Quark-Hadron phase transition at high chemical potential in relativistic heavy-ion collision

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Introduction

A transition from the confined phase to the plasma phase, the quark-gluon plasma (QGP), is expected at high temperature and/or chemical potential. The new findings about the nature of the QGP motivate us to investigate the phase structure of QCD matter.

The results of Lattice QCD calculations show that at small chemical potential and high temperature, the transition to the QGP phase is a smooth crossover [1], whereas a first order phase transition is expected at high chemical potential [2, 3]. In this, phenomenological studies are appropriate and significant. A phase transition is classified as a first order or crossover depending on the behaviour of free energy evolution and entropy.

A brief description of simple model

Many authors have suggested that the transition into QGP phase has a nature of either a first order or a weakly first order one [4]. In order to new findings about this state, we now extend the previous work using chemical potential. The quark mass is computed by replacing the factor T^2 to a good accuracy of temperature as $T^2+\mu^2/\pi^2$ [5]. Now the quark mass has dependence on temperature as well as on chemical potential. Thus it is defined as [6]:

$$m_q^2(T,\mu) = \gamma_q \frac{N}{\ln(1+\frac{k^2}{\Lambda^2})}\left(T^2+\frac{\mu^2}{\pi^2}\right) \quad (1)$$

where, $k = [\frac{\gamma N^{\frac{1}{3}} T^2 \Lambda^2}{2}]^{\frac{1}{4}}$ is known as momentum with $N = \frac{16\pi}{[33-2N_f]}$ and number of flavor $N_f = 3$. The parametrization factor $\gamma^2 = 2[\frac{1}{\gamma_q^2}+\frac{1}{\gamma_g^2}]$ with $\gamma_q = 1/6$ and $\gamma_g = 6\gamma_q$ [6] and Λ is QCD parameter.

Evolution of quark-gluon plasma

The authors [7] have studied free energy of a quark gluon plasma with the inclusion of curvature term using dynamical quark mass considering zero chemical potential. In the present work, we modify earlier calculation of Ref. [6] with the effect of chemical potential.

We calculate the free energy for quarks, F_q by modifying the density of states using finite quark mass at fix value of chemical potential. These modification are taken care with the inclusion of curvature term in the density of states. Free energy is taken as Ref. [6]:

$$F_q = \mp T g_q \int dk\rho(k)\ln(1\pm e^{-(\sqrt{m_q^2+k^2}-\mu)/T}) , \quad (2)$$

Similarly, free energy for gluons, F_g is taken as Ref. [6]. Where $\rho(k)$ is the density of states of the particular particle (quarks, gluons, pions etc.), and g_q is the degeneracy factor. The interface and pion free energy are given as Ref. [4, 6], Thus the total free energy F_{total} is calculated using all above energies and it is given as,

$$F_{total} = F_q + F_{gluon} + F_\pi + F_{interface} . \quad (3)$$

Using total free energy, we can calculate entropy which shows a nature of phase transition. However using modified quark mass dependent on finite temperature and chemical potential including curvature term, the to-

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tal free energy is calculated that explain the evolution of quark-gluon plasma and quark-hadron phase transition.

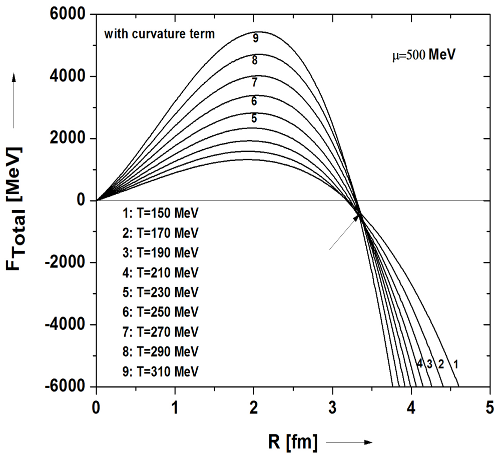

FIG. 1: Modified free energy F_{Total} with radius for various temperature T are shown at fix chemical potential μ=500 MeV.

Results and discussion

In order to discuss the quark-hadron phase transition, we present the modified results of free energy and entropy at various temperature and at fix value of high chemical potential incorporating curvature term.

In figure 1, we plot free energy with respect to droplet radius at μ = 500 MeV by varying the temperature. The bunching of curves provide more realistic picture for the stabilty of QGP droplet as shown by arrowhead. The amplitude (barrier height) of free energy goes on increasing as the temperature increases at high chemical potential including curvature term and also smooth cut at the phase boundary indicate that there is first order phase transition. We also observe that the size of QGP droplets goes on decreasing as the temperature increases. The results are compared with earlier work of Ref. [6, 7].

In figure 2, we found discontinuity in the entropy term at T∼ 190 MeV which shows transition is of first order. Our current results agree nicely with the recent results of lattice QCD simulation [2, 3].

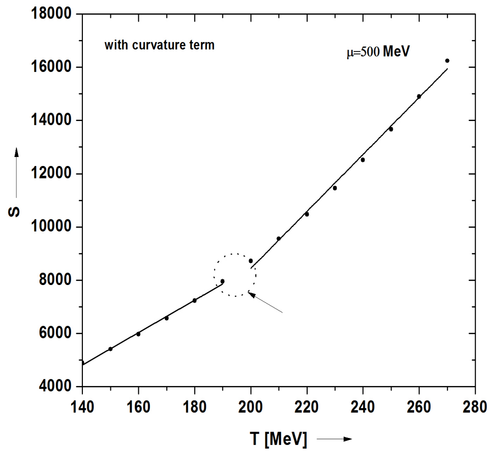

FIG. 2: Variation of entropy S is shown with temperature T at fix chemical potential μ=500 MeV.

Thus the use of finite quark mass with finite temperature and chemical potential including the curvature term helps in predicting the order of phase transition. The results are in good agreement with Lattice QCD simulation. Finally our results should be of relevance in connection with quark-hadron phase transition.

References

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