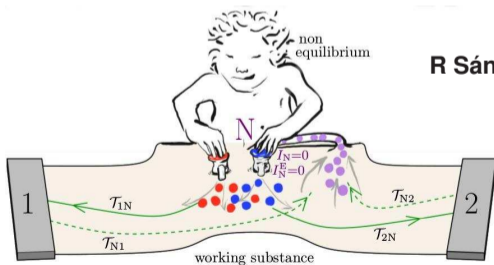




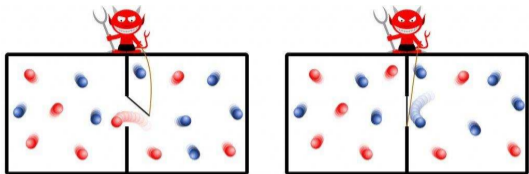
A non-equilibrium system as a demon

Robert S. Whitney

R Sánchez, J Splettstoesser, RW
arXiv:1811.02453



OVERVIEW



Maxwell (1867)

“... the hot system is getting hotter and the cold colder,
and yet **no work has been done**,

only the intelligence of a **very observant and neat-fingered being**

has been employed”



Detection

of **individual** particles



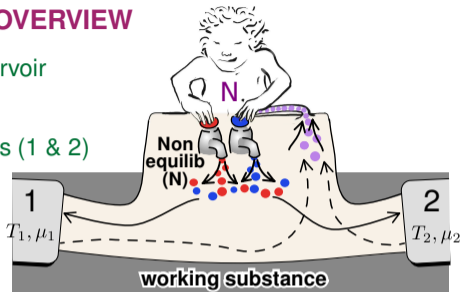
Here we propose demons WITHOUT this

OVERVIEW

DEMON = non-equilibrium reservoir

WORKING SUBSTANCE

= two equilibrium reservoirs (1 & 2)



♠ Demon **reduces** entropy of working substance **WITHOUT** supplying work or other energy

(i) Heat \rightarrow electric power (reservoirs cool down)

(ii) Heat flows cold \rightarrow hot

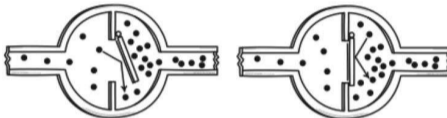
♠ **Practical use:** spatial separation of work & heat production?

Nanoscale thermal management

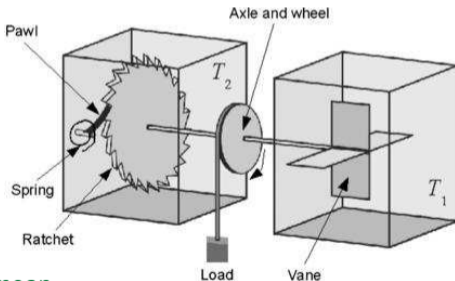
BRIEF HISTORY OF MAXWELL'S DEMON 1

♠ Maxwell's 2nd letter (undated): demon generate pressure difference
⇒ mechanical work

♠ Smoluchowski (1912)



♠ Feynman ratchet
(actually Smoluchowski, 1912)



⇒ He concluded: fluctuations mean
“mechanical” demons do NOT violate 2nd law

BRIEF HISTORY OF MAXWELL'S DEMON 2

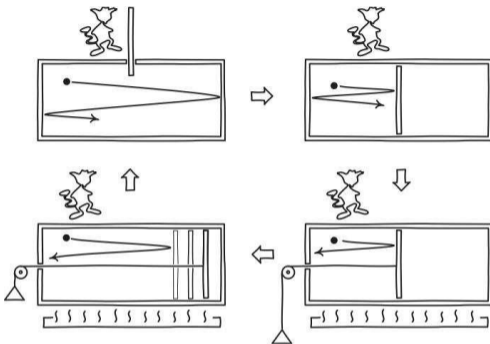
♠ Szilard Engine (1927)

J.D. Norton's sketch

www.pitt.edu/~jdnorton/

+ many papers on demons

Effect not destroyed
by fluctuations



♠ Bennett (1982) "Exorcizing Maxwell's demon"

