Lattice QCD Study for the Penta-Quark Potential

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We perform the first study of the static penta-quark potential [1] in SU(3) lattice QCD with β=6.0 and $16^3\times 32$ at the quenched level. We investigate the QQ-$\bar{\rm Q}$-QQ configuration as shown in Fig.1. With the smearing method [2-4] to enhance the ground-state component, we accurately measure the penta-quark potential $V_{\rm 5Q}$ from the penta-quark Wilson loop $\langle W_{\rm 5Q}\rangle$ as shown in Fig.2 in a gauge-invariant manner.

As the lattice QCD result, we find that the static penta-quark potential $V_{\rm 5Q}$ is well described by the sum of one-gluon-exchange (OGE) Coulomb term and multi-Y type linear term, i.e., the OGE plus multi-Y Ansatz [1],

$$\begin{aligned} V_{\rm 5Q} &= -A_{\rm 5Q}\{(\frac{1}{r_{12}}+\frac{1}{r_{34}})+\frac{1}{2}(\frac{1}{r_{15}}+\frac{1}{r_{25}}+\frac{1}{r_{35}}+\frac{1}{r_{45}}) \\ &\quad +\frac{1}{4}(\frac{1}{r_{13}}+\frac{1}{r_{14}}+\frac{1}{r_{23}}+\frac{1}{r_{24}})\}+\sigma_{\rm 5Q}L_{\rm min}+C_{\rm 5Q} \end{aligned} \quad (1)$$

with $r_{ij}\equiv|\mathbf{r}_i-\mathbf{r}_j|$ and $L_{\rm min}$ being the minimal length of the flux-tube linking five quarks. Note that there appear three kinds of Coulomb coefficients ($A_{\rm 5Q}$, $\frac{1}{2}A_{\rm 5Q}$, $\frac{1}{4}A_{\rm 5Q}$) in the penta-quark system, while only one Coulomb coefficient, $A_{\rm Q\bar{Q}}$ or $A_{\rm 3Q}$, appears in the Q$\bar{\rm Q}$ or the 3Q system. (In Eq.(1), $A_{\rm 5Q}$ corresponds to $A_{\rm 3Q}$ or $\frac{1}{2}A_{\rm Q\bar{Q}}$ in terms of the OGE result.)

Figure 3 shows typical examples of the lattice QCD result for the penta-quark potential $V_{\rm 5Q}$ [1]. The symbols denote the lattice data, and the curves denote the theoretical form of the OGE plus multi-Y Ansatz with ($A_{\rm 5Q}$,$\sigma_{\rm 5Q}$) fixed to be ($A_{\rm 3Q}$,$\sigma_{\rm 3Q}$) in the 3Q potential $V_{\rm 3Q}$ in Ref.[3]. (Note that there is no adjustable parameter for the theoretical curves besides an irrelevant constant $C_{\rm 5Q}$, since $A_{\rm 5Q}$ and $\sigma_{\rm 5Q}$ are fixed.) One finds a good agreement between the lattice data and the OGE plus multi-Y Ansatz.

From the comparison with the Q$\bar{\rm Q}$ and the 3Q potentials [2-4], the universality of the string tension and the OGE result are found among Q$\bar{\rm Q}$, 3Q and 5Q systems as

$$\sigma_{\rm Q\bar{Q}}\simeq\sigma_{\rm 3Q}\simeq\sigma_{\rm 5Q},\qquad \frac{1}{2}A_{\rm Q\bar{Q}}\simeq A_{\rm 3Q}\simeq A_{\rm 5Q}. \quad (2)$$

This result supports the flux-tube picture [2-5] on the confinement mechanism even for the multi-quark system [1].

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References

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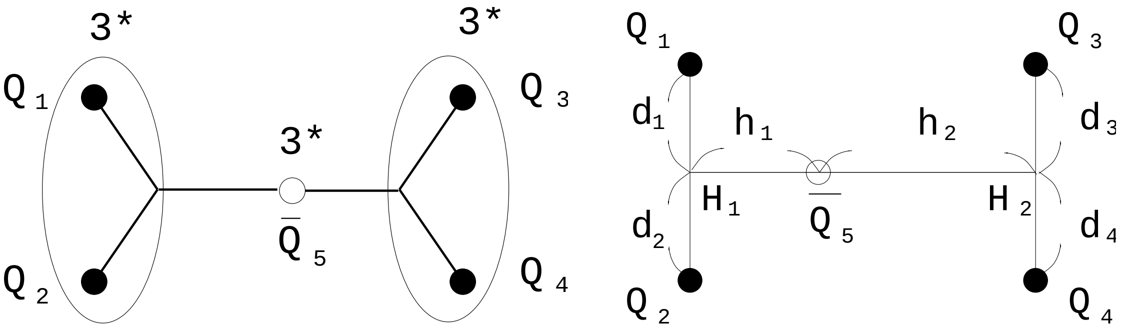

Figure 1: (a) The QQ-$\bar{\mathrm{Q}}$-QQ type configuration for the penta-quark system. The two QQ clusters belong to the $\mathbf{3}^*$ representation of the color SU(3). (b) A planar configuration of the penta-quark system. Here, we take $d_1 = d_2 = d_3 = d_4 \equiv d$ and $h_1 = h_2 \equiv h$.

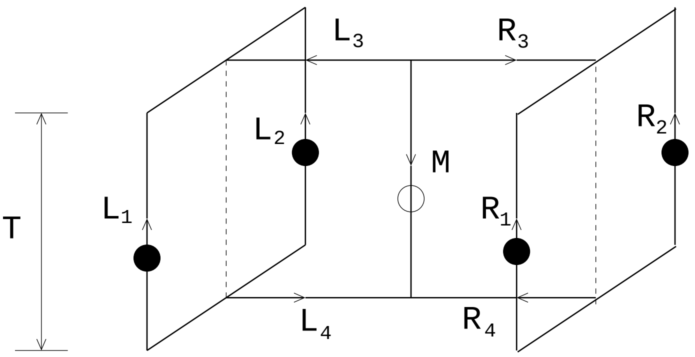

Figure 2: The penta-quark Wilson loop $W_{5\mathrm{Q}}$ for the penta-quark potential $V_{5\mathrm{Q}}$.

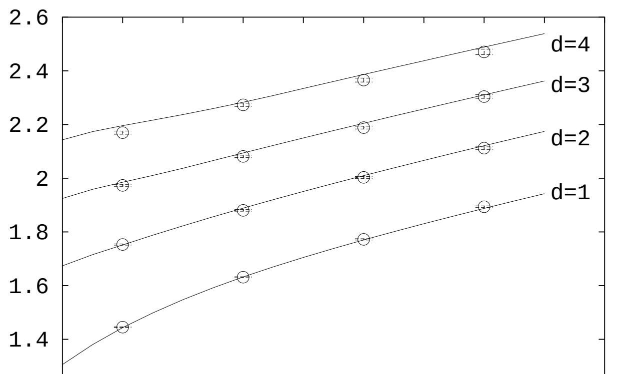

Figure 3: Lattice QCD results for the penta-quark potential $V_{5\mathrm{Q}}$. The symbols denote the lattice data, and the curves denote the theoretical form of the OGE plus multi-Y Ansatz [1]. A good agreement is found between the lattice data and the theoretical curves.