Physics of Information

"Information is physical"

Rolf Landauer

Physical limits to the power of a computer

Seth Llyod

Information and Physics

Every computational process proceeds in a physical system

Input

0 0 1 1 0 1 0

Computation

Physical process

Output

Today's computer use classical physics

"Classical Computers"

Die Church-Turing Hypothese

[Chu36] Alonzo Church. An unsolvable problem of elementary number theory. *Am. J. Math* 58:345 363 1936

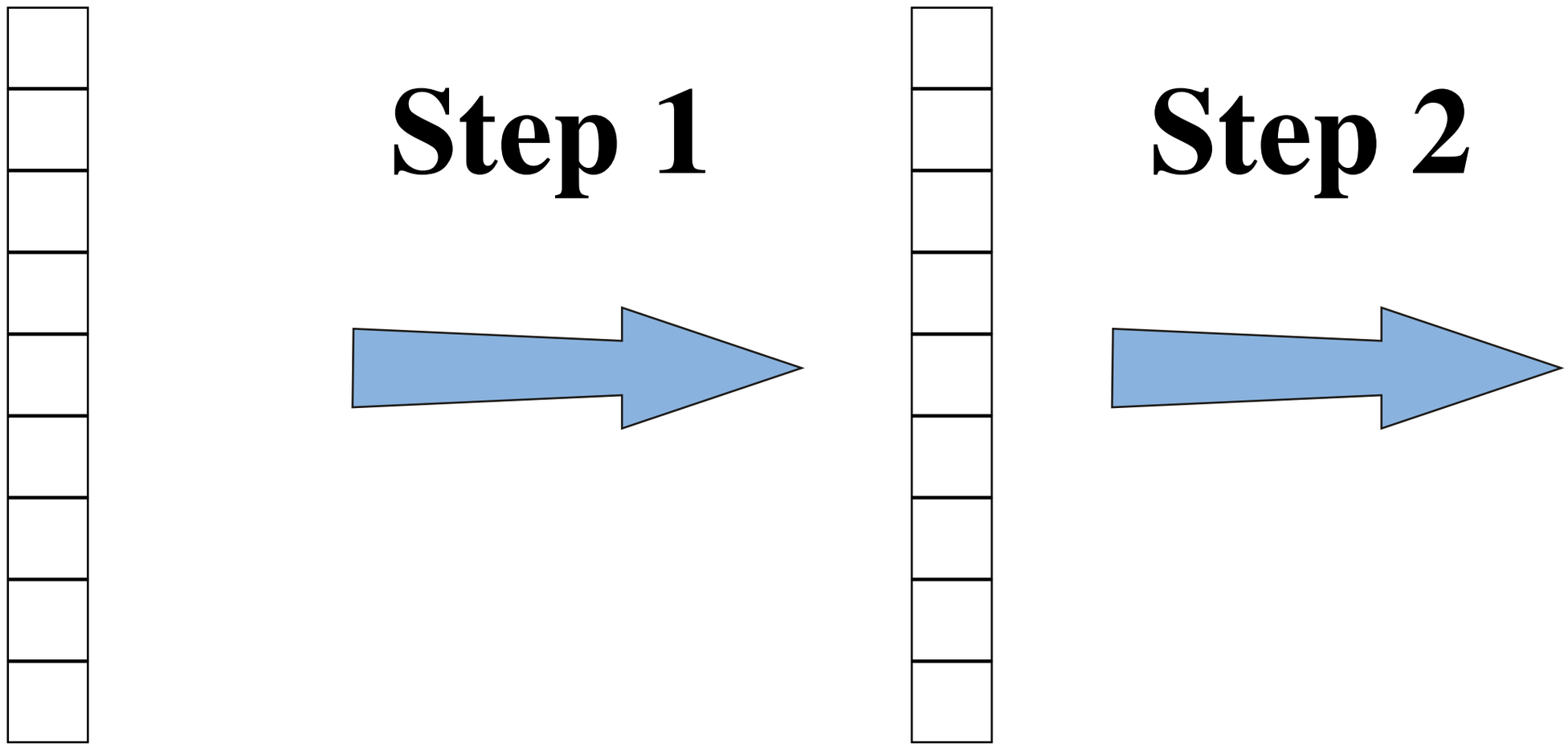
[Tur36] Alan M. Turing. On computable numbers, with an application to the Entscheidungsproblem. *Proc. Lond. Math. Soc. Ser.*, 42:230, 1936. See also ibidem 43:544

Eine Version:

“All computable functions are computable by Turing machine.”

