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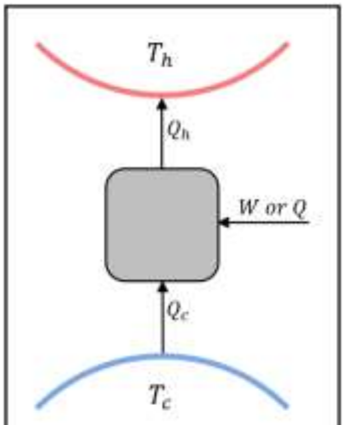
Thermodynamics of a Two-Qubit Absorption-Driven Heat Pump

or: A Very Small Refrigerator

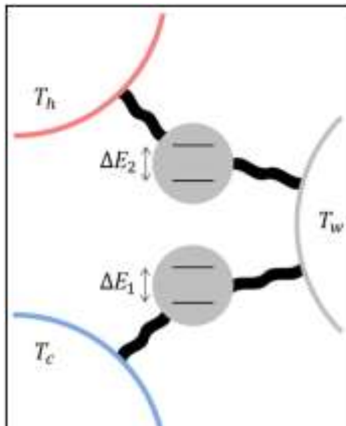
Absorption cooling has long been studied, ever since its discovery by Ferdinand Carré in 1858. The cooling process is driven by an additional heat source which assists heat transfer in a desired direction. Two Swedish engineering students, Baltzar von Platen and Carl Munters, presented an absorption refrigerator as their degree project in 1922. This refined absorption cooling process involved three fluids in a brilliant manner so that no mechanical parts were needed. The idea was turned into a patent and played a major role in the success of Electrolux AB.



The aim of a cooling process is to shuffle heat from one place to another. This is done through some active medium (the grey box) and an input of either work (W) or heat (Q).

The principal aim in a cooling process is to transfer heat from one heat reservoir to another through some active medium. The *vapor absorption cycle* and the *vapor compression cycle* are two main types of cooling processes. The main difference between the two is that absorption cooling requires an additional heat source, while the compression cycle is driven by a work input.

Now, almost a hundred years after von Platen's and Munter's patent, refrigerators are indeed commonplace products. Compression driven refrigerators dominate in consumer electronics, while there are other fields of application where absorption refrigerators are preferred. The question investigated in this master's project was how small an absorption refrigerator possibly can be. How could it further be understood in terms of fundamental physical processes, and how would it perform?



The grey circles represent the qubits, having two energy levels each. The black stripes indicate the connections between heat reservoirs and qubits.

The prerequisites for a general absorption driven refrigerator are three heat reservoirs with different temperatures and an active medium transferring the heat. When modelling this heat pump, the quest was to minimize the size of this active medium. Qubits were chosen as the building blocks to achieve this. A qubit is the quantum analogue of a classical bit and has the benefit of being conceptually simple. They are two-level quantum systems with some energy difference between these levels. As it turned out, two qubits are enough to constitute the active medium of an absorption-driven refrigerator. Both qubits are coupled to the assisting heat reservoir, while the other two heat reservoirs are connected to one qubit each.

The reason that compression refrigerators dominate the market today is that they outperform their absorption refrigerators in terms of efficiency. However, in this work it was shown that this needs not be true for their microscopical counterparts. The system design studied in this thesis is able to perform up the theoretical limit, the so-called Carnot limit, when the temperatures and energies involved are chosen appropriately. By running 1000 simulations, while varying the system parameters over the largest possible ranges, the efficiency of the cooling process could be studied. A vast majority of the parameter sets yielded an efficiency higher than 50% with respect to the theoretical limit, with some simulations reaching over 99%. These results present a possibility for efficient cooling of microscopic systems without the need for external work input.

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