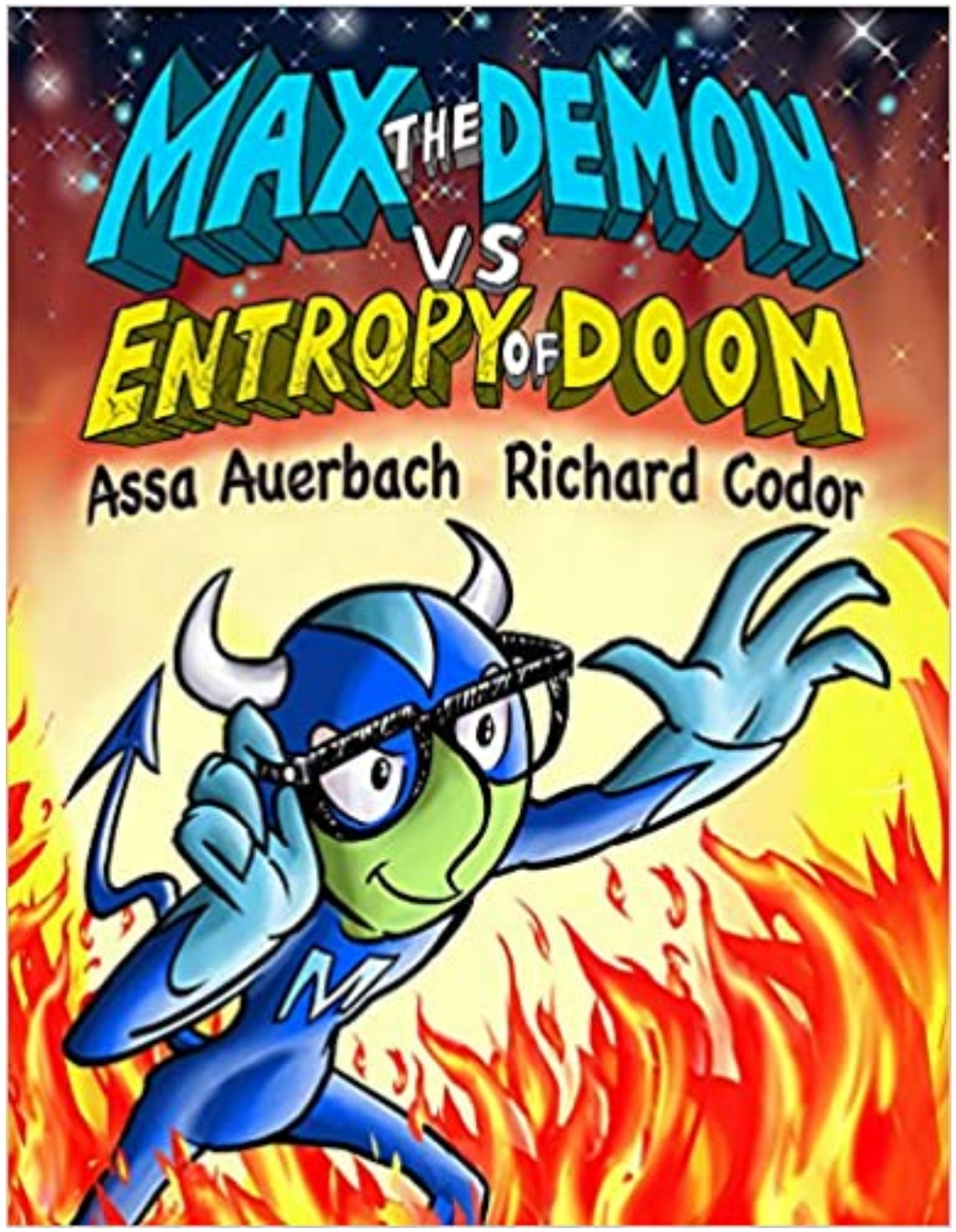
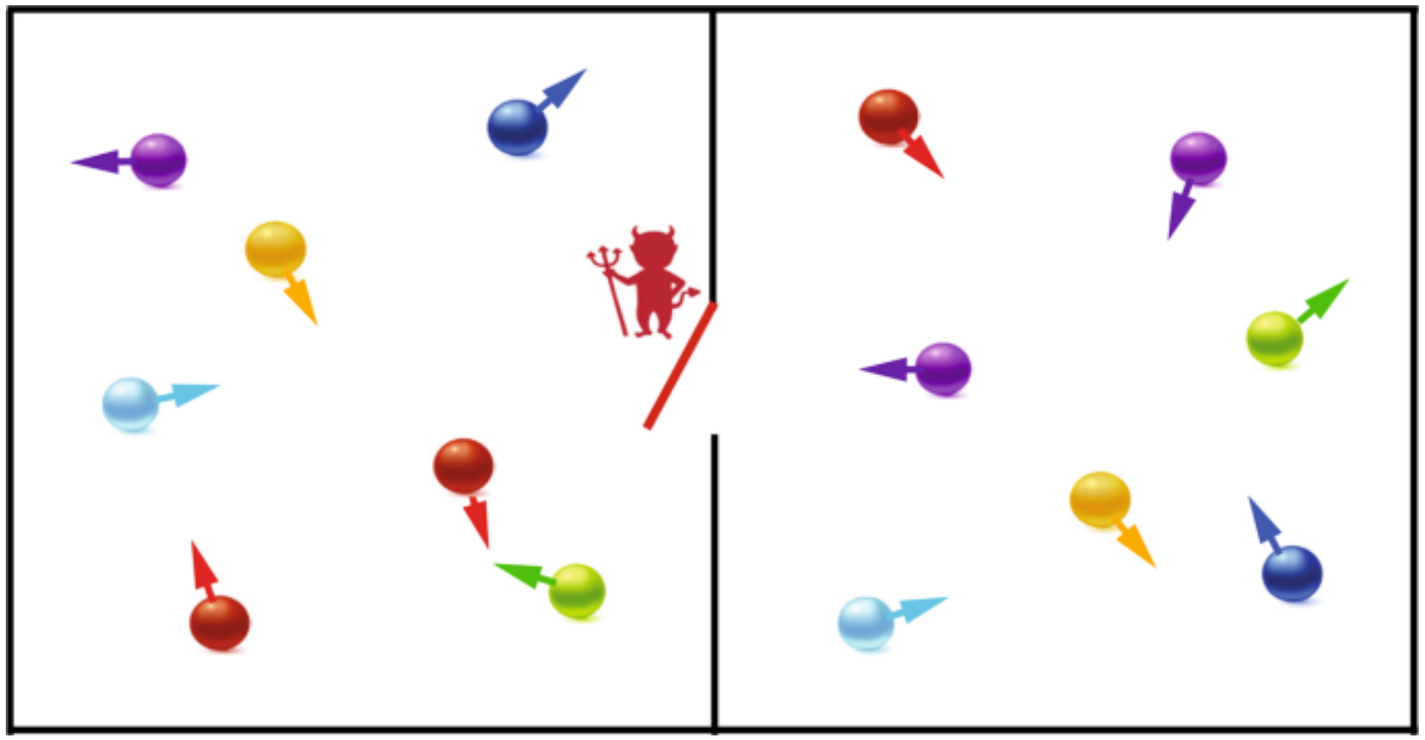
