D-mesons and charmonium states in hot isospin asymmetric strange hadronic matter

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1. Introduction

The study of the medium modifications of hadrons is an important topic of research in strong interaction physics, which is of relevance in the heavy-ion collision experiments as well as in nuclear astrophysics. The study of the mass modifications of D mesons is relevant in understanding their production as well as collective flow in the heavy-ion collision experiments. The CBM (Compressed Baryonic Matter) experiment at FAIR facility intends to explore the phase diagram of strongly interacting matter at high baryon densities and moderate temperatures in heavy ion collisions and the medium modification of the charm mesons are planned to be investigated in these experiments. The PANDA experiment of FAIR project, GSI, in the experiment with the annihilation of antiprotons on the nuclei, also intends to study D meson and charmonium spectroscopy [1]. On the theoretical side, the properties of D mesons have been investigated in the quark meson coupling (QMC) model [2]. In QMC model, $D(\bar{D})$ mesons are assumed to be bound states of a light quark (antiquark) and a charm antiquark (quark), and they interact with the nucleons through the exchange of scalar and vector mesons. These studies suggest that the D mesons undergo mass drop in the nuclear medium. The QCD sum rule (QSR) approach has also been used to study the medium modification of D mesons in the nuclear medium [3]. In the QCD sum rule approach, the in-medium properties of the hadrons, are related to the QCD ground state properties e.g. the quark and/or gluon condensates. The D ($\bar{D}$) mesons, which are made up of one light antiquark (light quark), according to the QSR approach, undergo appreciable medium modification in their masses, because of their interaction with the light quark condensates in the nuclear medium. The coupled channel approach has also been vastly used in the literature to study the mass modifications of D and $\bar{D}$ mesons in the nuclear medium at zero and finite temperatures [4].

The present paper is devoted to the study of medium modifications of D and $\bar{D}$ mesons in isospin asymmetric strange hadronic medium at finite temperatures. We also investigate the in-medium masses of the charmonium states, $J/\psi, \psi(3686)$ and $\psi(3770)$. The investigation of the mass modifications of D mesons and charmonium states are of direct relevance to observables like open charm enhancement and J/ψ suppression. The excited states of charmonium, considered as a major source of J/ψ mesons [5] could decay to $D\bar{D}$ pairs due to mass modifications of the D and $\bar{D}$ mesons in the medium. The medium modifications of the J/ψ mesons are observed to be small [6] as compared to the D meson mass modifications [3]. According to QCD sum rules, this is attributed to be due to the reason that the D mesons interact in the nuclear medium through light quark condensates, which undergo appreciable modification in the medium. On the other hand, within the QCD sum rule approach, the mass modifications of the J/ψ mesons in the leading order are due to the medium modifications of the gluon condensates, and the gluon condensates have negligible modifications in the medium as compared to the medium modifications of the light quark condensates. The mass modification of the charmonium states in the medium have also been calculated from the self energy of J/ψ due to the D meson loop [6] as well as due to

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the D^* meson loop [8]. The mass modification of the charmonium states due to the D-meson loop are observed to be smaller as compared to the effect due to the interaction with the gluon condensates, whereas, the mass modification of J/ψ due to the D^* meson loop is observed to be large [8]. In references [9] and [10], J/ψ suppression can be due to the formation of QGP since the charmonium dissociation rate is larger in QGP phase as compared to in the hadronic medium.

In the present investigation, the isospin asymmetric hyperonic matter is described by a chiral SU(3) model [11]. The chiral SU(3) model is then generalized to SU(4) to study the in-medium properties of the D and $\bar{D}$ mesons. However, since the chiral symmetry is broken for the SU(4) case by the large charm mass, we use the SU(4) symmetry only to derive the interactions of the D and $\bar{D}$ mesons in the hadronic medium, but use the observed values of the charmed hadron masses and empirical values of the decay constants [12]. In the present investigation, the medium modifications of the charmonium states are considered through the medium modification of a scalar dilaton field χ which is introduced in the effective chiral model to mimic the the trace anomaly of QCD and is related to the scalar gluon condensate of QCD [13]. The chiral SU(3) model used in the present work has already been used to investigate the medium modifications of the vector mesons [14, 15] and the optical potentials of the kaons and antikaons [16–18]. The properties of the D mesons in symmetric/asymmetric nuclear matter at zero and finite temperatures have also been studied [13, 19, 20] using the interactions of the charmed mesons, obtained by a generalization of the chiral SU(3) to SU(4). In the present investigation, we study the effects of the strangeness on the properties of the D and $\bar{D}$ mesons. The properties of charmonium states in isospin asymmetric hot nuclear medium arising due to the medium modifications of the dilaton field using the effective chiral model have been investigated [13, 21] and the present work studies the effects of strangeness on the in-medium masses of the charmonium states.

