# Static Three-Quark Potential in SU(3) Lattice QCD Monte-Carlo Simulation

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## Abstract

The static three-quark(3Q) potential is investigated in the SU(3) lattice QCD at the quenched level, using the standard Wilson action with $\beta = 5.7 (a \simeq 0.2\text{fm})$ and $12^3 \times 24$. With the 3Q Wilson loop, the ground-state 3Q potential $V_{3Q}$ is calculated for 16 patterns of the 3Q configuration, using the smearing technique, which enhances the ground-state overlap of the 3Q operator. With the accuracy better than a few %, the lattice QCD data for $V_{3Q}$ are well described by a sum of the Coulomb term, a constant and the linear term which is proportional to the minimal length $L_{\min}$ of the flux-tube linking the 3 quarks. Our results seem to support the Y-type flux picture rather than $\Delta$-type one. From the comparison of $V_{3Q}$ with the Q-$\bar{\text{Q}}$ potential, we find the universality of the string tension, $\sigma_{3Q} \simeq \sigma_{Q\bar{Q}}$ as well as the OGE relation on the Coulomb coefficient, $A_{3Q} \simeq \frac{1}{2} A_{Q\bar{Q}}$.

## 1. Theoretical Consideration

In this paper, we study the 3Q potential $V_{3Q}$ in the SU(3) lattice QCD. In the inter-quark potential, the short-distance behavior is described with the one-gluon-exchange (OGE) Coulomb potential originating from P-QCD, and the long-distance behavior seems characterized by the flux-tube picture, which is derived from the strong-coupling QCD. For instance, the quark-antiquark ($Q\bar{Q}$) static potential is well described as

$$V_{Q\bar{Q}} = -\frac{A_{Q\bar{Q}}}{r} + \sigma_{Q\bar{Q}} r + C_{Q\bar{Q}}. \tag{1}$$

In SU(3) QCD, there appears the 'junction' combining three flux tubes in the baryonic 3Q system, so that the Y-type flux formation is expected. Then, the 3Q potential $V_{3Q}$ is conjectured to be described as

$$V_{3Q} = -\sum_{i<j} \frac{A_{3Q}}{|\vec{r_i} - \vec{r_j}|} + \sigma_{3Q} L_{\min} + C_{3Q}, \tag{2}$$

where $L_{\min}$ denotes the minimal length of the flux tube linking the 3 quarks.

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## 2. Numerical Results

We investigate the 3Q potential $V_{3Q}$ using the 3Q Wilson loop in the SU(3) lattice QCD simulation. Here, the standard Wilson action is used with $\beta = 5.7$ ($a \simeq 0.2$ fm) on $12^3 \times 24$ lattice at the quenched level. To enhance the ground-state overlap of the 3Q operator, the smearing technique is applied on the spatial link variables. After the smearing, more than 80% ground-state overlap is achieved.

We show in Fig.1 the numerical result on $V_{3Q}$ for 16 patterns of the 3Q configuration, where 3 quarks are located at $(i,0,0),(0,j,0),(0,0,k)$ in $\mathbf{R}^3$. With the accuracy better than a few %, the 3Q potential is well reproduced by Eq.(2) with the parameters in Table 1. (As a comparison, we try to fit $V_{3Q}$ with $-\sum_{i<j}\frac{\tilde{A}_{3Q}}{|\vec{r}_i-\vec{r}_j|}+\tilde{\sigma}_{3Q}L_\Delta+\tilde{C}_{3Q}$ with the perimeter $L_\Delta$. In this $\Delta$-type fit, $\chi^2/N_{\rm DF}$ is more than 10.9, which seems too large to be acceptable.)

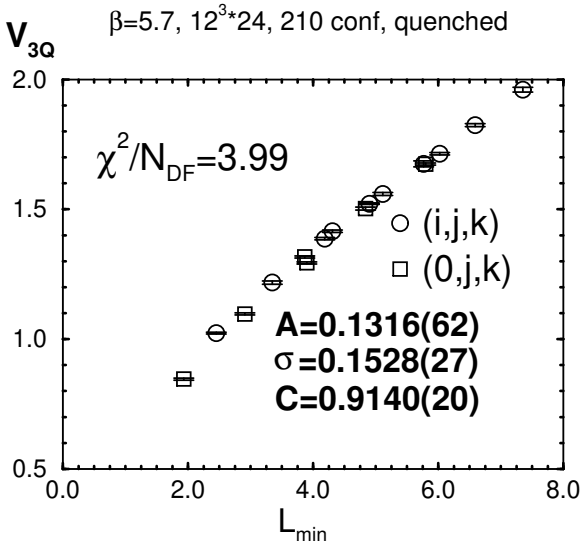


Fig.1 :
3 quark potential $V_{3Q}$ as the function of $L_{\rm min}$, the minimal length of flux linking 3 quarks, in the lattice unit. Apart from a constant, $V_{3Q}$ is almost proportional to $L_{\rm min}$ in the infrared region.

| | $A$ | $\sigma$ | $C$ |
|---|---|---|---|
| $Q\bar{Q}$ | 0.2793(116) | 0.1629(47) | 0.6293(161) |
| 3Q | 0.1316(62) | 0.1528(27) | 0.9140(201) |

Table 1:
The Coulomb coefficient, the string tension and the constant term for $Q\bar{Q}$ and 3Q potentials in the lattice unit.

Next, we compare the 3Q potential with the $Q\bar{Q}$ potential in terms of the fit parameters $(A_{3Q},\sigma_{3Q},C_{3Q})$ and $(A_{Q\bar{Q}},\sigma_{Q\bar{Q}},C_{Q\bar{Q}})$ as shown in Table 1.

- We find the OGE relation on the Coulomb coefficient as $A_{3Q} \simeq \frac{1}{2}A_{Q\bar{Q}}$.
- The universality of the string tension is found as $\sigma_{3Q} \simeq \sigma_{Q\bar{Q}}$.

To conclude, the lattice QCD data for $V_{3Q}$ are well reproduced by Eq.(2).