SNOLAB Journal Club

Richard Ford (SNOLAB), 29th July 2009

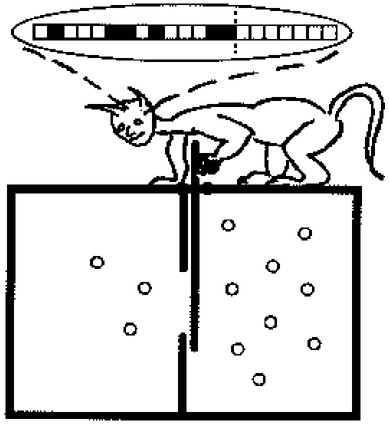
Paper: “Single-Photon Atomic Sorting: Isotope Separation with Maxwell’s Demon”, arXiv:1001.0944v2, May 2010.

Background: “Single-photon cooling at the limit of trap dynamics: Maxwell’s demon near maximum efficiency”, New Journal of Physics 11 (2009) 063044.

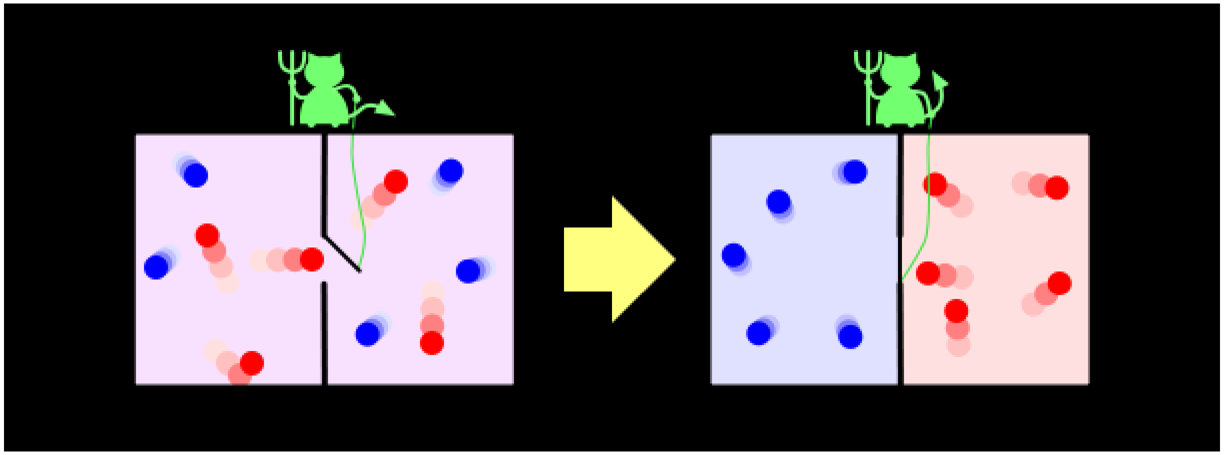
Maxwell’s Demon: A thought experiment to devise a way to break the 2nd law of thermodynamics.

2nd Law: In an isolated system not in equilibrium the entropy can only increase.

In the experiment the demon operates the trap door and sorts the gas molecules by speed, creating a temperature difference, and thus apparently breaking the 2nd law.



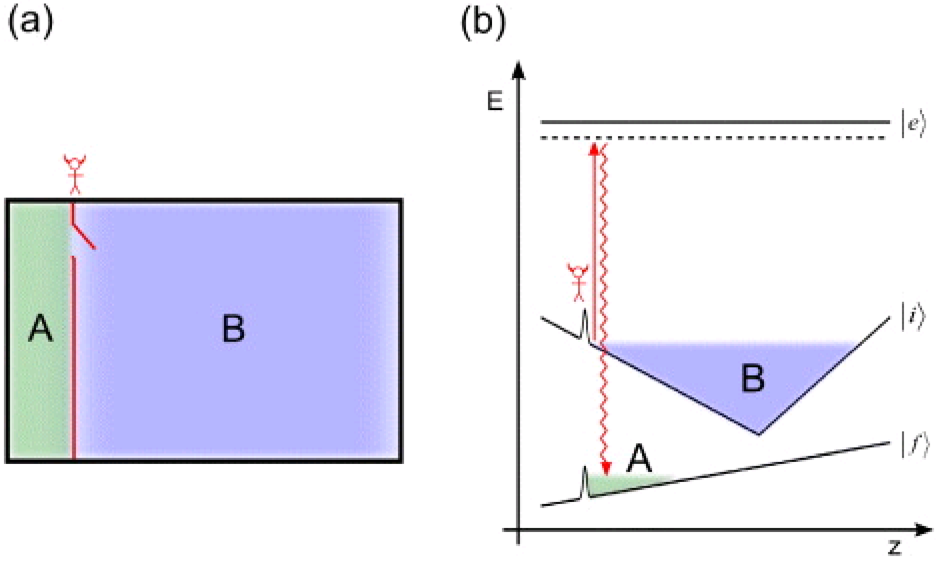
Turn’s out that if you include the demon in the analysis, who must expend energy to “measure” and “analyse” the molecules, can entropy increases.