Demon's memory: Starts cycle in state 0

Ends cycle in mixture 0 & 1

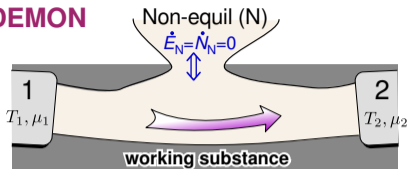
⇒ reset memory each cycle (Landauer erasure)

generates entropy (due to 2nd law) ⇒ 2nd law

THERMODYNAMIC FOR OUR DEMON

Non-equil reservoir N has
 $\Delta S_N \neq \Delta Q_N/T_N$

Hence steady-state
 $\dot{S}_N \neq J_N/T_N$



DEFINE "DEMON CONDITIONS":

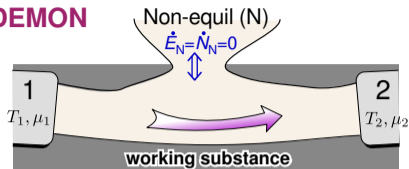
N provides no energy, particles or heat ($I_N = I_N^E = J_N = 0$)

... but its entropy increases $\dot{S}_N > 0$

$$\Rightarrow \text{2nd law: Total entropy} = \dot{S}_N + \frac{J_1}{T_1} + \frac{J_2}{T_2} \geq 0$$

$$\Rightarrow \text{1st law (energy conservation)} J_1 + J_2 + P = 0 \quad \text{for power output } P$$

THERMODYNAMIC FOR OUR DEMON



Case 1: power generation = particle flow from low μ_1 to high μ_2
with 1 & 2 at temp T

♠ non-zero power output: $P \leq T \dot{S}_N$

♠ Cooling 1 & 2: $J_1 + J_2 = -P$

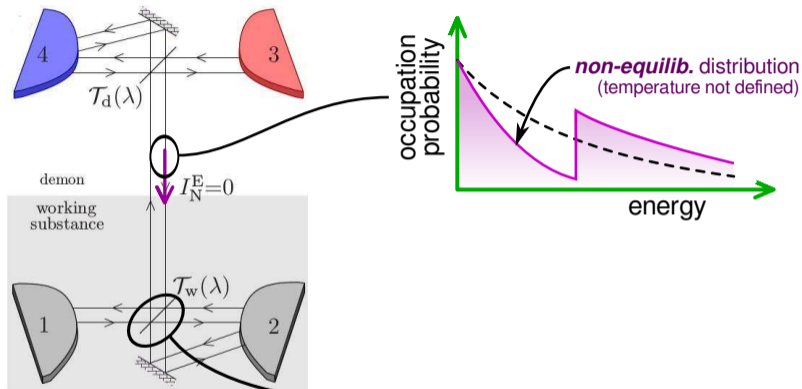
⇒ Apparent violation of Kelvin version of 2nd law

Case 2: refrigeration = heat flow from cold (1) to hot (2)
with no work by 1 or 2: $\mu_1 = \mu_2$