The outline of the paper is as follows. In section 2, we give a brief introduction to the effective chiral model used to study the medium modifications of the D and $\bar{D}$ mesons as well as the charmonium states in hot isospin asymmetric strange hadronic matter. We derive the dispersion relations for the D and $\bar{D}$ mesons from the Lagrangian density for these mesons, which are then solved to obtain their optical potentials in the strange hadronic matter at finite temperatures. We investigate the in-medium masses of the charmonium states J/ψ, $\psi(3686)$ and $\psi(3770)$ arising from the medium modification of a scalar dilaton field introduced in the effective chiral model to simulate the gluon condensates in the medium. We then present the expressions of the partial decay widths of the charmonium states to $D\bar{D}$ pairs, obtained within the $3P0$ model [7, 22, 23]. In section 3 we discuss the results obtained in the present investigation. We observe nodes in the decay widths at certain densities when we consider the mass modifications of the $(D\bar{D})$ mesons in the hadronic medium, as has been already observed in the literature [7]. However, appreciable modifications of these decay widths are found when the mass modifications of the charmonium states are also taken into account. Finally, in section 4, we summarize the findings of the present investigation and discuss possible outlook.

2. The effective chiral model

The chiral $SU(3)$ model [11] used in the present investigation for the study of the light hadrons is based on nonlinear realization of chiral symmetry and broken scale invariance [11, 14, 15]. A scalar dilaton field is introduced in the effective hadronic model to mimic the broken scale invariance of QCD [11, 13].

The effective hadronic chiral Lagrangian contains the following terms

$$\mathcal{L} = \mathcal{L}_{kin} + \sum_{W} \mathcal{L}_{BW} + \mathcal{L}_{vec} + \mathcal{L}_{0} + \mathcal{L}_{sclbr} + \mathcal{L}_{SB} \tag{1}$$

In Eq.(1), $\mathcal{L}_{kin}$ is the kinetic energy term, $\mathcal{L}_{BW}$ is the baryon-meson interaction term of meson of type W, in which the baryons-spin-0 meson interaction term generates the baryon masses. $\mathcal{L}_{vec}$ describes the dynamical mass generation of the vector mesons via couplings to the scalar mesons and contains additionally quartic self-interactions of the vector fields. $\mathcal{L}_0$ contains the meson-meson interaction terms inducing the spontaneous breaking of chiral symmetry and the term $\mathcal{L}_{sclbr}$ corresponds to the scale breaking potential [11, 13]. $\mathcal{L}_{SB}$ describes the explicit chiral symmetry breaking. To study the hadron properties at finite densities, we use the mean field approximation, where all the meson fields are treated as classical fields. In this approximation, only the scalar and the vector fields contribute to the baryon-meson interaction, $\mathcal{L}_{BW}$ since for all the other mesons, the expectation values are zero. The coupled equations of motion of the scalar fields (σ, ζ and δ) and the dilaton field, χ, obtained from the mean field Lagrangian density, are solved to obtain their values in the isospin asymmetric strange hadronic medium at finite temperatures. These medium dependent scalar fields are then used to obtain the optical potentials for the D and $\bar{D}$ mesons, as well as the in-medium masses of the charmonium states for given values of density, temperature, isospin asymmetry parameter, $\eta = -\frac{\sum_i I_{3i}\rho_i}{\rho_B}$, with ρ_i is the number density of the baryon of i-th type and the strangeness fraction, $f_s = \frac{\sum_i s_i \rho_i}{\rho_B}$, where s_i is the number of strange quarks of baryon i. The same procedure was used to study the properties of the D, $\bar{D}$ mesons as well as charmonium states for the isospin asymmetric hot nuclear matter (f_s=0) and the possibility of decay of the charmonium states to $D\bar{D}$ pairs in the hot nuclear medium was discussed in Ref. [13]. In the present work, we study also the effect of strangeness on the in-medium properties of these charmed mesons. As has already been mentioned, the medium modification of the masses of the charmonium states are investigated from the modification of the gluon condensates in the hadronic medium [6], which are related to the medium modification of the dilaton field in the effective chiral model used in the present investigation [13]. The comparison of the trace of the energy momentum tensor in QCD to the trace of the energy momentum tensor corresponding to the scale breaking term of the effective chiral model leads to the relation of the scalar gluon condensate to the dilaton field as [21, 24],

