Thermodynamics of finite-size systems

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In the last decade, the research on topological insulators (TIs) attracted much attention and culminated with the Nobel prize awarded to Kosterlitz, Thouless, and Haldane [1]. Topological insulators are materials that host symmetry-protected metallic edge states in an insulating (superconducting) bulk. Although they are well understood, a thermodynamic description of these materials remained elusive, firstly because the edges yield a non-extensive contribution to the thermodynamic potential, and secondly because topological field theories involve non-local order parameters, and cannot be captured by the Ginzburg-Landau formalism. Recently, this challenge has been overcome by using Hill thermodynamics [2].

Here, we show how to thermodynamically describe different topological models, such as the Kane-Mele [3] model for graphene in two dimensions, at zero temperature and how to calculate measurable quantities such as the heat-capacity and the density of states separately for the bulk and boundary. Moreover, we derive the topological phase diagram at finite temperatures using this thermodynamic description, and show that it displays a good agreement with the one calculated from the Uhlmann phase [4].

References

[1] The Nobel Prize in Physics 2016. Nobelprize.org. Nobel Media AB 2014.
[2] Quelle, A., Cobanera, E. & Morais Smith, C.T, PRB, 94 (2016).
[3] Kane, C.L. & Mele, E.J. PRL 95 (2005).
[4] Viyuela, O., Rivas, A. & Martin-Delgado, M.A., PRL 112 (2016).

Figures

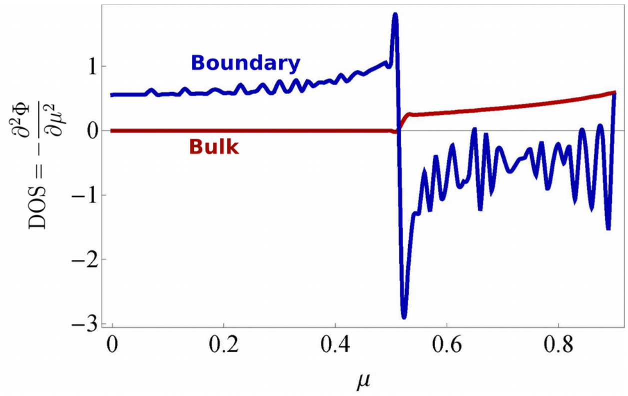

Figure 1: The thermodynamically calculated density of states (DOS) in the topological phase for the bulk (red) and boundary (blue) of the Kane-Mele model. Due to the presence of the edge states, we observe a finite density of states at the boundary before the first conduction band (μ <0.52), that drops to zero (noise) within this band. The DOS of the bulk is zero within the bulk gap, and becomes finite in the first conduction band.

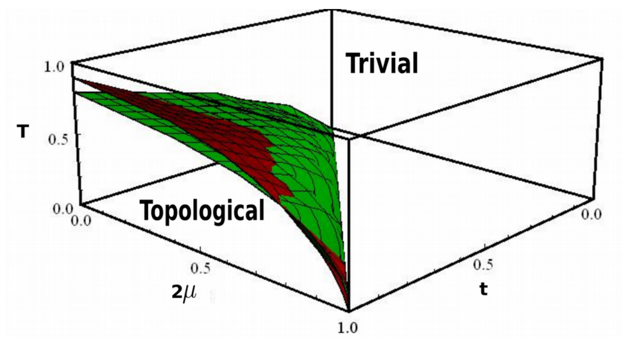

Figure 2: Finite-(low)temperature phase diagram of the superconducting Kitaev chain. The red curve is a result from the thermodynamic analysis, and the green curve is an analytical result obtained via calculating the geometric Uhlmann phase (a finite-temperature extension of the Berry phase) [4]. The results, obtained from two very different approached, give rise to the same phase diagram.