Do Demons Exist?

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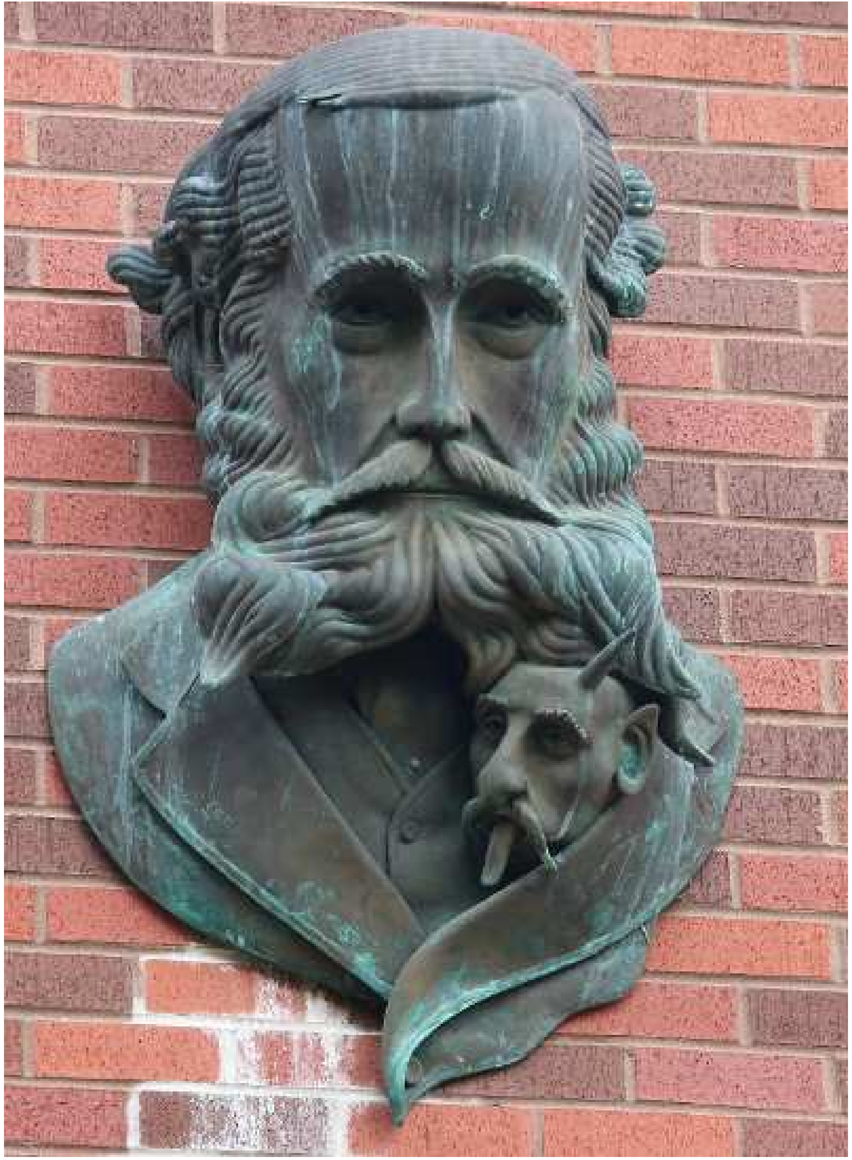
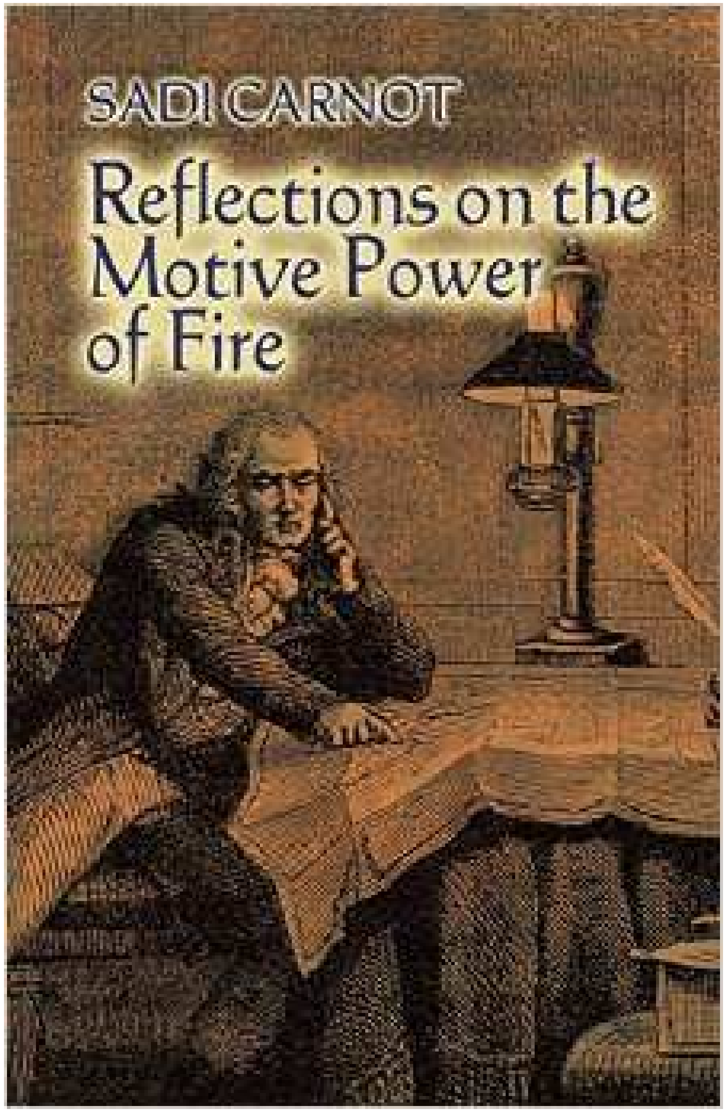


J.C. Maxwell and his Demon on the wall of the Science Building, University of Oregon, Eugene.

