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Vortex solutions and a novel role for R-parity in an $N = 2$-supersymmetric extension of Jackiw–Pi's chiral gauge theory

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ABSTRACT

In a previous work, we have been able to settle Jackiw–Pi's chiral gauge theory (CGT), originally proposed to describe Dirac fermions in graphene, in an $N = 1$ supersymmetric framework using a τ_3-QED prescription, defined by means of a single pair of gauge charged superfields, but without preserving a global phase symmetry associated, in the CGT, to the electric charge. In the present work, we propose another $N = 1$-generalisation which indeed preserves this symmetry, namely, a straightforward extension built upon a set of two pairs of (chiral) gauge-charged superfields plus an extra pair of electrically neutral superfields. We then further proceed to establish, via a dimensional reduction procedure, an $N = 2$ extension, allowing for the identification of non-perturbative

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features, as we put forward Bogomol'nyi equations and obtain vortex-like solutions saturating a topologically non-trivial bound. Remarkably, the bosonic projection of the $N = 2$ functional space onto the saturated regime analysed herewith reveals to be free from extra scalar degrees of freedom that would otherwise demand a phenomenological interpretation. The investigation of Jackiw–Pi's model within an $N = 2$ complex superspace is also motivated by the assumption that an R-parity-like symmetry could provide a route to incorporate the global phase-fermion number invariance as an external-like symmetry of the theory, thus associating electric charge in the CGT to the complex covariance (super-) space for the $N = 2$-D $= 3$ setup. We prove such a hypothesis to be realisable, as we build up the model endowed with all the symmetries required to further extend Jackiw–Pi's chiral gauge theory.

1. Introduction

As we have already done in Ref. [1], the chiral gauge model proposed by Jackiw–Pi [2] and other co-authors [3,4] to describe electrons in graphene is readdressed herewith as we seek for the enlargement of the set of defining symmetries. We propose supersymmetry (SUSY), an approach already presented in Ref. [1], but now with emphasis on analysing the $N = 2$-extension and on the realisation of the full set of symmetries defined in Jackiw et al.'s theoretical setup. With this purpose, we discuss the invariances of our $N = 2$-supersymmetric model, paying special attention to the (local) Jackiw–Pi's chiral gauge symmetry and the global phase symmetry, the latter initially proposed by Jackiw and co-authors to be associated to the electric charge of the electron. In this paper, we show that the global phase symmetry can be realised through an inherent $N = 2$-superspace-structure R-parity-like invariance, thus establishing an interesting connection between the conservation of the electric charge and an external (super-)space symmetry.

We also perform a phenomenological approach, as we work on finding vortex solutions. The relationship between SUSY and BPS-vortex solutions was proven in Refs. [5–8], where Bogomol'nyi equations emerge if half of the supersymmetries have the corresponding generator action onto the fields leading to a null result. By these means, we succeed to find vortices (also found in Jackiw–Pi's model), a numerical outcome of dual first-order differential equations that stem from null susy-transformation of fermions for just one susy-charge, as presented in detail in the sequel. Thus, as illustrated in the present work, SUSY may also be viewed as a possible theoretical mechanism on its own merit, to be used with the simple purpose of obtaining vortex solutions without any need of an a priori interpretation of superpartner fields. In this sense, it is very interesting that, for the specific BPS state obtained herewith, extra bosonic superpartners inherent to the SUSY-extension are shown to vanish, thus suppressing any need for interpreting them, if only the vortex solution is to be considered.

The present work is organised as follows: we shall review, in the next Section, some basic facts about the mentioned chiral gauge theory and, in Section 3, we shall set up the main aspects of its $N = 1$ supersymmetric generalisation, as done in the work of Ref. [1]. We then present an alternative $N = 1$ SUSY model augmented by an extra pair of $N = 1$ scalar superfields, and we discuss the features that distinguish the two proposals. Then, in Section 4, we shall explicitly build up an $N = 2$-supersymmetric action in $(2 + 1)$-dimension space–time, obtained as the result of a dimensional reduction procedure performed upon a suitable $N = 1$-D $= 3 + 1$ supersymmetric theory. We also present the proper R-Parity prescription that plays the role of the fermion number/electric charge global symmetry. We conclude Section 4 by exhibiting the $N = 2$-D $= 3$ SUSY functional that extends the action of Ref. [2], with full realisation of the complete set of proposed symmetries. In Section 5, Bogomol'nyi equations and corresponding vortex solutions are obtained, and numerical simulations are presented. Finally, conclusions and perspectives are depicted in the last Section.