QGP equation of state at small chemical potential

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Introduction

At high temperature and/or high chemical potential, quantum chromodynamics (QCD) predicts the order of phase transition from hadronic phase to the quark-gluon plasma phase. Such phase transition form a new state of matter, called the quark-gluon plasma (QGP) [1, 2].

It is now widely accepted that the ultra-relativistic heavy-ion collisions bring us information about the properties of QGP. One of the important goal of heavy-ion collisions is to explore the phase structure of hot and dense nuclear matter [1–3]. The determination of the QGP equation of state (EoS) is extremely important to the phenomenology of the quark-gluon plasma [4].

Model Description

Earlier we have calculated the free energy with effect of curvature term using dynamical quark mass [5] and further with finite quark mass [6]. Using these works, we now extend the calculations of QGP EoS of Ref. [7, 8] with the effect of small chemical potential in finite quark mass. The finite quark mass is now dependent on temperature and chemical potential and it is defined as:

$$m_q^2(T,\mu) = \gamma_q g^2(k) T^2 \left[1 + \frac{\mu^2}{\pi^2 T^2}\right] . \quad (1)$$

where, $g^2(k) = 4\pi\alpha_s$ and other parameters are used as Ref. [5, 6]. The parametrization factor $\gamma^2 = 2[\frac{1}{\gamma_q^2} + \frac{1}{\gamma_g^2}]$ is used with $\gamma_q = 1/6$ [6] and $\gamma_g = 0.02\gamma_q$ is used to fit into lattice QCD results.

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The free energy, F_i for quarks is modified with the inclusion of chemical potential and finite quark mass using Ref. [6–8]. It is defined as:

$$F_i = \mp T g_i \int dk \rho_i(k) \ln(1 \pm e^{-(\sqrt{m_i^2+k^2}-\mu)/T}) , \quad (2)$$

where $\rho_i(k)$ is the density of states of the particular particle i (quarks and gluons), and g_i is the degeneracy factor [7]. Using equation (2), we can calculate pressure and energy density using thermodynamic relation. It is given as Ref. [7, 8]:

$$P_i = -\frac{d}{dv} F_i . \quad (3)$$

The total pressure is the sum of the pressure due to all the constituents. Further the energy density is used as [7, 8],

$$\varepsilon = T\frac{d}{dT}P - P . \quad (4)$$

Using these relations, we calculate P/T^4 and ε/T^4. These relations are useful to study the quark gluon plasma equation of state using temperature and chemical potential dependent quark mass with curvature term. We can also compute entropy and speed of sound using above relation but here we are not taken into account.

Results

In Figures [1] and [2] we show the plots of P/T^4 and ε/T^4 with temperature (T) using small chemical potential including the curvature term. In both figures, we observe that

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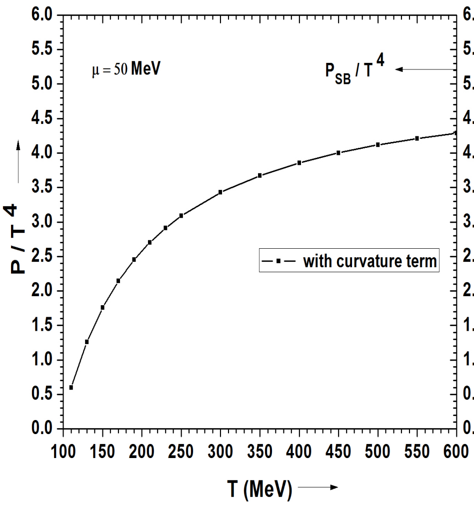

FIG. 1: The variation of P/T^4 with temperature (T) is shown at small chemical potential.

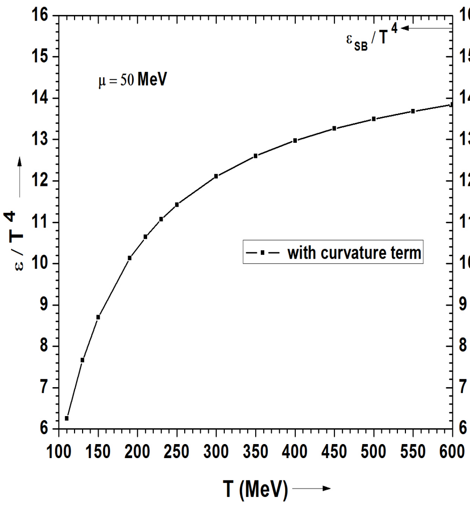

FIG. 2: The variation of ε/T^4 with temperature (T) is shown at small chemical potential.

there is small increment in all curves on account of introducing small chemical potential. The results are enhanced as comparison to the earlier work [7, 8]. Also thermodynamic variable such as pressure and energy density are nicely matched with the lattice QCD results especially at high temperature T$\sim$ 600 MeV. At such high temperature, P/T^4, ε/T^4 and entropy approach a value which is below the SB limit.

Therefore, our results using modified quark mass and chemical potential incorporating curvature term are in good agreement with our earlier work [7, 8]. It also shows that the theoretical model with the thermal correction in the quark mass including chemical potential and curvature term does not alter our previous results very much, in fact the change caused in the QGP EoS is improved significantly. Results are compared with the results of Ref. [7, 8]. Also the EoS predicted by other models are in conformity with lattice results [1–3].

Overall, the effect of chemical potential and modified quark mass shows a small increment in the results of QGP EoS. Therefore, our model results with the effect of chemical potential in quark mass and free energy with the inclusion of curvature term shows the useful information to study QGP EoS in high energy heavy-ion collisions.

References

[1] F. Brau and F. Buisseret, Phys. Rev. D **79**, 114007 (2009).

[2] F. Giacosa, Phys. Rev. D **83**, 114002 (2011).

[3] P. K. Srivastava, S. K. Tiwari, C. P. Singh, Phys. Rev. D **82**, 014023 (2010).

[4] N. Haque et al., J. High E. Phys **05**, 027 (2014).

[5] S. S. Singh et al., Pram. J. Phys. **74**, 27 (2010).

[6] Y. Kumar, JoP: Conf. Ser. **668**, 012110 (2016).

[7] D. S. Gosain and S. S. Singh, Int. J. Theo. Phys., **53**, 2688 (2014).

[8] Y. Kumar and S. S. Singh, EPJ Conf., **137**, 13008 (2017).