Thermoelectric effects in a weakly magnetized QGP

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Introduction

Ultrarelativistic heavy-ion collisions at the CERN SPS, BNL, RHIC and LHC accelerators reach center of mass energies that are much larger than the critical energy density required for a transition from hadrons to QGP[1]. Such collisions with a non-zero impact parameter produce large magnetic fields whose decay rate depends upon the electrical conductivity of the medium, which, if small enough, would cause only a small fraction of the initial magnetic field to survive by the time thermal equilibrium is achieved via interactions. This motivates us to study the thermoelectric response of the QGP medium via calculating the Seebeck and Nernst coefficients in the presence of a weak external magnetic field.

The deconfined medium thus created can possess a finite temperature gradient between the central and peripheral regions of the collisions, leading to diffusion of medium constituents from regions of higher temperature to regions of lower temperature, *i.e.* a thermocurrent. The resulting electric fields along and transverse to the direction of temperature gradient per unit temperature gradient, under equilibrium conditions are the Seebeck and Nernst coefficients, respectively[2].

The quark distribution function is assumed to deviate only slightly away from equilibrium ($\delta f \ll f_0$). This makes the relaxation time approximation of the Boltzmann transport equation, a suitable approach to calculate the aforementioned coefficients, with inter-particle medium interactions being encoded in the quasiparticle thermal masses calculated from perturbative QCD.

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Seebeck and Nernst coefficients

The temperature gradient and the generated electric field are taken to exist in the x-y plane while the external magnetic field is taken to be along the $\hat{z}$ direction. The individual coefficients (medium consisting of a single species of quarks and antiquarks) are given by

$$S_{\rm ind} = -\frac{C_1C_3 + C_2C_4}{C_1^2 + C_2^2}, \qquad (1)$$

$$(N|\vec{B}|)_{\rm ind} = \frac{C_2C_3 - C_1C_4}{C_1^2 + C_2^2}, \qquad (2)$$

where,

$$C_1 = q\int {\rm d}p\, p^4 \frac{\tau}{\epsilon^2(1+\omega_c^2\tau^2)}\big\{f_0(1-f_0) + \bar{f}_0(1-\bar{f}_0)\big\},$$

$$C_2 = q\int {\rm d}p\, p^4 \frac{\omega_c\tau^2}{\epsilon^2(1+\omega_c^2\tau^2)}\big\{f_0(1-f_0) - \bar{f}_0(1-\bar{f}_0)\big\},$$

$$C_3 = \beta\int {\rm d}p\, p^4 \frac{\tau}{\epsilon^2(1+\omega_c^2\tau^2)}\big\{(\epsilon+\mu)\bar{f}_0 (1-\bar{f}_0) - (\epsilon-\mu)f_0(1-f_0)\big\},$$

$$C_4 = \beta\int {\rm d}p\, p^4 \frac{\omega_c\tau^2}{\epsilon^2(1+\omega_c^2\tau^2)}\big\{-(\epsilon+\mu)\bar{f}_0 (1-\bar{f}_0) - (\epsilon-\mu)f_0(1-f_0)\big\}.$$

For the composite medium consisting of u and d quarks, the total coefficients are given by

$$S = -\frac{\sum\limits_{a=u,d}(C_1)_a\cdot\sum\limits_{a=u,d}(C_3)_a + \sum\limits_{a=u,d}(C_2)_a\cdot\sum\limits_{a=u,d}(C_4)_a}{\left(\sum\limits_{a=u,d}(C_1)_a\right)^2 + \left(\sum\limits_{a=u,d}(C_2)_a\right)^2}.$$

$$N|\vec{B}| = \frac{\sum\limits_{a=u,d}(C_2)_a\cdot\sum\limits_{a=u,d}(C_3)_a - \sum\limits_{a=u,d}(C_1)_a\cdot\sum\limits_{a=u,d}(C_4)_a}{\left(\sum\limits_{a=u,d}(C_1)_a\right)^2 + \left(\sum\limits_{a=u,d}(C_2)_a\right)^2}.$$

