Y-type Flux-tube Formation and Gluonic Excitations in Baryons — From QCD to Quark Model —

T.T. Takahashi[a], H. Suganuma[b] and H. Ichie[b]

[a] *Yukawa Institute for Theoretical Physics, Kyoto University, Sakyo, Kyoto 606-8502, Japan*
[b] *Faculty of Science, Tokyo Institute of Technology, Tokyo 152-8551, Japan*

We study the ground-state three-quark (3Q) potential $V_{\rm 3Q}^{\rm g.s.}$ and the excited-state 3Q potential $V_{\rm 3Q}^{\rm e.s.}$ using SU(3) lattice QCD[1-4]. For more than 300 different patterns of the 3Q systems, the ground-state potential $V_{\rm 3Q}^{\rm g.s.}$ is investigated in detail in 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, the ground-state potential $V_{\rm 3Q}^{\rm g.s.}$ is found to be well described with Y-Ansatz (Fig.1),

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

within the 1%-level deviation[1,2]. $L_{\rm min}$ 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.

The excited-state potential $V_{\rm 3Q}^{\rm e.s.}$ is also studied in lattice QCD with $16^3 \times 32$ at $\beta = 5.8, 6.0$ for more than 100 patterns of the 3Q systems[3,4]. The energy gap between $V_{\rm 3Q}^{\rm g.s.}$ and $V_{\rm 3Q}^{\rm e.s.}$, 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 degrees of freedom. (See Fig.4.)

Acknowledgements: The lattice-QCD Monte Carlo calculations have been performed on the supercomputers: NEC-SX5 at Osaka University and HITACHI-SR8000 at KEK.

References

[1] T.T.Takahashi, H.Matsufuru, Y.Nemoto, H.Suganuma, Phys. Rev. Lett. **86** (2001) 18.
[2] T.T.Takahashi, H.Suganuma, Y.Nemoto, H.Matsufuru, Phys. Rev. **D65** (2002) 114509.
[3] T.T. Takahashi and H. Suganuma, Phys. Rev. Lett. **90** (2003) 182001.
[4] H. Suganuma, T.T. Takahashi and H. Ichie, Nucl. Phys. **A** (2004) in press.
[5] H. Ichie, V. Bornyakov, T. Streuer and G. Schierholz, Nucl. Phys. **A721** (2003) 899; Nucl. Phys. **B** (Proc.Suppl.) **119** (2003) 751.

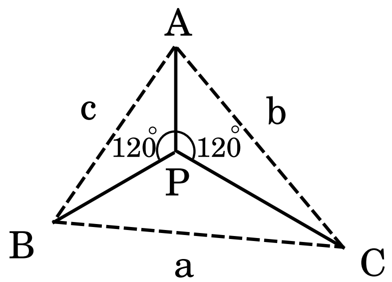

Figure 1: The flux-tube configuration of the 3Q system with the minimal value $L_{\rm min}$ of the total flux-tube length. There appears a physical junction linking the three flux tubes at the Fermat point P, and one finds $L_{\rm min} = {\rm AP} + {\rm BP} + {\rm CP}$.

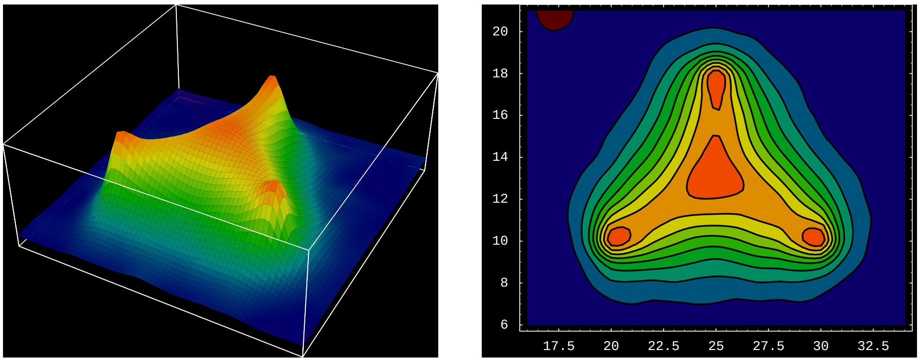

Figure 2: The lattice QCD result for the flux-tube profile in the spatially-fixed 3Q system in the maximally-abelian projected QCD[4,5]. The distance between the junction and each quark is about 0.5 fm.

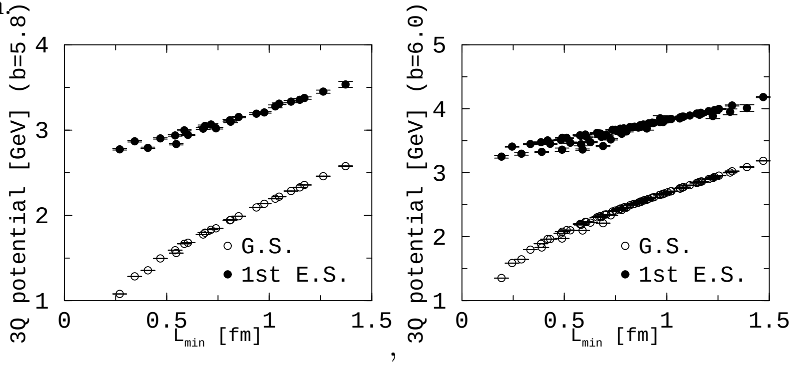

Figure 3: The lattice QCD results of the ground-state 3Q potential $V_{3Q}^{\rm g.s.}$ (open circles) and the 1st excited-state 3Q potential $V_{3Q}^{\rm e.s.}$ (filled circles) as the function of $L_{\rm min}$. The gluonic excitation energy is found to be more than 1GeV in the hadronic scale.

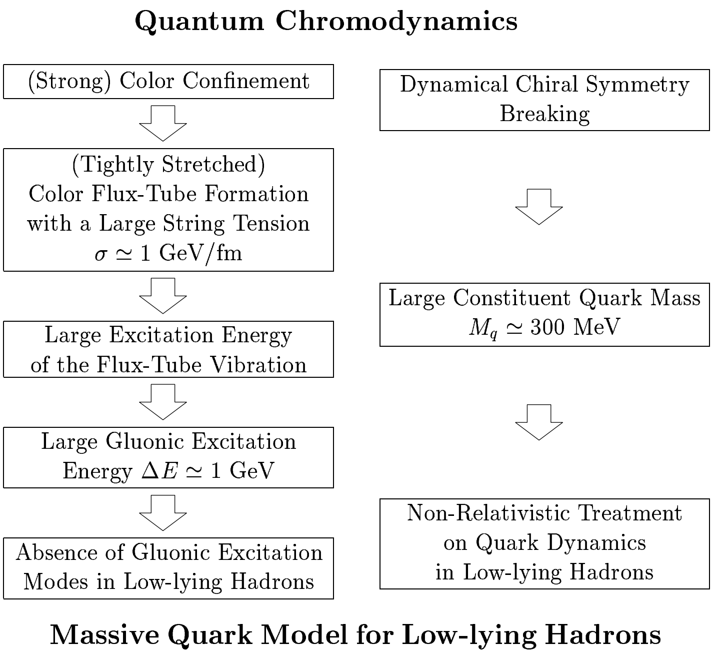

Figure 4: Connection from QCD to the success of the quark model for low-lying hadrons. The large gluonic excitation energy $\Delta E \simeq 1$GeV leads to the absence of the gluonic mode in the low-lying hadrons and brings about the great success of the quark model.