Carnot



Perpetual Motion Machines (PMM's) do not exist.

↓

All reversible machines have the same efficiency

↓

$$\oint \frac{dq}{T} = \oint dS = 0$$

↓

Entropy S is a state function.

Carnot 2

....this would be not only perpetual motion, but an unlimited creation of motive power without consumption either of caloric or of any other agent whatever. Such a creation is entirely contrary to ideas now accepted, to the laws of mechanics and of sound physics.

S. Carnot, *Réflexions...* p. 21.

1. There can be no machines more efficient than reversible machines.
2. If there are, entropy can not be defined.
3. Thermodynamics as we know it only exists if PMM's don't.

Who cares?

Einstein would:

> It is the only physical theory of universal content concerning which I am convinced that within the framework of the applicability of its basic concepts, it will never be overthrown.

A. Einstein, *Autobiographical Notes* (1946), 33.

General relativity prevents a perpetual motion machine in a gravitational field because of the gravitational redshift.

Who cares?

Planck would:

> Pursuing this idea I came to construct arbitrary expressions for the *entropy* which were more complicated than those of Wien ... but acceptable. Among those expressions my attention was caught by
>
> $$\frac{\partial^2 s_\nu}{\partial e_\nu^2} = \frac{\alpha}{e_\nu(\beta + e_\nu)}$$
>
> which comes closest to Wien's in simplicity and ... deserves to be further investigated.

Max Planck

... a piece of mathematical jugglery without any correspondence to anything real in nature

Who cares?

Wheeler, Bekenstein, Penrose, and Hawking would:

> In 1971 Wheeler stressed to me that black holes seem to provide a mechanism for violating the second law of thermodynamics. Mix the cup of hot tea with one of cold water and so create entropy. Then dump the lukewarm mix into a black hole. The newly made entropy disappears permanently from our sight — for we have no interest to follow it into the black hole and be lost..[]..So, Wheeler concluded triumphantly, the perfect crime — erasing an increase of entropy — has been perpetrated.

J.D. Bekenstein, *Stud. Hist. Phil. Mod. Phys.*, **32**, (2001), 514.

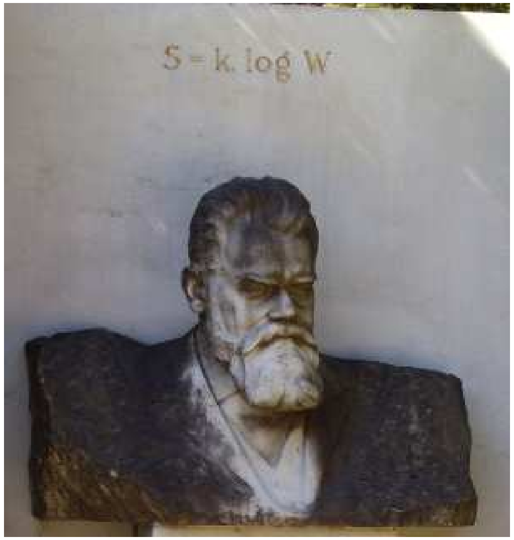
Black holes now have temperature and they radiate, all to save the second law.

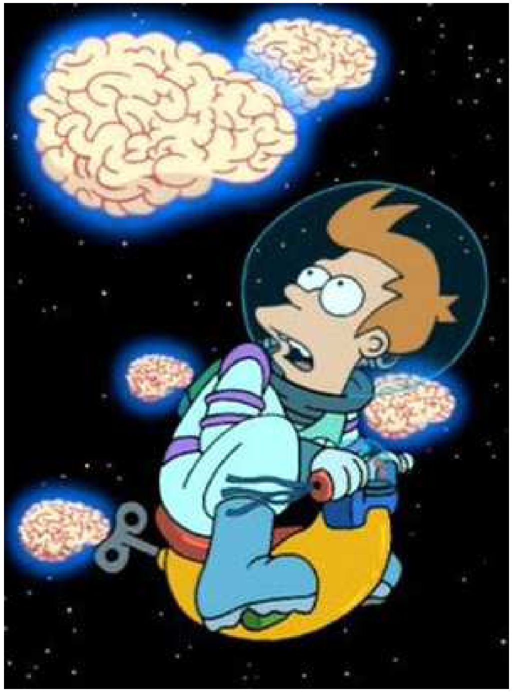
Irreversibility

Why, for example, should a group of simple, stable compounds of carbon, hydrogen, oxygen and nitrogen struggle for billions of years to organize themselves into a professor of chemistry? [....] If we leave a chemistry professor out on a rock in the sun long enough the forces of nature will convert him into simple compounds of carbon, oxygen, hydrogen and nitrogen, calcium, phosphorus and small amounts of other minerals ...

