High Density Quark Matter under Stress*

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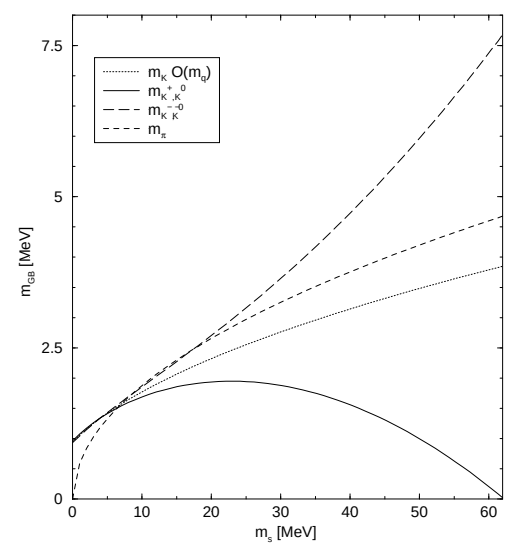
The study of hadronic matter in the regime of high baryon density and small temperature has revealed a rich and beautiful phase structure . One phase which has attracted particular interest is the color-flavor locked (CFL) phase of three flavor quark matter. This phase is expected to be the true ground state of ordinary matter at very high density. State of the art calculations are not sufficiently accurate to predict the critical density of the transition to CFL matter with any certainty. Current estimates typically range from $\rho_{crit} \sim (3-6)\rho_0$, where ρ_0 is the saturation density of nuclear matter. An exciting prospect is the possibility to put experimental constraints on the critical density from observations of neutron stars. Several proposals have been made for observables that are characteristic of different superfluid quark phases, and attempts are being made in order to include these phases in realistic neutron star structure calculations .

Initial work on the superfluid phases of QCD focussed mostly on idealized worlds with N_f flavors of massless fermions and no external fields. But in order to understand the matter at the core of real neutron stars the effects of non-zero masses and finite chemical potentials clearly have to be taken into account.

The main observation in this work was that a finite strange quark mass shifts the Fermi momentum of the strange quark with respect to the Fermi momentum of the light quarks. If the mismatch between the Fermi momenta is bigger than the gap then pairing between strange and non-strange quarks is no longer possible. The transition from CFL matter to quark matter with separate pairing among light and strange quarks (2+1SC) is predicted to occur at $m_s \sim \sqrt{p_F \Delta}$. Alford et al. observed that in the vicinity of this phase transition we expect to encounter inhomogeneous BCS phases analogous to the Larkin-Ovchinnikov-Fulde-Ferell (LOFF) phase in condensed matter physics . In the LOFF phase Cooper pairs have non-zero total momentum and as a consequence, pairing is restricted to certain regions of the Fermi surface.

In the present work we analyze CFL matter for strange quark masses and chemical potentials below the unlocking transition. We will argue that in this regime CFL matter responds to the external "stress" by forming a Bose condensate of kaons or pions . This effect can be understood as a chiral rotation of the CFL order parameter. The critical chemical potential behaves as $\mu_e \sim \sqrt{m m_s}\Delta/p_F$ and the critical strange quark mass as $m_s \sim m^{1/3}\Delta^{2/3}$, where m is the light quark mass, Δ is the gap, and p_F is the Fermi momentum. We note that parametrically, both the critical μ_e and $m_s^2/(2p_F)$ are much smaller than the gap.

Figure 1: Masses of mesons as a function of the strange quark mass.



[1] P. F. Bedaque and T. Schaefer, *Nucl.Phys. A697 (2002) 802-822]*