Asymmetric quark matter in Heavy ion collisions

Manisha Kumari* and Arvind Kumar
Dr. B R Ambdekar National Institute of Technology, Jalandhar, Punjab - 144011, INDIA

Introduction

The exploration of QCD phase diagram at moderate temperature and wide range of baryon densities have influenced many people working in this area of research as it has many effective application in nuclear physics and astrophysics. It is assumed that hadrons are actual ground state of strong interaction in conventional models. Witten statement give the idea that the strange quark matter (SQM) could be actual ground state relatively to normal nuclear matter [1]. Later on Farhi and Jaffe demonstrated that SQM is absolutely stable near the normal nuclear saturation density within large range of parameters [2]. Also dense quark matter has drawn a lots of interest due to recent progress in phenomenon color superconductivity. The ultrarelativistic heavy ion collision experiments in RHIC and LHC may lead to the formation of quark matter. Theoretical models based on the quark degrees of freedom, such as quark meson coupling model, MIT bag model, chiral quark mean field model, NJL model and extended PNJL model can be used to study properties of quark matter. In present study, we use chiral SU(3) quark mean field model at finite temperature and density to study equation of state of asymmetric strange quark matter relevant for heavy ion collision experiments.

Methodology

In chiral SU(3) quark mean field model total effective Lagrangian density is given by [3]

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{q0} + \mathcal{L}_{qM} + \mathcal{L}_{\Sigma\Sigma} + \mathcal{L}_{VV} + \mathcal{L}_{\chi SB} + \mathcal{L}_{\Delta m_s} + \mathcal{L}_h. \quad (1)$$

In above equation, $\mathcal{L}_{q0}$ represent the free part of massless quark, $\mathcal{L}_{qM}$ is quark meson field interaction term, $\mathcal{L}_{\Sigma\Sigma}$ and $\mathcal{L}_{VV}$ describe scalar and vector meson self interactions and the three terms $\mathcal{L}_{\chi SB}$, $\mathcal{L}_{\Delta m_s}$ and $\mathcal{L}_h$ introduce explicitly breaking of chiral symmetry.

The effective mass of quarks is generated through the coupling of quarks to non-strange meson field σ, the strange scalar meson field ζ and the scalar isovector meson field δ which incorporate the effect of isospin asymmetry in quark matter and is given by[3]

$$m_i^* = -(g_\sigma^i \sigma + g_\zeta^i \zeta + g_\delta^i \delta) + m_{i0}, \quad (2)$$

where g_σ^i, g_ζ^i and g_δ^i represent the coupling strength of different quarks with σ, ζ and δ fields respectively and m_{i0} is introduced to generate exact vacuum mass. The effective chemical potential of quark is expressed as

$$\mu_i{}^* = \mu_i - g_\omega^i \omega - g_\phi^i \phi - g_\rho^i \rho. \quad (3)$$

In above, g_ω^i,g_ϕ^i and g_ρ^i are the coupling strength of quark with ω, ϕ and ρ vector meson fields. Minimizing the thermodynamical potential density (Ω) of chiral SU(3) quark mean field model, coupled equations of motion of σ, ζ, δ and the dilaton field χ are derived [3]. Also, we can write the free energy density, F and pressure p as $F = \Omega + \sum_{i=u,d,s} \mu_i \rho_i$ and $p = -\Omega$, where ρ_i is number density. The β equilibrium may not be achieved as quark matter (QM) in heavy ion collision is metastable. The value of chemical potential of constituent quarks are determined by the total baryon density, ρ_B and strangeness fraction which is defined as f_s=ρ_s/ρ_B. The number of constituent quarks can be generally found unequal in HICs at RHIC/LHC and therefore, isospin asymmetry can be incorporated through definition [4]

$$\eta = 3\frac{\rho_d - \rho_u}{\rho_d + \rho_u}. \quad (4)$$

*Electronic address: manishak.phy.18@nitj.ac.in

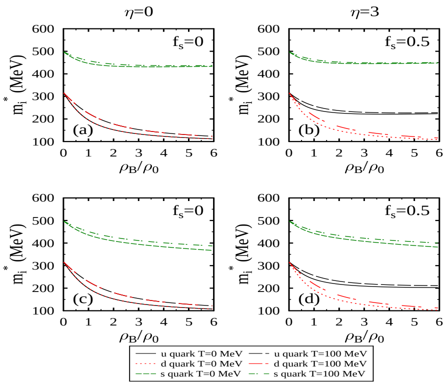

FIG. 1: (Color online)The effective mass of constituent quark as a function of baryonic density are plotted in above figure.

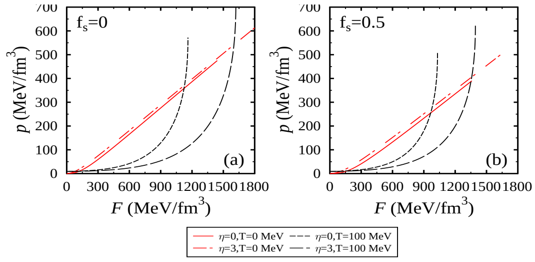

FIG. 2: (Color online) Equation of state (EoS) of quark matter.

Results and Discussion

In this section, we investigate the effective mass of constituent quarks and Equation of State (EoS) of asymmetric quark matter at finite density and temperature. Various parameters used in the present work are taken from Ref.[3].

In fig.1, we have shown the variation of medium modified quark masses m_i^* with baryonic density ρ_B, at temperatures T=0 and 100 MeV, strangeness fractions f_s=0 and 0.5, and isospin asymmetry η=0 and 3. For strange as well as non strange asymmetric quark matter, there is steep decrease in modified mass at lower values of density. However, for high density the decrease in m_u^* and m_d^* is quite smaller. In strange quark matter, m_s^* decrease more with baryonic density as compared to non strange quark matter. Further, in strange and non strange quark matter, as we from T=0 to T=100 MeV, the effective masses of constituent quark decrease. Finite isospin asymmetry of the medium causes mass splitting between u and d quarks.

In fig.2, we have plotted the pressure as a function of free energy density for quark matter at zero and finite value of isospin asymmetric and strangeness fraction. For given temperature of the medium, as we move from η=0 to finite asymmetry, pressure increase at given free energy density. This causes stiffness in the equation of state.

Summary

We have studied the effective masses and equation of state at finite density and temperature in strange as well as non strange asymmetric quark matter by using chiral SU(3)quark mean field approach. With the finite value of strangeness fraction of the asymmetric quark matter, the modified masses of u and d quarks do not show any significant change, whereas for m_s^*, a appreciable change is observed.

Acknowledgements

One of the author Manisha Kumari, sincerely acknowledge the support towards this work from Ministry of Science and Human Resources Development (MHRD), Government of India via Institute fellowship under National Institute of Technology Jalandhar.

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