Dominance of Abelian monopoles in equation of state of gluon plasma

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The properties of thermal quark–gluon plasma in QCD have attracted great interest in recent years. The plasma represents a strongly interacting medium made of gluons and quark with unusual properties: at temperatures slightly above the critical temperature T_c the QCD plasma can be considered as an ideal liquid rather than an ideal gas [1]. On the other hand various nonperturbative features of low-energy QCD can be successfully described by a dual superconductor model based on monopole condensation [2]. In this report we study the contribution of monopoles to the thermodynamical properties of plasma [3] following the suggestion [4] that the unexpected properties of the plasma can be described by a liquid state of Abelian monopoles. The monopoles are geometrically related to the center vortices, whose contribution to the plasma is reported elsewhere [3, 5].

The energy–momentum tensor $T_{\mu\nu} = 2\mathrm{Tr}\left[G_{\mu\sigma}G_{\nu\sigma} - \frac{1}{4}\delta_{\mu\nu}G_{\sigma\rho}G_{\sigma\rho}\right]$ of $SU(N)$ gauge theory is traceless because the *bare* Yang–Mills theory is a conformal theory. However, in quantum theory the conformal invariance is broken at the quantum level and the energy–momentum tensor exhibits a trace anomaly $\theta(T)$,

$$\theta(T) = \langle T^\mu_\mu \rangle = T^5 \frac{\partial}{\partial T}\frac{p(T)}{T^4}\,, \qquad p(T) = T^4 \int^T \frac{\mathrm{d}\,T_1}{T_1}\,\frac{\theta(T_1)}{T_1^4}\,, \qquad \varepsilon(T) = 3\,T^4 \int^T \frac{\mathrm{d}\,T_1}{T_1}\,\frac{\theta(T_1)}{T_1^4} + \theta(T)\,.$$

Knowledge of the trace anomaly allows us to calculate the pressure $p = p(T)$ and energy density $\varepsilon = \varepsilon(T)$ of the system, and lead to a derivation the corresponding equation of state, $p = p(\varepsilon)$

We calculate the contribution of monopoles to the trace anomaly using numerical lattice simulations. The magnetic monopoles are particle–like gluonic configurations which can be identified with singularities in the diagonal component of the gluonic field in the Maximal Abelian gauge [2]. The monopole contribution is

$$\theta^{\mathrm{mon}} = L_t^4 \left(a\frac{\partial\beta}{\partial a}\right)\sum_i \left(\frac{\partial f_i(\beta)}{\partial\beta}\right)\left[\langle \bar{S}_i^{\mathrm{mon}}\rangle_T - \langle \bar{S}_i^{\mathrm{mon}}\rangle_0\right]\,,$$

where $\bar{S}_i^{\mathrm{mon}} = S_i^{\mathrm{mon}}/(L_s^3 L_t)$ is a bulk average of ith two-point interaction term, S_i^{mon}, in the monopole action. We used $L_s^3 L_t$ lattices with $L_s = 16$ and $L_t = 4, 16$. The coupling constants of the monopole action $f_i = f_i(\beta)$, $i = 1, \ldots, 11$, are numerically determined with the help of the inverse Monte Carlo method [6] using 400 configurations.

The contribution of the monopoles to the trace anomaly θ/T^4 in $SU(3)$ lattice gauge theory is shown in Fig. 1. The deconfinement temperature is marked by the vertical solid line. The monopole-originated trace anomaly: (i) is consistent with zero in the confinement phase; (ii) starts to increase at $T \sim T_c$ approaching a maximum at a temperature slightly above T_c; (iii)is a positive quantity that increases at slower rate than T^4 for $T \gg T_c$. All these properties qualitatively match those of the original $SU(3)$ gluonic trace anomaly [7]. We conclude that the monopoles do contribute to the equation of state of the gluon plasma.

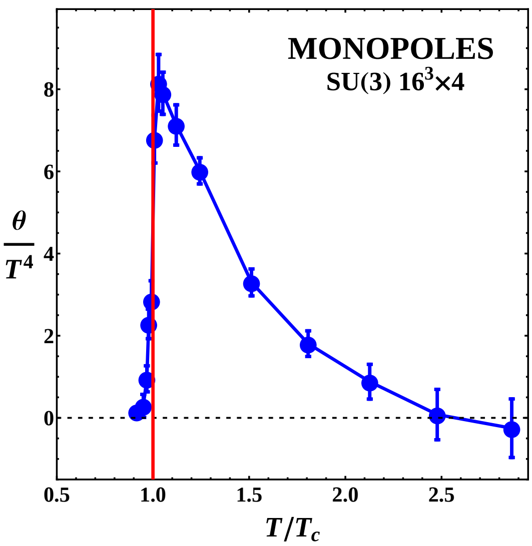

Figure 1: Contribution of the monopoles to the trace anomaly in $SU(3)$ lattice gauge theory.

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