Color Superconductivity in magnetized three flavor quark matter

Aman Abhishek
Senior Research Fellow

Physical Research Laboratory, Ahmedabad
Overview

1. Phase Diagram of Quantum Chromodynamics
2. Role of magnetic field
3. Superconductivity
4. Color Superconductivity in Magnetic field
5. Results
QCD phase diagram

http://inspirehep.net/record/1181776/plots
Effect of magnetic field at high temperature and high density

- Unusually high magnetic fields can be found in nature.
- In heavy ion collisions magnetic fields of the order of $15 m^2$ can be generated.\(^2\)
- Intense magnetic fields are also found in neutron stars and early universe.\(^3\)
- Lattice QCD shows magnetic fields can significantly affect the chiral condensate.\(^4\)
- Studies have been made in perturbative QCD and effective models too.

\(^{2}\)Int.J.Mod.Phys.Rev.D 81, 114031
Superconductivity

- Discovered by H.K. Onnes in 1911.
- Theoretical explanation given by BCS in 1957.
- Fermi Surface unstable in presence of attractive interaction.
- Similar phenomenon possible in presence of quark matter.

\[\text{http://inspirehep.net/record/805336}\]
Nambu Jona-Lasinio Model

\[ \mathcal{H} = \psi^\dagger (-i\alpha \cdot \nabla - qB \times \alpha_2 + \gamma^0 m)\psi \]

\[ - G_s \sum_{A=0}^{8} \left[ (\bar{\psi} \lambda^A \psi)^2 - (\bar{\psi} \gamma^5 \lambda^A \psi)^2 \right] \]

\[ - G_D \sum_{A=0}^{8} \left[ (\bar{\psi}^c \lambda^A \psi)^2 - (\bar{\psi}^c \gamma^5 \lambda^A \psi)^2 \right] \]

\[ + K \left[ det_f[\bar{\psi} (1 + \gamma_5)\psi] + det_f[\bar{\psi} (1 - \gamma_5)\psi] \right] \]

(1)
Thermodynamic Potential and Gap Equations

\[ \Omega = \Omega_{\frac{sc}{2}} + \Omega_{\frac{s}{2}} + \Omega^0 + \Omega^1 + 4G_s l_s^i l_s^d - 4k l_s^u l_s^d l_s^s + \frac{\Delta^2}{4G_D} - \frac{k}{4} l_s^3 l_D^2 \]

By minimizing the thermodynamic potential, one gets the following four self consistent gap equations.

- \( M_u = M_{0u} - 4G l_s^u + 2k l_s^s l_s^d \), where \( l_s^i = \langle \bar{\psi}^i \psi^i \rangle \)
- \( M_d = M_{0d} - 4G l_s^d + 2k l_s^s l_s^u \)
- \( M_s = M_{0s} - 4G l_s^s + 2k l_s^u l_s^d + k l_D^2 \)
- \( \Delta = (2G_D - \frac{1}{2}k l_s^s) l_D \), where \( l_D = \langle \bar{\psi}_c^i \gamma^5 \psi^j \rangle \epsilon^{ij} \epsilon^{3ab} \)

Charge neutrality Conditions

- \( \rho_E = \frac{2}{3} \rho u - \frac{1}{3} \rho d - \frac{1}{3} \rho s - \rho_e = 0 \)
- \( \rho_8 = \sum_i \frac{1}{\sqrt{3}} (2 \rho^{i1} - \rho^{i2} - \rho^{i3}) = 0 \)
Mass Vs. Magnetic Field (Without Charge Neutrality)

![Graph showing mass vs. magnetic field for different quark flavors.](Image)
Gaps Vs. Chemical Potential (Charge Neutral Matter)
Gaps for $\tilde{\epsilon}B = 0.1, 10 \, m^2_{\pi}$ (With charge neutrality)
Dispersion for Gapless mode

\[ \omega_{\pm}^{11} \equiv \omega_{\pm}^u = \bar{\omega}_{\pm} + \delta \epsilon_n \pm \delta \mu \]

\[ \omega_{\pm}^{21} \equiv \omega_{\pm}^d = \bar{\omega}_{\pm} - \delta \epsilon_n \mp \delta \mu \]
\[ \rho_{sc}^u = \sum_n \frac{\alpha_n \tilde{e}B}{(2\pi)^2} \int dp_z \left[ \frac{1}{2} \left( 1 - \frac{\bar{\zeta}_{n-}}{\bar{\omega}_{n-}} \right)(1 - \theta(-\omega_{n}^d)) - \frac{1}{2} \left( 1 - \frac{\bar{\zeta}_{n+}}{\bar{\omega}_{n+}} \right) \right] \]

\[ \rho_{sc}^d = \sum_n \frac{\alpha_n \tilde{e}B}{(2\pi)^2} \int dp_z \left[ \theta(-\omega_{n}^d) + \frac{1}{2} \left( 1 - \frac{\bar{\zeta}_{n-}}{\bar{\omega}_{n-}} \right)(1 - \theta(-\omega_{n}^d)) - \frac{1}{2} \left( 1 - \frac{\bar{\zeta}_{n+}}{\bar{\omega}_{n+}} \right) \right] \]
Density Mismatch (cont.)
THANK YOU