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Duality and confinement in $D = 3$ models driven by condensation of topological defects

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Abstract

We study the interplay of duality and confinement in Maxwell-like three-dimensional models induced by the condensation of topological defects driven by quantum fluctuations. To this end we check for the confinement phenomenon, in both sides of the duality, using the static quantum potential as a testing ground. Our calculations are done within the framework of the gauge-invariant but path-dependent variables formalism which are alternative to the Wilson loop approach. Our results show that the interaction energy contains a linear term leading to the confinement of static probe charges.

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1. Introduction

This work is aimed at studying the duality symmetry for certain 3D models coupled to sources of different dimensions that eventually condense due to quantum fluctuations, using the Quevedo–Trugenberger phenomenology [1] to the Julia–Toulouse mechanism [2]. In general studies in field theory, the presence of the duality between two models is verified through their equations of motion and the algebra of the observables. However, since quantum fluctuations may eventually drive the condensation of topological defects destroying the duality, we should be able to look for a distinct property to be used as a *point of proof* in the condensed phase. In this Letter we propose to use the effective potential between two static charges as such a *testing ground* for the existence of duality, after quantum fluctuations drive the condensation of topological defects. In principle one could check for this proposal studying the interplay

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between confinement and duality in an $U(1)$ gauge theory in D spacetime dimensions for Maxwell-like theories of totally antisymmetric tensors of arbitrary rank. However, due to technical difficulties in the computation of the effective static potential in arbitrary D dimensions we shall restrict ourselves to the case $D = 3$.

Based on the common knowledge coming from the continuum Abelian gauge theory, the assertion that the such a theory has a confining phase may sound strange. In fact the existence of a phase structure for the continuum Abelian U(1) gauge theory was obtained by including the effects due to compactness of U(1) group that dramatically change the infrared properties of the model [14,15]. These results, first found by Polyakov [3], have been confirmed by many distinct techniques basically due to the contribution of the vortices into the partition function of the theory. The condensation of these topological defects then lead to a structural change of the conventional vacuum of the theory into a dual superconductor vacuum. An interesting approach to this problem has recently been proposed by Kondo who derived the effective potential from a partition function that includes the contribution of all topologically nontrivial sectors of the theory [4].

In a previous paper [5] we have approached the problem in a phenomenological way using the Julia–Toulouse mechanism [2], as proposed by Quevedo and Trugenberger [1], that considers the condensation of topological defects. This study was undertaken for theories of compact antisymmetric gauge tensors of arbitrary ranks in D space–time dimensions that appear as low-energy effective field theories of strings. More specifically, using the Quevedo–Trugenberger phenomenology [1] we studied the low-energy field theory of a pair of compact massless anti-symmetric tensor fields, say A_p and B_q with $p + q + 2 = D$, coupled magnetically and electrically, respectively, to a large set of $(q - 1)$-branes, characterized by charge e and a Chern kernel Λ_{p+1} [6], that eventually condense. It has been argued that the effective theory that results displays the confinement property. The results of [5] show that the phenomenological action proposed in [1] incorporates automatically the contribution of the condensate of topological defects to the vacuum of the model or, alternatively, the nontrivial topological sectors as in [4].

It goes without saying that, on the grounds of the observed electric–magnetic duality, the same result should come through if the dual picture were adopted, i.e., by considering the reversed couplings with a $(p - 1)$-brane of charge g and Chern kernel Ω_{q+1}. Of course this seems to be mandatory if the system displays self-duality, e.g., if the sources have the same dimension and the tensors are of the same rank ($p = q$), which only occurs in even dimensions. The Julia–Toulouse mechanism for the condensation of magnetic charges, leading to confinement of electric charges is dual to the confinement of monopoles driven by the condensation of electric charges. However, the general results presented in [5] suggest that such a duality between the electric and magnetic views should survive also for systems not presenting self-duality, that is, when $p \neq q$. However a clear-cut verification of this possibility is still missing. To explicitly check for this manifestation of the duality phenomenon in the condensed phase using the effective static potential is our main motivation in this Letter.

The way we intend to fill up this gap is by studying specific examples in $D = 3$ since they will not display self-duality. Our calculations are done within the framework of the gauge-invariant but path-dependent variables formalism which are alternative to the Wilson loop approach. To consider this simpler situation seems to be our only possibility to check for the proposal of using the effective static potential as a *point of proof* for duality in the condensed phase since for higher dimensions such a computation becomes very messy. There is however an extra technical point of difficulty here. In this dimension one side of duality involves a scalar field which is not a gauge model. In fact it is not even a constrained theory. This poses some difficulties applying the above formalism to compute the effective static potential. An extension of the above mentioned method will be presented here that solves this problem. This is a new, although minor contribution of this work.

In the next section we discuss the duality both in the dilute and in the condensed phases. In particular we review the main points of the mechanism presented in [5] using the Quevedo–Trugenberger formalism. The phenomenological approach to the condensation of topological defects developed in [1] and the confinement potential for the effective theory of [5] are quickly reviewed in Section 2. In Section 3 we perform