$$\theta_\mu^\mu = \langle \frac{\beta_{QCD}}{2g} G^a_{\mu\nu} G^{\mu\nu a} \rangle + \sum_i m_i \bar{q}_i q_i \equiv -(1-d)\chi^4, \tag{2}$$

where the second term in the trace accounts for the finite quark masses, with m_i as the current quark mass for the quark of flavor, i. This term can be identified as the negative of the explicit chiral symmetry breaking term $\mathcal{L}_{SB}$ of equation (1) [21].

In the present work, we study the D and $\bar{D}$ mesons properties in isospin asymmetric strange hadronic matter, arising due to their interactions with the nucleons, hyperons, and the scalar mesons. The interaction Lagrangian density of the $D(\bar{D})$ meson has been described in detail in Ref. [25]. The dispersion relations for the D and $\bar{D}$ mesons are derived by the Fourier transformations of equations of motion, and are solved to obtain the energies of these mesons in the hot isospin asymmetric hyperonic medium.

We then study the medium modification of the masses of the charmonium states J/ψ, $\psi(3686)$ and $\psi(3770)$ in hot isospin asymmetric strange hadronic matter. In the literature the masses of the charmonium states have been calculated using QCD sum rules through the medium modifications of the lowest dimension gluon condensate operators which consists of the scalar and twist-2 gluon condensates [26]. These operators can, in turn, be written in terms of the color electric field, $\langle \frac{\alpha_s}{\pi} \vec{E}^2 \rangle$ and color magnetic field, $\langle \frac{\alpha_s}{\pi} \vec{B}^2 \rangle$. However, in the non-relativistic limit, as the Wilson coefficients for the magnetic field part vanish, the lowest dimension gluon condensates can be written in terms of the electric field part only and the mass shift of the charmonium states can be calculated as a second order Stark effect in QCD, as has been studied in Ref. [6]. The expression for the mass shift of the charmonium state, derived in the large charm mass limit is given as [27]

$$\Delta m_\psi = -\frac{1}{9}\int dk^2 |\frac{\partial\psi(k)}{\partial k}|^2 \frac{k}{k^2/m_c+\epsilon} \times\Big(\Big\langle\frac{\alpha_s}{\pi}E^2\Big\rangle - \Big\langle\frac{\alpha_s}{\pi}E^2\Big\rangle_0\Big). \quad (3)$$

In the above, m_c is the mass of the charm quark, taken as 1.95 GeV [6], m_ψ is the vacuum mass of the charmonium state and $\epsilon = 2m_c - m_\psi$ is the binding energy. $\psi(k)$ is the wave function of the charmonium state in the momentum space, normalized as $\int \frac{d^3k}{(2\pi)^3}|\psi(k)|^2 = 1$ [28]. In the present investigation, the wave functions for the charmonium states are taken to be Gaussian and are given as [7]

$$\psi(r) = \mathrm{N}' Y_l^m(\theta,\phi)(\beta^2 r^2)^{\frac{1}{2}l} e^{-\frac{1}{2}\beta^2 r^2} L_{N-1}^{l+\frac{1}{2}}\left(\beta^2 r^2\right) \quad (4)$$

where N' is the normalization constant, $\beta^2 = M\omega/\hbar$ characterizes the strength of the harmonic potential, $M = m_c/2$ is the reduced mass of the charm quark and charm antiquark system, and $L_p^k(z)$ is the associated Laguerre Polynomial.

