Trace anomaly property in dense quark matter

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Introduction

The thermodynamical properties of strongly interacting matter in thermal and dense medium plays an important role in understanding the wide range of physical phenomena such as Big Bang, heavy ion collision and internal dynamics of compact star. According to strange quark matter hypothesis the Strange Quark Matter (SQM) can be considered as ground state of hadronic matter [1, 2]. The properties of SQM are determined by quark interaction and are also significant for the QCD phase structure. Also, dense quark matter has drawn a lot of interest due to its existence in the core of neutron star. The construction of the heavy ion collision experiments such as RHIC, LHC and future CBM have generated remarkable opportunities to explore the properties of quark and nuclear matter. There are many 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, extended PNJL model and Chiral SU(3) Quark Mean Field (CQMF) model which can be used to study properties of quark matter. In present study, we use Polyakov extended CQMF (PCQMF) model at finite temperature and density to study thermodynamical properties of asymmetric strange quark matter which is relevant for heavy ion collision (HIC) experiments.

Methodology

In PCQMF model, the total effective Lagrangian density of SQM is given by [3]

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{q0} + \mathcal{L}_{qM} + \mathcal{L}_{\Sigma\Sigma} + \mathcal{L}_{VV} + \mathcal{L}_{\chi SB} + \mathcal{L}_{\Delta m_s} + \mathcal{L}_h - U(\Phi(\vec{x}), \bar{\Phi}(\vec{x}), T). \quad (1)$$

In above equation, $\mathcal{L}_{q0}$ is the free part of massless quark, $\mathcal{L}_{qM}$ describe quark meson field interaction term, $\mathcal{L}_{\Sigma\Sigma}$ and $\mathcal{L}_{VV}$ represent scalar and vector meson self interactions and $\mathcal{L}_{\chi SB}$, $\mathcal{L}_{\Delta m_s}$ and $\mathcal{L}_h$ are introduced to incorporate explicitly breaking of chiral symmetry. Moreover, $U(\Phi(\vec{x}), \bar{\Phi}(\vec{x}), T)$ is a temperature dependent Polyakov loop potential, where Φ and $\bar{\Phi}$ are Polyakov loop variable and its conjugate, respectively.

The effective chemical potential of quark is expressed as

$$\mu_i{}^* = \mu_i - g_\omega^i \omega - g_\phi^i \phi - g_\rho^i \rho. \quad (2)$$

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. In this model, the effect of temperature comes into picture through the Polyakov loop potential and scalar/vector density of constituent quarks. Minimizing the thermodynamical potential density (Ω) of PCQMF model, coupled equations of motion of σ, ζ, δ, χ, ω, ρ, ϕ, Φ and $\bar{\Phi}$ are derived [3]. Also, we can write the energy density, ϵ and pressure p as $\epsilon = \Omega + \sum_{i=u,d,s} \mu_i \rho_i + TS$ and $p = -\Omega$, where ρ_i is number density. In this work, the β equilibrium may not be achieved as quark matter in HIC is metastable. The number of constituent quarks can be generally found unequal in HICs at RHIC/LHC and therefore, the baryon and isospin chemical potential are defined as [4]

$$\mu_B = \frac{3}{2}(\mu_u + \mu_d), \quad (3)$$

and

$$\mu_I = \frac{1}{2}(\mu_u - \mu_d). \quad (4)$$

The trace anomaly can be incorporated through the trace of the energy-momentum tensor, $T^\mu_\nu = \epsilon - 3p$.

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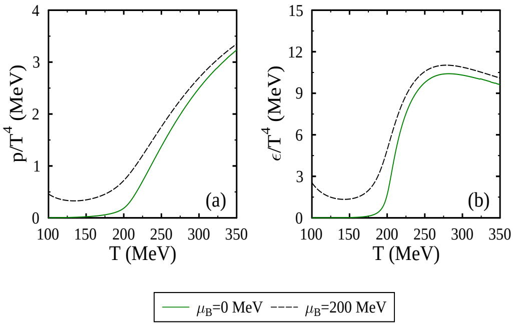

FIG. 1: (Color online)The pressure and energy density as a function of temperature at μ_B=0, 200 MeV and μ_I=-80 MeV are plotted in above figure.

Results and Discussion

In this section, we explore the thermal dependence of pressure density, energy density and trace anomaly from PCQMF model. Various parameters used in the present work are taken from Ref.[3, 5].

In fig.1, we have shown the variation of thermodynamical pressure and energy density with temperature T, at μ_B=0 and 200 MeV and μ_I=-80 MeV. At zero chemical potential, the pressure and energy density are smooth function of the temperature which is consistent with a crossover transition. These quantities are suppressed in low temperature regime and starts to increase with increase in temperature.

In fig.2, we have depicted the $(\epsilon - 3p)/T^4$ as a function of temperature for SQM at zero and finite value of baryonic chemical potential. The trace anomaly is small for confined phase and then increase with temperature. The smooth crossover could be identified by the change in $(\epsilon - 3p)/T^4$. It has been also noticed that the increasing μ_B causes smoothing of the temperature dependence and transition temperature.

Summary

We have combined CQMF model with the Polyakov loop potential in order to show the deconfinement transition and studied the pres-

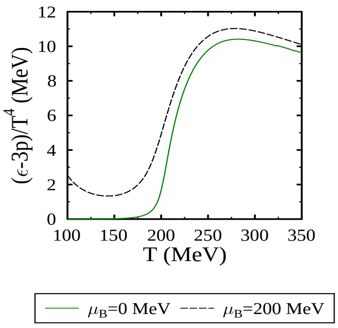

FIG. 2: (Color online) Trace anomaly as a function of temperature at μ_B=0, 200 MeV and μ_I=-80 MeV.

sure, energy density and trace anomaly as a function of temperature at μ_B=0, 200 MeV in SQM. All above investigation contribute to study the phase structure theoretically and experimentally at finite μ_B. In future, data observed in HIC experiments will give valuable information on μ_B dependence of Polyakov loop potential, which can be compared with these results.

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