Shear Viscosity of a pion gas in a thermomagnetic medium

Pallavi Kalikotay[1,2],* Snigdha Ghosh[3],
Nilanjan Chaudhuri[4,5], Pradip Roy[5,6], and Sourav Sarkar[4,5]
[1] *Department of Physics, Kazi Nazrul University, Asansol - 713340, West Bengal, India*
[2] *Department of Physics, Jadavpur University, Jadavpur-700032, West Bengal, India*
[3] *Government General Degree College at Kharagpur-II,*
Madpur, Paschim Medinipur - 721149, West Bengal, India
[4] *Variable Energy Cyclotron Centre, 1/AF Bidhannagar, Kolkata 700064, India*
[5] *Homi Bhabha National Institute, Training School Complex,*
Anushaktinagar, Mumbai - 400085, India and
[6] *Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata - 700064, India*

The strong magnetic field generated in non central heavy collisions at RHIC and LHC produce many novel and interesting phenomena. This external magnetic field also affects the space-time evolution of matter produced in heavy ion collisions. In [1] it was shown that the obtained values of electrical conductivity for a pionic system causes a significant delay in the decay of external magnetic field produced in non-central heavy ion collisions. The study of shear viscosity is important as it is essential for understanding the cross over between hadronic and quark matter. The estimation of shear viscosity in external magnetic field plays a crucial role in understanding the evolution of strongly interacting matter in non-central heavy ion collisions.

The external magnetic field introduces an anisotropy in the system and one obtains five different shear viscosity coefficients out of which one is longitudinal shear viscosity and the remaining four are transverse shear viscosities. In this work we have made an attempt to calculate the shear viscosity coefficients in the thermomagnetic medium (thermal medium in presence of non-zero magnetic field). The four transverse shear viscosity coefficients vary with relaxation time τ and cyclotron frequency ω_c as $\eta_1 \sim \frac{\tau}{1+(2\tau\omega_c)^2}$, $\eta_2 \sim \frac{\tau}{1+(\tau\omega_c)^2}$, $\eta_3 \sim \frac{\tau^2\omega_c}{1+(2\tau\omega_c)^2}$, $\eta_4 \sim \frac{\tau^2\omega_c}{1+(\tau\omega_c)^2}$

The behaviour of the shear viscosities in a thermomagnetic medium is explained using a $1/T^3$ kind of dependence of relaxation time in a thermomagnetic medium as shown in Fig.1. The temperature dependence of η_1/T^3 can be explained from $\eta_1/T^3 \sim \frac{\tau T}{1+(2\omega_c\tau)^2}$. For $\omega_c\tau << 1$, corresponding to lower eB values, $\eta_1/T^3 \sim \tau T \sim 1/T^2$ and for $\omega_c >> 1$, cor-

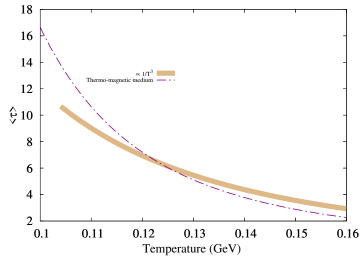

FIG. 1: The variation of the average relaxation time $\langle\tau\rangle$ of pions as a function of the temperature in a thermomagnetic medium.

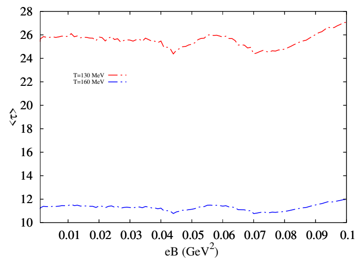

FIG. 2: The variation of the average relaxation time $\langle\tau\rangle$ of pions as a function of the magnetic field in a thermomagnetic medium.

