Relativistic Correction to Charmonium Dissociation Temperature

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J/ψ as a probe of QGP

- J/ψ suppression as a sign of QGP formation
- J/ψ is deeply bounded, which leads to a high dissociation temperature

$$T_d = (1.2{\sim}2)T_c$$

- m_c is very big(in our case 1.4 GeV)

Normally non-relativistic model is used

Question: The relativistic correction of the dissociation temperature?

A qualitative estimation

$$H = \sqrt{\mu^2 + p^2} - \mu + V(r)$$

$$\approx \frac{p^2}{2\mu} + V_{eff}$$

$$V_{eff} = V - \frac{p^4}{8\mu^3}$$

A deeper potential well should lead to a higher T_d

The covariant relativistic Schördinger equations

Derived from the two-body Dirac equation(TBDE)

for spin singlet u_0 (n^1L_L)

$$\left[-\frac{d^2}{dr^2}+\frac{J(J+1)}{r^2}+2m_wB+B^2-A^2+2\epsilon_wA+\Phi_D-3\Phi_{SS}\right]u_0=b^2u_0$$

for spin triplet $u_1^0\,(n^3L_L)$, $u_1^+(n^3L_{L+1})$ *and* $u_1^-(n^3L_{L-1})$

$$\left[-\frac{d^2}{dr^2}+\frac{J(J+1)}{r^2}+2m_wB+B^2-A^2+2\epsilon_wA+\Phi_D-2\Phi_{SO}+\Phi_{SS}+2\Phi_T-2\Phi_{SOT}\right]u_1^0=b^2u_1^0,$$

$$\left[-\frac{d^2}{dr^2}+\frac{J(J-1)}{r^2}+2m_wB+B^2-A^2+2\epsilon_wA+\Phi_D+2(J-1)\Phi_{SO}+\Phi_{SS}+\frac{2(J-1)}{2J+1}(\Phi_{SOT}-\Phi_T)\right]u_1^+$$
$$+\ \frac{2\sqrt{J(J+1)}}{2J+1}\left(3\Phi_T-2(J+2)\Phi_{SOT}\right)u_1^-=b^2u_1^+,$$

$$\left[-\frac{d^2}{dr^2}+\frac{(J+1)(J+2)}{r^2}+2m_wB+B^2-A^2+2\epsilon_wA+\Phi_D-2(J+2)\Phi_{SO}+\Phi_{SS}+\frac{2(J+2)}{2J+1}(\Phi_{SOT}-\Phi_T)\right]u_1^-$$
$$+\ \frac{2\sqrt{J(J+1)}}{2J+1}\left(3\Phi_T+2(J-1)\Phi_{SOT}\right)u_1^+=b^2u_1^-$$

u_1^+ $(L=J-1)$ and u_1^- $(L=J+1$) are coupled.

[H.W. Crater]

Interaction models

- $T = 0$, Cornell form

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

- $T \neq 0$, two limits

$$V(r,T) = F \quad \text{or}$$
$$V(r,T) = U = F + TS = F - T\partial F/\partial T$$

Considering Debye screening(fitting the lattice data)

[S. Digal et al., Eur. Phys. J. C 43 (2005) 71]:

$$F = -\frac{\alpha}{r}(e^{-\mu r} + \mu r) + \frac{\sigma}{\mu}[\frac{\Gamma\left(\frac{1}{4}\right)}{2^{\frac{3}{2}}\Gamma\left(\frac{3}{4}\right)} - \frac{\sqrt{\mu r}}{2^{\frac{3}{4}}\Gamma\left(\frac{3}{4}\right)} K_{\frac{1}{4}}(\mu^2 r^2)]$$

Interaction models

Separate the potential into two parts:

