Chiral magnetic effect

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"A good traveler has no fixed plans, and is not intent on arriving".

Lao Tzu

Quantum Chromo-Dynamics (QCD) is firmly established as the theory of strong interactions. At short distances the QCD running coupling constant is small due to the asymptotic freedom and quantities can be reliably evaluated in perturbation theory. At strong coupling, we still lack a reliable theoretical method for performing analytic calculations. As a consequence despite QCD has well known symmetries and established elementary constituents, its emergent behavior remains a mystery to us. For instance color confinement is not present in perturbation theory and still it is not clear how the asymptotic states of QCD perturbation theory, colored quarks and gluons, transform into the asymptotic states actually observed in experiment, the color-singlet hadrons. It is widely perceived that such non-perturbative dynamics originates in the topological sector of QCD. The SU(3) gauge group of QCD posses topological solutions: there exist certain special gluon configurations to which one can assign a winding number. These configurations induce an *axial anomaly* [1], i.e. transform left- into right-handed quarks or vice-versa. Moreover, as a result of the axial anomaly the interactions between these configurations and the quarks break the parity and charge-parity symmetry [2]. However, parity violation in strong interactions has never been detected and from measurement of neutron electric dipole moment we have a very little upper bound of charge-parity violation. Similar topological effects in electroweak theory cause the baryon number violation and may be responsible for at least a part of the observed baryon asymmetry in the Universe [3].

In a system with chiral imbalanced fermions, the interplay of quantum anomaly with a magnetic field create a charge current along the magnetic field [4]; this effect is known as *chiral magnetic effect* (CME). Observation of CME in quark-gluon plasma created with high energy collisions, where very intense magnetic fields with magnitude $eB \approx 10\, m_\pi^2 \approx 10^{18}$ G are present [5], will be direct experimental evidence for the existence of topologically nontrivial gluon configurations and for event-by-event parity and charge-parity violation. STAR Collaboration at RHIC has observed a charge-dependent azimuthal asymmetry [6] proving CME indirectly, although mundane backgrounds have to be excluded yet. But CME has been clearly observed in lattice calculations [7]. Instead, a direct measure of CME was done in condensed matter, for Weyl semimetals, specifically in zirconium pentatelluride $ZrTe_5$ [8].

The open problems for CME and for non-dissipative transport phenomena induced by quantum anomalies in general are numerous. As mentioned in heavy ion collisions the quantitative description of charge asymmetries is not fully accomplished. These effects arise naturally within relativistic hydrodynamics and it is interesting to study collective excitations that are not present in non-anomalous hydrodynamics, such as *chiral magnetic wave*. The theory of anomalous transport could also be important for technological applications since it allows transport of energy and information without dissipation. Particularly, the study of these effects on Weyl semimetals and other chiral materials seems promising. Furthermore, is still lacking a real-time dynamics of CME away from equilibrium, that could open the road to novel phenomena. For instance it has been argued that an out of equilibrium chiral magnetic effect in the early universe should leave a track of parity violation at cosmological scale in Cosmic Microwave Background [9].

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