R. Pirsig, *Lila*, p. 294

Boltzmann





Systems consist of massive numbers of particles obeying the laws of classical mechanics

↓

Statistical methods are necessary for the description, giving averages and fluctuations.

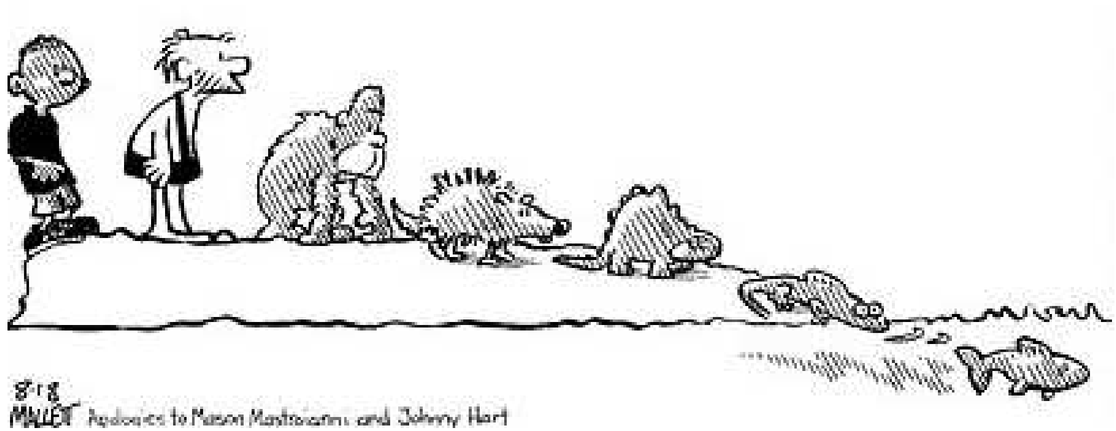
↓

$$S = k \ln W$$

↓

Fluctuations are governed by entropy.

Irreversibility



$$H(t) = \int d\vec{r} d\vec{v}\, f(\vec{r}, \vec{v}, t) \ln f(\vec{r}, \vec{v}, t)$$

Boltzmann was able to derive that:

$$\frac{dH}{dt} = \frac{1}{4} \int d\vec{r} \cdots d\vec{v}\,' \; (f' f_1' - f f') \ln \left(\frac{f f_1}{f' f_1'} \right) W(\vec{v}, \vec{v}_1 | \vec{v}\,', \vec{v}_1\,') \leq 0$$

It looks nice, but one of the assumptions (the so–called Stosszahlansatz) violates time reversibility.

Boltzmann

For surely the atoms did not hold council, assigning order to each, flexing their keen minds with questions of place and motion and who goes where. But shuffled and jumbled in many ways, in the course of endless time they are buffeted, driven along, chancing upon all motions, combinations. At last they fall into such an arrangement as would create this universe.

Lucretius, *De Rerum Natura*, 50 BC

There must then be in the universe, which is in thermal equilibrium as a whole and therefore dead, here and there relatively small regions of the size of our galaxy (which we call worlds), which during the relatively short time of eons deviate significantly from thermal equilibrium. Among these worlds the state probability increases as often as it decreases.

Ludwig Boltzmann, 1897.

How Low was the Entropy of the Universe?

Penrose estimates the total number of microstates of the visible universe to be of the order of $10^{10^{123}}$.

