Effect of Temperature on Saturation Density in Asymmetric Nuclear Matter

C. Das[1],* S. Mishra[2], and H. Nanda[3]
[1] *Department of Physics, Berhampur University, Bhanjabihar, Berhampur-760007, Odisha, INDIA*
[2] *Department of Physics, Parala Maharaja Engineering College, Sitalapalli, Berhampur-761003, Odisha, INDIA and*
[3] *Department of Physics, Silicon Institute of Technology, Patia, Bhubaneswar-751024, Odisha, INDIA*

Introduction

Equation of state (EOS) of asymmetric nuclear matter (NM) is the key factor to understand supernova explosion. The end product of this explosion is the neutron star with radius around 10km and temperature is about Fermi temperature. The study of the star at this stage is of particular interest as it forms a new form of matter under extreme conditions where neutrons out number the protons.

Many microscopic calculations are made to study the EOS of asymmetric nuclear matter considering both non-relativistic and relativistic approach. Mean fields are also basic ingredient for this calculation. These fields are calculated using realistic two-body nucleon-nucleon (N-N) interaction. In modern mean field approaches, density dependent term has been introduced into various version of N-N interaction in order to reproduce correct saturation property as well as ground state structure of finite nucleus. In this respect, our aim is to study how asymmetry changes saturation density at a given temperature and how saturation density is affected by thermal energy. We have performed the calculation for EOS of asymmetric nuclear matter at various values of temperatures at proton fractions y_p=0.3 and 0.4.

Model

Non-relativistic microscopic calculations are made in frame work of Brueckner-Goldstone expansion using density dependent two body Sussex interaction. This interaction produces correct saturation property in symmetric nuclear matter. In our formalism[1, 2], we have introduced proton fraction like $y_p = \frac{n_+}{n}$. Where $n = n_+ + n_-$ is the number density of nucleon. n_+ and n_- are number density of proton and neutron respectively. Zero temperature Brueckner theory is extended to finite temperature and we have started our formalism by writing the grand thermodynamic potential per unit volume.

$$\Omega = -P = -T \ln tr\, e^{-(H-\mu n)} \tag{1}$$

Where H, P, T, μ and n are Hamiltonian, pressure, temperature, chemical potential and number density respectively. The energy per nucleon in nuclear matter is calculated using the formula

$$E_n = \frac{1}{n} \sum_{\tau} \frac{2}{(2\pi)^3} \int_0^{\infty} d^3k n_\tau(k) \left(\frac{\hbar^2 k^2}{2m_\tau} + \frac{1}{2} U_\tau(k) \right) \tag{2}$$

Where τ, $n_\tau(k)$ and $U_\tau(k)$ are isospin, distribution function and single particle potential of nucleon. Single particle potential is calculated self-consistently from number density constraint.

Results

In FIG. 1, Energy per nucleon is plotted for proton fractions y_p=0.3 and 0.4 at various values of NM densities for a given value of temperature T = 10MeV. It is found that saturation density shifts towards higher value for

*Electronic address: chapaladas59@gmail.com

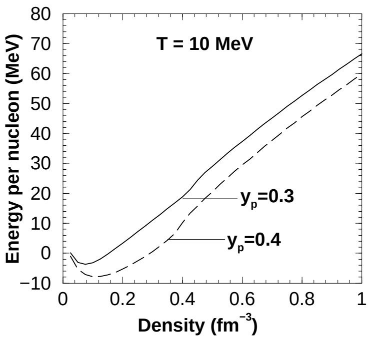

FIG. 1: Energy per nucleon for asymmetry nuclear matter for proton fractions $y_p = 0.3$ and 0.4.

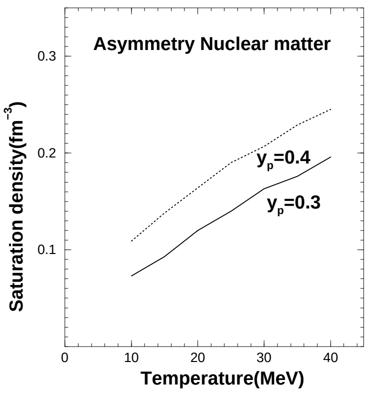

FIG. 2: Saturation density at various values of temperature of asymmetry nuclear matter for proton fractions $y_p = 0.3$ and 0.4.

higher value of proton fraction. It may be due to isospin effect. Similar trend of results are obtained by Harr and Malfliet[3] and Wiringa et al[4] at zero temperature. In FIG. 2, we have plotted saturation density at various values of temperatures for proton fractions $y_p =$ 0.3 and 0.4. It is observed that for a given value of proton fraction say y_p=0.3, saturation density increases with increase in temperature and for higher value of proton fraction, this density also shifts further towards a higher value. It may be due to mean field effect. In our earlier publication[5], it is already discussed that on enhancing thermal energy, attractive mean field of nucleon decreases for a given NM density and asymmetry where as,

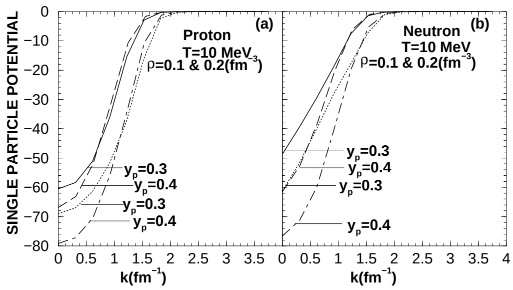

FIG. 3: Single particle potential for proton(a) and neutron(b) at various values of momenta.

kinetic energy part becomes more due to thermal excitation. In this calculation, we find from the FIG. 3 that attractive mean field increases with increase in nuclear matter density for a given temperature and proton fraction. While studying the effect of thermal energy on saturation density, we can explain that as at high density, mean field effect is large, in order to maintain equilibrium, saturation density shifts to higher value as temperature increases. Shifting of saturation density for higher value of proton fraction may be due to isospin effect i.e. the contribution of p-n interactions from isospin τ=0 and 1 channels enhances saturation density. Further, we can realize that for higher proton fraction, attractive mean field becomes larger, which needs high saturation density to maintain equilibrium.

References

[1] C.Das, R.Sahu and A.Mishra, Phys. Rev. **C75**, 015807-1 (2007).

[2] C.Das, P.Panda, A.Mishra and S. Mishra, Int. J. of M.Phys **D22**, 1350078 (2013).

[3] B.ter Haar and R. Malfliet, PRL **59**, 1652 (1987).

[4] R.B.Woringa, V. Fiks and A. Fabrocini, Phy. Rev.**C38**, 1010 (1988).

[5] C.Das, R.Sahu and R.K.Tripathi Phys. Rev. **C48**, 1056 (1993).