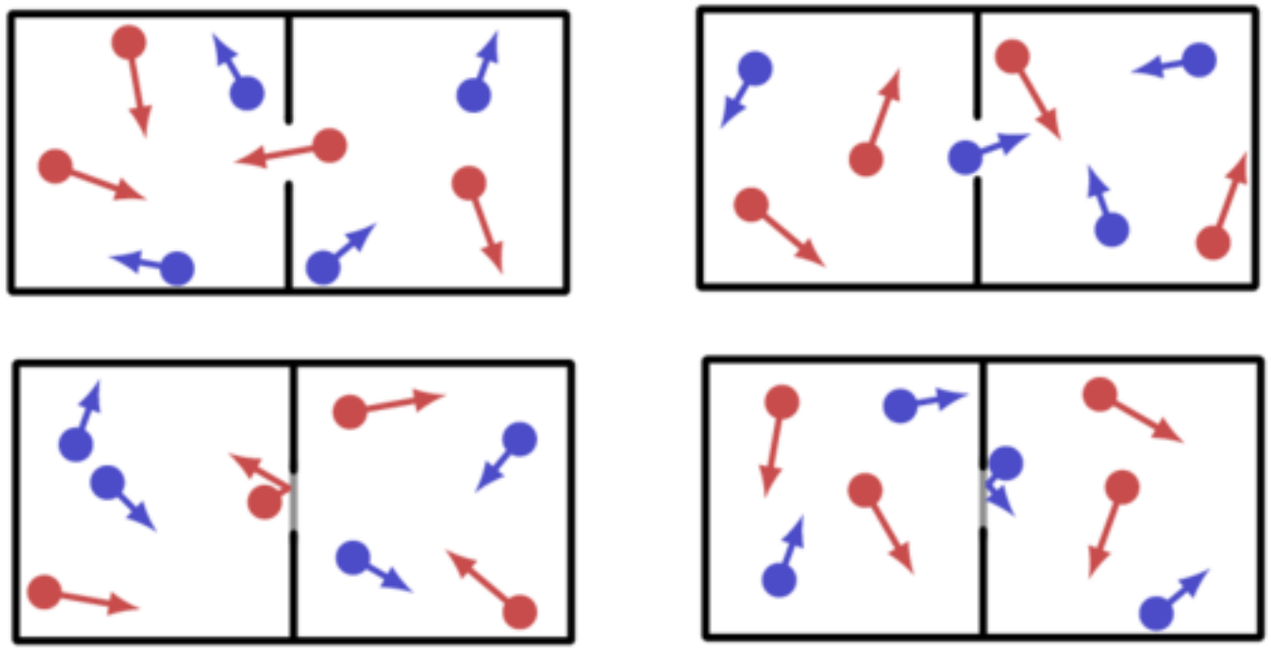
Maxwell's Demon