In the non-relativistic limit the color electric field part can be written in terms of the scalar gluon condensate. This, in turn, gives the formula for the mass shift of the charmonium states [13], which is solved to obtain the in-medium masses of the charmonium states.

A. Decay widths of the charmonium states to $D\bar{D}$ pairs

We now compute the partial decay widths of the charmonium states to $D\bar{D}$ pairs in the hot isospin asymmetric strange hadronic medium, by accounting for the internal structures of the parent and outgoing mesons using the 3P0 model [7, 22, 23].The medium modifications of the masses of the $D(\bar{D})$ and the charmonium states as calculated in the present investigation, modify the decay widths of the charmonium states to $D\bar{D}$ pairs in the medium. The charmonium state at rest decays to the D and $\bar{D}$ mesons and in the 3P0 model, this decay width is given as [23]

$$\Gamma_{\psi\to D\bar{D}} = 2\pi\frac{p_D E_D E_{\bar{D}}}{M_\psi}|M|^2, \quad (5)$$

where, M is the matrix element for the decay of the parent charmonium state to the $D\bar{D}$ pairs, p_D is the magnitude of the 3-momentum of the D $(\bar{D})$ meson, when the charmonium state ψ decays at rest. E_D and $E_{\bar{D}}$ are the energies of the outgoing D and $\bar{D}$ mesons given as $E_D = ({p_D}^2 + {m_D}^2)^{1/2}$ and $E_{\bar{D}} = ({p_D}^2 + {m_{\bar{D}}}^2)^{1/2}$, with m_D and $m_{\bar{D}}$ as the masses of the D and $\bar{D}$ mesons. In the isospin symmetric medium, the (almost) degeneracy in the masses of the D^+ and D^0 mesons, as well as in the masses of the D^- and $\bar{D}^0$ mesons, leads to the partial decay widths of the charmonium states to D^+D^- pair and $D^0\bar{D}^0$ pairs as approximately equal. However, in the isospin asymmetric medium, the mass splitting between the masses of the D^+ and D^0, as well as between the masses of the D^- and $\bar{D}^0$, lead to the partial decay widths for the channels when the charmonium state decays to D^+D^- and $D^0\bar{D}^0$ to be different. The decay widths for the charmonium states J/ψ, $\psi(3686)$ and $\psi(3770)$ decaying to $D\bar{D}$ (D^+D^- and $D^0\bar{D}^0$), are given as [7]

$$\Gamma(J/\psi\to D\bar{D}) = \pi^{1/2}\frac{E_D E_{\bar{D}}\gamma^2}{2M_{J/\psi}} \times \frac{2^8 r^3(1+r^2)^2}{3(1+2r^2)^5}x^3 \exp\Big(-\frac{x^2}{2(1+2r^2)}\Big) \quad (6)$$

$$\Gamma(\psi(3686)\to D\bar{D}) = \pi^{1/2}\frac{E_D E_{\bar{D}}\gamma^2}{2M_{\psi(3686)}} \times \frac{2^7(3+2r^2)^2(1-3r^2)^2}{3^2(1+2r^2)^7}x^3 \times \Big(1+\frac{2r^2(1+r^2)}{(1+2r^2)(3+2r^2)(1-3r^2)}x^2\Big)^2 \times \exp\Big(-\frac{x^2}{2(1+2r^2)}\Big), \quad (7)$$

$$\Gamma(\psi(3770) \to D\bar{D}) = \pi^{1/2} \frac{E_D E_{\bar{D}} \gamma^2}{2M_{\psi(3770)}} \frac{2^{11}5}{3^2}$$
$$\times \left(\frac{r}{1+2r^2}\right)^7 x^3 \left(1 - \frac{1+r^2}{5(1+2r^2)} x^2\right)^2$$
$$\times \exp\left(-\frac{x^2}{2(1+2r^2)}\right), \qquad (8)$$

