Less is more for Maxwell's Demon in quantum heat engines

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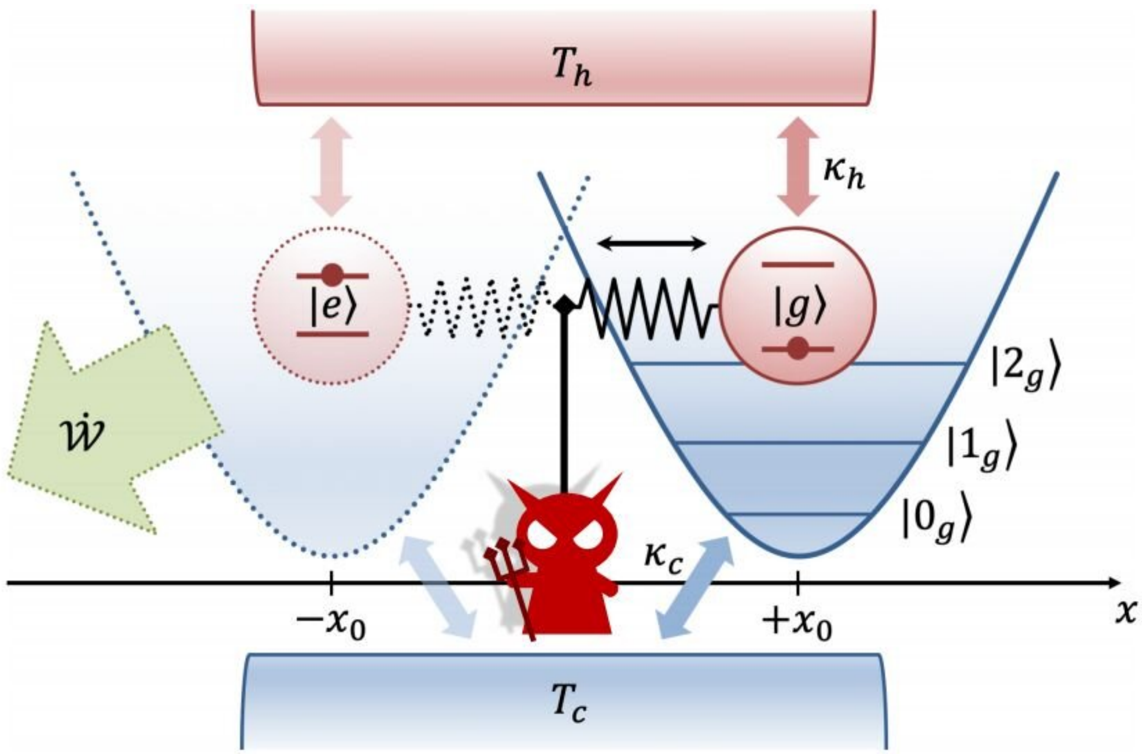

Limiting the abilities of Maxwell's demons helps reconcile some of the contentions around quantum heat engines. Credit: Stella Seah et al. arXiv:1908.10102 [quant-ph] (used with author's permission)

Over 150 years after the famous Scottish scientist James Clerk Maxwell first introduced the idea, the concept of Maxwell's demon continues to perplex physicists and information scientists. The demon he dreamed up in a thought experiment, which could sort fast and slow particles into separate sides of a container, seemed to violate the second law of thermodynamics. By taking into account the demon's memory, physicists were able to bring the demon in line with the laws of statistical mechanics for classical systems, but the situation grew contentious once again when quantum heat engines were proposed, as thermodynamics physicists and information theorists wrangled over viable explanations. Recent results from physical modeling may bring the different arguments together.

"We wanted to show a link between the information science and the thermodynamics," explains Stella Seah, a Ph.D. student at the National University of Singapore. Seah worked with Stefan Nimmrichter and Valerio Scarani at the Max Planck Institute for the Science of Light and also the National University of Singapore. By modeling a physical system with a "lesser Maxwell demon" that has only limited access to the system, they were able to show where increases in entropy come from, as well as whether that entropy leads to what might be described as quantum heat or genuine work done.

Quantum disputes

In quantum systems, measurements can change the state of a system, and this is where implications for the second law of thermodynamics creep in. If the measurement is incompatible with the quantum system—what quantum physicists would describe as a Hamiltonian that does not commute—then the measurement introduces energy. Whether this change in energy should be described as "work done" or "quantum heat" remains a thorny issue. Some would argue that with repeated measurements, the heat dissipates, that the energy is passive and cannot be harnessed, and that in any case, considering the measurement as a dissipative channel that only acts on the system erroneously ignores the measuring apparatus.

While disputes on the topic often occupy abstract realms of information theory and thermodynamics abstractions, Seah, Nimmrichter and Scarani were keen to develop a more pragmatic approach. They consider a system of a qubit in contact with a thermal reservoir that can promote it to an excited state. The qubit is coupled to a pointer that shifts position macroscopically depending on the internal state of the qubit. Seah suggests thinking of the pointer as like a spring, or perhaps a molecule oscillating in a quantum well, where the position for minimum energy shifts position depending on the qubit state.

The lesser of two demons

The key difference between this system and the usual scenarios Maxwell demons encounter is that the demon can only access information about the pointer. Using their model, Seah, Nimmrichter and Scarani revealed that with this lesser Maxwell demon the system could enable measurement feedback such as Rabi spin flips on the qubit that would be defined as useful work, as well as other increases in entropy that could be described as quantum heating.

The model seems to make significant inroads on an argument that has been waged for decades, but Seah says she was not really surprised to reach this result. "What did surprise me was when we found that if you use a macroscopic pointer, you get different behavior from a microscopic pointer." She explains that using a second qubit to act as a pointer in the model leads to the familiar thermodynamic behavior of an Otto cycle (which describes how some of the first mechanical engines of the industrial revolution operated). It is only when the position shifts of the pointer are greatly higher than thermal fluctuations that the measurement increases the entropy in a way that would be defined as work done. In addition, you don't need to make distinct strokes as for a classical heat engine. "You can make the measurements randomly and everything happens continuously, nice and smoothly," says Seah.

Next, she is interested in considering what happens for specific states (where there might be entanglement or supposition) and whether there might be any quantum advantage there.

More information: Stella Seah et al. Maxwell's lesser demon: A quantum engine driven by pointer measurements, *Physical Review Letters*, Accepted Manuscript. journals.aps.org/prl/accepted/ … 6648b29e45541d54460e . On *Arxiv*: arxiv.org/abs/1908.10102