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Z_2 x Z_3 Symmetry of Multferroic Vortices

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Hexagonal $REMnO_3$ (RE= rare earths) with RE=Ho-Lu, Y, and Sc, is an improper ferroelectric where the size mismatch between RE and Mn induces a trimerization-type structural phase transition, and this structural transition leads to three structural domains, each of which can support two directions of ferroelectric polarization. We reported that domains in h-$REMnO_3$ meet in cloverleaf arrangements that cycle through all six domain configurations, Occurring in pairs, the cloverleafs can be viewed as vortices and antivortices, in which the cycle of domain configurations is reversed. Vortices and antivortices are topological defects: even in a strong electric field they won't annihilate. These ferroelectric vortices/antivortices are found to be associated with intriguing collective magnetism at domain walls, reflecting the multiferroic nature of vortices. We have found that an intriguing, but seemingly irregular network of a zoo of multiferroic vortices and antivortices in h-$REMnO_3$ can be neatly analyzed in terms of graph theory, and this graph theoretical analysis reveals the emergence of $Z_2 \times Z_3$ symmetry in the vortices/antivortices network. In addition, poling or self-poling due to a surface charge boundary condition induces global topological condensation of the network through breaking of the Z_2 part of the $Z_2 \times Z_3$ symmetry. The opposite process of restoring the Z_2 symmetry can be considered as topological evaporation. It turns out that these Z_2xZ_3 vortices are, in fact, three-dimensional vortex loops, which result from the emergent continuous U(1) symmetry near the critical temperature. This spontaneous trapping of topological defects in the process of undergoing a continuous phase transition is important to understand numerous novel phenomena such as the early stage of universe after big bang. The so-called Kibble-Zurek mechanism was proposed for the trapping process of topological defects right after big bang. It appears that the Kibble-Zurek mechanism is also responsible for the network formation of multiferroic vortices, and thus, hexagonal $REMnO_3$ is a test bed for the birth of this cosmos.