Introduction to Biology Chapter 6

Ground Rules of Metabolism (Enzymes)

Introduction

In living systems, thousands of chemical reactions take place, many of them at the same time. These reactions are referred to as metabolic reactions or metabolism. Metabolic reactions follow the Laws of Thermodynamic: 1) Energy can be neither destroyed nor created; 2) Energy can be converted from a higher to lower grade. Each Metabolic reaction either requires energy input or liberates energy. This energy can be measured in terms of heat units - the calorie. Essentially, all of these metabolic chemical reactions involve substances called enzymes. Enzymes are protein molecules that can accelerate chemical reactions but are not themselves changed by the reaction. Such substances are called biological catalysts. The second focus of this week’s work is an examination of these enzymes and their functioning.

Course outcome:

Understand enzyme structure and function as governed by the under laying the Laws of Thermodynamic. Describe the function of Cofactors, Coenzymes and Prosthetic groups.

Learning goals:

After studying this week’s material you should:

1. Define the Laws of Thermodynamics
2. Be able to define the term “enzyme”.
3. Know how enzymes work in some situations and not others.
4. Describe how enzymes are either combined or split apart molecules.
5. Know how enzyme operations are controlled and regulated.
6. Be able to describe a oxidative reductive biochemical reaction and how Cofactors and Coenzymes facilitate these reactions

Assignments:

These will be found in the Week 5 Folder

1. Chapter 6, Enzymes in your text.
2. Visit the following URL

http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookEner1.html

This is from the same folks who brought you the previous site. The section titled Enzymes: Organic Catalysts is the portion of this page to focus on. Note the different ways enzyme activity is regulated. Pretty neat ways for molecules to interact I think. Be sure you study this material.

Visit these sites for Enzymes and how they function

http://faculty.nl.edu/jste/enzymes.htm

The University of Arizona offers a tutorial site with question for those willing to master chapter 6.
This site describes the energy balance of biological system. Simplified thermodynamics.

http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookEnzym.html

ATP and cellular energy

http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookATP.html
CHAPTER 6

We will be talking in chapter 7 about photosynthesis and in chapter 8 about respiration. This chapter serves as the nuts and bolts for the next 2 units.

Energy: Defined at the ability to do work against an opposing force.

A. Laws of Thermodynamics

1. First Law
   a. Energy can neither be created nor destroyed
      1) Energy can only change forms

Example: Light $\rightarrow$ Chemical $\rightarrow$ Mechanical

2. Second Law
   a. Energy is converted from a higher grade to lower grade or less usable form
   b. Energy is lost as heat in the process
   c. Entropy is the measure of heat or commonly referred to as disorder

B. Energy

1. Two types of energy that we should be aware of
   a. Potential energy: That is stored energy

Example: Water behind a dam site

b. Kinetic energy: That is the energy of movement

Example: Gasoline in a automobile represent Potential energy. However, when a car is moving the energy being expressed is potential energy.

C. Conservation of Mass Law

1. Reactants = Product

D. Transfer of Energy within biological systems

1. Metabolism: the ability to acquire, store & use energy.
   a. In biological systems there are various types of chemical reactions
      1) Anabolic reaction: energy is used to build macromolecules

Example: Amino acids used to build proteins
      2) Catabolic reactions: energy is derived from the break down of macromolecules

2. Biological chemical reactions are mediated by ENZYMES
   a. Enzymes act as a biological catalyst
      1) Speeding up a reaction
      2) Lowering the energy of activation
      3) And, not being consumed by the reaction

b. Enzymes
   1) are very specific for a particular substrate (reactant) to be acted upon
   2) function best within a critical temperature and Ph range
c. Enzyme helpers and Cofactors
   1) Coenzymes
      Vitamins; NAD⁺; FAD⁺; NADP⁺
   2) Cofactors; these are inorganic atoms of Iron; magnesium; manganese; zinc

**Enzymes**

- Enzymes are proteins that bind to a reactant (substrate) to form an *enzyme-substrate complex*.

- This binding is the interactions of relatively weak chemical bonds such as Hydrogen bonds.

- The formation of the enzyme-substrate complex is 3D in design taking place within an "active site" of the enzyme encouraging a chemical reaction to take place.

**Lock and key theory**

- One idea holds that the active site of the enzyme match. the shape of the substrate much like a key fits a lock:

**Induced-fit theory**

- Another idea holds that the substrate induces a change in the shape of the enzyme resulting in a very close fit of enzyme and substrate:

Although some enzyme function by the lock and key design, most enzyme function more like the induce-fit model.

**Inhibition of Enzymes Action**

- Each chemical reaction within a cell has to be carefully regulated.

= Competitive inhibition

This type of inhibition is reversible and is used by the cell for feed back processes.

- Slow Down -
The product of the enzyme reaction resembles the substrate that the product competes for the binding site within the enzyme.

Binding of the product to the active site limits substrate access to the site reducing the overall reaction rate.

= Noncompetitive Inhibition

Inhibition may result from binding of molecule to a separate site not too far from the active site. The molecular arrangement may block the substrate preventing the formation of an enzyme-substrate complex.

Example: Carbon monoxide blocks the active site of the heme-molecule preventing oxygen up-take. Or, penicillin block the active site of an enzyme necessary for the synthesis of bacterial cell walls.

Noncompetitive inhibitors tend to bind to the enzyme irreversibly.

Example: Carbamate insecticides act upon the choline-esterase enzyme causing respiratory lock up in poisoned insects or individuals

= Allosteric Regulation

Both positive and negative feed-back inhibition.

