Physical Principles in Biology
Biology 3550
Fall 2016

Lecture 37

Review of Quiz 4

and

Molecular Motors Part 2

Monday, 28 November

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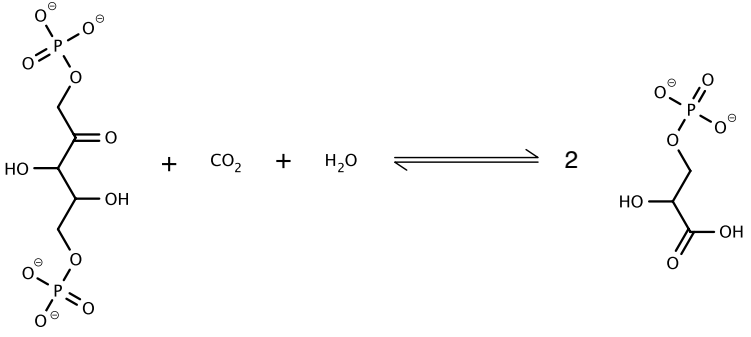
Quiz 4: Ribulose 1,5 bisphosphate Carboxylase



Ribulose 1,5-bisphosphate
(RubP)

3-phosphoglycerate
(3PG)

- Responsible for fixation of CO_2 into carbohydrates.
- Most abundant enzyme on Earth.

Quiz 4: Problem 2(a)

- Calculate ΔG for reaction when concentrations are:
  [3PG] = 1 mM
  [RubP] = 1 mM
  $[CO_2]$ = 8 μM
- $\Delta G = \Delta G^\circ + RT \ln Q$

$$Q = \frac{[3PG]^2}{[CO_2][RubP]} = \frac{(10^{-3}\,M)^2}{8{\times}10^{-6}\,M \times 10^{-3}\,M} = 125$$

$$Q = \frac{(1\,mM)^2}{8{\times}10^{-3}\,mM \times 1\,mM} = 125$$

Quiz 4: Problem 2(b)

$$\text{RubP} + CO_2 \rightleftharpoons 2\,3\,\text{PG}$$

- If $[CO_2]$ is increased from 8 μM to 250 μM, how will the thermodynamics of the reaction change?
  - ΔG

    Higher concentration of reactant makes reaction more favorable, so ΔG is more negative.

  - ΔH

    ΔH is heat absorbed by the reaction, per mole, at constant pressure. ΔH does not depend on concentrations of reactants or products.

  - ΔS_{sys}

    $$\Delta G = \Delta H - T\Delta S$$

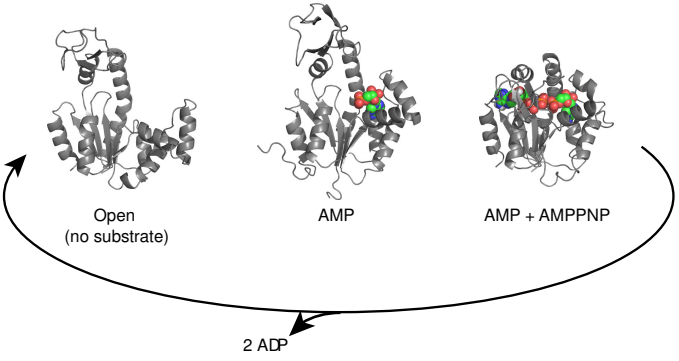
    To make ΔG more negative, ΔS must be more positive.

