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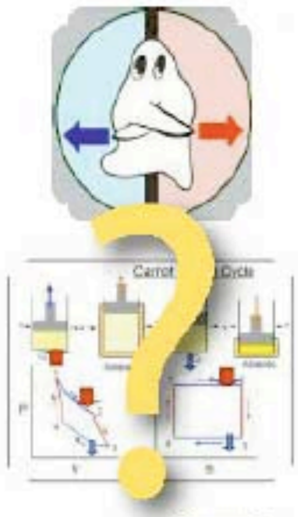
Optimization At a Small Scale

UCSD • July 20-21 • 2009

Home | Objective | Venue | Program | Additional Info | Participants | Tourist Info



Organizers

Katja Lindenberg, UCSD klindenberg@ucsd.edu

Christian Van den Broeck, Hasselt University
christian.vandenbroeck@uhasselt.be

Local Committee

Katja Lindenberg, UCSD klindenberg@ucsd.edu

Misha Galperin, UCSD migalperin@ucsd.edu

Massimiliano Esposito, UCSD maesposi@ucsd.edu

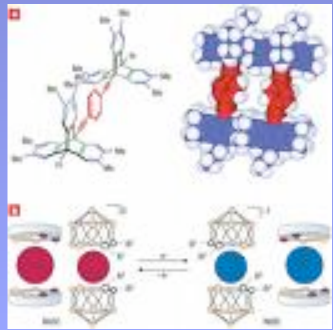
Sponsors

European Science Foundation
EPSD network
University of California San Diego
National Science Foundation
UCSD funds: Kurt Shuler, Misha Galperin, Katja Lindenberg

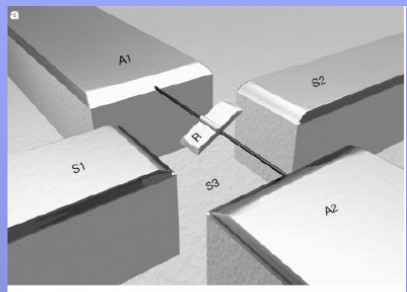
Patricia Edwins

Exploring The Physics of Small Devices

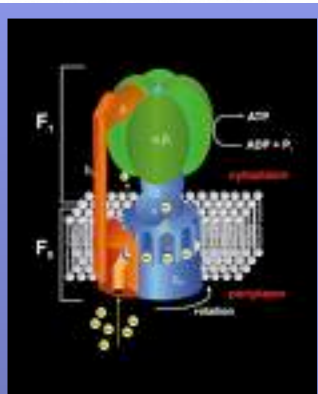
- Chemical



- Physical



- Bio-physical

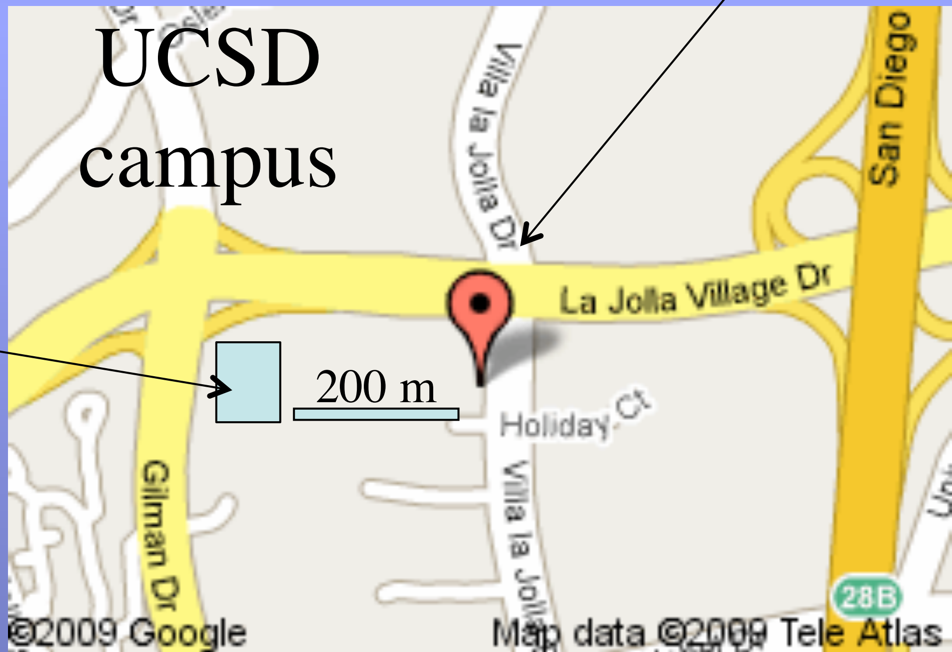


Austria	C. Dellago
Belgium Flemish	C. Van den Broeck
Belgium Walloon	P. Gaspard
Czech Republic	E. Hulicius
Finland	J. Pekola
Germany	U. Seifert
Ireland	J. Gleeson
Norway	A. Hansen
Spain	JMR Parrondo
Sweden	Hongqi Xu
Switzerland	MO Hongler

Tuesday night 6:30

El Torito (Mexican Restaurant)

