Study of chiral dependent charge and heat conductivity and their associated numbers in thermal QCD

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Introduction

The heavy-ion collisions in the CERN SPS, RHIC, BNL, and LHC accelerators are thoroughly studied to yield insights about nuclear matter properties under extreme conditions. The predictions of charged hadron elliptic flow from RHIC [1] and their theoretical explanations using dissipative hydrodynamics [2] provided the experimental evidence of existence of the transport processes in the QGP. These transport coefficients are not directly measurable experimentally, rather serve as input parameters in the theoretical modelling of experimental observables such as directed flow, elliptic flow etc. Charge transport turns out to be an effective signature of electromagnetic response in strongly interacting systems whereas heat transport plays a crucial role in hydrodynamic study of the system. Further, Knudsen number and Lorenz number give the idea about the collective behaviour of the system. The interactions among partons are accounted for by the quasiparticle mass of partons, in which the degeneracy in mass of chiral modes of quarks is lifted in the presence of a weak magnetic field.

Quasiparticle Model

The interaction among quasiquarks and quasigluons can be incorporated through medium dependent mass of quasiparticles which can be evaluated using oneloop perturbative thermal QCD. Gluons do not interact with magnetic field and hence they will possess the thermally generated mass as [3]

$$m_g^2 = \frac{1}{6} g^2 T^2 \left(C_A + \frac{1}{2} N_f \right).$$

The quark propagator in the presence of weak magnetic field can be expressed in the power series of $(q_f B)$ and hence the one-loop quark self energy upto $\mathcal{O}(q_f B)$ can be determined. Employing the general covariant structure of quark self energy in terms of chiral projection operator and Schwinger-Dyson equation, the effective quark propagator is obtained to be as

$$S^*(P) = \frac{1}{2} \left[P_L \frac{\not{L}}{L^2/2} P_R + P_R \frac{\not{R}}{R^2/2} P_L \right].$$

The static limit $(p_0 = 0, |\mathbf{p}| \to 0)$ of $L^2/2$ and $R^2/2$ will give the different medium generated mass for L and R mode thus lifting up the degeneracy in mass which is in contrast to the case of strong magnetic field as

$$m_L^2 = m_{th}^2 + 4g^2 C_F M^2,$$
$$m_R^2 = m_{th}^2 - 4g^2 C_F M^2.$$

Charge and heat transport

Assuming the distribution functions to deviate only slightly from equilibrium $(\delta f << f_0)$, the charge and heat transport coefficients are respectively obtained from Boltzmann equation under RTA as

$$\sigma_{\text{Ohmic}} = \frac{1}{6\pi^2 T} \sum_f g_f q_f^2 \tau_f \int dp \frac{p^4}{\varepsilon_f^2} \frac{1}{(1+\omega_c^2 \tau_f^2)} \left[f_f^0 (1 - f_f^0) + \bar{f}_f^0 (1 - \bar{f}_f^0) \right],$$

$$\sigma_{\text{Hall}} = \frac{1}{6\pi^2 T} \sum_f g_f q_f^2 \tau_f^2 \int dp \frac{p^4}{\varepsilon_f^2} \frac{\omega_c}{(1+\omega_c^2 \tau_f^2)} \left[f_f^0 (1 - f_f^0) - \bar{f}_f^0 (1 - \bar{f}_f^0) \right],$$

$$\kappa_{0/1} = \sum_f \frac{g_f \tau_f (\tau_f^{0/1})}{6\pi^2 T^2} \int dp \frac{p^4}{\varepsilon_f^2} \left[\frac{(\varepsilon_f - h_f)^2 \omega_c^{0/1}}{(1+\omega_c^2 \tau_f^2)} f_f^0 (1 - f_f^0) + \frac{(\varepsilon_f + \bar{h}_f)^2 (-\omega_c^{0/1})}{(1+\omega_c^2 \tau_f^2)} \bar{f}_f^0 (1 - \bar{f}_f^0) \right],$$

where, $\kappa_{0/1}$ is the thermal/Hall-type thermal conductivity.

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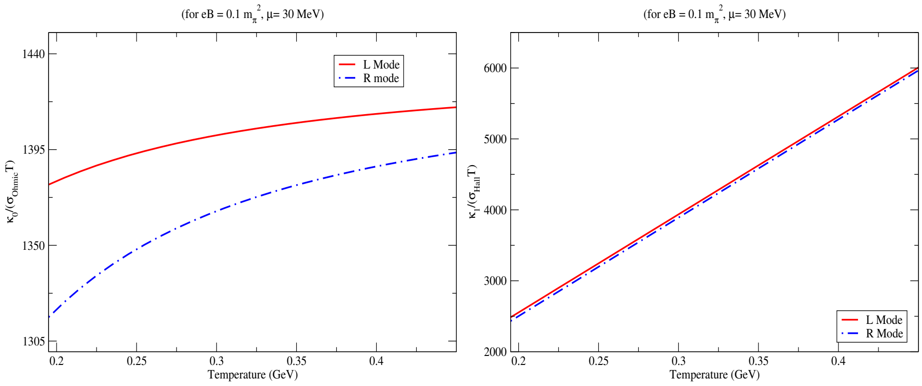

FIG. 1: Variation of Lorenz and Hall Lorenz number with temperature.

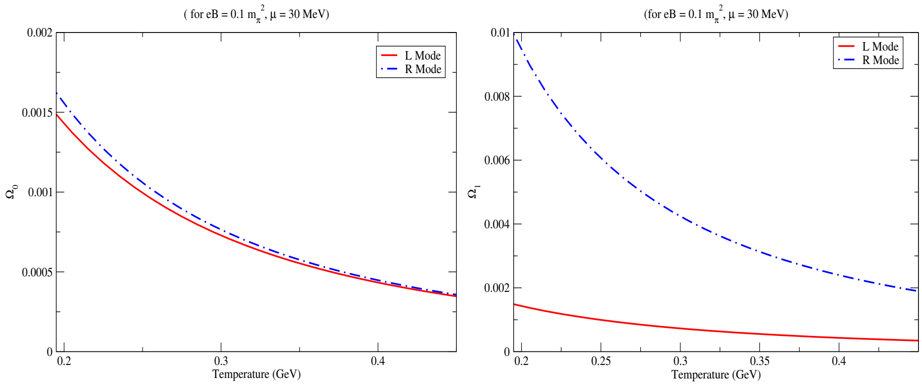

FIG. 2: Variation of Knudsen and Hall-type Knudsen number with temperature.

Lorenz and Hall Lorenz number

Using Wiedemann-Franz law, one can comprehend the relationship between charge and heat transfer coefficients. From Fig.(1), it is clear that Lorenz and Hall Lorenz number is not constant with temperature for both chiral modes, unlike metals where it is nearly the same at 273 and 373 K according to the Drude model, thereby violating the Wiedemann-Franz law.

Knudsen and Hall-type Knudsen number

The degree of thermalization in the fluid produced in heavy ion collision can be characterized by the dimensionless parameter known as Knudsen number. It is evident from Fig.(2) that the Knudsen number (Ω_0 and Ω_1) is less than unity for both modes in the presence of weak magnetic field at finite chemical potential thus ensuring the system to be in thermal equilibrium. A small value of Knudsen number implies large number of collisions, which bring the system back to local equilibrium.

References

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