Unit 4: Energy Considerations of Biological Activity

Overview:

This Unit concerns basic concepts of energy, the laws of thermodynamics and how they apply to biological systems, enzyme catalysts and coenzymes, ATP and chemiosmotic phosphrylation.

*** GENERAL NOTE TO TEACHER: You are about at the end of the first month of school. The students are probably feeling inundated and overwhelmed with material. Don't let them get discouraged or frustrated, just keep them moving. Keep them motivated and interested by directing them to any of the APBio Web sites. Save 5 minutes at the end of class occasionally for questions on the material or perhaps issues that have been raised in the news or media.**

Objectives:

- The students should become familiar and comfortable with the concept of energy and thermodynamics as applied to living systems and their environment.
- The students should become familiar and comfortable with the function of enzymes as catalysts.
- The students should become familiar and comfortable with the structure and function of coenzymes.
- The students should become familiar and comfortable with the structure and function of ATP and ADP and understand the meaning of the high-energy phosphate bond.
- The students should become familiar and comfortable with the Chemiosmotic Theory

Skills Attained:

- The students should have a working knowledge of energetic principles.
- The students should be able to state the First and Second Law of Thermodynamics and state how they apply to biological systems.
- The students should understand the structure and function of enzymes as catalysts.
- The students should understand the structure and function of allosteric enzymes.
- The students should understand the structure and function of co-enzymes.
- The students should understand the concept of the Chemiosmotic Theory.

The Unit Lessons: (Days 20-26)

- GENERAL NOTE TO TEACHER: Keep those study groups going. This helps with student motivation and responsibility.
- Assignments: Have the students read the relevant pages in their textbook before you cover it in class. They should have questions ready by then. Give any written homework after they've covered some of the material. I generally give homework on a weekly basis rather than daily….easier for me and it gives the students both the responsibility and the freedom to plan their homework. Also, as much as possible, try to plan the assessments around other tests the students may have.
- This unit is a bit of a break. The students have to recognize the structures of ATP, ADP, and co-enzymes, but they certainly don't need to memorize them! They have heard about most if not all of these concepts (with the likely exception of chemiosmotic phosphorylation), so it tends to be a bit easier. To me, this means you can use this unit to gain some time, if the other units took longer than expected. If you are on-target, you may be able to throw in a discussion on current events or issues.

Unit 4: Days 1-8

Unit 4:Day 1: CN: 4:1:A-D, PowerPoint Slides #180-190, Homework: Unit 4 Essays

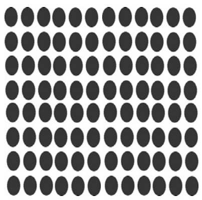
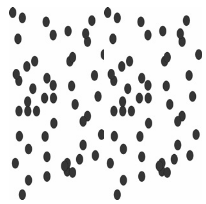
- **Thermodynamics:** The study of the conversion of forms of energy including heat energy. The students should be familiar with these Laws and equations from their chemistry classes.
- **Energy:** Energy is generally defined as the ability to do work.
  - ⊙ First Law of Thermodynamics: Energy is conserved—it can neither be created nor destroyed, only converted into another form of energy or into matter (which, itself, is another form of energy)
    - ❖ Mathematically: $E= mc^2$
      - ♦ I always emphasize this a lot—energy is never lost-- it may appear you have lost energy, but it is always converted to either another form (heat loss is particularly important in cells) or to mass (as in nuclear fusion reactions). The students have to keep in mind that in a cell, the energy balance sheet is always maintained.
    - ❖ Second Law of Thermodynamics: **(Class Notes 4:20B,Figures 2,3)**
      - ♦ The entropy of the Universe is increasing:
        - Entropy is a tough concept for many students. Entropy-- a measure of disorder or randomness in a system. Use a teenager's room to help explain entropy. There is a general tendency in the universe for "disorder" because the probability of "order" is so small. If order is defined as precise coordinates for every object, then disorder happens at the slightest misplacement. In a teenager's room, the chance of them misplacing a book, CD or whatever is much greater than the chance they will place the object in precisely the correct spot! Once they have the general idea (and they should have heard about entropy in chemistry classes), then get into the math of it:

$$\Delta S_{universe} = \Delta S_{system} + \Delta S_{surroundings}$$

- Define increasing disorder as a + ΔS. (Δ means change in and is always defined as final conditions – initial conditions)
  - ❖ Since $\Delta S_{universe}$ MUST be increasing (i.e. +) and the entropy of the cell is decreasing

