Physicists build quantum refrigerator based on four quantum dots

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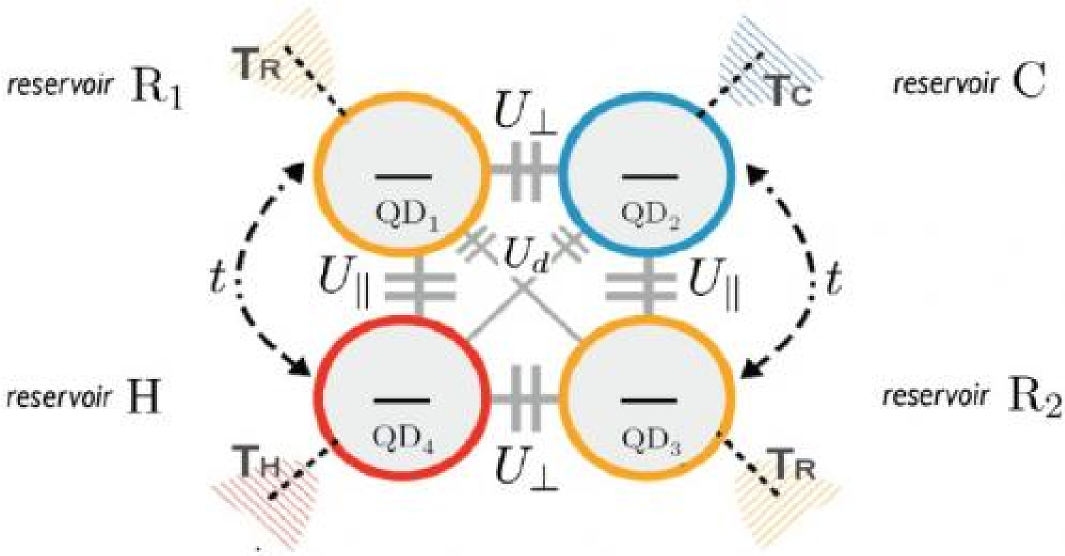

The proposed quadridot consists of four quantum dots that are weakly coupled to four thermal reservoirs. Scientists have theoretically shown that the quadridot can pump energy from the hot and cold reservoirs to the two room temperature reservoirs, thus cooling the quantum dot coupled to the cold reservoir to make it even colder than before. Credit: Venturelli, et al. ©2013 American Physical Society

(Phys.org) —With the goal of understanding the relation between thermodynamics and quantum mechanics, physicists have recently been investigating the fundamental limits of the smallest possible quantum refrigerator. As a refrigerator, the device must be able to transfer heat from one reservoir to another. In a new study, physicists have proposed a quantum refrigerator consisting of just four quantum dots, each in contact with a thermal reservoir. They theoretically show that this system can extract heat from the coldest reservoir and cool the nearby quantum dot, making it one of the smallest quantum refrigerators proposed to date.

The physicists, Davide Venturelli, Rosario Fazio, and Vittorio Giovannetti at the Scuola Normale Superiore in Pisa, Italy, have published their paper on the minimal quantum refrigerator in a recent issue of *Physical Review Letters*. Venturelli is also with the NASA Ames Research Center in Moffett Field, California, and Fazio and Giovannetti are also with the National Enterprise for nanoScience and nanotechnology (NEST) in Pisa.

The proposed system consists of four quantum arranged in a square configuration, which the researchers call a "quadridot." The scientists theoretically showed that this quadridot acts as a quantum refrigerator when coupled to four independent reservoirs (one hot, one cold, and two of intermediate temperature). The quadridot pumps energy in the form of electrons from the hot reservoir and the cold reservoir to the intermediate-temperature reservoirs. When properly tuned, the quadridot can cool the quantum dot in contact with the cold reservoir to a temperature that is lower than its original temperature.

This configuration overcomes one of the biggest difficulties in realizing self-contained quantum refrigerators, which is engineering the interaction among the hot-, cold-, and intermediate-temperature reservoirs. The quantum dot array provides a relatively simple way to achieve this three-body interaction that may be possible to experimentally realize in the future.

"At present, ours is only a theoretical proposal which is meant to prove that one such device can in principle be realized with current technology," Giovannetti told *Phys.org*. "We have, however, started talking with experimentalists from the NEST laboratory of Pisa to see how feasible it would be to implement our scheme. The main difficulty at present is associated with the low heat flux that we can produce in the system (indeed, even if the efficiency is theoretically high, the net flux the device can afford is small), and with the presence with 1/f noise introduced by the contacts in the model.

"At the theoretical level, we are currently trying to optimize the system performances by including in the analysis extra degree of freedom (e.g., the chemical potentials of the device's reservoirs, which for the moment were simply assumed to be degenerate)."

Understanding how thermodynamics works at the quantum level could lead to the ability to control heat transport in nanodevices, which could play a role in a wide variety of future nanoelectronics applications.

More information: Davide Venturelli, et al. "Minimal Self-Contained Quantum Refrigeration Machine Based on Four Quantum Dots." *PRL* 110, 256801 (2013). DOI: 10.1103/PhysRevLett.110.256801