Practical application: Ranque-Hilsch vortex tube

Single-Photon cooling

- Single-atom traps are often referred to as “maxwell’s demon” because single atoms or molecules are manipulated as the demon must do.
- The author’s have written previous papers about pumping atoms from magnetic states into non-magnetic states transferred to an optical trap, with Raman tuning to higer kinetic energies (like the demon operating the trap door)..



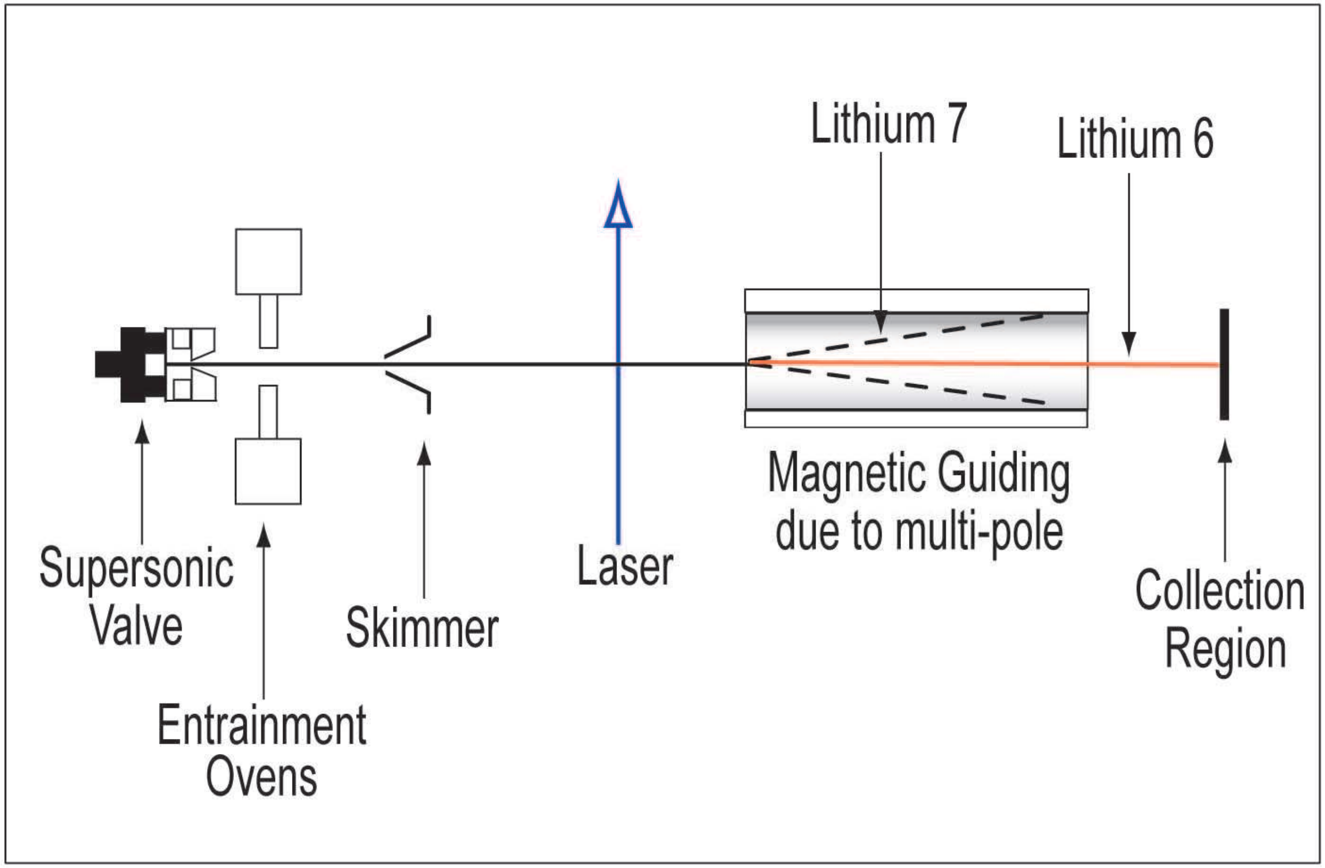
Isotope separation methods

- Isotope separation standard techniques: gaseous difussion and ultra-centrifuge. Many stages – very inefficient, and needs gas phase.
- Another method is mass spectroscopy, but inefficient due to electron-bombardment ionization and space-charge effects.
- Lately also have the laser ionisation method AVLIS (uses hyperfine structure to selectively tune), then selective photoionization. Limited by laser power and resonant charge exchange.
- This new method uses laser pumping to select on the magnetic moment differences, without ionisation.

Single-Photon Atomic Sorting

- Start with supersonic beam, in order to get a well collimated and uniform beam (few degree divergence and ~1% velocity spread). Desired element can be entrained into carrier gas flow.
- Laser acts as Maxwell’s demon. Atoms in the beam scatters the laser photon, so that total entropy increases, even though the beam becomes sorted (by isotope in this case, and not by velocity).
- Laser excites atomic state from |i> to |e>, with spontaneous de-excitation to state |f>. Magnetic moment of state |i> m_i is different than for |f> m_f.

Schematic of the isotope separation method for ^{7}Li/^{6}Li



A laser is tuned to the D_2-line of ^{7}Li (670.96 nm) and populates all the atoms into the $2^2S_{1/2}$ (F=2) manifold, forcing them to be anti-guided. Field about 50 G. Some 6Li lost due to sub-level projections. Beam mean velocity 800m/s with Li entrained in He beam.

