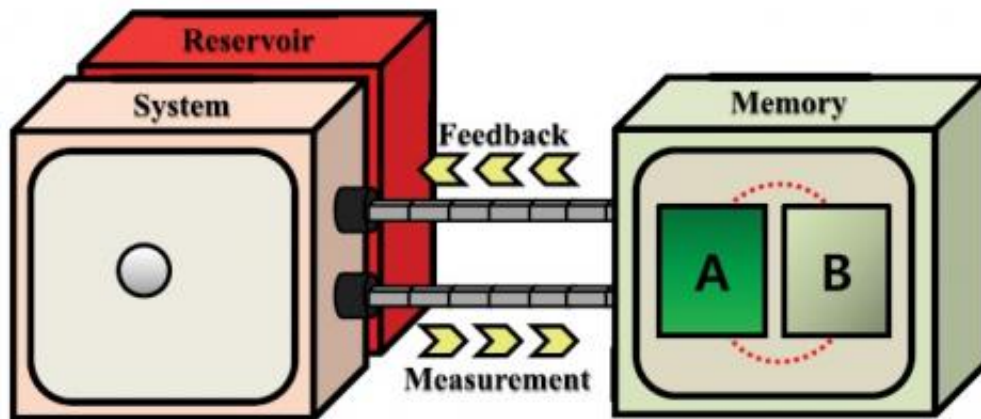


Maxwell's demon can use quantum information to generate work

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In the quantum information heat engine, the system is attached to the reservoir, and is measured and controlled by the memory consisting of a diatomic molecule with two entangled states. Credit: Park, et al. ©2013 American Physical Society

(Phys.org) —In theory, Maxwell's demon can decrease the entropy of a system by opening and closing a door at appropriate times to separate hot and cold gas molecules. But as physicist Leó Szilárd pointed out in 1929, entropy does not decrease in such a situation because the demon's measurement process requires information, which is a form of entropy. Szilárd's so-called information heat engine, now called the Szilárd engine (SZE), demonstrates how work can be generated by using information.

In the SZE and other heat engines devised since then, the information

that is used to generate work has always been classical information. Now for the first time, physicists have theoretically demonstrated that a heat engine can generate work using purely quantum mechanical information.

The researchers, Jung Jun Park and Sang Wook Kim from Pusan National University in Busan, Korea; Kang-Hwan Kim from the Korea Advanced Institute of Science and Technology (KAIST) in Daejeon, Korea; and Takahiro Sagawa from Kyoto University in Kyoto, Japan, have published their paper on their work in a recent issue of *Physical Review Letters*.

"It is known that classical information can be used to extract work, which is important because this saves the second law of thermodynamics!" Sang Wook Kim told *Phys.org*. "The mathematical expression of such work is given as the mutual information between the system and the measurement device multiplied by kT . Now for the first time we show that quantum information can also be used to extract work, and its mathematical expression is discord."

As the physicists explain, in many ways the new quantum heat engine is similar to the SZE. Both engines begin in thermodynamic equilibrium, and both have some kind of wall that separates the reservoir of molecules into two spaces. While the wall in the SZE is "perfect," in the quantum heat engine it is semi-permeable.

The demon and the type of molecules used are also different in the quantum heat engine. Here, the demon consists of not one but two memories, which the scientists physically demonstrate using a molecule containing two atoms. Each atom has two internal states that are physically equivalent to each atom's two spin states.

Before measurements are performed, the two atoms are prepared in a maximally entangled quantum state, and are also classically correlated.

But as measurements are performed to separate the molecules, the quantum entanglement between the two atoms decreases while the classical correlation does not. It is this [quantum entanglement](#), expressed here as quantum discord, that is used to generate work. The quantum discord measures the amount of quantum mechanical correlation compared to the total correlation (both quantum and classical).

Like the SZE, the quantum heat engine does not violate the second law of thermodynamics because entropy, in the form of information, never decreases in these systems. The physicists also note that the quantum heat engine is not cyclic, so the memory does not return to its initial maximally entangled state. In other words, the quantum information is not free, and work must be done to recover the initial state.

The researchers plan to further investigate the potential of generating work from quantum information in the future.

"First we are considering how to realize our engine in experiments," Sang Wook Kim said. "The example that we presented in our paper is just a gedanken experiment, implying that it is extremely hard to directly realize it. Second, we are studying the [quantum information heat engine](#) far from equilibrium. This is related to constructing a quantum fluctuation theorem with feedback control."

More information: Jung Jun Park, et al. "Heat Engine Driven by Purely Quantum Information." *PRL* 111, 230402 (2013). [DOI: 10.1103/PhysRevLett.111.230402](https://doi.org/10.1103/PhysRevLett.111.230402)

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