Heavy quarkonia in hot and dense strongly magnetized quark matter

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Abstract

We study the heavy quark potential in a hot and dense strongly magnetized QCD medium. For that purpose, we have calculated the real and imaginary parts of the resummed gluon propagator which get translated into the complex $Q\bar{Q}$ potential. We further evaluate the binding energy of the J/ψ and Υ using the real part of the potential while decay width with the help of imaginary part. We finally examined the competition between the binding energy and decay width to get the dissociation temperatures of the J/ψ and Υ for various strengths ($\mu = 60, 100$ MeV) of the quark chemical potential.

- Cornell Potential (in vacuum at $T = 0, B = 0$)

$$V(r) = -\frac{\alpha}{r} + \sigma r$$

- Medium modification to the $Q\bar{Q}$ potential ($T \neq 0, B \neq 0$) [Dumitru et al. PRD 79(2009)]

$$V(r; T, B, \mu) = C_F\, g^2 \int \frac{d^3p}{(2\pi)^3} (e^{ip.r} - 1)\, D^{00}(p_0 = 0, p)$$

• $D^{00}(p_0 = 0, p)$ is the static limit of the temporal component of resummed gluon propagator.

$\Longrightarrow$ We need gluon self energy in hot and dense strongly magnetized medium

- Gluon self energy in the magnetic field [Karmakar et al. EPJC 79 (2019)]

$$\Pi^{\mu\nu}(P) = b(P)B^{\mu\nu}(P) + c(P)R^{\mu\nu}(P) + d(P)M^{\mu\nu}(P) + a(P)N^{\mu\nu}(P)$$

- The projection tensors are defined as

$$B^{\mu\nu}(P) = \frac{\bar{u}^\mu \bar{u}^\nu}{\bar{u}^2} \qquad R^{\mu\nu}(P) = g_\perp^{\mu\nu} - \frac{P_\perp^\mu P_\perp^\nu}{P_\perp^2}$$

$$M^{\mu\nu}(P) = \frac{\bar{n}^\mu \bar{n}^\nu}{\bar{n}^2} \qquad N^{\mu\nu}(P) = \frac{\bar{u}^\mu \bar{n}^\nu + \bar{u}^\nu \bar{n}^\mu}{\sqrt{\bar{u}^2}\sqrt{\bar{n}^2}}$$

- The form factors are given by (taking the appropriate contractions)

$$b(P) = B^{\mu\nu}(P)\,\Pi_{\mu\nu}(P) \qquad c(P) = R^{\mu\nu}(P)\,\Pi_{\mu\nu}(P)$$

$$d(P) = M^{\mu\nu}(P)\,\Pi_{\mu\nu}(P) \qquad a(P) = \frac{1}{2}N^{\mu\nu}(P)\,\Pi_{\mu\nu}(P)$$

- Resummed Gluon propagator

$$D^{\mu\nu}(P) = \frac{(P^2-d)B^{\mu\nu}}{(P^2-b)(P^2-d)-a^2} + \frac{R^{\mu\nu}}{P^2-c} + \frac{(P^2-b)M^{\mu\nu}}{(P^2-b)(P^2-d)-a^2} + \frac{aN^{\mu\nu}}{(P^2-b)(P^2-d)-a^2}$$

- $D^{00}(P)$ in the static limit becomes ($R^{00} = M^{00} = N^{00} = 0$)

$$D^{00}(p_0=0,p) = -\frac{1}{(p^2+b(p_0=0,p))}$$

form factor a vanishes

- The form factor $b(p_0, p)$

$$b(P) = B^{\mu\nu}(P)\Pi_{\mu\nu}(P) = \frac{u^\mu u^\nu}{\bar{u}^2}\Pi_{\mu\nu}(P)$$

- Debye screening mass

$$\boxed{m_D^2 = (b+b_0)\bar{u}^2|_{p_0=0} = m^2_{\mathrm{q,D}} + m^2_{\mathrm{g,D}}}$$

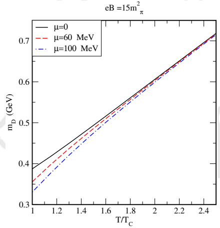
→ Here b_0 is the gluon loop contribution

