Shear viscosity of hot hadrons - contribution from strange mesons

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Nuclear collisions at Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) may produce a very hot and dense state of matter with quarks and gluons as its elementary constituents, this state of matter is known as quark-gluon plasma (QGP). The shear viscosity (η) to entropy density (s) ratio has recently been used to characterize the QGP created in the experiments conducted at RHIC and LHC. Therefore, microscopic calculations of shear viscous coefficient of both QGP and hot hadrons are crucially important. Hot hadronic system will be produced as a result of conversion of QGP to hadrons at the transition temperature.

In the present article, the focus is being made on how much the K meson component contributes to the shear viscosity in the hadronic matter.

For a hot hadronic medium, where kaons and pions are the main constituents, the shear viscosity can be written using the simplest one-loop expression for kaon (as shown in Fig. 1(a)) in the quasi-particle

$$\eta_K = \frac{4\beta}{30\pi^2}\int_0^\infty \frac{d\mathbf{k}\mathbf{k}^6}{{\omega_k^K}^2\Gamma_K} n_k(\omega_k^K)\{1+n_k(\omega_k^K)\}\,, \tag{1}$$

where $n_k(\omega_k^K) = 1/\{e^{\beta\omega_k^K} - 1\}$ represents the Bose-Einstein (BE) distribution function of kaon with energy $\omega_k^K = (\mathbf{k}^2 + m_K^2)^{1/2}$ and Γ_K is the in-medium thermal width of kaon.

The thermal width can be evaluated from the imaginary part of kaon self-energy at finite temperature by using Cutkosky's rule. Considering only πK^* and $K\phi$ loops for calculating kaon self-energy shown in Fig. 1(b), we can write total thermal width of kaon Γ_K as

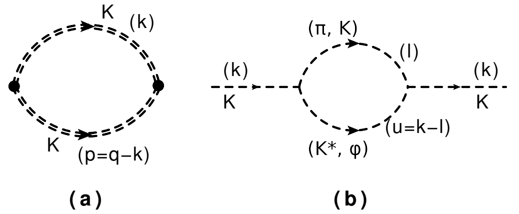

FIG. 1: The figure (a) represents viscous-stress tensor for the medium with constituents of K-meson upto one loop order having some finite thermal width, which can be derived from the kaon self-energy diagrams (b), where πK^* and $K\phi$ are possible intermediate loops.

$$\begin{aligned}\Gamma_K &= -\mathrm{Im}\Pi^R_{K(\pi K^*)}(k_0 = \omega_k^K, \mathbf{k})/m_K \\ &\quad -\mathrm{Im}\Pi^R_{K(K\phi)}(k_0 = \omega_k^K, \mathbf{k})/m_K\,,\end{aligned} \tag{2}$$

where $\Pi^R_{K(\pi K^*)}(k)$ and $\Pi^R_{K(K\phi)}(k)$ are kaon self-energies for πK^* and $K\phi$ loops. Superscript R stands for retarded component and subscripts represent the external (outside the bracket) and internal (inside the bracket) particles for the kaon self-energy graphs as shown in Fig. 1(b).

In Fig. 2, we have plotted shear viscosity of kaon component (solid line) by using (a) constant relaxation time $\tau = 1/\Gamma_K$ and (b) temperature (T) dependent relaxation time $\tau(T)$, calculated from Eq. (2). The corresponding results for pion component, taken from Ref. [2], are drawn by dotted line in

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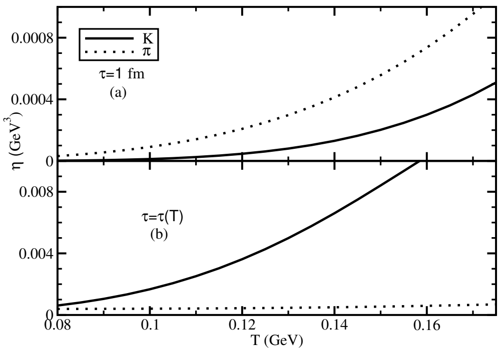

FIG. 2: Temperature dependence of the shear viscosities of kaon (solid line) and pion (dashed line) for (a) $\tau = 1$ fm and (b) $\tau = \tau(T)$.

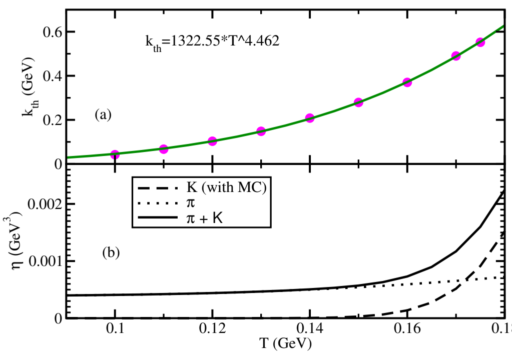

FIG. 3: Temperature dependence of (a) threshold momentum or momentum cutoff (MC) and (b) shear viscosity of kaon with MC (dashed line), pion (dotted line) and their total (solid line).

Fig. 2(a) and (b). We notice that η of kaon component for constant τ is smaller than η of pion but their roles just become opposite for temperature dependent relaxation time. This is because our calculated relaxation time or mean free path of kaon is much larger than that of pion, therefore, in that case, the kaon component of η dominates over the pion component η. The mean free path of kaon, calculated from the relation $\lambda_K = \mathbf{k}/(\omega_k^K \Gamma_K)$, is observed to exceed the dimension of matter formed at RHIC or LHC ($\sim$ 10 fm) in the high momentum domain. Therefore, we have numerically searched a threshold momentum $\mathbf{k}_{\rm th}$ or momentum cutoff for a certain temperature when $\lambda_K = 10$ fm. This $\mathbf{k}_{\rm th}$ is parametrized by $\mathbf{k}_{\rm th} = 1322.55 \times T^{4.462}$ and shown in Fig. 3(a). Now, we have used this $\mathbf{k}_{\rm th}(T)$ as upper limit of momentum integration of Eq. (1) as kaon with high momentum, whose $\lambda_K > 10$ fm, will not play any role in the dissipation process. We see that shear viscosity of kaon with MC (dashed line), as shown in Fig. 3(b), plays an important role beyond the $T = 0.150$ GeV with respect to pion component (dotted line) and our results indicate that kaon component may play dominant role than pion near the quark-hadron transition temperature. This fact is well in accordance with the results of Ref. [3, 4].

It may be mentioned here that we have included kaon-nucleon interaction in the evaluation of η and found that this contribution is insignificant.

Acknowledgments

MR, Snigdha Ghosh (CNT project No. 3/2/3012/VECC/R&D-I/1928) are supported from DAE. Sabyasachi Ghosh is financially supported from UGC Dr. D. S. Kothari Post Doctoral Fellowship under grant No. F.4-2/2006 (BSR)/PH/15-16/0060.

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