Marriott Residence Inn



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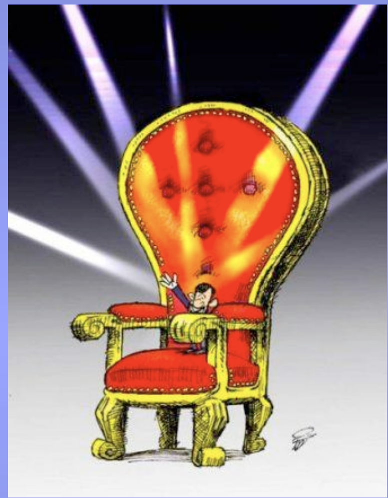
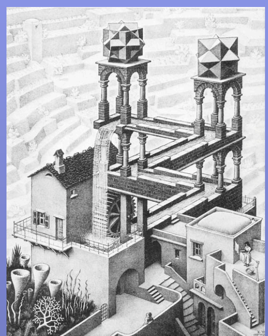
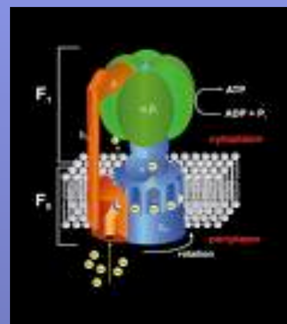
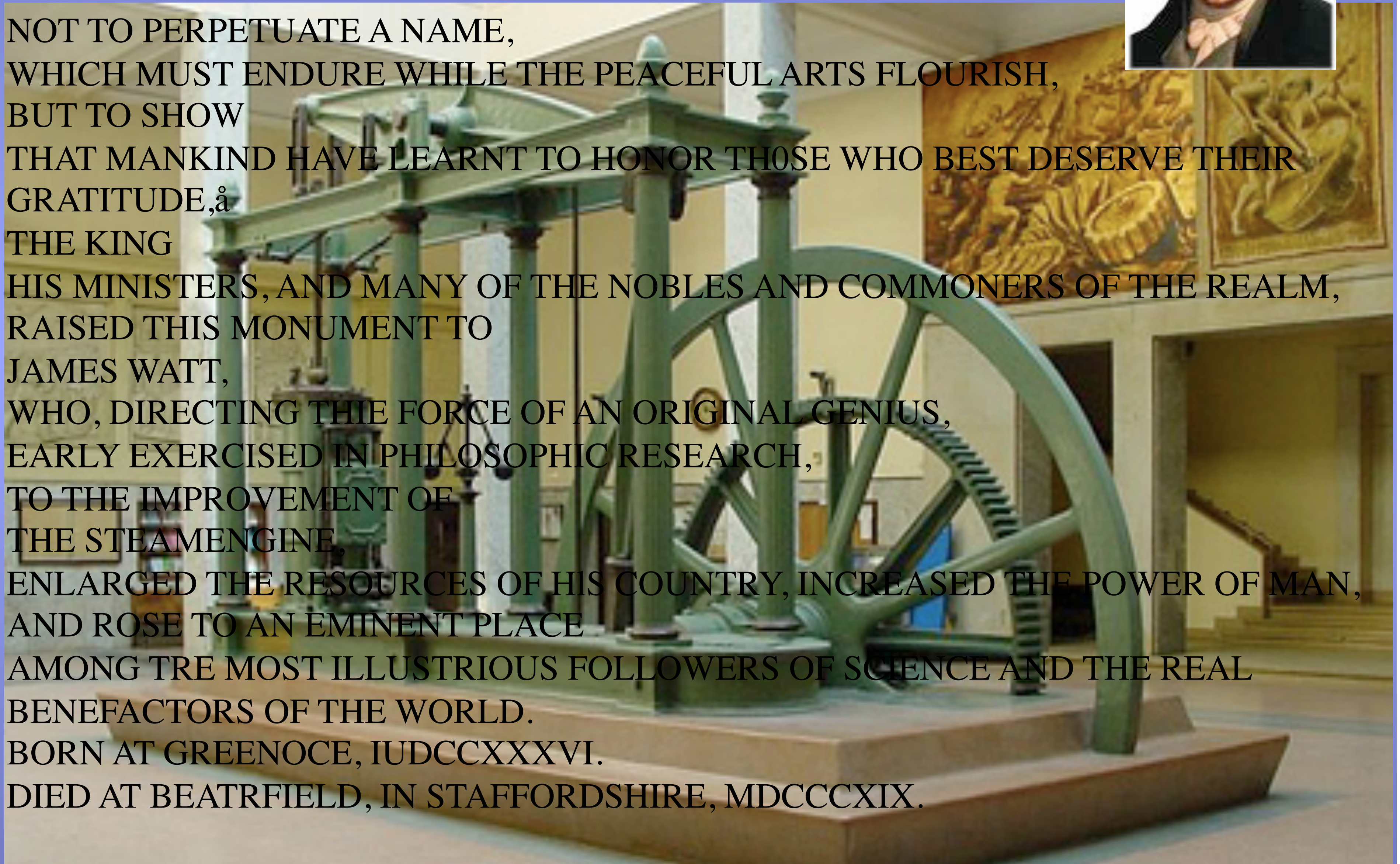


Universality of Efficiency At Maximum Power

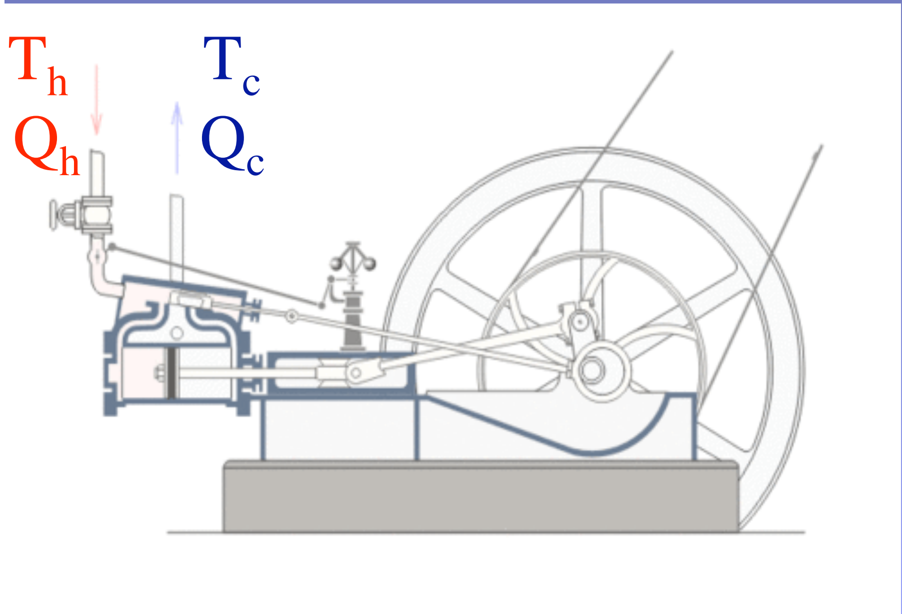


Christian Van den Broeck
Universiteit Hasselt
christian.vandenbroeck@uhasselt.be





NOT TO PERPETUATE A NAME,
WHICH MUST ENDURE WHILE THE PEACEFUL ARTS FLOURISH,
BUT TO SHOW
THAT MANKIND HAVE LEARNT TO HONOR TH0SE WHO BEST DESERVE THEIR GRATITUDE,å
THE KING
HIS MINISTERS, AND MANY OF THE NOBLES AND COMMONERS OF THE REALM,
RAISED THIS MONUMENT TO
JAMES WATT,
WHO, DIRECTING THIE FORCE OF AN ORIGINAL GENIUS,
EARLY EXERCISED IN PHILOSOPHIC RESEARCH,
TO THE IMPROVEMENT OF
THE STEAMENGINE,
ENLARGED THE RESOURCES OF HIS COUNTRY, INCREASED THE POWER OF MAN,
AND ROSE TO AN EMINENT PLACE
AMONG TRE MOST ILLUSTRIOUS FOLLOWERS OF SCIENCE AND THE REAL BENEFACTORS OF THE WORLD.
BORN AT GREENOCE, IUDCCXXXVI.
DIED AT BEATRFIELD, IN STAFFORDSHIRE, MDCCCXIX.

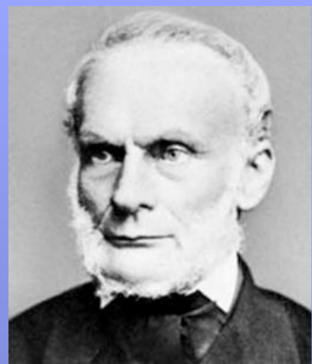


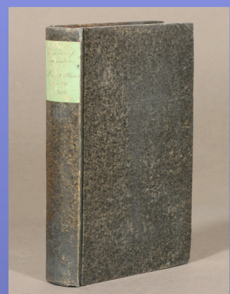
Réflexions sur la puissance motrice du feu et sur les machines propres a developper cette puissance.

