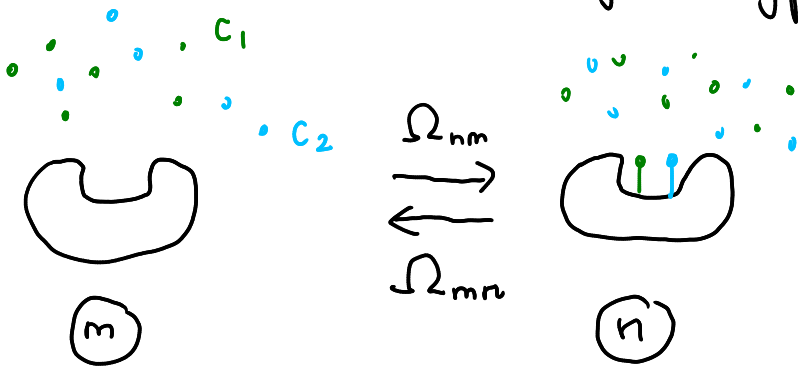
General scenario: many types of molecules in fluid around system

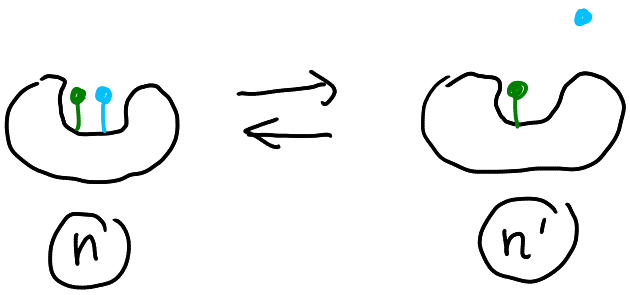
jth type $\Rightarrow$ conc. c_j



$$\frac{\text{binding}}{\text{unbinding}} = \frac{\Omega_{nm}}{\Omega_{mn}} = e^{-\beta(H_n - H_m - \mu_1 - \mu_2)}$$

$$\mu_j = \mu_0^j + k_B T \ln c_j$$

for every molec. that binds we get a μ_j term w/ a minus sign

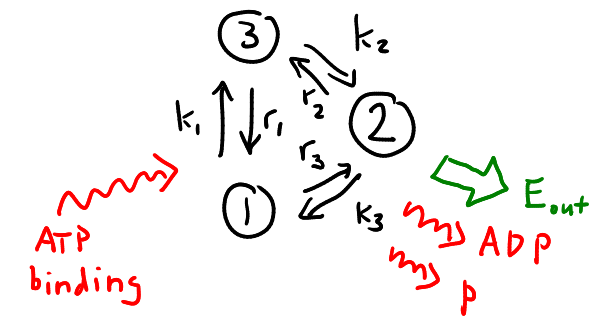


$$\frac{\Omega_{n'n}}{\Omega_{nn'}} = e^{-\beta(H_{n'} - H_n + \mu_2)}$$

unbinding / binding

unbinding : + sign

three state example (powered by chem. potential!)



A-P-P-P = ATP

A-P-P = ADP and P

$t \to \infty$ stationary state

$J_{31}, J_{23}, J_{12} \to J$ const.

$$J = \frac{k_1 k_2 k_3}{D}\left(1 - \frac{r_1 r_2 r_3}{k_1 k_2 k_3}\right)$$

D: func. of rates > 0

$$\frac{k_1}{r_1} = e^{-\beta(H_3 - H_1 - \underbrace{\mu_{ATP}}_{E_{in} \text{ for photon}})} \qquad \frac{k_2}{r_2} = e^{-\beta(H_2 - H_3)}$$

$$\frac{k_3}{r_3} = e^{-\beta(H_1 - H_2 + \underbrace{\mu_{ADP} + \mu_P + E_{out}}_{E_{out} \text{ for photon}})}$$

$$J = \frac{k_1 k_2 k_3}{D}\left(1 - e^{-\beta(\underbrace{\mu_{ATP} - \mu_{ADP} - \mu_P}_{\Delta\mu} - E_{out})}\right)$$

$\Delta\mu$ (E_{in} for photon)

$\equiv$ chem. potential diff of $ATP \to ADP + P$ reaction (hydrolysis)

$$\Delta\mu = \underbrace{\mu_0^{ATP} - \mu_0^{ADP} - \mu_0^{P}}_{12\ k_BT} + k_BT \ln \frac{C_{ATP}}{C_{ADP}\, C_P} \approx 21 - 29\ k_BT$$

in modern cells across all of life

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

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

power budget: $\dot{W}_{\text{net power in}} = \frac{1}{2}\sum_{nm} J_{nm} W_{nm} = J(\Delta\mu - E_{out})$

$t \to \infty$

$$= \underbrace{J\Delta\mu}_{P_{in}} - \underbrace{JE_{out}}_{P_{out}}$$

efficiency: $\eta = \frac{P_{out}}{P_{in}} = \frac{E_{out}}{\Delta\mu}$

$\approx 0.4 - 0.6$ for typical motor proteins (muscles)