Lattice QCD analysis of Q-$\bar{\mathrm{Q}}$ and 3Q potentials at zero and finite temperatures

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The three-quark (3Q) potential is directly responsible for the baryon properties and of great importance in the hadron physics. In contrast with lots of lattice studies on the quark-antiquark (Q$\bar{\mathrm{Q}}$) potential, there is no reliable lattice studies on the 3Q potential so far, and therefore the 3Q potential has been treated hypothetically and phenomenologically for a long time. Very recently, we perform the accurate and detailed calculation of the 3Q potential $V_{\rm 3Q}$ in SU(3) lattice QCD with the smearing method, which reduces the excited-state contamination. For more than 300 patterns of the 3Q configurations in total, we investigate $V_{\rm 3Q}$ on $12^3 \times 24$ lattice at $\beta = 5.7$ and $16^3 \times 32$ lattices at $\beta = 5.8$ and 6.0. We observe that the 3Q potential is well reproduced by a sum of a constant, the perturbative two-body Coulomb term due to the one-gluon-exchange (OGE) and the linear confinement three-body term proportional to the total length of the flux tube as

$$V_{\rm 3Q} = -A_{\rm 3Q} \sum_{i<j} \frac{1}{|\mathbf{r}_i - \mathbf{r}_j|} + \sigma_{\rm 3Q} L_{\rm min} + C_{\rm 3Q} \tag{1}$$

within a few % deviation. Here, $L_{\rm min}$ denotes the minimal length of the total flux tube. As the remarkable features, we observe the universality of the string tension as $\sigma_{\rm 3Q} \simeq \sigma_{\rm Q\bar{Q}}$ and the consistency with perturbative QCD as $A_{\rm 3Q} \simeq \frac{1}{2} A_{\rm Q\bar{Q}}$.

We study also the inter-quark potential at finite temperature. The quark-gluon-plasma (QGP), which is expected to be created above the critical temperature T_c, is now energetically investigated as a new phase of the matter in the RHIC project. For the important signal such as the J/ψ suppression, the thermal inter-quark potential is one of the key quantities. We investigate the 3Q potential at $T = 1.17 T_c$ and $T = 1.4 T_c$, where there may remain some nonperturbative effects, from the Polyakov loop correlations in anisotropic lattice QCD. We observe that the 3Q potential can be understood as the sum of the two-body Yukawa potential with the Debye screening mass of m as

$$V_{\rm 3Q} = -A_{\rm 3Q} \sum_{i<j} \frac{\exp(-m|\mathbf{r}_i - \mathbf{r}_j|)}{|\mathbf{r}_i - \mathbf{r}_j|}. \tag{2}$$

We find the OGE-like relation in the coefficient as $A_{\rm 3Q} \simeq A_{\rm QQ} \simeq \frac{1}{2} A_{\rm Q\bar{Q}}$ above T_c.

References

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