($-\Delta S_{system}$) (because it is becoming more ordered and organized), then $\Delta S_{surroundings}$ must be large and positive. A cell apparently disobeys the second law, but it can only do so with a very large expenditure of energy and at the cost of releasing a lot of heat to the surroundings. (The system can be defined for the students as the part of the universe that you are looking at—the cell or the organism. The surroundings are everything else.)

Figure 2: Order Figure 3: Disorder

Higher Energy States = Higher Entropy States

LOWER ENERGY STATES = LOWER ENTROPY STATES

A system (cell) becomes more ordered (Lower Entropy) by organizing itself. This requires energy, which the cell obtains from a source like the sun. Excess energy is released in the form of heat or stored in chemical bonds.

- ❖ A cell increases the entropy of the surroundings by exchanging heat (ΔH—enthalpy which is heat under conditions of constant pressure) with the surroundings.

  - Activity: Rubber Band Entropy

- Gibb's Free Energy (ΔG): The Gibb's Free Energy can be defined to the students as the amount of energy available to do useful work. If it is negative for a particular reaction, no additional energy was required—the energy was already stored in the form of chemical bonds and the reaction is spontaneous (it also means that then products have less free energy than the reactants). If it (ΔG) is positive, the cell needs to obtain energy from some source (e.g. the sun). The First Law states that whatever energy goes into a cell must be conserved. This conservation takes place by the making or breaking of chemical bonds. Whatever energy goes into making the bonds is released in the breaking of those bonds. (1^{st} Law) The heat that results from these reactions is returned to the surroundings to increase the entropy of the surroundings. (2^{nd} Law)

+ΔH: Endergonic Reaction (Energy Absorbed)

-ΔH: Exergonic Reaction (Energy Released)

+ΔS: Increase in entropy

-ΔS: Decrease in Entropy

T: Temperature in Kelvin—always positive

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

Unit 4: Days 1-8

The cell seems to fly in the face of the 2nd Law of Thermodynamics because it decreases its entropy. However, the cell does this by increasing the entropy of its surroundings by the overall release of heat energy. Thus, the overall entropy of the **UNIVERSE** is increased.

In a cell, many reactions are spontaneous. Those that are not are often made spontaneous or made to happen by the use of catalytic enzymes.

- Example of the First Law using ΔG: In cellular respiration, glucose is metabolized:

$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6\ H_2O +$ **ENERGY**

ΔG= -686kcal/mole

In photosynthesis, glucose is synthesized:

$6CO_2 + 6\ H_2O +$ Light **ENERGY** $\longrightarrow C_6H_{12}O_6 + 6O_2$

ΔG= +686kcal/mole

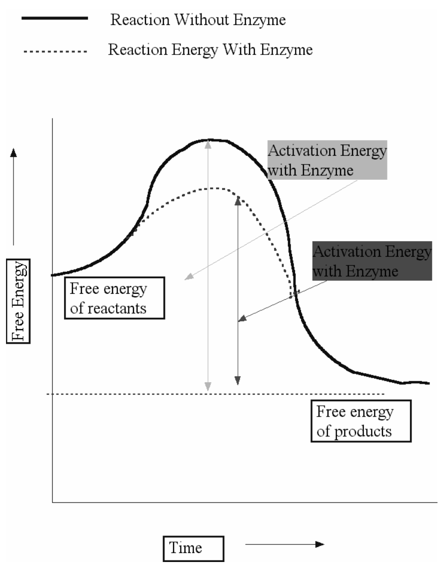
Have the students notice that these are reverse processes and that the magnitude of ΔG is the same, only the sign is different.

