Mesonic excitations in a hot and magnetized quark matter in the NJL model

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Study of quantum chromodynamics (QCD) matter under the influence of external magnetic fields have unveiled many significant properties of strong interaction which justifies the significant amount of research that has been conducted in recent times. Apart from it's own theoretical intricacies, the possibility of experimental realization in highly relativistic collisions of heavy ions at RHIC and LHC where magnetic fields $eB \approx 15m_\pi^2$ can be generated which is strong enough to bring noticeable influence on strongly interacting sector, sets the platform for investigation of these magnetic effects. Furthermore, since light mesons have a direct connection with the dynamics of chiral phase transition in QCD the study of the properties of these excitations in the medium at under high magnetic fields has a direct relevance.

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. In this gluon-less model, the QCD interactions are replaced by effective self-interactions, such that it respects the global symmetries of the QCD action. The NJL lagrangian is given by [1]

$$\mathscr{L} = \bar{\psi}(i\partial\!\!\!/ - m)\psi + G\left\{(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\tau\psi)^2\right\}. \quad (1)$$

where m is current quark mass. The scalar interaction term gives rise to the so-called quark condensate or chiral condensate given by

$$\langle\bar{\psi}\psi\rangle = i\int \frac{d^4p}{(2\pi)^4}\ \mathbf{Tr}\left[S(p,M)\right] \quad (2)$$

where $S(p,M)$ is the 'dressed propagator' of quarks with m replaced by constituent quark mass, M, which is evaluated by solving the so called *'gap equation'* expressed as

$$M = m - 2G\left\langle\bar{\psi}\psi\right\rangle. \quad (3)$$

In Fig.[1] the evolution of effective quark mass

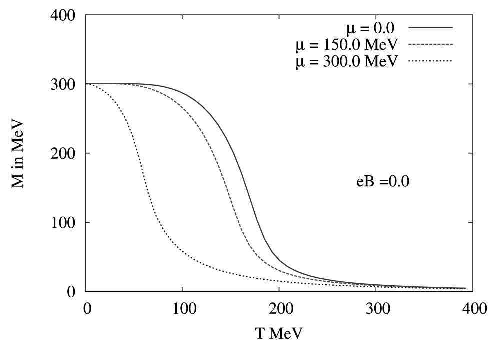

FIG. 1: Variation of constituent quark mass with temperature for different quark chemical potentials at zero external magnetic field.

as a function of temperature obtained from Eq.(3) in the two-flavour NJL model by taking thermal propagator using the real time formalism of thermal field theory. Note that, with the increase of temperature the constituent mass drops to near zero. Moreover, the transition to small masses occurs earlier and more rapidly for higher values of chemical potential.

Our main aim in this work is to study the effect of the anomalous magnetic moment

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(AMM) of quarks on the properties of low lying mesonic modes such as the sigma, pion and rho which arise in qq scattering in the NJL model. We aim to investigate the consequences on chiral symmetry restoration in the presence of a magnetic field as well as on the onset of magnetic catalysis or the inverse magnetic catalysis effect.

The weak field expansion of quark propagator for non-vanishing moment(κ) is given by [2]

$$S_B(p) = \hat{F}(p, m, m_1)\Delta_F(p, m_1)\Big|_{m_1=m} \tag{4}$$

where,

$$\begin{aligned}
&\hat{F}(p, m, m_1) = (\not{p} + m) \\
&+(qB)i\gamma^1\gamma^2\left(\not{p}_{\|} + m\right)\hat{A}_1 \\
&+(\kappa B)(\not{p} + m)\, i\gamma^1\gamma^2\,(\not{p} + m) \\
&-2(qB)^2\left\{p_\perp^2(\not{p}_{\|} + m) - \not{p}_\perp\left(p_{\|}^2 - m^2\right)\right\}\hat{A}_3 \\
&+(qB)(\kappa B)\left\{4\not{p}_{\|}\left(\not{p}_{\|} + m\right) - p^2 + m^2\right\}\hat{A}_2 \\
&+(\kappa B)^2(\not{p} + m)\left(\not{p}_{\|} - \not{p}_\perp + m\right)(\not{p} + m)\hat{A}_2 \\
&+\mathcal{O}(B^3)
\end{aligned} \tag{5}$$

$$\Delta_F(p, m_1) = \frac{-1}{p^2 - m_1^2 + i\epsilon} \tag{6}$$

and

$$\hat{A}_n = \frac{(-1)^n}{n!}\frac{\partial^n}{\partial(m_1^2)^n} \tag{7}$$

In Fig. [2] we show the variation of the constituent quark mass with magnetic field by solving Eq.(3) using the propagator given by Eq.(4) and the set of values for κ for up and down quarks have been chosen following [3]. It is seen that the quark mass actually decreases significantly with the inclusion of AMM. The increase of mass with the magnetic field in vacuum indicates magnetic catalysis (MC) which has also been seen in case of nucleon mass variation in Walecka model [2]. The increase of quark mass with the inclusion of AMM is less compared to the case when AMM is ignored indicating the weakening of MC effect.

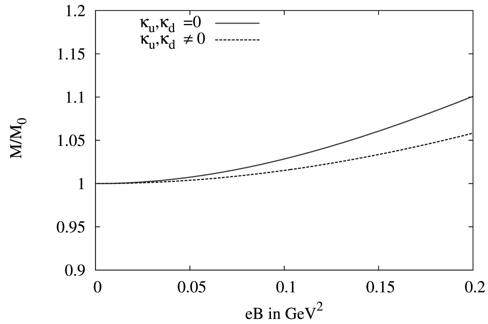

FIG. 2: Variation of constituent quark mass with the background magnetic field

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