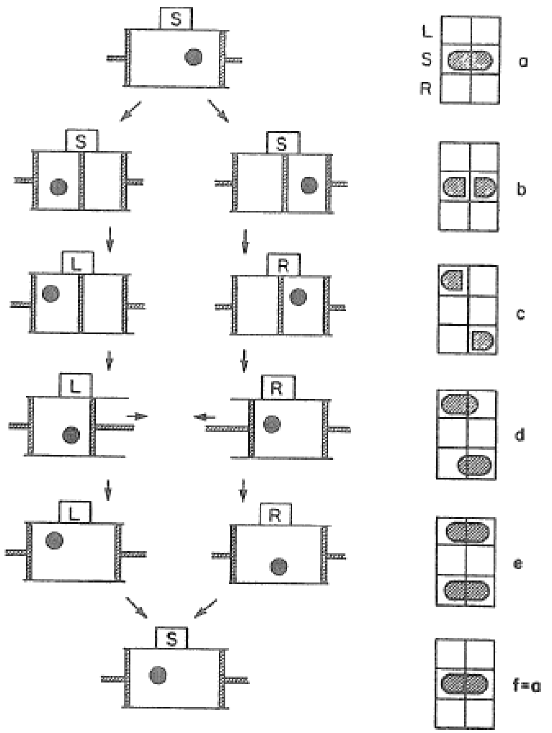

Fig. 12. A one-molecule Maxwell's demon apparatus.

Figure 12 shows the cycle of operation of a one-molecule Maxwell's demon apparatus. The left side of the figure shows the apparatus, and the right side shows the sequence changes in its phase space, depicted schematically as a product of a horizontal coordinate representing the location of the molecule and a vertical coordinate representing the physical state of the demon's "mind." The demon's mind has three states: its standard state S before a measurement, and two states $\mathbb{L}$ and $\mathbb{R}$ denoting the result of a measurement in which the molecule has been found on the left or right, respectively. At first (a) the molecule wanders freely throughout the apparatus and the demon is in the standard state S, indicating that it does not know where the molecule is. In (b) the demon has inserted a thin partition trapping the molecule on one side or the other. Next the demon performs a reversible measurement to learn (c) whether the molecule is on the left or the right. The demon then uses this information to extract $kT \ln 2$ of isothermal work from the molecule, by inserting a piston on the side not containing the molecule and allowing the molecule to expand (d) against the

piston to fill the whole apparatus again (e). Notice that a different manipulation is required to extract work from the molecule depending on which side it is on; this is why the demon must make a measurement, and why at (d) the demon will be in one of two distinct parts of its own phase space depending on the result of that measurement. At (e) the molecule again fills the whole apparatus and the piston is in its original position. The only record of which side the molecule came from is the demon's record of the measurement, which must be erased to put the demon back into a standard state. This erasure (e–f) entails a twofold compression of the occupied volume of the demon's phase space, and therefore cannot be made to occur spontaneously except in conjunction with a corresponding entropy increase elsewhere. In other words, all the work obtained by letting the molecule expand in stage (d) must be converted into heat again in order to compress the demon's mind back into its standard state.

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The Thermodynamics of Computation—a Review

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Computers may be thought of as engines for transforming free energy into waste heat and mathematical work. Existing electronic computers dissipate energy vastly in excess of the mean thermal energy kT, for purposes such as maintaining volatile storage devices in a bistable condition, synchronizing and standardizing signals, and maximizing switching speed. On the other hand, recent models due to Fredkin and Toffoli show that in principle a computer could compute at finite speed with zero energy dissipation and zero error. In these models, a simple assemblage of simple but idealized mechanical parts (e.g., hard spheres and flat plates) determines a ballistic trajectory isomorphic with the desired computation, a trajectory therefore not foreseen in detail by the builder of the computer. In a classical or semiclassical setting, ballistic models are unrealistic because they require the parts to be assembled with perfect precision and isolated from thermal noise, which would eventually randomize the trajectory and lead to errors. Possibly quantum effects could be exploited to prevent this undesired equipartition of the kinetic energy. Another family of models may be called Brownian computers, because they allow thermal noise to influence the trajectory so strongly that it becomes a random walk through the entire accessible (low-potential-energy) portion of the computer's configuration space. In these computers, a simple assemblage of simple parts determines a low-energy labyrinth