Binding of molecules to the allosteric type enzyme results in a shape change of the enzyme. This shape change may or may not enhance the active site responsiveness to the substrate.

3. Metabolic pathway
   a. series of chemical reaction

   Reactants ----> Product

   enzyme 1   enzyme 2
   reactants ----> intermediate ----> intermediate ----> Final
   Product     Product     Product

   b. energy used or released
      1) Endergonic reactions use energy
      2) Exergonic reactions release energy
E. Oxidation - Reduction Reaction

1. An **oxidation** reactions: will loose electrons
2. Reduction reactions: will gain electrons
   under the category of reduction reactions are those cases were a molecule will gain
   both electrons and hydrogen

\[ \text{H}^+ + e^- \rightarrow \text{H} \text{ (hydrogen atom)} \]

**Ex.:** NAD$^+$ + H$^+$ + e$^-$ ---> NADH

Oxidized Reduced
Addendum

I. METABOLISM

A. Metabolism (Greek: change)
One can think of an organism's chemical processes as a big map

Metabolism is concerned with managing the material and energy resources
of the cell

Some processes of metabolism break molecules down and this is called
CATABOLISM

Other processes build complicated molecules from simpler ones and this
is called ANABOLISM

Both the catabolic and anabolic pathways are downhill and uphill
biological processes

In chapter 2 we talked about matter as taking up space and has mass.
Now we will talk about energy.

Energy is defined as the capacity to do work: to move things against an
opposing force

FORMS OF ENERGY

Moving energy is considered kinetic energy. This is the form of action
energy.

On the other hand, resting energy or that form of energy with a potential
to do work is said to be POTENTIAL ENERGY. Water behind a dam such as on
Columbia river has potential energy.

The form of energy important to biologist is chemical energy. That energy stored in
molecular bonds.

ENERGY TRANSFORMATION

Energy can be converted from one form to another. When plants through the
use of chlorophyll traps and converts sun light energy chemical energy
(or sugars) are derived.

The plant’s chemical energy is released through cellular respiration.

This process of energy exchange from sun light to plant photosynthesis
to cellular respiratory activities is energy transformed not unlike
burning gasoline in a car’s engine to derive mechanical thrust.

The study of energy transformation that occurs in nature is called
thermodynamics
The First Law of Thermodynamics

States that energy neither be created nor destroyed; just transferred or transformed.

Energy is a constant in the universe.

The electric company merely converts one form of energy, say water power, into other forms of usable energy: electricity.

The Second Law of Thermodynamics

Since energy must be conserved it must be accounted for. The Second Law of Thermodynamics states that for every energy transformation the Universe becomes a little more disordered. The study of this form of disorder is called entropy.

A system becomes more ordered is at the expense of the rest of the universe.

Life is highly ordered process. Life has low entropy. This seems like a contradiction in terms of the second law of thermodynamic however organisms are open systems reacting with the surroundings. We, as humans, take in starch, proteins, and other complex molecules and replaces them with carbon dioxide (CO$_2$), water and other small simple molecules.

If we stop and consider that each time we convert one form of energy into another form of energy there is a loss of energy value incurred.

In most energy transformation - energy is at least partly converted to heat.

For example: some figures stated that as high as 75% of the energy converted in a car’s engine goes out the tail pipe as heat.

The heat does no work and maybe considered a loss except, perhaps, in biological systems where heat warms a body.

Chemical Energy

Chemical reaction rearranges atoms of molecules breaking old bonds and making new ones. Energy must be absorbed by the molecules to break their bonds. This quantity of energy necessary to break these bonds is called the BOND ENERGY.

The expression of energy absorbed by bonding is expressed in kilocalorie per mole of bonds broken or formed (kcal/mol). A chemical calorie unit is different from a food calory unit. Remember one calorie of heat can] raise 1g of water 1 degree centigrade.
The stronger the bond the greater the energy needs are to break those bonds.

<table>
<thead>
<tr>
<th>Bonds</th>
<th>Energy (kcal/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-C</td>
<td>83</td>
</tr>
<tr>
<td>C-H</td>
<td>99</td>
</tr>
<tr>
<td>C-O</td>
<td>84</td>
</tr>
<tr>
<td>C=O</td>
<td>174</td>
</tr>
<tr>
<td>O-H</td>
<td>111</td>
</tr>
<tr>
<td>O=O</td>
<td>118</td>
</tr>
</tbody>
</table>

**HEAT OF REACTION**

As chemical bonds break or form the reaction either takes up energy or liberates energy.

For example can compute the energy required to initiate the burning of methane gas and its liberation of energy as related to heat.

**Enzyme**

<table>
<thead>
<tr>
<th>Reactants</th>
<th>mediated reaction</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄ + 2O₂</td>
<td>------------------</td>
<td>CO₂ + 2H₂O</td>
</tr>
</tbody>
</table>

From the table we can see

**Bonds broken (energy absorbed)**

\[ 4 \text{ C - H} \times 99 = 396 \text{ kcal} \]
\[ 2 \text{ O = O} \times 118 = 236 \text{ kcal} \]

\[ \text{Total} = 632 \text{ kcal} \]

**Bonds formed (energy released)**

\[ 2 \text{ C = O} \times 174 = 348 \text{ kcal} \]
\[ 4 \text{ O - H} \times 111 = 444 \text{ kcal} \]

\[ \text{Total} = 792 \text{ kcal} \]

160 kcal released (represented as -160 kcal)

Remember a negative sign is energy liberated.