Advanced Cell Biology. Lecture 8

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Outline

Macromolecules in cells

Cells and energy

Outline

Previous final question: the answer

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Write a sequence complementary to **ATTGGAAGC**
Is it from DNA or RNA?

- TAACCTTCG
- DNA

Most frequent macromolecules

- Polymer molecules generate most of cell dry weight (30% of total weight)
- Proteins are 15%, nucleic acids 7%, lipids and polysaccharides 2% each

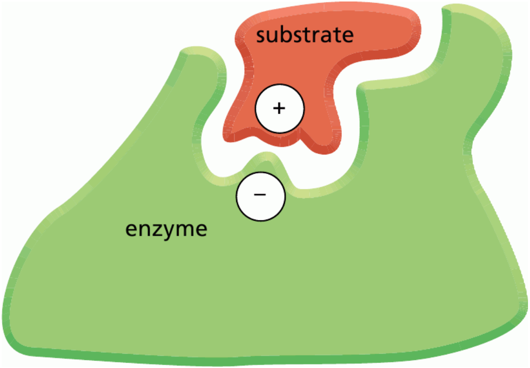
Noncovalent bonds, conformations and binding

- Non-covalent bonds are responsible from shaping of macromolecules
- Almost every macromolecule has different shaping variants—**conformations**
- Intermolecular binding is also due to noncovalent bonds

Types of noncovalent bonds

- Hydrophobic forces
- Van der Waals attractions: due to fluctuation of electric charges
- Electrostatic, including hydrogen

Binding with noncovalent (electrostatic) bonds



Metabolism

- **Metabolism** is the sum of all chemical reactions in living organism
- **Catabolism** is the part of metabolism responsible for degrading complex molecules
- **Anabolism** is the opposite part

Metabolism

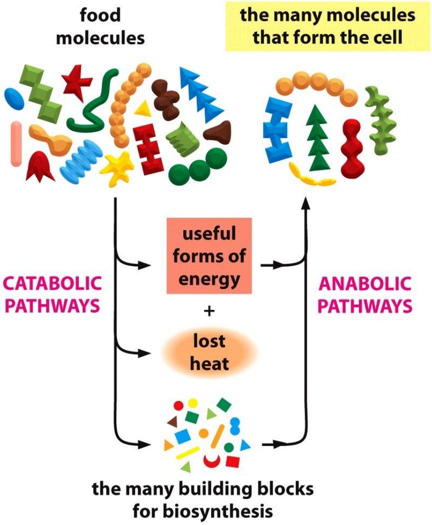


Figure 3-2 Essential Cell Biology 3/e (© Garland Science 2010)

Second law of thermodynamics

- Thermodynamic definition (Rudolf Clausius): *No process is possible whose sole result is the transfer of heat from a body of lower temperature to a body of higher temperature.*
- Simplistic definition: *In isolated system, disorder is always increasing*
- To revert initial order, energy should be spent
- Generally speaking, **entropy** is a measure of disorder (better—measure of randomness)
- In strict sense, entropy is $dS = \frac{\delta Q}{T}$, where Q is amount of heat and T—absolute temperature (constant)

