Forward rotation

\( \varepsilon \)

energy to lift the pawl

\( \varepsilon + L\theta \)

work done on load
determines work provided by one tooth

\( f_1' = Z^e \varepsilon e^{-\theta f_1} \)

Boltzmann factor for work provided by vane

\( \nu f_1' \)

ratcheting rate with \( \nu \) attempt frequency

\( \varepsilon L f_1' \theta \)

power delivered

\( \varepsilon \)

energy provided to ratchet

Backward rotation

\( \varepsilon \)

energy to lift the pawl

\( L\theta \)

work provided by load

\( \varepsilon + L\theta \)

energy given to vane

\( f_2^b = Z^b e^{-\theta f_2} \)

Boltzmann factor for tooth slip

\( \nu f_2^b \)

slip rate with \( \nu \) attempt frequency

Equilibrium and reversibility

ratcheting rate = slip rate

\( f_1' = f_2^b \)

Reversible process by increasing the load infinitesimally from equilibrium \( L_{eq} \). This forces a rotation leading to heating of reservoir 1 with \( dq_1 = \varepsilon + L_{eq} \theta \) and cooling of reservoir 2 as \( dq_2 = - \varepsilon \):

\[ \frac{dq_1}{\tau_1} - \frac{dq_2}{\tau_2} = \frac{\varepsilon + L_{eq} \theta}{\tau_1} - \frac{\varepsilon}{\tau_2} \]

isentropic process

Ratchet Brownian motor

Angular velocity of ratchet:

\[ \Omega = 0 \nu \left( f_1' - f_2^b \right) = 0 \nu \varepsilon \left( e^\frac{\varepsilon}{kT} - e^{-\frac{\varepsilon}{kT}} \right) \]

Without load:

\[ \Omega \left( e^\frac{kT}{\varepsilon} - e^{-\frac{kT}{\varepsilon}} \right) \]

Equal temperatures:

\[ \Omega(L) = \frac{e^{\frac{kT}{\varepsilon}} - e^{-\frac{kT}{\varepsilon}}}{e^{\frac{kT}{E}} - 1} \]

Escherichia coli ATP synthase


Kinesin

Driven Brownian ratchets

Diffusion in asymmetric potentials

Molecular gears

Myosin


R. Dean Astumian, Science 276, 917-922.

http://chem.iupui.edu/Research/Robertson/Robertson.html#Gears

http://www.sciencemag.org/feature/data/1049155.shl

Myosin

http://www.chemEng.psu.edu/Research/Robertson/Robertson.html#Gears

Myosin

Diffusion in asymmetric potentials

Kinesin

Molecular gears

Myosin

DNA transport by a micromachined Brownian ratchet device

Joel S. Bader et al., PNAS 96, 13165 (1999)

Geometrical Brownian ratchet I


Geometrical Brownian ratchet II

Unidirectional molecular rotation

T. Ross Kelly et al., Nature 401 (1999) 150

Chemically driven rotation

Light driven rotation

N. Koumura et al., Nature 401 (1999) 152
Maxwell's demon

W. Smoluchowski (1941):
No automatic, permanently effective perpetual motion machine can violate the second law by taking advantage of statistical fluctuations (Feynman: the demon is getting hot). Such device might perhaps function if operated by intelligent beings.

The second law is safe from intelligent beings as long as their abilities to process information are subject to the same laws as those of universal Turing machines.

Fluctuations of μm-sized trapped colloidal particles


Noise ratchet

\[ \Sigma = \frac{1}{\tau} \int_{t_0}^{t_\text{opt}} f_\text{opt}(t) dt \]

Entropy production