Abstract

I. INTRODUCTION

II. FORMALISM

A. Generalized Uncertainty Principle

B. Impact of Generalized Uncertainty Principle on Nuclear Matter

Nuclear matter and finite nuclei can be describe by RMF models. The Lagrangian density of RMF models is defined as [1]:

$$\mathcal{L} = \mathcal{L}_N + \mathcal{L}_M + \mathcal{L}_{int}, \tag{1}$$

where the contribution of free nucleons in finite nuclei is

$$\mathcal{L}_N = \sum_N \overline{\psi}_N \left(i\gamma_\mu \partial^\mu - M_N\right) \psi_N, \tag{2}$$

with the sum taken over all nucleons N in nuclei. Nuclear matter is thermodynamic limit of finite nuclei where in this limit, $N \to \infty$, volume $\to \infty$ but the densities are finite. Therefore, in this limit, we have $\sum_N \to \int d^3k$. Note that the interactions between nucleons are mediated by the exchange of scalar-isoscalar σ, vector-isosaclar ω, and vector-isovector ρ, mesons, respectively. Furthermore, the corresponding mesons have self-interactions. The interaction Largrange density for finite nuclei taken following form [2]:

$$\begin{aligned}
\mathcal{L}_{int} = & \sum_N g_\sigma \sigma \overline{\psi}_N \psi_N - \sum_N g_\omega V_\mu \overline{\psi}_N \gamma^\mu \psi_N \\
& - \sum_N g_\rho \mathbf{b}_\mu \cdot \overline{\psi}_N \gamma^\mu \boldsymbol{\tau} \psi_N - \frac{1}{3} b_2 \sigma^3 - \frac{1}{4} b_3 \sigma^4 \\
& + \frac{1}{4} c_3 \left(V_\mu V^\mu\right)^2 \\
& + d_2 \sigma \left(V_\mu V^\mu\right) + f_2 \sigma \left(\mathbf{b}^\mu \cdot \mathbf{b}_\mu\right) + \frac{1}{2} d_3 \sigma^2 \left(V_\mu V^\mu\right).
\end{aligned} \tag{3}$$

For free mesons, the Lagrangian density is as follows

$$\mathcal{L}_M = \mathcal{L}_\sigma + \mathcal{L}_\omega + \mathcal{L}_\rho, \tag{4}$$

where the explicit form of each term is

$$\mathcal{L}_\sigma = \frac{1}{2}\left(\partial_\mu\sigma\partial^\mu\sigma - m_\sigma^2\sigma\right), \tag{5}$$

$$\mathcal{L}_\omega = -\frac{1}{2}\left(\frac{1}{2}\omega_{\mu\nu}\omega^{\mu\nu} - m_\omega^2 V_\mu V^\mu\right), \tag{6}$$

$$\mathcal{L}_\rho = -\frac{1}{2}\left(\frac{1}{2}\boldsymbol{\rho}_{\mu\nu}\cdot\boldsymbol{\rho}^{\mu\nu} - m_\rho^2\mathbf{b}_\mu\cdot\mathbf{b}^\mu\right). \tag{7}$$

Within the mean field approximation, σ, $V^\mu(V_0, 0)$, and $\mathbf{b}^\mu(\mathbf{b}_0, 0)$ are σ, ω, and ρ fields, respectively, and $\omega_{\mu\nu}$ and $\boldsymbol{\rho}_{\mu\nu}$ are the anti-symmetric tensor fields of ω and ρ meson. Note that for the case NS matter, the β-stability condition should be satisfied. Therefore, the electrons and muons (leptons) should be exist in the NS matter. The contribution of non-interacting leptons to the total Lagrangian density is as follows

$$\mathcal{L}_L = \sum_L \overline{\psi}_L\left(i\gamma_\mu\partial_\mu - m_L\right)\psi_L. \tag{8}$$

In the following we will discuss the impact of the phase space deformation due to GUP on nuclear matter and NS. However, due to the leptons contribution on EOS of a NS is not significant, to simplify the problem, we assume that the phase space of leptons do not deform due to GUP; therefore, the expression for the zero component of the vector (lepton number) density and the energy density and pressure derived from Eq. (8) take the standard expressions [3]. Using the RMF calculation procedure [3], we obtained the modified nucleon number densities for matter due to phase space deformation caused by GUP as

$$\rho_N^* = \frac{2}{(2\pi)^3}\int_0^{k_f^N}\frac{d^3k}{(1+\beta k^2)^2}, \qquad N = p, n. \tag{9}$$

Similarly, scalar number densities for protons and neutrons are expressed as follows:

$$\rho_{s\ N}^* = \frac{2}{(2\pi)^3}\int_0^{k_f^N}\frac{M_N^*}{\sqrt{\frac{1}{\beta}\left(\tan^{-1}[\sqrt{\beta}k]\right)^2 + {M_N^*}^2}}\frac{d^3k}{(1+\beta k^2)^2}, \tag{10}$$

where $M_N^* = M_N + g_\sigma\sigma$. The total energy density can be calculated as follows:

$$\epsilon = \sum_{N=n,p}\epsilon_N^* + g_\omega(\rho_p^* + \rho_n^*) + \frac{1}{2}g_\rho(\rho_p^* - \rho_n^*) + U + \sum_{L=e,\mu}\epsilon_L, \tag{11}$$

where the meson contribution is as follows:

$$\begin{aligned} U = {} & \frac{1}{2}m_s^2\sigma^2 - \frac{1}{2}m_\omega^2 V_0^2 + \frac{1}{2}m_\rho^2 b_0^2 \\ & + \frac{1}{3}b_2\sigma^3 + \frac{1}{4}b_3\sigma^4 - \frac{1}{4}c_1 V_0^4 \\ & - d_2\sigma V_0^2 - f_2\sigma b_0^2 - \frac{1}{2}d_3\sigma^2 V_0^2, \end{aligned} \tag{12}$$

and the nucleon contributions are as follows:

$$\epsilon^*_N = \frac{2}{(2\pi)^3}\int_0^{k_f^N} \sqrt{\frac{1}{\beta}\left(\tan^{-1}[\sqrt{\beta}k]\right)^2 + {M^*_N}^2}\frac{d^3k}{(1+\beta k^2)^2}. \tag{13}$$

The explicit expressions for P_r is

$$P_r = \sum_{M=n,p}\frac{1}{3}{P^*_r}^N - U + \sum_{L=e,\mu}\frac{1}{3}P_L, \tag{14}$$

with[?]

$${P^*_r}^N = \frac{2}{(2\pi)^3}\int_0^{k_f^N} \frac{k^2}{\sqrt{\frac{1}{\beta}\left(\tan^{-1}[\sqrt{\beta}k]\right)^2 + {M^*_N}^2}}\frac{d^3k}{(1+\beta k^2)^2} \tag{15}$$

C. Neutron Stars Model

III. RESULTS AND DISCUSSIONS

IV. CONCLUSIONS

ACKNOWLEDGMENT

[1] A. Sulaksono and B. K. Agrawal, *Nucl. Phys. A* **895**, 44 (2016).

[2] C. J. Horowitz and J. Piekarewicz, *Phys. Rev. Lett.* **86**, 5647 (2001).

[3] N. K. Glendenning, *Compact Stars, Nuclear Physics, Particle Physics, and General Relativity* (Springer, New York, 1997).