Temperature Effects in Quark Matter Symmetry Free Energy

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Introduction

The symmetry free energy in nucleonic system, denoting the free energy difference between isospin asymmetric and symmetric nuclear matter, has been a hot topic [1]. Since the quark matter in relativistic heavy - ion collisions at RHIC - BES or FAIR - CBM energies as well as in compact stars is isospin asymmetric, the quark matter symmetry free energy is also an important quantity affecting the EOS of the system. There is a world wide interest in symmetry free energy as it provides a key to understand the isospin asymmetry property of the matter. Quark matter symmetry free energy is related to the isospin splitting of u and d quarks constituent. This is similar to the case of nuclear matter symmtery free energy which is related to the isospin splitting of neutron and proton ratio. The main objective of present work is to investigate the effects of temperature in quarks symmetry free energy based on Quark Quasiparticle model [2, 3] by employing the effective Bag function $B^*(\mu)$ which is varying with chemical potential. In the quark quasiparticle model, the quarks are considered as quasiparticles which gain an effective mass reproduced by the interaction with the other quarks in high dense matter.

Theoretical Framework

The δ, is asymmetry parameter for pure quark matter and defines as the ratio of isospin quark matter number density n_3^Q to the total quarks matter number density n_B^Q as,

$$\delta = -n_3^Q/n_B^Q = -3(n_d - n_u)/(n_d + n_u), \quad (1)$$

where, isospin quark matter number density, $n_3^Q = n_d - n_u$ and quark matter number density $n_B^Q = \frac{1}{3}(n_d + n_u)$. The Free energy per baryon number of asymmetric quark matter consisting of u, d and s quarks, can be expanded in terms of isospin asymmetry parameter δ as,

$$F(n_B, \delta, n_s) = F_0(n_B, \delta = 0, n_s) + F_{sym}(n_B, n_s)\delta^2 + \quad higher \quad terms \quad (2)$$

In above Eq.(2), the term $F_0(n_B, \delta = 0, n_s)$ represents the free energy per baryon number in pure three flavor quark matter with equal particle fraction of u and d quarks. $F_{sym}(n_B, n_s)$, represents the symmetry free energy of quarks matter and can written as,

$$F_{sym}(n_B, n_s) \simeq \frac{1}{\delta^2}[F(n_B, \delta, n_s) - F(n_B, \delta = 0, n_s)]$$

where F $= \frac{\mathcal{F}}{n_B}$ and $\mathcal{F}$ is the free energy density of quark matter. In our case, we have used the EOS of the Quark Quasiparticle model.

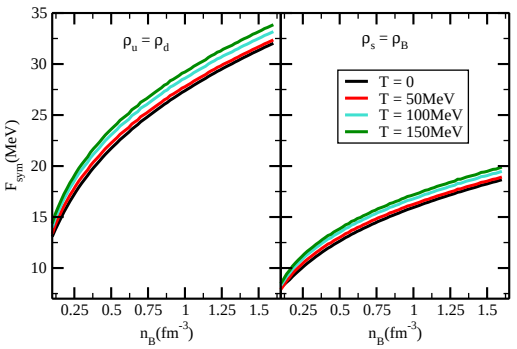

FIG. 1: (color online) Symmetry free energy, plotted as a function of baryon density with m_u = 5MeV, m_d = 5MeV, m_s = 100MeV with increase in temperature.

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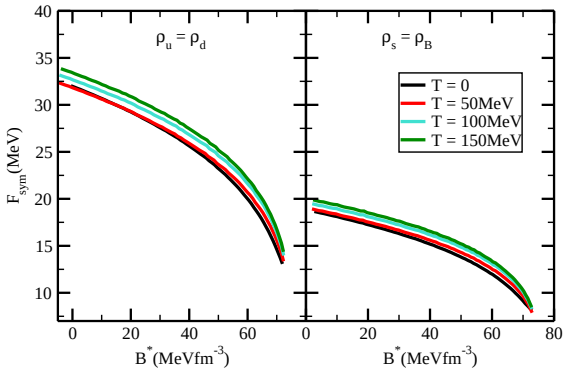

FIG. 2: (color online) Symmetry free energy, plotted as a function of baryon density with m_u = 5MeV, m_d = 5MeV, m_s = 100MeV with increase in temperature.

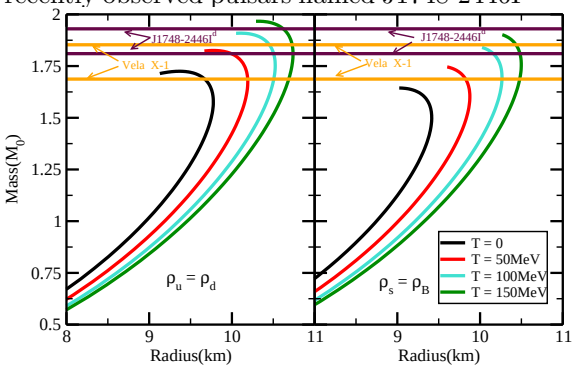

FIG. 3: (color online) Mass - Radius relationship with increase in temperature at m_u = 5MeV, m_d = 5MeV, m_s = 100MeV

1. Results and Discussions

In Figure (1), we displayed baryon number density dependence of the Quark symmetry free energy in Quark Quasiparticle model. It is found that quark symmetry free energy increases monotonically with increasing baryon number density. In addition, it is obvious from Figure(1) that at each baryon number density, the symmetry free energy increases as the temperature increases. We have considered two typical cases, i.e., two - flavor u - d quark matter with $n_s = 0$ and u - d - s quark matter with $n_s = n_B$. The latter roughly corresponds to the situation inside Quark stars where s quarks may have equal fraction as up and down quarks. It is found here that F_{sym} is decreased in the presence of strange quarks for our Quark Quasiparticle model. In Figure (2), we show the effective bag function dependence of the Quark symmetry free energy whose result is quite obvious because our Effective Bag Function is also continuosly deacreasing with increase in density. Left panel is for two - flavor u - d quark matter and right panel is for u - d - s quark matter. Table(I) and Figure(3), shows the mass-radius relationship of two flavour and three flavour Quarks Star under the influence of temperature which is compared with the mass limits of recently observed pulsars named J1748-2446I^d and Vela X-1 having masses of $1.91^{+0.02}_{-0.10}$ and $1.77\pm0.083 M_\odot$ respectively.

TABLE I: For Quark Star, the variation in gravitational maximum mass in unit of solar $M_\odot$, gravitational radius R in km and $R_{1.4}$ in km.

ud			
T(MeV)	$M_{max}(M_\odot)$	$R(km)$	MI($10^{45} gcm^2$)
0	1.72	9.38	0.932
50	1.82	9.79	1.072
100	1.90	10.11	1.223
150	1.96	10.32	1.309
uds			
T(MeV)	$M_{max}(M_\odot)$	$R(km)$	MI($10^{45} gcm^2$)
0	1.64	9.03	0.835
50	1.74	9.60	1.021
100	1.84	10.02	1.169
150	1.90	10.26	1.254

References

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