Symmetry energy parameters in pion-dressed asymmetric nuclear matter

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Introduction

Nuclear symmetry energy $\varepsilon_{\mathrm{sym}}$ and its parameters, such as, the density slope *L* and curvature K_{sym} play very important roles in nuclear physics and astrophysics. Their role in studying observables like neutron skin thickness in heavy nuclei on the one hand, and gravitational binding energy, curvature, core-crust transition density of neutron stars, on the other, have been subjects of intense experimental, observational and theoretical scrutiny during the last decade [1,2]. However, much deliberation still continues on understanding the density dependence of $\varepsilon_{\mathrm{sym}}$ at super- and sub-saturation densities and constraining of *L* and K_{sym} at both of these density regimes. It has been shown earlier by us [3] that the nuclear matter equation of state (EoS) can be adequately modeled by including nucleon-nucleon (*N*-*N*) interactions through ω-mesons (short-range repulsion), *s*-wave pion-pairs (for medium and long-range attraction) and ρ-mesons (for isospin-dependent interactions) in the non-relativistic limit. Here we present the calculations of the symmetry energy and its parameters ($\varepsilon_{\mathrm{sym}}$, *L* and K_{sym}) in our model of "pion-dressed" asymmetric nuclear matter.

The Model

In the non-relativistic limit, the Hamiltonian of the pion-nucleon system in the coordinate space can be written as

$H(x) = H_N(x) + H_\pi(x) + H_{int}(x)$ … (1)

with the terms on the right hand-side of the equation, representing respectively the free single nucleon, free pion-pair and the nucleon-meson interaction parts of the Hamiltonian. Following the procedure elaborated in [3], the energy density ε of the cold asymmetric nuclear matter in our model is given by

$\varepsilon = (h_N + h_\pi + h_\omega + h_\rho)$ ………………(2)

where the terms on the right represent the free nucleon kinetic energy, the pion-pair kinetic and interaction energies, the ω-meson and ρ–meson contributions respectively. This energy density ε is parameterized below as function of nuclear density ρ and asymmetry parameter y. The model contains four self-consistently fitted parameters, namely, three interaction-strength parameters: the π-π short-range repulsion strength and range parameters: a and r_π and the ω- and ρ-interaction strength parameters: G_ω and G_ρ. The four self-consistently fitted parameters are obtained by fixing, at nuclear saturation density $\rho_0 = 0.15$ fm^{-3}, four nuclear matter properties, namely the binding energy per nucleon at -16 MeV, pressure at zero, compressibility at 260 MeV and symmetry energy at 31 MeV.

Symmetry energy and its parameters

The energy density $\varepsilon(\rho, y)$ of asymmetric nuclear matter can be written as

$\varepsilon(\rho, y) = \varepsilon_0(\rho) + \varepsilon_{\mathrm{sym}}(\rho)\, y^2 + O(y^4)$..(3),

where $\rho = (\rho_n + \rho_p)$ is the density of the nuclear matter, the sum of neutron and proton densities (ρ_n and ρ_p respectively), and the isospin asymmetry parameter $y = (\rho_n - \rho_p)/\rho$. The first term $\varepsilon_0(\rho)$ in eq. (3) is the energy density of symmetric nuclear matter (SNM; with asymmetry y = 0). The second term, namely, the Symmetry energy $\varepsilon_{sym}(\rho)$ is further expanded in terms of bulk nuclear matter properties defined at the nuclear saturation density ρ_0 and the small excursions thereof in terms of $\delta = \frac{(\rho-\rho_0)}{\rho_0}$

$$\varepsilon_{sym}(\rho) = \varepsilon_{sym}(\rho_0) + \frac{L}{3}\,\delta + \frac{K_{sym}}{18}\delta^2 + O(\delta^3) \qquad \text{........(4)}$$

On the right hand side of eq.(4) from left to right, we have $\varepsilon_{sym}(\rho_0)$, the symmetry energy at saturation density, the density slope $L = 3\,\rho_0 \frac{\partial \varepsilon_{sym}(\rho)}{\partial \rho}|_{\rho=\rho_0}$ and the curvature parameter $K_{sym} = 9\,\rho_0^2 \frac{\partial^2}{\partial \rho^2}\varepsilon_{sym}(\rho)|_{\rho=\rho_0}$. The later two properties represent the density dependence of the symmetry energy around normal nuclear saturation density.

Results & Discussion

We have carried out the calculations of these three bulk properties in our model of pion-pair dressed nuclear matter and have compared the results with those obtained from standard models using interactions like the NL3, Quark-Meson Coupling (QMC) and Typel & Wolter (TW) [4]. We observe that the results produced by our model compare very well with these models although the degree of complexity of our model is much lower. These results are presented in the Fig. 1 below.

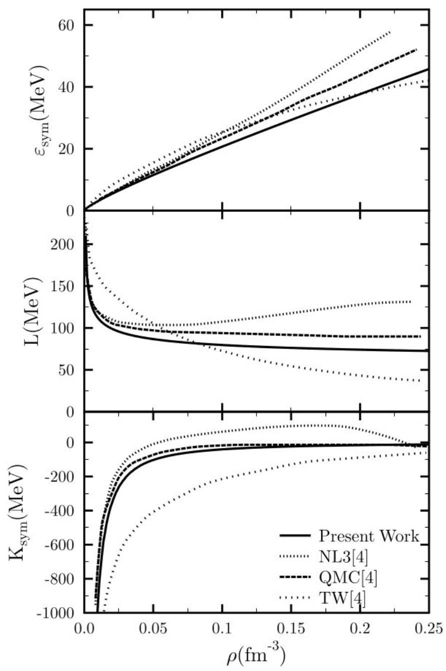

Fig.1: Top to Bottom: The Symmetry Energy ε(sym), Density slope parameter L and the curvature parameter K(sym) as functions of nuclear density. The solid curves represent the present work, and other curves are based on the data retrieved from [4].

References

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