Quantum thermodynamics with nanospintronic devices

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In recent years there has been an increasing interest in the thermodynamics of nanoscopic systems operating far from equilibrium [1]; this is due to both their fundamental importance (e.g., in biochemical processes occurring in cells) and their possible applications (e.g., as thermoelectric devices converting heat into work). In particular, the studies of such systems facilitated the discovery of new physical laws describing the universal properties of thermodynamic fluctuations (e.g., fluctuation theorems) as well as revealed a deep connection between thermodynamics and information theory. Nanoelectronic systems have been found to be attractive candidates for the study of thermodynamic phenomena occurring at the nanoscale level due to ease of control of their parameters and relative simplicity of their theoretical description [2]. However, the role of electronic spin in nanoscopic thermodynamic processes has been so far largely unexplored.

Here I show that the spin degree of freedom can be utilized to investigate novel thermodynamic phenomena. This is demonstrated on the example of nanospintronic devices based on quantum dots attached to spin-polarized leads. The first part of my presentation shows that the coherent spin dynamics, induced by an external magnetic field, can be used to reduce the power fluctuations in thermoelectric generators, thus improving the stability of their operation [3]. Most notably, the fluctuations can be reduced below the lowest value allowed for incoherent systems by a so called thermodynamic uncertainty relation [4]. The second part shows that the system of two exchange-coupled quantum dots can be used to realize a Maxwell's demon-like behavior: one dot can cool down its environment with a uniform temperature, converting heat into work, without the energy transfer to the second dot [5]. This paradox, apparently violating the second law of thermodynamics, can be solved by relating the entropy transfer between the dots to the information carried by a spin current; a quantitative description of such a phenomenon can be provided by means of a quantum information theory [6].

References:

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This work has been supported by the National Science Centre, Poland, under the Project No. 2016/21/B/ST3/02160.