Protection of the surface states in topological insulators: Berry phase perspective

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Topological insulator is a newly established exotic state of matter that has been intensively discussed in the field of condensed-matter nanophysics since the last couple of years. Though it is undistinguishable from ordinary band insulators in the bulk in the sense it has a gapped spectrum with its Fermi energy lying in that gap, on the surface it exhibits a protected gapless state, i.e., it behaves like a metal on its surface. The central issue that has been discussed so far was on the existence of such a metallic surface state protected by the topological non-triviality of the gapped bulk band structure.

Here, we attempt to clarify the remaining question, "why does such a gapless state appear only on the surface?" In the lattice implementation of a topological insulator, one may be able to regard, e.g., an atomic-scale isolated closed object, like a cubic bubble in the bulk, or an atomic-scale rectangular-prism-shaped hole also as a surface (see FIG. 1). However, we know from (numerical) experiments that the protected surface state appears only on its macroscopic surfaces even in the case of sparse lattice systems, exhibiting no symptom of penetrating into the bulk. Why is the surface state non-invasive [1] into the bulk? What prevents it from penetrating into the sparsely filled interior of the lattice models? We will argue that this is a consequence of the Berry phase pi associated with the spin connection characteristic to the topological insulator surface states (see FIG. 2).

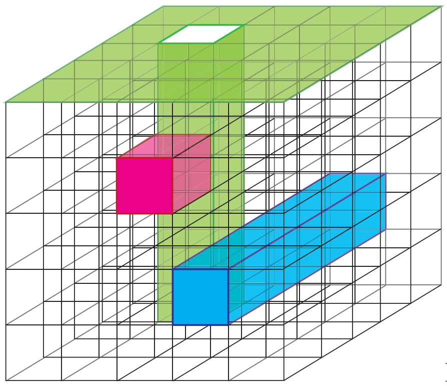
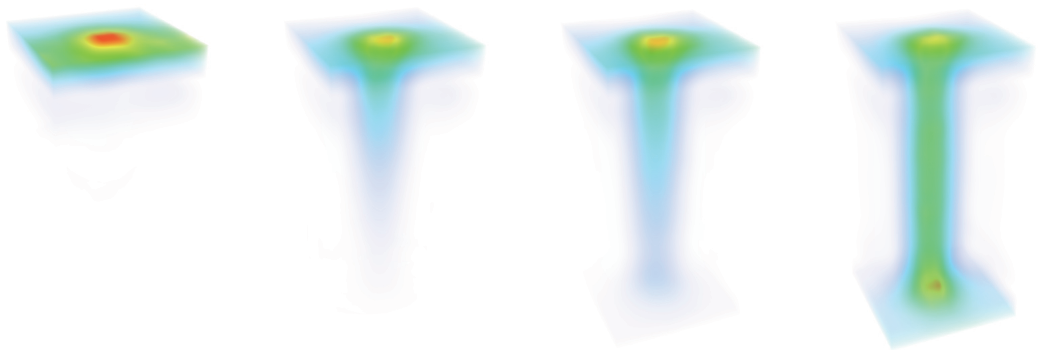


FIG. 1



$\Phi = 0.7\pi$ $\Phi = 0.9\pi$ $\Phi = 0.95\pi$ $\Phi = \pi$

FIG. 2 The surface state tends to penetrate into the bulk along an external flux Phi cancelling the Berry phase pi.

[1] K.-I. Imura, Y. Takane, arXiv:1211.2088.