Second law

Equality Sign: Reversible Process

Ueber die bewegende Kraft der Wärme und die Gesetze, welche sich daraus für die Wärme selbst ableiten lassen





$$\frac{W}{Q_h} \leq \eta_c$$

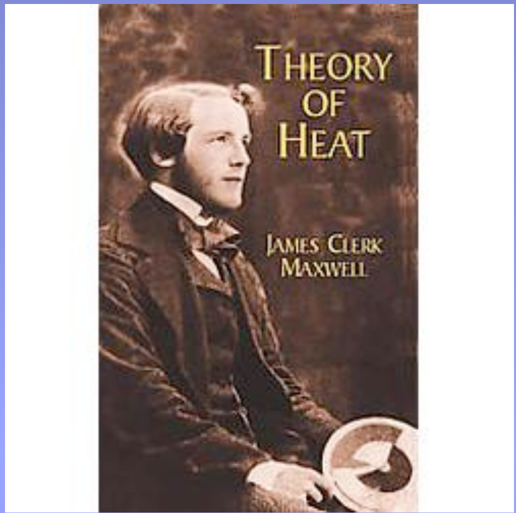
$$\eta_c = 1 - \frac{T_c}{T_h}$$

$$W = Q_h - Q_c$$

$$\Delta S = \frac{Q_h}{T_h} + \frac{Q_c}{T_c} \geq 0$$

$$\Delta S = \int_{rev} \frac{dQ}{T} \geq 0$$

Exceed Carnot at Small Scale?



Yes?

$$\eta = \frac{W}{Q_h} \leq 1 - \frac{T_c}{T_h}$$

Maxwell's demon at work

Figure 6

$T_c = T_h$

Physik. Zeitschr. XIII, 1912. v. Smoluchowski, Molekularphänomene 1069

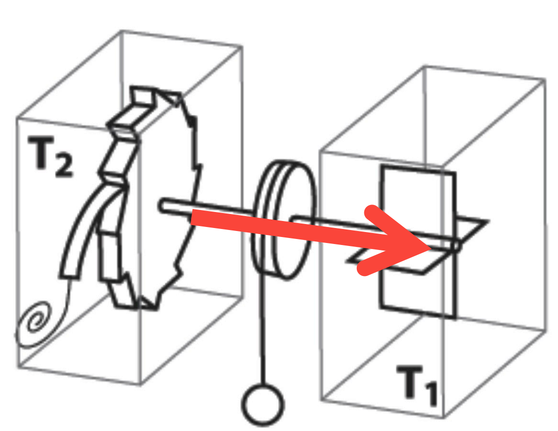
M. v. Smoluchowski (Lemberg), *Experimentell nachweisbare, der üblichen Thermodynamik widersprechende Molekularphänomene*

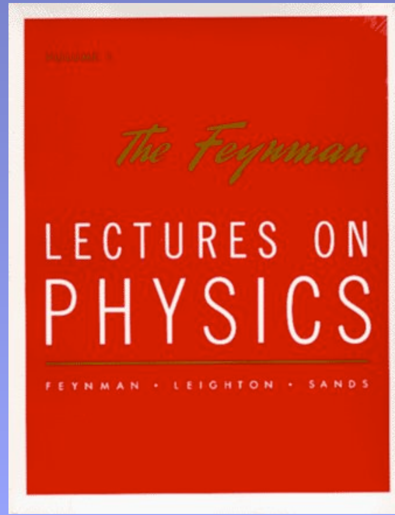
.... Theoretisch noch einfacher und übersichtlicher ist das Beispiel des Torsionsfadens. Bringen wir anstatt des Spiegels unten ein Zahnrad mit einer Sperrklinke (mit Zwangsführung) an, welche nur einseitige Drehung zuläßt. Infolge der fortwährenden Schwankungen wird das Zahnrad eine Drehung, der Faden eine Torsion erfahren, welche dauernd zu nutzbarer Arbeit am Aufhängepunkt verwendet werden könnte. Es wäre diese Vorrichtung analog einer Spielbank, welche die Gesetze des Zufalls systematisch korrigiert.
Die Schwierigkeit der technischen Ausführung bildet da keinen Einwand, wenn die Sache prinzipiell möglich ist.

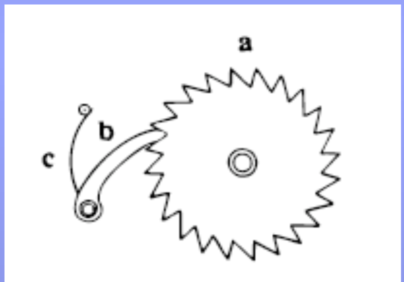
No!

Erase 1 bit: $\Delta S = k_B \ln 2$

$$\eta = \frac{W}{Q_h} \leq 1 - \frac{T_c}{T_h}$$







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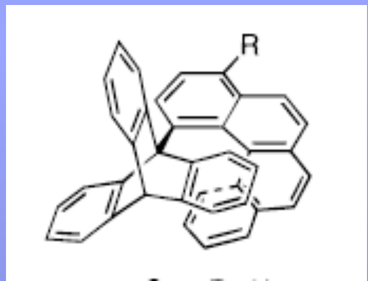


J. Org. Chem. **1998**, *63*, 3655−3665

New Molecular Devices: In Search of a Molecular Ratchet

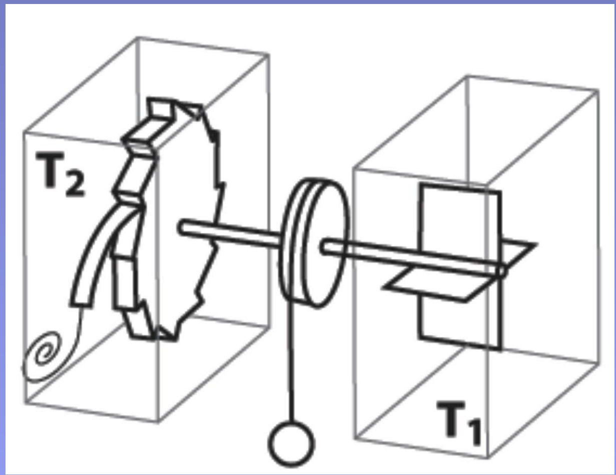
T. Ross Kelly,* José Pérez Sestelo,† and Imanol Tellitu‡

Irreversible Heat Flux

J. Parrondo P. Espagnol, Am J Phys 64, 1125 (1996)
C. Van den Broeck, R. Kawai, and P. Meurs, PRL.93, 090601 (2004)

Below Carnot at Small Scale?

Under Steady State Conditions?



