Open Charm Mesons and Charmonium states in Magnetized Nuclear Matter

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Introduction

The effect of strong magnetic fields of the order of QCD scale on the properties of hadrons has recently received significant interest due to the phenomenological consequences in the relativistic heavy ion collisions. The strength of the magnetic fields could be as large as $eB \sim 2{m_\pi}^2 \sim 6 \times 10^{18}$ Gauss in the Relativistic Heavy Ion Collider(RHIC) at Brookhaven National Laboratory (BNL) and eB $\sim 15{m_\pi}^2 \sim 10^{19}$ Gauss in the Large Hadron Collider(LHC) at CERN [1, 2]. Such high values of magnetic fields are produced at the very early stages of collision. Since charm quarks are also formed at the early stages of collision owing to their large mass, the charm quark systems are sensitive to magnetic fields [3]. The chiral condensates in QCD are found to be modified in the presence of magnetic fields. As the hadrons interact with these condensates, their properties are also subjected to modifications in the magnetized hadronic matter. The magnetic field also introduces mixing between the spin eigenstates of open charm mesons as well as between charmonium states[3–5]. Here the pseudoscalar meson mix with the longitudinal component of the corresponding vector meson. Hence the properties of open charm mesons and charmonium states undergo modifications in magnetized nuclear matter.

Masses of open charm mesons and charmonia

In the present work, we have investigated the in-medium masses of the pseudoscalar $(D(D^0,\ D^+))$, $\bar{D}(\bar{D^0},\ D^-)$ and the vector $(D^*(D^{*0},\ D^{*+})$, $\bar{D}^*(\bar{D}^{*0},\ D^{*-})$ open charm mesons, as well as the pseudoscalar ($\eta_c \equiv \eta_c(1S)$, $\eta_c' \equiv \eta_c(2S)$) and the vector charmonium states (J/ψ, $\psi(2S)$, $\psi(1D) \equiv \psi(3770)$), in the presence of the magnetic field. Here we use a chiral SU(3) Lagrangian model based on non-linear realization of chiral symmetry and the broken scale invariance of QCD which is generalized to chiral SU(4) to include the charm degrees of freedom[6, 7]. Within the chiral model, the modifications of light quark condensates are calculated from the modification of the scalar fields (σ, ζ, δ) and that of gluon condensates are calculated from the medium change of the dilaton field (χ), introduced through a scale breaking term in the Lagrangian. The mass modifications of open charm mesons arise due to their interactions with nucleons, and the scalar fields (σ, ζ and δ) in the presence of the magnetic field [6]. The in-medium masses of the vector D^*,$\bar{D}^*$ mesons are calculated by assuming that the magnitude of their mass shifts due to the interaction with the medium are similar to that of pseudoscalar open charm mesons.The charged $D^\pm(D^{*\pm})$ mesons will have additional positive(negative) mass modifications in magnetic fields through Landau quantization. The mass modifications of charmonium states in the magnetized medium are calculated through the modifications of the dilaton field χ [7]. The masses of these mesons are observed to drop in the medium compared to vacuum.

The spin mixing of the pseudoscalar charmonium state and the vector charmonium state, as well as similar mixing of the open charm meson states are taken into account through the effective Lagrangian interaction [3–5]. The spin mixing results in a positive mass shift of the longitudinal component of

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the vector mesons and a negative mass shift for the pseudoscalar mesons leading to a level repulsion. For charged mesons, the effect of Landau quantization is observed to be dominant at small magnetic fields and the direction of mass shift due to spin mixing is opposite to the direction of mass shift due to Landau quantization. The magnitude of spin mixing in the medium is observed to be larger for charmonium states whereas for open charm mesons such a medium dependence is weak. The spin mixing of charmonia will have observational consequences on their dilepton spectra and on the production of the charmonium states as well as open charm mesons in ultra- relativistic heavy ion collision experiments, e.g., at RHIC and LHC.

Decay Widths of $\psi(1D)$ to $D\bar{D}$ within $^3P_0$ model

From the obtained in-medium masses of open charm mesons and $\psi(1D)$, we have also calculated the partial decay widths of $\psi(1D)$ to $D\bar{D}$ pair in the magnetized medium, using a light quark pair creation model namely the $^3P_0$ model [8]. In this model, a light quark-antiquark pair is created in the $^3P_0$ state, and this light quark (antiquark) combines with the heavy charm antiquark (charm quark) of the decaying charmonium state at rest, resulting in the production of the open charm (D, $\bar{D}$) mesons. In general, at large magnetic fields, the positive mass shift of the longitudinal component of $\psi(1D)$ due to the spin mixing effect, enhances the value of its partial decay width as shown in FIG. 1. It is observed that Γ_2 increases initially as a function of a magnetic field, and thereafter Γ_2 decreases due to the polynomial nature of the expression of decay width. Hence the dominant decay of $\psi(1D)$ is through neutral $D^0\bar{D}^0$ channel approximately up to eB=$7{m_\pi}^2$ and above this magnetic field, D^+D^- decay channel becomes dominant. This will have observable consequences on the suppression of $\psi(1D)$ (and hence of J/ψ) as well as a higher yield for D^0, $\bar{D}^0$ mesons at low to intermediate magnetic fields and higher yield for D^+, D^- mesons at relatively larger magnetic fields.

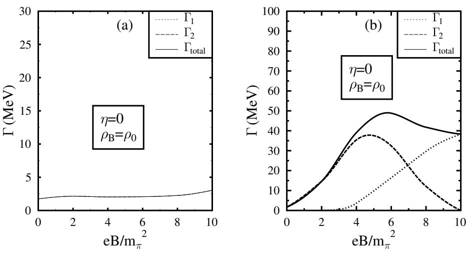

FIG. 1: Partial decay widths of $\psi(1D)$ to (1) D^+D^-,(2) $D^0\bar{D}^0$, and the total of two channels (1+2),are plotted as functions of eB/m_π^2 for symmetric nuclear matter($\eta = 0$) at nuclear saturation density. In panel (a) spin mixing is ignored and in panel (b), spin mixing is considered.

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