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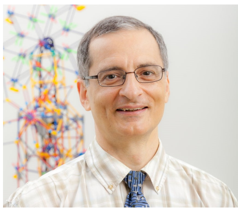

Co-Investigators

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Project Title

Exploring the fundamental limits set by thermodynamics in the quantum regime

Project Summary

You wake-up in the morning, go downstairs to your kitchen, and reach into your refrigerator for a cold glass of orange juice. You switch on your television, powered by electricity coming from some far-off power station. You get into your car, switch on its engine, and drive to work. You pass a park, filled with trees and plants all converting sunlight into sugars. In the park, there is a water-driven wheel which drives a small fountain. All of these are examples of heat engines, designed, or evolved, to extract work from heat (like in your car), or to turn work into a heat-gradient (like in your refrigerator).

In the 18th and 19th centuries engineers like James Watt, and physicists like Nicolas Carnot, Lord Kelvin, Rudolf Clausius, realized that the operations of these complex mechanisms, or engines, could be understood in terms of just a few basic principles. These ultimately became the "Laws of thermodynamics" which tell us the limits of how much work and energy we need to spend, or can extract, based on simple quantities like temperature, pressure, and entropy.

In the modern world, engines are ubiquitous, optimized, and fundamentally important for our day-today lives. However, as we push the technological limits of how small we can build devices, particularly for computation, one reaches a regime where quantum mechanics comes to the forefront. In this "nano-scale" world the traditional rules of classical mechanics, on which the laws of thermodynamics are based, no longer apply, and we must understand how engines built on this scale operate when influenced by quantum laws.

So far it is clear in some cases quantum mechanics may slow down the engine performance, which has been termed an unwanted "quantum friction". The primary goal of our project is to first realize a welldefined engine operating in this regime where quantum effects dominate, and then apply some "quantum lubrication", or tricks based on the rules of quantum mechanics, which allow us to speed up and overcome this unwanted friction. Our plan is to use two different types of devices. The first, based on superconducting materials developed in the University of Aalto in Finland, are designed in such a way that their current and voltage obey quantum rules. The second, based on more traditional "silicon" technologies developed in RIKEN in Japan, will use the intrinsic quantum degrees of freedom of single electrons.

A secondary goal we wish to investigate is the role of "entanglement", a type of non-local correlation that builds up between two quantum systems. So far whether this can contribute to the operation of a quantum heat engine is not clear, and we plan to explore how different types of engines can potentially make use of this uniquely quantum 'fuel'.

In the future, the insights we gain from these experiments will not only lay down the foundations of the "laws of quantum thermodynamics", but also allow us to operate quantum devices, like quantum computers, as quickly as we possibly can, which will allow for faster computation at the nanoscale, and better heat control.

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