Behaviour of Pressure using PNJL and Quasi-Particle Approach with a Strong Magnetic field

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Introduction

The assertion that matter can exist in a deconfined state referred to as Quark-Gluon Plasma has been substantiated, particularly under conditions of elevated temperatures prevalent during the early stages of the universe. The Polyakov loop functions as a pivotal order parameter, serving as a discerning indicator of the transition from confinement to deconfinement, a transition characterized by the spontaneous breaking of center symmetry [1]. The dynamic behavior of the Polyakov loop offers a profound framework for comprehending the intricate phenomena manifesting within the extraordinary state of QGP.

In recent times, there has been a growing recognition of the pivotal role that robust magnetic fields may play in advancing our understanding of various fundamental aspects of the universe and the intricacies of matter. These magnetic fields have been implicated in several critical areas of research [2]. Astonishingly, magnetic fields of extraordinary intensity, ranging from 10^{19} to 10^{20} Gauss, can be generated within heavy-ion colliders [3, 4]. However, it's important to note that these magnetic fields exist for only a fleeting moment [5]. Studies employing Lattice QCD simulations have revealed that magnetic fields can impact the equation of states [6]. So, in this paper, we focus to find the pressure using PNJL and Quasi-Particle model introducing a suitable magnetic field for 2 flavours.

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A brief description of PNJL and Quasi-Particle Model

Within the PNJL model, the interplay between the chiral and deconfinement order parameters allows for an exploration of the thermodynamics governing both transitions, all within a cohesive theoretical framework with effective quark mass using Quasi-Particle approach in the presence of magnetic field. Our journey towards calculating diverse thermodynamic properties begins with the computation of the thermodynamic potential employing the PNJL Model with the suitable invironment of magnetic field [7].

$$\Omega = U(\phi,\bar{\phi},T) + \frac{\sigma^2}{2G} - 2N_f T\int \frac{d^3p}{(2\pi)^3}\{ln[1+ 3(\phi+\bar{\phi}e^{-(E_p-\mu_o)/T})e^{-(E_p-\mu_o)/T}+ e^{-3(E_p-\mu_o)/T}] + ln[1+3(\bar{\phi}+ \phi e^{-(E_p-\mu_o)/T})e^{-(E_p-\mu_o)/T}+ e^{-3(E_p-\mu_o)/T}] - 6N_f\int \frac{d^3p}{(2\pi)^3}E_p\theta(\Lambda^2-\overrightarrow{p}^2) \quad (1)$$

In this equation, the auxiliary field σ is the chiral condensate given by $\langle\sigma\rangle = G\langle\phi\bar{\phi}\rangle$. In thermodynamic potential $E_p = \sqrt{\overrightarrow{p}^2 + m_{eff}^2 + 2eB}$, where p is the momentum, eB is the magnetic field and m_{eff} is effective quark mass obtained from Quasi-Particle model [8]. It is taken as,

$$m_{eff}^2 = m_c^2 + \sqrt{2}m_c m_q + m_q^2$$

with m_c is the current quark mass term and m_q is the quark mass term. Here, we define the thermal value of quark mass [9, 10]:

$$m_q^2(T) = \gamma_q(g^2(p))T^2 \quad (2)$$

Here, all factors are the well defined in Ref. [9, 10].

The thermodynamic potential incorporates a potential function denoted as $U(\phi, \bar{\phi}, T)$, which governs the behavior of Polyakov loop.

The process of numerically determining the values of σ, ϕ, and $\bar{\phi}$ involves taking partial derivatives of the thermodynamic potential Ω with respect to σ, ϕ, and $\bar{\phi}$ and subsequently equating these derivatives to zero, all within the context of a specified temperature value T at $\mu = 0$.

$$\frac{\partial \Omega}{\partial \sigma} = 0, \quad \frac{\partial \Omega}{\partial \phi} = 0, \quad \frac{\partial \Omega}{\partial \bar{\phi}} = 0 \quad (3)$$

Given that the Polyakov loop assumes a non-zero value that gradually approaches unity in the regime of high temperatures during de-confinement, we have chosen to initialize our approximation with $\phi = \bar{\phi} = 1$. Furthermore, by expressing the chiral condensate in terms of the quark mass, we are able to treat these terms as constants, simplifying the formulation into a temperature-dependent function. Upon acquiring the field values through Eq. (3), we subsequently employ them to compute the pressure by substituting them into Eq. (1). The thermodynamic pressure is computed in the presence of magnetic field at zero chemcial potential. It is used as:

$$P = -\Omega(T, \mu = 0) \quad (4)$$

Result and Conclusion

We study pressure thermodynamic observable obtained from the PNJL and Quasi-Particle model in the presence of magnetic field for two flavours. To assess the reliability and validity of our findings, we employ lattice QCD data as a reference, facilitating a robust comparison with experimental outcomes. This approach not only allows us to scrutinize the consistency of our results but also permits an exploration of trends across various temperature ranges, revealing a notable alignment with the patterns observed

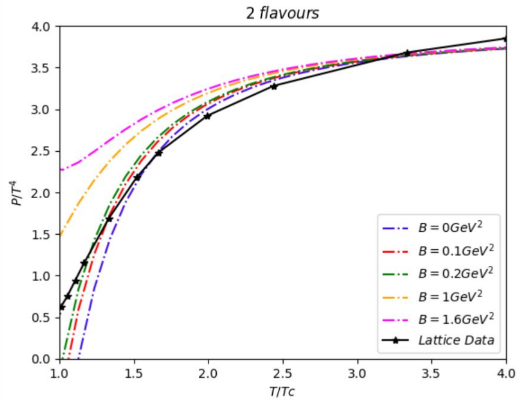

FIG. 1: Pressure v/s temperature is shown in the presence of magnetic field for 2 flavours.

in lattice QCD simulations with and without magnetic field. Our observations on pressure matches well with the results of lattice QCD for various value of magentic fields. This remarkable agreement serves as compelling evidence for the robustness, consistency, and accuracy of our model.

Considering these intriguing findings, our curiosity is piqued by the prospect of investigating how the system of Quark-Gluon Plasma (QGP) behaves within the environment of the powerful magnetic fields generated during collisions of heavy ion beams in the colossal accelerators located at BNL and CERN. These diverse avenues of exploration collectively motivate our research into the PNJL and Quasi-Particle model under the compelling influence of these strong magnetic fields.

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