last time: $p_n(t) \to p_n^s$

for const. Ω corresponding to a connected graph

thermodyn. quantities:

$$E(t) = \sum_n p_n(t) E_n$$
$$S(t) = -k_B \sum_n p_n(t) \ln p_n(t)$$
$$F(t) = E(t) - T S(t)$$

combined 1st + 2nd law:

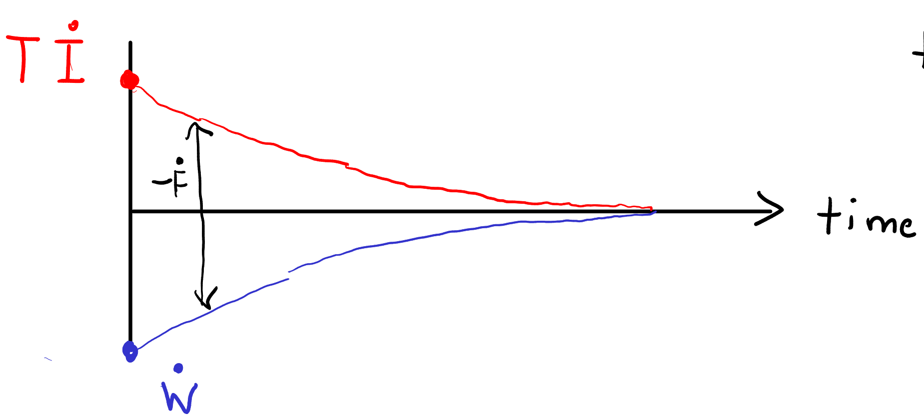
$$\underset{\frac{dF}{dt}}{\overset{\shortparallel}{\dot{F}(t)}} = \dot{W}(t) - T \underbrace{\dot{I}(t)}_{\geq 0}$$

$t \to \infty$: $\dot{E}, \dot{S}, \dot{F} \to 0$

$$\dot{W} - T\dot{I} \to 0$$

case I: $\dot{W} < 0$ sys. does net work on outside

$\dot{I} > 0$ by definition

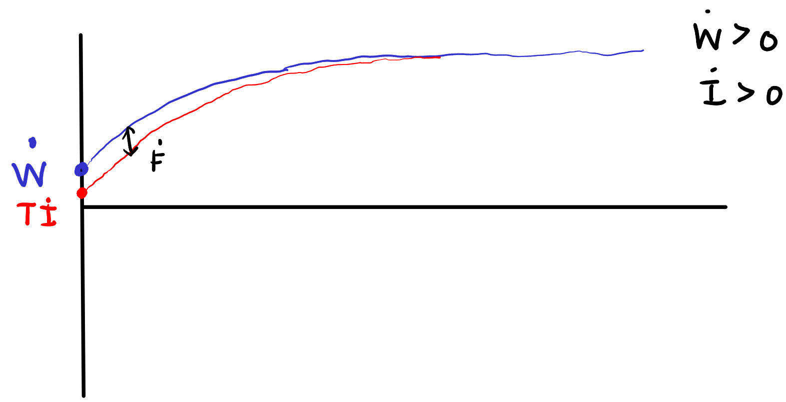


$t \to \infty$: get an ESS ($\dot{I} \to 0$)

Case II: $\dot{W} > 0$ as $t \to \infty$

(continuous supply of work from outside on sys, so that net $\dot{W} > 0$)

possibility:



$\dot{W} = T\dot{I} > 0$

NESS
(b/c $\dot{I} > 0$)

long-term limit $(t \to \infty)$

$$\dot{W} = P_{in} - P_{out} = \underbrace{T\dot{I}}_{P_{diss}} > 0$$

$\dot{W}$: net power into sys

P_{in}: input power (all pos. terms)

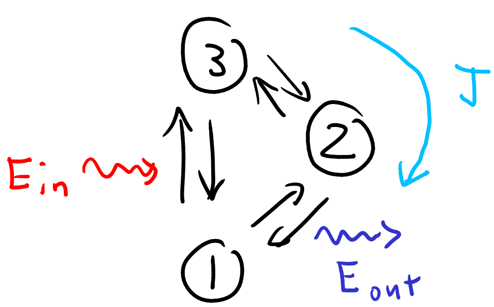
P_{out}: output power (all neg. terms)

P_{diss} = power dissipated as heat into env.

any interesting biology: $P_{diss} > 0$

$\dot{I} > 0 \Rightarrow$ NESS

return to light-sensitive protein model:



stationary current (same in all edges)

$$J \propto 1 - e^{-\beta(E_{in} - E_{out})}$$

if $E_{in} > E_{out} \Rightarrow J > 0$ NESS

$t \to \infty$:

$$\dot{W} = \frac{1}{2} \sum_{nm} J_{nm} W_{nm}$$

$$= \underbrace{J E_{in}}_{P_{in}} - \underbrace{J E_{out}}_{P_{out}}$$

$$= T \dot{I} = P_{diss}$$

$$J = J_{31} = J_{23} = J_{12}$$
$$J_{31} = -J_{13}, \quad J_{23} = -J_{32}, \quad J_{12} = -J_{21}$$

$W_{31} = E_{in}$ $\quad W_{12} = -E_{out}$

$W_{13} = -E_{in}$ $\quad W_{21} = E_{out}$

$$P_{diss} = J(E_{in} - E_{out}) \Rightarrow E_{in} > E_{out} \text{ for } P_{diss} > 0$$