Quantum effects in thermodynamics:

Significance of the vacuum state and measurement
in the framework of thermal operations.

Description for the general public

Among many physical theories, thermodynamics is the one which has never been wrong. It applies to a whole variety of physical systems, from black holes in distant galaxies, through extremely complicated semiconductor devices in our smartphones, up to atomic interactions in the nanoscale regime. However, it was only recently that people realized that thermodynamic systems behave *differently* when we look at their evolution on the atomic scale. Differently not in the sense that thermodynamics was wrong. Rather, that the notions we have been using for so long are not good enough to describe the very delicate intricacies implied by the laws of quantum mechanics.

One of such astonishing features is the fact that in the atomic regime, the standard second law of thermodynamics, which governs how thermodynamic systems evolve, splits into a whole family of "second laws", each of them enforcing a different physical constraint on the thermodynamic evolution. It is highly important to understand how ordinary thermodynamic laws translate into the nano-scale regime in order to harness the exceeding potential of quantum phenomena.

This project aims at studying two remarkable and purely quantum features from thermodynamic perspective. The first of them involves the notion of the vacuum state in thermodynamic batteries. Precisely, our aim is to understand what is the special role of the battery ground state and how it can be used to boost the efficiency of thermal machines. All nano-scale devices must ultimately draw energy from an external battery source, and that is why understanding the very delicate features of these sources is highly important. The second quantum feature studied in this project involves the notion of quantum measurement. We want to investigate the intimate connection between the amount of information acquired when measuring a quantum system and the work needed to perform this measurement.

Thermodynamics has never been so ardently admired since the invention of a steam engine. This is because miniaturization of devices is now forcing researchers to extend standard notions of thermodynamics to the quantum realm. This is a challenging, but very rewarding task. We believe that our results will have wide applications in small systems, ranging from quantum computers, up to biological nano-devices.