In the above, $r = \frac{\beta}{\beta_D}$ is the ratio of the harmonic oscillator strengths of the decaying charmonium state and the produced $D(\bar{D})$-mesons, $x = p_D/\beta_D$ and γ is a measure of the strength of the 3P0 vertex [7, 23] . Few comments regarding the above expressions for the decay widths may be in order. We might note here that the momentum dependence of the matrix element, M of equation (5) for the decay of charmonium state to $D\bar{D}$ pair arises from an overlap integral of the wave function of the decaying charmonium with the same of the D and $\bar{D}$ mesons within the 3P0 model [7, 29]. This overlap integral in general is a polynomial multiplied by a gaussian in the magnitude of 3-momentum, p_D of the produced $D(\bar{D})$ in the center of mass frame. Therefore, the nodes of the wave functions in the coordinate space can lead to nodes in the momentum, p_D for the decay amplitude. In particular, the polynomial part in equation (7) arises from the radial part of the corresponding 2^3S_1 wave function of $\psi(3686)$ charmonium state, while the same in equation (8) arises from the orbital angular momentum part of the wave function of 1^3D_1 wave function of $\psi(3770)$ state [7]. The magnitude of the $D(\bar{D})$, p_D depends only upon the masses of the charmonium and the $D(\bar{D})$ mesons and hence the medium modifications of the masses of these mesons can lead to vanishing of the decay widths at finite densities and temperatures. Such suppression of the decay widths arising from the internal structure of the mesons has already been observed for strong decays of charmonium in the vacuum [29] as well as in the medium [7]. In the present study, we also observe such a suppression of the decay widths for the decay of the charmonium states in the isospin asymmetric hot strange hadronic matter, as shall be discussed in the following section.

3. Results and Discussions

In this section, we present the numerical results of our investigation of the in-medium properties of D and $\bar{D}$ mesons and of the charmonium states in isospin asymmetric strange hadronic matter at finite temperatures, as well as the effects of these modifications on the decay of the charmonium states to the $D\bar{D}$ pairs in the hadronic medium. The decay widths of the charmonium states to the $D\bar{D}$ pairs have also been studied using the mass modifications of the charmonium states and $D(\bar{D})$ mesons calculated within the present model as well as accounting for the internal structure of these mesons using the 3P0 model.

The effects of various terms of Lagrangian density on the energies of D and $\bar{D}$ mesons in isospin asymmetric hot hadronic matter have been studied in Refs. [13, 20, 25]. In the present calculations, we observe a drop in the masses of the D as well as $\bar{D}$ mesons. The mass drop is seen to be larger in the presence of hyperons in the medium. In the present investigation, for symmetric nuclear matter at zero temperature, we obtain the mass shifts of about -77 and -27 MeV for the D^+ and D^- mesons. Due to the different masses of the D^+ and D^0 mesons, as well as of the D^- and $\bar{D}^0$ mesons, in the isospin asymmetric hadronic medium, and due to the modifications of the masses of the charmonium states, the production cross sections, yield and the collective flow are expected to be different for the D^+ and D^0, as well as, for the D^- and $\bar{D}^0$ mesons in the isospin asymmetric hadronic environment. The present investigation shows a stronger isospin dependence of the masses of the D^+ and D^0, as compared to the masses of the D^- and $\bar{D}^0$ mesons, particularly at high densities and this is observed to be more dominant at higher values of the strangeness fraction. This should show up in the experimental observables of the ratios of D^+/D^0 as well as $D^-/\bar{D}^0$ in the production cross-section from the high density matter resulting from compressed baryon matter (CBM) experiment at the FAIR project in the future facility at GSI.

We then investigate how the behavior of the dilaton field χ in the hot asymmetric strange hadronic matter affects the in-medium masses of the charmonium states J/ψ, $\psi(3686)$ and $\psi(3770)$. The values of the mass shift of J/ψ for the isospin symmetric medium at zero temperature are found to be $-4.35(-2.96)$ MeV and $-26.37(-25.95)$ MeV for f_s=0(0.5) at $\rho_B = \rho_0$ and $4\rho_0$ respectively, and these values are modified to $-4.16(-2.9)$ MeV and $-23.9(-26.06)$ MeV for η=0.5. These mass shifts are for the situation when the finite quark mass term is taken into account in the trace anomaly and hence the gluon condensate which is calculated is a combined effect of the modifications of the scalar dilaton field as well as the quark condensates through the scalar σ and ζ fields. In Ref. [6], the mass modifications of the charmonium states were calculated in the symmetric nuclear medium at zero temperatures using QCD second order Stark effect in the linear density approximation. The mass shifts for the charmonium states J/ψ, $\psi(3686)$ and $\psi(3770)$ were found to be $-8, -100$ and -140 MeV respectively at the nuclear matter saturation density.