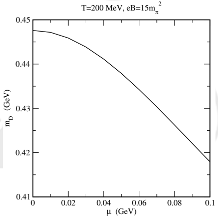
$$m^2_{\mathrm{g,D}}(T) = g^2 T^2 \left(\frac{N_c}{3}\right) \longleftarrow$$ Gluon loop Contribution

$$m^2_{\mathrm{q,D}}(T,\mu;B) = \sum_f g^2 \frac{|q_f B|}{4\pi^2 T} \int_0^\infty dk_3 \left\{ n^+(E_1)(1-n^+(E_1)) + n^-(E_1)(1-n^-(E_1)) \right\}$$

→ $n^+(E_1)$ and $n^-(E_1)$ are distribution functions for quarks and anti-quarks

$$n^\pm(E_1) = \frac{1}{e^{\beta(E_1 \mp \mu)}+1}, \quad E_1 = \sqrt{k_3^2 + m_f^2}$$





$\Longrightarrow$ The Debye mass gets reduced at finite quark chemical potential μ and this reduction is more pronounced at lower temperature region

- Real and imaginary parts of the resummed propagator [Guo et al. PRD 100, (2019)]

$$\mathrm{Re}\, D^{00}(p_0=0,p) = -\frac{1}{p^2+m_D^2} - \frac{m_G^2}{(p^2+m_D^2)^2} \longleftarrow \boxed{\text{Due to dimension two gluon condensate}}$$

$$\mathrm{Im}\, D^{00}(p_0=0,p) = \sum_f \frac{g^2|q_fB|m_f^2}{4\pi}\frac{1}{p_3^2(p^2+m_D^2)^2} + \frac{\pi T m_g^2}{p(p^2+m_D^2)^2} + \frac{2\pi T m_g^2 m_G^2}{p(p^2+m_D^2)^3}$$

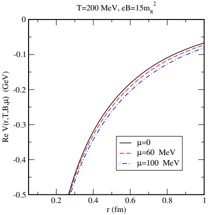
- Real and imaginary parts of the medium modified $Q\bar{Q}$ potential

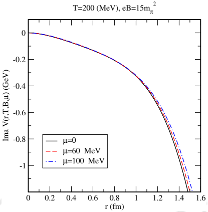
$$\mathrm{Re}\, V(r;T,B,\mu) = -\frac{4}{3}\alpha_s\left(\frac{e^{-\hat{r}}}{r} + m_D(T,\mu,B)\right) + \frac{4}{3}\frac{\sigma}{m_D(T,\mu,B)}\left(1-e^{-\hat{r}}\right)$$

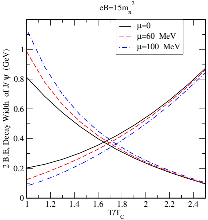
$$\mathrm{Im}\, V(r;T,B,\mu) = \sum_f \alpha_s g^2 m_f \frac{|q_fB|}{3\pi^2}\left[\frac{\pi}{2m_D^3} - \frac{\pi e^{-\hat{r}}}{2m_D^3} - \frac{\pi\hat{r}e^{-\hat{r}}}{2m_D^3} - \frac{2\hat{r}}{m_D}\int_0^\infty \frac{pdp}{(p^2+m_D^2)^2} \times \int_0^{pr}\frac{\sin t}{t}dt\right] - \frac{4}{3}\frac{\alpha_s T m_g^2}{m_D^2}\psi_1(\hat{r}) - \frac{16\sigma T m_g^2}{3m_D^4}\psi_2(\hat{r})$$

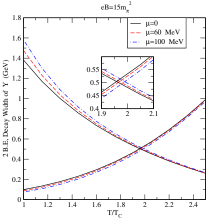
where $\psi_1(\hat{r}) \approx -\frac{1}{9}\hat{r}^2\left(3\ln\hat{r} - 4 + 3\gamma_E\right), \quad \psi_2(\hat{r}) \approx \frac{\hat{r}^2}{12} + \frac{\hat{r}^4}{900}\left(15\ln\hat{r} - 23 + 15\gamma_E\right)$

Results and Conclusions









$\Longrightarrow$ In the presence of the quark chemical potential ($\mu \neq 0$), we notice

- The real part of $Q\bar{Q}$ potential becomes more attractive in comparison to $\mu = 0$ case (due to the less color screening)
- The magnitude of the imaginary part gets decreased
- The binding energy gets enhanced
- The decay width is reduced
- The dissociation temperature of J/ψ and Υ rises

	T_D (in terms of T_c), $eB = 15\ m_\pi^2$	
State	J/ψ	Υ
μ =0	1.64	1.95
$\mu = 60$	1.69	1.97
$\mu = 100$	1.75	2.00