Asymmetric quark matter in (2+1)-flavor Polyakov quark meson model

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Introduction

Heavy-ion collision experiments around the world aim at the study of hadronic and quark matter under extreme conditions of temperature and density in order to understand the dynamics of phase structure in proximity of confinement-deconfinement as well as chiral transitions. Along-with different experimental setups, many effective models like Linear sigma model, Quark meson (PQM) model, Nambu-Joan-Lasinio (NJL) model, Chiral quark mean field (CQMF) model based on underlying symmetries of QCD contribute in the investigation of hot and dense matter. To incorporate the effects of deconfinement, these theoretical approaches are being extended by employing Polyakov-loop potential. In our current work, we have applied (2+1)-flavor Polyakov loop extended Quark meson model augmented with vector interactions to explore the effect of non-vanishing isospin chemical potential in strongly interacting quark matter. This model is based on the confinement and chiral symmetry breaking properties of QCD.

Methodology

Polyakov-loop extended quark meson model effectively attributes to hadronic properties of low-energy QCD. The total Lagrangian for N_f flavors is written as [1]

$$\begin{aligned}\mathcal{L} = \bar{\psi}(i\,\partial\!\!\!/ - g\phi)\psi + \mathrm{Tr}\left(\partial_\mu \phi^\dagger \partial^\mu \phi\right) \\ -m^2\,\mathrm{Tr}\left(\phi^\dagger\phi\right) - \lambda_1\left[\mathrm{Tr}\left(\phi^\dagger\phi\right)\right]^2 - \\ \lambda_2 T_r\left(\phi^t\phi\right)^2 + c\left(\det(\phi) + \det\left(\phi^\dagger\right)\right) \\ + \mathrm{Tr}\left[H\left(\phi+\phi^\dagger\right)\right]. \end{aligned} \quad (1)$$

In the current study, the standard model is extended by the inclusion of vector interaction term which provides a repulsive contribution to total Lagrangian and thus gives a better description of phase structure. The interaction of quarks through vector mesons is represented as [1]

$$\mathcal{L}_V = -\frac{1}{4}V^{\mu\nu}V_{\mu\nu} + \frac{m_v^2}{2}V^{a\mu}V_\mu^a - g_V^a\bar{\psi}\gamma^\mu T^a\psi V_\mu^a, \quad (2)$$

here V_μ^a represents vector meson fields. Due to the effect of vector term, the effective chemical potential of quarks is shifted and is given in terms of quark chemical potential (μ_q), isospin chemical potential (μ_I), and strangeness chemical potential (μ_s) as

$$\begin{aligned}\mu_u &= \mu_q + \mu_I - g_\omega\omega - g_\rho\rho \\ \mu_d &= \mu_q - \mu_I - g_\omega\omega + g_\rho\rho \\ \mu_s &= \mu_q - \mu_S - g_\phi\phi,\end{aligned} \quad (3)$$

where ω, ρ and ϕ represent vector fields. Including all these, the total thermodynamic potential for PQM model is given by

$$\begin{aligned}\Omega\left(\sigma_u,\sigma_d,\sigma_s,\omega,\rho,\phi,\Phi,\bar{\Phi};T,\mu_f\right) = U(\sigma_u, \\ \sigma_d,\sigma_s) + \Omega_{q\bar{q}}^{vac}\left(\sigma_u,\sigma_d,\sigma_s\right) + \mathcal{U}\left(\Phi,\bar{\Phi}:T,\mu_f\right) \\ +\Omega_{q\bar{q}}^{th}\left(\sigma_u,\sigma_d,\sigma_s,\omega,\rho,\phi,\Phi,\bar{\Phi}:T,\mu_f\right),\end{aligned} \quad (4)$$

here μ_f is effective quark chemical potential. The first term in above equation describes the mesonic interactions, second term is the fermionic vacuum contribution, third term is the Polyakov-loop potential[2] and last term arises from coupling between meson fields and Polyakov loop variables.The parameter values for PQM model are taken from [3].

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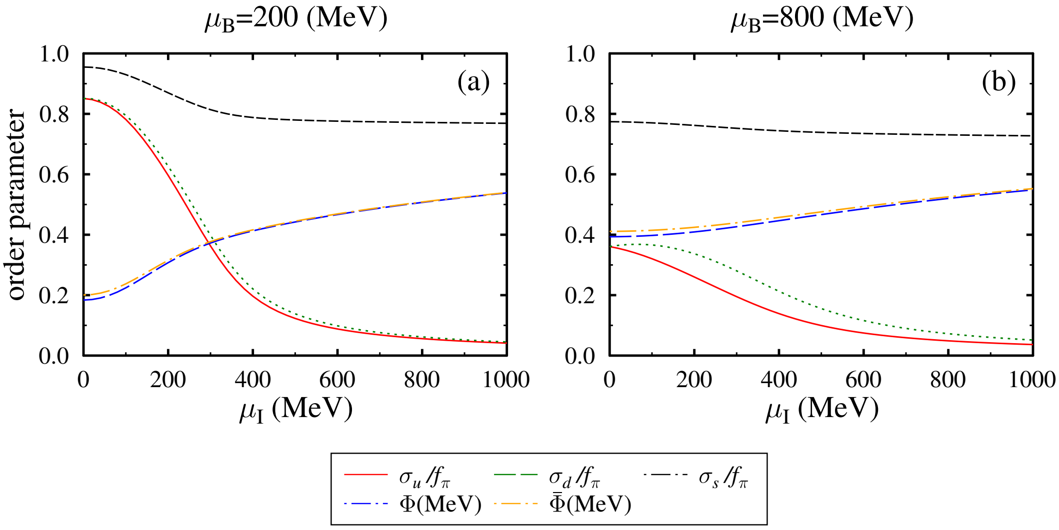

FIG. 1: Order parameters σ_u, σ_d, σ_s, Φ and $\bar{\Phi}$ as a function of isospin chemical potential (μ_I)at temperature, T=163 MeV and baryon chemical potential, μ_B = 200 and 800 MeV

Results and Discussion

In this section, we have discussed the effect of isospin and quark chemical potential on order parameters of PQM model. The expectation values for scalar and vector fields are calculated by minimizing the thermodynamic potential with respect to different fields at values of density and temperature. In Fig. 1, it is observed that value of quark condensates decreases and the value of Polyakov-loop variables increases with increasing isospin chemical potential at different values of μ_B. Due to the opposite contribution of μ_I term as well as the contribution of vector-isovector ρ meson to u and d quarks in eqn. 3, the splitting in the condensates σ_u and σ_d is observed. This splitting in σ_u and σ_d becomes more significant at higher values of μ_B. The value of μ_s shows no considerable change with increasing μ_I as strange chemical potential is taken zero in current study. The fall in values of μ_s with increasing μ_I is only due to interaction with light quark condensates and Polyakov-loop variables. Due to deconfinement at higher values of μ_B, the slope of Φ and $\bar{\Phi}$ shows a very small change. In conclusion, the inclusion of isospin chemical potential modifies the phase structure of QCD and hence play a significant role in identifying the transition temperature more precisely.

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