The chiral sigma model with Dirac sea in nuclear matter and finite nuclei

S. Tamenaga, A. Haga, Y. Ogawa and H. Toki
Research Center for Nuclear Physics (RCNP), Ibaraki, Osaka 567-0047, Japan

The chiral sigma model provides good saturation property for nuclear matter and produces the magic number 28 by pionic correlation in finite nuclei[1]. However, the magic number appears at N=18 instead of N=20 because the incompressibility is too large (K=650[MeV]) in this model. Here, we study the effect of the Dirac sea in the chiral sigma model for nuclear structure. The chiral sigma model is a renormalizable model, and it is important to include the Dirac sea in this model. In the non-chiral model (Walecka model) it is known that the contribution of the Dirac sea is about 10% to 20% and reduces the incompressibility. We try to include the Dirac sea within relativistic Hartree approximation in the chiral sigma model.

We take the relativistic Hartree approximation (RHA) for the nucleon propagator. The nucleon propagator with the RHA has the four divergence diagrams. We must remove these divergences by adding the counter terms. Because the chiral sigma model has the chiral symmetry, the counter terms need to respect the symmetry[2]. We obtain the counter terms with the chiral symmetry, but the counter terms remain arbitrary and the total effective potential has the instability. We suppose the new chiral symmetric renormalization (NCSR) which includes the higher-order counter terms of sigma and pi mesons.

$$\delta\mathcal{L}_{CTC}^{NCSR} = aM^2(\sigma^2+\pi^2) + b(\sigma^2+\pi^2)^2 + \frac{c}{M^2}(\sigma^2+\pi^2)^3 + \frac{d}{M^4}(\sigma^2+\pi^2)^4. \tag{1}$$

Using these counter terms, we take the adequate renormalization conditions. With this renormalization, we can remove both arbitrariness and divergence. As a result, the total effective potential becomes stable. We can include the Dirac sea in the chiral sigma model.

We purpose the new chiral symmetric renormalization. This renormalization scheme has the higher-order terms of sigma and pi mesons. We need these terms to renormalize completely the non-linear sigma meson interactions. It is known that the incompressibility decreases around 300[MeV] in the chiral sigma model with higher-order terms[3]. So we reconstruct the chiral sigma model with higher-order terms to make nuclei stable in infinite and finite systems. In nuclear matter this model provides the good saturation properties and good incompressibility. By adding the higher-order terms the incompressibility reduces around experimental value and in finite nuclei s-state locates at the resonable plase as we expect. However the effective mass 0.85M is quite a large in the chiral sigma model. Therefore it is impossible to produce the magic number 20 due to the large effective mass despite of good incompressibility. We consider the charge- and parity-projected Hartree calculation and the effect of tensor couplings for omega and rho mesons in order to solve the problem at N=20.

References

[1] Y. Ogawa, H. Toki, S. Tamenaga, H. Shen, A. Hosaka, S. Sugimoto, K. Ikeda, Prog. Theor. Phys. **111** (2004), 75.

[2] T. Matsui and B. D. Serot, Ann. of Phys. **144** (1982), 107.

[3] P. K. Sahu and A. Ohnishi, Prog. Theor. Phys. **104** (2000), 1163.