110 Quantum Heat Engines

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Contemporary society faces the challenge of generating "mechanical work" in a clean and efficient way with the environment. Quantum Heat engines (QHEs) use quantum matter as their working substance, thus having unusual and exotic properties. For example, it has been proposed that if the reservoirs are also of quantum mechanical nature these could be engineered into quantum coherent states or into squeezed thermal states thus allowing for an enhancement of the engine efficiency beyond the classical Carnot limit. One of the simplest theoretical implementation for QHEs is a system composed by a single particle in a one-dimensional potential well [1]. The different trajectories are driven by a quasistatic deformation of the potential well, by applying and external force. The problem has been studied in the literature in the context of a non relativistic particle and, more recently, we studied an extension of the problem into the relativistic regime by considering the single particle Dirac spectrum [1].

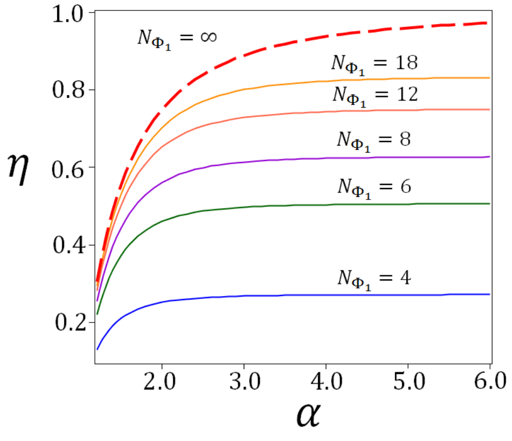

Fig. 1 *The efficiency of the Iso-energetic cycle,calculated from Eq.(1), is represented as a function of the expansion parameter* $\alpha > 1$.

We recently proposed [2] yet a different alternative, by introducing the concept of a magnetically driven quantum heat engine (MQHE). The basic idea is to combine the confining effects of a cylindrical potential well, which physical represents an accurate model for a semiconductor quantum dot, and an external magnetic field.We worked with a cylindrical GaAs semiconductor quantum dot with a typical electronic effective mass of $m^* = 0.067 m_0$ and a typical confining radius $\sim l_d \sim 20 - 100$ nm. We obtain an expression for the efficiency of the MQHE in the Iso-energetic cycle:

$$\eta(N_{\phi_1}, \alpha) = 1 - 3\frac{\Theta_1(\alpha\alpha_1)}{\Theta_1(1)} \frac{\ln\frac{\Theta_1(\alpha\alpha_1\alpha_3)}{\Theta_1(\alpha\alpha_1)}}{\ln\frac{\Theta_1(1)}{\Theta_1(\alpha_1)}} \qquad (1)$$

where we have defined $\Theta_1(\alpha) = \sqrt{1 + \frac{N_{\phi_1}{}^2}{\alpha^4}}$, and N_ϕ is the number of magnetic flux quanta piercing the dot.

In the case of a quantum Carnot cycle, we proved that its efficiency depends only on the ratio between the temperatures of the cold and hot reservoirs:

$$\eta^C = 1 - \frac{T_C}{T_H} \qquad (2)$$

These results reflect the conceptual robustness of thermodynamics.

References

[1] E. Muñoz and F. J. Peña, Phys. Rev. E **86**, 061108 (2012).
[2]E. Muñoz and F. J. Peña, Phys. Rev. E **89**, 052107 (2014).