Entropy

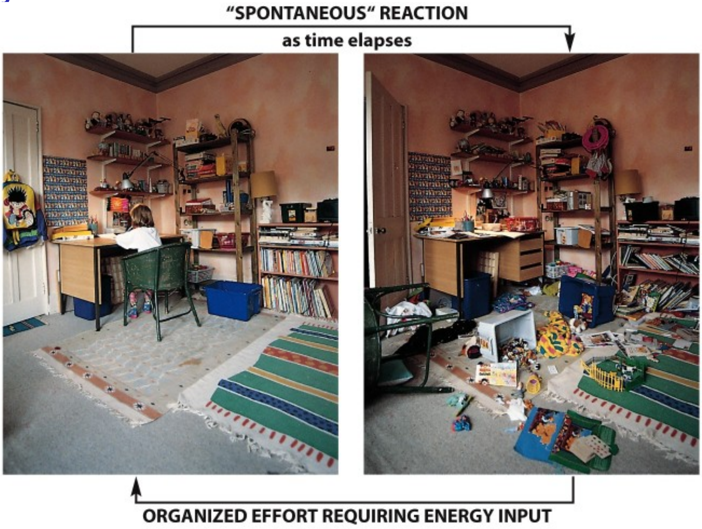
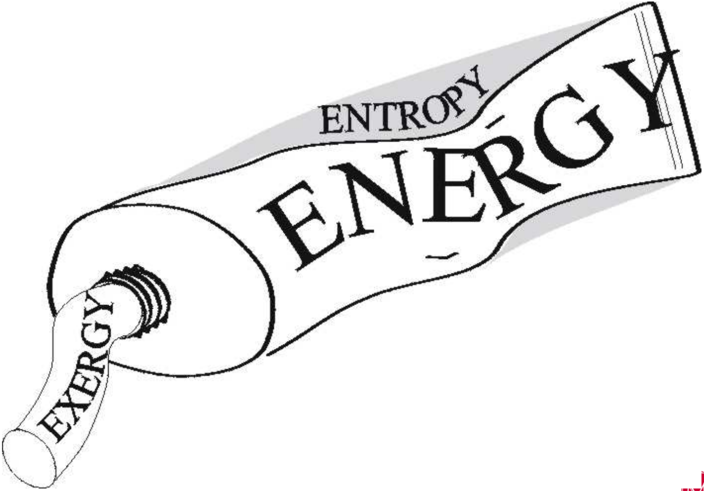


Figure 3-4 Essential Cell Biology 3/e (© Garland Science 2010)

Triumph of entropy: "post-apocalyptic world"

Entropy explained: energy tube



Different forms of energy

- Mechanical energy: potential and kinetic
- Heat energy
- Electromagnetic energy
- All forms are inconvertible; and **first law of thermodynamics** says that *energy never disappears*, it only changes its form

Photosynthesis

- The way of transforming light energy to energy of chemical bonds
- The schematic description is:
  light energy + CO_2 + H_2O $\rightarrow$ sugars + O_2 + heat energy
- Part of anabolism

Cellular respiration

- Almost opposite process
- Schematic description:
  sugars + $O_2 \rightarrow CO_2 + H_2O$ + chemical energy (ATP)
- Part of catabolism

Oxidation and electron transfer

- Cellular respiration is based on oxidation, taking electrons off
- Converse reaction is reduction; together they are *redox* reactions
- For organic molecules, typical oxidation sequence is: carbohydrates $\rightarrow$ alcohols $\rightarrow$ aldehydes $\rightarrow$ organic acids $\rightarrow CO_2$

Enzymes and energy of activation

- Most of processes need the *energy of activation*
- **Enzymes** could lower activation barriers

Energy of activation

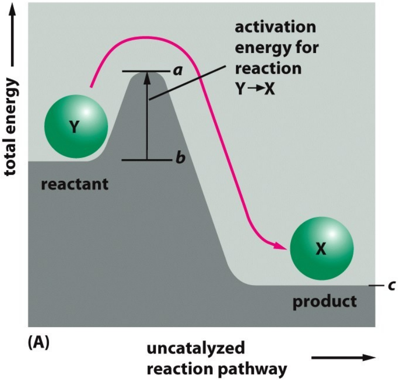


Figure 3-12 Essential Cell Biology 3/e (© Garland Science 2010)

Catalysis movie

Enzyme terminology: catalysis and substrate

- Enzyme binds with **substrate**,
- then catalyze conversion of substrate into **product**,
- and returns untouched to the initial state

Catalysis terms

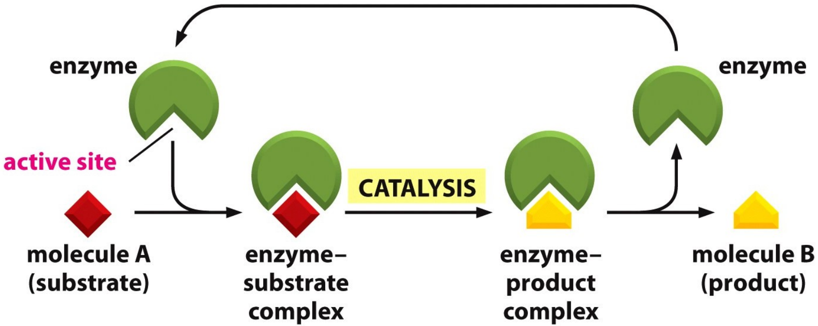


Figure 3-15 Essential Cell Biology 3/e (© Garland Science 2010)

