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Quarkonium Suppresion and Entropic Force

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An entropic force is a phenomenological force resulting from the entire system's statistical tendency to increase its entropy, rather than from a particular underlying microscopic force.

Example: free expansion of an ideal gas (Joule experiment)

$$P(V,T) = T\left(\frac{\partial S}{\partial V}\right)_T + \left(\frac{\partial U}{\partial V}\right)_T$$

Pressure P: in general energetic & entropic components.

Here $(\partial U/\partial V)_T = 0$, so that the pressure of an ideal gas

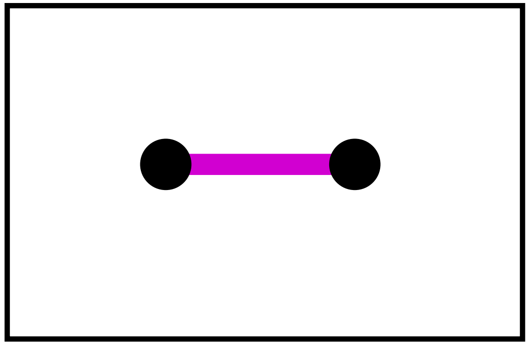
$$P(V,T) = T\left(\frac{\partial S}{\partial V}\right)_T = K(V,T)$$

is a purely entropic force.

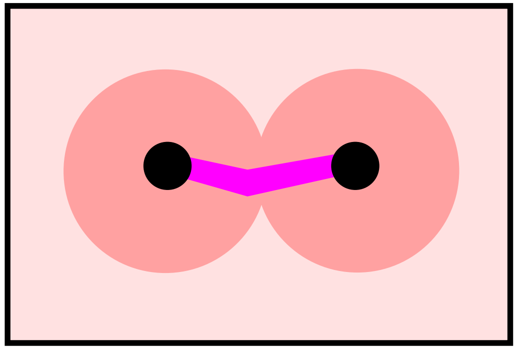
Windmill: entropic   Watermill: energetic

Quarkonium in deconfined medium: two distinct effects

- medium modifies $Q\bar{Q}$ interaction (string softens/melts)
- medium interacts with individual Q (polarization clouds)



in vacuum



in QGP

For $Q\bar{Q}$ separation $r = 0$: no clouds,
formation with increasing r

increasing r implies increasing entropy,
$\exists$ entropic force separating $Q\bar{Q}$ pair

Potential model for in-medium quarkonium binding

$$\left[2m_Q - \frac{1}{m_Q}\nabla^2 + V(r,T)\right]\Phi_i(r,T) = M_i(T)\Phi_i(r,T).$$

in vacuum $V(r, T = 0) = \sigma r$ (modulo Coulombic term)

in medium $V(r,T) = \ ?$ Common: screened string potential

$$V(r,T) = \sigma r \left[\frac{1 - e^{-\mu r}}{\mu r}\right] = \frac{\sigma}{\mu}[1 - e^{-\mu r}]$$

temperature dependence given through screening mass $\mu(T)$

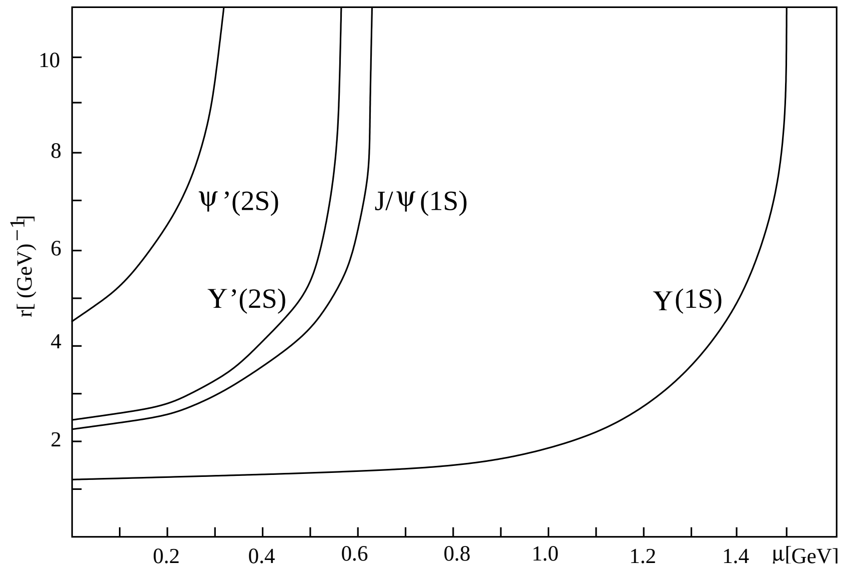
only for $\mu \leq \mu_i$, bound state i exists:

μ_i specifies dissociation temperature T_i for state i

as $\mu \to \mu_i$, bound state radius diverges: $r_i \to \infty$

binding energy vanishes: $2m_Q + \sigma/\mu - M_i(T) \to 0$

What is a quarkonium state
– of radius 10 fm
– of binding energy 10 MeV
in a medium of temperature
200 MeV ∼ scale 1fm?