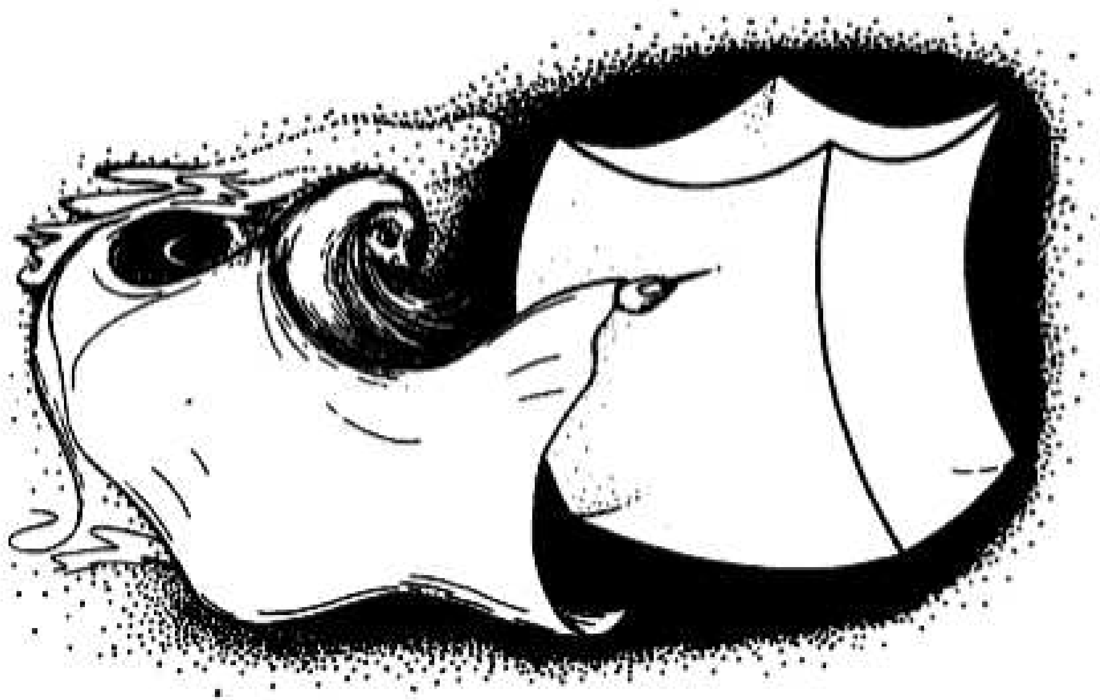


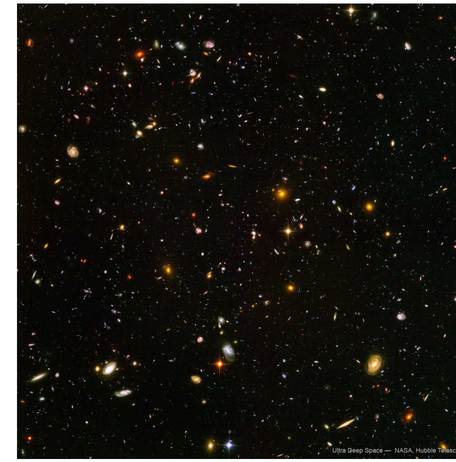
FIGURE 30. In order to produce a universe resembling the one in which we live, the Creator would have to aim for an absurdly tiny volume of the phase space of possible universes —about $1/10^{10^{123}}$ of the entire volume, for the situation under consideration. (The pin and the spot aimed for are not drawn to scale!)

The Emperor's New Mind, p.343

Universe or just one brain?

Spontaneous formation of a single brain...

has a much higher probability than of a galaxy...



and a much, much, much, much, much... higher probability than a universe.

In fact the probability of formation of the universe one second ago with all memories and history is much cheaper (entropywise) than a Big Bang 15 billion years ago.

Early Attempts to create a PMM

Damit wäre ach der terroristische Nimbus des zweiten Hauptsatzes zerstört, welcher ihn als vernichtendes Princip des gesammten Lebens des Universums erscheinen lässt, und zugleich würde die tröstliche Perspective eröffnet, dass das Menschengeslecht betreffs der Umsetzung von Wärme in Arbeit nicht einzig auf die Interventionen der Steinkohle oder der Sonne angewiesen ist, sondern für alle Zeiten einen unerschöpflichen Vorrath verwandelbar Wärme zur Verfüging haben werde.

Loschmidt, 1876.

The purpose of this paper is to call attention to a natural process that appears to constitute an exception to the second law of thermodynamics,

...

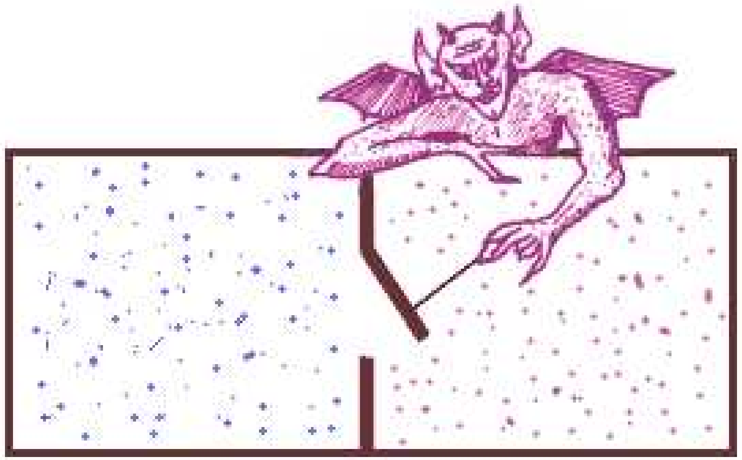
At the same time does it not rather behove us to look to a time when, *through increase of knowledge*, a means of recurrence may possibly be discovered, whereby physical change is continued, rather than to look to the purposeless end of a chaos of uniform temperature and uniform distribution of matter .

S.T. Preston, *Nature*, 1878.

Maxwell's Demon

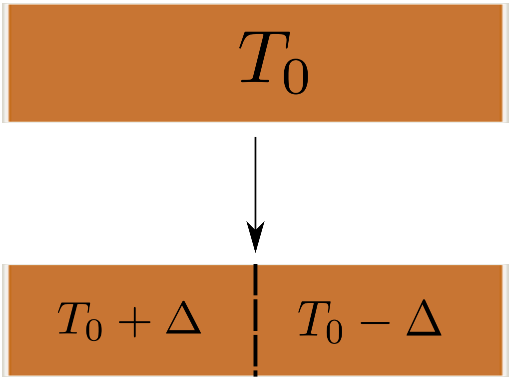
> Or in short if heat is the motion of finite portions of matter and if we can apply tools to such portions of matter so as to deal with them separately then we can take advantage of the different motion of different portions to restore a uniformly hot system to unequal temperatures or to motions of large masses. *Only we can't, not being clever enough.*

J.C. Maxwell. *Scientific Letters* 2, 331–332.



If the "neat–fingered being" opens the door for the hot molecules coming from the left, it separates hot from cold. This can be done with no expendure of energy, and hence appears to violate the second law.

