Equation of state of spin asymmetric QGP matter

Kausik Pal*
Department of Physics, Serampore College, Serampore 712201, India.

I. Introduction

At the extreme conditions of temperature and/or density the hadrons are expected to dissolve into their more fundamental constituents *viz.* quarks and gluons, forming a new state of matter called Quark Gluon Plasma (QGP). The possibility of creating high temperature QGP by colliding heavy ions in the laboratory and studying this phase of matter has been the goal of experiments at CERN SPS and at the Relativistic Heavy Ion Collider (RHIC) facility at Brookhaven National Laboratory (BNL). ALICE, ATLAS and CMS Collaborations at the Large Hadron Collider (LHC) have provided further impetus to these studies. This experimental search of the QGP needs reliable theoretical estimates of various signals which depend on the pressure, entropy, deconfinement temperature and the equation of state (EOS) etc.

II. Thermodynamic properties and Equation of state

In this section I calculate the thermodynamic properties, like energy density (E), pressure ($\mathcal{P}$), entropy density ($\mathcal{S}$), free energy ($\mathcal{E}$), for QGP matter with explicit spin dependent quarks by using a MIT bag model with fixed bag pressure $\mathcal{B}$. The MIT bag model considers free particles confined to a bounded region by the bag pressure. The bag constant ($\mathcal{B}$) is the difference between the energy densities of non-interacting and interacting quarks. Within this model, I assume the QGP is composed of the light quarks only, i.e. the up and down quarks which interact weakly, and the gluons which are treated as almost free [1]. I consider the color symmetric forward scattering amplitude of two quarks around the Fermi surface by the one gluon exchange interaction [2].

The total energy density of the QGP is given by [1, 3], $E_{QGP} = E_q + E_g + \mathcal{B}$, where $E_q = E_{kin} + E_{ex}$ is quark energy density and the energy density of gluons is E_g. Since our system is ultra-relativistic, the pressure is given by $\mathcal{P} = \frac{1}{3}E$. Then the pressure of the system is determined to be $\mathcal{P}_{QGP} = \mathcal{P}_q + \mathcal{P}_g - \mathcal{B}$. Once the value of $\mathcal{P}$ is determined, one can readily calculate the entropy density of the system by evaluating $\mathcal{S}_{QGP} = \frac{\partial}{\partial T}(\mathcal{P}_{QGP})$. The thermodynamic properties of the system can be obtained by using the Helmholtz free energy relation $\mathcal{E}_{QGP} = E_{QGP} - T\mathcal{S}_{QGP}$. All these parameters are depend on $\xi = (n_q^+ - n_q^-)/(n_q^+ + n_q^-)$, the spin polarization parameter with $0 \leq \xi \leq 1$, as I consider spin asymmetric QGP matter. Here n_q^+ and n_q^- correspond to the densities of spin-up and spin-down quarks, respectively [2]. For the numerical estimation of all these quantities, we take $\alpha_c = \frac{g^2}{4\pi} = 0.2$, as the coupling constant of QCD and the bag pressure $\mathcal{B} = 208$ MeV fm^{-3} for zero hadronic pressure.

In the upper panel of Fig. 1, it is shown that at the same baryon density the pressure is larger for the interacting cases in comparison with the non-interacting one and if the interaction strength increases also the pressure raises further. Thus the interaction makes easier the quarks transition to the deconfined phase at lower density. Therefore, the interaction of the QCD coupling constant reduces the value of the density to reach a transition. In the lower panel of Fig. 1, it has been observed that at a constant temperature, the pressure of QGP is larger for polarized quarks than for unpolarized ones. Thus the equation of state of spin asymmetric QGP matter becomes stiffer by increasing the baryon density (temperature)

*Electronic address: `kausik.sinp@gmail.com`

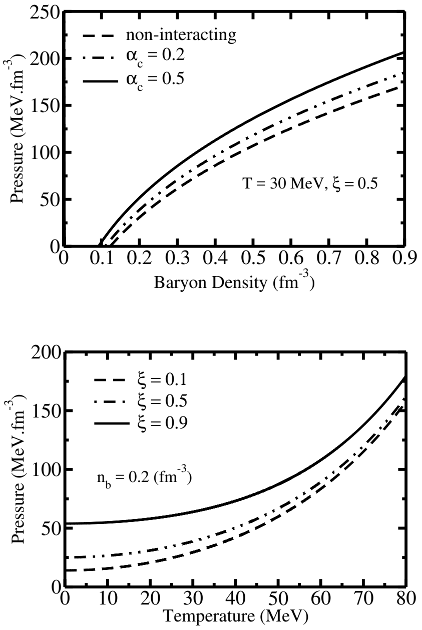

FIG. 1: The pressure for different coupling constants as a function of baryon density (upper panel) and the pressure as a function of temperature for various ξ (lower panel).

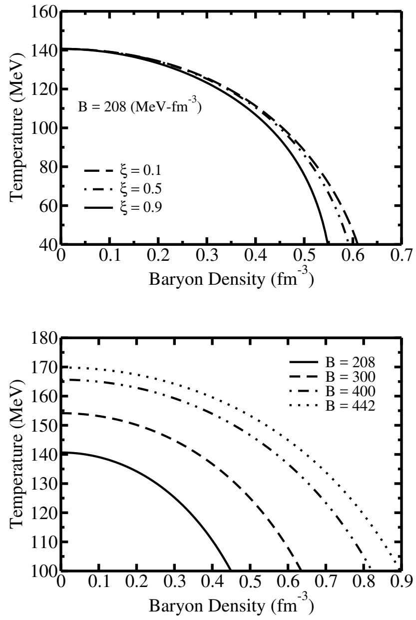

FIG. 2: The phase diagram with different ξ (upper panel) and with different bag pressure (lower panel).

[1, 3].

The QGP phase diagrams are depicted in Fig. 2; in the upper panel, we see that the critical temperature is independent of the polarization parameter while critical density is different for unpolarized and polarized QGP. On the other hand, in the lower panel it is shown that the critical temperature and density for the phase transition are different for different bag pressures and the critical values increase when increasing the bag pressure. It is shown that the critical temperature for the deconfined phase transition lies between $130 < T_c < 170$ MeV. When the bag pressure is about 442 MeV fm^{-3}, the estimated results for critical temperature, i.e. $T_c = 170$ MeV, is consistent with the lattice results [4]

III. Discussions

It has to be mentioned that our results depend on the values of the bag pressure while a change in the value of the QCD coupling does not have any dramatic effect in our calculations. Within the scope of the present model, the value of T_c obtained here, is close to the lattice QCD prediction. Here, the critical parameters are determined from the phase boundary by using the condition that the bag pressure ($\mathcal{B}$) is independent of chemical potential (μ) and temperature (T), but in realistic cases $\mathcal{B}$ may depend on both.

References

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