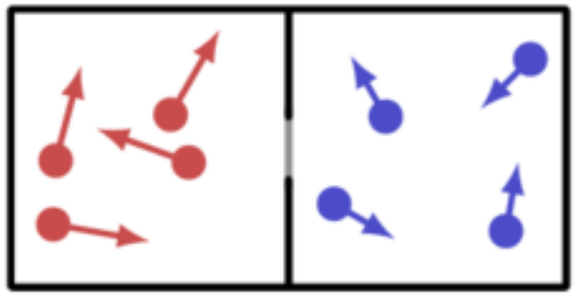


Maxwell (1871), reprinted in Leff & Rex (1990)

... if we conceive of a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are as essentially finite as our own, would be able to do what is impossible to us. For we have seen that molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform, though the mean velocity of any great number of them, arbitrarily selected, is almost exactly 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 molecules 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.

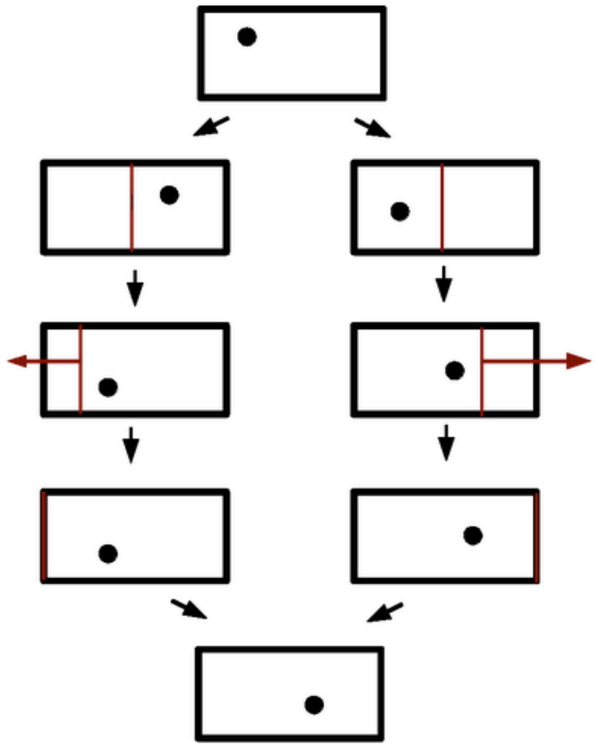






Szilard ``engine”

single molecule in box in contact with heat reservoir T



Moving partition extracts from reservoir work
$Q=-kT\ln(2)$ so $\Delta S = -k\ln(2)$

… but only by knowing which way to move partition.
1 bit of information ``negentropy” $\Delta S = +k\ln(2)$

Mark G. Raizen, *Science* **324**, 1403 (2009)

