In-medium properties of D_s and D_s^* mesons in magnetic matter - effects of spin-mixing

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Introduction

Heavy flavour mesons consist of one or more quark (antiquark) belonging to the heavy flavors (charm or bottom). The study of the in-medium properties (masses, decay widths etc.) of the heavy flavour hadrons is a topic of extensive research in the high energy, heavy-ion collision experiments. The estimation of strong magnetic fields produced in the peripheral ultra relativistic heavy-ion collision experiments at LHC, RHIC [1] has initiated a lot of research on hadron properties in presence of magnetic fields. There is a profuse production of the open heavy flavour mesons at the early stages of the collisions, where produced magnetic field can still be large. Thus, the effects of magnetic fields on the heavy flavor mesons should have important observable consequences in such high energy collisions.

Theory

The open heavy flavour mesons, D, comprise of a charm quark (antiquark) and a light antiquark (quark). The in-medium masses of the pseudoscalar ($J^P = 0^-$), open strange-charm mesons, $D_s^\pm$ ($\bar{s}c/\bar{c}s$), are studied in the magnetized nuclear matter, within an effective hadronic model. The effective model Lagrangian is the generalization of the chiral $SU(3)$ model to $SU(4)$ (to incorporate the charm flavor). The original version of the chiral $SU(3)$ model is based on the non-linear realization of chiral $SU(3)_L \times SU(3)_R$ symmetry [2]. The QCD broken scale-invariance is incorporated through a logarithmic potential in the scalar dilaton field, χ, which simulates the gluon condensates of QCD, within the chiral $SU(3)$ model. The present investigation is restricted to the nuclear matter case, in presence of an external magnetic field. From the interaction Lagrangian of the pseudoscalar mesons (D_s) in the generalized chiral model, the dispersion relations are obtained for the D_s mesons [3]. The medium modifications of D_s mesons are obtained in terms of the scalar densities of nucleons ($\rho_i^s; i = p, n$) and the fluctuations in the strange quark condensate ($\zeta \sim \langle \bar{s}s \rangle$). The fluctuations of the heavy quark condensate ($\zeta_c \sim \langle \bar{c}c \rangle$) is neglected here. The dispersion relations for the $D_s^\pm$ mesons are obtained from the Fourier transform of their equations of motions, within the chiral effective model [3]

$$-\omega^2 + \vec{k}^2 + m_{D_s}^2 - \Pi_{D_s}(\omega, |\vec{k}|) = 0 \qquad (1)$$

The in-medium self energy functions, $\Pi(\omega, |\vec{k}|)$ of D_s mesons are given by

$$\Pi(\omega, |\vec{k}|) = \left[\frac{d_1}{2f_{D_s}^2}(\rho_p^s + \rho_n^s) - \frac{\sqrt{2}}{f_{D_s}}(\zeta' + \zeta_c') \right] \times (\omega^2 - \vec{k}^2) + \frac{m_{D_s}^2}{\sqrt{2} f_{D_s}}(\zeta' + \zeta_c') \qquad (2)$$

Here, The prime on the fields (ζ', ζ_c') indicate the fluctuations from their vacuum expectation values (ζ_0', ζ_{c0}'). The solutions for ω at $\vec{k} = 0$ give the masses for $D_s^\pm$ mesons in the nuclear medium. The effects of magnetic field due to the Landau energy levels of protons and the anomalous magnetic moments of nucleons in the magnetized nuclear matter, are included in the chiral model Lagrangian, via modified number (ρ_i) and scalar densities (ρ_i^s) of nucleons ($i = p, n$) [4], The masses of the charged ($D_s^\pm$) mesons have additional contribution from the lowest Landau level (LLL)

$$m_{D_s^\pm}^{eff} = \sqrt{m_{D_s^\pm}^{*2} + |eB|} \qquad (3)$$

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The mass shifts of vector mesons (D_s^*) are [5]

$$m^*_{D_s^{*\pm}} - m^{vac}_{D_s^{*\pm}} = m^*_{D_s^{\pm}} - m^{vac}_{D_s^{\pm}} \quad (4)$$