Thermal $X_1=\Delta T/T^2$ Mechanical $X_2=F/T$

Heat flux J_1 Rotation Speed J_2

$$J_1 = L_{11}X_1 + L_{12}X_2$$
$$J_2 = L_{21}X_1 + L_{22}X_2.$$


$$L_{11} \geq 0 \qquad L_{22} \geq 0$$
$$L_{11}L_{22} - L_{12}L_{21} \geq 0.$$

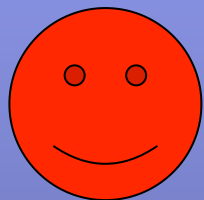
Carnot efficiency?

C. Van den Broeck, Adv Chem Phys **135**, 189 (2007)

$$d_iS/dt = J_1X_1 + J_2X_2 \geq 0$$

Reversible: $d_iS/dt=0$ hence $\eta=\eta_c$. If $J_1= J_2 =0$ for X_1 and X_2 nonzero.
Only possible if determinant of matrix L is zero: $L_{11}L_{22}=(L_{12})^2$

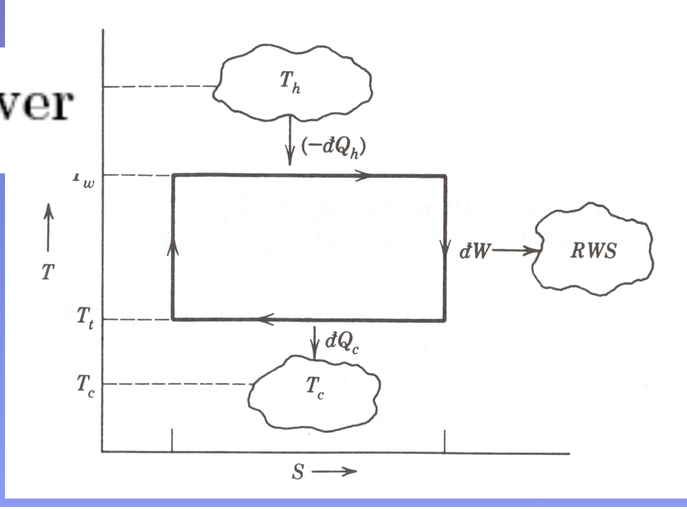
Carnot efficiency



Architectural constraint of strong coupling $J_2/J_1= L_{21}/L_{11}$.

$$L_{11}L_{22}=(L_{12})^2$$

Thermodynamic efficiency at maximum power



FL Curzon B Ahlborn

Am. J. Phys. 43, 22 (1975)

Efficiency at maximum power

$$1-\eta_C = \frac{T_c}{T_h}$$

$$\eta = \frac{W}{Q_h} \overset{endoreversible}{\underset{approximation}{=}} 1 - \sqrt{\frac{T_c}{T_h}}$$

Plant	T_h (K)	T_c (K)	η_{obs}	η_{CA}	η_{opt}	η_{opt} ($I = 0.8$–0.9)
Doel 4 (nuclear PWR, Belgium)[a]	566	283	0.350	0.293	0.405	0.297–0.357
Almaraz II (nuclear PWR, Spain)[b]	600	290	0.345	0.305	0.420	0.315–0.373
Sizewell B (nuclear PWR, UK)[c]	581	288	0.363	0.296	0.410	0.302–0.361
Cofrentes (nuclear BWR, Spain)[b]	562	289	0.340	0.283	0.393	0.282–0.343
Heysham (nuclear AGR, UK)[c]	727	288	0.4	0.371	0.501	0.410–0.460

Exact in linear approx. for : $\mathbf{L_{11}L_{22}=(L_{12})^2}$

C. Van den Broeck, Phys Rev Lett 95, 190602 (2005)

$$\eta = \eta_C/2 + \eta_C^2/8 + 6\eta_C^3/96$$

Thermal $X_1=\Delta T/T^2$

Heat flux J_1

Mechanical $X_2=F/T$

Motion J_2

$$\eta = \frac{W}{Q} = \frac{\dot{W}}{\dot{Q}} = -\frac{FJ_2}{J_1} = -\frac{\Delta T}{T}\frac{X_2J_2}{X_1J_1} = -\eta_C \frac{X_2J_2}{X_1J_1}$$

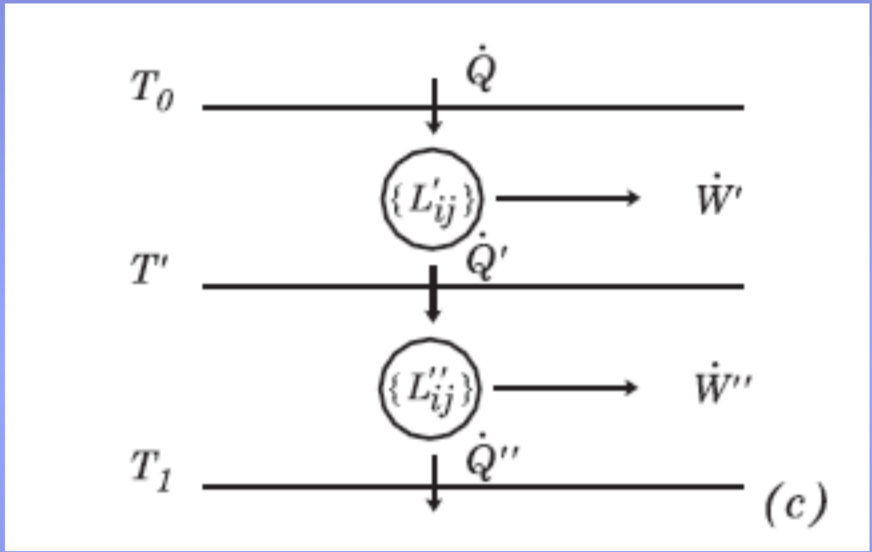
$$\overset{strong}{\underset{coupling}{=}} -\eta_C \frac{X_2L_{21}}{X_1L_{11}} \overset{\max}{\underset{power}{=}} \frac{1}{2}\eta_C$$

$$\overset{\max}{\underset{power}{?}} \; X_2(L_{21}X_1 + L_{22}X_2) \text{ max for } \frac{X_2}{X_1} = -\frac{L_{21}}{2L_{22}}$$

