Locating the Critical Point in QCD Phase Diagram

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Introduction

The existence of critical point in the studies of QCD phase diagram has attracted considerable theoretical and experimental attention recently. The phase diagram of quark matter is still not understood either experimentally or theoretically. The existence of a critical point in the conjectured QCD phase diagram was proposed a long time ago [1], the absence of the CEP in the phase diagram was also noticed in some recent lattice calculations [2]. Thus the location and the existence of the CEP in the phase diagram is still a matter of debate. In this paper, we use an EOS for HG fireball which is recently proposed by us [3]. Moreover, we use two different kind of phenomenological model known as bag model and quasiparticle model (QPM) to derive the Equation of state (EOS) for the QGP phase. Furthermore, we construct the phase boundary by equating the QGP pressure with that of HG pressure. We draw the phase boundary line and the end of the line determines the coordinates of the CEP. We also find the existence of a crossover transition lying beyond CEP. Finally we compare our findings with those obtained in various other models.

1. EOS for a Hadron gas

Recently we have proposed a thermodynamically consistent excluded volume model for hot and dense hadron gas (HG) [3]. We use full quantum statictics. The pressure of the HG phase after incorporating excluded volume correction in this model can be given as:

$$p_{HG}^{ex} = T(1-R)\sum_i I_i\lambda_i + \sum_i P_i^{meson}, \quad (1)$$

where R is the fractional occupied volume by the baryons and λ_i is the fugacity of the ith baryon . Furthermore, the first term represents the pressure due to all types of baryons where excluded volume correction is incorporated and the second term gives the total pressure due to all mesons in HG having a point-like size.

2. Bag Model (BM)

Let us first consider QGP and we assume that it consists of massless quarks (u,d), their antiquarks and gluons only. So the pressure of QGP can be written in the bag model as [3]:

$$\begin{aligned} P_{QGP} &= \frac{37}{90}\pi^2T^4 + \frac{1}{9}\mu_B^2T^2 + \frac{\mu_B^4}{162\pi^2} \\ &-\alpha_S\left[\frac{11}{9}\pi T^4 + \frac{2}{9\pi^2}\mu_B^2T^2 + \frac{1}{81\pi^3}\mu_B^4\right] \\ &+\frac{8\alpha_S^{3/2}T}{3\pi^2\sqrt{2\pi}}\left[\frac{8\pi^2T^2}{3} + \frac{2}{9}\mu_B^2\right]^{3/2} - B \end{aligned} \quad (2)$$

where α_S is the coupling constant for strong interaction and μ_B is the baryonic chemical potential. Moreover, B is the confining bag pressure.

3. First Quasiparticle Model (QPM I)

Gorenstein and Yang formulated a thermodynamically-consistent quasiparticle model for a gluon plasma at μ_B=0 and later they extended it for the QGP having a finite value of μ_B [4]. In this model, after reformulating the statistical mechanics and incorporating the additional medium contribution, the pressure p for a system of quasiparticles can be written as :

$$p(T,m) = p_{id} - B(T,\mu_B), \quad (3)$$

The first term on the right hand side of the equation is the standard ideal gas expression.

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The second term represents the medium contribution.

4. Second Quasiparticle Model (QPM II)

The second thermodynamically consistent quasiparticle model is given by Bannur [5]. Bannur used the definition of average energy and average number of particles and derived all the thermodynamical quantities from them in a consistent manner.In this model, pressure of system at $\mu_q = 0$ can be obtained as:

$$\frac{p(T,\mu_q=0)}{T} = \frac{p_0}{T_0} + \int_{T_0}^{T} dT \frac{\epsilon(T,\mu_q=0)}{T^2}, \tag{4}$$

where p_0 is the pressure at a reference temperature T_0. We have used p_0=0 at T_0=100 MeV in our calculation. Moreover, ϵ is the energy density. Using the relation between the number density n_q and the grand canonical partition function, we can get the pressure for a system at finite μ_B :

$$p(T,\mu_q) = p(T,0) + \int_0^{\mu_q} n_q d\mu_q. \tag{5}$$

5. Results and Discussion

In Fig.1, we have shown the phase boundary obtained, using Gibbs' criteria, in our model. Surprisingly we find here that the first-order deconfining phase transition line ends at a critical end point (CEP). It is interesting to find that the critical points obtained by us lie closer to CEP of some lattice calculation [6]. We also find a crossover region existing beyond the critical point where HG pressure which is solely dominated by mesonic pressure term in Eq.(6), is always less than the QGP pressure. Therefore, no phase transition exists in this region. Since the temperature is much higher, the thermal fluctuations break mesonic constituents of HG into quarks, antiquarks and gluons.

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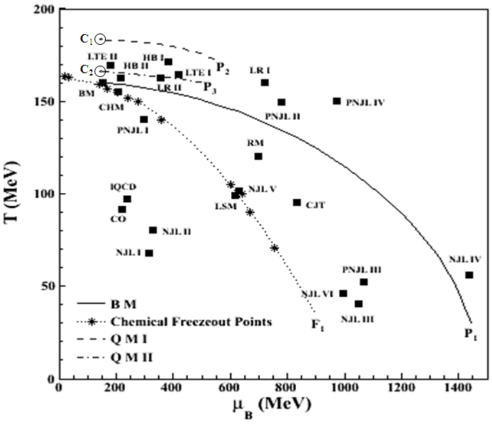

FIG. 1: The location of QCD critical point in QCD phase diagram. P_1 is the phase boundary in BM, P_2 is the phase boundary in QPM I and P_3 is the phase boundary in QPM II. F_1 is the chemical freezeout line obtained using our HG model. BM ($T_{CEP} = 160MeV, \mu_{CEP} = 156MeV$) is the CEP on P_1 obtained in bag model, $C_1(T_{CEP} = 183MeV, \mu_{CEP} = 166MeV)$ is the CEP on P_2 obtained in QPM I and $C_2(T_{CEP} = 166MeV, \mu_{CEP} = 155MeV)$ is the CEP on P_3 obtained in QPM II. The labels used in the figure are taken from Ref. [7] and reference therein.

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