- Define for the students:
  - ❖ Exergonic (energy releasing) and Endergonic (energy absorbing) reactions. Students may remember the terms exothermic and endothermic--these are heat releasing and heat absorbing reactions respectively, and do not necessarily give information about the energy status, as do the terms exergonic and endergonic. Exothermic reactions are generally exergonic and vice versa. However, for example, the evaporation of water is endothermic yet the reaction is exergonic—the absorption of heat is offset by the large entropy increase.

Unit 4:Day 2: CN:4:2:A-H PowerPoint Slides #191-211

- Define/explain:
  - ❖ Enzymes are catalytic proteins without which biochemical reactions would be so slow as to make life, as we know it energetically impossible. Enzymes are proteins which may be modified by glycosylation (addition of sugars), phosphorylation (addition of phosphate groups) or by the addition of lipids. Enzymes are exquisitely specific and sensitive to changes in pH (the addition of a hydrogen to an enzyme's active site may be sufficient to render it non-functional) and to temperature (enzymes are proteins and tend to denature i.e. lose their 2^0, 3^0 or 4^0 conformations (shape) at higher temperatures.) Catalysts are defined as substances that increase the rate of a reaction by lowering the energy of activation necessary for that reaction to proceed without themselves being used up in the reaction—enzymes are the ultimate recyclers.

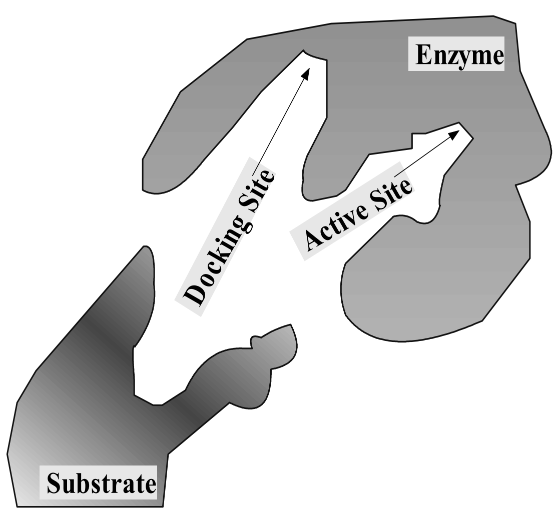
Figure 4: Activation Energy



❖ Catalysts:

- Speed up the rate of the reaction—by lowering the activation energy (lopping off the top of the hill)
- Are themselves unchanged—they can be recycled.
- Are specific
- May require cofactors
- Have an active site (Lock and Key hypothesis). May also have a "docking site".
- Are regulated by the organism so that the rate of product formation correlates with the cell's needs.
- Enzymes are specific **(Figures 5,6,7)** Lock and Key hypothesis. Induced Fit is only a modification of lock and key—induced fit takes into account the experimental evidence of a conformational change in the substrate, the enzyme or both.

Figure 5: Enzyme Reactions: The Active Site and the Enzyme-Substrate Complex



- The Docking Site provides an anchor for the protein.
- It is at the active site that bonds are broken and re-made.

