Quarkonium dissociation properties at finite chemical potential in relativistic heavy ion collisions

Vineet Kumar Agotiya$^a$, Siddhartha Solanki$^a$ and Manohar Lal$^a$

$^a$Department of Physics, Central University of Jharkhand Ranchi, India, 835 205

E-mail: agotiya81@gmail.com

Abstract. Using the quasi-particle Debye mass we have mapped the quarkonium properties at finite baryonic chemical potential which is obtained by approximated medium modified potential at $T=0$ through the dielectric function. We study the dissociation temperature and baryonic chemical potential dependence of binding energy of heavy quarkonia states for full QCD case and estimated the ground state patterns of the $J/\psi$ states.

1. Introduction

The study of quarkonium properties in relativistic heavy ion collisions is useful for verifying the existence of a Quark-Gluon Plasma (QGP) [1]. As we know that bound state of quarkonia via $J/\psi$ or $\Upsilon$ mesons have larger life time comparatively to the medium produced in nucleus-nucleus collision. The potential models are used to calculate the binding energy using Schrodinger equation in which a potential is modified by the fourier transformation, which is medium dependent at finite temperature and baryonic chemical potential [2, 3]. In strongly interacting QGP [4], we can considers all possible hadronic particles even at $T > T_c$ and explain non-ideal behavior of QGP near $T_c$. It is assumed that once the charmonium dissociates the light quarks combining with the heavy quarks by hadronization, if the charmonium states are dissociates [5]. Therefore 60% of the observed $J/\psi$’s particles comes from in a hadronic collisions and the remaining coming from the decays of $\chi_c$ and the $\psi'$, excited charmonium states. Since each $c\bar{c}$ bound state dissociates at a different temperature with the point of reproducing the charmonium suppression pattern in the heavy ion collision [6, 7, 8, 9]. At finite temperature there are two speculative lines of studies to determine the quarkonium spectral functions which are potential models [10] and lattice QCD [11]. In this present work, we have studied quarkonia dissociation properties at finite chemical potential using quasiparticle debye mass [12]. For this we have studied both perturbative and non-perturbative term in cornell potential to get the heavy quark chemical potential through dielectric function at finite temperature and baryonic chemical potential. To describe these bound states of quarkonia we need exact potential obtained from lattice QCD, like the cornell potential at $T = 0$, has been derived from perturbative non-quantum chromodynamics from the zeroth order matching coefficient. Because of various difficulties arises in the affective field theories at the finite temperature extension, the lattice base potential becomes important. Till it is an open Question, which energy that is free energy or internal energy taken as potential which describe the bound state of quarkonia. We have studied quarkonium dissociation in the quark matter of high baryon density and minimum temperature by using quasiparticle Debye mass, for that purpose we have using the heavy quark chemical potential.
by calculating the perturbative and non-perturbative terms in the cornell potential through the dielectric function at finite temperature and baryonic chemical potential and also using Debye mass from a quasiparticle picture of hot QCD medium. Finally we have calculate the binding energy and dissociation temperature of the charmonium state.

2. Finite baryonic chemical potential
The quark and anti quark potential plays active role in understanding the fate of quark-antiquark bound states in the hot quark gluon plasma medium. Here we likely work with the medium modified Cornell potential [2, 13, 14], that contains the Coulombic as well as the string part. We transform the medium modified potential using fourier transform:

$$V(r,T,\mu_f) = \left(\frac{2\sigma}{m_D^2(T,\mu_f)} - \alpha\right) \exp(-m_D(T,\mu_f)r) - \frac{2\sigma}{m_B^2(T,\mu_f)r} + \frac{2\sigma}{m_D(T,\mu_f)} - \alpha m_D(T,\mu_f)$$

The approximate potential in the limiting case \(r \gg \frac{1}{m_D}\) as,

$$V(r,T,\mu_f) \approx -\frac{2\sigma}{m_B^2(T,\mu_f)r} - \alpha m_D(T,\mu_f)$$

We make use of this approximated potential to solve Schrodinger equation for the investigation of Binding Energy and Quarkonium dissociation temperature.

