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Chiral current generation in QED by longitudinal photons

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Abstract

We report the generation of a pseudovector electric current having imbalanced chirality in an electron–positron strongly magnetized gas in QED. It propagates along the external applied magnetic field **B** as a chiral magnetic effect in QED. It is triggered by a perturbative electric field parallel to **B**, associated to a pseudovector longitudinal mode propagating along **B**. An electromagnetic chemical potential was introduced, but our results remain valid even when it vanishes. A nonzero fermion mass was assumed, which is usually considered vanishing in the literature. In the quantum field theory formalism at finite temperature and density, an anomaly relation for the axial current was found for a medium of massive fermions. It bears some analogy to the Adler–Bell–Jackiw anomaly. From the expression for the chiral current in terms of the photon self-energy tensor in a medium, it is obtained that electrons and positrons scattered by longitudinal photons (inside the light cone) contribute to the chiral current, as well as the to pair creation due to longitudinal photons (out of light cone). In the static limit, an electric pseudovector current is obtained in the lowest Landau level.

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1. Introduction

Nowadays the influence of the magnetic fields in relativistic quantum systems, like electron–positron plasma and quark–gluon plasma (QGP) [1], is an important subject for its diverse applications. In [2] it was shown that a magnetic field in the presence of imbalanced chirality induces a current along the magnetic field. This is called Chiral Magnetic Effect in a QGP [3, 4], which is caused by the topological gluon field configurations that couple to quarks via the QCD axial anomaly [5–10]. The chiral magnetic effect in a QGP has important applications in the experiments of heavy ion collisions. An active experimental program exists to investigate the properties of this hot phase of matter (QGP) by using the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC).

In several papers about of the chiral magnetic effect the chirality is introduced through a non-vanishing chiral chemical potential factor [3,11]. In our paper, as done in [12], we introduced an electromagnetic chemical potential μ, but our results remain valid for $\mu = 0$ (as it happens in the chiral magnetic effect in QCD). On the other hand, to obtain a full understanding of the chiral magnetic effect, it is desirable to include the dynamics leading to a net chirality. In our paper the pseudovector longitudinal mode propagating along **B** is associated to the chiral charge density in a massive charged medium in the context of QED.

Usually, in current literature for the axial anomaly, it is assumed zero fermion mass [11,13]. This has the advantage that particles have definite helicity, but as pointed out by [12] the approximation is not realistic. For instance, in the presence of magnetic fields, it has unavoidable difficulties, since dealing with charged massless particles implies the arising of divergent magnetic moments.

As different from [12], we start by establishing a difference between the chiral symmetry breaking due to nonzero mass (which we may name as scalar or dynamical), compatible with thermodynamical equilibrium (since in it at each instant an equal number of left and right particles are expected to be on the average) and the pseudoscalar chiral symmetry breaking, arising from the non-vanishing term $\mathfrak{G} = \frac{1}{4}\mathbf{E}\cdot\mathbf{B}$, which leads to non-equilibrium processes of electric current and transport of charge. In what follows we want to show that a chiral magnetic effect arises in QED due to an anomaly relation for the axial current in a medium (not in vacuum: it is a purely quantum magnetic effect in a medium) of massive and magnetized charged fermions. The axial character will refer to the average density in momentum space of those particles and antiparticles having a common helicity. If a perturbative electric field **E**, associated to a longitudinal pure electric mode (pseudovector mode), is applied to the electron–positron system in thermodynamic equilibrium in the presence of a very strong external magnetic field **B**, such that $\mathbf{E} \parallel \mathbf{B}$, it produces an axial current leading to the breaking of the previously existing statistical chiral balance of the densities of charged particles.

The existence of huge magnetic fields in *compact objects* is an established fact (typical measured surface magnetic fields are about 10^{12} G, although in the case of the *magnetar* subclass, it is believed that they can be as high as 10^{15} G [14]). Therefore these objects are the best place to find direct experimental evidence of the chiral magnetic effect in magnetized charged plasmas. The electric current along **B**, associated to a chirality imbalance induced by longitudinal photons, could have astrophysical implications [15–17].

We remind that in a medium, as different from vacuum, there is a non-vanishing four-velocity vector $u_\mu \neq 0$. We must recall that also in absence of external fields in the charged medium there are three electromagnetic modes, two transverse and one longitudinal [18]. The two transverse modes correspond to photon spin projections ± 1 along its momentum **k**, their dispersion equa-

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