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Energy conversion at the nanoscale: exploiting non-thermal resources

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Nanoscale engines are becoming increasingly common, manifested for example in on-chip processors that transduce energy and particles between reservoirs to perform tasks like cooling. However, when compared to macroscopic energy-transducing engines, quantum thermoelectric devices might operate on time and length scales where their environmental energy reservoirs cannot be accurately described by well-defined thermal distributions. As a result, the reservoirs are not characterized by a specific temperature or chemical potential. Furthermore, due to this time and spatial miniaturization, fluctuations in the resulting energy and particle flows become significant.

Instead of conforming to a thermal picture, we propose to use the non-thermal nature to create devices which are potentially more efficient and precise than their thermal counterparts.
In response to these challenges, we aim to investigate the energy and particle transduction of a prototype thermoelectric device operating between a non-thermal and thermal reservoir. Assuming ideal coherent quantum transfer, particle and energy flows will be examined using scattering theory.

First, by addressing specific tasks such as efficiently cooling a reservoir with minimal resources, we will propose and define performance metrics to achieve these objectives. In the presence of a non-thermal environment, the traditional categorization of energy into heat and work is no longer applicable. Consequently, we will quantify the non-thermal resources required to accomplish the task through entropy currents and the provided non-equilibrium free energy.

Second, we will optimize these metrics based on defined tasks such as cooling power for reservoir cooling and/or minimizing particle current noise during task execution by designing optimal particle transmission between the reservoirs. The proposed procedure leads to a transmission filter between the reservoirs determined by the shape of the non-thermal distribution.

These procedures serve as an initial exploration into characterizing and utilizing non-thermal resources, which may encourage a broader discussion on the use of non-standard resources to accomplish unconventional tasks in various fields of physics and nanoscience.

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