PhD project: Investigating the thermodynamic cost of Quantum Information Processing tasks with a nanomechanical platform

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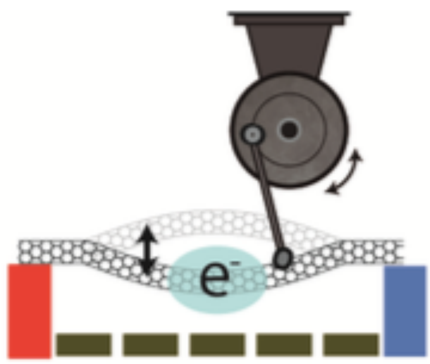
This is a theoretical physics PhD project based at the University of Exeter to start in autumn 2020.

Background: Landauer showed that information processing tasks are not thermodynamically neutral, quite the contrary: erasure of bits of information when in an environment at temperature *T* requires thermodynamic work, and this energy is dissipated as heat in the erasure process [1]. The fundamental realization that information is linked to physical laws, such as the laws of thermodynamics, was the starting point for the development of quantum information theory. However, the link between *quantum* information processing tasks and thermodynamics is only now being fully made. Quantum thermodynamics is a new research field where thermodynamics is studied in the small-system size limit where fluctuations become non-negligible, weak coupling between system and environment cannot be assumed, and a fully quantum mechanical description may be needed [2].

Project: This project is concerned with building theoretical models and predictions to quantify the thermodynamic work needed to perform certain quantum information processing tasks, such as Landauer erasure [1] and work extraction from coherences [3]. The aim of this project is to develop the theoretical understanding of work extraction from coherence for new experimental platforms on which these predictions can be tested, and answering if and when thermodynamic cycles could benefit from making use of coherences. A particular experimental platform that we will focus on is a new nanomechanics experiment that is being built by Dr Natalia Ares' group [4]. Regular visits of the Exeter theory PhD student to the experimental group in Oxford, as well as visits to the other team members in Grenoble/Madrid, will be part of the PhD project.

The experimental platform being set up in Oxford, see Figure, combines the mechanical motion of a suspended carbon nanotube (indicated with the up-down arrow) with the quantum states of an electron in a quantum dot (indicated by the blue circle). The pillars over which the carbon nanotube is suspended are electron reservoirs which act as heat baths at different temperatures. The up-down motion of the tube is strongly coupled to the quantum dot state, as recently demonstrated [4].



This setup provides a new, highly controlled platform that is suited to reveal the thermodynamic value of information in the *quantum* regime for the first time. The mechanical motion can act as a direct probe of the work done on the quantum dot, i.e. work extracted from the quantum dot can be stored in the mechanics and then reused (depicted by the wheel).

First steps in this PhD project: You will begin with revisiting Landauer's erasure protocol and deriving protocols for work extraction from coherence [3]. You will gain understanding of key issues such as "where did the work go" and "what entropy should one use" to assess information changes and energetic exchanges in the quantum regime. With the help of your supervisors, you will learn how to theoretically model the nanomechanical platform, see Figure, and adapt Landauer erasure and coherence work extraction protocols for this two-level system. We will work closely with the experimental group in Oxford to discuss progress and measurement results, as well as the philosophical implications of our findings. It is expected that these first experimental tests of work associated with quantum states/coherences can bring up entirely new perspectives on the thermodynamic cost of quantum information processing, which we hope to explore. We may also explore alternative platforms for the work-from-coherence protocol, including continuous-variable Bose-Einstein condensates that allow highly coherent manipulation and superconducting qubits where coherent interaction between qubit and cavity has been demonstrated [5].

References:

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