Lattice QCD analysis of the ground-state 3Q potential and the excited-state 3Q potential

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We perform the detailed analysis of the ground-state three-quark (3Q) potential $V_{3Q}^{\rm g.s.}$ and the excited-state 3Q potential $V_{3Q}^{\rm e.s.}$ using SU(3) lattice QCD[1−4]. For more than 300 different patterns of the 3Q systems, we investigate the ground-state potential $V_{3Q}^{\rm g.s.}$ in detail using SU(3) lattice QCD with $12^3 \times 24$ at $\beta = 5.7$ and with $16^3 \times 32$ at $\beta = 5.8, 6.0$ at the quenched level. As a result, we find that the ground-state potential $V_{3Q}^{\rm g.s.}$ is well described with Y-ansatz (Fig.1) as

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

with the accuracy better than 1%.[1,2] Here, $L_{\rm min}$ is the minimal value of total flux-tube length. Such a Y-type flux tube profile is actually observed in recent lattice QCD[4,5], as shown in Fig.2.

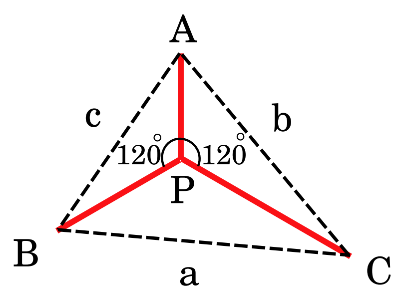

Figure 1: The flux-tube configuration of the 3Q system with the minimal value $L_{\rm min}$ of the total flux-tube length. There appears a physical junction linking the three flux tubes at the Fermat point P, and one finds $L_{\rm min} = \rm AP + BP + CP$.

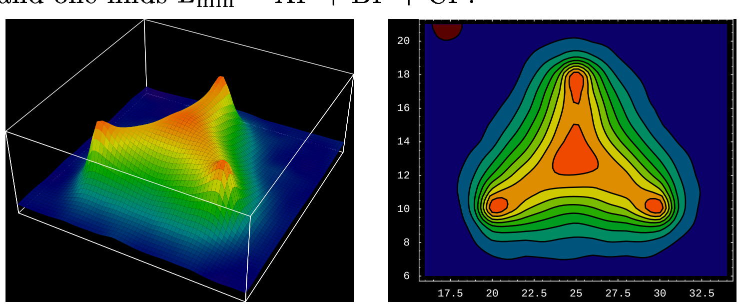

Figure 2: The lattice QCD result for the flux-tube profile in the spatially-fixed 3Q system in the maximally-abelian projected QCD[4,5]. The distance between the junction and each quark is about 0.5 fm.

We also study the excited-state potential $V_{3Q}^{e.s.}$ using lattice QCD with $16^3 \times 32$ at $\beta = 5.8$ for 24 patterns of the 3Q systems[3,4]. The energy gap between $V_{3Q}^{g.s.}$ and $V_{3Q}^{e.s.}$, which physically means the gluonic excitation energy, is found to be about 1GeV in the typical hadronic scale as shown in Fig.3. This large gluonic excitation energy, which is relatively large compared with the excitation energy of the quark origin, gives the reason of the success of the simple quark model without explicit gluonic excitation modes. (See Fig.4.)

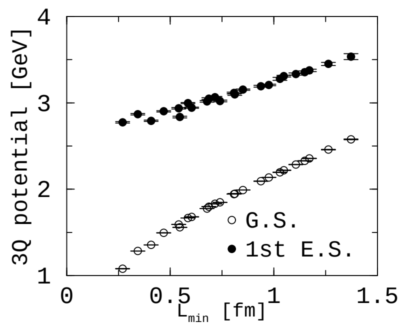

Figure 3: The lattice QCD results of the ground-state 3Q potential $V_{3Q}^{g.s.}$ (open circles) and the 1st excited-state 3Q potential $V_{3Q}^{e.s.}$ (filled circles) as the function of $L_{\min}$. The gluonic excitation energy is found to be more than 1GeV in the hadronic scale.

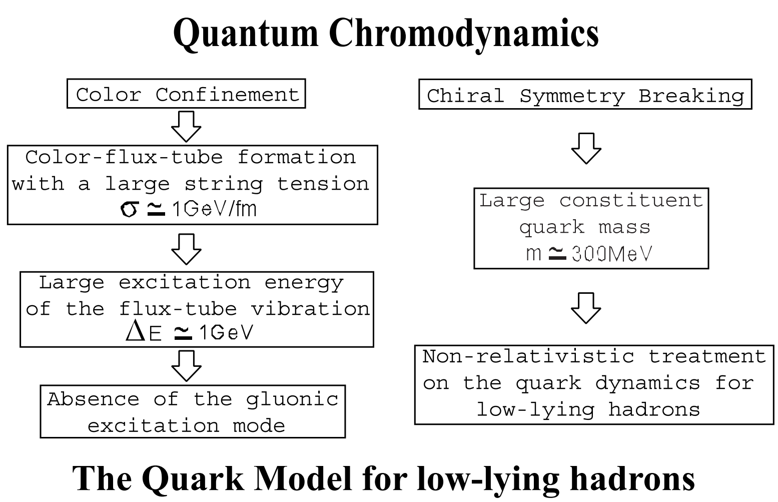

Figure 4: Connection from QCD to the success of the quark model for low-lying hadrons. The large gluonic excitation energy $\Delta E \simeq$ 1GeV leads to the absence of the gluonic mode in the low-lying hadrons and brings about the great success of the quark model.

References

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