Vacuum instability in electric fields via AdS/CFT: Euler-Heisenberg Lagrangian and Planckian thermalization[†]

K. Hashimoto[*1*2] and T. Oka[*3]

Extreme environments, such as a strong electric field, is one of the frontiers to test physical systems and to reveal new physical phenomena. Particle physics is not an exception. The physics of quantum fields in strong external electric fields, *i.e.*, "strong-field quantum field theory" has a very long history which even dates back to the development era of QED. Nevertheless, the dynamics of quantum fields and their vacuum in strong electromagnetic fields has not been understood well yet, both theoretically and experimentally. One of the present frontiers of strong field QFT is to understand the instability of strongly interacting systems such as the confining vacuum in QCD.

A particular interest is a relation between the confinement in QCD and the strong electric field. Because quarks have electric charges, a strong electric field can induce a vacuum decay at which pairs of a quark and an antiquark are produced from the vacuum to cancel the background electric field. However to estimate the threshold critical electric field, as well as to describe the physical decay process, is a difficult problem, because of several reasons; first, QCD is strongly coupled so the standard perturbative calculation does not work at low energy, and second, strong electromagnetic fields induces effective multi-photon vertices resulting in a complicated nonlinear electromagnetic effective action.

The renowned method for analyzing strongly coupled system, such as QCD, is the AdS/CFT correspondence[1)]. This is a well-developed tool in string theory which enables us to analyze strongly coupled QCD analytically. In this paper, we apply the gauge/gravity duality to a certain strongly coupled QCD-like gauge theory, and analyze the instability caused by a strong electric field.

We analyze vacuum instability of strongly coupled gauge theories in a constant electric field using AdS/CFT correspondence. The model is the $\mathcal{N}=2$ 1-flavor supersymmetric large N_c QCD in the strong 't Hooft coupling limit.[2)] We calculate the Euler-Heisenberg effective Lagrangian $\mathcal{L}(E)$, which encodes the nonlinear response and the quantum decay rate of the vacuum in a background electric field E, from the complex D-brane action in AdS/CFT. We find that the decay rate given by $\mathrm{Im}\,\mathcal{L}(E)$ becomes nonzero above a critical electric field set by the confining force between quarks. A large E expansion of $\mathrm{Im}\,\mathcal{L}(E)$ is found to coincide with that of the Schwinger effects in QED, replacing its electron mass by the confining force.

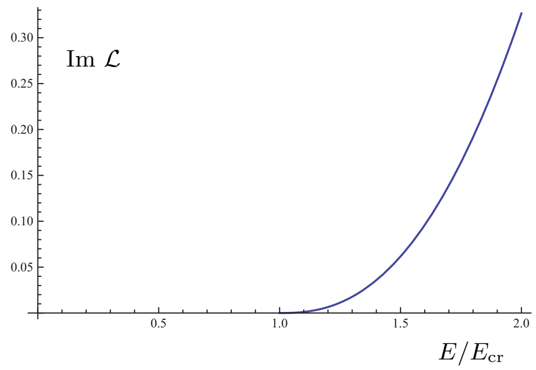

Fig. 1. The imaginary part of the lagrangian of our massive supersymmetric QCD. We find a critical electric field beyond which the instability is detected. The critical electric field means the breaking of the quark confinement.

Then, the time-dependent response of the system in a strong electric field is solved non-perturbatively, and we observe a universal thermalization at a shortest timescale "Planckian thermalization time" $\tau_{\rm th} \sim \frac{\hbar}{k_B T_{\rm eff}^{\infty}} \sim \frac{\hbar}{k_B} E^{-1/2}$. Here, $T_{\rm eff}^{\infty}$ is an effective temperature which quarks feel in the nonequilibrium state with nonzero electric current, calculated in AdS/CFT as a Hawking temperature. Stronger electric fields accelerate the thermalization, and for a realistic value of the electric field in RHIC experiment, we obtain $\tau_{\rm th} \sim 1$ [fm/c], which is consistent with the believed value.

The main result of the present paper is an analytic computation of the full electromagnetic effective Lagrangian for a strongly coupled QCD-like gauge theory. In particular, the imaginary part of the effective Lagrangian shows the decay rate of the vacuum of the gauge theory. The computed imaginary part is shown in Fig. 1.

References
1) J. M. Maldacena, Adv.Theor.Math.Phys. **2** (1998) 231.
2) A. Karch and E. Katz, JHEP **0206** (2002) 043.

† Condensed from the article in JHEP 10 (2013) 116
*1 RIKEN Nishina Center
*2 Department of Physics, Osaka University
*3 Department of Engineering Science, the University of Tokyo