SCIENTIFIC AMERICAN MARCH 2011

Demons, Entropy, and the Quest for Absolute Zero

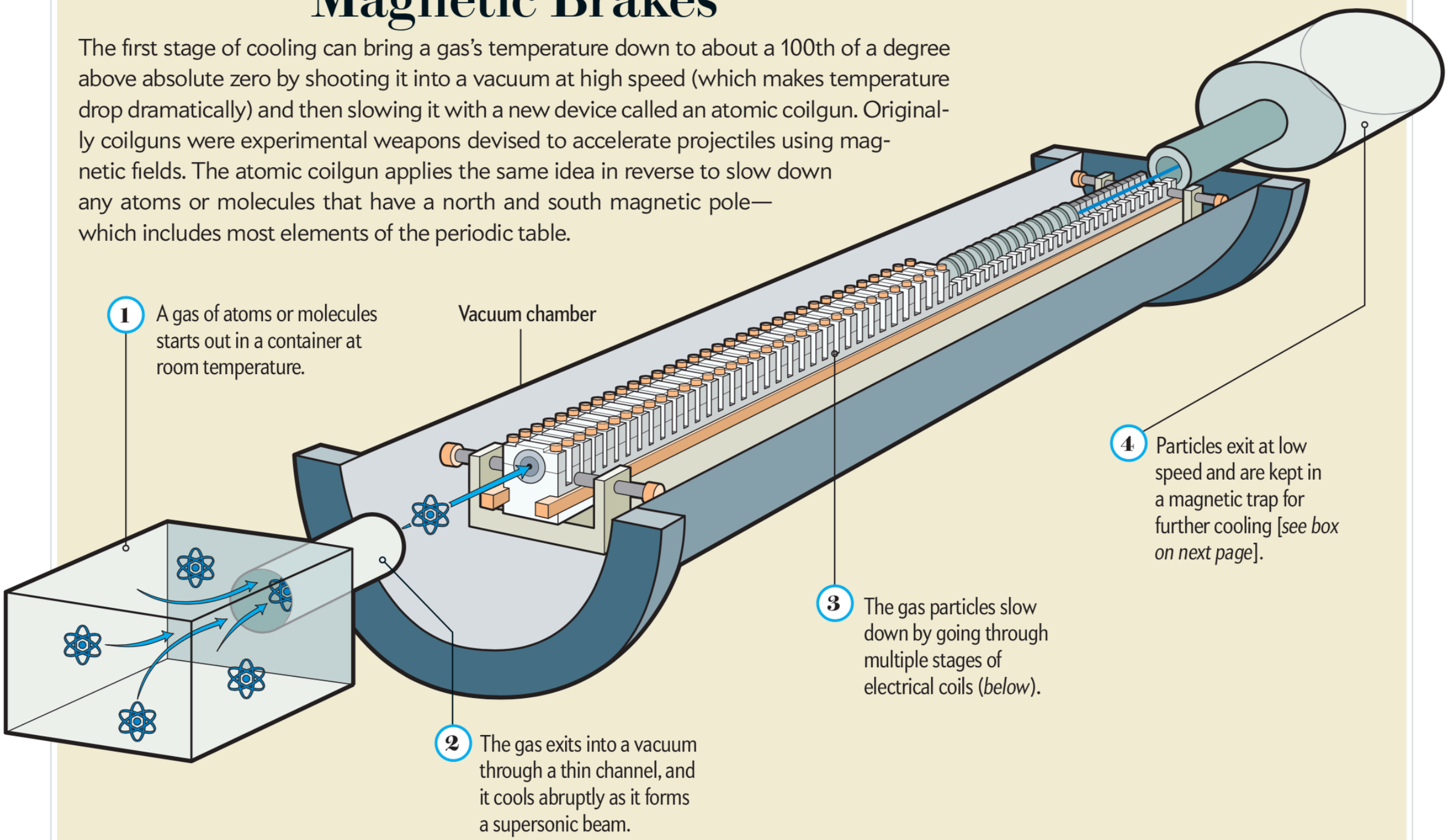
A 19th-century thought experiment has turned into a real technique for reaching ultralow temperatures, paving the way to new scientific discoveries as well as to useful applications

By Mark G. Raizen

Technique of “atomic coil gun” cools a gas to hundredths of a degree above absolute zero.