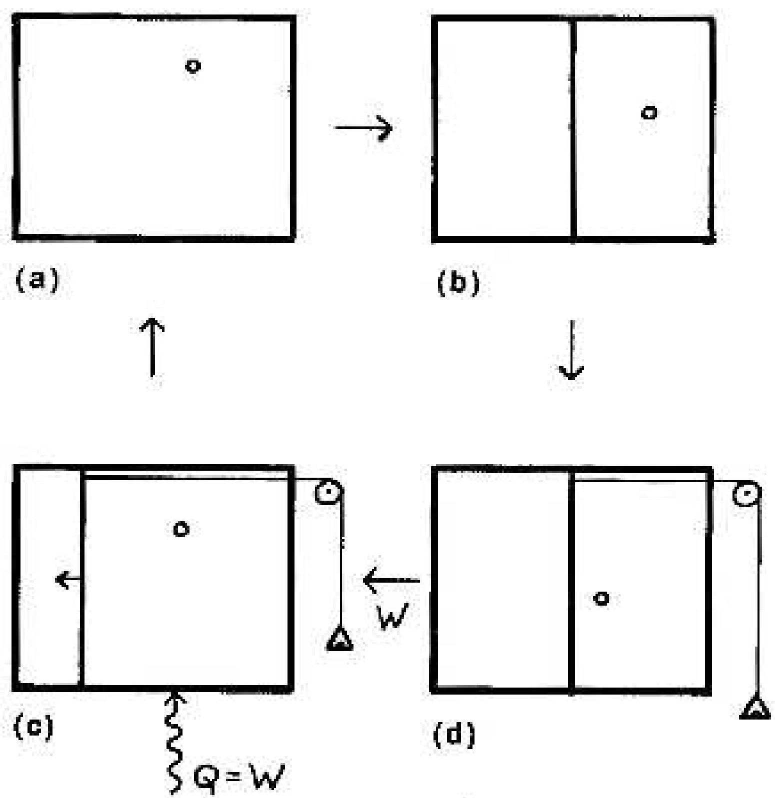
Work from heat



Block of 1 kg Cu, heat capacity 0.39 kJ/K.
Temperature difference 2Δ, either by demon or spontaneous.

- Entropy change: $\Delta S = \frac{C}{2} \ln \left(1 - \frac{\Delta^2}{T_0^2}\right) < 0$
- Work from a reversible machine: $w = C \frac{\Delta^2}{T_0}$
- Final temperature: $T_f = \sqrt{T_0^2 - \Delta^2}$
- Probability of such a fluctuation: $P = e^{\Delta S / k_B}$
- Spontaneous fluctuations: ≈ 1 fK.
- Energy is conserved.

Szilards One–Molecule Gas



Look where the atom is, and on the basis of that decide how to attach the weight. The work performed is equal to the heat to keep the atom at the same temperature.

Amount of work: $w = k_B T \ln 2$. Entropy loss: $\Delta S = -k_B \ln 2$.

Landauer's 'Solution'

- To decide if the molecule is on the left or the right we need 1 bit of information.
- For a cyclic process, the information needs to be erased.
- When information is erased, heat is generated.
- Heat dissipated in the environment increases entropy.
- The amount of entropy generated is $R \ln 2$.

Entropy and Information.

> The second law is a law about information — it operates at the level of information, not energy, and hence requires a separate bookkeeping system for information in order to impose the law. An implication of this line of thinking is that a description of physics based only on energy bookkeeping (i.e. a Hamiltonian/Lagrangian mechanics with energy as the generator of time evolution for the system) is incomplete. Of course the energy and information bookkeeping systems must be consistent with each other, but the dynamics of information is independent and equally necessary to describe the world.

T.L. Duncan and J.S. Semura, p. 22–23.

So: Burning a book with a story generaties more heat than burning a book with only random letters?

Not Everyone Agrees

> The relationship between entropy and lack of information has led many authors, notably Shannon, to introduce "entropy" as a measure for the information transmitted by cables and so on.[...] It must be stressed here that the entropy introduced in information theory is *not* a thermodynamic quantity and that the use of the same term is rather misleading.

D. ter Haar, *Elements of Statistical Mechanics*, p. 161.

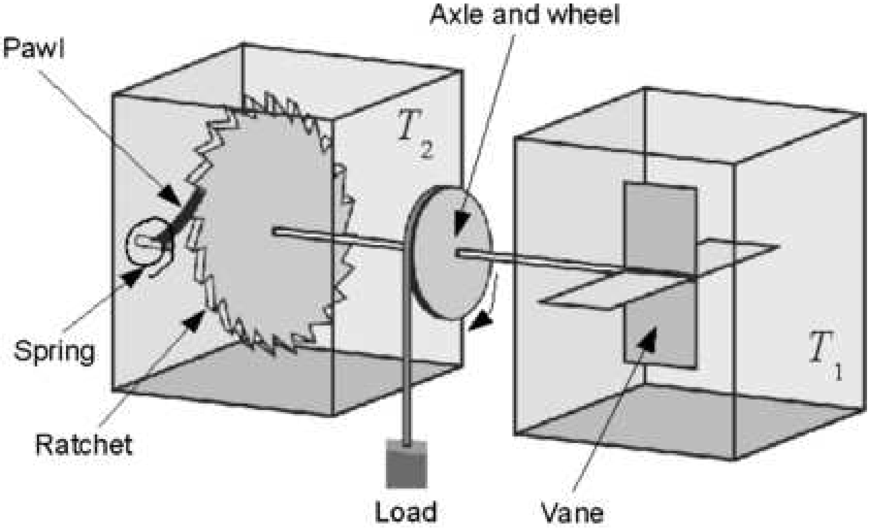
Does the enthalpy of formation or the molar entropy of:

