Magnetic instability in AdS/CFT : Schwinger effect and Euler-Heisenberg Lagrangian of Supersymmetric QCD[†]

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The renowned Schwinger effect[1)]creation process of electron-positron pairs in strong electric fields, is a big challenge in the field of non-linear quantum field theory. Although the Schwinger limit $E \sim m_e^2$ has not been reached by the direct experiments such as strong lasers, similar effective setups in materials are actively investigated. Theoretical foundation of the Schwinger effect was to evaluate the imaginary part of the effective action of QED under a constant electromagnetic field, the Euler-Heisenberg Lagrangian[2)] which dates back to 1936. The Euler-Heisenberg Lagrangian is a generating function of nonlinear electromagnetic responses of the vacuum. In its expression, the electric field couples to the magnetic field in a complicated and nonlinear manner, and the total effective Lagrangian is a starting point in the research of strong fields in QED, including the non-perturbative Schwinger effect.

In our previous paper[3)], two of the present authors derived an Euler-Heisenberg Lagrangian for a supersymmetric QCD in the strong coupling limit, by using the AdS/CFT correspondence but the Maxwell electric field) is applied, a quark antiquark pair is created. The nontrivial part is the gluon interaction at strong coupling in QCD. The quarks are confined, and between the quark and the antiquark a confining force (a QCD string) is present to bind them. If the electric field is strong enough, the quarks are liberated. This truly nonperturbative process is of importance, not only because it can be a realistic phenomenon occurring in the universe, but also because it may be a touchstone for understanding the quark confinement.

There are at least two cases in which the QCD Schwinger effect may play an important role: First, the heavy ion collision experiment, and second, magnetars (neutron stars with a very strong magnetic field). In the heavy ion collisions, very strong electric fields are generated by the the electric current induced by heavy ions passing by each other. Since the magnetic field is time dependent, there appears strong electric field as well, and it may be related to the formation of the quark gluon plasma. On the other hand, magnetars are known to be the most dense place in the universe, and the strong magnetic field accompanied by some electric field can occur and affect the core structure of the stars, possibly having a quark phase inside. In these examples, the understanding of QCD and Schwinger effect in strong electric and magnetic fields can be tested by experiments/observations and serves as a playground at which we can test our theoretical knowledge on strongly coupled quantum field theories.

The result of Ref.[3)] is summarized as follows; The Euler-Heisenberg Lagrangian of strongly coupled $\mathcal{N} = 2$ supersymmetric QCD at large N_c limit was calculated in the presence of a constant electric field using the AdS/CFT correspondence. Its imaginary part explicitly evaluated is found to agree with large electric field expansion of the Schwinger effect of $\mathcal{N} = 2$ supersymmetric QED (once the QCD string tension is replaced by the electron mass). However, there, only the electric field was considered. In this paper, we include the full dependence of the magnetic field, which is important as is obvious from the physical situations explained above.

Here we summarize the finding of the present paper:

- We obtain the Euler-Heisenberg Lagrangian of the $\mathcal{N} = 2$ supersymmetric QCD in a constant electromagnetic field, at strong coupling and large N_c limit.
- We evaluate the imaginary part of the Euler-Heisenberg Lagrangian, and find that the rate of the quark antiquark creation diverges at zero temperature for massless quarks.
- The divergent rate can be regularized, i.e., the vacuum is unstable but the lifetime becomes finite, by either introducing finite temperature or a quark mass.
- We compute the real part of the Euler-Heisenberg Lagrangian, and show the disappearance of Cotton-Mouton effect in an expansion with the electromagnetic field.
- The imaginary part of the Euler-Heisenberg Lagrangian for a small quark mass is shown to coincide with that of $\mathcal{N} = 2$ supersymmetric QED, at the leading order in electron mass. The agreement is found also for the real parts responsible for the Cotton-Mouton effect.

References

1) J. S. Schwinger, Phys. Rev. **82**, 664 (1951).
2) W. Heisenberg and H. Euler, Z. Phys. **98**, 714 (1936)
3) K. Hashimoto and T. Oka, JHEP **1310**, 116 (2013) [arXiv:1307.7423].

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