An Enzyme that Moves: Adenylate Kinase

$$\mathrm{ATP} + \mathrm{AMP} \rightleftharpoons \mathrm{ADP} + \mathrm{ADP}$$

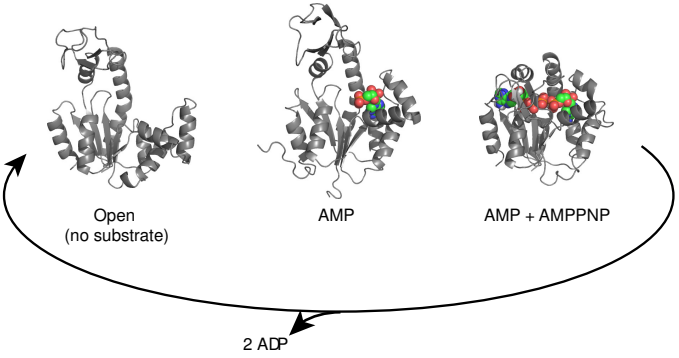
- Functions to recover ATP from ADP, when ATP reserves are low.
- $\Delta G^{\circ} \approx 0$ and $K_{\mathrm{eq}} \approx 1$

An Enzyme that Moves: Adenylate Kinase



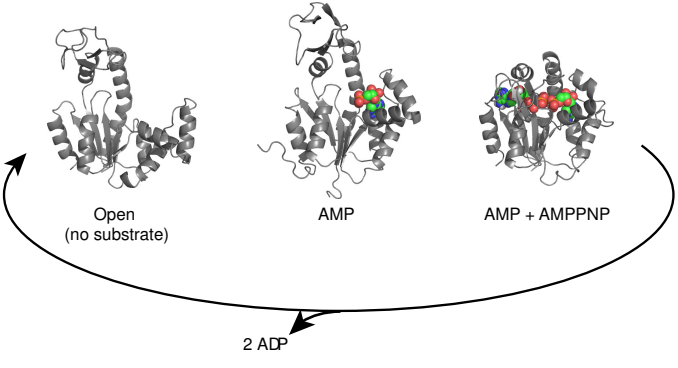
- Substrate binding induces structure to change, enclosing substrates.
- Closed structure protects ATP from being hydrolyzed and releasing phosphate.
- After conversion of ATP + AMP to two ATP molecules, structure reopens to release ADP.

An Enzyme that Moves: Adenylate Kinase



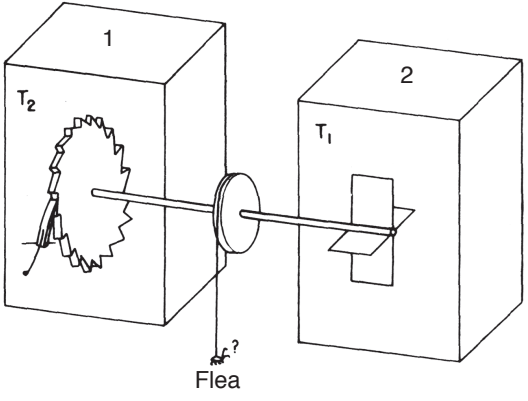
- What causes enzyme to move?
  - Presence or absence of substrates favors different conformations.
  - Weak interactions that stabilize conformations act over relatively short distances.
  - Brownian motion allows sampling of conformations.

An Enzyme that Moves: Adenylate Kinase



- Suppose that ATP, AMP and ADP are at equilibrium concentrations, and $\Delta G = 0$.
  - Will the protein stop moving?
  - Could the motions be used to do work?

A “Brownian Ratchet”



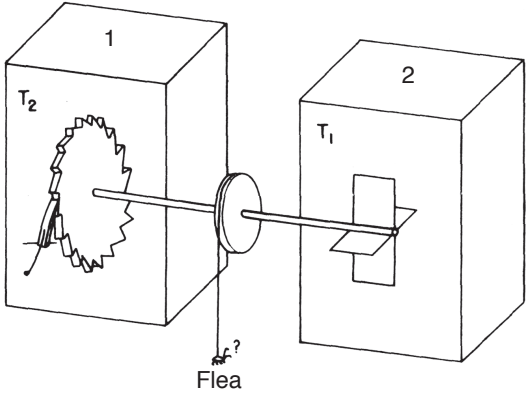
- Thermal motions of gas molecules in compartment 2 make paddle wheel jiggle back and forth.
- Ratchet mechanism in compartment 1 allows motion in only one direction.
- String is wound onto the pulley and the flea is slowly lifted.
- Will this work?

