Entropic destruction of heavy quarkonium in non-Abelian plasma from the holographic correspondence[†]

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The studies of heavy quarkonium at finite temperature are expected to advance the understanding of QCD plasma and to clarify the nature of the deconfinement transition. It was originally proposed[1)] to use the quarkonium suppression in heavy ion collisions as a way to detect the Debye screening in the quark-gluon plasma. The subsequent experimental studies of quarkonium production at different energies however revealed a puzzle – the charmonium suppression observed at RHIC (lower energy density) appeared stronger than at LHC (larger energy density). This is in contrast to both the Debye screening scenario[1)] and the thermal activation through the impact of gluons. One possible solution to this puzzle is the recombination of the produced charm quarks into charmonia.

However, recently it was argued[2)] that an anomalously strong suppression of charmonium near the deconfinement transition can be a consequence of the nature of deconfinement. The argument put forward in Ref.2 was based on the lattice QCD results indicating a large amount of entropy associated with the heavy quark-antiquark pair placed in the quark-gluon plasma. This entropy S was found on the lattice to grow as a function of the distance L between the quark and antiquark. The proposal of[2)] is that this entropy should thus lead to the emergent entropic force

$$F = T\,\frac{\partial S}{\partial L}, \tag{1}$$

where T is the temperature of the plasma. It has been found that the balance of the attractive force from the internal interaction and the repulsive entropic force indicates a strong suppression of charmonium states near the deconfinement transition. The leading role of the entropic force in the deconfinement transition itself has been conjectured, as well as a possible link of the observed peak in the entropy near the deconfinement transition to the "long string" condensation.

In this paper, we investigate the microscopic origin of the entropy associated with the heavy quark pair in non-Abelian plasma using the holographic correspondence (the AdS/CFT correspondence). We conclude that the narrow and strong peak in the entropy associated with the heavy quark pair near the transition temperature is indeed related to the nature of deconfinement, and in holographic description originates from the entropy of a long fundamental string at the bottom of the confining geometry which would be absorbed into a black hole horizon after a deconfinement transition. It is absent in the conformal $\mathcal{N} = 4$ supersymmetric Yang-Mills theory, but emerges in a confining Yang-Mills theory obtained by compactification of the fifth dimension. On the boundary, this entropy has to be attributed to long-range, delocalized excitations entangled with the heavy quark pair that can indeed be described as the "long string".

The origin of this peak in the holographic description is intriguing – it arises because the heavy quark pair acts as an eyewitness of the black hole formation in the confining (at low temperatures) bulk geometry. This process of black hole formation is the dual holographic representation of the deconfinement transition on the boundary. From this viewpoint, the entropy associated with the quark-antiquark pair is the right quantity to detect the temperature at which the deconfinement occurs.

We also study the entropic force in holographic setup of strongly coupled gauge theories. It turns out that the entropic force associated with the distribution of the quarks is at a sub-leading order in the strong coupling expansion in terms of the 'tHooft coupling constant, while the entropic force of the QCD string is comparable to the quark-antiquark force. However a reasonable evaluation of the sub-leading term shows that the Einstein entropic force increases such that the critical distance of the quark pair to be destructed entropically is shortened.

Our proposal of using the entropy associated with the heavy quark-antiquark pair to detect the deconfinement transition is somewhat similar to the idea of using the entanglement entropy as an order parameter of deconfinement. The difference is that the order parameter discussed in is the von Neumann entanglement entropy of a spatial region with a boundary, while we consider the Gibbs entropy. In terms of the boundary theory, the entropy of the quark-antiquark pair likely emerges from the entanglement of a "long string" connecting the quark and antiquark with the rest of the system. It would be interesting to clarify this issue further as it may improve our understanding of both deconfinement and confinement.

References

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