Chapter 8 Lecture Notes: Metabolism - Energy and Enzymes

“Life is sustained by the trapping and use of energy, a process made possible by enzymes”

I. Energy and work
   A. Energy
      1. capacity to do work
         a) Chemical work – synthesis of complex biological molecules from much simpler ones
         b) Transport work – transporting molecules in and out of cell
         c) Mechanical work – change in physical location of organisms, cells, or structures in cells
      2. What is the ultimate source of energy? light energy from sunlight
      3. What is the energy cycle? Fig. 8-1
         • light energy from the sun is trapped by pigments and converted to chemical energy during photosynthesis
         • chemical energy is used to convert CO₂ into organic molecules
         • organic molecules are used as energy by other organisms which generate CO₂
   B. How do we measure energy? Thermodynamics (analysis of the energy change in a system)
      1. Two laws:
         a) Energy is neither created nor destroyed
         b) Processes proceed to increased disorder in the universe
      2. Free energy of reaction
         a) amount of energy available to do work
         b) negative value = spontaneous reaction (exergonic)
         c) positive value = requires energy input to occur (endergonic)
         d) ?G = ?H – T?S
            (1) ?H = enthalpy = heat content: more negative is exothermic
            (2) ?S = entropy: more positive is more random
         e) only measures where the reaction lies at equilibrium NOT how long it takes to reach equilibrium
   C. How is energy transferred in the cell? High energy bonds – chemical bonds that release large amount of energy upon hydrolysis
      1. ATP (Fig. 8-2)
         a) energy currency of the cell (energy is trapped in phosphate bonds)
         b) can couple ATP hydrolysis (release of energy) with an energetically unfavorable reaction
      2. CoA
II. Redox reactions
A. Reactions in which electrons move from donor (reducing agent) to acceptor (oxidizing agent). Note that the reactions occur in pairs: there must be a donor and an acceptor.
B. Frequently, the electron moves as a hydrogen atom (proton + electron).
C. Biochemically important because oxidation of a highly reduced compound (like glucose) results in the production of chemical energy in the form of ATP.
D. Terminology
   1. Oxidation = removal of electrons from a substance; substance is oxidized
   2. Reduction = addition of electrons to a substance; substance is reduced
   3. Reducing agent (reductant) = agent that donates electrons (and therefore looses them and so is oxidized in the process)
   4. Oxidizing agent (oxidant) = agent that accepts electrons (and therefore is reduced and so is reduced in the process)
   5. Reactions are generally written as reductions: \( 2 \text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2 \)
   6. Reduction potential \( (E_0) \) is the tendency of a substance to loose/donate electrons: the more negative the number, the more the tendency to donate electrons (Table 8-1)
E. Example reaction:
   Reaction #1: \( 2 \text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2 \) \( E_0 = -0.42 \)
   Reaction #2: \( \frac{1}{2} \text{O}_2 + 2\text{e}^- + 2\text{H}^+ \rightarrow \text{H}_2\text{O} \) \( E_0 = +0.82 \)

   How do we know which reaction goes in which direction (i.e. who is oxidized and who is reduced)? ANSWER: reduction potential – reaction with more negative reduction potential will donate the electrons (oxidation)

   Reaction #1 written as oxidation: \( \text{H}_2 \rightarrow 2 \text{H}^+ + 2\text{e}^- \)
   Reaction #2 written as reduction \( \frac{1}{2} \text{O}_2 + 2\text{e}^- + 2\text{H}^+ \rightarrow \text{H}_2\text{O} \)
   Total reaction: \( \text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O} \)

This reaction results in the release of free energy \( (\Delta G = -nF \times E_0) \) which is proportional to the number of electrons transferred \( (n) \) and the difference between the \( E_0 \) of the reactions.

F. The electron tower (see attached)
   1. The reduced substances at the top have the greatest amount of potential energy
   2. As electrons fall from the top of the tower (exergonic reaction) they are caught (accepted) by compounds lower on the tower. This is a redox reaction.
   3. Compounds on the top are typically electron donors, compounds in the middle can be either donors or acceptors, and compounds at the bottom are acceptors.
   4. The further the "fall" the greater the free energy release \( (\Delta G) \)
G. Electron carriers

1. Electron transfer in redox reactions involves intermediates known as electron carriers

2. Nicotinamide adenine dinucleotide (NAD\(^+\)) and Nicotinamide adenine dinucleotide phosphate (NADP\(^+\)) (Fig. 8-8)
   a) Coenzymes that associate with various proteins to carry electrons as hydrogen atoms
   b) NAD is generally used for catabolic reactions
   c) NADP is generally used for anabolic reactions
   d) \(\text{NAD}^+ + 2e^- + 2 \text{H}^+ \rightarrow \text{NADH} + \text{H}^+\) (frequently written as NADH though)

3. Flavoproteins: Proteins that have the prosthetic group flavin to carry electrons as hydrogen atoms
   a) Flavin adenine dinucleotide (FAD): \(\text{FAD} + 2e^- + 2 \text{H}^+ \rightarrow \text{FADH}_2\)
   b) Flavin mononucleotide (FMN): \(\text{FMN} + 2e^- + 2 \text{H}^+ \rightarrow \text{FMNH}_2\)

4. Cytochromes: Proteins with the prosthetic group heme (Fig. 8-11) (which contains an iron atom that actually carries the electron): \(\text{Fe}^{3+} + 2e^- \rightarrow \text{Fe}^{2+}\)

5. Nonheme iron proteins

6. Ubiquinone: Lipid based electron carrier (Fig. 8-10)
III. Enzymes
   A. Protein catalysts that increase the RATE of a reaction but do not alter the equilibrium
   B. Components of an enzyme
      1. Protein
      2. Cofactor (optional)
         a) Prosthetic group – firmly attached
         b) Coenzyme – loosely attached
   C. Classes
      1. According to the substrates that they act upon
      2. Table 8-2
   D. Mechanism of enzyme reactions
      1. Decrease the energy of activation of a reaction (energy required to bring the reactants together in the proper orientation to yield a transition state that then decomposes to yield products) (Fig. 8-13)
      2. How? (Fig. 8-14)
         a) Effectively concentrates the reactants
         b) Brings the reactants together in the correct orientation at a site on the enzyme called the active (or catalytic) site
   E. Effect of environment on enzyme activity
      1. low substrate = lower speed of reaction
      2. pH optimum
      3. temperature optimum
   F. Effect of inhibitors on enzyme activity (important for drug development)
      1. Competitive = directly competes with the substrate for the enzyme's active site
      2. Noncompetitive = binds to the enzyme (but not at the active site) to alter the enzyme structure which makes the enzyme less active