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.

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