The medium modifications of the masses of D and $\bar{D}$ mesons can have relevance to the experimental observable of J/ψ suppression in relativistic heavy ion collision experiments. Due to the drop in the mass of the $D\bar{D}$ pair in the hadronic medium, it can become a possibility that the excited states of charmonium $\psi(3686)$ and $\psi(3770)$ can decay to $D\bar{D}$ pairs [20] and hence the production of J/ψ from the decay of these excited states can be suppressed. Even at some densities it can become a possibility that the J/ψ itself decays to $D\bar{D}$ pairs. The effects of the medium modifications of the $D(\bar{D})$ mesons on the decay widths for the decay of the charmonium states to $D\bar{D}$ pairs has been studied accounting for the internal structure of these mesons using the 3P0 model [7]. In this model, it was observed that the decay width does not increase monotonically with drop in the masses of the $D(\bar{D})$ mesons with density as one would naively expect. On the contrary, the decay widths after an increase initially with decrease in the D($\bar{D}$) meson masses was seen to decrease with further drop in these masses and nodes were observed in the decay widths of the charmonium states $\psi(3686)$ and $\psi(3770)$ [7]. In the present investigation, we study the effects of the mass modifications of the $D(\bar{D})$ mesons as well as of the charmonium states in the isospin asymmetric hyperonic medium on the partial decay widths of the charmonium states to D^+D^- as well as $D^0\bar{D}^0$ pairs. We also observe nodes in the partial decay widths of the charmonium states $\psi(3686)$ and $\psi(3770)$, as has already been observed in the literature [7], when the mass modifications of the $D(\bar{D})$ mesons are taken into account, but the mass modifications of the charmonium masses are neglected. However, there are observed to be significant modifications to these partial decay widths, when the mass modifications of the charmonium states are also taken into account. There are no nodes observed even up to a density of about $6\rho_0$, when the in-medium masses of the charmonium states are also taken into account.

We compute the partial decay widths of the charmonium states to $D\bar{D}$ pairs by accounting for the internal structure of these mesons using the 3P0 model. These decay widths are calculated by using the expressions as given by equations (6), (7) and (8), which are computed from the matrix element for the specific charmonium state decaying to $D\bar{D}$ pair. The wave functions for the charmonium state as well as the $D(\bar{D})$ mesons are assumed to be of harmonic oscillator, with strengths β and β_D respectively. As one might observe from the expressions for the decay widths of the charmonium states to $D(\bar{D})$ given by equations (6), (7) and (8), the dependence of these decay widths on the medium is through the magnitude of the center of mass momentum of the produced $D(\bar{D})$ meson, p_D, written as x in dimensionless units ($x = p_D/\beta_D$). The value of p_D depends on the medium through the modifications of the masses of the charmonium state, as well as on the masses of the $D \equiv (D^0, D^+)$ and $\bar{D} \equiv (\bar{D}^0, D^-)$ mesons. In Fig. 1, we show the partial decay widths of (i) $\psi \rightarrow D^+D^-$, (ii) $\psi \rightarrow D^0\bar{D}^0$ and (iii)