*Electronic address: orionpallavi@gmail.com

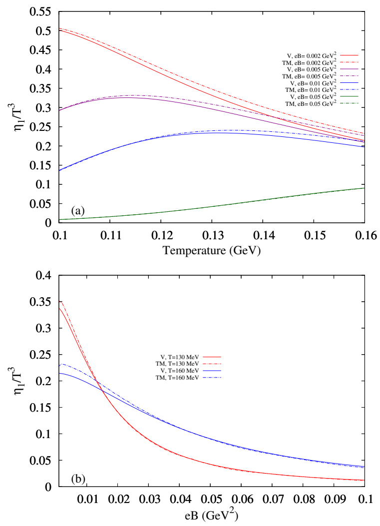

FIG. 3: Variation of η_1/T^3 with temperature and different magnetic field strengths. The solid and dashed curves correspond to the estimations of η_1/T^3 in vaccuum (V) and thermomagnetic medium (TM) respectively.

responding to higher eB values $\eta_1/T^3 \sim T^4$ as seen in Fig.[3(a)].At intermediate eB values the variation of η_1/T^3 is non-monotonic which is due to the interplay of both temperature and magnetic field.

The variation of η_1/T^3 with eB comes from $\eta_1/T^3 \sim \frac{\tau}{1+(2\omega_c\tau)^2}$. As τ is approximately constant with eB as seen in Fig.[2], the η_1/T^3 variation with temperature can be explained using the values of ω_c. Thus with the increase in ω_c, η_1/T^3 decreases monotonically as evident from Fig.[3(b)]. In a thermomagnetic medium, $\eta_1/T^3 \propto \tau$ for lower eB values and $\eta_1/T^3 \propto \frac{1}{\tau}$ for higher eB values, thus for lower (higher) eB values η_1/T^3 is higher (lower) compared to its vacuum counterpart.

The variation of η_3/T^3 with temperature is given by $\eta_3/T^3 \sim \frac{\tau^2 T}{1+(2\omega_c\tau)^2}$. At low eB values $\eta_3/T^3 \sim 1/T^5$ whereas for higher eB values $\eta_3/T^3 \sim T$ which is in agreement with Fig.4(a). Variation of η_3/T^3 with eB can be explained using $\eta_3/T^3 \sim \frac{\tau^2\omega_c}{1+(2\omega_c\tau)^2}$. τ^2 appearing in the numerator has an effect of causing oscillations due to the eB dependence of τ and $\frac{\omega_c}{1+(2\omega_c\tau)^2}$ renders a Breit-Wigner like structure as evident from Fig.4(b).

In a thermomagnetic medium, η_3/T^3 increases for all values of eB. It must be noted that η_2 and η_4 will show variations with temperature and magnetic field similar to that of η_1 and η_3 respectively.

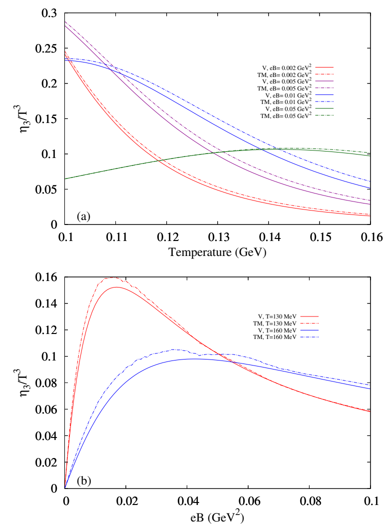

FIG. 4: Variation of η_3/T^3 with temperature and different magnetic field strengths. The solid and dashed curves correspond to the estimations of η_1/T^3 in vaccuum (V) and thermomagnetic medium (TM) respectively.

The calculated values of shear viscosity coefficients in a thermomagnetic medium experiences a significant change compared to its vacuum counterpart. This is expected to have important consequences on the space-time behaviour of non-central heavy ion collisions.

References

[1] P. Kalikotay, S. Ghosh, N. Chaudhuri, P. Roy and S. Sarkar, Phys. Rev. D 102, 076007 (2020).