Cooling by Powering the Quantum Hall Effect

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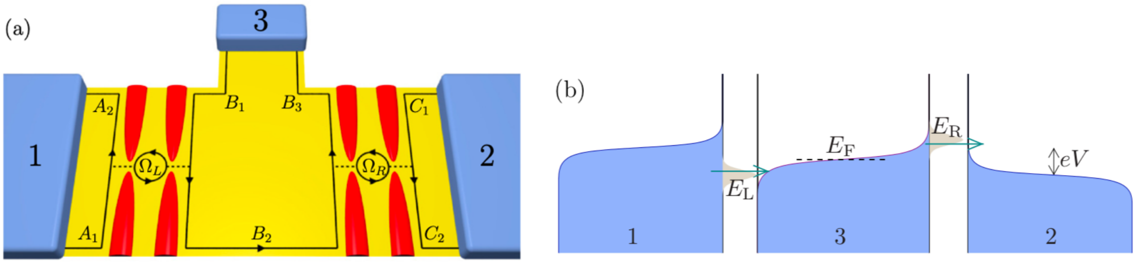
One of the main goals of quantum thermodynamics is the creation of energy harvesters and coolers working in nanometer scales. Thermoelectric phenomena could lead to efficient devices operating at very low temperatures, especially when charge and heat currents can be spatially separated. One can use chirality induced by external magnetic fields in quantum Hall conductors to effectively decouple energy and particle fluxes. We propose a multiterminal two-dimensional chiral conductor to work as a refrigerator with good coefficient of performance [1]. Our results suggest that the device would be able to cool by 60 mK when the base temperature is 150 mK, thus paving the way to the employment of chiral coolers in nanochips.



Our proposal is depicted in the panel (a) above. The setup consists of a two-dimensional electron gas (the yellow region) attached to three fermionic baths (blue regions). Baths 1 and 2 are current terminals while bath 3 is a voltage probe whose electrochemical potential adjusts itself to maintain zero net current. Due to the presence of a perpendicular magnetic field (not shown here), electrons move along edge channels with well defined propagation direction (black lines). Key to our proposal is the energy-dependent scattering induced by two quantum dots (left L and right R) generated by the finger gates indicated with the red regions. The dots are energy filters when their energy levels are tuned in an appropriate way, as sketched in panel (b). Thus, electrons injected from bath 1 occupy states in bath 3 below the Fermi energy whereas thermally excited electrons in the same bath are extracted into bath 2. As a consequence, the third bath becomes cooled carrying no charge current, which minimizes the Joule dissipation. Our analysis fully takes into account the nonlinear regime of transport within a scattering-matrix formalism. We find the optimal cooling conditions and give a physically intuitive interpretation, namely, the thermopowers of L and R dots should have opposite signs for the device to work. Moreover, our theory predicts that there exists an optimal value of the applied voltage that minimizes the temperature measured at the cooled bath. The optimal value can be also manipulated by varying the coupling between the dots and the edge states, which gives to our device great power and tunability.

[1] D. Sánchez, R. Sánchez, R. López, and B. Sothmann, Phys. Rev. B **99**, 245304 (2019).