And the contribution of LLL (for S_z part) is

$$m^{eff}_{D_s^{*\pm}} = \sqrt{m^{*2}_{D_s^{*\pm}} + (1 + gS_z)|eB|} \quad (5)$$

In an external magnetic field, there is a level repulsion between the longitudinal component of vector meson ($D_s^{*||}; S_z = 0$) and the pseudoscalar meson (D_s), accounting for the spin-magnetic field interaction, also referred to as spin-mixing. The shifts are given as [6]

$$m^{mixed}_{V,P} = m^{eff}_{V,P} \pm \Delta m^* \quad (6)$$

where, $\Delta m^* = \frac{\Delta m}{2}\left[(1 + \chi^2_{s.m})^{1/2} - 1\right]$ with $\chi_{s.m} = \frac{-g}{2\Delta m}\left(\frac{q_1 B}{m_1} - \frac{q_2 B}{m_2}\right)$; g is chosen to be 2; $q_i; i = 1, 2$ is the electric charge of quark (in units of the electron charge $|e|$); m_1 and m_2 are the constituent masses for the charm quark (1550 MeV) and strange quark (486 MeV). Δm is the in-medium mass difference between the D_s^* and D_s mesons, as obtained from previous discussion.

Results and Discussion

The in-medium masses of the $D_s^{\pm}$ mesons, in the magnetized nuclear matter, are calculated within the chiral effective model. The parameters (in MeV) are $f_{D_s} = 250$, $m_{Ds} = 1968.35$, $D_s^* = 2112.2$ and $d_1 = 2.56/m_K, m_K = 498$ MeV. The masses are obtained from the dispersion relation in magnetized nuclear matter at finite density. Additional effects of magnetic field through the LLL on the masses of the charged mesons ($D_s^{\pm}$) are considered. The spin-magnetic field interaction Hamilton [6], is used to study the positive (negative) mass shifts of $D_s^{*||}(D_s)$ mesons with magnetic field. The LLL effects on the masses, as obtained from the dispersion relations at finite density matter, lead to a monotonic rise with magnetic field for both D_s and $D_s^{*||}(S_z = 0)$ (shown by solid lines). The spin-mixing effects lead to a rise (drop) of $D_s^{*||}$ [plots.(c)-(d)] (D_s [plots.(a)-(b)]) mesons with increasing magnetic field, $|eB|$ (in units of m_π^2), at nuclear matter saturation density, ρ_0 and for isospin asymmetry parameter, $\eta = 0, 0.5$ (shown by the dashed lines), as shown in Fig.1. The effects of anomalous magnetic moments (AMM) of the nucleons are taken into account through a tensorial interaction term in the chiral model Lagrangian, at finite magnetic field. The in-medium partial decay widths of $\Psi(4040) \rightarrow D_s^+ D_s^-$ due to their modified masses, may affect the yield of open charm and charmonium states in the peripheral, high energy, heavy-ion collisions.

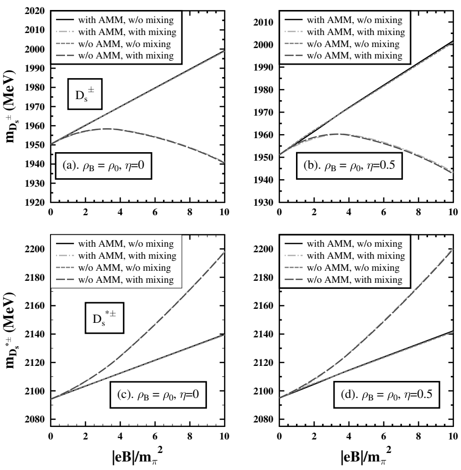

FIG. 1: In-medium masses (in MeV) of $D_s^{\pm}$ and $D_s^{*\pm}$ mesons are plotted as a function of magnetic field, $|eB|/m_\pi^2$, at $\rho_B = \rho_0$ and for $\eta = 0,\ 0.5$.

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