Open charm mesons in hot asymmetric strange hadronic matter – a QCD sum rule approach

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Introduction

The study of the properties of hadrons under extreme conditions of temperature and/or density is an important subject of research in strong interaction physics. The topic is of direct relevance for the experimental observables of the relativistic heavy-ion collision experiments, as well as, is relevant for study of the bulk properties of compact objects, e.g., the neutron stars. The spectral modifications of heavy flavour hadrons, e.g., the charm mesons will particularly be investigated at the future facility at GSI, Darmstadt. In the present work, within the QCD sum rule approach, we investigate the masses of the open charm mesons [1, 2] in isospin asymmetric strange hadronic medium at finite temperature.

QCD sum rule appraoch

The QCD sum rule approach relates the hadronic properties, encoded in spectral functions, to the QCD condensates [3]. The basic ingredient is the two-point correlation function given as

$$\Pi(q) = i\int d^3x e^{-iq.x}\langle\Omega|T(j(x)j(0)^\dagger)|\Omega\rangle,$$

where, $|\Omega\rangle$ is the physical ground state. Unlike the case of vacuum, the two-point correction function in the hadronic medium has contributions which are odd in q_0. This can be written in terms of even and odd functions of q_0 as $\Pi(q_0,\vec{q}) = \Pi^e(q_0,\vec{q}) + q_0\Pi^o(q_0,\vec{q})$, with $\Pi^e(q_0,\vec{q}) = \frac{1}{2}(\Pi(q_0,\vec{q}) + \Pi(-q_0,\vec{q}))$ and $\Pi^o(q_0,\vec{q}) = \frac{1}{2q_0}(\Pi(q_0,\vec{q})-\Pi(-q_0,\vec{q}))$. It might noted here that $\Pi^{e(o)}(q_0,\vec{q})$ depends on q_0^2. The Borel transformed sum rules for the even and odd parts are given as [2]

$$\tilde{\Pi}^e_{OPE} = \left[\int_{-\infty}^{s_0^-} + \int_{s_0^-}^{s_0^+} + \int_{s_0^+}^{\infty}\right]\frac{\mathrm{sdsIm}\Pi(s)}{\pi}e^{-\frac{s^2}{M^2}}$$

and

$$\tilde{\Pi}^o_{OPE} = \left[\int_{-\infty}^{s_0^-} + \int_{s_0^-}^{s_0^+} + \int_{s_0^+}^{\infty}\right]\frac{\mathrm{dsIm}\Pi(s)}{\pi}e^{-\frac{s^2}{M^2}}.$$

In the above equations, the subscript 'OPE' denotes the operator product exapnsion $\langle\Omega|T(j(x)j(0)^\dagger)|\Omega\rangle = \sum_n C_n(x-y)\langle\Omega|O_n|\Omega\rangle$, with $\langle\Omega|O_n|\Omega\rangle$ as the QCD condensates for the operators O_n and $C_n(x-y)$ are the Wilson coefficients, $s_0^\pm$ are the continuum thresholds, for the particle (antiparticle) and M is the Borel mass. For the spectral function, the ansatz $\mathrm{Im}\Pi(s) = \pi F_+(s-m_+) - \pi F_+(s-m_-)$ is employed, where, $m_\pm$ correspond to the mass of the particle (antiparticle). We choose the continuum thresholds as $s_0^\pm = \pm s_0$ similar to the case of vacuum. In the present work, we study the in-medium masses of the pseudoscalar open charm (D, $\bar{D}$, D_s and $\bar{D_s}$) mesons in hot asymmetric strange hadronic matter, using the operator product expansion upto mass dimension 5. These are obtained from the QCD condensates calculated within a chiral SU(3) model. The mixed quark-gluon condensate $\langle\bar{q}_i g_s\sigma.Gq_i\rangle$ in the operator product expansion is obtained from the in-medium quark condensate $\langle\bar{q}_i q_i\rangle$, by using the relation $\langle\bar{q}_i g_s\sigma.Gq_i\rangle = 2\lambda_q^2\langle\bar{q}_i q_i\rangle$. The mass splittings between the particles (D^+, D^0 and D_s^+ for $q_i = d, u, s$ respectively) and their antiparticles (D^-, $\bar{D}^0$ and D_s^-) in the hadronic medium arise from the values of $\langle {q_i}^\dagger q_i\rangle$, $\langle {q_i}^\dagger iD_0^2 q_i\rangle$ and $\langle {q_i}^\dagger g_s\sigma.Gq_i\rangle$ of the odd part of the spectral function.

