Electrical and Hall conductivities of a pion gas in thermal and magnetic medium

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

Due to the collision geometry in non central heavy ion collisions at RHIC and LHC, a strong magnetic field of the order of 10^{18}G or larger is generated. This magnetic field can produce significant influence on the matter created in heavy ion collisions. In the presence of magnetic field the evolution of the matter is studied using Magnetohydrodynamics (MHD). Transport coefficients goes as an input into the hydrodynamic equations. Electrical conductivity is one of the important transport coefficients in the formulation of MHD. Phenomenologically, a large electrical conductivity in a non-central heavy ion collision implies that the magnetic field thus generated sustains for a longer time. From earlier studies it has been found that due to the smaller electrical conductivity value in hadronic matter, the magnitude of magnetic field is quite small. The various physical quantities evaluated for hadronic matter in magnetic field will undergo minor changes as compared to the quark matter. Hence, we try to evaluate the electrical conductivity in magnetic medium taking into account the combined effects of finite temperature and magnetic field.

In this work, we evaluate the electrical and hall conductivities of a system of pion gas using the kinetic theory approach in the relaxation time approximation. We obtain the explicit expression for the various components of the conductivities using the Boltzmann transport equation in presence of magnetic field [1]. The relaxation time has been evaluated using the thermal field theoretical techniques.

The thermal medium has an effect of increasing the average relaxation time compared to its vaccum counterpart as seen in Fig.1. This is due to the additional decay and scattering of ρ and σ in the thermal bath.

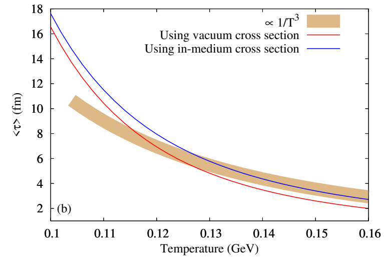

FIG. 1: The variation of the average relaxation time $\langle\tau\rangle$ of pions as a function of the temperature calculated using the vacuum and in-medium cross sections. The average relaxation time shows a $1/T^3$ kind of behaviour.

In Fig.2 (a)-(c) we study the variation of σ_0/T with temperature, magnetic field and also highlight the medium effects. The tempertaure dependance of σ_0/T is given by $\frac{\tau T}{1+(\omega_c\tau)^2}$ where, τ is the relaxation time and ω_c is the cyclotron frequency. At low magnetic field, $\omega_c\tau << 1$, hence $\sigma_0/T \sim \tau T \sim \frac{1}{T^2}$ and at high magnetic field, $\omega_c\tau >> 1$ hence $\sigma_0/T \sim \frac{T}{\tau} \sim T^4$ which is evident from Fig.2(a) and (b) respectively. σ_0/T depends on magnetic field as $\frac{1}{1+(\omega_c\tau)^2}$. As magnetic field increases, ω_c increases implying σ_0/T decreases with magnetic field. The medium effects can be understood from the medium

---

[*] Electronic address: `orionpallavi@gmail.com`

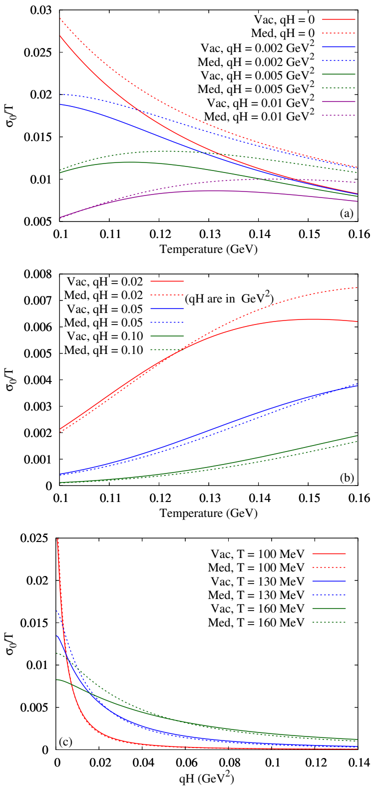

FIG. 2: Variation of σ_0/T with temperature and different magentic field strengths. The solid and dashed curves correspond to the estimations of σ_0/T using the vacuum and in-medium cross sections, respectively.

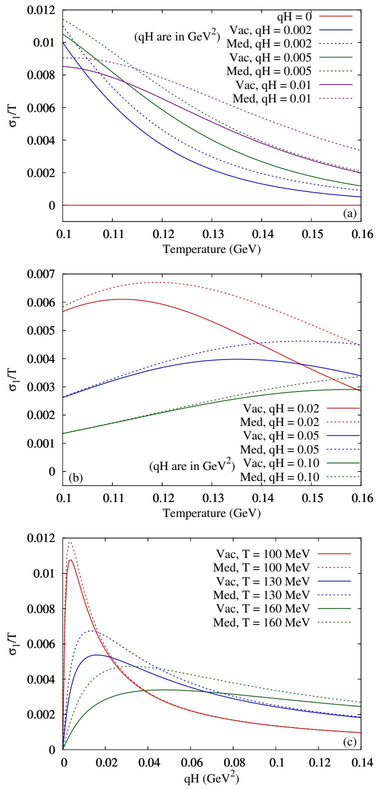

FIG. 3: Variation of σ_1/T with temperature and different magentic field strengths. The solid and dashed curves correspond to the estimations of σ_0/T using the vacuum and in-medium cross sections, respectively.

effects on relaxation time. At low magnetic field $\sigma_0/T \sim \tau$, hence medium effect increases σ_0/T. At high magnetic filed, $\sigma_0/T \sim \frac{1}{\tau}$, hence medium effect decreases σ_0/T.

We now investigate the temperature dependance of σ_1/T which is given by relation $\frac{\tau^2 T}{1+(\omega_c\tau)^2}$. At low magnetic field, $\omega_c\tau << 1$ hence $\sigma_1/T \sim \tau^2 T \sim \frac{1}{T^5}$ and at high magnetic field, $\omega_c\tau >> 1$ hence $\sigma_1/T \sim T$ which is clearly seen in Fig.3(a) and (b). σ_1/T shows magnetic field dependance through the relation $\frac{\omega_c}{1+(\omega_c\tau)^2}$ which is a Breit-Wigner function of the magnetic field as shown in Fig.3(c). Medium effects can be understood from the relation $\sigma_1/T \sim \frac{\tau^2\omega_c}{1+(\omega_c\tau)^2}$, which results in the increasing magnitude of σ_1/T for any value of magnetic field under the use of in medium cross section.

The calculated electrical conductivity is seen to be sufficient for causing a significant delay in the decay of the external magnetic field in a heavy ion collision. This leads to the conclusion that, a weak magnetic field can be present in the later stage of a heavy ion collision (in hadronic phase) and could be phenomenologically relevant.

References

[1] Phys. Rev. D 102, 076007 (2020).