Implementation of an autonomous Maxwell demon in a quantum motor

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The relationship between thermal fluctuations and irreversibility has been the subject of much debate since the time of James Clerk Maxwell (1867). It was Maxwell himself who proposed that an observer capable of measuring the velocity of individual particles in a gas, the Maxwell's demon, could completely extract all the energy from the gas, contradicting the second law of thermodynamics [1]. To resolve this paradox, Rolf Landauer postulated in 1961 that any logically irreversible operation performed on a system [2] leads to a dissipation of thermodynamic entropy. For example, the entropy dissipated by deleting a single bit of information from a memory (an irreversible logical operation) is associated, according to Landauer's principle, with a thermodynamic entropy dissipation $S = T \log 2$. Accordingly, Maxwell's demon would also dissipate heat when measuring particles, limiting its efficiency.

In this work, we try to relate the previous theory with the new experimental implementations developed in nanoscience. A recent example is quantum nanomotors based on carbon nanotubes, where electrical conduction through the nanotube produces mechanical oscillations in it [3]. At very low temperatures, this class of devices is extremely sensitive to the conditions of its environment. Using a simple model, we demonstrate how this system is capable of extracting energy from the environment in the form of useful work, forming a true autonomous Maxwell's demon. In the same way, we relate the efficiency of the process to the ability of the system to correlate with its environment and compute each fluctuation. Interestingly, the main consequence of our results affects the thermodynamic efficiency of computers manufactured at the nanoscale, where due to fluctuations in the environment, the entropy dissipated when deleting, creating or manipulating information is greater than Landauer predicted.

References

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