Physicists create first photonic Maxwell's demon

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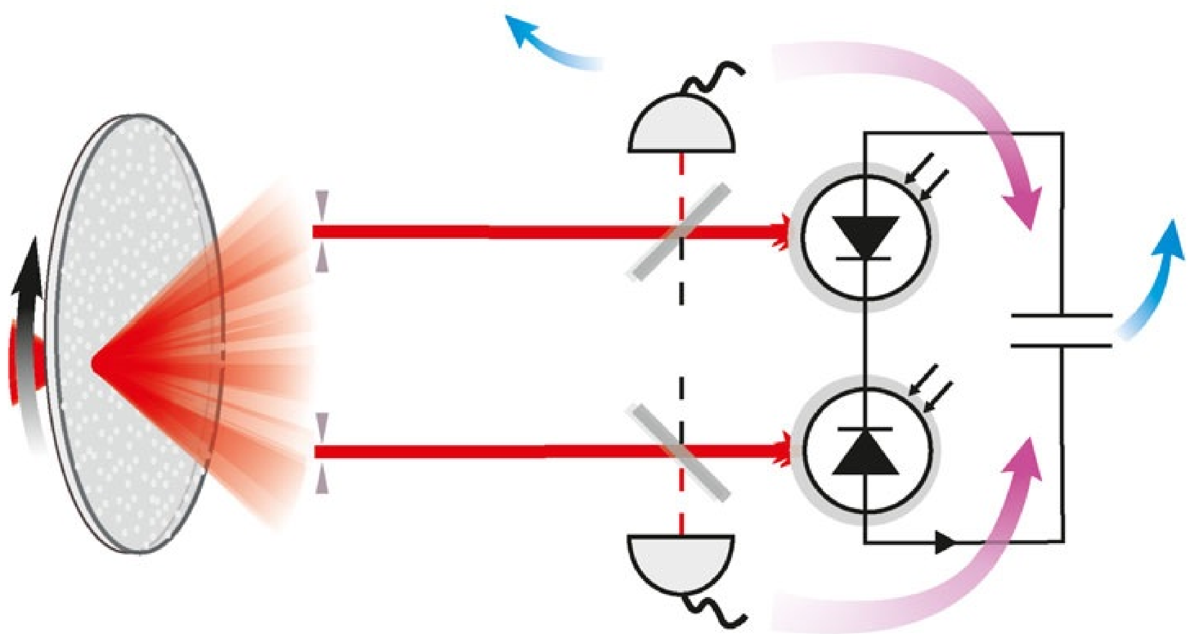

Experimental setup of the photonic Maxwell's demon: The demon's measurement is implemented by high transmittance beam splitters (BS) and highly sensitive avalanche photodiodes (APDs). The two photodiodes are the work extraction mechanism that use the imbalance in the pulse energies created by the demon to charge a capacitor. Credit: Vidrighin, et al. ©2016 American Physical Society

(Phys.org)—Maxwell's demon, a hypothetical being that appears to violate the second law of thermodynamics, has been widely studied since it was first proposed in 1867 by James Clerk Maxwell. But most of these studies have been theoretical, with only a handful of experiments having actually realized Maxwell's demon.

Now in a new paper, physicists have reported what they believe is the first photonic implementation of Maxwell's demon, by showing that measurements made on two light beams can be used to create an energy imbalance between the beams, from which work can be extracted. One of the interesting things about this experiment is that the extracted work can then be used to charge a battery, providing direct evidence of the "demon's" activity.

The physicists, Mihai D. Vidrighin, et al., carried out the experiment at the University of Oxford and published a paper on their results in a recent issue of *Physical Review Letters*.

"Our work shows how photonics can be used as a platform to investigate the relation between energy and information," coauthor Oscar Dahlsten, at the University of Oxford and the London Institute for Mathematical Sciences, told *Phys.org*.

In the original thought experiment, a demon stands between two boxes of gas particles. At first, the average energy (or speed) of gas molecules in each box is the same. But the demon can open a tiny door in the wall between the boxes, measure the energy of each gas particle that floats toward the door, and only allow high-energy particles to pass through one way and low-energy particles to pass through the other way. Over time, one box gains a higher average energy than the other, which creates a pressure difference. The resulting pushing force can then be used to do work. It appears as if the demon has extracted work from the system, even though the system was initially in equilibrium at a single temperature, in violation of the second law of thermodynamics.

Over the years, physicists have resolved this apparent paradox by explaining that, even though the demon may not do work directly on the system, the demon does gain information from its measurements. Erasing this information from the demon's memory requires work, so that overall there can be no net gain in work.

In the photonic version, the physicists replaced the boxes of gas particles with two pulses of light. They implemented the demon using a combination of a photodetector, which can measure the number of photons from each pulse, and a feed-forward operation, which like the open door can escort the brighter beam (with more photons) in one direction and the dimmer beam (with fewer photons) in the other. The different beams fall on different photodiodes, which generate an electric current that goes to a capacitor, but from opposite directions. If the pulse energies were equal, they would cancel out. But the imbalance in the pulse energies—and in the resulting photoelectric charge—is what charges the capacitor.

Even though the researchers did not aim to realize optimal work extraction, it's possible that some type of Maxwell's demon could one day have practical applications.

"Often we have more information available than thermodynamics supposes," Dahlsten said, explaining that things are normally not fully random and have a degree of predictability. "We can then use demon set-ups such as this one to extract work, making use of that information. Similarly, we can use extra information to reduce work costs of, for example, cooling systems. Personally I think that sort of technology will have a real impact on meeting the energy challenge facing the world."

Due to differences between the photonic implementation and previous implementations of Maxwell's demon, traditional theoretical models do not provide a clear path for connecting work extraction to the information acquired by measurement in a fundamental way. So the researchers derived a new model that accounts for the subtleties of the new set-up, in which they relate work extraction to the information acquired by measurement.

The researchers hope that the new model will lead to a better understanding of the link between information and thermodynamics, which is necessary for understanding thermodynamics at the microscale and below. As the scientists explain, recent developments of technologies consisting of just a single or few particles require a better understanding of microscale thermodynamics, similar to how the steam engine drove scientists to better understand macroscopic thermodynamics in the 19th century.

A theory of of microscale thermodynamics could have a variety of applications, including making energy-harvesting technology more efficient. It could also allow researchers to investigate the role of quantum coherence in thermodynamics, with applications in quantum information technologies.

"We are already thinking of ways in which features such as entanglement can be introduced in future experiments based on this one, as our interests gravitate around quantum information," Dahlsten said.

More information: Mihai D. Vidrighin, et al. "Photonic Maxwell's Demon." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.116.050401 , Also at arXiv:1510.02164 [quant-ph]