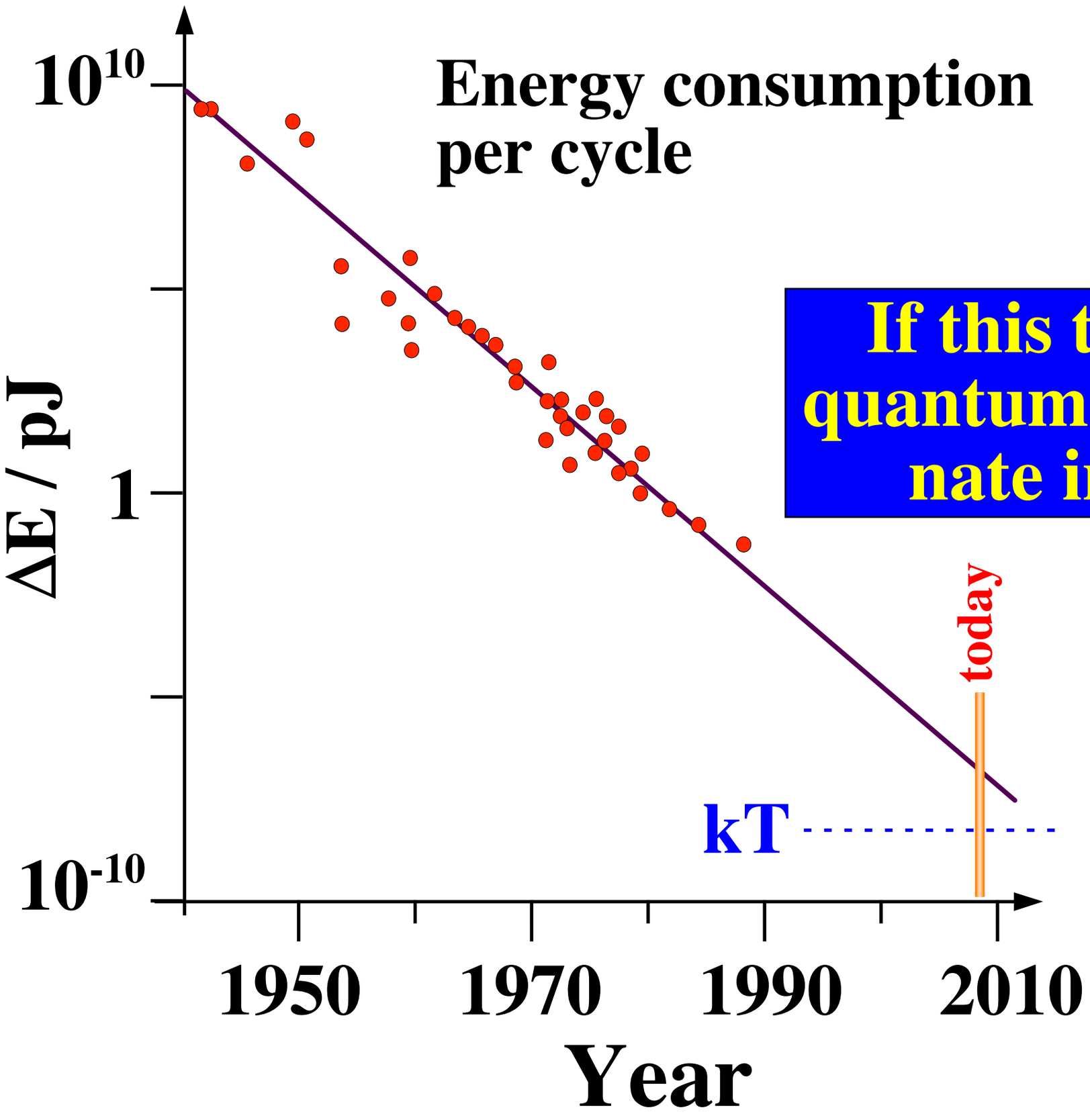
Computable: algorithm exists that terminates

