Speed of Sound in the presence of magnetized QGP

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Introduction

The role of magnetic field play an important role in the study of the evolution of the early universe [1], in strange quark matter and neutron star physics [2, 3] and may affects thermodynamic observables in case of non-central high energy heavy-ion collisions. It indicated that very intense magnetic field of $10^{19} - 10^{20}$ G, might be generated in heavy-ion colliders [4]. Such an intense magnetic field strength appears in heavy-ion collisions only on limited distances and exists for a very short time. Thus providing a possible signature of QGP.

Many authors [5] have studied that the thermodynamic quantities increases well with the magnetic field. Therefore, the current study focuses on a speed of sound of QGP in non-zero magnetic field. A phenomenological model is developed to check the behaviour of speed of sound with the different values of magnetic fields that is up to $eB = 0.4\ GeV^2$ and for a wide range of temperatures 110 MeV $< T <$ 300 MeV.

A brief description of Model

The model is used as quasiparticle model which might be better improve to the Lattice QCD simulation results to produce equation of state of quark-gluon plasma with the zero and non-zero magnetic field. Based on earlier model [6], the effective quark mass is suitably modified using magnetic field. Therefore, the effective quark mass in the presence of magnetic field is called as magnetized effective quark mass (MEQM) [7].

In the presence of a constant magnetic field (along the z-axis), the single particle energy eigen value is given by [8],

$$E^{B\dagger} = \left[k^2 + M^B_{eff}\right]^{1/2} \ , \qquad (1)$$

$$M^B_{eff} = M^2_{eff} + eB(2n + s + 1) \ , \qquad (2)$$

M^B_{eff} is the MEQM. M^2_{eff} is the effective quark mass and it is defined as [6, 9],

$$M^2_{eff} = \mathfrak{m}_c{}^2 + \sqrt{2}\mathfrak{m}_c m_q + m_q{}^2 \ . \qquad (3)$$

Where m_c and m_q are current and thermal mass of quark [6, 10]. The values $n = 0, 1, 2, ...$, are the principle quantum numbers for allowed Landau levels, $s = \pm 1$ refers to spin up $(+)$ or down $(-)$ states, and k is the component of particle momentum along the direction of the external magnetic field. Setting $2\nu = 2n + s + 1$. In the strong magnetic field, the quarks are rarely excited thermally to the higher Landau levels, so only the lowest Landau levels $n = 0$ are populated.

Free energy in the presence of magnetic field

The modified free energy for quarks is defined in the presence of magnetic field along z-axis using Ref. [6, 10]. It is defined as:

$$F^{B\dagger} = F^0_q + F^B_q = F^0_q - eBM \ , \qquad (4)$$

where M is the magnetization. Here F^0_q is the free energy for fermions (quarks) in the limit of zero magnetic field [6, 10] and F^B_q is the free energy in the presence of magnetic field. It is defined as in Ref. [3],

$$F^B_q = -T g_q eB \int \rho_q(k) \ln[1 + e^{-E^{B\dagger}/T}] dk. \qquad (5)$$

The free energy for gluons will remain same as the gluons are not affected by the presence of

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a magnetic field, so the highest scale for them in a medium is still the temperature. The free energy for bosons (gluons) and interface term are taken same as in Ref. [6, 10]. Finally we calculate total free energy F_{total}:

$$F_{total} = F^{B\dagger} + F_{gluon} + F_{interface} \ . \tag{6}$$

The above total modified free energy can be useful to describe the evolution of QGP. Thus we can compute the speed of sound C_S^2 (Square) using total free energy with and without the magnetic field.

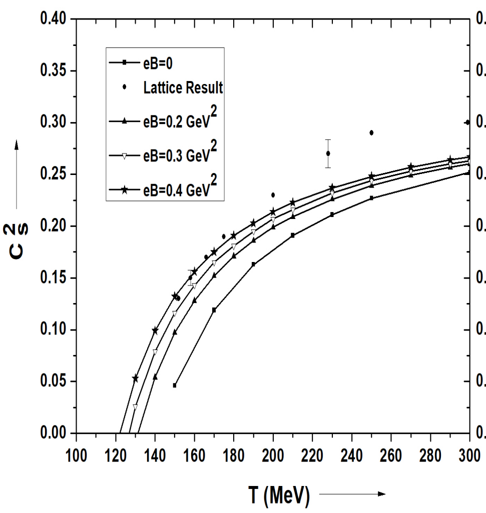

FIG. 1: The speed of sound C_S^2 with temperature (T) is plotted with the variation of magnetic field.

Results and discussion

The square of speed of sound (C_S^2) with temperature (T) is shown in the given figure. The presented result is significantly affected by the magnetic field, even at moderate values of B. Results are appreciably well and enhanced from other theoretical work and Lattice QCD simulations [5, 7, 10, 11]. Thus, the results are fairly good and confront to recent Lattice QCD results.

The work is to explore how the speed of sound in a hot medium affects in the presence of a strong magnetic field, which may be produced in the non-central events of ultra-relativistic heavy ion collisions. All thermodynamic observables have contributions from both quarks and gluons, where the quark contribution is affected strongly by the magnetic field whereas, the gluon part is largely unaffected in the presence of strong magnetic field. The current observations could have interesting implications on the expansion dynamics of the medium produced at RHIC and LHC in the presence of a strong magnetic field, which may influence the outcomes of various signatures. Using this modified model, the speed of sound is determined for a wide range of temperatures and magnetic fields up to $eB = 0.4GeV^2$. Finally we conclude that the model results with the help of effective quark mass dependent on magnetic field are significant. Overall the model outcomes can be favourable to describe the important properties of QGP created in the collisions of massive nuclei at RHIC and LHC.

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