Propose:
entropic force breaks up quarkonium states before they reach dissociation point from two-body potential treatment

Consider thermodynamics of QGP with and without a static $Q\bar{Q}$ pair at separation r,

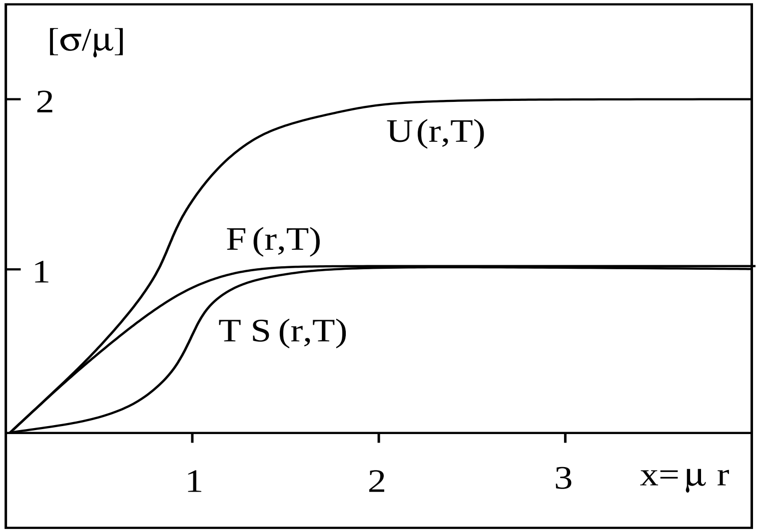
form differences of thermodynamic potentials

free energy $\quad F(r,T) = \frac{\sigma}{\mu}[1 - e^{-x}]$

entropy $\quad TS(r,T) = -T\left(\frac{\partial F(r,T)}{\partial T}\right)_r = \frac{\sigma}{\mu}[1-(1+x)e^{-x}]$

internal energy

$U(r,T) = TS(r,T) + F(r,T)$

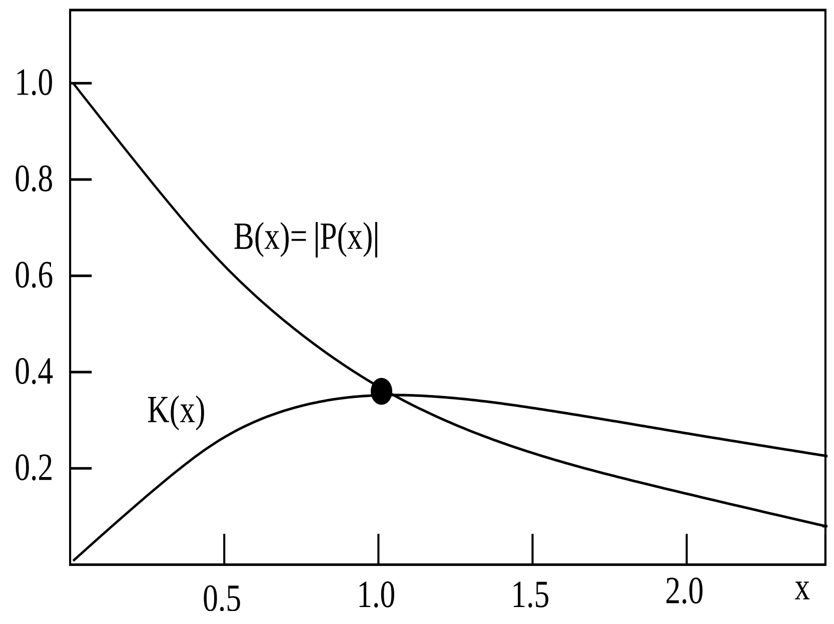


what forces correspond to these potentials?

attractive pressure $P(x) = -\left(\frac{\partial F(r,T)}{\partial r}\right)_T = -\sigma\, e^{-x}$

