Axial current generation by P-odd domain in QCD matter†

I. Iatrakis,[*1] S. Lin,[*2] and Y. Yin[*3]

It is believed that parity-odd domains are produced in heavy ion collisions. The effect of parity odd domains can be modeled by an external θ field, which couples to topological charge density $q = \frac{g^2}{32\pi^2}\epsilon^{\mu\nu\rho\sigma} tr G_{\mu\nu}G_{\rho\sigma}$, where g is the strong coupling constant and G is the gluon field strength. An external θ field can induce nonvanishing q. According to the axial anomaly equation

$$\partial_\mu J^\mu_A = -2q, \tag{1}$$

a nonvanishing q can generate chiral imbalance, which can be characterized by axial chemical potential μ_A. The μ_A is a key component of the chiral magnetic effect (CME). The CME predicts the generation of electric current along an external magnetic field in deconfined quark-gluon plasma with chiral imbalance[1)]

$$\mathbf{j}_V = \frac{N_c e^2}{2\pi^2}\mu_A \mathbf{B}. \tag{2}$$

The CME is currently being intensvely researched through heavy ion collision experiments at relativistic heavy ion collider (RHIC) and large hadron collider (LHC). The goal of this paper is to explore the response of the axial current to the θ field and the backreaction of the axial charge to the θ field.

We can write the response of q to θ as $q(\omega, k) = -G^R(\omega, k)\theta(\omega, k)$, with the response function in the hydrodynamic limit given by

$$G^R(\omega, k) = -\chi - \frac{i\Gamma_{CS}\omega}{2T} - \frac{\kappa_{CS}}{2}k^2 + \cdots. \tag{3}$$

Here, the first term represents the topological susceptibility, which is highly suppressed in deconfined quark-gluon plasma. The second term is the Chern-Simon (CS) diffusion, where Γ_{CS} is the diffusion rate. This term is known to be responsible for axial charge generation. The third term is present when the external θ field is spatially inhomogeneous. We note that the corresponding transport coefficient κ_{CS} is measurable on the lattice in the static limit $\omega \to 0$. It measures the response of q to spatial inhomogeneity of the θ field. More interestingly, we found in a model-independent way that it leads to the generation of axial current along the gradient of θ

$$\mathbf{j}_A = \kappa_{CS}\nabla\theta. \tag{4}$$

We also confirmed the current through a holographic model calculation.[2)] It is worth noting that the holographic calculation also considers the contribution of the conventional diffusive current. We argued that this current could be phenomenologically important in the context of heavy ion collisions as compared to the chiral separation effect and the chiral electric separation effect. A schematic view of axial current generation is shown in Fig.1.

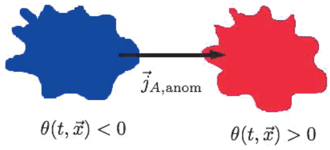

Fig. 1. A schematic view of axial current generation along the gradient of the θ field.

We also considered the backreaction of the axial charge to the effective θ field. In the homogeneous limit $k = 0$, the θ field generates an axial charge density

$$n_A = \frac{\Gamma_{CS}}{T}\theta \tag{5}$$

through the diffusion of the topological charge and axial anomaly. Using axial charge susceptibility χ_A (not to be confused with topological susceptibility), it gives rise to an axial chemical potential

$$\mu_A = \left(\frac{\Gamma_{CS}}{\chi_A T}\right)\theta. \tag{6}$$

Following Ref.[3)], we identify μ_A with $\partial_t\theta$. By comparing this with Eq. 6, we obtain an exponential decay for the effective θ field with the decay time scale set as $\tau_{sph} = \frac{\chi_A T}{2\Gamma_{CS}}$. The physical reason for the backreaction is that the presence of axial charge modifies the gluon potential such that the topological charge density is changed to partially balance out the axial charge. This results in a damping of the topological nontrivial configurations like sphaleron. Thus, we refer to τ_{sph} as the sphaleron damping rate. In terms of the θ field, it is realized as the exponential decay of the field. We also confirmed the backreaction in a holographic model calculation.[2)]

References
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† Condensed from the article in Phys. Rev. Lett. **114**, 25 (2015)
*1 Department of Physics and Astronomy, Stony Brook University
*2 RIKEN Nishina Center
*3 Department of Physics, Brookhaven National Laboratory