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Analytic superconducting tubes

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Abstract

We show a formalism that allows to construct analytical solutions describing superconducting tubes as solutions of two relevant theories, both from a theoretical and phenomenological point of view; scalar electrodynamics and the Skyrme model. First, we show that the equations for a charged scalar field admit kink solutions propagating through a superconducting cylinder without the need to introduce external fields. These solutions can be interpreted as self-sufficient long-standing excitation that, in principle, could be built in nanotubes of twisted bi-layer graphene. Second, we construct superconducting tubes with arbitrary topological charge in the Skyrme model. These are appropriate for describing states of nuclear pasta, that is, crystalline structures of degenerate matter at high densities, which are expected to exist inside neutron stars.

Main results

Soliton solutions describing superconducting tubes can be constructed in relevant field theories using as fundamental ingredients ansätze that go beyond spherical symmetry, including light-like degrees of freedom and coupled to $U(1)$ gauge fields describing a force free plasma (FFP). We present the first topologically non-trivial analytical solutions of crystals of superconducting tubes in three spatial dimensions as solutions of Skyrme theory; a model that represents the low energy sector of Quantum Chromodynamics [1-3]. The electromagnetic field generated by these solitons has two very relevant characteristics. The first is that the generated current has a superconducting character; even if the Maxwell potential vanishes, the current cannot be zero because it is topologically protected. The second characteristic is that these crystals are natural sources of FFP. In fact, the electromagnetic field strength satisfy the so-called FFP condition, being the FPP type configurations one of the most important types in plasma physics. In particular, these are fundamental in many astrophysical situations.

A similar construction can be carried in scalar electrodynamics, where the electromagnetic field of the solitons is transported in a two-dimensional cylinder [4]. We show the main physical properties of both configurations and outline possible future applications.

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References

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