Investigation of Quark Binding Potential in QGP

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Abstract:The dissociation energy of heavy meson like $b\bar{b}$ and $c\bar{c}$ have been studied considering quark-quark internal potential when the respective meson are in quark Gluon Plasma(QGP). The interquark potential gets screened by the presence of QGP. Representing the quark-quark potential by Cornell potential, the dissociation energy and critical screening length have been estimated. The results are compared with the other theoretical estimates existing in literature.

The Hamiltonian for a $q\bar{q}$ system can be represented

$$H(r,T) = \frac{\overrightarrow{p}^2}{2m_{re}} + V_{q\bar{q}(r,T)} \tag{1}$$

where m_{re} is the reduced mass of the $q\bar{q}$ system,$V_{q\bar{q}}(r,T)$ is the interquark binding potential. The quark-antiquark potential can be represented as phenomenological Cornell potential [1] which runs as:

$$V(r,0) = -\frac{\alpha_s}{r} + K^{'}r \tag{2}$$

where $K^{'}$ is the coefficient for confinement, α_s is the parameter proportional to the strong coupling constant and r is radius of heavy mesons. In the thermodynamic environment of quarks and gluons the interquark potential gets modified due to the color screening so that the q$\bar{q}$ potential can be represented as:

$$V(r,T) = -\frac{Ze^{-\lambda r}}{r}[-\frac{\alpha_s}{r} + K^{'}r] \tag{3}$$

where Z is a constant and is equal to 1 GeV^{-1} and λ is a temperature dependent screening length which is parameterized as $\lambda(T) = \lambda(0)[1 - T/T_C]^{-0.2}$ and $\lambda(0) = 0.2GeV$[1]. Solution of equation (1) with the potential in (3)will lead a temperature dependent binding energy. Considering the wave function [3]

$$\Psi_K = B_k r^k e^{-(\beta/2)} Y_{l,m}(\theta,\phi) \tag{4}$$

K = 0,1,2,..... and l = 0,1,...

here B_k is normalization constant and can be represented as:

$$B_k = [\frac{\beta^{2k+3}}{(2k+2)!}]^{1/2} \tag{5}$$

where β is variational parameter [3].

The dissolution energy is the quantity which accounts the vanishing of bound states. The value of dissolution energy is positive for bound states and is negative for continuum which leads to the condition:

$$E^{n,l}_{dis}(\lambda(T)) = 0 \tag{6}$$

With the trial wave function the expression for the binding energy becomes:

$$\langle H\rangle = -2\pi\beta^3[\frac{2K^{'}}{(\beta+\lambda)^3} - \frac{\alpha_s}{(\beta+\lambda)}] + \frac{\pi\beta^2}{2m_r} \tag{7}$$

where $K^{'} = 0.92\ GeV^2$[4] and $\alpha_s = 0.471$ [2]. We have considered first three radial excitation corresponding to J/ψ and Υ for n=1, l=0, $\psi^{'}$ and $\Upsilon^{'}$ for n=2, l=0 and $\psi^{''}$ and $\Upsilon^{''}$ for n=3, l=0 and χ_c and χ_b for n=2, l=1. We have estimated the critical $\lambda(\lambda_C(T))$ with different values of β and results are furnished in Table No.1 and other theoretical works are given[1] and [3] in table 2.

Table 1: Estimated critical temperature dependent screening length($\lambda_c(T)$) in GeV with different values of variational parameter (β) in GeV.

S.No	States	β=0.1GeV	β=0.2GeV	β=0.3GeV	β=0.4GeV	β=0.5GeV
1	J/ψ	0.6391	0.7048	0.7127	0.6924	0.6577
2	$\psi^{'}$	0.3274	0.4437	0.5189	0.5706	0.5975
3	$\psi^{''}$	0.2042	0.2963	0.3632	0.4140	0.4466
4	χ_c	0.3641	0.4395	0.5153	0.5682	0.5771
5	Υ	0.9341	1.0353	1.0506	1.0315	0.9938
6	$\Upsilon^{'}$	0.4331	0.6197	0.7342	0.8244	0.9146
7	$\Upsilon^{''}$	0.2639	0.3910	0.4860	0.5641	0.6197
8	χ_b	0.5023	0.5893	0.7160	0.8132	0.8551

Table 2:Comparision of critical temperature dependent screening length ($\lambda_c(T)$) with others

S.No	States	Our work β=0.2GeV	Other works ref.[1] Model (1)	ref.[1]Model(2)	ref.[3]
1	J/ψ	0.7048	0.70	1.022	0.67
2	$\psi^{'}$	0.4437	0.36	0.565	0.05
3	$\psi^{''}$	0.2963	0.32	0.425	
4	χ_c	0.4395	0.34	0.580	0.32
5	Υ	1.0353	1.55	1.95	1.09
6	$\Upsilon^{'}$	0.6197	0.66	0.095	0.52
7	$\Upsilon^{''}$	0.3910	0.42	0.65	
8	χ_b	0.5893	0.57	0.925	0.66

It has been observed that the value of critical screening length with variational parameter β = 0.2 GeV agrees with the estimation of [1] using the model-1. The study of critical screening length is of utmost importance for the study of QGP. In the present work we have studied the effect of quark potential which is represented by Cornell potential.

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