The effect of mass asymmetry in infinite nuclear matter

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Introduction

Due to the availability of advance lab facilities, the formation of exotic nuclei more towards the drip-line are possible. The values of proton and neutron number difference are increase in drip-line region. Thus, asymmetry in the nuclear system play an important role in this region. For producing the observed properties like binding energy, charge radius and quadrupole deformation parameter of these drip-line nuclei, one should look for such model which cooperate with these asymmetry of the system. In the present scenario, uncertainty in neutron skin thickness is large. As a proposal of PREX-II to measure the neutron skin upto 1% accuracy, if we able to measure the skin data accurately then we can predict the symmetry energy precisely because both quantities related to each other. Recently, it is realized that the effective field theory motivated relativistic mean field (E-RMF) model of Furnstahl et al. [1], the coupling of $\delta-$meson is not taken into account. Also the effect of $\rho-$ and $\omega-$ meson cross coupling is neglected. The importance of $\delta-$ meson [2] and the cross coupling of ω and $\rho-$mesons [3] can not be neglected while studying the nuclear and neutron matter properties in the relativistic mean field models. The effect of cross-coupling of $\omega-$ and $\rho-$ meson in nuclear matter system is reported by us in Ref. [4]. Here, our aim is to see the effect of $\delta-$meson, scalar-isovector on the pressure, energy density and symmetry energy at full range of baryonic density. The G2 Lagrangian with cross coupling term and contribution of $\delta-$meson is given by

$$\begin{aligned} \mathcal{L} &= \mathcal{L}_{G2+\Lambda_v} + \mathcal{L}_\delta \qquad (1) \\ \mathcal{L}_\delta &= \frac{1}{2}\left(\partial_\mu \overrightarrow{\delta}.\partial^\mu \overrightarrow{\delta} - m_\delta^2 \delta^2\right) \end{aligned}$$

The details of the Lagrangian $\mathcal{L}_{G2+\Lambda_v}$ can be found in Ref. [4]. In the Lagrangian (Eqn. 1), we have taken one more degree of freedom by introducing the $\delta-$meson. This meson arises due to the asymmetry in the mass of neutron and proton. This mass difference play very important role in drip-line nuclei. We can solve the Euler-Lagrangian equation to find the equation of motion for the Fermions and $\sigma-, \omega-, \rho-$ and $\delta-$ mesons. By using these equations and energy momentum tensor, we able to find pressure and energy density. In Fig. 1(a), we have given the binding energy per nucleon at full range of baryonic density at different value of $\delta-$ meson coupling constant. The zoom part of energy density at low density is shown in Fig. 1(c). In the Fig. 1(b), pressure density plotted. We compared calculated results with the experimental and theoretical data. As shown in the figure 1(a), binding energy per nucleon decreases at low baryonic density and at higher density increases with g_δ. In figure 1(b), pressure density increases with g_δ values. The pressure density at various g_δ coupling constant lying in the experimental data (stiff). It is also seen that the variation in the energy and pressure density are directly affect the mass and radius of the neutron star.

The symmetry energy of the system is defined as the energy difference of pure neutron matter to symmetry nuclear matter. Analytical expression of symmetry energy can be written in separate contribution of kinetic part, $\rho-$ meson and $\delta-$ meson as:

$$E_{sym}(\rho) = E_{sym}^{kin}(\rho) + E_{sym}^{\rho}(\rho) + E_{sym}^{\delta}(\rho)$$

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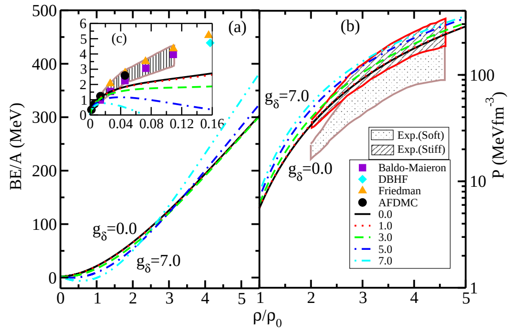
FIG. 1: Energy and pressure density with different value of coupling constant along with the baryonic density



$$E_{sym}(\rho) = \frac{k_F^2}{6E_F^*} + \frac{g_\rho^2 \rho}{8m_\rho^{*2}} - \frac{1}{2}\rho \frac{g_\delta^2}{m_\delta^2}\left(\frac{m^*}{E_F}\right)^2,$$

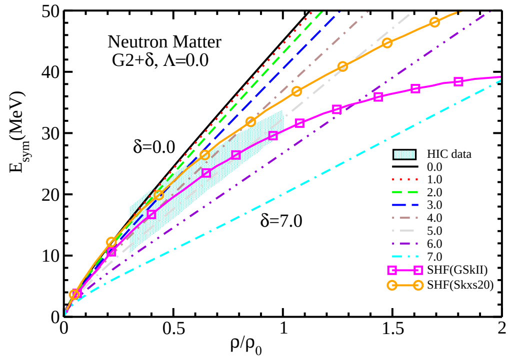
where the effective energy $E_F^* = \sqrt{(k_F^2 + m^{*2})}$, k_F is the Fermi momentum and the effective mass $m^* = m - g_s\phi_0$. The effective mass of the $\rho-$meson modified because of nonlinear coupling $(\rho-\omega)$ interaction and is given by

$$m_\rho^{*2} = \left(1 + \eta_\rho \frac{g_\sigma \sigma}{m_B}\right) m_\rho^2 + 2g_\rho^2(\Lambda_v g_v^2 \omega_0^2),$$

where m_ρ is the mass of the ρ-meson. It is noted that the non-linear isoscalar-isovector coupling (Λ_v) modified the density dependent of E_{sym} without affecting the saturation properties of the symmetry nuclear matter (SNM). In E-RMF model, the symmetric nuclear matter saturates at a Fermi momentum of $k_F = 1.00\ fm^{-1}$ with $E \sim 16.0$ MeV, compressibility of $K_0 = 215$ MeV and symmetry energy of E_{sym}= 36.42 MeV.

We have plotted the symmetry energy of nuclear matter with different value of $\delta-$ meson coupling constant along the baryonic density ρ in Fig. 2. Here, we change the g_δ value from 0.00 to 7.0 which is within the naturalness limit of the coupling constant. We compare our results with the HIC data [5] and some non-relativistic models [6, 7]. From our analysis, we can say that $\delta-$ meson coupling is very important in softening the symmetry energy.

FIG. 2: Effect of coupling parameter of $\delta-$meson with nucleon on symmetry energy E_{sym} with baryonic density ρ.



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