Measurements

Velocity:

$$v = \int_0^p [J_1(x) + J_2(x)]\, dx$$

Rate of ATP consumption:

$$r = \int_0^p [\alpha_1(x)P_1(x) - \alpha_2(x)P_2(x)]$$

Generalized forces:

- External force : F_{ext}
- Chemical potential : $\Delta\mu$

Conditions for motion(1)

No ATP excess: $\Delta\mu = 0$

$$\Downarrow$$

$$\frac{\omega_1(x)}{\omega_2(x)} = e^{\frac{W_1(x)-W_2(x)}{K_B T}}$$

$$\Downarrow$$

Steady states $=$ Boltzmann distributions

$$\Downarrow$$

$$F_{ext} = 0 \Rightarrow v = 0, \; r = 0$$

$$\Downarrow$$

Detailed balance for the total transition rates must be broken by ATP excess.

Conditions for motion(2)

Symmetric potential:

$$\begin{aligned} W_i(x) &= W_i(-x) \\ \omega_i(x) &= \omega_i(-x) \end{aligned}$$

$$\Downarrow$$

$$P_i(x) = P_i(-x)$$

$$\Downarrow$$

$$\int_0^p J_i(x)dx = 0$$

$$\Downarrow$$

Polar symmetry is also necessary for motion.