

Thermodynamic Properties of Magnetized Quark Matter

Second Latin American Workshop on Electromagnetics Effects in QCD

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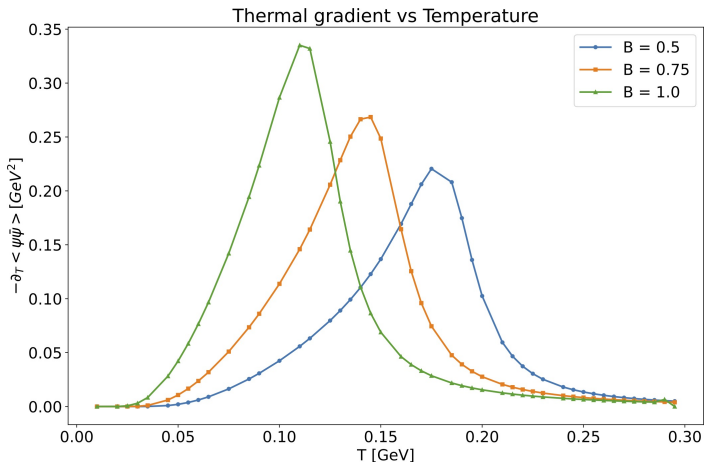
Context and Motivation

- Quark matter in intense magnetic fields is relevant for:
 - **Magnetars**: Neutron stars with fields $\sim 10^{15}$ G
 - Quark-gluon plasma in heavy-ion collisions
- **Problem**: Lattice QCD shows **Inverse Magnetic Catalysis** (IMC)
- **Challenge**: Standard NJL model doesn't reproduce IMC without modifications

What is IMC?

Inverse Magnetic Catalysis

Decrease of chiral transition temperature with magnetic field strength



Methodology: Modified NJL Model

- **Effective Lagrangian:**

$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \bar{\psi}(\not{D} - m)\psi + G[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\vec{\tau}\psi)^2]$$

- **Gap equation:**

$$M = m_0 - 2G\langle\bar{\psi}\psi\rangle$$

- **Magnetic field:** Covariant derivative

$$D_\mu = \partial_\mu - iQA_\mu$$

- **Condensate equation:**

$$-\langle\bar{\psi}\psi\rangle = \frac{3TM}{4\pi^{3/2}} \sum_{f=u,d} |q_f B| \int_{\tau_{uv}^2}^{\tau_{tr}^2} d\tau \frac{e^{-M^2\tau}\Theta_2(0, e^{-4\pi^2 T^2 \tau^2})}{\tau^{1/2} \tanh(|q_f B|\tau)}.$$

Innovation

Thermo-magnetic
coupling:

$$G(eB, T)$$

Thermo-magnetic Coupling

Proposed form

$$G(eB, T) = G(0, T) \left(\frac{1 + ax^2 + bx^3}{1 + cx^2 + dx^4} \right)$$

- x : magnetic field strength
- Parameters a, b, c, d fitted to Lattice QCD
- Represents interaction weakening with eB

Results: Quark-Antiquark Condensate

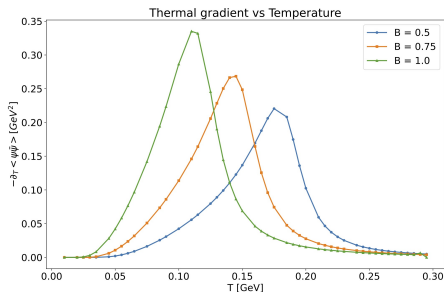


Figure: With thermo-magnetic coupling

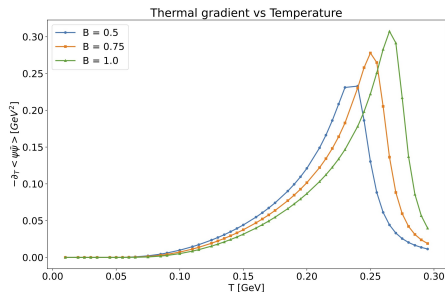


Figure: With constant coupling

IMC successfully reproduced!

Thermodynamic Properties

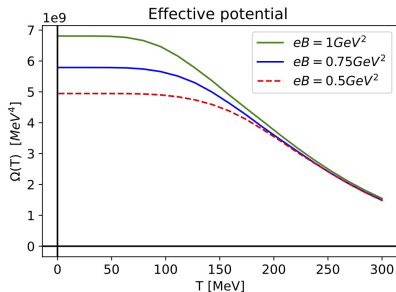


Figure: Effective potential

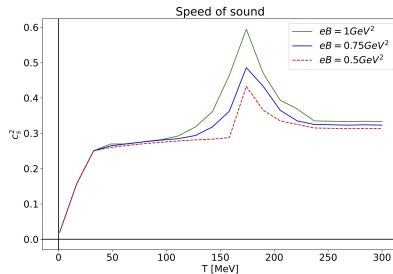


Figure: Speed of sound c_s^2

$$\langle \bar{\psi}\psi \rangle = -\frac{\partial \Omega}{\partial m}$$

$$c_s^2 = \frac{-\partial \Omega / \partial T}{\partial \epsilon / \partial T}$$

Conclusions

- ✓ IMC reproducible with $G(eB, T)$ dependent coupling
- ✓ Consistent description of thermodynamic properties
- ✓ Confirmation: QCD interaction weakens with B

Future Work

- Extension to 3-flavor models
- Finite density effects

Thank you!

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References:

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Bandyopadhyay et al. Eur. Phys. J. C 83, 489 (2023)