Figure 6: The Enzyme-Substrate Complex

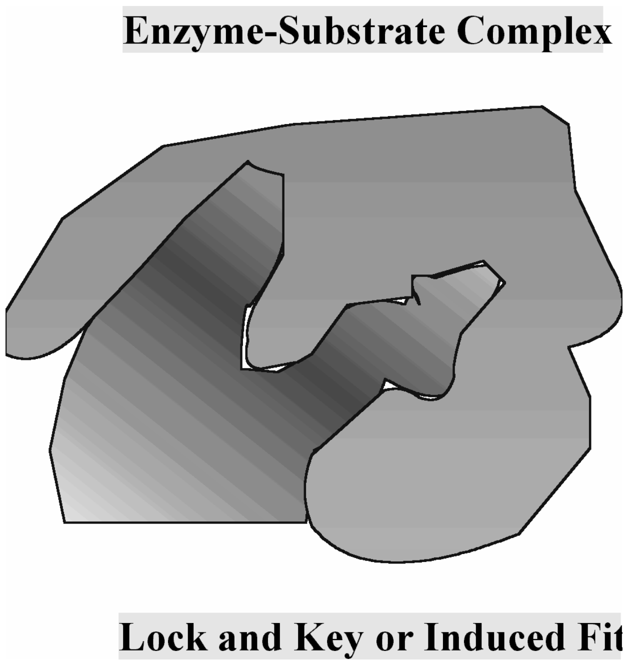
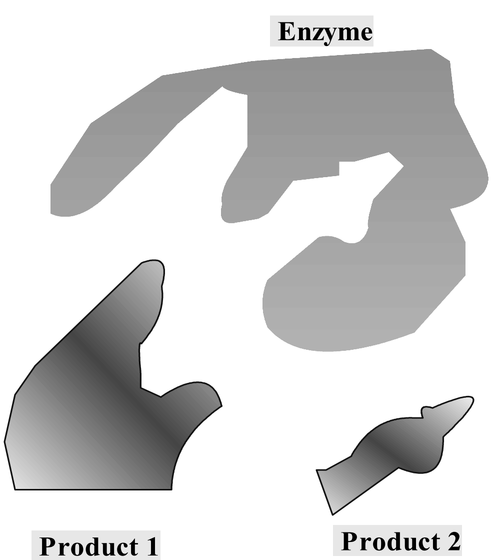


Figure 7: Enzyme and Products



The Enzyme remains unchanged and ready for the next substrate molecule.

Enzyme specificity is based on the 3-dimensional shapes of the enzyme and its substrate.

- ❖ How enzymes work: Enzymes lower the activation energy of the reaction—the activation energy is the amount of energy that needs to be put into the system in order for the reaction to occur. Collision theory of chemical reactions should be reviewed here—the collision theory states that in order for a reaction to occur, molecules must first collide, they must have sufficient energy and they must be in the proper orientation. Enzymes have solved these problems in one fell swoop—the collision itself is taken care of because the substrate or substrates lodge in the enzyme's active site. This also takes care of the orientation problem—the substrate won't be IN the active site unless it is properly oriented. Finally, the enzyme lowers the activation energy—mainly by accomplishing the first two items. Induced fit also implies that bond energies in the substrate(s) may be lowered, thereby decreasing the activation energy.
- ❖ Collision activity
  Activation energy /Activated Complex (transition state): The activation energy is the amount of energy required to get the reaction moving—its' an energy barrier that the enzyme helps the substrate to overcome. The diagram looks like a hill, and that's an appropriate analogy—if you have to roll a rock to the other side of a hill, you have to expend energy to get to the top. (There is always someone who wants to go <u>around</u> the hill—just tell them there's quicksand or snakes all around!) The activated complex (also known as transition state) is the intermediate enzyme-substrate complex.

<u>Unit 4:Day3: CN:4:3:A-F, PowerPoint Slides #212-222</u>

- ❖ Factors influencing a biochemical/Enzyme reactions:
  - Temperature/pH dependence: Most enzymes have a relatively narrow range of temperature and pH where they are active. Mention here that this is one reason for the existence of homeostatic mechanisms—without the proper maintenance of temperature and pH, enzymes would be non-functional and therefore life, at least our understanding of life, would be radically different. Further, some classes of biochemicals, especially proteins are themselves temperature dependent—any protein, enzyme or not, may denature if the temperature is too high. pH dependence is based on ionization. It is especially important for amino acids with ionizable side chains, proteins and fatty acids.