An apparent macroscopic violation of the second law of thermodynamics in a quantum system

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Researchers at UCM and CSS have encountered a partial violation of the second law of thermodynamics in a quantum system known as Hofstadter lattice. This partial violation has no place within the framework of classical physics.

A Hofstadter lattice is a theoretical model with a square two-dimensional network through which quantum particles like electrons or photons circulate. Moreover, when one of these particles completes a closed path in the network, the particle acquires a quantum phase.

This system models a class of two-dimensional materials (similar to graphene) with properties so unusual that they are outside the typical classification of conductors or insulators, and are instead described as topological insulators.

One of the most striking properties displayed by this system is the presence of edge currents, while the interior does not allow for any conduction. In addition, these edge currents are remarkably strong even in the presence of impurities in the material, which has put them on the scientific community's radar for applications in spintronics, photonics and quantum computing.

In an article published in the journal *Scientific Reports*, researchers Ángel Rivas and Miguel A. Martin-Delgado of the Department of Theoretical

Physics at UCM and CCS explain that they have studied the thermodynamic properties of this system by placing it in the presence of two heat sources, one hot and one cold. To do so, they have formulated a quantum theory that describes this situation and solved the dynamical equations.

What predicts the theoretical calculations is that the transport of heat presents a behavior far beyond the typical features of classical thermodynamics. Specifically, on one edge of the material a current is induced that flows from a cold spot to a hot spot. This is contrary to thesecond law of thermodynamics, under which it is not possible for heat to flow spontaneously from a cold body to a warmer one.

From a technological point of view, the second law of thermodynamics limits the practical energy efficiency of devices such as engines, batteries, refrigerators, solar cells, etc.

A Partial Violation

However, when the remainder of the edges and the interior of the material are taken into account, the second law is restored. This "partial" violation is an effect of this type of exotic quantum system that does not fit within the framework of classical physics.

Furthermore, these currents also display robustness to the presence of impurities that observe certain symmetry patterns related to the position of the thermal sources and the dissipative dynamics they induce.

This new phenomenon, called "dissipative symmetry-protection," has never been observed before and could give rise to new applications that are not only interesting but of practical utility.

The research takes places within a quantum simulation framework, a discipline that seeks to study such materials through artificial devices with similar characteristics obtained by quantum control techniques, such as photonic networks and ultra-cold atoms.

These results will lead to new and unexpected applications in the development of quantum technologies, such as quantum simulators or quantum memories, presenting more stability and operating under realistic conditions subject to temperature fluctuations.

More information: Ángel Rivas et al. Topological Heat Transport and Symmetry-Protected Boson Currents, *Scientific Reports* (2017). DOI: 10.1038/s41598-017-06722-x

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