Bulk viscosity from the Polyakov–Nambu–Jona-Lasinio model

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Introduction

The insufficiency of ideal fluid dynamics to reproduce certain expected results threw light on the necessity of dissipative effects. The viscosity coefficients give an estimate of the hydrodynamical evolution of fluid dissipative processes. Not only do they provide information about the deviation of the system from ideal hydrodynamics, they also give us a picture of the fluid dynamics and critical phenomena. In this work we concentrate on the effects of bulk viscosity. Bulk viscosity bears essential significance like in the context of violation of scale invariance. Now, the smallness of sound velocity being directly related to the former, it becomes obvious that bulk viscosity will show a peak-like nature in the critical region. Bulk viscosity manifests itself by an addition of the diagonal term $\pi\delta^{ij}$ to the stress tensor T^{ij} in the local rest frame. In this work we take resort to the Kubo formalism [1] which relates viscosity coefficients to the correlation functions of the energy-momentum (E-M) tensor. It can be shown that the bulk viscosity ζ is obtained as,

$$\begin{aligned}\zeta \quad &= \tfrac{1}{9\omega_0}[-6(-F_\pi^2 M_\pi^2 - F_k^2 M_k^2) + (T\tfrac{\partial}{\partial T} \\ &+\mu\tfrac{\partial}{\partial\mu} - 2)\textstyle\sum_f m_f < \bar{q}_f q_f >_* + 16|\epsilon_v| \\ &+Ts(\tfrac{1}{c_s^2} - 3) + (\textstyle\sum_f \mu_f \tfrac{\partial}{\partial\mu_f} - 4)T^5 \tfrac{\partial(\frac{P}{T^4})}{\partial T}] \quad (1)\end{aligned}$$

In this work, we use a 2+1 flavor Polyakov-Nambu-Jona-Lasinio(PNJL) model considering upto eight quark interaction terms. The details of the terminology and mechanism and also details of the model can be found in [2].

Results and Discussions

To have a qualitative idea regarding the nature of specific bulk viscosity $\frac{\zeta}{s}$, we initially use the simplified kinetic approximation. In AdS/CFT for a system of photon gas radiated from massive particles, $\zeta \geq 2\eta(\frac{1}{3} - c_s^2)$. Near transition region, the square of speed of sound, c_s^2 shows the highest deviation from conformal invariance. This causes specific bulk viscosity, $\frac{\zeta}{s}$ to attain a maximum around that region. The result from our model is portrayed in Fig. 1. Now for detailed estimate of the bulk viscosity we employ the Kubo formalism. The bulk viscosity being directly related to the strength of interaction, which being maximum around transition region causes the hike in bulk viscosity near T_c as is observed in the left panel of Fig. 2. Here we have plotted ζ for three representative values of ω_0. At this point it will be interesting to see its behavior as we move to the non-zero quark chemical potential (μ_q) domain, shown in right panel of Fig. 2 with ω_0 =1GeV. The peaks now appear at the corresponding transition temperatures. Keeping in mind the importance of dimensionless quantities, we now opt to compute the specific bulk viscosity, $\frac{\zeta}{s}$. This is shown in the left panel of Fig. 3 for vanishing chemical potential vis-a-vis Lattice QCD predictions [3]. The sharp rise in $\frac{\zeta}{s}$ is attributed mainly to the behavior of trace anomaly discussed earlier. Results in the non-zero μ_q section are shown in the right panel of Fig. 3, which indicate the importance of incorporating effects of bulk viscosity especially in the data analysis of upcoming experiments at GSI.

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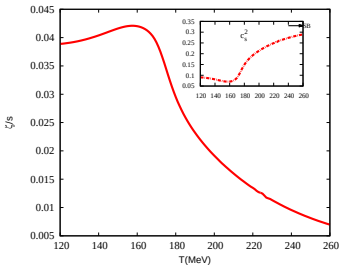

FIG. 1: (color online)Predicting the nature of specific bulk viscosity as a function of temperature at vanishing chemical potential from kinetic theory approaches.

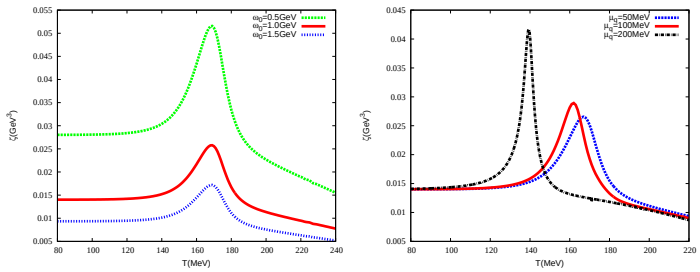

FIG. 2: (color online)ζ as a function of temperature at zero and non-zero quark chemical potentials.

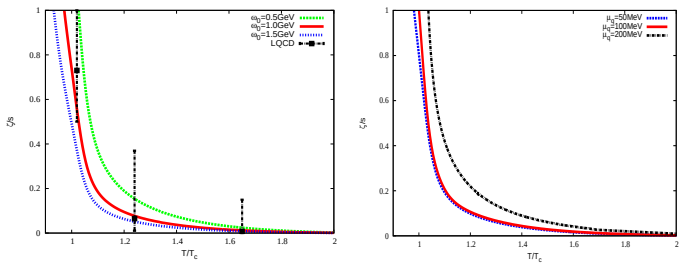

FIG. 3: (color online)$\frac{\zeta}{s}$ as a function of temperature at vanishing as well as finite chemical potentials.

Conclusions

The behavior of bulk viscosity as predicted in our model at vanishing chemical potential meets the general predictions made from the kinetic theory approach. The specific bulk viscosity shows a quick rise around the transition region where the system possesses maximum strength of interaction. In the non-zero chemical potential domain, the results show the importance of incorporation of this effect especially in the upcoming experiments at GSI.

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