♠ negative heat flow: $J_1 \geq -\frac{T_1 T_2}{T_2 - T_1} \dot{S}_N$

⇒ Apparent violation of Clausius version of 2nd law

OPTICAL DEMON



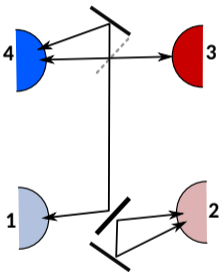
PARTIALLY REFLECTIVE MIRROR

- energy-dependent reflectivity
- breaking of $1 \leftrightarrow 2$ symmetry

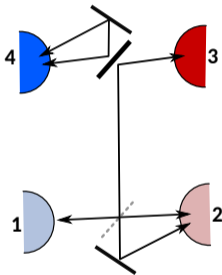
OPTICAL DEMON: example of how it works

consider temperatures: $T_4 < T_1 < T_2 < T_3$

Energy $< \mathcal{E}_D$



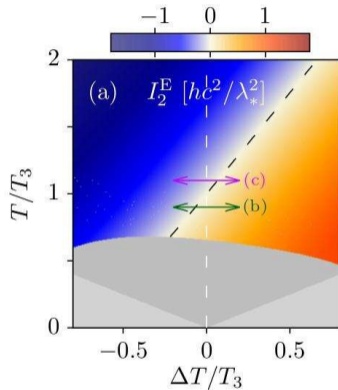
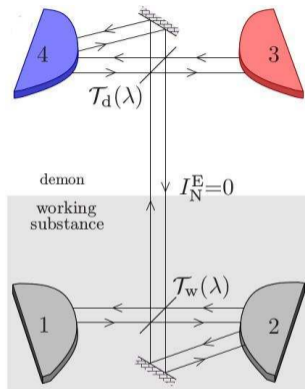
Energy $> \mathcal{E}_D$



- Low energies: heat flows $1 \rightarrow 4$
- High energies: heat flows $3 \rightarrow 2$

NET EFFECT : heat flow $1 \rightarrow 2$
when $T_1 < T_2$

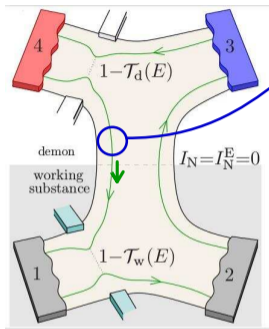
OPTICAL DEMON



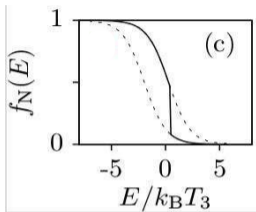
Spatial separation:

- Work production \Rightarrow working substance
- Entropy production \Rightarrow demon

QUANTUM HALL DEMON



NON-EQUIL DISTRIBUTION

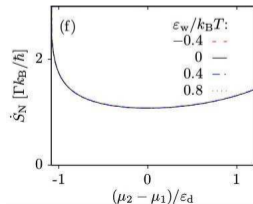
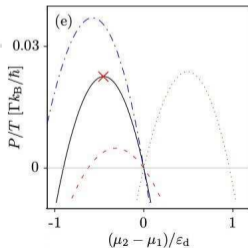
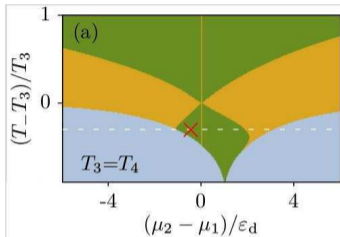
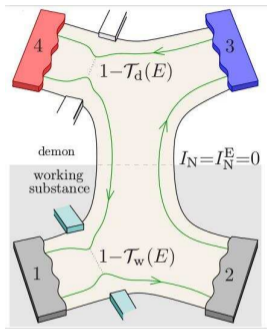


Solve using Landauer-Buttiker scattering theory for 4 reservoir system

\Rightarrow calculate I_i & I_i^E

energy & particles conserved

QUANTUM HALL DEMON



WORK IN PROGRESS: CONNECTION TO ERGOTROPY??

thank to Luis Correa for suggestion

Francica, Goold, Plastina, and Paternostro, NPJ Quantum Info (2017)

Mini-review:

Ghosh, Niedenzu, Mukherjee, and Kurizki, arXiv:1803.10053

Them: non-thermal state = squeezed — pump cycles (driven) ??

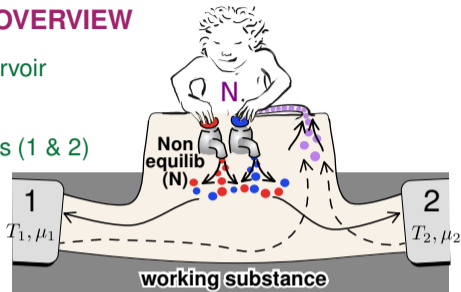
Us: non-thermal state = classical — steady-state (undriven)

OVERVIEW

DEMON = non-equilibrium reservoir

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= two equilibrium reservoirs (1 & 2)



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Nanoscale thermal management