$$V(r,T) = A(r,T) + B(r,T)$$

For $V = F$

$$A(r,T) = -\frac{\alpha}{r}e^{-\mu r}$$

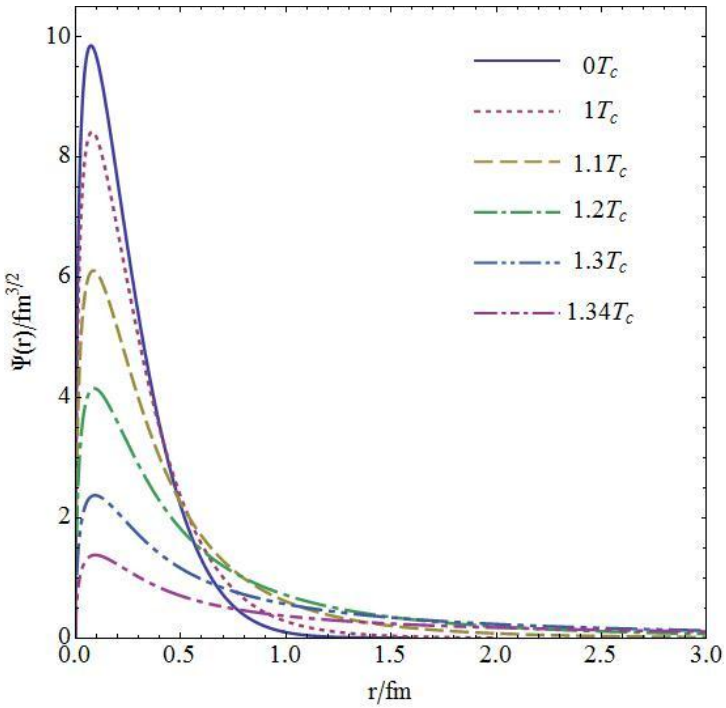
$$B(r,T)=\frac{\sigma}{\mu}\left[\frac{\Gamma\left(\frac{1}{4}\right)}{2^{\frac{3}{2}}\Gamma\left(\frac{3}{4}\right)} - \frac{\sqrt{\mu r}}{2^{\frac{3}{4}}\Gamma\left(\frac{3}{4}\right)}K_{\frac{1}{4}}(\mu^2 r^2)\right] - \alpha\mu$$

All terms in the equations can be expressed in A and B

Numerical results

$J/\psi : 1^3S_1$

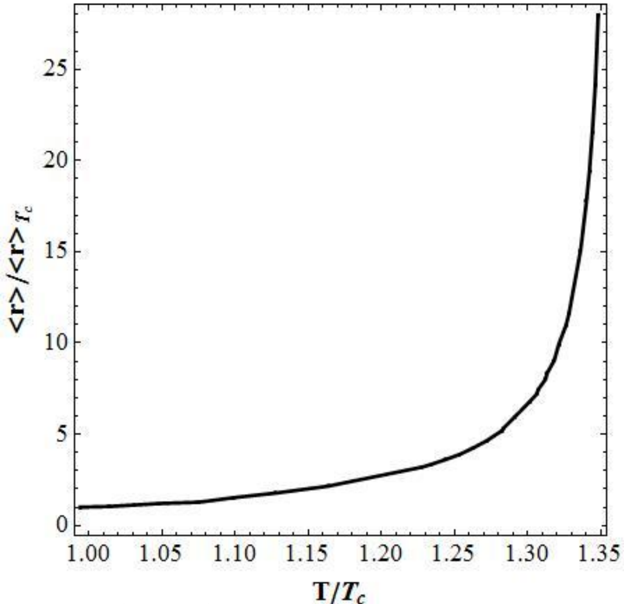
S-wave functions at different temperature for $V = F$:



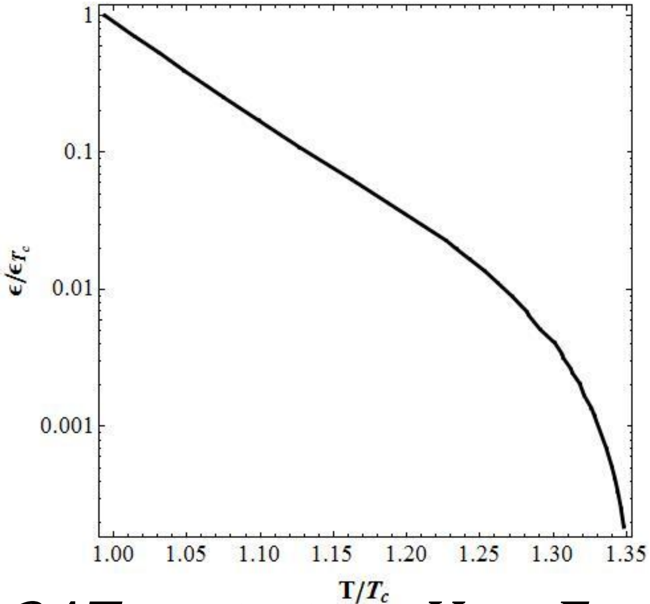
The wave functions expand rapidly above T_c

Numerical results

The average size of J/ψ for $V = F$:



The binding energy of J/ψ for $V = F$:



The dissociation temperature is $1.34T_c$ in the limit $V = F$.
In the other limit $V = U$,it is $2.38T_c$.
For χ_0, T_d is just around T_c .

Conclusion

- The relativistic effect makes Charmonium survive a higher temperature.
- The dissociation temperature of J/ψ increases from $1.26T_c$ to $1.34T_c(7\%)$ in the limit $V = F$ and in the other limit $V = U$, it increases from $2.1T_c$ to $2.38T_c(13\%)$
- On average, there is a relativistic correction of about 10% for Charmonium dissociation temperature.