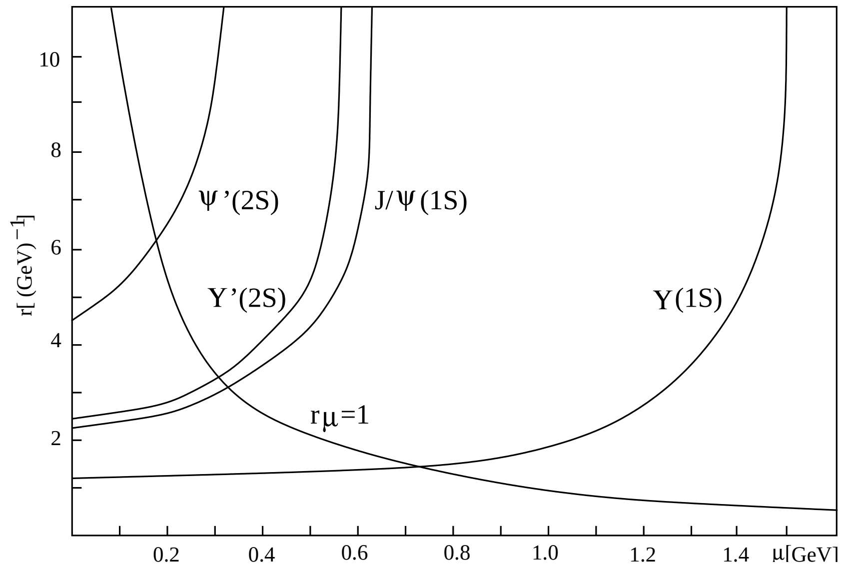
repulsive entropic force $K(x) = T\left(\frac{\partial S(r,T)}{\partial r}\right)_T = \sigma\, x\, e^{-x}$

at $x = \mu r = 1$: $r_{Q\bar{Q}} = r_D$
entropic force
reaches maximum and
overtakes binding force,
bound state dissociates



Apply to quarkonium radii

Schrödinger equation with screened string potential neglects effects of entropic force



Example:

– at $\mu(T) = 0$, $r_{J/\psi} = 0.4$ fm

– at $\mu(T) = 00.32$ GeV, $r_{J/\psi} = 0.6$ fm:

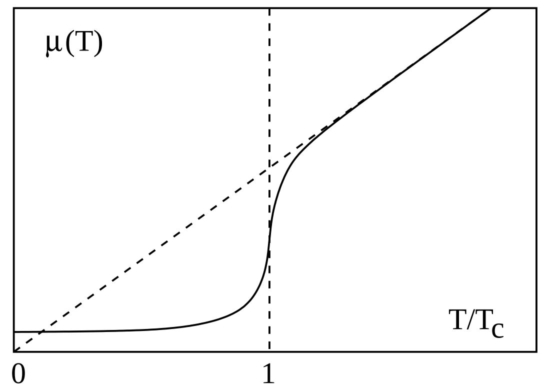
entropic force takes over

for larger $\mu(T)$, i.e., for larger T, no more bound state J/ψ

Now turn to more realistic world: free energy

$$F(r,T) = \frac{\sigma}{\mu}(1 - e^{-\mu r}) - \alpha \left(\frac{e^{-\mu r}}{r} + \mu \right)$$

Coulombic term & more general $\mu(T)$



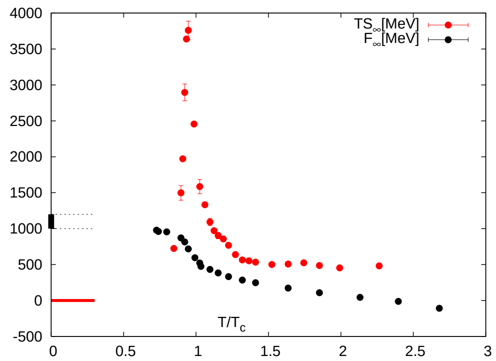
$$B(r,T) = \left[\sigma + \frac{\alpha}{r^2}(1 + \mu r) \right] e^{-\mu r}$$ **binding force**

$$K(r,T) = (T\mu') \left[\sigma r + \alpha \mu \right] e^{-\mu r}$$ **entropic force**

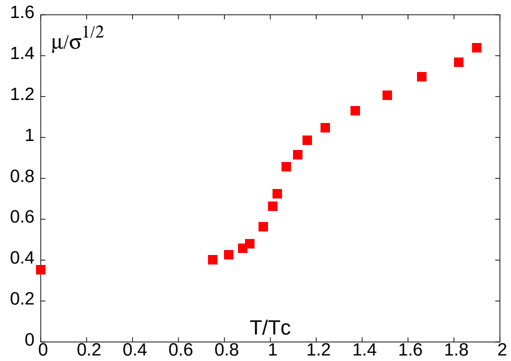
NB: critical behavior ($\mu' \to \infty$) affects only entropic force!