3. Quasiparticle Debye mass
In the quasi-particle model, a system of interacting massless quarks and gluons can be described as "massive" non-interacting quasiparticle. The mass of quasiparticle is not independent and it is retain the quantum number of quark and gluon [3, 17]. To carry out our calculation, we used effective charges for the quasi-gluons and quarks based quasi-particle Debye mass for full QCD as:

$$m_D^2(T,\mu_f) = T^2\left(\frac{N_c}{3} Q_g^2 + \frac{N_f}{6} + \frac{N_f}{2\pi^2} (\frac{\mu_f^2}{T^2}) Q_q^2\right)$$

where, \(Q_g\) and \(Q_q\) are the effective charges which are given by the equations:

\[Q_g = 2\pi a_s g_0, \quad Q_q = 6\pi a_s f_0\]
Here, we are using the temperature dependence Debye mass, $m_{QP}$ in full QCD with $N_f = 3$ and to calculate the temperature dependence binding energy in strongly interacting QGP medium.

4. Binding energy and dissociation temperature

In this section, we have to studied the quarkonium properties (i.e. B.E and dissociation temperature) using baryonic chemical potential for the ground state of $c\bar{c}$ and using the solution of Schrodinger equation to understand the bound state properties of quarkonium state in hot QGP medium.

$$Q_g^2 = g^2(T)\frac{6PolyLog[2,z_g]}{\pi^2}$$

$$Q_q^2 = g^2(T)\frac{-12PolyLog[2,-z_q]}{\pi^2}.$$  \hspace{1cm} (4)

5. Results and Discussion

Here we have been obtained that the temperature variation of binding energy of $J/\psi$ with different values of $\mu_b$. Here we can see that in the left pannel of figure 1, the variation of binding energy with temperature is decreases with increasing the values of $\mu_b$. And same behaviour of binding energy is also shown in right pannel of figure 1, in the right pannel we observed that...
Table 1. Dissociation properties for $J/\psi$ at different temperature

| $T$ (MeV) | $\mu_D$ (GeV) | $\frac{\Delta \mu_D}{\mu_b}$ (MeV) |
|-----------|---------------|----------------------------------|
| 150       | 375.297       | 565.310                          |
| 160       | 336.631       | 603.005                          |
| 170       | 252.970       | 640.693                          |

the variation of binding energy of $J/\psi$ with $\mu_b$ is also decreases with increases the values of temperature. But it has been observed that in the left panel of the figure 2, the binding energy (of $J/\psi$ varies with $\mu_b$ at constant temperature ($T = 150 MeV$)) is increases with increases the values of anisotropy. Similarly in the right panel of figure 2 the binding energy have the same variation with temperature at constant $\mu_b$ ($\mu_b=1000 MeV$). The present result after introducing quasiparticle debye mass with $\mu_b$ and finite Chemical Baryonic Potential are very useful to study the properties of Quarkonia such as the state of Charmonium and Bottomonium. We are listed the values of dissociation chemical potential for $J/\psi$ at different temperature in table1. The dissociation chemical potentials of $J/\psi$ at $T = 150$ and $160$ MeV is found to be $375$ GeV and $337$ GeV respectively.

6. Conclusion
We have concluded that using the quasi-particle Debye mass we have mapped the quarkonium properties at finite baryonic chemical potential which is obtained by approximated medium modified potential at $T = 0$ through the dielectric function. We have been obtained the temperature dependent variation of binding energy of $J/\psi$ with different values of $\mu_b$ and the same variation with $\mu_b$ at different values of temperature. We have been also observed that the binding energy of $J/\psi$ varies with $\mu_b$ as well as temperature is increases with increasing the values of anisotropy.

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8. References
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