Impact of Dirac sea and PV mixing on properties of charm mesons in magnetized hot strange matter

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Introduction

The study of the hadronic matter properties at extreme density and/or temperature is an important subject of research. This has direct relevance in understanding the observables from heavy-ion collision experiments and to get insights into the physics of dense compact objects. Exploring the behaviour of hadrons under strong external magnetic field is important in light of estimation that the strong magnetic fields (of the order of $2m_\pi^2$ and $15m_\pi^2$ in RHIC and LHC experiments, respectively) can be produced in non-central ultra-relativistic heavy-ion collisions. In the present work, we investigate the properties of pseudoscalar D and $\bar{D}$ mesons and also the charmonium state, $\psi(3770)$, in isospin asymmetric strange hadronic medium at finite temperature in presence of an external magnetic field [1]. We consider the impact of magnetized Dirac sea of baryons (nucleons and hyperons) and also investigate the effect of the mixing of the pseudoscalar (S=0) and vector (S=1) states (PV mixing) in our calculations [1, 2].

Chiral hadronic model

To investigate the properties of charmed mesons in the present work, we use a generalization of a chiral SU(3) model, based on the nonlinear realization of chiral symmetry and the broken scale invariance property of QCD [3], to SU(4) sector to include the interactions of the charm mesons. In the chiral hadronic model, the interactions between the baryons are mediated through the scalar fields (the non-strange isoscalar field, σ, the strange isoscalar field, ζ and the isovector field δ) and the vector fields (non-strange isoscalar ω, strange isoscalar ϕ and non-strange isovector ρ). We use the mean field approximation for the study of the charmed mesons in the magnetized strange hadronic matter. The trace anomaly property of QCD is mimicked through a scalar dilaton field, χ, the value of which is expressed in terms of the expectation value of scalar gluon condensate in the medium. In order to investigate the properties of hadrons within the model under external magnetic field, we start with the thermodynamic potential given by [1]

$$\Omega = \Omega^{mag}_{\rm Dirac} + \Omega_{med} - \mathcal{L}_{vec} - \mathcal{L}_0 - \mathcal{L}_{SB} - \mathcal{V}_{vac},$$

where $\Omega^{mag}_{\rm Dirac}$ and Ω_{med} denote the contributions of the magnetized Dirac sea and Fermi sea of the nucleons and hyperons. The scalar and vector fields are obtained by minimizing the thermodynamic potential Ω for given values of temperature, magnetic field, baryonic density , ρ_B, the isospin asymmetry parameter, $\eta = -\frac{\Sigma_i \tau_{3i}\rho_i}{\rho_B}$, the strangeness fraction, $f_s = \frac{\Sigma_i |s_i| \rho_i}{\rho_B}$, where, τ_{3i} and $|s_i|$ denote the 3^{rd} component of isospin quantum number and number of strange quarks in i^{th} baryon, respectively. The in-medium masses of D and $\bar{D}$ mesons are calculated from the solutions of the dispersion relations, obtained from the interaction Lagrangian density of these mesons with baryons and scalar fields. For the charged charmed mesons, addition contribution to the effective masses from lowest Landau levels is taken into the calculations,

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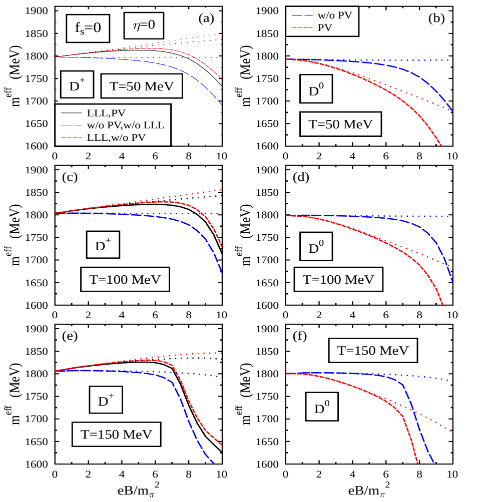

FIG. 1: In-medium masses of D^+ and D^0 mesons plotted as functions of eB/m_π^2 accounting for Dirac sea contributions and compared with results without DS contributions (dotted lines).

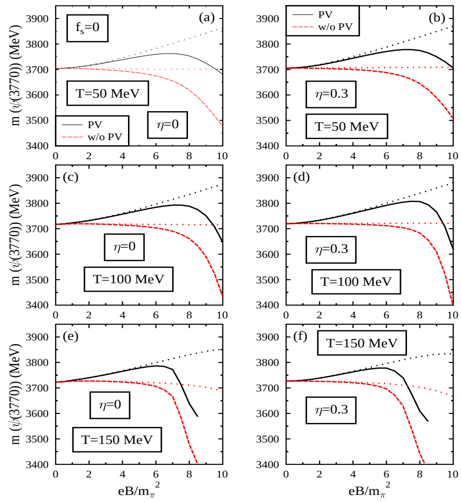

FIG. 2: In-medium mass of $\psi(3770)$ plotted as function of eB/m_π^2 accounting for Dirac sea contributions and compared with results without DS contributions (dotted lines).

i.e, $m^{eff}_{D^\pm} = \sqrt{m^{*2}_{D^\pm} + |eB|}$. The in-medium masses of charmonium are calculated from the medium change of the scalar gluon condensate, given in terms of the medium modification of the dilaton field χ. The PV mixing effects are incorporated for the masses of the open charm mesons and charmonium (due to $D(\bar{D}) - D^*(\bar{D}^*)$ and $\psi(3770) - \eta_c'$ mixings) through a phenomenological Lagrangian $\mathcal{L}_{PV\gamma} \sim \tilde{F}_{\mu\nu}(\partial^\mu P)V^\nu$, the coupling parameter for the interaction is determined from the vacuum decay width of $V \to P\gamma$. The decay with of $\psi(3770)$ to $D\bar{D}$ is calculated using the $^3P_0$ model [1].

Results and discussions

In the presence of finite Dirac sea, accounting for AMMs of baryons, the inverse magnetic catalysis, which is decrease of the magnitude of the scalar field (proportional to the light quark condensates) with increase in the magnetic field, is observed in the nuclear medium, whereas, the opposite effect of magnetic catalysis is observed when hyperons are included in the medium. These are reflected in the masses of the open and hidden charm mesons, shown in Figs. 1 and 2. Including the DS effects, the mass of the charged D meson in magnetized nuclear matter is observed to initially rise (due to the LLL contributions) and drop as the magnetic field is raised further. The PV $(D - D^*)$ mixing is observed to cause a further drop in the mass of D meson, which is observed to be larger for the neutral D^0 mesons as compared to D^+ mesons at higher magnetic fields. Qualitatively, similar behaviour is observed for $\bar{D}$ mesons and for the masses of $\psi(3770)$ when the Dirac sea effects are taken into consideration. The mixing with pseudoscalar meson, η_c' leads to an increase in the mass of $\psi(3770)$. The PV mixing is observed to impact significantly the decay width of $\psi(3770) \to D\bar{D}$ pairs [1, 2].

References

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