

Induced Vacuum Magnetic Flux in the Background of a Linear Topological Defect. The case of fermion matter

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In many theoretical models describing the evolution of the early Universe, topological defects appear, in particular in the form of magnetic cosmic strings [Vil]. String models are used not only in the physics of the early Universe, but also in the physics of hadrons and continuous media. In particular, structures analogous to cosmic strings arise in the theory of superconductivity. Here, they are associated with Abrikosov vortices - tubes of magnetic flux in superconductors of the second kind at a temperature below the critical temperature. We will consider a model of the topological defect (magnetic cosmic string) as an impenetrable for the fermion matter field tube with a magnetic field inside. A certain boundary condition must be imposed on the surface of the magnetic tube, which is impermeable to the fields, to model the cosmic string. The peculiarity of fermionic matter is that this boundary condition cannot be the usual Neumann, or Dirichlet, or Robin condition. In this case, the condition of self-adjointness of the Dirac Hamiltonian should be applied.

An important effect is the induction of a magnetic flux outside the magnetic cosmic string in the vacuum of fermion matter. Theoretical study of this process allows one to constrain the values of boundary conditions parameters. Since analytical solutions for this process are extremely complex, numerical modelling is necessary for their analysis, which is the subject of this work.

It has been shown previously that in $2 + 1$ space-time [Sit2019], a straight magnetic cosmic string of non-vanishing transverse size induces a magnetic field in the vacuum of the quantum relativistic charged spinor matter field. The corresponding analytical dependencies for the induced magnetic flux were obtained for $3 + 1$ space-time [Sit2021]. However, the analytical dependencies, which are quite complex for analysis even in $2 + 1$ space-time, in the case of generalization to 3 spatial dimensions, become prohibitively complex for direct calculation and analysis. Therefore, the analysis of the obtained dependencies and the exclusion of non-physical boundary conditions on their basis is an independent problem for numerical calculations.

Directly integrating the corresponding expression has shown to be highly challenging due to its complexity, so it was decided to find a similar function that would be easier to integrate. To do this, we first find the interpolation function and then extrapolate it. As a result, we investigate the induced magnetic flux in the vacuum of a fermionic field in the background of a magnetic cosmic string, and compute it. For the case of boundary condition self-adjoint extension parameter $\theta = 0$, it was shown that the induced magnetic flux in $(3 + 1)$ -dimensional space-time (in dimensionless units) is significantly larger than in $(2 + 1)$ dimensions for small values of the tube radius, specifically with tube thickness $mr_0 < 0.16$, see Fig.1.

The requirement that the total induced vacuum flux be finite restricts the set of admissible boundary conditions to a single choice: the MIT bag boundary condition, self-adjoint extension parameter $\theta = 0$. In contrast, the case $\theta = \pi$, which yields a finite induced magnetic flux in $(2 + 1)$ -dimensional space-time, leads to an infinite induced flux in $(3 + 1)$ dimensions. All other values of the self-adjoint extension parameter θ are nonphysical and lead to infinite induced magnetic flux in the vacuum of the fermion matter field.

\begin{figure}[t]\centering

\includegraphics[width=0.95\columnwidth]{Fig1.png}

\caption{Induced vacuum magnetic flux in dimensionless units in $2+1$ space-time ($em^{-1}\Phi_1^{(d=2)}$), and in $3+1$ space-time $e\pi\Phi_1^{(d=3)}$ as function of the tube thickness mr_0 for the case of boundary condition self-adjoint extension parameter $\theta = 0$.}

\label{pic1}

\end{figure}

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Primary author: Mrs ПИЛИПЧУК, Юлія (Educational and Research Institute of Physics and Technology, National Technical University of Ukraine \ «Igor Sikorsky Kyiv Polytechnic Institute)

Co-authors: Mr НАКАЗНИЙ, Павло (Educational and Research Institute of Physics and Technology, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute»); Prof. ГОРКАВЕНКО, Володимир (Faculty of Physics, Taras Shevchenko National University of Kyiv)

Presenter: Mrs ПИЛИПЧУК, Юлія (Educational and Research Institute of Physics and Technology, National Technical University of Ukraine \ «Igor Sikorsky Kyiv Polytechnic Institute)

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