Maxwell's demon in the quantum Zeno regime

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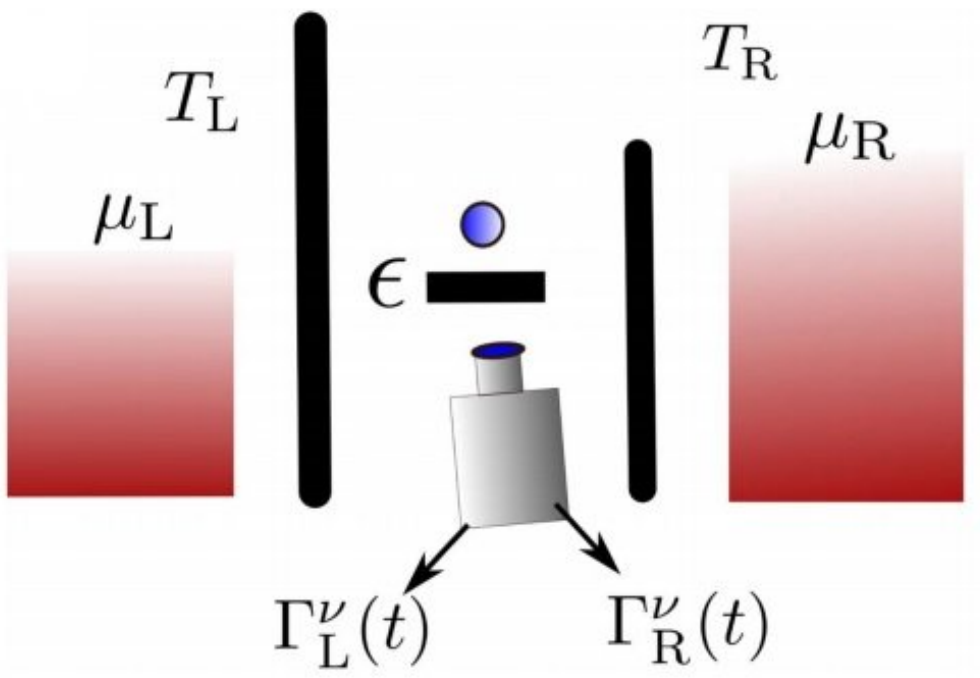

Two reservoirs are connected by a quantum dot. The Maxwell's demon monitors the quantum dot and adjusts the tunnel barriers, generating a current. Credit: Engelhardt and Schaller. Published in the *New Journal of Physics*

In the original Maxwell's demon thought experiment, a demon makes continuous measurements on a system of hot and cold reservoirs, building up a thermal gradient that can later be used to perform work. As

the demon's measurements do not consume energy, it appears that the demon violates the second law of thermodynamics, although this paradox can be resolved by considering that the demon uses information to perform its sorting tasks.

It's well-known that when a quantum system is continuously measured, it freezes, i.e., it stops changing, which is due to a phenomenon called the quantum Zeno effect. This leads to the question: what might happen when Maxwell's demon enters the quantum Zeno regime? Will the demon's continuous measurements cause the quantum system to freeze and prevent work extraction, or will the demon still be able to influence the system's dynamics?

In a paper published in the *New Journal of Physics*, physicists Georg Engelhardt and Gernot Schaller at the Technical University of Berlin have theoretically implemented Maxwell's demon in a single-electron transistor in order to investigate the actions of the demon in the quantum Zeno regime.

In their model, the single-electron transistor consists of two electron reservoirs coupled by a quantum dot, with a demon making continuous measurements on the system. The researchers demonstrated that, as predicted by the quantum Zeno effect, the demon's continuous measurements block the flow of current between the two reservoirs. As a result, the demon cannot extract work.

However, the researchers also investigated what happens when the demon's measurements are not quite continuous. They found that there is an optimal measurement rate at which the measurements do not cause the system to freeze, but where a chemical gradient builds up between the two reservoirs and work can be extracted.

"The key significance of our findings is that it is necessary to investigate

the transient short-time dynamics of thermoelectric devices, in order to find the optimal performance," Engelhardt told *Phys.org*. "This could be important for improving nanoscale technological devices."

The physicists explain that this intermediate regime lies between the quantum regime in which genuine quantum effects occur and the classical regime. What's especially attractive about this regime is that, due to the demon's measurements, the total energy of the system decreases so that no external energy needs to be invested to make the demon work.

"Due to the applied non-Markovian method, we have been able to find a working mode of the demon, at which—besides the build-up of the chemical gradient—it also gains work due the measurement," Engelhardt explained.

Going forward, it may be possible to extract work from the chemical gradient and use it, for example, to charge a battery. The researchers plan to address this possibility and others in the future.

"In our future research, we aim to investigate potential applications," Engelhardt said. "Feedback processes are important, for example, in many biological processes. We hope to identify and analyze quantum transport processes from a feedback viewpoint.

"Furthermore, we are interested in feedback control of topological band structures. As topological effects strongly rely on coherent dynamics, measurements seem to be an obstacle for feedback control. However, for an appropriate weak measurement, which only partly destroys the coherent quantum state, a feedback manipulation might be reasonable."

More information: G Engelhardt and G Schaller. "Maxwell's demon in the quantum-Zeno regime and beyond." *New Journal of Physics*. DOI:

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