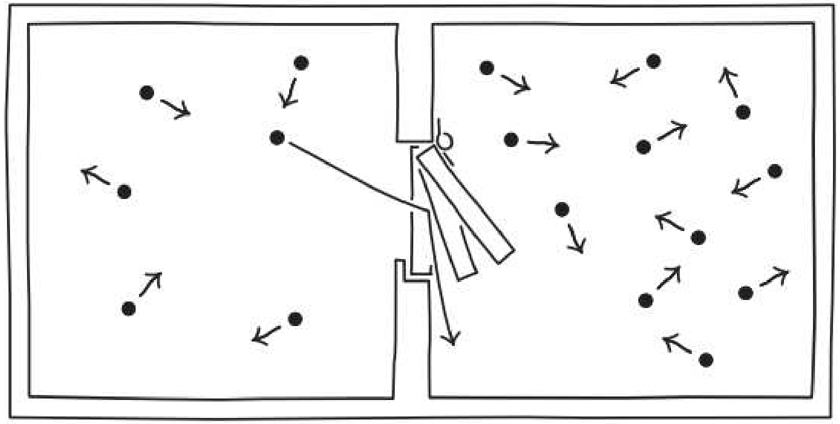
GGA ATT GGA GCA GTT CTG AAG GTA TTA ACC ACA GGA TTG CCC GCC CTC ATA AGT TGG ATT
Gly Ile Gly Ala Val Leu Lys Val Leu Thr Thr Gly Leu Pro Ala Leu Ile Ser Trp Ile

AAA CGT AAG AGG CAA CAG GGT TAG
Lys Arg Lys Arg Gln Gln Gly END

depend on the fact that this codes for melittin?

Feynman's Ratchet and Smoluchowski's Trapdoor





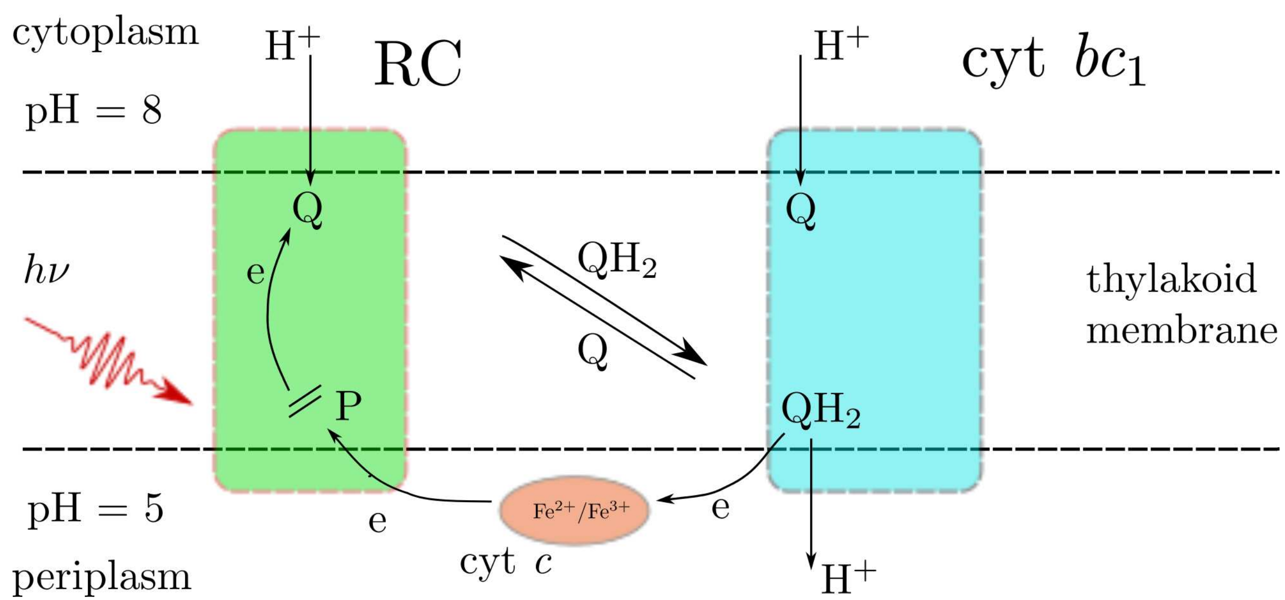
Living Systems

> Thus, $1-T/T_r$ represents a kind of efficiency horizon beyond which negative entropy is produced and the second law is not obeyed. As this is impossible for a heat machine, it serves to underline the difference between photosynthetic photochemistry and a heat machine.

Jennings *et al.*, 2005.

Unfortunately the paper is filled with errors and misconceptions (well, not according to Jennings *et al.* still.)

Photosynthesis Simplified



All that bacterial photosynthesis accomplishes is the transport of protons over a membrane against the gradient. It performs work using heat from the photon. One 870 nm photon can transport two protons.

