Single-reservoir heat engine: Controlling the spin

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Thermodynamical equilibrium is usually associated with thermalisation and thermal reservoirs. However, it is now possible to engineer spin-polarised atomic gases to act as reservoirs of spins and replace the traditional thermal reservoirs. In the absence of magnetic fields, the internal spin states of the atoms are energy degenerate. This means that in reaching statistical equilibrium, conservation of spin angular momentum takes on a dominant role and energy conservation is satisfied trivially. Not surprisingly, new feats are now possible. Indeed, we have recently argued that information can be erased at a cost in terms of spin angular momentum and no energy [1]. This result would contradict Landauer's erasure principle which asserts that information erasure is associated with an energy cost. Given that Landauer's principle is equivalent to the Second Law of thermodynamics, it would also call for a revision of thermodynamics at the nanoscale. Here we describe an experimental proposal to convert the thermal energy of a single reservoir (a gas of trapped atoms) into useful work (as coherent radiation).

The working fluid of the engine is a cloud of cold atoms trapped in an optical dipole trap. The atoms have a ground electronic state with hyperfine quantum number $F{=}1$ and are prepared in the $M{=}{-1}$ state. A red-detuned coherent Raman π pulse acting between the $M{=}{-1}$ and $M{=}1$ states via an excited state extracts thermal energy. The extracted energy appears as increased coherent light via stimulated Raman emission. Hot atoms are transferred by the pulse from the $M{=}{-1}$ to the $M{=}1$ state. As such, the internal spin degree of freedom of the atoms plays the role of Maxwell's demon in remembering which atoms were the hot ones. In order to complete a thermodynamic cycle these atoms need to be returned to their original $M{=}{-1}$ state. A spin reservoir comprising a cloud of cold atoms trapped in a separate optical dipole trap is used for this. Let its atoms have a hyperfine $F{=}\frac{1}{2}$ ground state with atoms initially prepared in the $M{=}{-\frac{1}{2}}$ state. The working fluid and the spin reservoir clouds are brought together, allowing spin angular momentum to be redistributed among the atoms by collisions, and then separated. As a result the atoms of the working fluid are returned (nearly) to their $M{=}{-1}$ state at a loss of polarisation of the spin reservoir. Essentially entropy is decoupled from the motional degree of freedom of the atoms and transferred into the spin degree of freedom as the thermal energy is extracted as coherent light. The heat engine demonstrates the use of the new means of erasing information at a cost of spin angular momentum [1]. Implications for the Second Law will be discussed.

[1] J.A. Vaccaro and S.M. Barnett, Proc. R. Soc. A **467** (2011) 1770-1778.