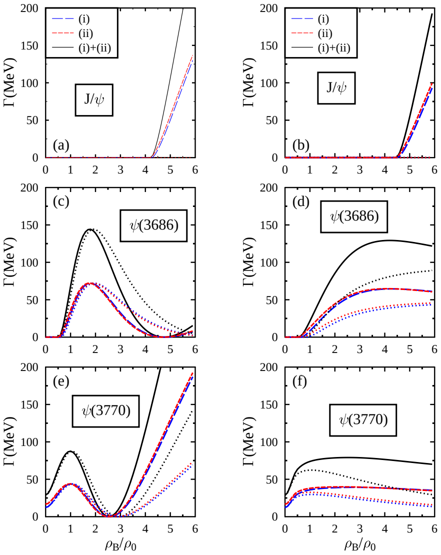

FIG. 1: The partial decay widths of the charmonium states to (i) D^+D^-, (ii) $D^0\bar{D}^0$ and (iii) the sum of the two channels ((i)+(ii)) in the isospin symmetric strange hadronic matter (η=0,f_s=0.5), accounting for the medium modifications of the $D(\bar{D})$ mesons. These are shown in subplots (a), (c) and (e), when the mass modifications of the charmonium states are neglected and (b), (d) and (f), the partial decay widths are shown when the mass modifications of the charmonium states are also taken into account. These results are compared to the case of f_s=0, shown as dotted lines.

$\psi \rightarrow D^+D^-$ and $\psi \rightarrow D^0\bar{D}^0$, for the charmonium state, ψ as J/ψ, $\psi(3686)$ and $\psi(3770)$ for zero temperature, for the symmetric (η=0) hadronic matter. These have been shown for the value of strangeness fraction, f_s=0.5 and have been compared with the case of nuclear matter (f_s=0). For the case of symmetric nuclear matter (η=0 and f_s=0), the decay width of the charmonium state $\psi(3686)$ vanishes below a density of $\rho_B = 0.6\rho_0$ as the mass of the charmonium state is smaller than the mass of the $D(\bar{D})$ pair (D^+D^- as well as $D^0\bar{D}^0$) for these densities. For densities above this value of the density, the magnitude of p_D is seen to increase with density. However, at high densities, the increase is seen to be much slower when the density is increased still further. The decay width for the decay of $\psi(3686) \rightarrow D\bar{D}$, which is a combined effect of the polynomial as well as the gaussian parts, is seen to have an initial increase with density and then a drop as the density is further increased. However, one does not observe any nodes in the partial width even up to a density of about $6\rho_0$. With the inclusion of strangeness in the medium, the behavior of the decay width of $\psi(3686) \rightarrow D\bar{D}$ with density is seen to be similar to as in the nuclear matter. However, due to smaller values of the masses of the $D(\bar{D})$ mesons, leading to higher values of the center of mass momentum, p_D, there is faster suppression of the polynomial part of the decay width leading to nodes in the decay width of $\psi(3686)$ to D^+D^- as well as to $D^0\bar{D}^0$ at a density of about 4.5 ρ_0, as can be seen in the subplot (c) in figure 1. Such nodes have been already observed in the literature in the decay widths of the charmonium states $\psi(3686)$ and $\psi(3770)$ to $D\bar{D}$ [7], when the drop in the masses of the $D(\bar{D})$ mesons was incorporated. The decay of $\psi(3770) \rightarrow D\bar{D}$ is possible in vacuum as the mass of $\psi(3770)$ is higher than the mass of the $D\bar{D}$ pair. For $\psi(3770)$, there is seen to be initial increase in p_D as a function of density and then a drop with further increase in the density when the modifications of the $D(\bar{D})$ masses as computed in the present investigation, are taken into account. However, there is seen to a strong suppression of the decay width with density due to the polynomial part, $\left(1 - \frac{1+r^2}{5(1+2r^2)}x^2\right)^2$ of the expression for the decay width given in equation (8). Consequently, in the present investigation, there are seen to be nodes in the partial decay widths of the charmonium states $\psi(3686)$ and $\psi(3770)$ to $D\bar{D}$ pairs at densities of about $4.5\rho_0$ and 2.8 ρ_0 respectively in symmetric strange hadronic matter, when the mass modifications of the D and $\bar{D}$ mesons are taken into account, but the modifications of the charmonium masses are neglected. For J/ψ, for densities above the threshold density for the decay of J/ψ to $D\bar{D}$ pairs, the decay width is seen to increase monotonically with density, and there is no polynomial part in the the expression of the decay width of J/ψ (see equation (6)) and so no nodes are observed in the decay width of J/ψ to $D\bar{D}$ pair.

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