- Work performed per two photons:

$$w = \Delta\mu = -2 \times 2.3 \times k_B T \Delta pH = 5.71 \times 10^{-20}\,\mathrm{J} \qquad (1)$$

- Heat taken from T_h:

$$q_h = \frac{hc}{\lambda} = 2.28 \times 10^{-19}\,\mathrm{J} \qquad (2)$$

- Heat dumped at low temperature (First law of Thermodynamics):

$$q_l = q_h - w = 1.71 \times 10^{-19}\,\mathrm{J} \qquad (3)$$

Heat, Work, and Entropy II

- Entropy change of the high temperature reservoir:

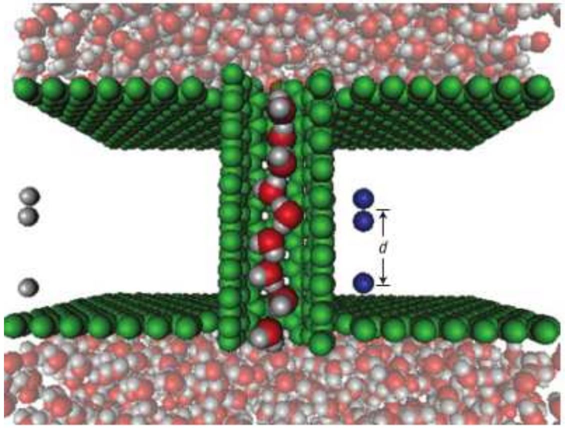
$$\Delta S_h = -\frac{2.28 \times 10^{-19}}{1100} = -3.8 \times 10^{-23}\,\mathrm{J/K} \tag{4}$$

- Entropy change of the low temperature reservoir:

$$\Delta S_l = \frac{1.71 \times 10^{-19}}{300} = 5.7 \times 10^{-22}\,\mathrm{J/K} \tag{5}$$

Total change of entropy: $\Delta_{\mathrm{tot}} S > 0$; efficiency: 25%; Carnot efficiency: 73%.

Membranes



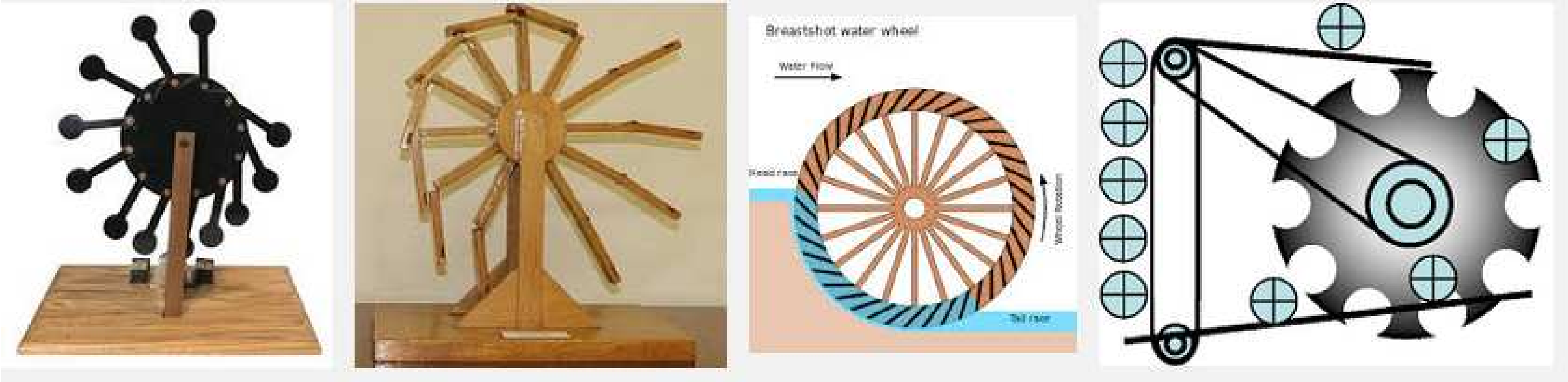
X. Gong *et al.* Nature 2007.

The design uses a combination of charges positioned adjacent to a nanopore...[].. where water can be easily driven by external fields in a concerted fashion. These findings may provide possibilities for developing water transport devices that function without osmotic pressure or a hydrostatic pressure gradient

One may argue that the pump we designed looks like a perpetual mobile. We should point out that extra energy is required to constrain the charges at their original positions, which is the key to the pumping ability.

Unfortunately this is based on a “feature” in Gromacs. (G. Groenhof)

And Besides:



One may argue that the wheel we designed looks like a perpetual mobile. We should point out that extra energy is required to constrain the masses at their original positions, which is the key to the rotating ability.

It does not work in a gravitational field either.

Nanotechnology

- Too much to list and comment upon, see literature list for a few prominent writers.
- In simulations it all seems to work.
- But in real life no one has succeeded so far.

However:

> Prospects are good for laboratory construction and testing of this solid state Maxwell demon in the near future.

D. Sheehan *et al.*, 2002.

PMM of the Second Kind, Helplessly Hoping?

In a recent paper the author introduces the concept of a vacuum capacitor spontaneously charged harnessing the heat absorbed from a single thermal reservoir at room temperature.[· · ·] In section 3 we show that if very weak provisos on the physical characteristics of the capacitor are fulfilled, then a nonzero current should flow across the device, allowing the generation of potentially usable voltage, current and electric power out of a single thermal source at room temperature.

G. D'Abramo, *Physica A* , **390**, (2011), 482.

Will we ever be clever enough?