N-bit register



N qubits

Cooler Computers



If this trend continues, quantum effects will dominate in 10 - 20 years

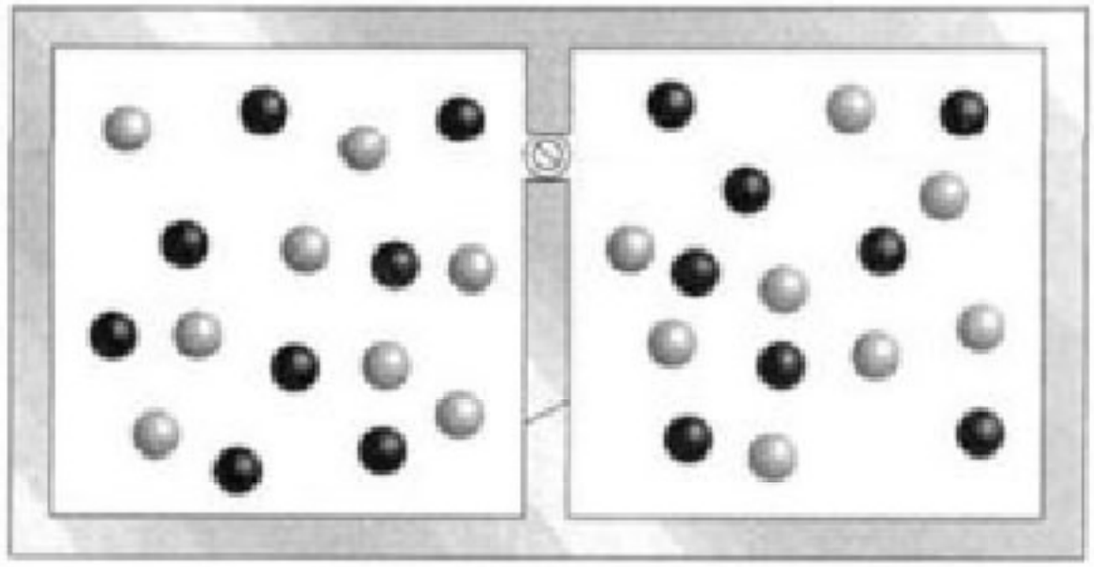
"Brownian Motion"
Switches become unstable

Maxwell's Demon

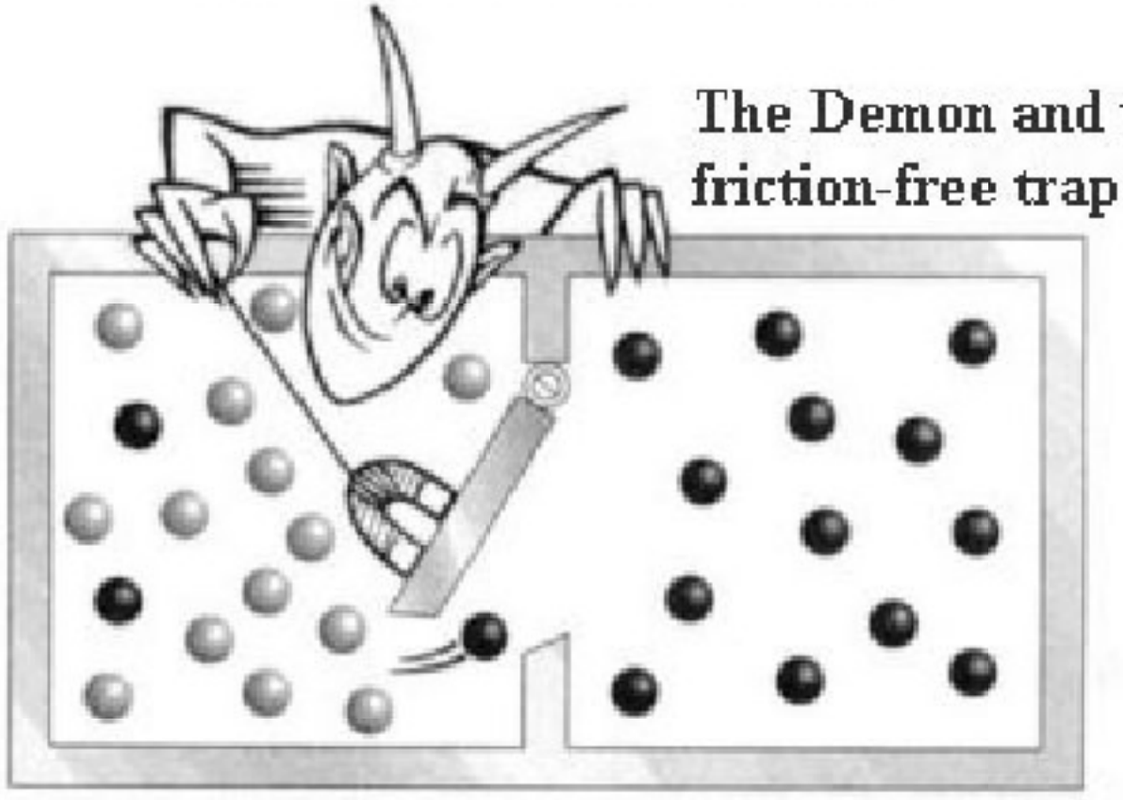
If we conceive a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are still essentially finite as our own, would be able to do what is at present impossible to us. For we have seen that the molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform... Now let us suppose that such a vessel is divided into two portions, A and B, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole, so as to allow only the swifter molecules to pass from A to B, and only the slower one to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of thermodynamics.

