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Static Energy in (2+1+1)-Flavor Lattice QCD: Scale Setting and Charm Effects

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We present results for the static energy in $(2+1+1)$-flavor QCD over a wide range of lattice spacings and several quark masses, including the physical quark mass, with ensembles of lattice-gauge-field configurations made available by the MILC Collaboration. We obtain results for the static energy out to distances of nearly 1 fm, allowing us to perform a simultaneous determination of the scales r_1 and r_0 as well as the string tension, σ. For the smallest three lattice spacings we also determine the scale r_2. Our results for $\frac{r_0}{r_1}$ and $r_0\sqrt{\sigma}$ agree with published $(2+1)$-flavor results. However, our result for $\frac{r_1}{r_2}$ differs significantly from the value obtained in the $(2+1)$-flavor case, which is most likely due to the effect of the charm quark. We also report results for r_0, r_1, and r_2 in fm, with the former two being slightly lower than published $(2+1)$-flavor results. We study in detail the effect of the charm quark on the static energy by comparing our results on the finest two lattices with the previously published $(2+1)$-flavor QCD results at similar lattice spacing. We find that for $r > 0.2$~fm our results on the static energy agree with the $(2+1)$-flavor result, implying the decoupling of the charm quark for these distances. For smaller distances, on the other hand, we find that the effect of the dynamical charm quark is noticeable. The lattice results agree well with the two-loop perturbative expression of the static energy incorporating finite charm mass effects. This is the first time that the decoupling of the charm quark is observed and quantitatively analyzed on lattice data of the static energy.

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