Masses and Decay widths of charm mesons: Effects of (inverse) magnetic catalysis

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Introduction

We investigate the in-medium masses of the pseudoscalar $(D, \bar{D})$ and vector $(D^*, \bar{D}^*)$ open charm mesons in isospin asymmetric magnetized nuclear matter, accounting for the effects of Dirac sea. The masses are used to study the in-medium partial decay widths of $D^* \to D\pi$ $(\bar{D}^* \to \bar{D}\pi)$ and $\Psi(3770) \to D\bar{D}$, using the $^3P_0$ model. The in-medium masses of the open charm mesons are calculated from their interactions with the nucleons and scalar mesons within the generalized chiral effective model, in terms of the scalar and number densities of nucleons and the scalar fields fluctuations. The free energy of the magnetized vacuum with Landau energy levels and anomalous magnetic moments (AMMs) of the charged fermions in the single fermion energies are taken into account in the Dirac sea contribution. The light quark condensates are modified considerably with magnetic field, leading to (inverse) magnetic catalysis due to the magnetized Dirac sea effects. The magnetic field causes modifications to occur due to the mixing of the pseudoscalar and longitudinal component of the vector mesons, along with the lowest Landau level contribution to the ground state energy of the charged mesons as point particle correction. For the charmonium state $\Psi(3770)$, the effects of the magnetized Dirac sea are incorporated to the mass modifications through the medium modified scalar dilaton field χ within the chiral model. The in-medium masses and decay widths of the open charm and charmonium mesons thus obtained should have important observable consequences in the production of the open charm mesons and charmonia in the peripheral ultra-relativistic heavy-ion collision experiments, where huge magnetic fields are expected to be created [1].

The in-medium charm mesons

The in-medium masses of the open charm $(D, \bar{D}$ and the excited state of charmonium $\Psi(3770)$ in magnetized nuclear matter are calculated as per the chiral effective model which is originally based on the non-linear realization of chiral $SU(3)_L \times SU(3)_R$ symmetry and the QCD scale-symmetry breaking effects [2]. The latter is realized through a logarithmic potential in terms of the scalar dilaton field χ. The magnetized Dirac sea contributes to the scalar densities of the nucleons within the chiral model. The coupled equations of motion for the scalar fields are derived from the chiral model Lagrangian density under the classical scalar fields approximation, including the medium effects through the number $(\rho_{p,n})$ and scalar $(\rho^s_{p,n})$ densities of protons and neutrons in the nuclear matter. There are contributions of the Landau energy levels of protons and anomalous magnetic moments (AMMs) of nucleons through $\rho_{p,n}$ and $\rho^s_{p,n}$ in the general Lagrangian density, apart from the magnetized Dirac sea contribution [3]. The sea contribution for the spin-1/2, electrically charged fermions is given by the free energy of the magnetized vacuum [4]. In the mean-field approximation, $\Omega_{N,sea}$ takes the form of free fermions by including all interactions to the in-medium mass term. The dispersion relation for the D mesons are obtained from the Fourier transforms of the equations of motions of the mesons obtained from the generalized chiral $SU(4)$ Lagrangian, given by

$$-\omega^2 + \vec{k}^2 + m^2_{D(\bar{D})} - \Pi_{D(\bar{D})}(\omega, |\vec{k}|) = 0, \quad (1)$$

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where $\Pi_{D(\bar{D})}$ denotes the self energy and $m_{D(\bar{D})}$ is the vacuum mass of the D ($\bar{D}$) meson. Mass shifts for the D^* mesons are obtained from that of the D mesons which further receive mass contribution from the lowest Landau level (for the charged ones). Effects of pseudoscalar-vector (PV) mixing are considered whereby, mixing occurs between the longitudinal component of the vector and the pseudoscalar producing modifications in the charm meson states. Mass modifications for $\Psi(3770)$ depend on the medium modification of the scalar dilaton field χ [3, 5]. The partial decay widths of the vector meson state $\Psi(3770)$ to the pseudoscalar meson states $D(\bar{D})$ mesons are studied considering the effects of the magnetized Dirac sea on their masses, using the $^3P_0$ model [6]. In the $^3P_0$ model, a light quark-antiquark pair is created in the $^3P_0$ state (with quantum numbers similar to vacuum, $J^{PC} = 0^{++}$), and this light quark (antiquark) combines with the heavy charm antiquark (quark) of the decaying parent meson at rest, resulting in the production of the open charm $D(\bar{D})$ mesons.

Results and Discussions

The in-medium masses of the charm mesons are observed to increase (decrease) with magnetic field at $\rho_B = 0$ (ρ_0) due to magnetic (inverse) catalysis (considering AMMs of nucleons). When the AMMs of the nucleons are not taken into account, the effect of catalysis occurs and the masses of the mesons increase with magnetic field. Additional contribution of the lowest Landau level are added accordingly to the charged pseudoscalar and the vector mesons. PV mixing is performed which gives rise to negative and positive mass shifts to the pseudoscalar and longitudinal components of the vector mesons, respectively, on the mixing pairs $(D - D^{*||}), (\bar{D} - \bar{D}^{*||}), (\eta_c(2S) - \Psi(3770)^{||})$ respectively. The decay width for the channel $\Psi(3770) \to D\bar{D}$ is plotted at $\rho = 0, \rho_B$ where ρ_B is the nuclear matter saturation density and comprises of two sub-channels (I) $\Psi(3770) \to D^+D^-$ and (II) $\Psi(3770) \to D^0\bar{D}^0$. They are plotted individually with their decay widths given in

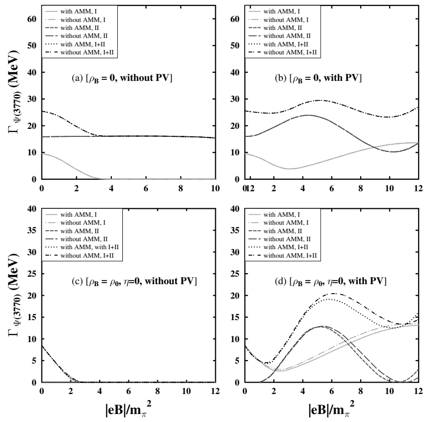

FIG. 1: The decay widths (in MeV) of $\Psi(3770) \to D^+D^-$ (I) and $\Psi(3770) \to D^0\bar{D}^0$ (II) and the total (I+II), are plotted as functions of $|eB|/m_\pi^2$, at $\rho_B = 0, \rho_0$ and $\eta = 0$, including the Dirac sea (DS) effects.

units of MeV against an increasing magnetic field in natural units of $|eB|/m_\pi^2$. Figures (a) and (b) show the decay widths in vacuum, (c) and (d) in nuclear medium. We can see that in figures (b) and (d), where PV mixing is done, the decay widths is somewhat larger than the figures (a) and (c). We also observe an increase and decrease of decay width with magnetic field.

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