Chromomagnetic Catalysis of Chiral Symmetry Breaking and Color Superconductivity

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In accordance with modern knowledge, the QCD vacuum at low temperature and density is characterized by the confinement phemomenon, i.e. quarks and gluons are not observed, since they are confined into hadrons, and the color symmetry is not broken. Two nonperturbative features are inherent to the QCD vacuum in this phase. One is the nonzero value of the gluon condensate $\langle F^a_{\mu\nu}F^{a\mu\nu}\rangle$, where $F^a_{\mu\nu}$ is the field strength tensor of the gluon fields. Another one is the nonzero chiral condensate $\langle\bar{q}q\rangle$ which signals about dynamical chiral symmetry breaking. As a consequence, the low baryon density matter is the ordinary nuclei (or hadron) matter composed from individual hadrons (in this case the characteristic baryon density is about ρ_0=0.16 fm^{-3}). So the hadron matter can be described by effective theories with point-like hadron fields (Walecka model etc). At densities near the chiral phase transition density (about several times ρ_0) hadrons are overlapped and lose their individuality. (Such baryon densities are typical for the cores of neutron stars or may be reached in the future ion-ion experiments.) In this case the baryon matter is the totality of quarks, i.e. it is no more, but the quark matter. So, it should be described in the framework of effective models with point-like quarks, as the Nambu – Jona-Lasinio model (NJL) etc.

Recently, in the NJL type model approaches it was demonstrated that at high baryon densities a colored diquark condensate $< qq >$ might appear which signals color superconductivity (CSC) and spontaneous breakdown of color $SU_c(3)$ symmetry. However, in such an investigations of the CSC phenomenon only the chiral condensate $< \bar{q}q >$ was taken into account leaving aside the gluon condensate (another nonperturbative characteristic of the QCD vacuum). On the other hand, at moderate densities, there might persist yet a rather large value of the gluon condensate which significantly might change the common picture of the CSC formation.

In the paper [1] the systematic investigation of the CSC in the framework of an NJL model with $< qq >$ and $< \bar{q}q >$-condensates were performed in the presence of several types of external chromomagnetic fields which simulate the gluon condensate. For simplicity, we constrained ourselves to a (3+1)-dimensional $SU(2)_L\times SU(2)_R$ chirally symmetric NJL model with two flavored quarks:

$$L=\bar{q}\gamma^\nu(i\partial_\nu+gA^a_\nu(x)\frac{\lambda_a}{2})q+G[(\bar{q}q)^2+(\bar{q}i\gamma^5\vec{\tau}q)^2]+4G[i\bar{q}_c\varepsilon\epsilon^b\gamma^5q][i\bar{q}\varepsilon\epsilon^b\gamma^5q_c], \qquad (1)$$

In order to understand the genuine role of an external chromomagnetic field in the CSC phenomenon we removed from considerations other factors which might produce the CSC as the chemical potential. The external chromomagnetic field H (introduced by A_μ) was considered to belong to the algebra of the residual $SU_c(2)$ group, i.e. it might penetrate into the CSC phase. We have found that for sufficiently small values of the coupling constants G's the gap equations for the chiral and diquark condensates have only trivial solution $< qq >= < \bar{q}q >= 0$. If H is switched on, then $< \bar{q}q >\neq 0$ or $< qq >\neq 0$, i.e. the chiral or the color symmetries of the model is spontaneously broken down. **Hence, just the external**

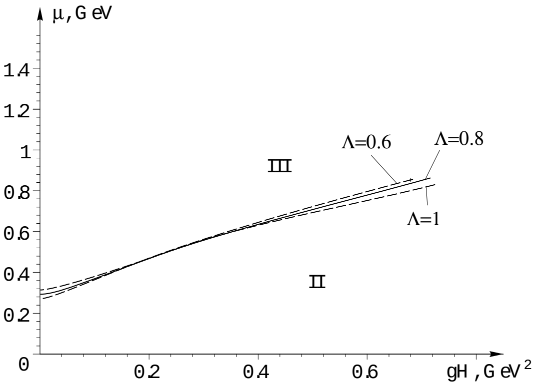

Figure 1: Phase portrait of the model in terms of variables (μ, gH) at $T = 0$ for three values of the cutoff parameter $\Lambda = 0.6, 0.8, 1$ GeV. Regions II, III describe the phase with broken chiral symmetry and the CSC phase, respectively.

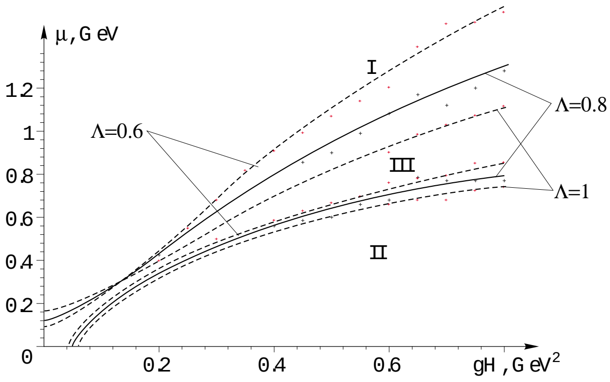

Figure 2: Phase portrait of the model in terms of variables (μ, gH) at $T = 0.15$ GeV for three cutoff values $\Lambda = 0.6,\ 0.8,\ 1$ GeV. The included phase I is the symmetrical one with zero condensates.

chromomagnetic field induces the appearence of nontrivial gaps and promotes the symmetry breaking. This phenomenon is known as the chromomagnetic catalysis effect of dynamical symmetry breaking.

In the article [2] we took into account the chemical potential μ as well. The phase portraits of the model for physically acceptable values of coupling constants are depicted on the Figs 1,2. It turns out that boundaries between phases have a rather weak dependence on the cutoff parameter Λ. The main conclusion of our investigations is that the inclusion of an external chromomagnetic field can significantly change the phase portrait, obtained at $H = 0$. Indeed, at $H = T = 0$ the values of the chemical potential corresponding to the CSC phase approximately lie in the interval $\mu > 0.3$ GeV (see Fig. 1). If the external chromomagnetic field is switched on, then at $gH_{phys} \approx 0.6$ GeV^2 the CSC can be observed at $\mu > 0.7$ GeV only. The same is true at nonzero temperature: critical values of the chemical potential are significantly larger at $H \neq 0$, than at $H = 0$ (see Fig. 2). Finally, one should note that at $\mu \neq 0, T \neq 0$ the external chromomagnetic field can induce the CSC phase transition as well. For example, at $T = 0.15$ GeV and $\mu = 0.8$ GeV there is a critical point gH_c at which a phase transition from the symmetric phase I to the CSC phase III occurs (see Fig. 2).

References

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