Effect of strong magnetic field on the complex heavy quark potential

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Introduction

In recent years there has been a great interest regarding the physics of strongly interacting matter in the presence of strong external magnetic fields. The main interest was triggered by the fact that magnetic fields can be created in a laboratory. When two relativistic heavy ion collide with a non-zero impact parameter, a huge magnetic field is produced in the collision region, i.e. $B = m_\pi^2 = 10^{18}$ Gauss at the RHIC energies and $B = 15m_\pi^2 = 1.5\times10^{19}$ Gauss at the LHC energies [1]. Such a huge magnetic field may have existed in the early Universe as an origin of the present large scale cosmic magnetic field. How the properties of strongly interacting matter are modified by such magnetic fields has been the subject of many theoretical efforts [2]. The various theoretical investigations, based both on lattice QCD and model studies, have predicted many interesting phenomena affecting the properties of strongly interacting matter in the presence of strong magnetic backgrounds, it is still not certain to what extent such phenomena will be detectable in heavy ion experiments.

In this aspect, effects regarding the physics of heavy quark bound states ($Q\bar{Q}$) are of particular interest, since they are more sensitive to the conditions taking place in the early stages. They are considered as the most powerful probes to study the deconfining properties of the thermal strongly interacting medium. Matsui and Satz [3] predicted a suppression of the production rate of quarkonium states, being caused by the shortening of the screening length for color interactions in the QGP. As regards the effects more directly related to color interactions, various studies have considered the possible influence of an external magnetic field on the static quark-antiquark potential [4].

In this work we are interested to see the magnetic field induced modification of the static quark-antiquark potential. We show the effect of strong homogeneous magnetic field on the Debye screening and landau damping induced thermal width obtained from the imaginary part of the potential. In our calculation, we have also considered confining term along with Coulombic term. It is reasonable to study the effects of the confining (string) term above the deconfinement temperature (T_c) [5] due to the deviations from perturbative calculations and the ideal gas behavior beyond T_c.

The heavy quark complex potential is obtained by correcting both the Coulombic and confining terms in the Cornell potential with the dielectric permittivity. The medium and magnetic effects are incorporated by an in-medium permittivity. The dielectric permittivity can be written as [6]

$$\epsilon^{-1}(\vec{k}, m_D) = \frac{k^2}{k^2+m_D^2} - i\pi T\frac{k m_D^2}{(k^2+m_D^2)^2}, \tag{1}$$

where m_D is the Debye mass in the presence of magnetic field as defined in [7]. Magnetic field affects the quark loop in the gluon polarization tensor. After incorporating the gluonic contribution in the Debye mass we have:

$$\begin{aligned} m_D^2 &= \frac{4\pi\alpha_s(T)T^2N_c}{3} + \sum_{n_f}\frac{2|q_f|Bg^2}{2\pi T} \\ &\times \int_0^\infty \frac{dk}{2\pi}\tilde{f}(E_k)(1-\tilde{f}(E_k)), \end{aligned} \tag{2}$$

where $E_k = \sqrt{k^2 + m_f^2}$. Clearly the first term in Eq.[2] is from the gluon loop and second is from the light quark loop which gets affected by magnetic field. Further, we have taken the lowest Landau level (LLL) contribution only. This is a reasonable appex as quarkonia are produced during initial stages of collision when B is very high. Fig.[1] shows the variation of the real part of the quark-antiquark potential for different values of the magnetic field at $T = 200$ MeV. From the figure we found that the screening increases with the increase in magnetic field which results in the early dissociation of quarkonium states in the presence of magnetic field.

Fig[2] shows the variation of the imaginary part of the potential for different values of the magnetic field at $T = 200$ MeV. The imaginary part of the potential increases in magnitude with the increase in magnetic field which leads to a broadening of the decay width. It is important to discuss that whether the dissociation mechanism (screening versus Landau damping) remains the same in the presence of strong homogeneous magnetic field. Therefore, we also calculate the decay width from the imaginary part of the potential. We found that decay width increases slowly with the increase in magnetic field which results in the modification of the quarkonium dissociation temperature. From these results we conclude that presence of magnetic field results in the early dissociation of quarkonia in a thermal medium.

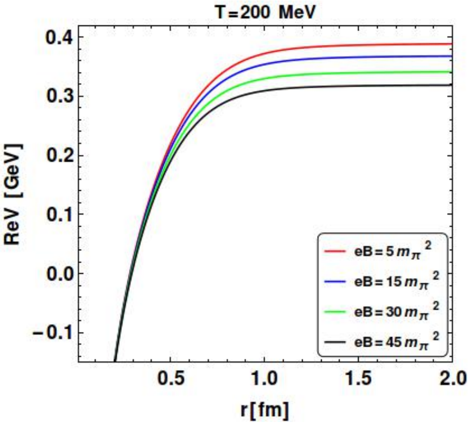

FIG. 1: Real part of the potential for various values of magnetic field at $T = 200$ MeV

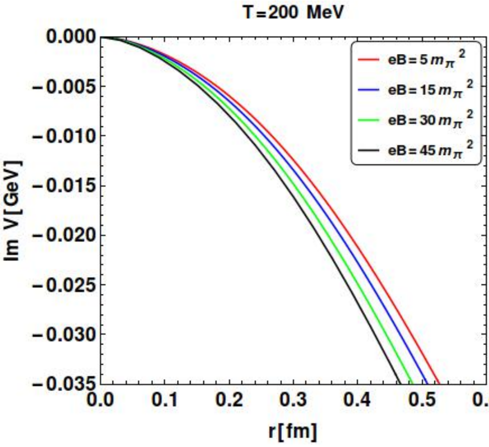

FIG. 2: Imaginary part of the potential for various values of magnetic field at $T = 200$ MeV

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