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Higgsless superconductivity from topological defects in compact BF terms

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Abstract

We present a new Higgsless model of superconductivity, inspired from anyon superconductivity but P- and T-invariant and generalisable to any dimension. While the original anyon superconductivity mechanism was based on incompressible quantum Hall fluids as average field states, our mechanism involves topological insulators as average field states. In D space dimensions it involves a $(D-1)$-form fictitious pseudovector gauge field which originates from the condensation of topological defects in compact low-energy effective BF theories. In the average field approximation, the corresponding uniform emergent charge creates a gap for the $(D-2)$-dimensional branes via the Magnus force, the dual of the Lorentz force. One particular combination of intrinsic and emergent charge fluctuations that leaves the total charge distribution invariant constitutes an isolated gapless mode leading to superfluidity. The remaining massive modes organise themselves into a D-dimensional charged, massive vector. There is no massive Higgs scalar as there is no local order parameter. When electromagnetism is switched on, the photon acquires mass by the topological BF mechanism. Although the charge of the gapless mode (2) and the topological order (4) are the same as those of the standard Higgs model, the two models of superconductivity are clearly different since the origins of the gap, reflected in the high-energy sectors are totally different. In 2D this type of superconductivity is explicitly realised as global superconductivity in Josephson junction arrays. In 3D this model predicts a possible phase transition from topological insulators to Higgsless superconductors.

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1. Introduction

Anyon superconductivity [1] was briefly very popular in the early 90s as a possible mechanism for the high-T_c cuprates. The idea, based on the possibility of fractional statistics [1] in 2 space dimensions (2D), involves fermions interacting with a fictitious, statistical Chern–Simons (CS) gauge field [2] which turns them into anyons by attaching magnetic flux to their charge density. In the average field approximation the fermions feel a collective, uniform fictitious magnetic field. If the Chern–Simons coupling constant is chosen so that an integer number of Landau levels are filled, the fermion state has a gap. A specific coherent fluctuation of the fermion density *together* with the statistical gauge field, however, is gapless. This massless mode is protected from decaying into particle–hole excitations by the average field gap and leads to anyon superfluidity. It can be shown that the origin of the massless mode is not the spontaneous breaking of a symmetry but, rather, the necessary restoration of the commutativity of translations which is broken in the average field approximation [3]. The most studied case is that of two filled Landau levels, corresponding to semions, or half fermions since, in this case, the charge order parameter of the resulting superconductor is 2 [1]. Unfortunately, the high-T_c cuprates do not exhibit the P and T violations necessarily implied by the superconductivity mechanism based on anyons and thus the idea of anyon superconductivity was quickly abandoned.

In this paper we revisit the anyon superconductivity mechanism to show that it can be made P- and T-invariant and extended to three space dimensions (3D), where it can be realised upon a phase transition from topological insulators [4]. To this end we start from the pure gauge formulation of [5]. We do not consider the usual case of semions (half-fermions) but, rather, we concentrate on the simple case in which the statistical interaction turns the fermions into bosons. By soldering together two fermion fluids of opposite spin, interacting with the same fictitious statistical gauge field and filling their respective first Landau levels in the average field approximation, one obtains a single gapless mode with charge 2. The remaining degrees of freedom organise themselves into a massive *vector* particle (with two polarisations in 2D) of unit charge, rather than a single neutral, scalar Higgs boson. This massive vector is described by two Chern–Simons terms of opposite parity and the same absolute value of the coupling constant. The P and T symmetries are preserved.

We show that this type of P- and T-invariant Higgsless superconductivity can be reformulated by a rotation of the degrees of freedom as a charge and a vortex fluids interacting with each other by a mutual Chern–Simons term. The vortices interact additionally with a pseudovector statistical gauge field which, however, has no self-action. In this formulation, superfluidity arises as follows. In the average field approximation the statistical gauge field provides a uniform charge for the vortices. A charge arises instead of a magnetic field as in standard anyon superconductivity since here the statistical gauge field is a pseudovector. Note, however, that this emergent charge has to be distinguished from the intrinsic charge coupling to real electromagnetic fields, as has been stressed in [6]. The vortices are subject to the Magnus force [7], which, in 2D, is the exact dual of the Lorentz force and they are thus quantised into (dual) Landau levels. When an integer number of Landau levels is filled the vortices have a gap; this happens in particular for the ground state configuration with no vortices at all. This gap for vortices is nothing else than the Meissner effect. Due to the mutual Chern–Simons term, a generic intrinsic charge fluctuation corresponds to a local variation in the charge distribution felt by the vortices. Exactly as in the original mechanism of anyon superconductivity, this must be accompanied by an excitation of vortex–antivortex pairs through the Landau level gap [8]. Generic intrinsic charge fluctuation are thus also gapped. If, however, the intrinsic charge fluctuation is accompanied by an emergent charge fluctuation such