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Electrical conductivity of (an-)isotropic quark gluon plasma

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Abstract. In this article, we have calculated one of the transport coefficient viz. electrical conductivity of the quark gluon plasma (QGP) phase which exhibits an anisotropy in the momentum space. Relativistic Boltzmann’s kinetic equation has been solved in the relaxation-time approximation to obtain the electrical conductivity. We have used the quasiparticle description to define the basic properties of QGP through the distribution functions of partons.

1. Introduction
A recent observation at heavy ion collisions is that a strong electromagnetic field is created in the peripheral collisions. Thus a lot of interest arises in the study of electrical conductivity ($\sigma_{el}$) which is a transport coefficient and quantifies the effect of electric field on the medium produced in these experiments [1-3]. With the discovery of “most perfect fluid ever generated” in heavy ion collision experiments, another important observation has been made that the fluid possesses momentum-space anisotropies in the local rest frame (LRF) [4]. This has important implications for both dynamics and signatures of the QGP. In this work our main motivation is to calculate the electrical conductivity of an anisotropic QGP phase using the Relativistic Boltzmann’s kinetic equation. We have used the quasiparticle description to define the basic properties of QGP as earlier we have shown that quasiparticle description successfully provides the proper and realistic thermodynamical and transport behaviour of QGP phase [5].

2. Model Description
One can obtain the expression for $\sigma_{el}$ by solving relativistic Boltzmann’s kinetic equation under an external electromagnetic field using relaxation time approximation as follows [6]:

$$\sigma_{el}^{iso} = \frac{2}{T} \sum_f g_f q_f^2 \int \frac{d^3p}{(2\pi)^3} \frac{p^2}{E_f^2} \tau_f \times \mathcal{J}_f^0 (1 - \mathcal{J}_f^0),$$

(1)

where the subscript $f$ implies summation over the flavors. Here we have taken up, down and strange flavors only.

The anisotropic distribution relevant for uRHICs can be approximated by removing particles with the large momentum component along the direction of anisotropy, $\mathbf{n}$ as [6]:

$$f_{aniso}(\mathbf{p}) = f_{iso}\left(\sqrt{p^2 + \xi(\mathbf{p} \cdot \mathbf{n})^2}\right),$$

(2)
where \( f_{\text{iso}} \) is an arbitrary isotropic distribution function and \( \xi \) is the anisotropic parameter. For weakly anisotropic systems (\( \xi \ll 1 \)), one can expand the quark distribution function as follows:

\[
f_{\text{aniso}}(x, p; T) = \frac{1}{e^{E_f/T} + 1} - \frac{\xi}{2E_f/T} (p \cdot n)^2 \frac{e^{E_f/T}}{(e^{E_f/T} + 1)^2}
\]

\[
= f^0 - \frac{\xi}{2E_f/T} (p \cdot n)^2 f^0 e^{E_f/T},
\]

(3)

where \( p \equiv (p \sin \theta \cos \phi, p \sin \theta \sin \phi, p \cos \theta) \) and \( n \equiv (\sin \alpha, 0, \cos \alpha) \). \( \alpha \) is the angle between \( p \) and \( n \). After substituting the anisotropic distribution function in Eq. (1), the expression of electrical conductivity in anisotropic medium is modified as [6]:

\[
\sigma_{\text{el}}^{\text{aniso}}(\mu_q = 0) = \frac{1}{2\pi^2 T} \sum_f g_f q_f^2 \int dp \frac{p^4}{E_f^3} \tau_f (1 - f^0_f) - \xi \frac{1}{6\pi^2 T} \sum_f g_f q_f^2 \int dp \frac{p^6}{E_f^3} \tau_f (f^0_f)^2 e^{E_f/T}
\]

\[
= \sigma_{\text{el}}^{\text{iso}} - \xi A,
\]

(4)

We also generalize the electrical conductivity in an anisotropic medium for \( \mu_q \neq 0 \) [6]:

\[
\sigma_{\text{el}}^{\text{aniso}}(\mu_q \neq 0) = \frac{1}{2\pi^2 T} \sum_f g_f q_f^2 \int dp \frac{p^4}{E_f^3} \tau_f ^{(1 - f^0_f)} + \tau_f (f^0_f)^2 e^{E_f/T}
\]

\[
- \xi \frac{1}{12\pi^2 T^2} \sum_f g_f q_f^2 \int dp \frac{p^6}{E_f^3} \tau_f (f^0_f)^2 e^{E_f/T},
\]

(5)

where \( f^0_f \) and \( f^0_{\bar{f}} \) are the equilibrium distribution function for a quark and anti-quark of flavour \( f \), respectively.

**Figure 1.** Variation of \( \sigma_{\text{el}}^{\text{aniso}} \) with respect to temperature for different values of \( \xi \).

**Figure 2.** Variation of \( \sigma_{\text{el}}^{\text{aniso}} \) with respect to temperature at zero as well as finite \( \mu_q \).