Enzyme performance

- Two numbers are using for measuring enzyme performance: V_{max} and K_M
- V_{max} is maximal available reaction rate
- K_M is the concentration of substrate when the rate is $V_{\mathrm{max}}/2$

Enzyme performance

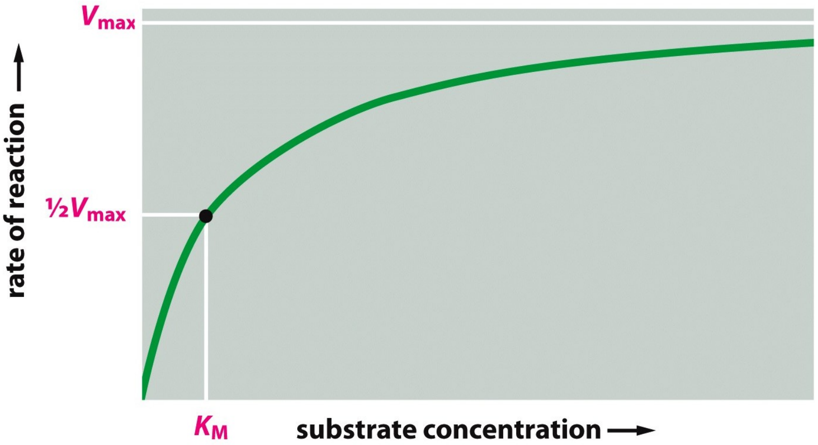


Figure 3-24 Essential Cell Biology 3/e (© Garland Science 2010)

Free energy

- Gibbs energy, or G, is another entropy avatar
- If G increases ($\Delta G > 0$), chemical system becomes more disordered and give energy out (e.g., in form of heat)
- If G decreases ($\Delta G < 0$), chemical system becomes more ordered and takes energy

Standard free-energy change

- Simple chemical reaction like $X \rightarrow Y$ depends on reagent concentrations, $[X]$ and $[Y]$
- Free energy (Gibbs energy) will also depend on concentration
- To standardize G, we are using $\Delta G^{\circ} = \Delta G - RT \ln \frac{[X]}{[Y]}$, where R (gas constant) and T (absolute temperature) are constants

Chemical equilibrium

- Chemical reactions are going on until they reach a state of **chemical equilibrium**
- In the equilibrium, reaction is going in both directions without changing concentration of participating chemicals: $X \rightleftharpoons Y$

Equilibrium constant

- On the stage of equilibrium, **equilibrium constant** $K = \frac{[X]}{[Y]}$, and $\Delta G = 0$ (why?*)

- Consequently, standard free-energy on the stage of equilibrium is:

$$\Delta G^\circ = \Delta G - RT \ln \frac{[X]}{[Y]} = -RT \ln K = -0.616 \ln K = -1.42 \log K$$

Equilibrium constant

- On the stage of equilibrium, **equilibrium constant** $K = \frac{[X]}{[Y]}$, and $\Delta G = 0$ (why?*)

  *Because equilibrium reaction does not take of give any energy

- Consequently, standard free-energy on the stage of equilibrium is:

$$\Delta G^{\circ} = \Delta G - RT \ln \frac{[X]}{[Y]} =$$
$$-RT \ln K = -0.616 \ln K =$$
$$-1.42 \log K$$

Equilibrium constant in complex reactions

- In complex reactions, K depends on concentrations of all participants
- E.g., for $A + B \rightleftharpoons AB$: $K = \frac{[AB]}{[A][B]}$
- If reaction has several steps, all changes of free-energy are additive

Final question (2 points)

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Reaction $X \rightleftharpoons Y$ is on the stage of equilibrium.
$K = 1$, $[X] = 2$ mole/l

What is $[Y]$?

Summary

- All metabolic reactions need energy
- Some reactions are endoenergetic ($\Delta G > 0$, some are exoenergetic ($\Delta G < 0$)
- On the stage of equilibrium, all reactions at +37°C have $\Delta G^{\circ} = -1.42 \log K$

For Further Reading

A. Shipunov.
Advanced Cell Biology [Electronic resource].
2011—onwards.
Mode of access: http://ashipunov.info/shipunov/school/biol_250

B. Alberts et al.
Essential Cell Biology. 3rd edition.
Garland Science, 2009.
Chapter 2, *Chapter 3*: 58–100.