Feynman, R. P., Leighton, R. B. & Sands, M. (2013). *The Feynman Lectures on Physics*, volume I, chapter 46. Basic Books

`http://www.feynmanlectures.caltech.edu/I_46.html`

Clicker Question #3

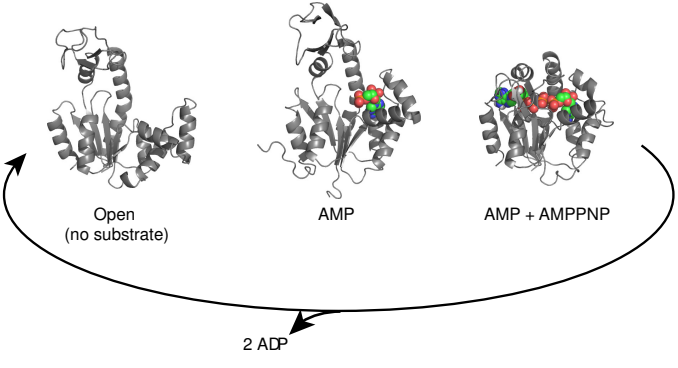
Will the Brownian ratchet lift the flea?



1. Yes
2. Only if the temperature of compartment 1 is greater than that of 2.
3. Only if the temperature of compartment 2 is greater than that of 1.
4. No

All answers count for now.

An Enzyme that Moves: Adenylate Kinase



- Suppose that ATP, AMP and ADP are at equilibrium concentrations, and $\Delta G = 0$.
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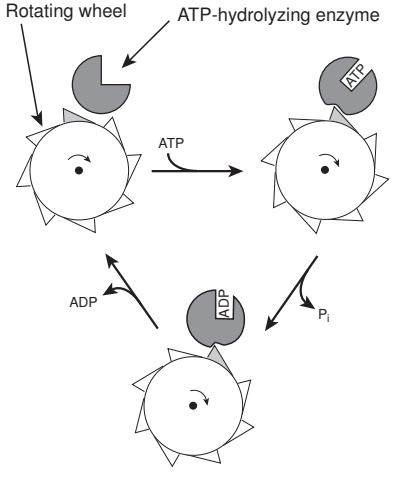
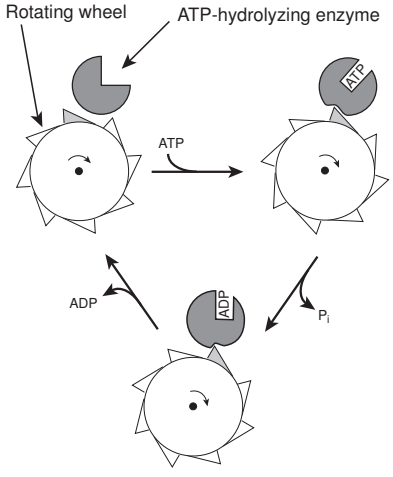
A Hypothetical ATPase Ratchet



- Enzyme changes conformation during catalytic cycle.
- Changes in enzyme conformation control motion of the wheel.
- Steps in the cycle
  1. Enzyme binds ATP and changes conformation.
  2. Wheel moves forward.
  3. ATP is hydrolyzed and phosphate ion is released.
  4. Enzyme changes conformation and wheel moves forward.
  5. ADP is released.
  6. Enzyme returns to original conformation and wheel moves forward.

A Hypothetical ATPase Ratchet



- Direction of the wheel rotation is linked to direction of catalyzed reaction:

  $ATP \rightleftharpoons ADP + Pi$

- If ATP, ADP and P_i are at equilibrium concentrations:

  $\Delta G = 0$, and wheel moves randomly in both directions.

- If ATP, ADP and P_i concentrations make $\Delta G < 0$:

  Forward reaction is favored, and wheel moves preferentially in clockwise direction.

- If ATP, ADP and P_i concentrations make $\Delta G > 0$:

  Reverse reaction is favored, and wheel moves preferentially in counter-clockwise direction.

- What if the wheel is turned by an outside force?