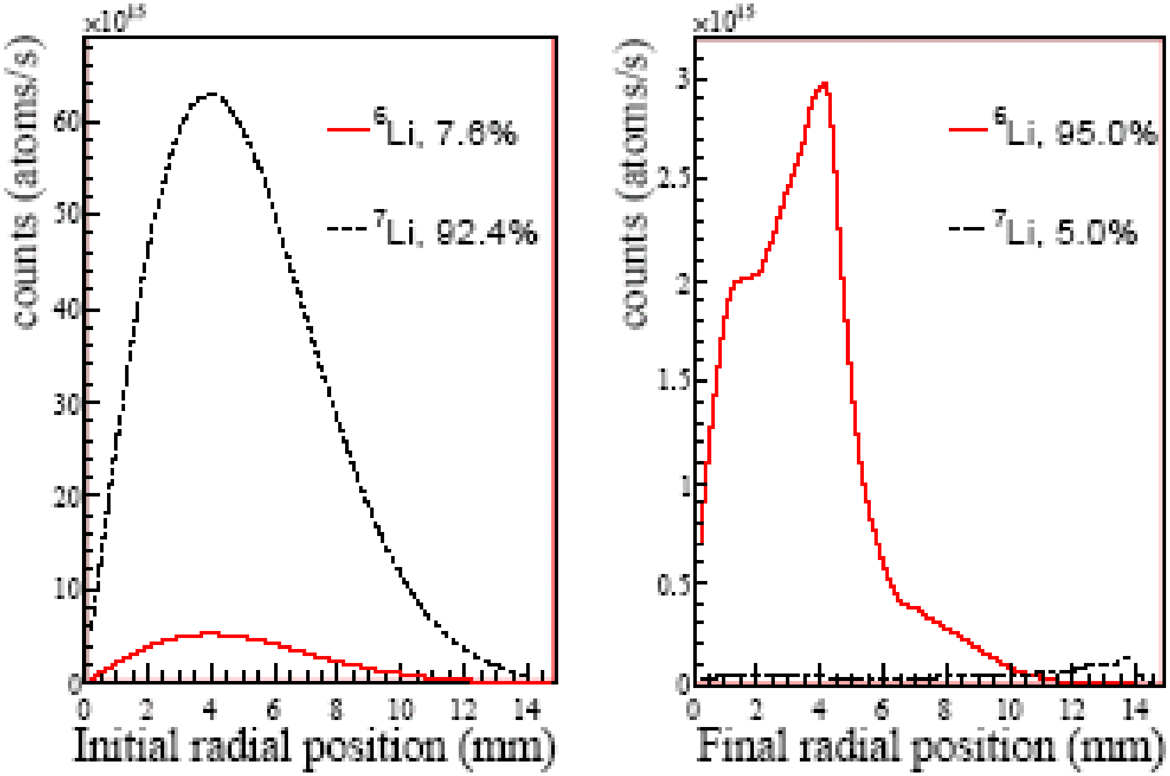


FIG. 2: The radial positions of the two lithium isotopes as they enter the magnetic gradient that separates them isotopically, followed by their radial positions upon exiting.

Simulation results of isotope separations with single-photon sorting

Target Isotope	Natural Abundance	Laser λ (nm)	Ground State	Guiding Length (m)	Enrich-ment	Collected Isotope %
^{6}Li	7.6%	670.96	$^{2}S_{1/2}$	Quad. 0.5	95.0%	36.8%
^{44}Ca	2.1%	272.2	$^{1}S_{0}$	Hex. 2.0	99.9%	9.0%
^{150}Nd	5.6%	471.9	$^{5}I_{4}$	Hex. 2.0	97.9%	23.0%