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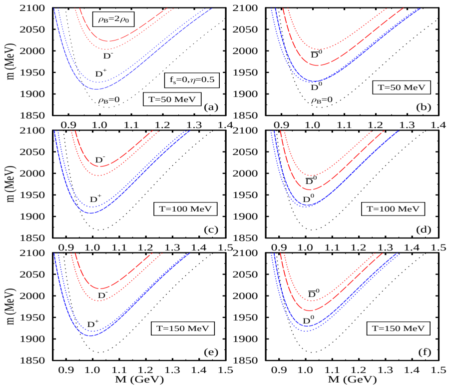

FIG. 1: Masses of $D^{\pm}$ (in panels (a), (c) and (e)) and $D^0(\bar{D^0})$ (in panels (b), (d) and (f)) mesons plotted versus the Borel mass M for T=50, 100 and 150 MeV in asymmetric nuclear matter (for isospin asymmetry parameter, $\eta = 0.5$), and compared to the case of η=0 (shown as short-dashed lines) for $\rho_B = 2\rho_0$. The result for $\rho_B = 0$ is shown as the dotted line.

Chiral SU(3) model

The chiral SU(3) model [4, 5] is based on a non-linear realization of chiral symmetry and incorporates the broken scale invariance of QCD through introduction of a scalar dilaton field, χ. The interactions between the baryons are mediated through the scalar and vector fields. The values of these fields in the hot asymmetric strange hadronic matter, in mean field approximation, are obtained by minimizing the thermodynamic potential Ω. The medium modifications of the quark condensates $\langle \bar{q}_i q_i \rangle$, with $q_i \equiv u, d, s$ for $i = 1, 2, 3$, are obtained from the medium modifications of the non-strange and strange scalar-isoscalar fields (σ and ζ), and the scalar-isovector field, δ, whereas, the scalar gluon condensate ($\langle \frac{\alpha_s}{\pi} G^a_{\mu\nu} G^{a\mu\nu} \rangle$ and the expectation value of the twist-2 tensorial gluon operator, $\left\langle \frac{\alpha_s}{\pi} \left(G^a_{\mu\sigma} G^a{}_{\nu}{}^{\sigma} u^\mu u^\nu - \frac{1}{4} G^a_{\mu\sigma} G^{a\mu\sigma} \right) \right\rangle$, are obtained from the in-medium value of the dilaton field, χ. The effects of the scalar and twist-2 gluon condensates on the heavy quarkonia masses were studied in Refs. [6, 7], using QCD sum rule approach.

Results and Discussions

The quark condensates ($\langle \bar{u}u \rangle$, $\langle \bar{d}d \rangle$ and $\langle \bar{s}s \rangle$) are obtained from the scalar fields and the scalar and twist-2 gluon condensates are calculated from the dilaton field, χ, within the chiral SU(3) model for isospin asymmetric strange hadronic matter at finite temperatures. For the chosen parameters ($m_u = m_d$=6 MeV, m_s=185 MeV, m_c=1.5 GeV, λ_q=1.2 GeV^2, the vacuum masses for the D and $\bar{D}$ mesons are obtained to be around 1870 MeV for s_0=7.5 GeV^2, and, the mass of $D_s^{\pm}$ is obtained to be around 1916 MeV for s_0=15 GeV^2. At finite densities, the mass of the antiparticle $D^-(\bar{D^0})$ is observed to be higher than $D^+(D^0)$ in the hot nuclear matter, as shown in figure 1. However, the opposite effect of the mass of D_s^+ to be higher than the mass of D_s^+ is observed in nuclear matter, whereas, the non-zero value of $\langle s^\dagger s \rangle$ in the strange hadronic matter leads to the antiparticle (D_s^-) mass to be higher than that of D_s^+ in hyperonic medium. Thus in the mass splitting between the particle and antiparticle arising due to the odd part of the spectral function, the term $\langle q_i^\dagger q_i \rangle$ dominates over the dimension 5 operators $\langle {q_i}^\dagger i D_0^2 q_i \rangle$ and $\langle {q_i}^\dagger g_s \sigma . G q_i \rangle$. The isospin asymmetry is observed to lead to drop in the mass of $D^-(\bar{D^0})$ as compared to the case of isospin symmetric case, and the effect is observed to be appreciable for higher values of the baryon density.

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