Effect of strong magnetic field on the interplay of momentum, heat and charge transports in a hot QCD matter

Binoy Krishna Patra and Shubhalaxmi Rath
Department of Physics, Indian Institute of Technology Roorkee
binoy.purva@gmail.com, shubhalaxmirath@gmail.com

Introduction

- The peripheral events of ultra-relativistic heavy ion collisions produce extremely strong magnetic fields.
- High energetic areas where strong magnetic fields might exist: (1) Peripheral heavy ion collisions ($10^9$ G to $10^{12}$ G), (2) Cores of compact stars ($10^{15}$ G to $10^{16}$ G).
- The early universe (much higher than the above cases).
- Depending on the electrical conductivity, the magnetic field may remain strong during the lifetime of the partonic medium.
- Thus, it is interesting to explore the effect of strong magnetic field on the interplay of momentum, heat and charge transports in a hot QCD matter.
- Magnetic field breaks the rotational symmetry. So, momentum gets separated into transverse ($p_{\perp}$) and longitudinal ($p_z$) components and in SMF limit, $p_{\perp} \gg p_z$. Thus, an anisotropy is created.

Different anisotropies

- Anisotropic parameter $\eta = \frac{p_{\perp}}{p_{\parallel}}$.
- Isotropic distribution functions:
  $$f^{\text{iso}}_{\text{el}}(p^T) = \frac{1}{\sqrt{2\pi}m}, \quad f^{\text{iso}}_{\text{el}}(p^L) = \frac{1}{\sqrt{2\pi}m},$$
  where $T = 1/\beta$ and $\omega_i = \sqrt{p^2 + m^2}$.
- Expansion-driven anisotropic distribution functions:
  $$f^{\text{aniso}}_{\text{el}}(p^T) = f^{\text{iso}}_{\text{el}}(p^T) \left[ \frac{\xi(p^2 / 2m^2) f^{\text{iso}}_{\text{el}}(p^T) - f^{\text{iso}}_{\text{el}}(p^L)}{\xi(p^2 / 2m^2) f^{\text{iso}}_{\text{el}}(p^T) - 1} \right],$$
- Magnetic field-driven anisotropic distribution function:
  $$f^{\text{aniso}}_{\text{el}}(p^L) = \frac{1}{\sqrt{2\pi}m} \left[ \frac{\xi(p^2 / 2m^2) f^{\text{iso}}_{\text{el}}(p^T) - f^{\text{iso}}_{\text{el}}(p^L)}{\xi(p^2 / 2m^2) f^{\text{iso}}_{\text{el}}(p^T) - 1} \right],$$
  where $p^L = (0, 0, p_z)$ and $f_{\text{el}} = \frac{1}{\sqrt{2\pi}m}$.

Quasiparticle masses:

- Pure thermal medium: $m_{\text{el},\text{iso}} = \frac{1}{\sqrt{2\pi}m}, \quad m_{\text{el},\text{ex}} = \frac{1}{\sqrt{2\pi}m} (\sqrt{1 + \frac{\zeta}{\eta} m_B^2}).$
- Thermal medium in strong magnetic field: $m_{\text{el},\text{iso}} = \frac{1}{\sqrt{2\pi}m} (\sqrt{1 + \frac{\zeta}{\eta} m_B^2}), \quad m_{\text{el},\text{ex}} = \frac{1}{\sqrt{2\pi}m} (\sqrt{1 + \frac{\zeta}{\eta} m_B^2}).$
- Effective quasiparticle masses in the presence of strong magnetic field get enhanced as compared to the masses at zero magnetic field.

Shear and bulk viscosities

- For a nonequilibrium system, $T^{\mu\nu} - T^{\text{eq}}_{\mu\nu} + \Delta T^{\mu\nu}$.
- The traceless and trace parts of $\Delta T^{\mu\nu}$ give the shear and bulk viscosities, respectively.
  $$\Delta T^{\mu\nu} = -\eta \left( \theta^{\mu\nu} - \theta^{\text{eq}}_{\mu\nu} - \frac{\theta_{\text{eq}}^{\text{iso}}}{\theta_{\text{eq}}^{\text{ex}}} \theta^{\text{iso}}_{\mu\nu} - \frac{\theta_{\text{eq}}^{\text{aniso}}}{\theta_{\text{eq}}^{\text{ex}}} \theta^{\text{aniso}}_{\mu\nu} \right).$$
- In the strong magnetic field regime, components of velocity transverse to the magnetic field vanish. Thus, only $\Delta T^{\text{II}} (\Delta T^{\text{II}})$ component survives:
  $$\Delta T^{\text{II}} = -\eta \left( \theta^{\text{II}} - \theta^{\text{eq}}_{\text{II}} - \frac{\theta_{\text{eq}}^{\text{iso}}}{\theta_{\text{eq}}^{\text{ex}}} \theta^{\text{iso}}_{\text{II}} - \frac{\theta_{\text{eq}}^{\text{aniso}}}{\theta_{\text{eq}}^{\text{ex}}} \theta^{\text{aniso}}_{\text{II}} \right).$$
- The flow of heat in a medium: $Q = -\omega_{\parallel} f_{\text{el}}$.
- In strong magnetic field case:
  $$Q_{\text{1}} = \sum_{\text{species}} \frac{\partial f_{\text{el}}}{\partial E_{\text{el}}} \bigg|_{\text{eq}} \int dp_{\perp} p_{\perp}^{\parallel} f_{\text{el}} - t_B^{\parallel} h_B f_{\text{el}}.$$