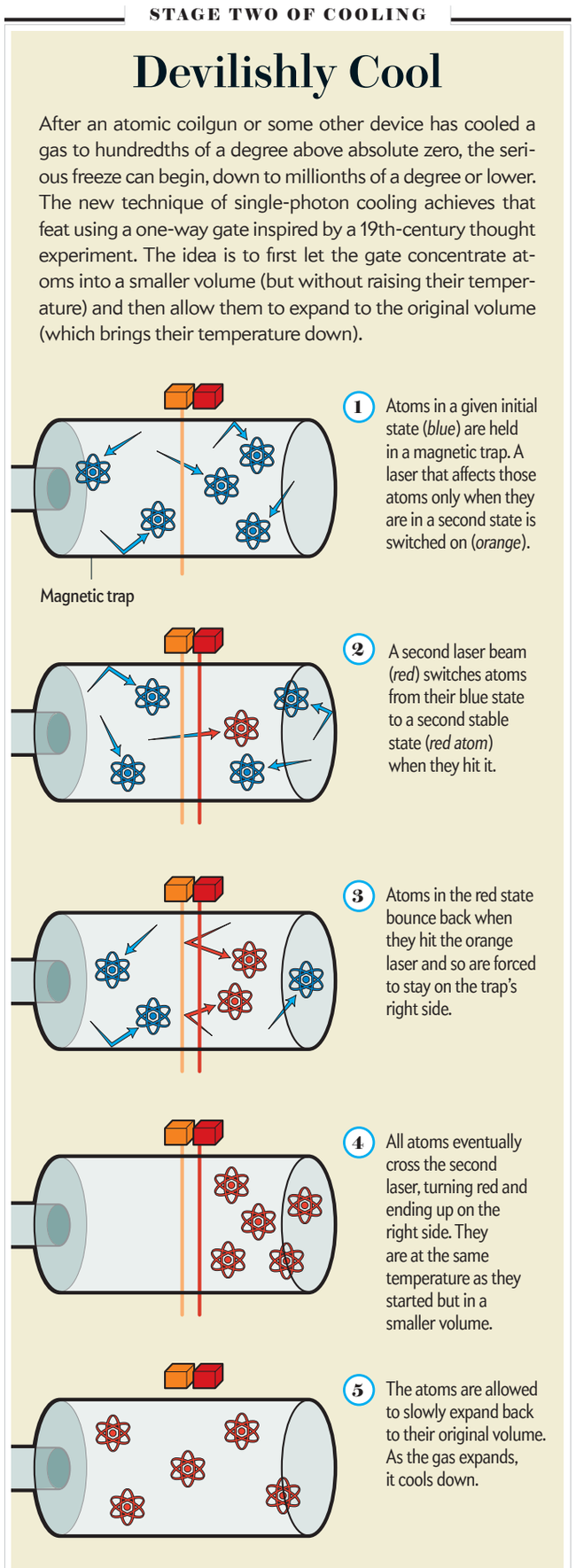
Magnetic Brakes

The first stage of cooling can bring a gas's temperature down to about a 100th of a degree above absolute zero by shooting it into a vacuum at high speed (which makes temperature drop dramatically) and then slowing it with a new device called an atomic coilgun. Originally coilguns were experimental weapons devised to accelerate projectiles using magnetic fields. The atomic coilgun applies the same idea in reverse to slow down any atoms or molecules that have a north and south magnetic pole—which includes most elements of the periodic table.



Next trick,
“single photon cooling”
T < 10E-6 K

Single photon cooling



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One-way gate: Atom turns from blue state to red state by scattering of single photon. Photon has entropy

$$S/\langle N\rangle = 3.60\ k$$

…we pointed out that when an atom scatters one photon, the photon carries away with it information about that atom—and thus a tiny quantum of entropy. Moreover, whereas the original photon was part of an orderly train of pho- tons (the laser beam), the scattered photons go off in random directions. The photons thus become more disordered, and we showed that the corresponding increase in the entropy of the light exactly balanced the entropy reduction of the atoms because they get confined by the one-way gate. Therefore, single- photon cooling works as a Maxwell demon in the very sense envisioned by Leo Szilard in 1929.