thermal quarkonium features in (2+1) finite T lattice QCD

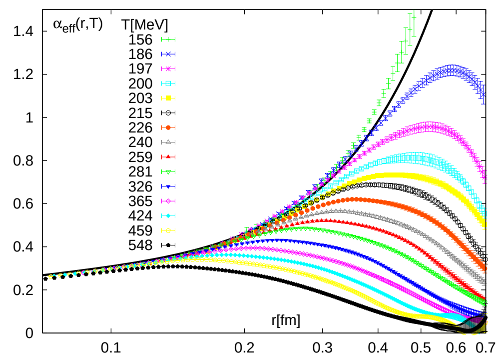
[Kaczmarek & Zantow 2007]



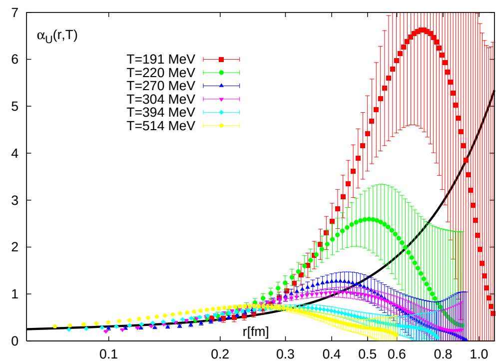
$F(\infty, T)$ & $TS(\infty, T)$



$\mu(T)$

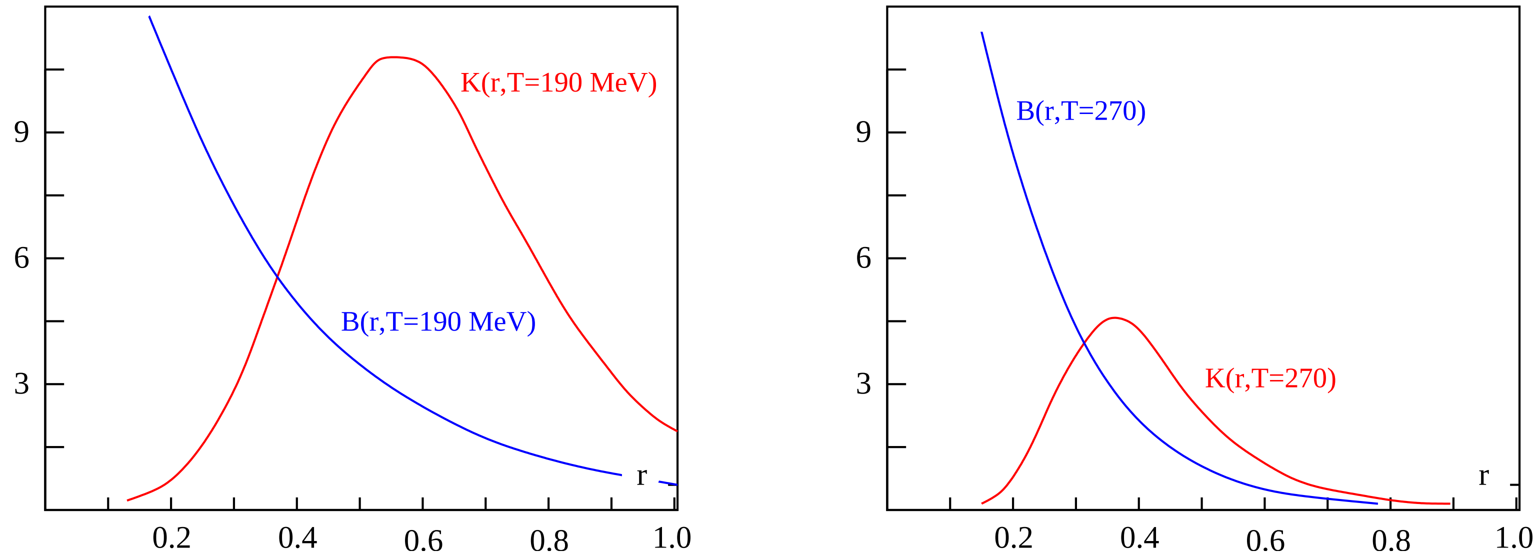


$r^2 B(r, T)$



$r^2[K(r, T) + B(r, T)]$

Use this to extract binding and entropic forces, compare



near T_c: strong entropic variation;

– consequences on charmonium?

– two-body treatment inadequate

– need to include entropic forces.