Shear Viscosity from finite volume PNJL model

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Introduction

Experiment of relativistic heavy ion collider (RHIC) has created a nearly perfect fluid [1–3], where shear viscosity to entropy density (η/s) ratio is so small that it almost reaches the lower bound ($\eta/s = 1/4\pi$) [4]. In the high temperature domain however, the theoretical calculations using perturbative methods surprisingly do not lead to such small value of η/s. There it behaves as weakly interacting gas, having relatively large value (10-20 times larger than lower bound) [5]. To resolve this discrepancy between experimental and theoretical values, different alternative calculations, based on effective QCD models [6] and hadronic models [7] have been studied in recent times. Some estimations are also done from the direction of transport simulations [8] and Lattice QCD calculations [9]. These analysis were carried out for infinite size systems. Effects of finiteness in system volumes have not however been considered which we are studying in this work.

Shear Viscosity

Green-Kubo relation [10] connects transport coefficients like shear viscosity η to their respective thermal fluctuation or correlation functions. Our aim of this work is to calculate the viscous coefficient of quark matter under the framework of PNJL model and to notice their changes because of the finite size consideration of medium. Here, we start with the following expression,

$$\eta = \frac{g}{15T}\int \frac{d^3\vec{k}}{(2\pi)^3}\tau_Q\left(\frac{\vec{k}^2}{\omega_Q}\right)^2 [f_Q^+(1-f_Q^+) + f_Q^-(1-f_Q^-)] \; ; \tag{1}$$

described in [11]. The method of Relaxation Time Approximation (RTA) has been used for the purpose.

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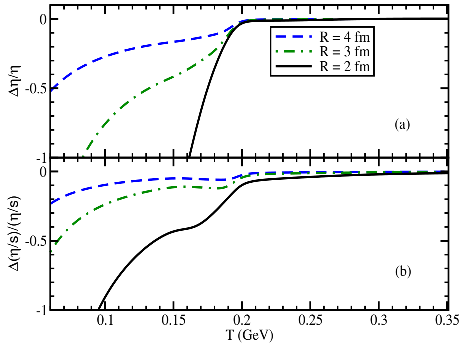

FIG. 1: Difference between the results of finite and infinite R for the quantities - shear viscosity η (a) and shear viscosity to entropy density ratio η/s (b).

Results and discussions

Using Eq. (1), we can generate $\eta(T)$ for different values of R following the technique described in [11]. Fig. 1(a) shows relative change in η, defined as,

$$\frac{\Delta\eta}{\eta} = \frac{\eta(R=\infty) - \eta(R)}{\eta(R=\infty)} \; , \tag{2}$$

The negative values of $\Delta\eta/\eta$ below $T = 200$ MeV indicate that shear viscosity gets enhanced because of finite size effect. In one

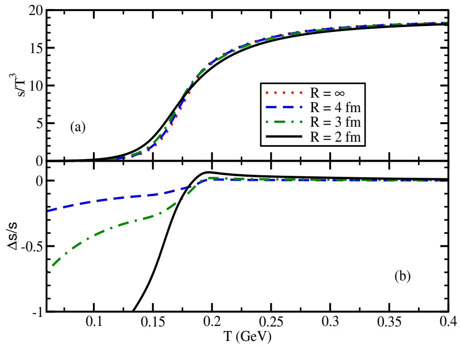

FIG. 2: (a) T dependence of entropy density, normalized by T^3 for different values of R. (b) Difference between finite and infinite matter results for entropy density.

side, η should be decreased because of lower momentum cutoff in Eq. (1), while on other side, reduction of constituent quark mass for finite R will act on the integrand part of Eq. (1) to enhance the values of η. Latter source dominates over the former one, therefore, a net enhancement of $\eta(T < 200$ MeV) is observed in our results. Next, to discuss the finite size effect on η/s, shown in Fig. 1(b), let us focus on entropy density s, obtained from the thermodynamical potential Ω. Figs. 2(a) and (b) show the T dependences of s/T^3 and $\Delta s/s$ for different values of R. When this finite size effect of s at low T enters into the quantity η/s, a less amount of enhancement of η/s has been found with respect to the enhancement of η. For example, at $T = 170$ MeV and $R = 2$ fm in Fig. (1), we see that 70% enhancement in η shrinks to 40% enhancement in η/s. Also, for vanishing chemical potential, we observe only cross-over transitions, which is true for all R. So no discontinuity in η or η/s is observed. However, with decreasing R, T_c is supposed to decrease [12] and that is visible in Fig. 1(b). The locations of slight bending there, grossly representing the transition region, shift towards lower T with decrease in R.

Summary

As a first attempt to investigate the qualitative changes brought about by finite size effect on transport coefficients of quark matter, we have adopted here a simple idea of taking non-zero lower momentum cut-off under the framework of PNJL model. The results indicate a considerable change in low temperature region. Further investigation in terms of quantitative accuracy is in process.

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References

[1] P. Romatschke and U. Romatschke, Phys. Rev. Lett. **99**, 172301 (2007).

[2] M. Luzum and P. Romatschke, Phys. Rev. C **78**, 034915 (2008).

[3] V. Roy, A. K. Chaudhuri and B. Mohanty, Phys. Rev. C **86**, 014902 (2012).

[4] P. Kovtun, D. T. Son, and O. A. Starinets, Phys. Rev. Lett. 94, 111601 (2005).

[5] P. B. Arnold, G. D. Moore, and L. G. Yaffe, J. High Energy Phys. 11, 001 (2000); 05, 051 (2003).

[6] S. K. Ghosh, S. Raha, R. Ray, K. Saha, S. Upadhaya, Phys. Rev. **D 91**, 054005 (2015).

[7] S. Mitra, S. Ghosh, and S. Sarkar Phys. Rev. **C 85**, 064917 (2012).

[8] N. Demir and S.A. Bass Phys. Rev. Lett. **102**, 172302 (2009).

[9] H. B. Meyer, Phys. Rev. **D 76**, 101701 (2007); Phys. Rev. **D 82**, 054504 (2010).

[10] M. S. Green, J. Chem. Phys. 22, 398 (1954); R. Kubo, J. Phys. Soc. Jpn. 12 **570** (1957).

[11] K. Saha, S. Ghosh, S. Upadhaya, and S. Maity, Phys. Rev. D **97** 116020 (2018).

[12] A. Bhattacharyya, S. K. Ghosh, R. Ray, K. Saha and S. Upadhaya, Euro. phys. Lett. **116** 52001 (2016).