Wiedemann-Franz Law for the Strongly Interacting Matter in a Color String Percolation Approach

S. K. Tiwari[1],* P. Sahoo[2],† and R. Sahoo[2]‡
[1] *Muzaffarpur Institute of Technology, Muzaffarpur, Bihar - 842003, INDIA and*
[2] *Discipline of Physics, School of Basic Sciences, Indian Institute of Technology Indore, Simrol, Khandwa Road, Indore- 453552, INDIA*

Introduction

Transport coefficients are the important probes in understanding the QCD matter created in high-energy heavy-ion collisions. Among all the transport coefficients, the electrical and thermal conductivities have got special significance in studying the time evolution of the created matter. The space-time evolution of the created matter can be quantified by the energy-momentum dissipation. The distortion in momentum distribution, due to velocity gradient gives rise to viscous forces. Thermal dissipation also happens due to temperature gradient in the system, which can be described in terms of thermal conductivity (κ). A very strong electromagnetic field of the order of m_π^2 is expected to generate in the early stages of non-central heavy-ion collisions. The electrical conductivity (σ_{el}) plays an important role to understand the impact of the fields on the created electromagnetically charged QCD matter. It provides a measure of the electric current being induced in the response of the early stage electric field [1]. The ratio of thermal and electrical conductivity reflects the competition between heat transport and momentum transport in the medium, respectively, leading to the verification of Wiedemann-Franz Law for a QCD matter.

We have used color string percolation method to estimate thermal conductivity (κ), electrical conductivity (σ_{el}) and their ratio as a function of temperature.

Formulation

The electrical conductivity in the color string percolation model (CSPM) using relaxation time approximation is given by [2],

$$\sigma_{\rm el} = \frac{1}{3T}\sum_{\rm k=1}^{M} q_{\rm k}^2 n_{\rm k}\lambda_{\rm mfp}. \quad (1)$$

Now, considering the density of up quark (u) and its antiquark ($\bar{u}$) in the calculation, we get the expression for $\sigma_{\rm el}$ as [2],

$$\sigma_{\rm el} = \frac{1}{3T}\frac{4}{9}e^2 n_{\rm q}(T)\frac{L}{(1-e^{-\xi})}. \quad (2)$$

Here, the pre-factor 4/9 reflects the fractional quark charge squared ($\sum_{\rm f} q_{\rm f}^2;\ q_{\rm f} = \frac{2}{3}$) and $n_{\rm q}$ denotes the total density of quarks or antiquarks. Here, e^2 in the natural unit is taken as $4\pi\alpha$, where $\alpha = 1/137$.

The expression of the thermal conductivity for strongly interacting matter is,

$$\kappa = \frac{\sum_k \pi^2 n_k \lambda_{\rm mfp}}{9} \quad (3)$$

The above equation in the context of CSPM is reduced as,

$$\kappa = \frac{\pi^2}{9}\frac{\sum_{k=partons} n_k L}{(1-e^{-\xi})} \quad (4)$$

The detailed formulation of electrical and thermal conductivities can be found in [2].

*Electronic address: sktiwari4bhu@gmail.com
†Electronic address: pspragatisahoo@gmail.com
‡Electronic address: Raghunath.Sahoo@cern.ch

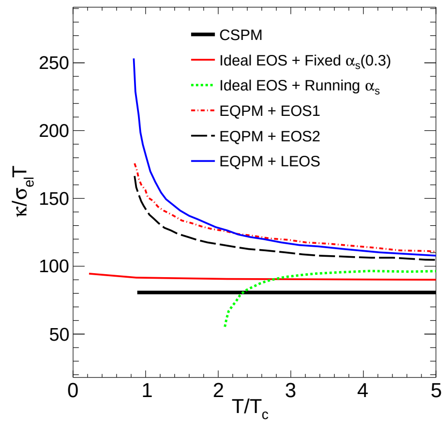

FIG. 1: The ratio of thermal conductivity and electrical conductivity as a function of T/T_c is shown for various EOS.

Results and Discussions

Fig. 1 shows the Wiedemann-Franz law as a function of $\mathrm{T/T_c}$, where T_c is the critical point. The black solid line represents the results calculated using CSPM. The red solid and green dotted lines show the results of Ideal EOS for various coupling strength. The red dash-dotted, black dotted and blue lines are the results obtained in different versions of quasiparticle model. We notice that, $\kappa/\sigma_{el}T$ is almost independent of $\mathrm{T/T_c}$ in CSPM. The results of CSPM are closer to the Stefan-Boltzmann (SB) limit of an ultra-relativistic gas of gluons and quarks. The solid red and green dashed lines are the results calculated in the framework of ideal EOS for quarks and gluons. The former is for the fixed strong coupling strength ($\alpha_s = 0.3$), which showing a weak dependence on temperature particularly at a lower $\mathrm{T/T_c}$, however the latter for running coupling constant first increases with $\mathrm{T/T_c}$ and becomes constant at a higher temperatures. Again, we represent the effective fugacity quasiparticle model (EQPM) results with its various versions [1]. The results calculated in EQPM shown by the solid blue, red dash-dotted and black dashed lines in the figure initially decrease rapidly and saturate at a higher $\mathrm{T/T_c}$.

Conclusions

In this work, for the first time we use a color string percolation approach to study the temperature dependence of Wiedemann-Franz law for strongly interacting matter. We have compared CSPM results with various versions of effective fugacity quasiparticle model (EQPM) and ideal equation of state (EOS) for quarks and gluons degrees of freedom. We find a temperature independent behaviour of ratio of thermal to electrical conductivity in CSPM approach and ideal EOS while EQPM results initially decrease with temperature and then saturate afterwards. Due to lack of lattice data, a theoretical study of Wiedemann-Franz law for strongly interacting matter with color degrees of freedom could be important in understanding its behaviour near critical temperature.

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