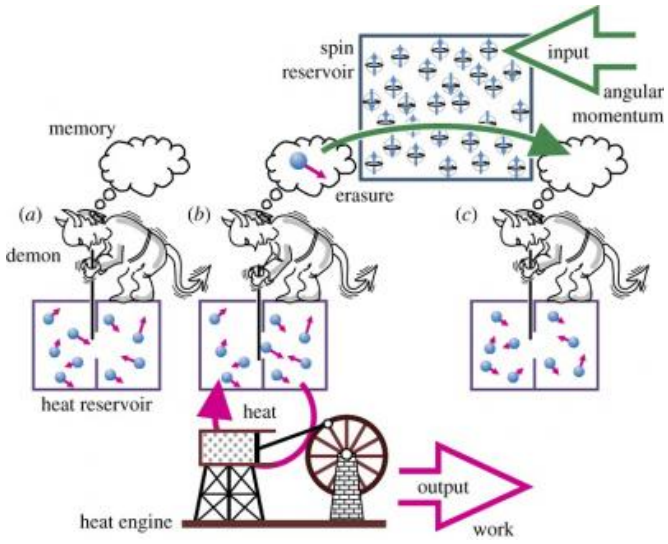
Scientists show how to erase information without using energy

25 January 2011, By Lisa Zyga



Maxwell's demon can extract work from a single heat reservoir at a cost of spin angular momentum. In step (a), the demon has no memory and the gas in the heat reservoir is in thermal equilibrium. In step (b), the demon divides the reservoir in two, trapping the fastest moving molecules on the right side, and uses a heat engine operating between the two partitions to extract work. In step (c), the demon's memory is erased using a spin reservoir and the two partitions are allowed to return to equilibrium. Image credit: Joan A. Vaccaro, et al. Fig. 1. ©2011 Royal Society.

(PhysOrg.com) -- Until now, scientists have thought that the process of erasing information requires energy. But a new study shows that, theoretically, information can be erased without using any energy at all. Instead, the cost of erasure can be paid in terms of another conserved quantity, such as spin angular momentum.

In the study, physicists Joan Vaccaro from Griffith University in Queensland, Australia, and Stephen Barnett from the University of Strathclyde in Glasgow, UK, have quantitatively described how information can be erased without any energy, and they also explain why the result is not as contentious as it first appears. Their paper is published in a recent issue of the Proceedings of the Royal Society A.

Traditionally, the process of erasing information requires a cost that is calculated in terms of energy - more specifically, heat dissipation. In 1961, Rolf Landauer argued that there was a minimum amount of energy required to erase one bit of information, i.e. to put a bit in the logical zero state. The energy required is positively related to the temperature of the system's thermal reservoir, and can be thought of as the system's thermodynamic entropy. As such, this entropy is considered to be a fundamental cost of erasing a bit of information.

However, Vaccaro and Barnett have shown that an energy cost can be fully avoided by using a reservoir based on something other than energy, such as spin angular momentum. Subatomic particles have spin angular momentum, a quantity that, like energy, must be conserved. Basically, instead of heat being exchanged between a qubit and thermal reservoir, discrete quanta of angular momentum are exchanged between a qubit and spin reservoir. The scientists described how repeated logic operations between the qubit's spin and a secondary spin in the zero state eventually result in both spins reaching the logical zero state. Most importantly, the scientists showed that the cost of erasing the qubit's memory is given in terms of the quantity defining the logic states, which in this case is spin angular momentum and not energy.

The scientists explained that experimentally realizing this scheme would be very difficult. Nevertheless, their results show that physical laws do not forbid information erasure with a zero energy cost, which is contrary to previous studies. The researchers noted that, in practice, it will be especially difficult to ensure the system's energy degeneracy (that different spin states of the qubit

and reservoir have the exact same energy level). But even if imperfect conditions cause some energy loss, there is no fundamental reason to assume that the cost will be as large as that predicted by Landauer's formula.

The possibility of erasing information without using energy has implications for a variety of areas. One example is the paradox of Maxwell's demon, which appears to offer a way of violating the second law of thermodynamics. By opening and closing a door to separate hot and cold molecules, the demon supposedly extracts work from the reservoir, converting all heat into useful mechanical energy. Bennett's resolution of the paradox in 1982 argues that the demon's memory has to be erased to complete the cycle, and the cost of erasure is at least as much as the liberated energy. However, Vaccaro and Barnett's results suggest that the demon's memory can be erased at no energy cost by using a different kind of reservoir, where the cost would be in terms of spin angular momentum. In this scheme, the demon can extract all the energy from a heat reservoir as useful energy at a cost of another resource.

As the scientists explained, this result doesn't contradict historical statements of the second law of thermodynamics, which are exclusively within the context of heat and thermal reservoirs and do not allow for a broader class of reservoirs. Moreover, even though the example with Maxwell's demon suggests that mechanical work can be extracted at zero energy cost, this extraction is associated with an increase in the information-theoretic entropy of the overall system.

"The maximization of entropy subject to a constraint need apply not only to heat reservoirs and the conservation of energy," Vaccaro explained to *PhysOrg.com.*

The results could also apply to hypothetical Carnot heat engines, which operate at maximum efficiency. If these engines use angular momentum reservoirs instead of thermal reservoirs, they could generate angular momentum effort instead of mechanical work.

As for demonstrating the concept of erasing information at zero energy cost, the scientists said that it would take more research and time.

"We are currently looking at an idea to perform information erasure in atomic and optical systems, but it needs much more development to see if it would actually work in practice," Vaccaro said.

She added that the result is of fundamental significance, and it's not likely to have practical applications for memory devices.

"We don't see this as having a direct impact in terms of practical applications, because the current energy cost of information erasure is nowhere near Landauer's theoretical bound," she said. "It's more a case of what it says about fundamental concepts. For example, Landauer said that information is physical because it takes energy to erase it. We are saying that the reason it is physical has a broader context than that."

More information: Joan A. Vaccaro and Stephen M. Barnett. "Information erasure without an energy cost." *Proceedings of the Royal Society A*. DOI:10.1098/rspa.2010.0577