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A Modified Szilard Engine*

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Abstract

We propose a modification of the Szilard engine which seems to circumvent the problem of accumulation of information.

The second law of thermodynamics, which states that the entropy of any closed system may not spontaneously decrease, seems at first sight to be violated by the possibility of a 'Maxwell's Demon,' which filters molecules of a gas according to their energy, thus creating a temperature gradient within a closed system at constant energy.

The *reductio ad absurdam* of the Maxwell Demon is termed the Szilard Engine, shown in Fig. 1. It consists of a chamber containing a single molecule, and a partition which may be used to divide the chamber into two parts. When the partition is raised, it confines the molecule to half of the original volume, apparently decreasing the entropy of the system. The contradiction with the Second Law is made apparent if we imagine reversibly closing the empty half of the chamber, then lifting the partition and converting the pressure from the molecule to usable work as the chamber expands again to its original size.

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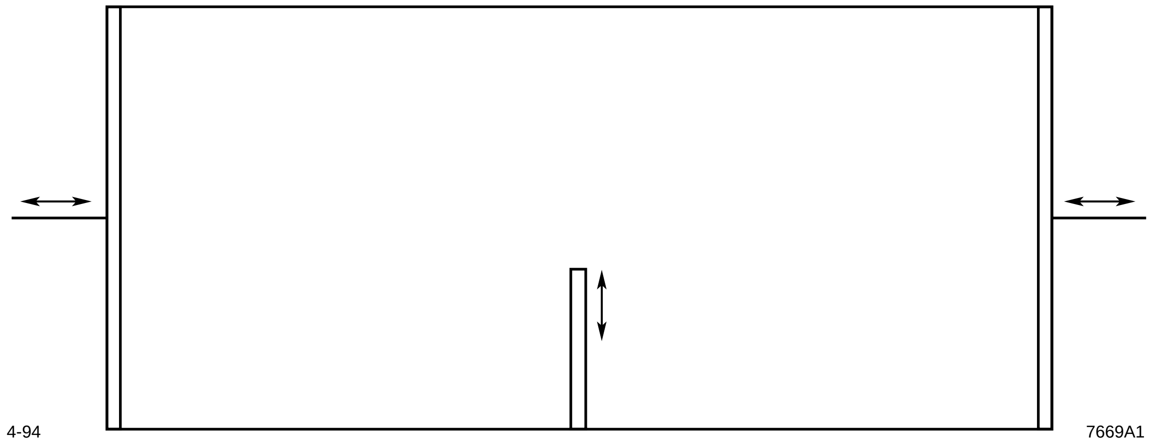

FIG. 1. The Szilard Engine. The chamber contains a single molecule, and the pistons at either end may be moved reversibly.

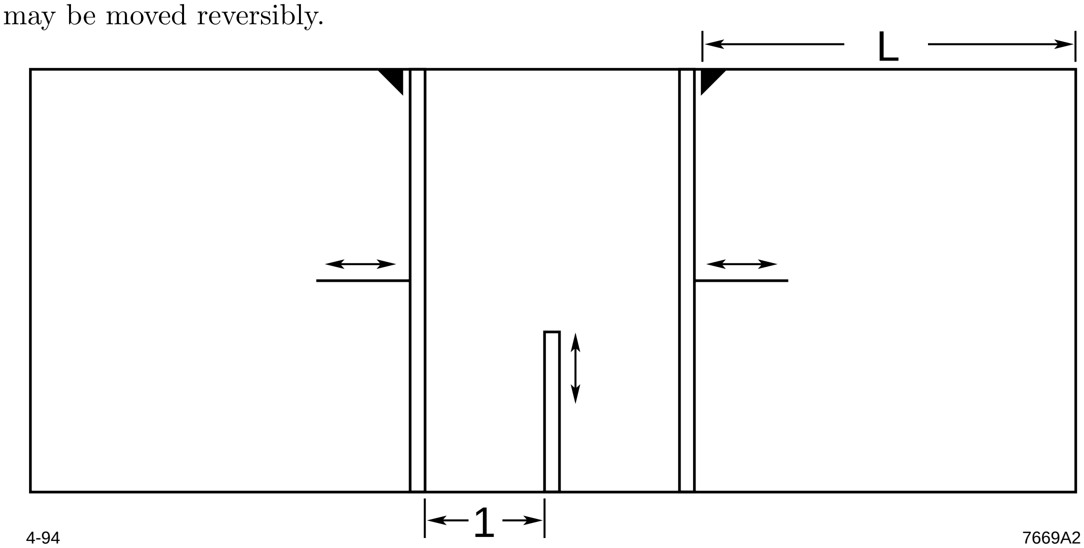

FIG. 2. Our modification of the Szilard Engine. Each of the three chambers contains one molecule. The dark triangles represent classical 'doorstops.'

The second law is rescued by consideration of the information generated during the process [1]. To reversibly close half of the chamber, we must perform a measurement which determines the position of the molecule. If the resulting information is stored, the process is no longer truly repeatable; if it is discarded, the single bit of entropy gained through the operation of the Szilard Engine is lost again when the register is cleared.

At a more fundamental level, we can see that raising the partition does not in itself decrease the entropy until a measurement of the position of the molecule is performed.

The purpose of this report is to propose a modification of the Szilard Engine which seems to avoid the above drawback, and thus to place the second law in renewed jeopardy. This modification is illustrated in Fig. 2; there are three chambers, each containing one molecule.

Again, we raise the partition, separating the central chamber into two halves. One of those halves will be empty, and the peripheral chamber to that side will expand into it irreversibly. The Engine does not monitor which chamber expanded; it simply waits until the size of the central chamber decreases to a fraction $(1+\epsilon)/2$ of its original value. The partition is then lowered, and the chamber is allowed to expand reversibly to its original extent. The amount of work thus harvested is equal to (in bits)

$$\log_2\Big(\frac{2L}{(1+\epsilon)(L+1)}\Big) \simeq 1 - \log_2(1+L^{-1}) - \frac{\epsilon}{\ln 2}. \tag{1}$$

The Engine then returns to its original state and repeats the process.

Since no information is gained or stored in this process, it appears truly repeatable. In effect, the presence of the peripheral chambers lowers the entropy cost of resolving the indeterminacy of the location of the molecule from 1 bit to $\log_2(1+L^{-1})$ bits; if we take $L > (2e^{-\epsilon}-1)^{-1}$, this represents an improvement over the usual Szilard Engine.

Since the Engine follows a single path (raise partition, wait for compression, lower partition, wait for expansion) with no branchings, it needs only to remember its current state, and no information is accumulated. Thus the entropy gained by operation of our modified Szilard engine is not simply stored in an accreting memory, but is harvested as work.

We thank C. Munger for helpful conversations.

References

1. For a discussion of Szilard Engines, see C. G. Bennett, *Scientific American* **257**, No. 5, p. 108, and references therein.