Study of the Nuclear matter properties for Hybrid EoS

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1. Introduction

The proposal that the quark matter with strangeness (strange matter) rather than the Hadron Matter (HM) might be the true ground state of Quantum Chromodynamics (QCD) was first pointed out by E. Witten [1]. Both HM and the Quark Matter (QM) are studied extensively using different models which are in good agreement with the experimentally measured quantities. There are various methods to combine these two phases of matter to obatin a single Hybrid Equation of State (EoS). However, the search for a unified model (HM+QM) to explain the high dense matter objects like Neutron stars hasn't gained much success. The effective mean field models are successful in describing the properties of both finite nuclei and infinite nuclear matter. The QM is also studied by employing different models. The requirement is to find a unified EoS where we study the infinite nuclear matter as a quark core and a hadronic crust.

In the present work, we study the hybrid EoS and its properties by combining the HM EoS with QM EoS using double tangent construction [2].

2. Formalism

To describe the hadron matter, we employ Effective-field-theory motivated Relativistic Mean-Field (E-RMF) model. The E-RMF Lagrangian [3] contains all self- and cross-couplings. The expressions for the energy density and pressure are given in Ref. [4]. For Neutron Star (NS) matter, the β-equilibrium condition and charge neutrality must be satisfied, which are

$$\mu_p = \mu_n - \mu_e \tag{1}$$

and

$$q_{total} = \sum_{i=n,p} q_i k_i^3/(3\pi^2) + \sum_l q_l k_l^3/(3\pi^2) = 0 \tag{2}$$

which implies, $n_p = n_e$.

For quark matter, we employ MIT Bag model to describe the Unpaired Quark Matter (UQM)[5]. In this model, we consider u,d and s quarks with masses $m_u = m_d$=5.0 MeV and m_s = 150 MeV. The expression for the quark pressure for different flavors q (q=u,d,s) is

$$P_Q = \frac{1}{4\pi^2}\sum_q \left\{ \mu_q k_q \left(\mu_q^2 - \frac{5}{2}m_q^2\right) + \frac{3}{2}m_q^4 ln\left(\frac{\mu_q + k_q}{m_q}\right)\right\} \tag{3}$$

where, $k_q = \sqrt{\mu_q^2 - m_q^2}$ is the Fermi momentum.

The total pressure is given by

$$P = P_Q + P_l - B \tag{4}$$

where, P_l is the leptonic pressure and B is the Bag constant.

The energy density is given by

$$\mathcal{E} = -P + \sum_i \mu_i n_i \tag{5}$$

where, $i = u, d, s, e^-, \mu^-$

To obatin single Equation of State, we use double tangent construction [2]. The double tangent gives the energy density for the densities at which two phases coexist. Fig.[1] shows the mixed EoS for different Bag values.

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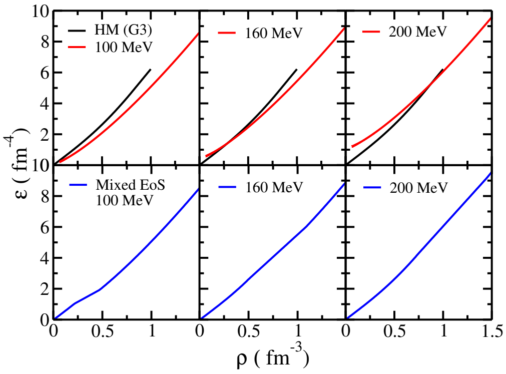

FIG. 1: Mixed EoS for HM (G3)+ QM (UQM) using different Bag constants.

3. Results and Discussion

We have studied the properties of hybrid EoS using different parameter sets (NL3, IOPB-I and G3) for Hadronic Matter and Quark Matter with different Bag constants. We varied the Bag constant $B^{1/4}$ from 100-200 MeV and calculated the nuclear matter properties like Symmetry energy and its derivatives for the Hybrid EoS. Fig.[2] shows the Symmetry energy (J), slope (L), curvature (K_{sym}) and Q_{sym} as a function of Bag constant $B^{1/4}$.Its clear that the values of symmetry energy and other parameters are high for a hybrid star than that for a pure hadronic one. Furthermore we see that all the quantities increase (for G3 and IOPB-I sets) as we increase the bag constant. However for NL3 mixed EoS, the symmetry energy and its slope (L) decrease initially with the bag constant till $B^{1/4}$ = 180 MeV and then it increases for $B^{1/4}$= 200 MeV, showing a complete different behaviour than the rest of EoS's.

The symmetry energy as a function of density is shown in Fig.[3]. For all parameter sets (NL3, IOPB-I and G3), the symmetry energy increases with the density. For IOPB-I and G3, the symmetry energy shows a rapid increase for bag constants $B^{1/4}$= 180 and 200 MeV. The symmetry energy and its density dependence have a strong correlation between the pressure (at $\rho \approx \rho_0$) inside a neutron star and its radius [6].The values of the parameters L, K_{sym} and Q_{sym} have a huge impact on the Radius-Mass relation of a neutron star.With the values obtained for a hybrid EoS, it will be interesting to see their effect on the NS mass, radius and other important quantities.

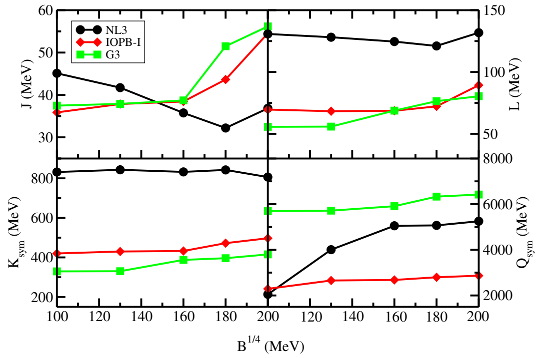

FIG. 2: NM properties as a function of Bag constant for different Mixed EoS.

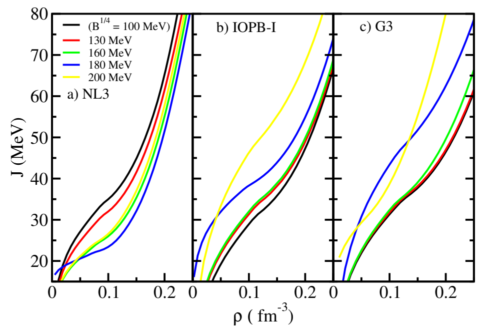

FIG. 3: Symmetry energy as a function of density for different Mixed EoS.

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