Simon van der Meer and the anti-proton beam
W,Z boson discovery 1983

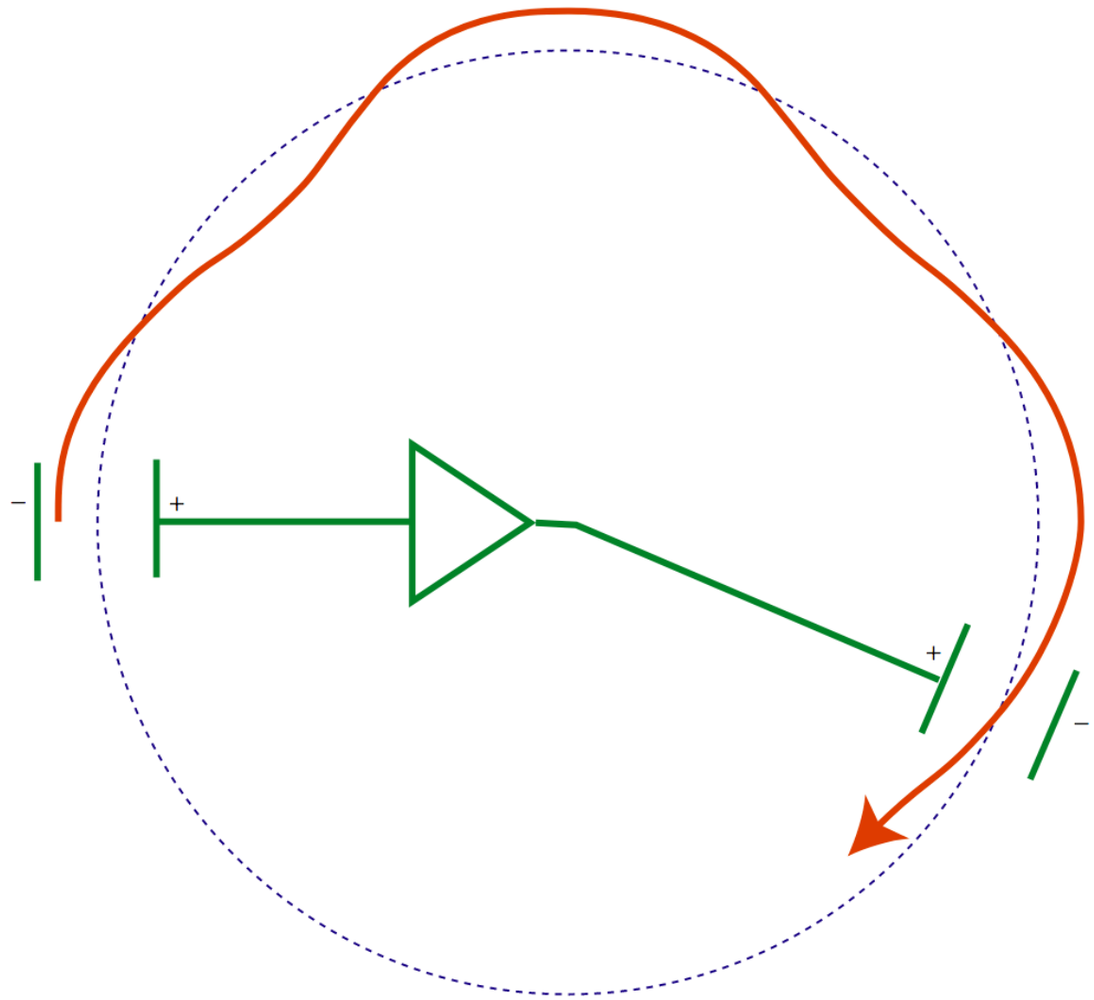

Figure 1. A cartoonist's view of a transverse stochastic cooling system.

cooling of beam in transverse direction

figure from "Stochastic Cooling Overview", John Marriner
NIM A, 532 (1–2): 11–18, arXiv:physics.acc-ph/0308044,

https://www.nobelprize.org/uploads/2018/06/meer-lecture.pdf

Such a system resembles Maxwell's demon, which is supposed to reduce the entropy of a gas by going through a very similar routine, violating the second law of thermodynamics in the process. It has been shown by Szilard1 that the measurement performed by the demon implies an entropy increase that compensates any reduction of entropy in the gas. Moreover, in practical stochastic cooling systems, the kicker action is far from reversible; such systems are therefore even less devilish than the demon itself.