Concatination property

suppose *efficiency* $\eta = \frac{\dot{W}}{\dot{Q}} = \eta(\frac{T_1}{T_0})$

is unchanged upon inserting heat bath



$$\eta(\frac{T_1}{T_0}) = \frac{\dot{W}'+\dot{W}''}{\dot{Q}} = \frac{\eta(\frac{T'}{T_0})\dot{Q} + \eta(\frac{T_1}{T'})\dot{Q}'}{\dot{Q}}$$

$$= \frac{\eta(\frac{T'}{T_0})\dot{Q} + \eta(\frac{T_1}{T'})(\dot{Q} - \eta(\frac{T'}{T_0})\dot{Q})}{\dot{Q}}$$

$$t = \frac{T_1}{T_0} \qquad x = \frac{T_1}{T'}$$

$$\eta(t) = \eta(t/x) + \eta(x)(1 - \eta(t/x)) \qquad \forall x \quad T_0/T_1 < x < 1$$

implies:

$$\Rightarrow \boxed{\eta(t) = 1 - t^{\alpha}}$$

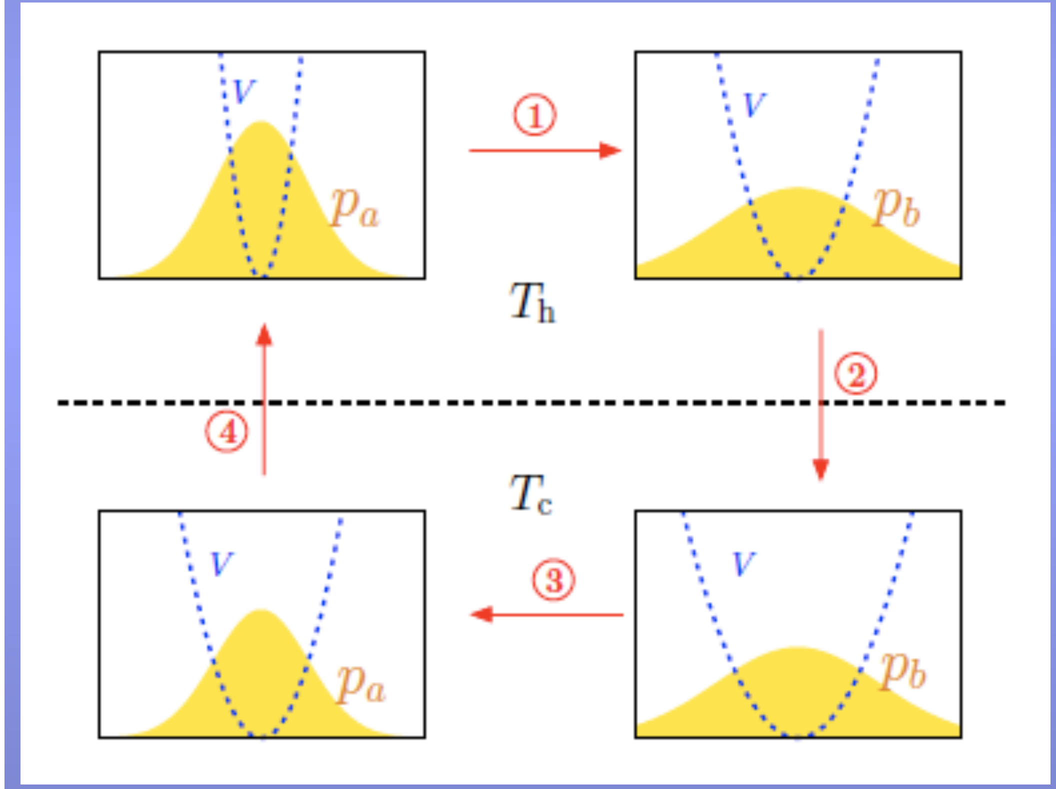
$\alpha = 1$ *Carnot*

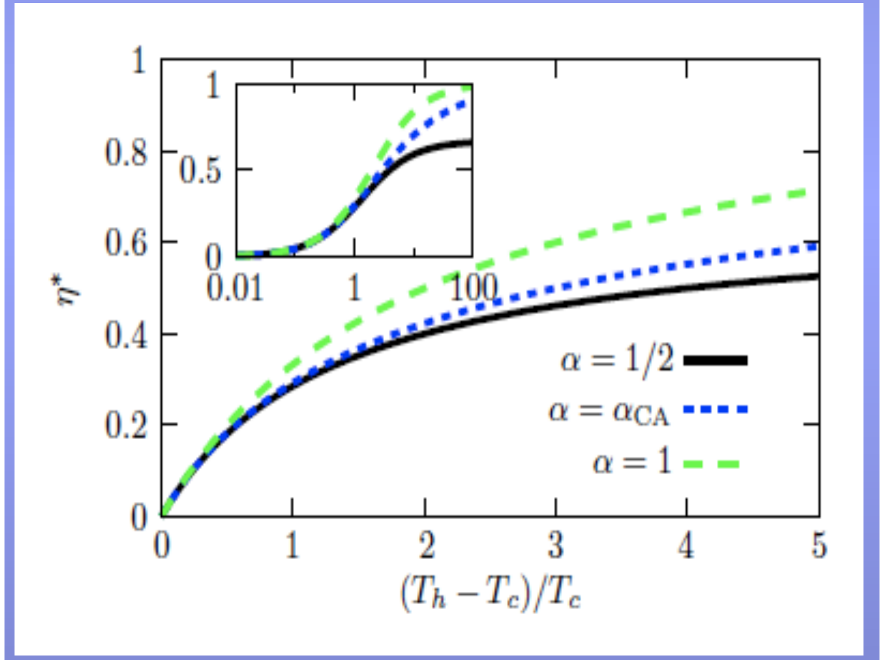
$\alpha = 1/2$ *Curzon Ahlborn*

Carnot Cycle for Brownian particle

$$\eta = \eta_C/2 + \eta_C^2/8 + 3\eta_C^3/96$$

T. Schmiedl U. Seifert, EPL 81, 20003 (2008)

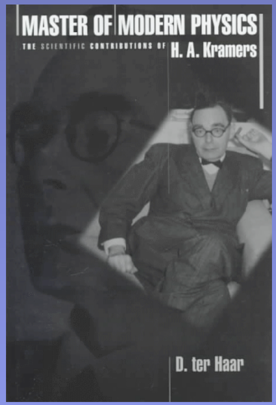




Thermal Engine via Kramer's Escape

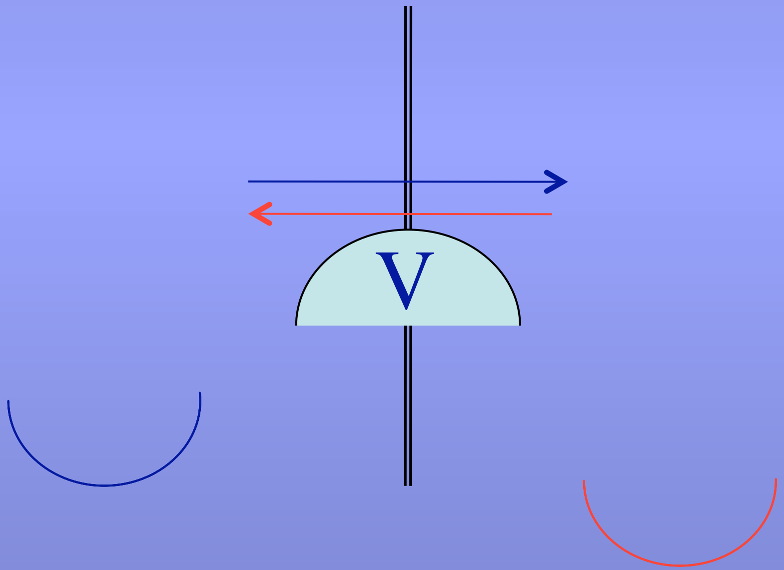
$$\eta = \eta_C/2 + \eta_C^2/8 + 7\eta_C^3/96$$