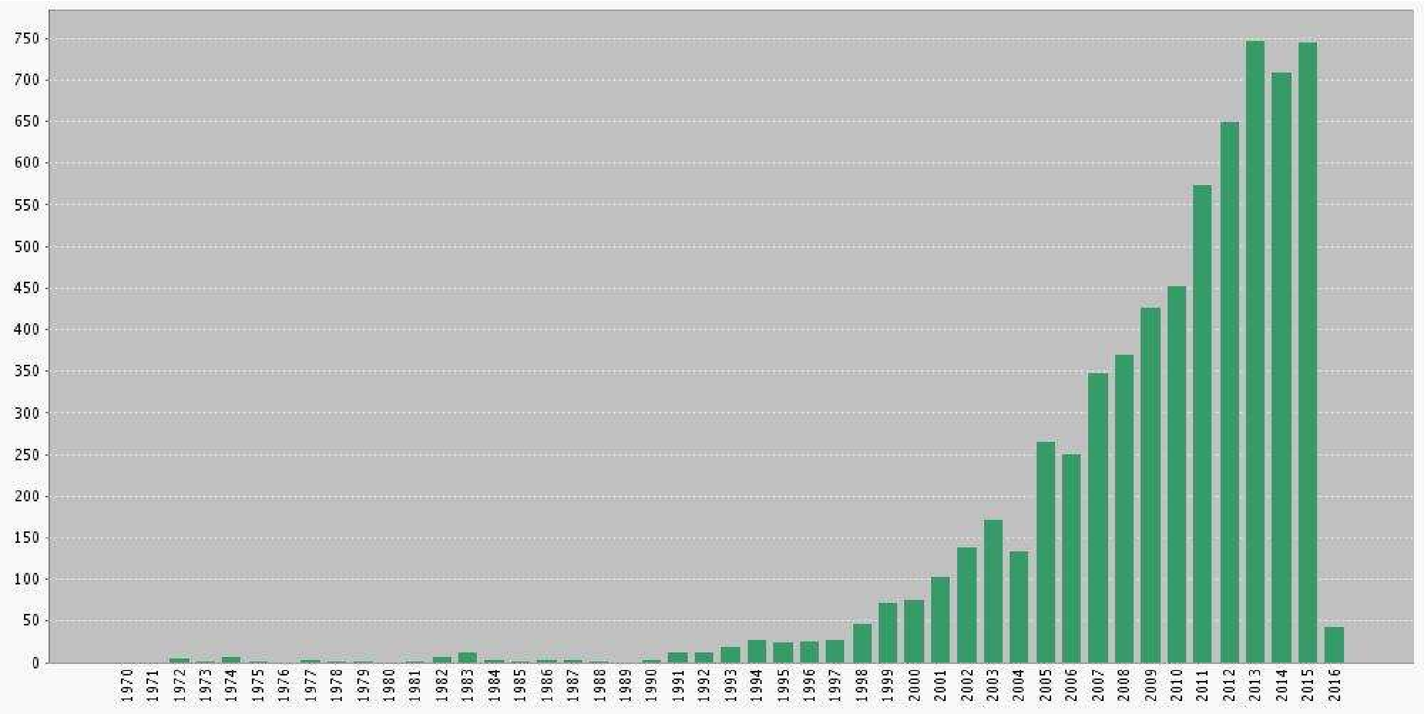
> In fact it would seem reasonable to define life as being characterized by a capacity for evading this law. If probably cannot evade the laws of atomic physics, which are believed to apply as much to the atoms of a brain as to the atoms of a brick, but it seems able to evade this statistical laws of probability.

James Jeans, 1933, p. 280.

> Whether the details of my calculations turn out to be correct or not, I think I have shown that there are good scientific reasons for taking seriously the possibility that life and intelligence can succeed in molding this universe of ours to their own purposes.

F. Dyson, 1979.

Demonic Papers



Number of times Maxwell's demon finds its way into citations.

The Last Question

And it came to pass that AC learned how to reverse the direction of entropy.

But there was now no man to whom AC might give the answer of the last question.

No matter. The answer – by demonstration – would take care of that, too.

For another timeless interval, AC thought how best to do this. Carefully, AC organized the program.

The consciousness of AC encompassed all of what had once been a Universe and brooded over what was now Chaos.

Step by step, it must be done.

And AC said, "LET THERE BE LIGHT!"

And there was light –

I. Asimov.

(AC = Automatic Computer, if you want a pdf of the story, let me know.)

Other Infinite Universes

1. Boltzmann: the (infinite) universe is in thermal equilibrium. Fluctuations bring small parts out of equilibrium, leading to a local low entropy state. We are now in a period where the universe is decaying back to equilibrium. Since the universe is infinite in time and space, this will happen an infinite number of times, in all possible variations.

2. Hugh Everett III: Many Worlds Interpretation of quantum mechanics. Every time the wavefunction seems to collapse in our universe, it is not really collapsing, but a new universe splits off for the other possible choices. Actually believed by about 20% of physicists.

3. Andrei Linde: Every now and then a quantum fluctuation produces a big bang. The universe that comes into existence has arbitrary properties of the constants, so most of them amount to nothing, but in some of them, like our own, the constants are just right (This is the *Goldilocks Principle*) and life as we know it can evolve.

Universes Thicker than Blackberries

4. David Lewis: Every logically possible universe is out there, somewhere.

5. Lee Smolin: Spawning of universes is governed by Darwinian principles: if universes do better (whatever that may be, building intelligent structures?) the chance that they become more prevalent becomes larger. Universes with the good constants start to prevail.

6. Roger Penrose: Cycles of Time. The universe starts with a Big Bang, and then proceeds to the Big Crunch. A conformal transformation turns this into a new Big Bang. Traces of black hole collisions in the previous universe may still be visible in the cosmic background radiation.

Wanna go around again?

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