James Clark Maxwell, Theory of heat, 1871

Maxwell's Demon



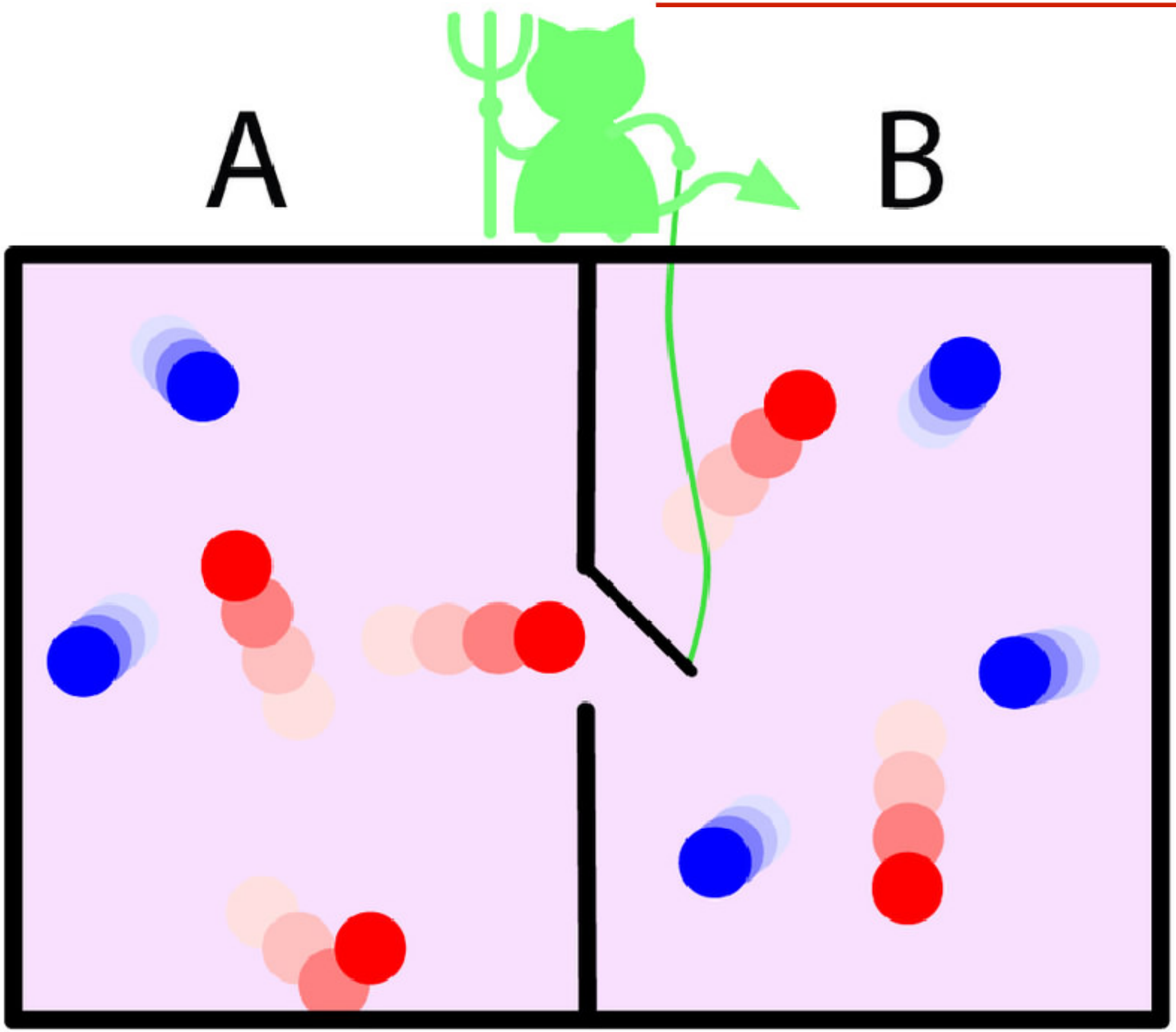
System at Equilibrium



