Brownian heat engine: A model

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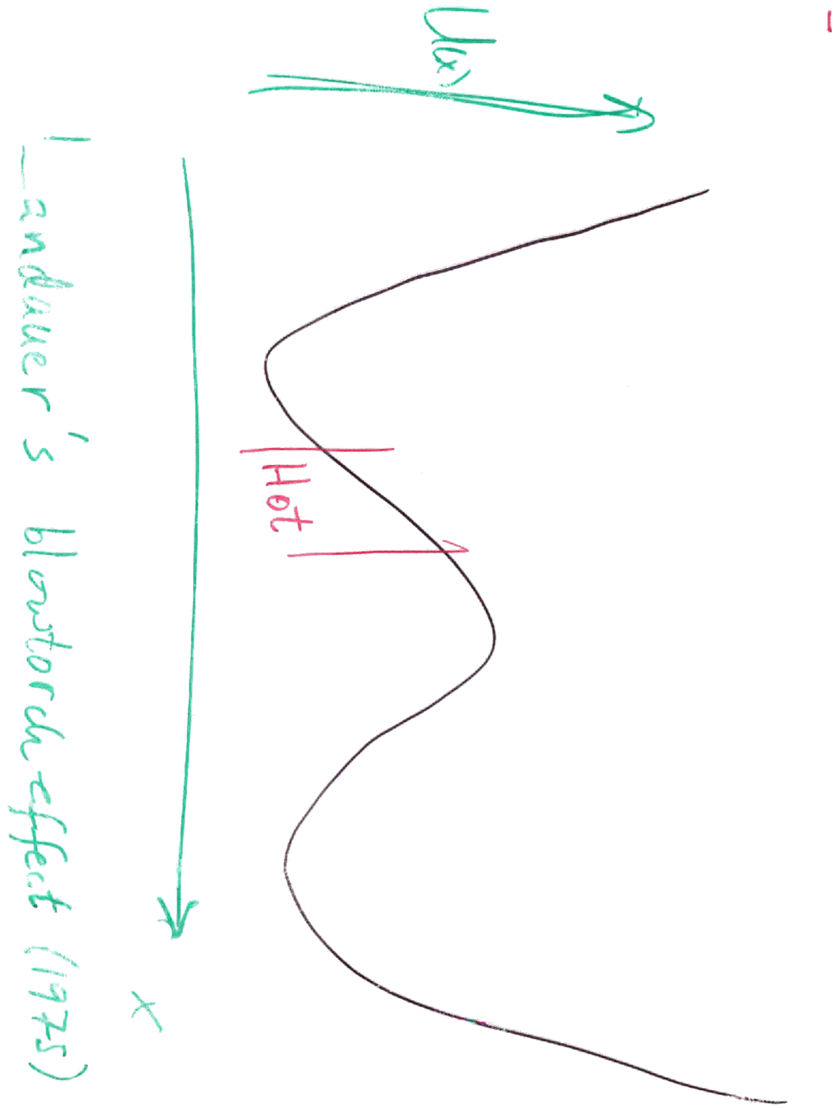

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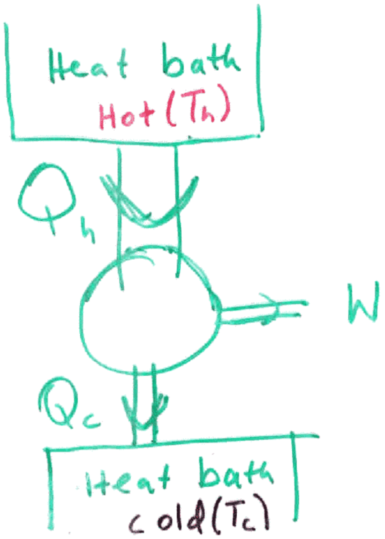
Heat engine



$$\text{Efficiency } \eta = \frac{W}{Q_h}$$

Reverse heat engine

$$COP = \frac{Q_c}{W}$$

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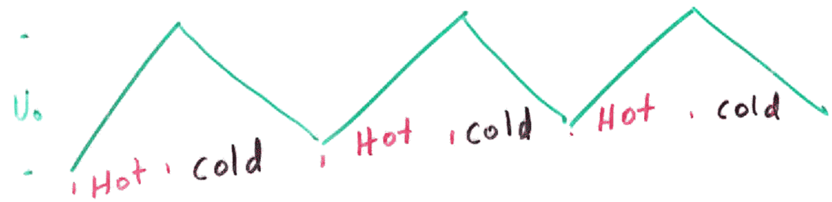

