The effect of renormalization in the massless sigma model for finite nuclei

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We study the effect of one-loop corrections from nucleon together with those from boson in the massless linear sigma model, where we perform the Coleman-Weinberg (CW) renormalization procedure [1]. This renormalization procedure has a mechanism of spontaneous symmetry breaking due to radiative corrections. We apply this CW scheme to the system of fermions and bosons with chiral symmetry where the negative-mass term of bosons does not exist. Spontaneous chiral symmetry breaking is derived from the contribution of fermion and boson loops which generates the masses of nucleon and scalar meson dynamically. We obtain a stable renormalized effective potential in the chiral model for the first time [2].

We apply the massless linear sigma model to finite nuclei. Since the repulsive force is necessary to describe the nuclei, we introduce the omega meson, whose mass is also generated dynamically due to the spontaneous chiral symmetry breaking in the massless sigma model [3]. The renormalized effective potential is given by

$$V_{\rm all}^{R} = \frac{1}{4}\lambda\left(\phi^2+\boldsymbol{\pi}^2\right)^2 + \frac{\gamma-1}{8\pi^2}g_\sigma^4(\phi^2+\boldsymbol{\pi}^2)^2\left[\ln\left(\frac{\phi^2+\boldsymbol{\pi}^2}{m^2}\right)-\frac{25}{6}\right]-\varepsilon\phi, \quad \gamma=\left|\frac{V_B^R}{V_F^R}\right| = \frac{3\left(4\lambda^2+\widetilde{g_\omega}^4\right)}{8g_\sigma^4},$$

where γ is defined as the absolute ratio of boson loop potential to nucleon loop potential and m is renormalization scale in order to avoid the logarithmic singularity [1]. Almost all of parameters are determined by the spontaneous chiral symmetry breaking and experimental values. We can obtain the stable effective potential in the chiral model as shown in the left-hand side of Fig. 1. The total loop potential is a reasonable magnitude due to cancellation between the large positive potential from the nucleon loop and the large negative one from the boson loop ($\gamma > 1$). Furthermore its sign is negative and as a result the total renormalized loop potential is to be an important role of the spontaneous chiral symmetry breaking as well as the negative-mass term of the linear sigma model. The right-hand side of Fig. 1 shows the baryon density distribution in ^{16}O with the massless chiral sigma model. The difference between the chiral sigma model and the massless chiral sigma model is the loop corrections for potential and wave function. In particular the renormalization of wave function is important for the finite system with the surface [4]. The baryon density distribution becomes more smooth in spite of the large incompressibility. The effect of Dirac sea changes the density distribution in the interior region and surface region. When the model has the large changes for the distribution, the effect of the wave function renormalization appears drastically in the central region.

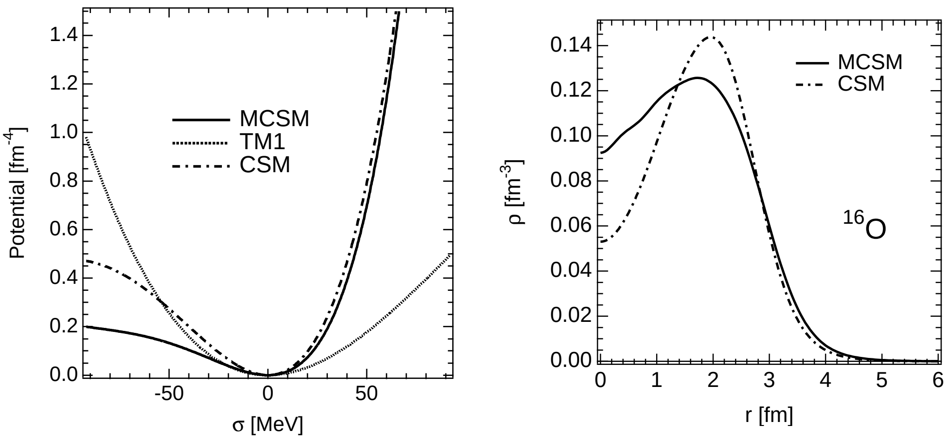

Figure 1: **The effective potential as a function of sigma field, and the baryon density distribution in ^{16}O with the chiral sigma model (CSM) and with the massless chiral sigma model (MCSM).**

References

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