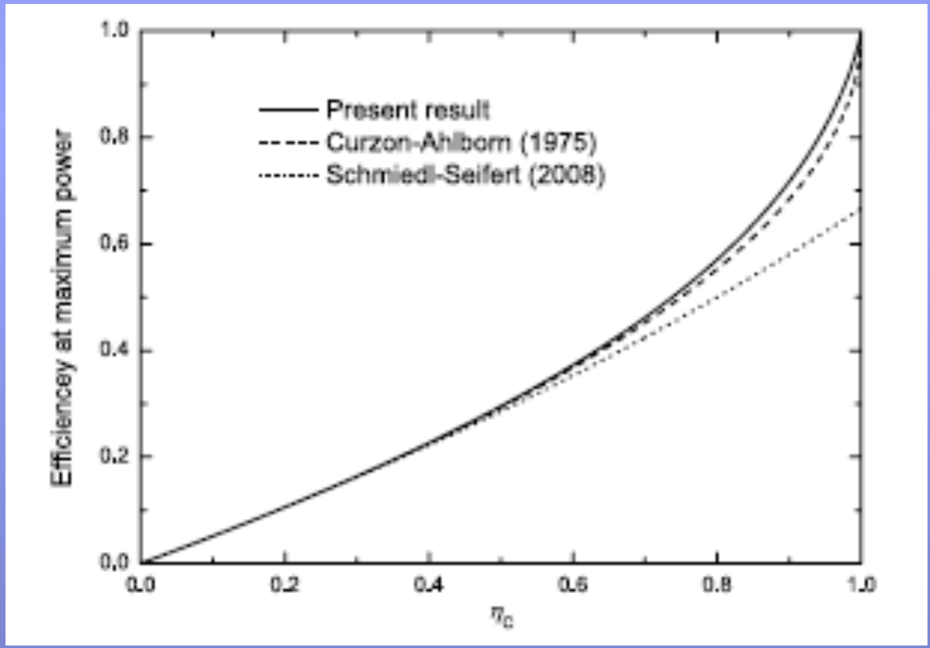
Z.C. Tu, J Phys 41, 312003 (2008)



classical particle

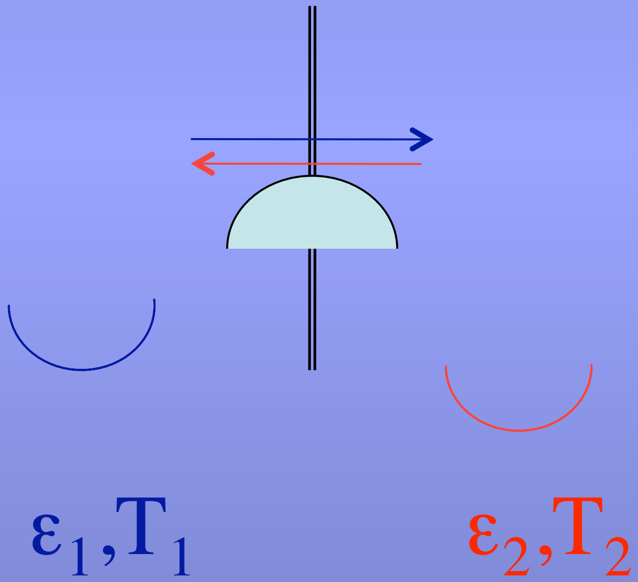
$$W = a\ e^{-(V-\varepsilon)/T}$$





ε_1, T_1 ε_2, T_2

$$W = a \; e^{-(V-\varepsilon)/T}$$



$$W_{\rightarrow} = a \; e^{-x_1} \qquad x_1 = (V-\varepsilon_1)/T$$

$$W_{\leftarrow} = a \; e^{-x_2} \qquad x_2 = (V-\varepsilon_2)/T$$

$$P = \dot{W} = a(e^{-x_2} - e^{-x_1})(\varepsilon_1 - \varepsilon_2) = aT_2(e^{-x_2} - e^{-x_1})\left[x_2 - (1-\eta_c)x_1\right]$$

$$\dot{Q} = a(e^{-x_2} - e^{-x_1})(V - \varepsilon_2) = a(e^{-x_2} - e^{-x_1})T_2 x_2$$

$$\eta = \frac{\dot{W}}{\dot{Q}} = 1 - (1-\eta_c)\frac{x_1}{x_2}$$

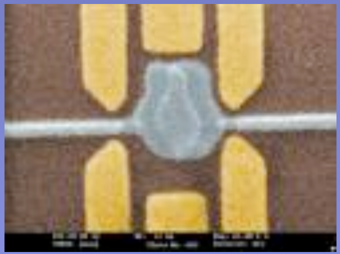
$$\frac{\partial P}{\partial x_2} = 0 \Rightarrow (e^{-x_2} - e^{-x_1}) = e^{-x_2}\left[x_2 - (1-\eta_c)x_1\right]$$

$$\frac{\partial P}{\partial x_1} = 0 \Rightarrow (e^{-x_2} - e^{-x_1})(1-\eta_c) = e^{-x_1}\left[x_2 - (1-\eta_c)x_1\right]$$

$$x_1 = 1 - \frac{1}{\eta_c}\ln(1-\eta_c) \qquad x_2 = \; 1 - \frac{1-\eta_c}{\eta_c}\ln(1-\eta_c)$$

$$\eta = \frac{(\eta_c)^2}{\eta_c - (1-\eta_c)\ln(1-\eta_c)} \approx \frac{\eta_c}{2} + \frac{(\eta_c)^2}{8} + \frac{3(\eta_c)^3}{96}$$