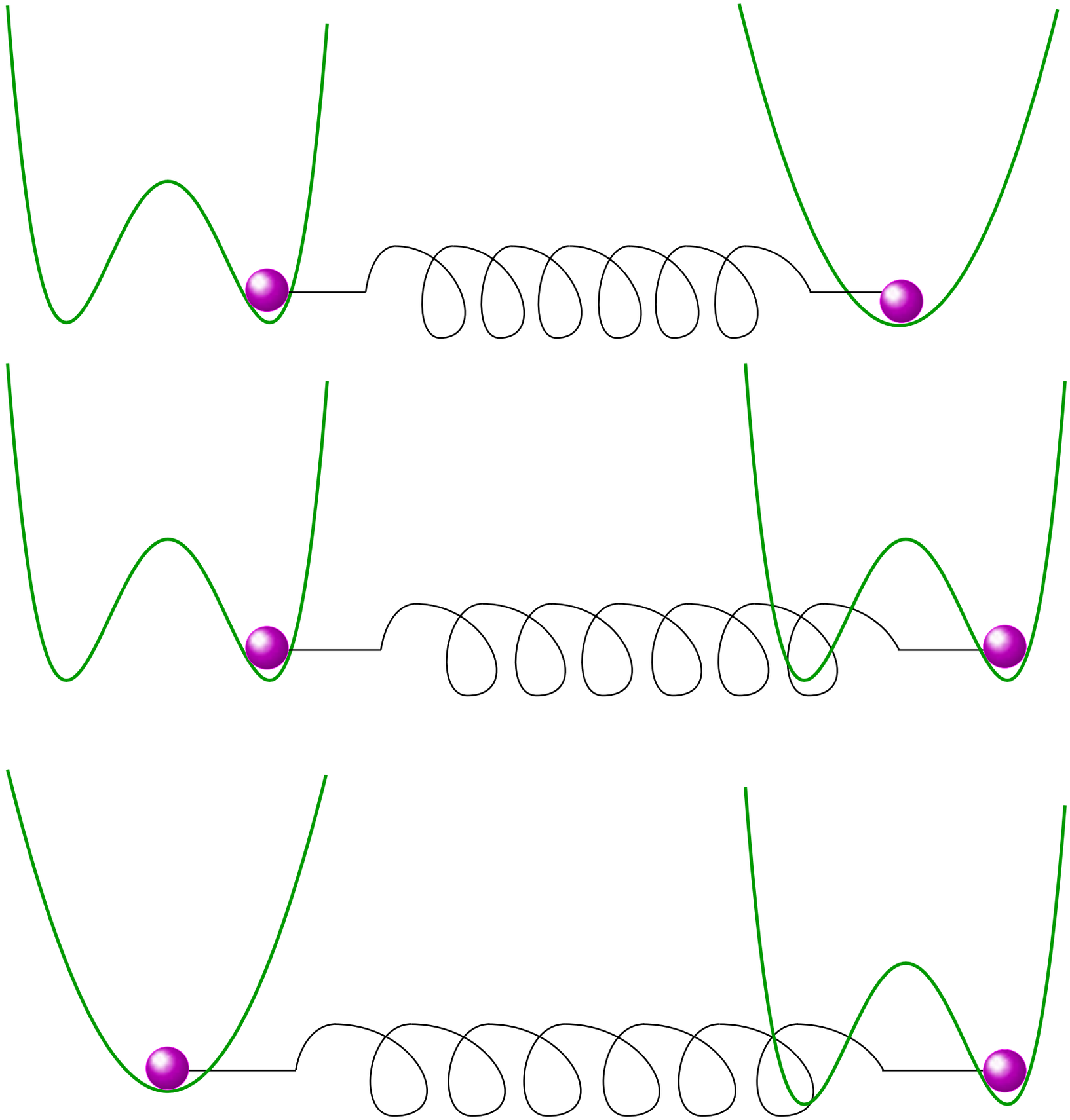
The Demon and the friction-free trap door

System with Lower Entropy
(in violation of the Second Law)