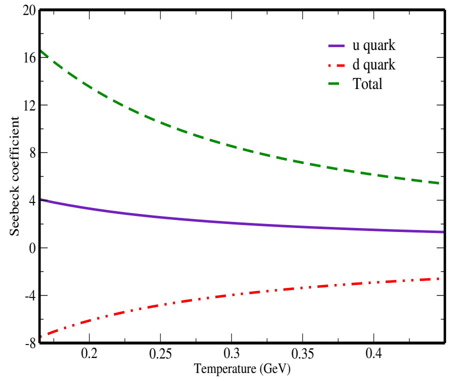

FIG. 1: Variation of individual and total Seebeck coefficients with T for μ=50 MeV, eB=m_π^2.

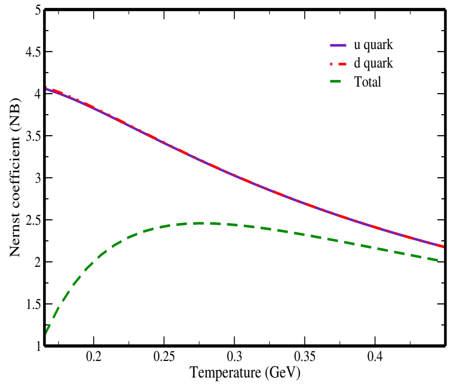

FIG. 2: Variation of individual and total Nernst coefficients with T for $\mu = 50$ MeV, $eB = m_\pi^2$.

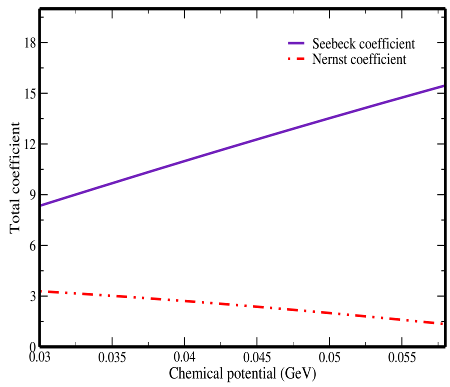

FIG. 3: Variation of total Nernst and Seebeck coefficients with μ for $T = 200$ MeV, $eB = m_\pi^2$.

We use a strong coupling constant g that is explicitly dependent on the temperature T, magnetic field B and the chemical potential μ. The thermal mass (squared) of quarks is taken to be $g^2T^2/6$ with magnetic field dependence entering implicitly via g. Further, the relaxation time, τ used in this work has been evaluated in [3] and depends explicitly on T and μ.

From Fig.(1), we see that the sign of the individual Seebeck coefficients depend on the sign of the electric charge of the particle. The magnitudes of both the individual and total coefficients decrease with temperature. This is because of the fact that the number density $(n - \bar{n})$ decreases with T for a fixed μ. From Fig.(2), it is evident that the individual Nernst coefficients are independent of the magnitude and sign of the electrical charge of the particle and record a decreasing trend with temperature. The total Nernst coefficient initially rises with T and thereafter exhibits a slope reversal at around $T = 275$ MeV. We have found that the temperature at which this reversal takes place is higher for a higher value of μ. Fig.(3) shows that while the total Seebeck coefficient increases with μ, the Nernst coefficient of the composite medium decreases with μ for a fixed T.

The critical parameters in Seebeck and Nernst coefficients are the chemical potential and magnetic field, respectively, in the sense that the Seebeck coefficients go to zero at $\mu = 0$ and the Nernst coefficients are zero at $B = 0$. This is understandable since $\mu = 0$ implies equal and opposite thermocurrents due to quarks and antiquarks, which cancel out, leading to $S = 0$. In the absence of B, there would be no Lorentz force on the charges and hence, no Nernst effect. The increase in the magnitudes of Seebeck and Nernst coefficients with μ and B, respectively, is along expected lines.

References

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