Dynamical gluon mass at nonzero temperature in the instanton vacuum model

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Introduction

Instanton Liquid Model

QCD vacuum at $T \neq 0$

Gluons at non-zero temperature

Discussion
The properties of QCD vacuum are important. We consider them in the instanton liquid model (ILM) at non-zero temperature for the mean instanton size $\rho(T)$ and density $n(T)$.

- Gluon propagator gives a contribution to the one-gluon exchange perturbative $Q\bar{Q}$ potential.
- Temperature dependencies of dynamical gluon mass in ILM.
The vacuum (=the ground state) is made of zero-point oscillations of the fields \( A_i(x, t) \) on top of classical field configurations \( A_{\text{class}}(x, t) \).

- **up**: action density, before and after smearing
- **down**: so-called topological charge density

- Computer simulations of the Yang-Mills vacuum [L. Negele et al.]
Classical solutions of Yang-Mills equation

- Instanton as a large fluctuation of the gluon field in imaginary time corresponding to quantum tunneling from one of minimum of the potential energy to the neighbor one
- Generalization of standard instanton to $T \neq 0$: periodic instanton of Harrington and Shepard (1978)
- Action density of the periodic instanton with trivial holonomy as function of $z, t$ at fixed $x = y = 0$. 
The ILM manages to describe all the nonperturbative physics using only two main parameters the average instanton size $\bar{\rho}$ and density $n$.

Phenom. (Shuryak1981), Var. (Diakonov-Petrov1983) $n^{-1/4} = R \approx 1 \text{ fm}$, $\rho \approx 0.33 \text{ fm}$; Lattice (Negele1999): $R \approx 0.89 \text{ fm}$, $\rho \approx 0.36$ Our with $1/N_c$ corr: $R \approx 0.76$, $\rho \approx 0.32$
The figure on the left represents ratio of instanton sizes $\bar{\rho}^2(x)/\bar{\rho}^2(0)$ while right one ratio of instanton densities $n(x)/n(0)$ as functions of $x = \bar{\rho}_0 T$ corresponding to the variational estimates from Refs. [E. Shuryak and others, Seungil Nam] at the phenomenological values of $\bar{\rho}(0) = 1/3 \, fm$ and $n(0) = 1 \, fm^{-4}$. 

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Periodic scalar "gluon" propagator in periodical instanton field is

\[ \Delta_{I}^{ab}(x, y) = \Delta_{0}^{ab}(x, y) + \Delta_{1}^{ab}(x, y) + \Delta_{2}^{ab}(x, y) \]

\[ \Delta_{0}^{ab}(x, y) = \frac{1}{2} \text{tr} \frac{\tau_{a}F(x, y)\tau_{b}F(y, x)}{\Pi(x)4\pi^{2}(x - y)^{2}\Pi(y)} \]

\[ F(x, y) = 1 + \sum_{m} \frac{\rho^{2}(\tau x_{m})(\tau^{+}y_{m})}{x_{m}^{2}y_{m}^{2}} \]

\[ \Delta_{1}^{ab}(x, y) = \frac{1}{2} \text{tr} \sum_{m} \frac{\tau_{a}F(x, y_{m})\tau_{b}F(y_{m}, x)}{\Pi(x)4\pi^{2}(x - y_{m})^{2}\Pi(y)} \]

\[ \Delta_{2}^{ab}(x, y) = \sum_{m} \frac{C^{ab}(x, y_{m})}{\Pi(x)4\pi^{2}\Pi(y)} \]

\[ \sum_{m} C^{ab}(x, y_{m}) = \sum_{r \neq s} \frac{\rho^{2}x^{a}}{x_{r}^{2}x_{s}^{2}} \sum_{m} \frac{\rho^{2}y^{b}}{y_{r+m}^{2}y_{s+m}} \]
Gluons at $T \neq 0$

- Solve zero mode problem;
- Average gluon propagator in ILM by means Pobylitsa Eq. and find dynamical electric gluon mass $M_g(q, T)$

$$M_s(q, T) \approx M_{s,0,1}(q, T) = \left[ \frac{3 \bar{\rho}^2(T)n(T)}{(N_c^2 - 1)} \right]^{1/2} F(q, T),$$

$$F(0, 0) = 1, \quad F(q, T) \leq F(q, 0) = q \bar{\rho}K_1(q \bar{\rho}).$$
Ratio of $M_s(x)/M_s(0)$

- Relation between real and scalar color field propagators mass is $M_{el}(0,0) = 2^{1/2}M_s(0,0) = 362\,MeV$

- Here $x = T\rho, x_c = 0.25, M_g(x) = M_g(0,T)$, $M_g$-strength of gluon-instanton interaction.

Profile function $F(T=0)$
- $Q\bar{Q}$ and QCD vacuum properties are correlates very much. QCD vacuum = ILM is applicable for the $Q\bar{Q}$, since instanton average size $\rho \sim 1/3\, fm \sim Q\bar{Q}$ sizes, while density $n \sim 1\, fm^{-4}$.

- In ILM at $T \neq 0$ $\rho(T)$ and $n(T)$ are gradually decreasing functions which lead to essential changes of ILM contributions to $Q\bar{Q}$ potential. They must be taken into account in analysis of heavy quarks production processes.

- We applied our result to the calculations of temperature dependencies of the heavy quarkonium properties.
Thanks for attention!!!