Nuclear matter properties at finite temperature within Extended relativistic mean field model

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I. INTRODUCTION

The properties of cold nuclear matter can be studied by imposing the constraints of bulk nuclear matter properties at the saturation density, \( \rho_0 = 0.16 fm^{-3} \); recent experimental limits establish the following values: symmetry energy \( E_{\text{sym}} = 30 \pm 5 MeV \) \cite{5}, slope of symmetry energy \( L = 88 \pm 25 MeV \) \cite{2}, and incompressibility coefficient \( K = 240 \pm 20 MeV \) \cite{3}. It is considered theoretically that the density dependence of symmetry energy can be represented by \( E_{\text{sym}}(\rho_0) = 31.6(\rho/\rho_0)^{\gamma} \) with \( \gamma=0.69-1.05 \) at subnormal density \cite{2}, which led to the extraction of a value for the slope of the nuclear symmetry energy of \( L = 88 \pm 25 MeV \). This symmetry energy value is also in harmony with the symmetry energy obtained from the isoscaling analysis of the isotope ratio in intermediate energy heavy-ion collisions \cite{4}. The Lagrangian density for the extended relativistic mean field (ERMF) model can be written as \( \mathcal{L} = \mathcal{L}_{BM} + \mathcal{L}_s + \mathcal{L}_\omega + \mathcal{L}_p + \mathcal{L}_{\omega\rho} \) \cite{5}. The Lagrangian terms and the Euler-Lagrangian equations for ground state expectation values of the meson fields are same as in \cite{5}. At finite temperatures the baryon vector density \( \rho_B \), scalar density \( \rho_s \), and charge density \( \rho_p \) are,

\[
\rho_B = \frac{\gamma}{(2\pi)^3} \int_0^{k_B} d^3k \left( n_i - \bar{n}_i \right), \rho_s = \frac{\gamma}{(2\pi)^3} \int_0^{k_B} d^3k \frac{M_B^*}{\sqrt{k^2 + M_B^*}} \left( n_i + \bar{n}_i \right), \rho_p = \langle \Psi_B \gamma^{0 \ 1 \ 2 \ 3} \Psi_B \rangle \left( n_i + \bar{n}_i \right),
\]

where, \( \gamma \) is the spin-isospin degeneracy. The \( M_B^* = M_B - g_B \sigma - g_{B*} \sigma^* \) is the baryon effective mass, \( k_B \) is its Fermi momentum and \( \tau_B \) denotes the isospin projections of baryon B. The thermal distribution function in these expression are defined by

\[
\frac{1}{e^{E/E_{\text{mol}} + 1}} - \frac{1}{e^{E/E_{\text{mol}} + 1}}
\]

where \( E_i = \sqrt{k^2 + M_i^2} \) and \( \mu_i^* = \mu - g_i N \omega \).

The symmetry energy \( E_{\text{sym}} \), the slope \( L \), and incompressibility \( K \) can be evaluated as

\[
E_{\text{sym}}(\rho) = \frac{1}{2} \frac{d^2E(\rho, \delta)}{d\delta^2} \bigg|_{\delta=0}, L = 3\rho_0 \frac{dE_{\text{sym}}(\rho)}{d\rho} \bigg|_{\rho=\rho_0}, K = 9\rho_0^2 \frac{d^2E_{\text{sym}}(\rho)}{d\rho^2} \bigg|_{\rho=\rho_0},
\]

where \( \rho_0 \) is the saturation density, \( E(\rho, \delta) \) is the energy per nucleons at a given density \( \rho \) and asymmetry parameter \( \delta = \frac{(\rho_d - \rho_p)}{\rho_0} \) and \( E_0(\rho) = E(\rho, \delta = 0) \) is the energy per nucleon for symmetric matter.

II. RESULT AND DISCUSSIONS

We study the properties of symmetric and asymmetric nuclear matter for BSR1-BSR21 parametrizations of the ERMF model at temperatures of 0 and 30 MeV \cite{5, 6}. The nuclear symmetry energy is a fundamental input to understand the exotic nuclei, heavy-ion collision data and many other astrophysical phenomena. Therefore, recently many efforts have been made to extract the information on the magnitude and density dependence of symmetry energy of nuclear matter. In Fig. 1 we present the values of \( E_{\text{sym}}(\rho_0) \) at saturation density as a function of \( \Delta r \) the neutron skin thickness in the \( ^{208}\text{Pb} \) nucleus for various model parametrizations. The squares represent the parametrizations BSR1-BSR7 having \( \omega \)-meson self coupling parameter \( \zeta = 0.00 \), the triangles represent the parametrizations BSR8-BSR14 having \( \zeta = 0.03 \), and the circles represent the parametrizations BSR15-BSR21 having \( \zeta = 0.06 \). The values of \( \Delta r \) varies from

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0.16 to 0.28 fm in steps of 0.02 fm. It is observed that at saturation density symmetry energy changed beyond \( T \geq 20 \) MeV by a very small amount with respect to \( T = 0 \) MeV for the all parametrizations of the ERMF model. In Fig. 2, in the lower panel we present the slope of symmetry energy and in the upper panel we present the incompressibility coefficient for nuclear matter as a function of \( \Delta r \). The incompressibility coefficient for symmetric nuclear matter decreases up to a maximum of 12.5% at temperature \( T = 30 \) MeV with respect to \( T = 0 \) MeV for the BSR1 parametrization, which provides stiffer EOS with neutron star gravitational mass \( M = 2.5M_\odot \) [5]. The variation in the values of \( K \) is a minimum of 7% for the BSR21 parametrization, which provides the softest EOS with neutron star gravitational mass \( M = 1.74M_\odot \) [5]. It is found that variation in the values of symmetry energy becomes reasonably large as the value of neutron skin thickness increases, where as the value for the slope of symmetry energy remains unaffected at temperature \( T = 0 \) and 30 MeV. The value of incompressibility coefficient is sensitive to \( \zeta \) and indicates the change at \( T = 30 \) MeV.

**References**