Effect of anomalous magnetic moment of quarks on chiral and de-confinement transition in pNJL model

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The presence of external magnetic field leads to emergence of many exotic phenomena of strongly interacting matter which speaks in favour of the significant amount of researches that has been carried out in recent times. Now it is well known that in non-central heavy ion collisions at RHIC and LHC can produce magnetic fields $eB \approx 15m_\pi^2$ which is sufficient to bring noticeable influence on the vacuum properties of quantum chromodynamics (QCD). Thus the possibility of experimental realization sets the platform for investigation of these magnetic field dependent effects. However, the detailed first principle analysis involves a great deal of complexities as the large coupling strength of QCD in low energy regime hinders the use of perturbative approach.

The Nambu Jona-Lasinio (NJL) model of QCD, which is capable of capturing some of the non-perturbative aspects of the strongly interacting matter, provides a useful framework to probe the phase structure of QCD at arbitrary temperatures and chemical potentials. On the other hand, it is well known that the center symmetry of the color gauge group and of the Polyakov loop can be used to describe color confinement. Thus the Polyakov NambuJona-Lasinio (pNJL) model has been introduced in which the true confinement of QCD is replaced by statistical confinement and an effective interaction among the chiral condensate and the Polyakov loop is realized by a covariant coupling of quarks with a background temporal gluon field.

In a recent study [1] it was demonstrated that, inclusion of AMM of quarks leads to decrease in critical temperature for chiral symmetry broken to restored phase with increasing magnetic field which can be identified as inverse magnetic catalysis (IMC).

The Lagrangian of the two-flavour pNJL-model considering the AMM of free quarks in presence of constant background magnetic field is given by

$$\begin{aligned}\mathscr{L} &= \bar{\psi}(x)\left(i\not{D} - m + \gamma_0\mu_q + \frac{1}{2}\hat{a}\sigma^{\mu\nu}F_{\mu\nu}\right)\psi(x) \\ &\quad + G\left\{\left(\psi(\bar{x})\psi(x)\right)^2 + \left(\psi(\bar{x})i\gamma_5\tau\psi(x)\right)^2\right\} \\ &\quad - \mathcal{U}\left(\Phi,\bar{\Phi};T\right) \qquad (1)\end{aligned}$$

where the constituent quarks interact with the Abelian gauge field A_μ and the $\mathrm{SU_c}(3)$ gauge field $\mathcal{A}_\mu$ via the covariant derivative

$$D_\mu = \partial_\mu - i\hat{q}A_\mu - i\mathcal{A}^a_\mu. \qquad (2)$$

In this work we adopt Polyakov loop effective potential following [2]

$$\begin{aligned}\frac{\mathcal{U}\left(\Phi,\bar{\Phi};T\right)}{T^4} &= -\frac{b_2(T)}{2}\bar{\Phi}\Phi - \frac{b_3}{6}\left(\Phi^3 + \bar{\Phi}^3\right) \\ &\quad + \frac{b_4}{4}\left(\bar{\Phi}\Phi\right)^2. \qquad (3)\end{aligned}$$

All the other terms appearing in Eq. (1) are defined in [1, 2]. Now employing mean field approximation in Eq. (1) (see [1] for details) one can obtain constituent quark mass (M), expectation values of Polyakov loop Φ and $\bar{\Phi}$ using the following stationarity conditions

$$\frac{\partial\Omega}{\partial M} = 0; \qquad \frac{\partial\Omega}{\partial\Phi} = 0; \qquad \frac{\partial\Omega}{\partial\bar{\Phi}} = 0;$$

which leads to three coupled integral equations. Since, the constituent quark mass and the Polyakov loops are effective fields associated with the order parameters of chiral and

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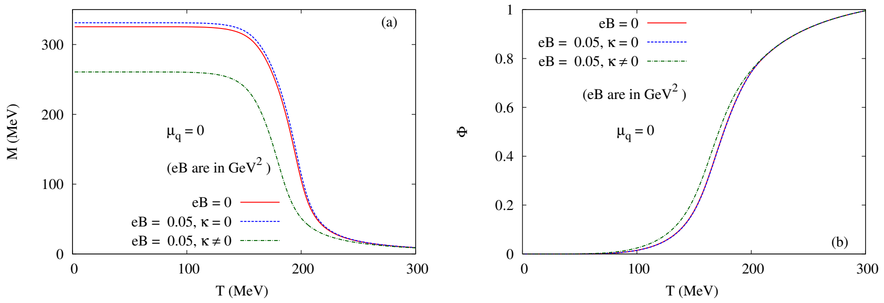

FIG. 1: Variation of M and Φ as function of T for different values of eB and κ_f

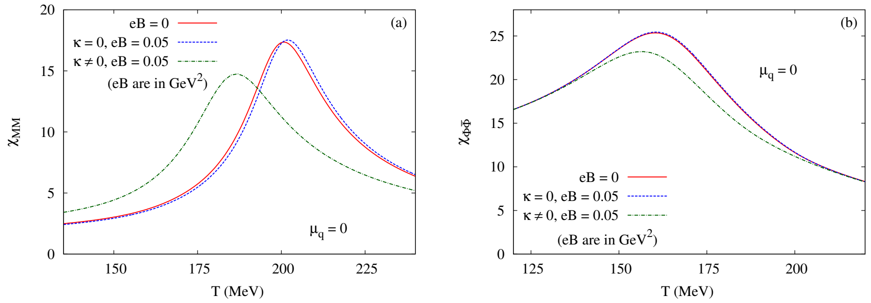

FIG. 2: Variation of χ_{MM} and $\chi_{\Phi\bar{\Phi}}$ as function of T for different values of eB and κ_f

de-confinement symmetry, the susceptibilities corresponding to these fields show signals of phase transitions.

In Figs. 1 (a) and (b) we have shown the variation of M and Φ as function of T at vanishing chemical potential for three different cases (I) $eB = 0$ (II) $eB = 0.5$ GeV^2, $\kappa = 0$ and (III) $eB = 0.5$ GeV^2, $\kappa \neq 0$. It is evident that in all the cases, M almost remains constant up to $T \approx 100$ MeV and the transition from chiral symmetry broken (with $M \neq 0$) to the restored phase (i.e.,$M \approx m \approx 0$), is a smooth crossover. As we turn on the magnetic field M increases w.r.t. it's value at $eB = 0$ for all values of T. An opposite behaviour is observed when we include finite values of AMM of quarks which decrease M substantially for all T. Fig 1 (b) shows that the transition from confined to de-confined phase is a rapid crossover in all the cases considered in the above mentioned plots. In Fig. 2 (a) and (b) we have plotted the variation of chiral (χ_{MM}) and de-confinement ($\chi_{\Phi\bar{\Phi}}$) susceptibility for the three cases previously mentioned. It is evident that when only the background magnetic field is taken into consideration chiral transition temperature (T_C^{χ}) moves towards higher values of temperature implying magnetic catalysis (MC). On the contrary, inclusion of AMM of quarks results in decrease in T_C^{χ} which can be identified as IMC. Furthermore, inclusion of AMM of quarks decreases de-confinement transition temperature (T_C^{d}) substantially which is evident from Fig. 2 (b).

References

[1] N. Chaudhuri, S. Ghosh, S. Sarkar and P. Roy, Phys. Rev. D **99**, no. 11, 116025 (2019)

[2] C. Ratti, M. A. Thaler and W. Weise, Phys. Rev. D **73**, 014019 (2006)