Thermo-electric quantum dot

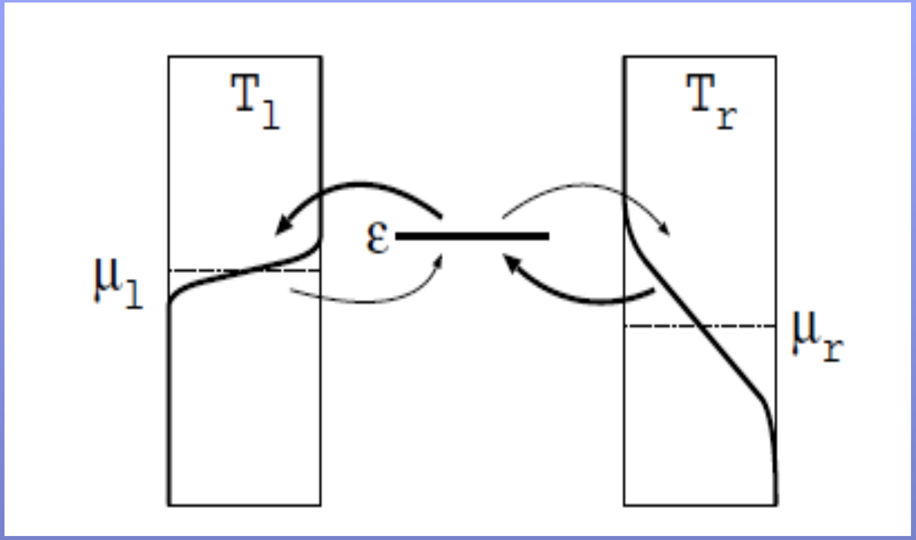


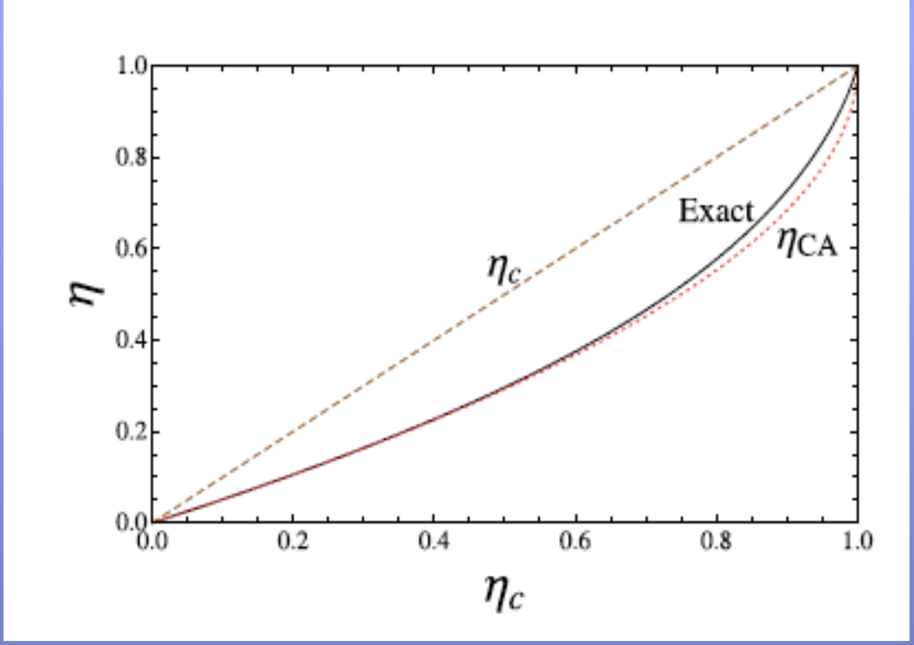
M. Esposito K. Lindenberg C. Van den Broeck
EPL 85，60010 (2009)

$$\eta = \eta_C/2 + \eta_C^2/8 + (7+a)\eta_C^3/96$$

fermions

$$W_{in} = af \quad W_{out} = a(1-f) \quad f = \frac{1}{e^{(\varepsilon-\mu)/T}+1}$$





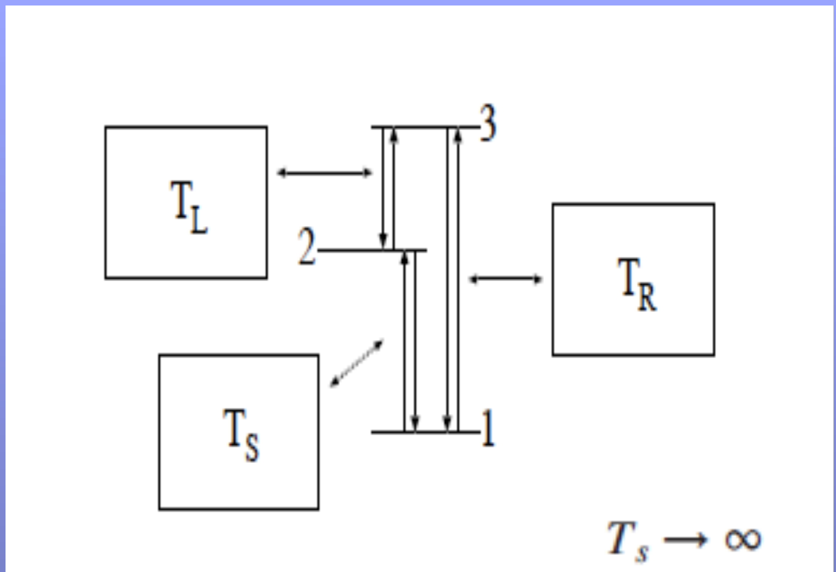
Maser

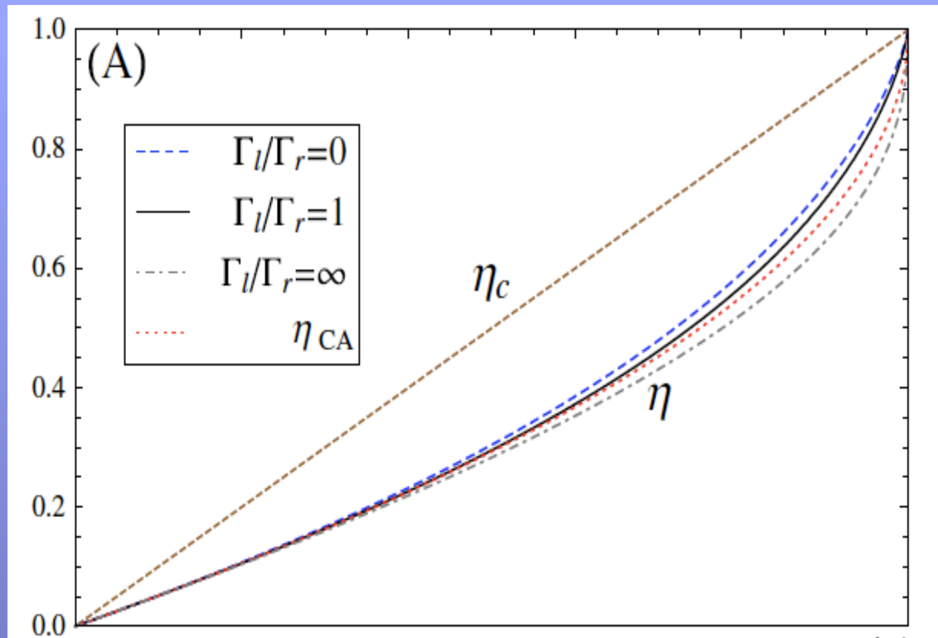
M. Esposito K. Lindenberg C. Van den Broeck

