of-mass system for the elastic case. We write the amplitude for the diagram in a schematic manner as

$$\mathcal{M}_{NN} = F_S(\vec{P},\vec{q})(\bar{B}B)^2 + F_V(\vec{P},\vec{q})(\bar{B}\gamma_\mu B)^2 + \cdots \ , \tag{1}$$

$$\vec{P} = \vec{p}\,' + \vec{p}, \quad \vec{q} = \vec{p}\,' - \vec{p}. \tag{2}$$

In Eq. (1), we have defined the coefficients F_S and F_V as scalar and vector interactions, respectively. In general the amplitude is highly non-local as the symmetric loop diagram implies.

Now we discuss the functions F_S and F_V in the local approximation(P=0). We define interaction ranges by

$$R_i^2 \equiv -6 \frac{1}{F_i(q^2)} \frac{\partial F_i}{\partial q^2}\bigg|_{q^2\to 0}, \tag{3}$$

where i denotes S or V. We plot the ranges as the functions of the nucleon size in Fig. 2

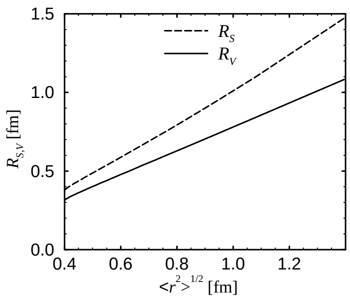

Figure 2: The relation between interaction ranges and nucleon sizes. The horizontal line is the nucleon mean square radii.

We obtain the result that R_S and R_V are 1.0 and 1.2 times larger than the nucleon size. This interactions switch on at such short ranges where two nucleons have overlaps. Interaction strengths and masses are extracted by the following fit

$$|F_i(0,0)| = \frac{g_i^2}{m_i^2}. \tag{4}$$

Then we plot masses and strengths as the functions of the nucleon size in Fig. 3

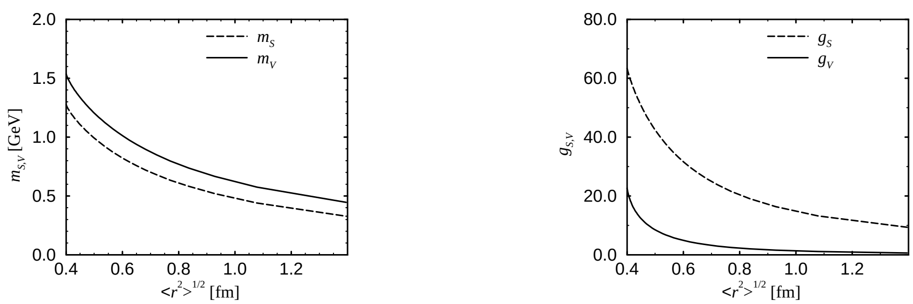

Figure 3: The relation between interaction masses and nucleon sizes (left panel) and interaction strengths and nucleon sizes (right panel).

If we take the nucleon size 0.8 fm, which is considered as the bare nucleon size, then the masses are 0.65 GeV for scalar and 0.8 GeV for vector types. These results reasonably agree with the phenomenological masses of σ and ω exchange. On the other hand, for interaction strengths, g_S and g_V becomes 23 and 4. These may be compared with the empirical values $g_S \sim 10$ and $g_V \sim 14$. In the present calculation, the attractive scalar interaction becomes stronger than the repulsive vector one. Since we neglect axial-vector diquarks, strengths are strongly affected by the inclusion of both of two diquarks. On the other hand, interaction ranges and masses are not affected much. We expect that the inclusion of axial-vector diquarks contributes to the vector type repulsion. Now, we progress our work to include axial-vector diquarks.

References

[1] L. J. Abu-Raddad, A. Hosaka, D. Ebert, and H. Toki, Phys. Rev. **C66**, 025206(2002).

[2] K. Nagata and A. Hosaka, hep-ph/0312161, Prog. Theor. Phys, to be published.