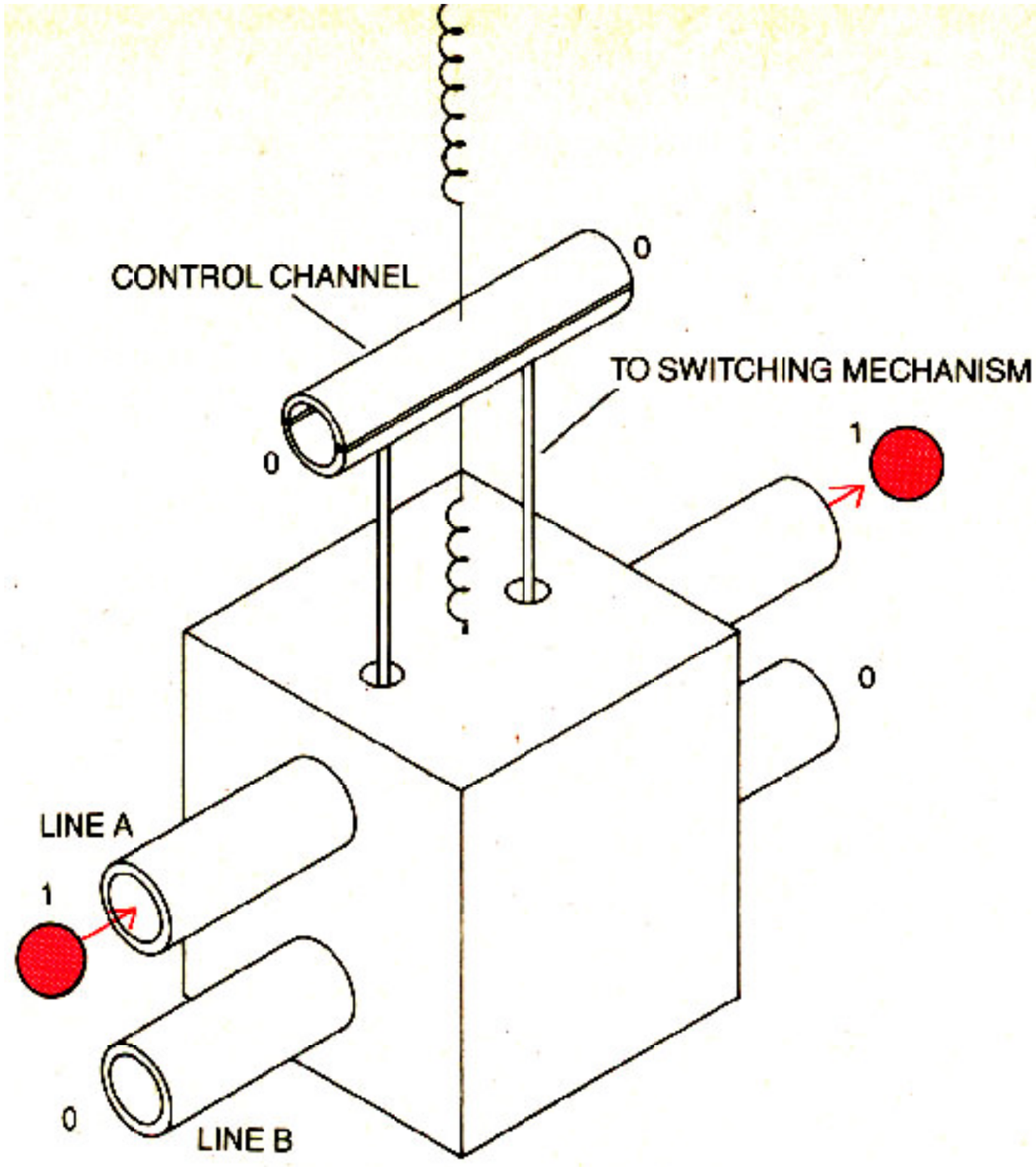
Maxwell's Demon

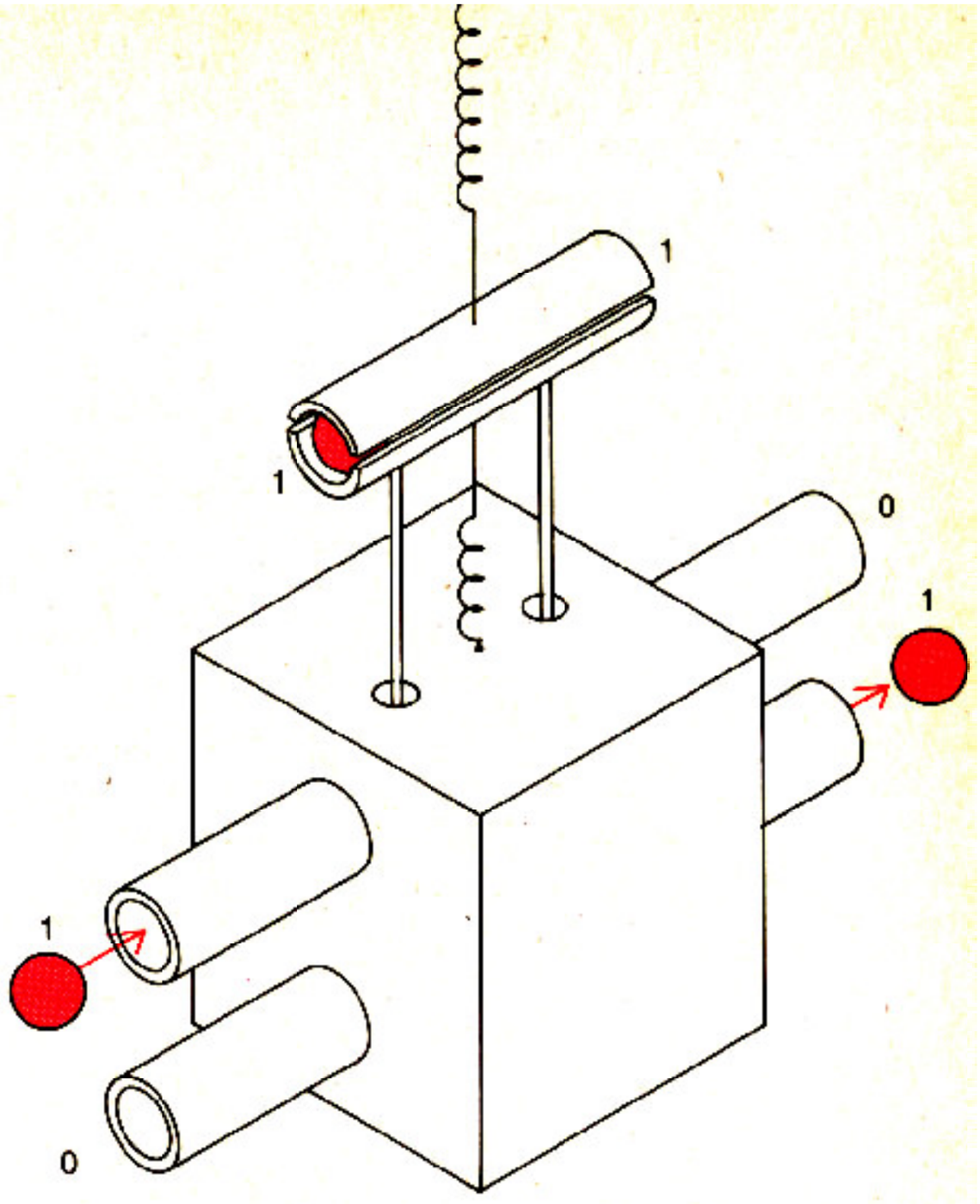


Reversible Copy

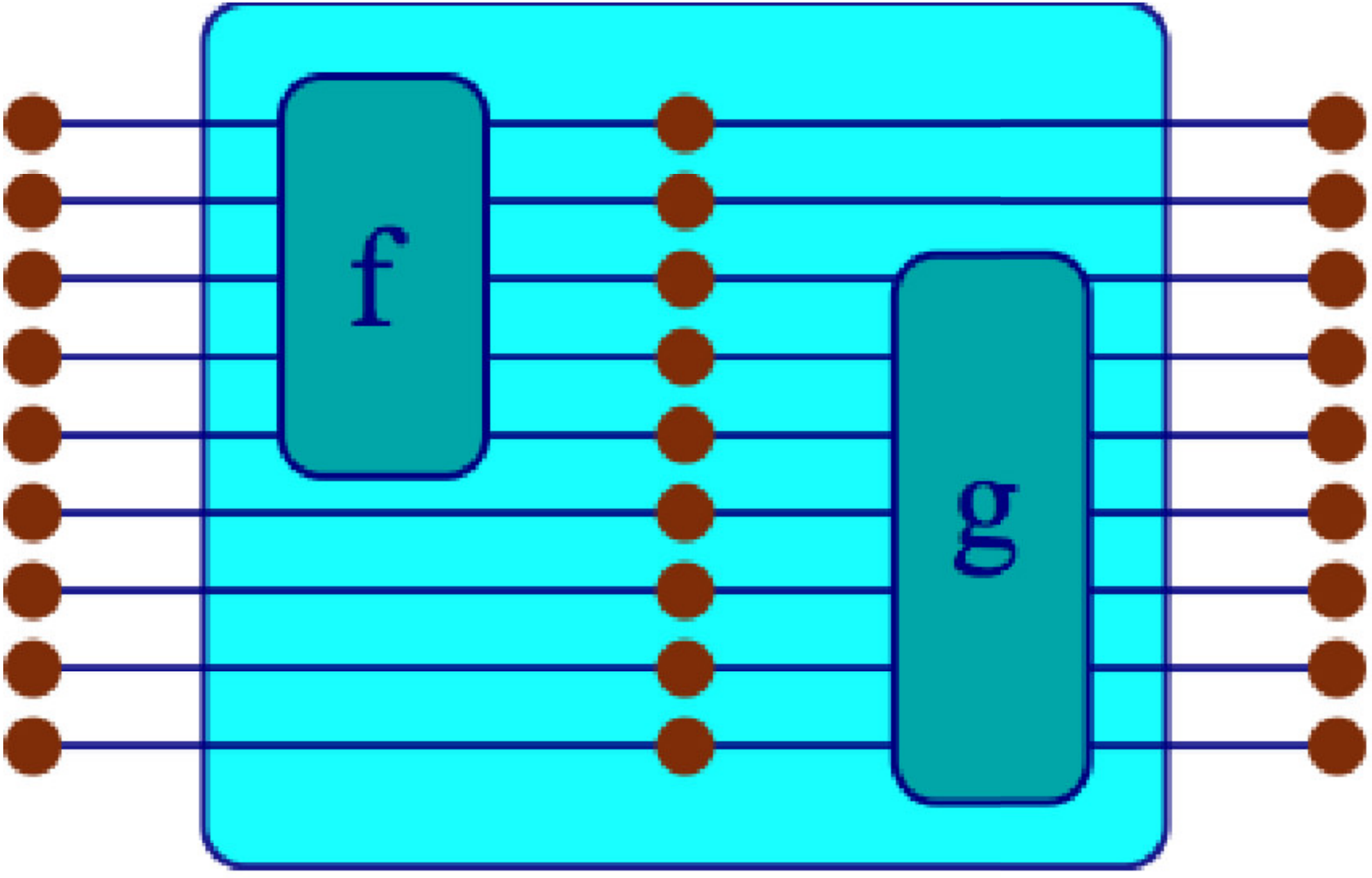


Mechanical Fredkin Gate





Reversible Gates



The Ultimate Laptop

S. Lloyd, Nature 406, 1047-1054 (2000).

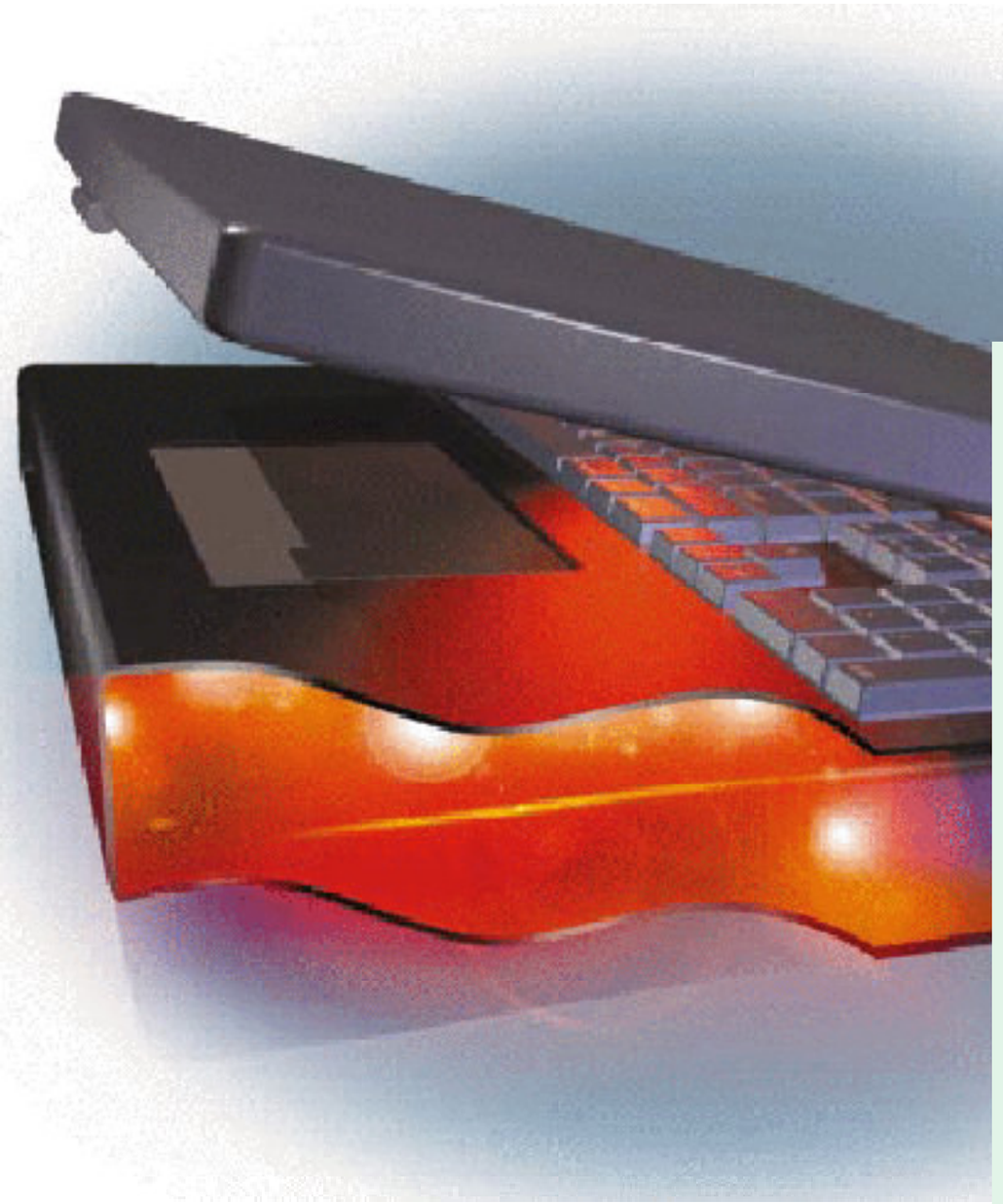


Figure 1 The ultimate laptop. The 'ultimate laptop' is a computer with a mass of 1 kg and a volume of 1 l, operating at the fundamental limits of speed and memory capacity fixed by physics. The ultimate laptop performs $2mc^2/\pi\hbar = 5.4258 \times 10^{50}$ logical operations per second on $\sim 10^{31}$ bits. Although its computational machinery is in fact in a highly specified physical state with zero entropy, while it performs a computation that uses all its resources of energy and memory space it appears to an outside observer to be in a thermal state at $\sim 10^9$ degrees Kelvin. The ultimate laptop looks like a small piece of the Big Bang.