TABLE I: Simulation results of isotope separation from single-photon atomic sorting.

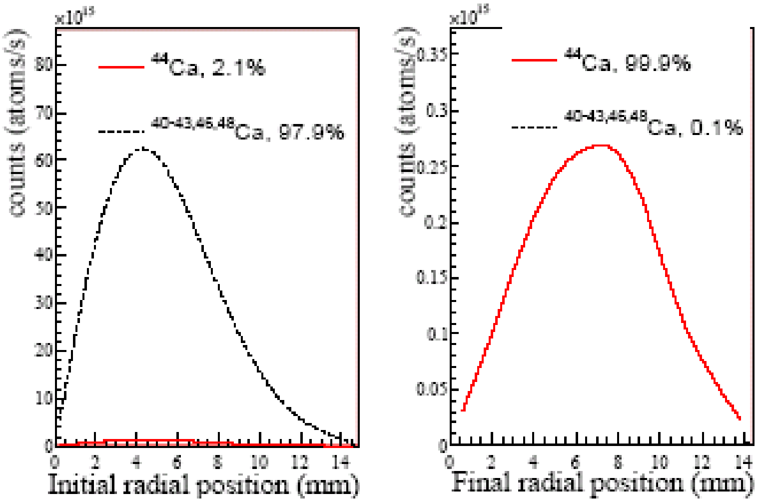


FIG. 4: The radial positions of the calcium isotopes as they enter the magnetic gradient that separates them isotopically, followed by their radial positions upon exiting.

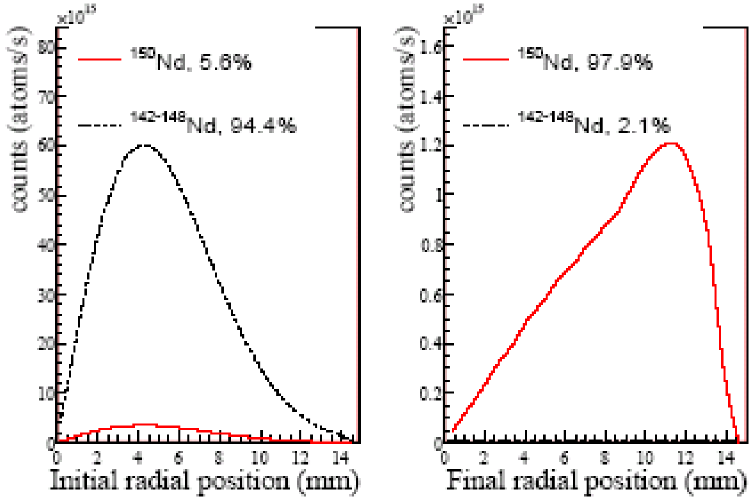


FIG. 5: The radial positions of the neodymium isotopes as they enter the magnetic gradient that separates them isotopically, followed by their radial positions upon exiting.