P-wave charmonia in hot and dense magnetized nuclear matter

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Introduction

The effect of strong magnetic field on the in-medium properties of hadrons has taken a lot of interest due to its application in ultrarelativistic heavy ion collison (HIC) experiments. In these HICs, strong magnetic fields of the order $eB\sim 2-15\ m^2{}_\pi$ ($1m^2{}_\pi = 2.818\times10^{18}$ G) are believed to be produced [1]. The QCD vacuum properties such as quark and gluon condensates get modified with the interaction of external magnetic fields. The magnetic field dependence of these condensates reflects in the in-medium mass of charmonia. The S-wave J/ψ not only produce directly, but also through the decay of higher charmonium states. In order to understand the J/ψ suppression mechanism, it is important to study the in-medium properties of charmonia in higher mass states. In this investigation, we have used chiral SU(3) model and QCD sum rules to calculate the magnetic field effect on in-medium masses of P-wave χ_{c0} and χ_{c1} charmonium states. The result of this work may be helpful to understand the possible outcomes of experiments like Compressed Baryonic Matter (CBM) at FAIR.

Methodology

Using QCD sum rules[2], the in-medium mass of scalar χ_{c0} and axial vector χ_{c1} mesons can be written as

$$m^{*2} \simeq \frac{M^J_{n-1}(\xi)}{M^J_n(\xi)} - 4m_c^2\xi. \quad (1)$$

where, M^J_n is the n^{th} moment of the meson and is given as

$$M^J_n = A^J_n(\xi)\times \left[1 + a^J_n(\xi)\alpha_s + b^J_n(\xi)\phi_b + c^J_n(\xi)\phi_c\right], \quad (2)$$

where, $A^J_n(\xi)$, $a^J_n(\xi)$, $b^J_n(\xi)$ and $c^J_n(\xi)$ are the Wilson coefficients and ξ is normalization scale. These coefficients for scalar and axial vector current are listed in [3]. Here, ϕ_b and ϕ_c depend upon scalar gluon condensate, $G_0 = \left\langle \frac{\alpha_s}{\pi} G^a_{\mu\nu} G^{a\mu\nu}\right\rangle$ and tensorial gluon condensate, $G_2 = \left\langle \frac{\alpha_s}{\pi} G^a_{\mu\sigma} G^{a}{}_{\nu}{}^{\sigma}\right\rangle$.

Within the chiral SU(3) model, G_0 and G_2 are calculated in terms of σ, ζ and dilaton field χ, whose coupled equation of motion are solved at finite density and temperature in the presence of external magnetic field[4, 5]. The magnetic field induced mass-shift of χ_c meson calculated using eq. (1) is given as

$$\Delta m^*_B = m^*_B - m^*_{B0} \quad (3)$$

where, m^*_B is the in-medium charmonium mass in finite magnetic field and m^*_{B0} is the in-medium mass in zero magnetic field.

Results and Discussion

In fig. (1), results are shown for strong external magnetic field, eB=$5m^2{}_\pi$ and $7m^2{}_\pi$ at ρ_B=$4\rho_0$, and temperature T=0 and 100 MeV and compared with zero magnetic field situation. Also, we have used the moments in the ranges $4 \le n \le 7$. Further, we have used ξ=1 and corresponding running charm quark mass m_c = 1.2 GeV as well as nuclear saturation density, ρ_0=0.15 fm^{-3}. The interaction of χ_{c0} and χ_{c1} in nuclear matter causes decrease in the mass of these mesons from vacuum value. In the absence of external magnetic field (eB=0), the mass-shift of χ_{c0} and χ_{c1} are observed to be -8.18(-28.66) and -7.11(-33.06) MeV at ρ_B=ρ_0($4\rho_0$) and temperature T=0 MeV. Including the effect of magnetic field along with the finite density and temperature more decrease in mass is observed. For example, at T=0 MeV, for ρ_B=ρ_0($4\rho_0$), above values of mass-shift of χ_{c0} modifies to -9.74(-34) and -10.62(-41.12) MeV for eB=$5m^2{}_\pi$ and

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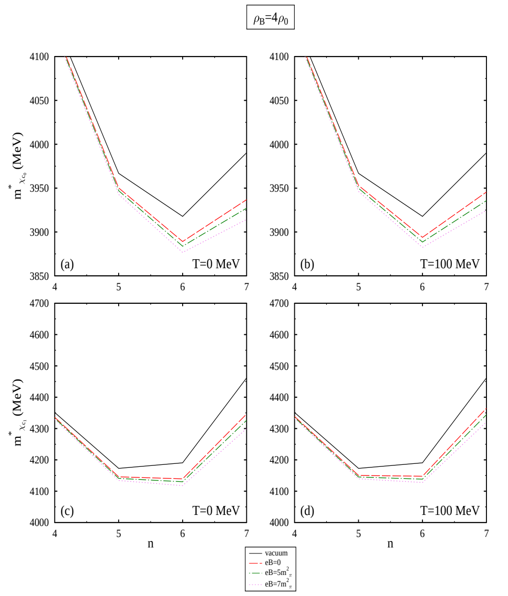

FIG. 1: (Color online)The in-medium mass of χ_{c_0} and χ_{c_1} meson plotted as a function of n in nuclear matter, at T=0 and 100 MeV, baryonic density, ρ_B=4ρ_0 and in different values of magnetic field, eB.

	Δm^*_B(MeV)	T=0 MeV		T=100 MeV	
		ρ_0	$4\rho_0$	ρ_0	$4\rho_0$
χ_{c0}	$\Delta m^*_{B_{50}}$	-1.56	-5.34	-1.13	-5.20
	$\Delta m^*_{B_{70}}$	-2.44	-12.46	-1.89	-11.48
χ_{c1}	$\Delta m^*_{B_{50}}$	-1.47	-9.32	-1.06	-9.18
	$\Delta m^*_{B_{70}}$	-2.49	-21.63	-1.77	-20.06

TABLE I: In the above table, we tabulate the effect of magnetic field on the mass-shift of χ_{c0} and χ_{c1} mesons. Here, $\Delta m^*_{B_{50}}$ represents mass-shift between eB= 5 $m^2{}_\pi$ and eB=0 (similar for $\Delta m^*_{B_{70}}$).

$7m^2{}_\pi$ respectively. For χ_{c1} meson, the mass-shift of χ_{c0} modifies to -8.58(-42.13) and -9.40(-54.5) MeV. Further, as we move from T=0 to T=100 MeV, the negative mass-shift of these mesons decrease.

In table (I), we listed the values of mass-shift of χ_{c0} and χ_{c1} meson at finite magnetic field from zero magnetic field. It can be seen, in-medium effects are more appreciable at high baryon densities. This is due to σ, ζ and dilaton field χ, which vary more appreciably at high densities and results in the large modifications of gluon condensates. In Ref. [6], the mass-shift of χ_{c_0} and χ_{c_1} is also calculated as a funtion of T/T_c in the absence of magnetic field. In this article, it is observed that the masses of both mesons decrease with the increase in T/T_c.

Summary

The negative shift in mass of χ_{c0} and χ_{c1} is observed on the application of external magnetic field. We noticed that the magnitude of mass-shift increases with the increase in magnetic field and baryonic density. However, it decreases with the increase in temperature. Consequently, this mass spectra may be used to study the decay of P-wave charmonia into lower charmonia states. Also, It may help to understand the experimental observables arising from non-central heavy-ion collision experiments.

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