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Kinklike structures in models of the Dirac–Born–Infeld type

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ABSTRACT

The present work investigates several models of a single real scalar field, engendering kinetic term of the Dirac–Born– Infeld type. Such theories introduce nonlinearities to the kinetic part of the Lagrangian, which presents a square root restricting the field evolution and including additional powers in derivatives of the scalar field, controlled by a real parameter. In order to obtain topological solutions analytically, we propose a first-order framework that simplifies the equation of motion ensuring solutions that are linearly stable. This is implemented using the deformation method, and we introduce examples presenting two categories of potentials, one having polynomial interactions and the other with nonpolynomial interactions. We also explore how the Dirac–Born–Infeld kinetic term affects the properties of the solutions. In particular, we note that the kinklike solutions are similar to the ones obtained through models with standard kinetic term and canonical potential, but their energy densities and stability potentials vary according to the parameter introduced to control the new models.

1. Introduction

Topological defects are localized structures that appear in several branches of physics. They are of interest in particular in high energy physics [1,2], where they may have implications in the evolution of the Universe during phase transitions and in other scenarios, and also in condensed matter systems [3,4], where they may appear to model interfaces intersecting distinct regions of the space. Among the diversity of defects that arise in classical field theories, the one-dimensional

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static solutions of equations of motion described by scalar fields, known as kinks, are the simplest topological structures, which have been studied by several authors; see, e.g., Refs. [1–12]. For instance, kink structures may be employed in the study of kink–antikink pairs production from particle scattering [5] and in investigations involving kink–antikink collisions [6,7]. They are also important to researches based on braneworld scenarios, accompanied by the thick or compact profile, with a single extra dimension of infinite extent [8–11]. Besides, they have been studied within the context of theories with modified kinematics with other motivations [12].

Scalar field theories with nonstandard kinetic term admit the presence of topological structures, also known as k-defects, that lead to interesting consequences for several physical situations [13–22]. For instance, in Refs. [13,14], general topological properties of k-defects and k-vortices, where the gauge field is preserved in its canonical form, were discussed in connection with cosmological applications. In this case in particular, the nonlinearities there introduced by the kinetic term lead to the presence of a new mass scale which might alter some characteristics associated to the formation of cosmic strings during phase transitions in the early universe. In Refs. [15,16] the authors develop a study containing the linear stability of defect structures with modified profile, including the presence of compactons [17,18,20], that is, of solutions with compact support [19]; similar modifications are also analyzed in the braneworld contexts in Refs. [21,22].

Another interesting issue arises when the kinetic term is specifically of the Dirac–Born–Infeld (DBI) type [14,23–27]. Originally, the DBI theory was introduced to eliminate problems with divergence of electron self-energy in classical electrodynamics [28]. Posteriorly, such reasoning passed to be explored in studies involving fields with unusual kinetic terms; for example, it has been used for the construction of instanton solutions [25], for the considerations of global strings [23], for the description of global vortex solutions [14,24], for the representation of twinlike models which develop through distinct systems supporting exactly the same topological structure [26], and also for the formulation of models admitting soliton solutions [27]. Following these lines, the present paper consider a modification on the field dynamics, where the kinetic part is DBI-like, and we study the existence of kinklike defects for several new models not yet investigated in the literature. Generally, these kinds of modifications add new nonlinear terms to the Lagrangian and make the study very complicate to be solved exactly; nevertheless, the aim of the current work is to solve analytically the equations of motion ensuring the presence of defect structures and discuss some of their features, such as the energy density and stability potential.

To achieve these goals we establish a first-order framework that simplifies the equations of motion, in a way compatible with the description given by Bogomoln'yi–Prasad–Sommerfeld (BPS) [29]. We adopt the deformation procedure [30] developed to help us to search for exact solutions in systems with generalized dynamics [20]. This method has been successful in providing results concerning the presence of analytical solutions for physical problems engendering nonlinear dispersion [20] and so it will be useful here. In this work we deal with two categories of scalar field models, one described by polynomial self-interactions and the other by nonpolynomial ones.

In order to explore how the DBI kinetic effects modify the properties of the topological solutions, we organize the work as follows. In the next section, we review the general formalism for a field theory with nonstandard kinetic term. In Section 3 we specify the field dynamics consistently with the DBI concept. We suggest a first-order treatment which solves the equation of motion and ensures the linear stability of the solutions. Also, in order to explore further potentials we incorporate the deformation procedure. In Section 4 we present several examples of DBI models, engendering polynomial and nonpolynomial interactions. There, all the solutions are found exactly and their main characteristics are studied in details. We also note that, if the parameter which regulates the high-order powers in the derivatives of ϕ is very large, then the outcome can be compared with the corresponding standard theory. We end the work including our comments and conclusions in Section 5.

2. Generalized formalism

We start dealing with a generalized theory of a real scalar field, described by the Lagrangian density

$$\mathcal{L}(\phi, X) = F(X) - V(\phi), \tag{1}$$