Density and temperature dependence of symmetry energy and incompressibility within relativistic mean field model

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Introduction

The behavior of nuclear matter at high density and finite temperature is one of the challenging problems in contemporary modern nuclear physics. Efforts are being made using various models to understand the symmetry energy and incomressibility. The density dependence of symmetry energy influences the nature and stability of the phases of compact star (CS), the feasibility of direct URCA cooling process within interior of CS, the composition and thickness of inner crust of CS, the frequency of its crustal vibrations and radius of CS. Many correlations have been studied to understand the density behavior of symmetry energy . However, the fundamental origin of this apparent evolution of symmetry energy is still not clear, and it is particularly important to understand to what degree its evolution depends on the density and /or temperature of nuclear matter. Apart from symmetry energy, the nuclear matter equation of state (EOS) also depend upon the values of incompressibility [1]. In recent times the giant monopole resonance has made it possible to find the value of incompressibility [2]. Accurate knowledge of the density and temperature dependence of symmetry energy and incompressibility can lead to plausible EOS of the asymmetric matter. The Lagrangian density for the ERMF model describes the interactions from self and mixed terms for the scalar-isoscalar (σ), vector-isoscalar (ω), and vector-isovector (ρ) mesons [3]. For completeness the Lagrangian density for the extended ERMF model can be written as,

$$\mathcal{L} = \mathcal{L}_{\mathcal{BM}} + \mathcal{L}_\sigma + \mathcal{L}_\omega + \mathcal{L}_\rho + \mathcal{L}_{\sigma\omega\rho}. \qquad (1)$$

The description of the various terms of the Lagrangian and the Euler-Lagrangian equations for ground state expectation values of the meson fields are provided in Ref. [3, 4]. The symmetry energy E_{sym} and incompressibility K can be evaluated as

$$E_{sym}(\rho) = \frac{1}{2}\frac{d^2E(\rho,\delta)}{d\delta^2}\bigg|_{\delta=0} \qquad (2)$$

$$K = 9\rho_0^2\frac{d^2E_0(\rho)}{d\rho^2}\bigg|_{\rho=\rho_0} \qquad (3)$$

where ρ_0 is the saturation density, $E(\rho.\delta)$ is the energy per nucleons at a given density ρ and asymmetry parameter $\delta = (\frac{\rho_n-\rho_p}{\rho_n+\rho_p})$ and $E_0(\rho) = E(\rho, \delta = 0)$ is the energy per nucleon for symmetric matter. In the present work we have employed parametrization sets of the ERMF model, BSR1 - BSR21 [3, 5], generated by varying the ω meson self-coupling ζ and neutron skin thickness Δr for the ^{208}Pb nucleus. These parametrizations have been obtained so as to reproduce the nuclear structure properties in finite nuclei and bulk properties of nuclear matter at nuclear saturation density [3]. The parametrization sets BSR1-BSR7 correspond to the value of ω meson self-coupling $\zeta = 0.0$, sets BSR8-BSR14 correspond to $\zeta = 0.03$, and sets BSR15-BSR21 correspond to $\zeta = 0.06$, and for each parametrization set the value of neutron skin thickness of ^{208}Pb varies from 0.16 to 0.28 fm in intervals of 0.02 fm. In Fig. 1 we compare the density dependence of the incompressibility coefficient

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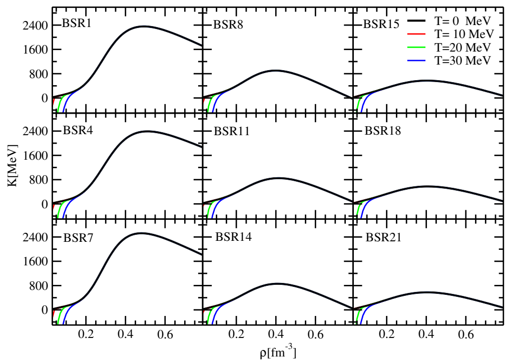

FIG. 1: (Color online) The density dependence of the incompressibility coefficient is plotted at temperatures of 0, 10, 20, and 30 MeV for various parametrizations.

at finite temperatures for various parametrizations with cold nuclear matter. It is found that the incompressibility coefficient at finite temperature has shown change below neutron saturation densities $\rho_0 = 0.15$ fm^{-3} only, and K gain maximum value in the range of densities of ~ 0.4 to $0.5 fm^{-3}$. The maximum value is very sensitive to ζ, remains almost same on varying Δr, and decreases with increasing temperature. We study the density dependence of symmetry energy at low densities. It was found that symmetry energy is very sensitive to temperatures at lower density ($\sim 0 - 0.1 fm^{-3}$) but independent of temperature at higher densities. We also studied variation for symmetry energy with change in ζ and Δr parameter. It is found that the temperature dependence of symmetry energy is more sensitive to the small values of Δr. Although the symmetry energy decreases with rise in temperature but at very low density ($\sim 0.02 fm^{-3}$) the trend reverses. In Fig.2 the comparison of the theoretical results of symmetry energy compiled with BSR11 parametrization with NL3 and TM1 parametrization of relativistic mean field theory at temperature of 0 MeV and 30 MeV as a function of density. It can be visualized from the figure that except incompress-

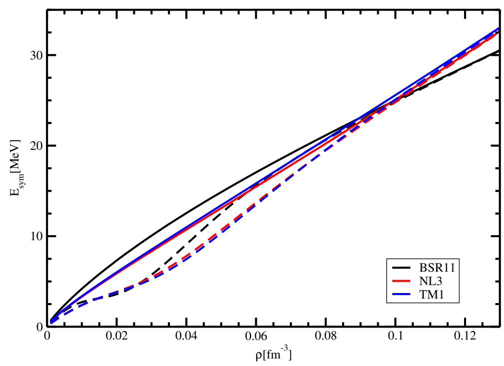

FIG. 2: (Color online)The comparison of the theoretical results of symmetry energy (E_{sym}) compiled with BSR11 parametrization with NL3 and TM1 parametrization of relativistic mean field theory at temperature of 0 MeV and 30 MeV as a function of density. The solid and dashed black line represent BSR11 parametrization, red line represent NL3 parametrization, and blue line represent TM1 parametrization. The solid line represent 0 MeV temperature whereas the dashed lines are for a temperature of 30 MeV.

ibility for NL3 parametrization, all the parameter yield almost same values of bulk properties whereas equation of state varies reasonably.

References

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