Physicists investigate erasing information at zero energy cost

February 22 2017, by Lisa Zyga

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(Phys.org)—A few years ago, physicists showed that it's possible to erase information without using any energy, in contrast to the assumption at the time that erasing information must require energy. Instead, the scientists showed that the cost of erasure could be paid in terms of an arbitrary physical quantity such as spin angular momentum—suggesting that heat energy is not the only conserved quantity in thermodynamics.

Investigating this idea further, physicists Toshio Croucher, Salil Bedkihal, and Joan A. Vaccaro at the Centre for Quantum Dynamics, Griffith University, Brisbane, Queensland, Australia, have now discovered some interesting results about the tiny fluctuations in the spin cost of erasing information. The work could lead to the development of new types of heat engines and information processing devices.

As the scientists explain in a new paper published in *Physical Review Letters*, the possibility that information can be erased at zero energy cost is surprising at first due to the fact that energy and entropy are so closely related in thermodynamics. In the context of information, information erasure corresponds to entropy erasure (or a decrease in entropy) and therefore requires a minimum amount of energy, which is determined by Landauer's erasure principle.

Since Landauer's erasure principle is equivalent to the second law of thermodynamics, the zero-energy erasure scheme using arbitrary conserved quantities can be thought of as a generalized second law of thermodynamics. This idea dates back to at least 1957, when E. T. Jaynes proposed an alternative to the second law in which heat energy is thought of in a more general way than usual, so that heat incorporates other kinds of conserved quantities.

Applying this framework to information erasure, in 2011 Vaccaro and Stephen Barnett showed that the energy cost of information erasure can be substituted with one or more different conserved quantities—specifically, spin angular momentum.

One important difference between heat energy and spin angular momentum is that, while heat may or may not be quantized, spin angular momentum is an intrinsically quantum mechanical property, and so it is always quantized. This has implications when it comes to accounting for tiny fluctuations in these quantities that become significant when designing systems at the nanoscale.

Scientists have only recently investigated these fluctuations in the context of the Landauer principle, where they found that these fluctuations are quickly suppressed by something called the Jarzynski equality. This means that heat energy fluctuations have only a very tiny probability of violating the Landauer principle.

In the new study, the scientists have for the first time investigated the corresponding discrete fluctuations that arise when erasing information using spin.

Among their results, the researchers found that the discrete fluctuations are suppressed even more quickly than predicted by the corresponding Jarzynski equality for "spinlabor"—a new term the scientists devised that means the spin equivalent of work. This is the first evidence of beating this bound in an information erasure context. The quick suppression means that the fluctuations have an extremely low probability of using less than the minimal cost required to erase information using spin, as given by the Vaccaro-Barnett bound, which is the spin equivalent of the Landauer principle.

"Our work generalizes fluctuation relations for erasure using arbitrary conserved quantities and exposes the role of discreteness in the context of erasure," Bedkihal told *Phys.org*. "We also obtained a probability of violation bound that is tighter than the corresponding Jarzynski bound. This is a statistically significant result."

The scientists also point out that this process of erasing information with spin has already been experimentally demonstrated, although it appears to have gone unnoticed. In spin-exchange optical pumping, light is used to excite electrons in an atom to a higher energy level. For the electrons to return to their lower energy level during the relaxation process, atoms and nuclei collide with each other and exchange spins. This entropy-decreasing process can be considered analogous to erasing information at a cost of spin exchange.

Overall, the new results reveal insight into the thermodynamics of spin and could also guide the development of future applications. These could include new kinds of heat engines and information processing devices based on erasure that use inexpensive, locally available resources such as spin angular momentum. The researchers plan to further pursue these possibilities in the future.

"The erasure mechanism can be used to design generalized heat engines operating under the reservoirs of multiple conserved quantities such as a thermal reservoir and a spin reservoir," Bedkihal said. "For example, one may design heat engines using semiconductor quantum dot systems where lattice vibrations constitute a thermal reservoir and nuclear spins constitute a polarized spin reservoir. Such heat engines go beyond the traditional Carnot heat engine that operates under two thermal reservoirs."

More information: Toshio Croucher, Salil Bedkihal, and Joan A. Vaccaro. "Discrete Fluctuations in Memory Erasure without Energy Cost." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.118.060602, Also at arXiv:1604.05795 [quant-ph]

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