Strongly interacting matter in magnetic field

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Inverse magnetic catalysis effect on the chiral phase transition is investigated in the frame of SU(2) NJL model with Pauli-Villars regularization scheme. We consider two scenarios, the chiral chemical potential μ_5 caused by sphalerons and magnetic inhibition of mesons π_0. With different chiral chemical potential, we always obtain magnetic catalysis in the mean field calculation, due to the enhancement of Fermi surface of the pairing fermions by μ_5. On the other hand, when going beyond the mean field approximation by including the feed-down from mesons to quarks, the competition between the magnetic catalysis effect of quarks and magnetic inhibition effect of mesons leads to the transition from inverse magnetic catalysis to delayed magnetic catalysis with increasing magnetic field.

KEYWORDS: chiral symmetry, inverse magnetic catalysis, chiral chemical potential, beyond mean field

1. Introduction

The phase structure of quantum chromodynamics (QCD) at finite magnetic field, temperature and density attracts much attention in recent years, due to its relation to the evolution of the early universe, relativistic heavy ion collisions and compact stars. Since the strongest magnetic field in nature may be generated in the initial stage of relativistic heavy ion collisions. The initial magnitude of the field can reach $eB \sim (1 - 100)m_\pi^2$ in collisions at the Relativistic Heavy Ion Collider and the Large Hadron Collider [1–5], where e is the electron charge and m_π the pion mass in vacuum. The magnetic field can reach 10^{18-20} Gauss, in the core of magnetars [6, 7]. Furthermore, it is indicated that the extremely strong magnetic field, $B \sim 10^{23}$ Gauss, are generated via cosmological electroweak and quark-hadron phase transition [8, 9]. Therefore, how the strong magnetic field changes the QCD phase structure becomes an interesting and open question, see [10–12] for recent reviews.

The use of lattice simulations proved to be invaluable to understand the underlying dynamics at finite temperature and magnetic field, although it has difficulties at finite density and electric field. The consensus of three-color lattice simulation is that the background magnetic field aids chiral symmetry breaking at vanishing temperature and density, which is called magnetic catalysis [13–15]. In contrast and rather surprisingly, the behavior of the condensate drastically changes when the temperature is in the near-critical region, and leads to the decreasing critical temperature for chiral phase transition, which is called inverse magnetic catalysis [15–17]. Moreover, the critical temperature of chiral phase transition is a complicated function of the magnetic field, the current quark mass, and color degree of freedom. While inverse magnetic catalysis occurs at rather small current quark mass [15–17], most of the lattice simulations at sufficiently large current quark masses show the catalysis behavior of critical temperature [14]. Besides, lattice simulation in two-color QCD indicates that the critical temperature decreases for weak magnetic fields and increases for strong magnetic fields [18], which is different from the inverse magnetic catalysis at $eB < 3.25$ GeV$^2 \sim 180m_\pi^2$ in three-color QCD [15–17].