Monopole gas in three dimensional SU(2) gluodynamics

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The dual superconductor model [1] was invented to explain the confinement of color in non-Abelian gauge theories. The model assumes that the non-Abelian vacuum can be considered as a medium of Abelian monopoles. Infrared properties of the non-Abelian gauge theory in the confinement phase are governed by the monopole condensate while in the deconfinement phase the condensate is absent. The Abelian monopoles are singular configurations of the gluonic field. These configurations can be identified with the help of the Abelian projection method [2]. Numerical simulations show that the dual superconductor is realized in four dimensional non-Abelian gauge theories [3].

We discuss non-perturbative features of three-dimensional SU(2) gauge model which has a relation to high-temperature QCD. The most interesting features are the confinement of color and the mass gap generation (analogues of, respectively, "the spatial confinement" and "the magnetic screening", in the 4D SU(2) gauge model at $T \neq 0$). The Abelian monopole dynamics of this model was previously investigated both by analytical (phenomenological) [4] and numerical [5] approaches. Taking into account the success of the monopole confinement mechanism in 4D [3] it is natural to expect that in 3D SU(2) model the dominant contributions both to the string tension and to the screening mass is given by the Abelian monopoles. We try to describe the action of the Abelian monopoles by a Coulomb gas model. This choice is motivated by the well-known analytical result [6] in the 3D Georgi-Glashow model:

$$Z = \sum_{N=0}^{\infty} \frac{\zeta^N}{N!} \Biggl[\prod_{a=1}^{N} \int d^3 x^{(a)} \sum_{q_a=\pm 1}\Biggr] \exp\Bigl\{-\frac{g_M^2}{2} \sum_{\substack{a,b=1 \\ a\neq b}}^{N} q_a q_b \, D(x^{(a)} - x^{(b)})\Bigr\} \,. \tag{1}$$

Here x_a and q_a are, respectively, the position and the charge (in units of a fundamental magnetic charge, g_M) of a^{th} continuum monopole. ζ is the fugacity parameter and the Coulomb interaction is represented by the inverse Laplacian D, $-\partial_i^2 D(x) = \delta^{(3)}(x)$. To match the continuum model with the lattice SU(2) model, we use the method of blocking from continuum (BFC) [7, 8]. The values of the parameters of the Coulomb gas model in the continuum limit, Eq.(1), can be obtained by fitting the numerical results for monopole density by the analytical prediction.

We have shown that the dynamics of the Abelian monopoles in the three–dimensional SU(2) gauge model can be described by the Coulomb gas model. Using a novel method, called the blocking of the monopoles from continuum, we calculated the monopole density and the Debye screening mass in continuum using the numerical results for the (squared) monopole charge density. The self-consistency of the results was checked by the independent analysis of the lattice monopole action. We conclude that the Abelian monopole gas in the 3D SU(2) gluodynamics is not dilute. This conclusion agrees qualitatively with observation [9] made at RHIC that in the quark gluon plasma at high temperatures the gluons are not weakly interacting. Nevertheless, the continuum values of the monopole density ($\rho = 0.174(2)\,\sigma^{3/2}$) and the Debye screening mass ($M_D = 1.77(4)\,\sigma^{1/2}$) – obtained with the help of the dilute monopole gas model – are consistent within the accuracy of 25% with the known data obtained from independent measurements.

The numerical simulations have been performed on NEC SX-5 at RCNP, Osaka University.

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