Phase Structure of SU(2) QCD at Finite Baryon Density

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Recently, QCD at finite density has become the center of wide interest in hadron/nuclear physics. Based on effective models and the perturbative calculations at very high density, it is widely believed that QCD has a very rich phase structure including many interesting phenomena such as diquark condensation, color-flavor-locking; they may be realized at heavy ion collisions, neutron stars and supernova explosions. First principle calculations using lattice QCD is highly desirable.
However, when we step out into finite chemical potential, the fermion determinant $\det D$ becomes complex in general; Monte Carlo simulation based on Eucledian path integral

$$Z = \int \mathcal{D}\mathcal{U} \det \mathcal{D} \mathrm{e}^{-\mathcal{S}_{\mathcal{G}}} \ , \tag{1}$$

does not work.
Two-Color QCD is an exceptional case. Due to the pseudo-reality of SU(2) group, the path integral measure is real, and it is possible to study the structure of the theory with use of the Monte Carlo simulation. After the first calculation[1], no simulation had been done for many years. Analysis in Ref.(2), however, has encouraged us to study this QCD-like theory in order to understand the phase structure of QCD, and there have been many color SU(2) lattice calculations with chemical potential[3-5].
Here we investigate the finite density state of SU(2) QCD, using the Wilson fermions and Iwasaki improved gauge action. In this analysis, the ratio of fermion determinants is evaluated at each step of the Metropolis link update, by help of the Woodbery formula. We study the phase diagram together with critical chemical potential in $\beta - \kappa - \mu$ parameter space by measuring thermodynamical quantities, such as, baryon number density, Polyakov line, and the energy density of gluon sector. The susceptibility of the Polyakov line with respect to the chemical potential has a peak, which suggests the existence of a phase transition. Behaviors of the meson and diquark propagators at finite chemical potential are also investigated. Based on these physical quantities we discuss the mechanism of the phase transition at finite density.

References

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