Brownian particle in a ratchet potential (with/without load)

highly viscous medium

alternately placed hot and cold bath

U_0, T_h, T_c, L_h, L_c, γ (coef. of friction) and f (load)

J current

v average drift velocity

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For $L_h = L_c$ and $f = 0$

$$J = \frac{1}{2\gamma(T_h+T_c)}\left(\frac{U_0}{L_c}\right)^2\left[\frac{1}{e^{\frac{U_0}{T_h}}-1} - \frac{1}{e^{\frac{U_0}{T_c}}-1}\right]$$

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Energetics?

Per cycle

$$Q_h = U_0 + (\gamma v + f)L_h + \tfrac{1}{2}k_B(T_h - T_c)$$

$$Q_c = U_0 - (\gamma v + f)L_c + \tfrac{1}{2}k_B(T_h - T_c)$$

$$W = (\gamma v + f)(L_h + L_c)$$

$$\eta = \frac{W}{Q_h}$$

At quasistatic limit ($J \to 0^+$)

$$\eta \longrightarrow 1 - \frac{T_c}{T_h} = \eta_{carnot}$$

is a resultant of currents to the
: $J = J_+ - J_-$.
that the model acts as a heat en-
s to the right. The particle under-
rein during each cycle it is first in
egion of width L_1 and then with
h L_2. We take account of energy
regions neglecting energy trans-
lue to the particle's recrossing of
the regions [4,14]. As the particle
egion it absorbs energy, Q_h, which
climb up the potential $(U_0 + fL_1)$
$\gamma v L_1$ (v being the particle's aver-
qual to $J(L_1 + L_2)$) to overcome
g force so that

$$U_0 + (\gamma v + f)L_1. \quad (7)$$

cold region will absorb energy as
n the potential hill while at the
ergy due to the drag force in the
et heat, Q_c, absorbed by the cold

$$U_0 - (\gamma v + f)L_2. \quad (8)$$

e by the engine in one cycle will
etween Q_h and Q_c so that

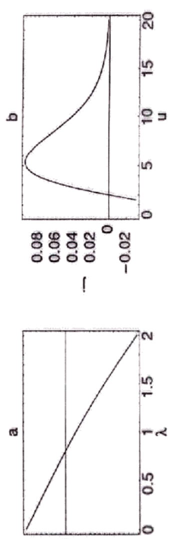

Fig. 2. (a) Plot of j versus λ for $\tau = 1$, $\ell = 2$ and $u = 4$. (b) Plot of j versus u for $\tau = 1$, $\ell = 2$ and $\lambda = 0.4$.

It is worth noting that the magnitude of the load at this point of zero current is exactly equal to what is usually called the stall force for molecular engines [5,21]. When we evaluate the expressions for both η and P_{ref} as we approach this boundary, we analytically find that they are exactly equal to the values for efficiency of the Carnot engine and for COP of the Carnot refrigerator, respectively: $\lim_{J\to 0^+} \eta = \frac{T_h - T_c}{T_h}$ and $\lim_{J\to 0^-} P_{ref} = \frac{T_c}{T_h - T_c}$. Hence, this boundary at which current is zero corresponds to the quasistatic limit be it from the heat engine side or from the refrigerator side. Only for this quasistatic limit ($v \to 0$) will the heat engine operate reversibly, i.e., the entropy production is zero. This result agrees with the comment given by Jülicher et al. [5]. However, the derivation of equation (10) of Derényi et al. [4] and its implications do not hold for a heat engine delivering a finite task in a

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Optimization

One extreme:

extract maximum work possible
$\Rightarrow$ quasistatic time $\to \infty$

Another extreme

perform task in shortest possible time.
$\Rightarrow$ Costs energy.

W

W_{min} W_{max}

$\Omega = 2W - W_{max} - W_{min}$

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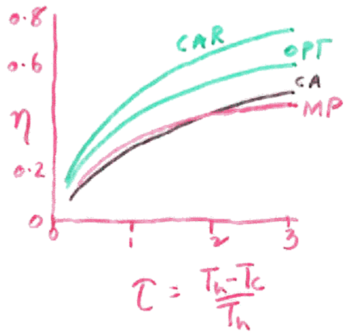

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Brownian heat engine

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