Electromagnetic instability in holographic QCD†

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Schwinger effect[2)] is one of the most interesting phenomena in particle physics. This is a phenomenon that a pair creation of charged particles occur under an external field such as an electromagnetic field. Schwinger obtained the creation rate of an electron positron pair by evaluating the imaginary part of Euler-Heisenberg Lagrangian[1)], which is an effective Lagrangian for a constant electric field. This rate Γ is derived as $\Gamma \sim \exp\left(-\pi m_e^2/eE\right)$ to leading order and has a form with a negative power in the gauge coupling e. So the Scwinger effect is a non-perturbative effect. Here, m_e is the electron mass and E is an electric field. A critical electric field necessary energy for the electron positron pair creation is $E_{\rm cr} \sim m_e^2 c^3/e\hbar$, and the strength is about 10^{18} [V/m]. So, it is a phenomenon which shows up only under strong electromagnetic fields.

Recently, we have seen advance in research on a strong electromagnetic field in both theoretical and experimental aspects of hadron physics. At the heavy ion collision in RHIC and LHC, it is expected that a strong magnetic field is generated by a collision of charged particles accelerated at about the speed of light.

Within the AdS/CFT framework, the quark pair creation rate in the strongly coupled $\mathcal{N} = 4$ supersymmetric Yang-Mills theory was obtained in[3)]. On the other hand, two of the present authors obtained the vacuum decay rate, which can be identified as the creation rate of quark-antiquark pairs, in $\mathcal{N} = 2$ supersymmetric QCD(SQCD) by using a different method[4)] in AdS/CFT correspondence: *the imaginary part of the probe D-brane action.* D3-D7 brane system corresponds to $\mathcal{N} = 4$ supersymmetric $SU(N_c)$ Yang-Mills theory including an $\mathcal{N} = 2$ hypermultiplet in the fundamental representation of the $SU(N_c)$ gauge group. They obtained the creation rate of the quark antiquark in the $\mathcal{N} = 2$ SQCD under a constant electric field by evaluating the imaginary part of the D7-brane action. Then, the present authors evaluated the imaginary part of the D7-brane action including not only a constant electric field but also a constant magnetic field and obtained the creation rate of the quarks and antiquarks in the $\mathcal{N} = 2$ SQCD[5)].

We summarize the properties of the creation rate in both electric and magnetic fields obtained in[5)] for $\mathcal{N} = 2$ SQCD as follows. We derived the Euler-Heisenberg Lagrangian for a constant electromagnetic field in $\mathcal{N} = 2$ SQCD at large N_c and at strong coupling. Then, we obtained the creation rate of the quarks and antiquarks by evaluating the imaginary part of the Lagrangian. We found that the creation rate diverges at a zero temperature in the massless quark limit while it becomes finite when we introduce a nonzero temperature. The divergence of the creation rate is influenced not only by a constant electric field but also by a constant magnetic field. The results in SQCD showed similarities with the creation rate of the electron positron pair in $\mathcal{N} = 2$ supersymmetric QED(SQED) in constant electromagnetic field.

In this paper, we study the quark antiquark pair creation in *non-supersymmetric* QCD at large N_c at strong coupling, and the imaginary part of D8-brane action in a constant electromagnetic field. The holographic models are the Sakai-Sugimoto model[6)] and its deformed version. Our findings in this paper are as follows:

- We derive the Euler-Heisenberg Lagrangian for confining gauge theories: the Sakai-Sugimoto model and the deformed Sakai-Sugimoto model. We obtain the creation rate of the quark antiquark pair under the electromagnetic field, by evaluating the imaginary part of the D-brane actions.
- The imaginary part is found to increase with the magnetic field parallel to the electric field, while it decreases with the magnetic field perpendicular to the electric field. So the vacuum instability strongly depends on the direction of the applied magnetic field relative to the electric field.
- We obtain a critical value of the electric field, i.e., the Schwinger limit, by using the condition that the D-brane action has the imaginary part. In the case of the Sakai-Sugimoto model, the critical electric field corresponds to a QCD string tension between a quark and an antiquark.

As for the first part among above, a result with only an electric field was reported in Ref. 7). We analyze generic electric and magnetic fields in this paper.

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