PRL 102,130602 (2009)

$$\eta = \frac{\eta_c}{2} + \left(1 - \frac{3(\Gamma_l - \Gamma_r)}{(\Gamma_l + \Gamma_r)(3\cosh\alpha + \sinh\alpha)}\right)\frac{\eta_c^2}{8} + \mathcal{O}(\eta_c^3),$$

bosons $W_{abs} = \Gamma n \quad W_{emis} = \Gamma(1+n) \quad n = \frac{1}{e^{h\nu/T} - 1}$

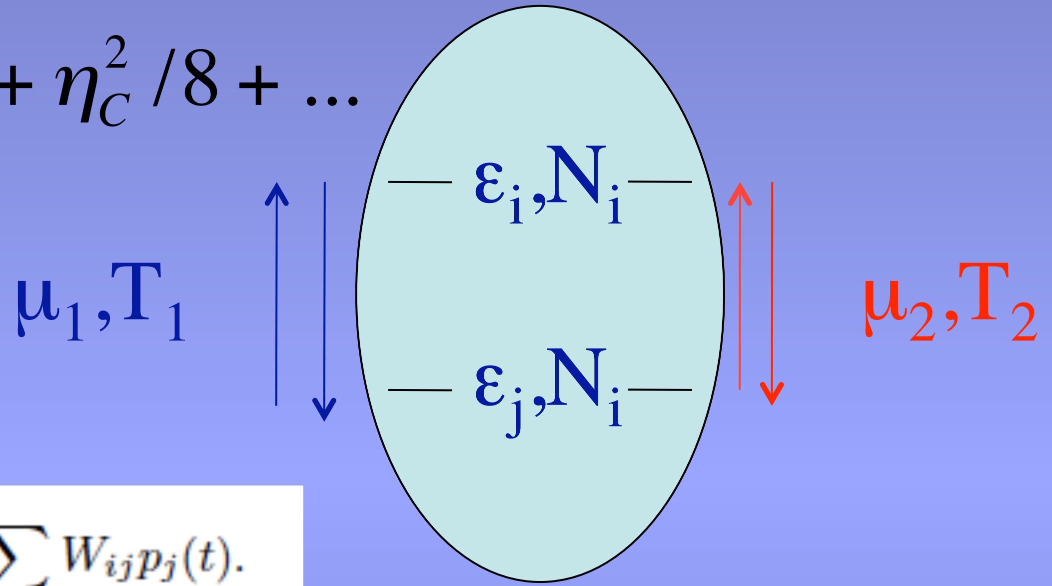




Stochastic Thermodynamics: General Proof of 1/8

M. Esposito K. Lindenberg C. Van den Broeck PRL 102,130602 (2009)

$$\eta = \eta_C/2 + \eta_C^2/8 + \ldots$$



$$\dot{p}_i(t) = \sum_j W_{ij} p_j(t).$$

$$\frac{W_{ji}^{(\nu)}}{W_{ij}^{(\nu)}} = \exp\left\{\beta_\nu\left[(\epsilon_i - \epsilon_j) - \mu_\nu(N_i - N_j)\right]\right\}.$$

$$\dot{S}_i(t) = \sum_{i,j,\nu} W_{ij}^{(\nu)} p_j(t) \ln \frac{W_{ij}^{(\nu)} p_j(t)}{W_{ji}^{(\nu)} p_i(t)} \geq 0.$$

$$\eta = \frac{\eta_c}{2} + \left(1 + \frac{M}{\partial_{x_l} L}\right)\frac{\eta_c^2}{4} + \mathcal{O}(\eta_c^3).$$

$$\mathcal{I} = L\mathcal{F} + M\mathcal{F}^2 + \mathcal{O}(\mathcal{F}^3)$$

$$\mathcal{I}(x_r, x_l) = -\mathcal{I}(x_l, x_r).$$

Conclusion

Time-reversibility in linear regime

Symmetry Onsager matrix

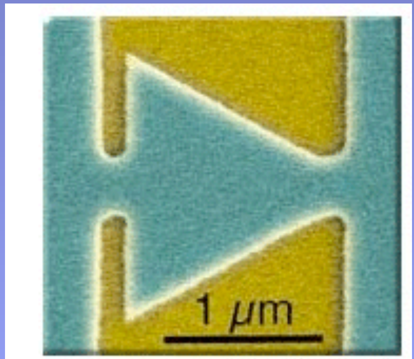
Prigogine minimum entropy production

Efficiency at max power $\eta=\eta_c/2$

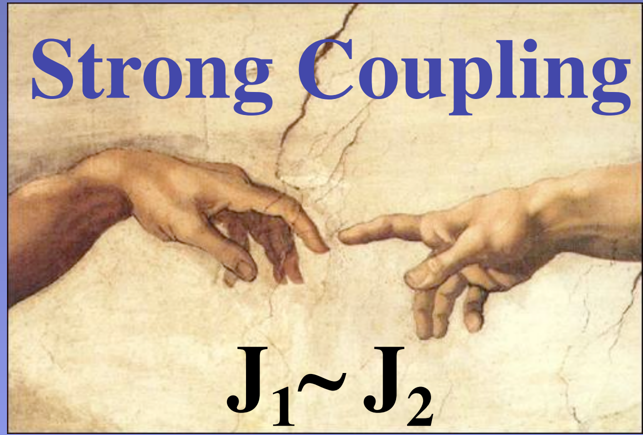
Time-reversibility in nonlinear regime

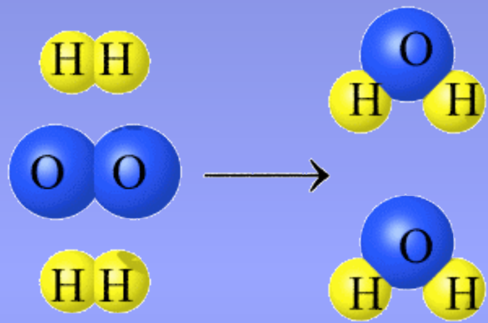
Efficiency at max power $\eta=\eta_c/2+\eta_c^2/8$

(strong coupling, spatial symmetry)



Electron microscopic image of a quantum dot ratchet

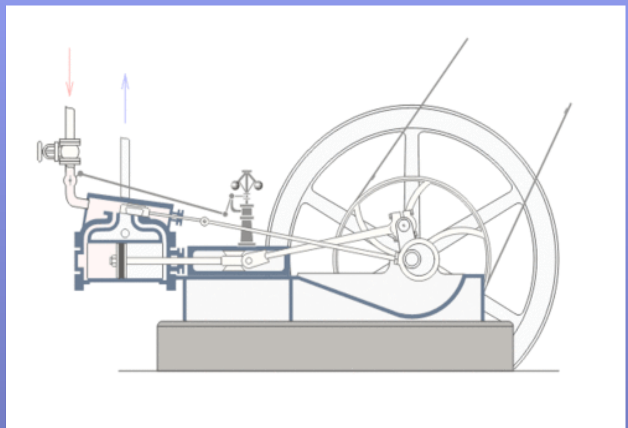




Thermal

Chemical Machines

Entropic




I want to be important
NOW