# Power from simplest steady-state quantum heat engine

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1959 - ...

Our quantum heat engine

TLS population inversion lifts weight I.

TLS population inversion lifts weight II.

Which battery?

# 1959 - ...


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# Our quantum heat engine

- recources: hot and cold heat bath (like in classical)
- working medium: 3- (or 4-) level system (genuine quantum)
- work extraction: battery (like in classical)

Operation

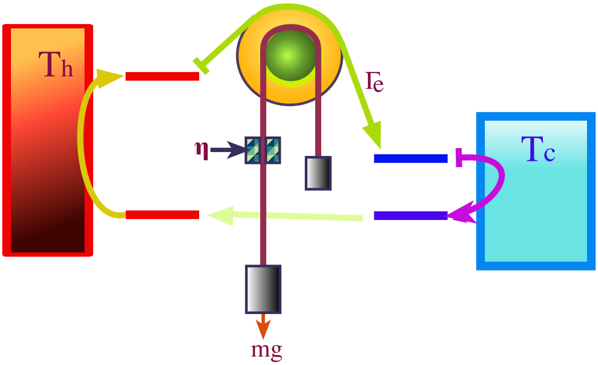
- continuous (non-cyclic)
- exact steady state
- constant power

Model

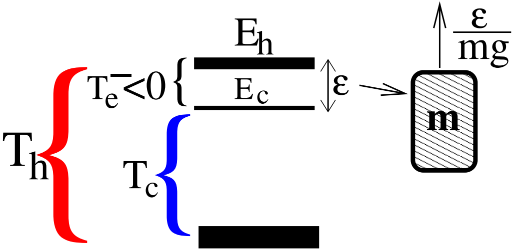
- start with full quantum
- deduce effective master eq. for working medium
- deduce effective master eq. for battery
- search for battery steady state at constant power

# TLS population inversion lifts weight I.

$$\frac{T_c}{T_h} < \frac{E_c}{E_h} \qquad T_e^- = \frac{E_h - E_c}{\frac{E_h}{T_h} - \frac{E_c}{T_c}} < 0$$



# TLS population inversion lifts weight II.




$$\frac{dz}{dt} = \Gamma_e \left( e^{-\varepsilon/k_B T_e^-} - 1 \right) \frac{\varepsilon}{mg} - gt$$

Friction $\ddot{z} = \cdots - \eta \dot{z}$ prevents weight's falling:

$$\frac{dz}{dt} = \Gamma_e \left( e^{-\varepsilon/k_B T_e^-} - 1 \right) \frac{\varepsilon}{mg} - \frac{g}{\eta}$$

Fluctuation at optimum friction $\eta$:

$$(\Delta z)^2 \sim \Gamma_e \left( e^{-\varepsilon/k_B T_e^-} + 1 \right) \left( \frac{\varepsilon}{mg} \right)^2 t + \frac{\hbar}{m} t$$

# Which battery?

- harmonic oscillator (Levy, D. Kosloff 2016)
  - Steady coherent state needs active control (flywheel).
  - Without control: fluctuations dominate deposited energy, phase of oscillation is indefinite, useless for "work".
- lifted weight (Levy, D., Kosloff in preparation)
  - Lifting needs friction(!) upon vertical motion.
  - Steady state would need active control as well.
  - Without active control: deposited potential energy $\propto t$, moderate fluctuations $\propto \sqrt{t}$, useful for "work".
- electric — we haven't yet studied, but, apparently:
  - Steady state, constant power (current) is common,
  - even without active control.
  - Are there hidden recources?