Biology 132 – Lecture 16 & 17 – Mitochondria and Energy

Learning Objectives
6-9: Explain how an enzyme lowers the required energy of activation for a reaction.
6-10: Describe specific ways enzymes are regulated.
7-1: Write a summary reaction for aerobic respiration, showing which reactant becomes oxidized and which becomes reduced.
6-8: Relate the transfer of electrons (or hydrogen atoms) to the transfer of energy.
3-5: Distinguish among monosaccharides, disaccharides, and polysaccharides. Compare storage polysaccharides with structural polysaccharides.
7-2: List and give a brief overview of the four stages of aerobic respiration.
7-3: Indicate where each stage takes place in a eukaryotic cell.
4-10: Compare the functions of mitochondria and chloroplasts and discuss ATP synthesis by each of these organelles.
7-5: Define chemiosmosis and explain how a gradient of protons is established across the inner mitochondrial membrane.
7-6: Describe the process by which the proton gradient drives ATP synthesis in chemiosmosis.
7-8: Compare and contrast aerobic and anaerobic pathways and fermentation; include the mechanism of ATP formation, the final electron acceptor, and the end products.

Energy of Activation: Exergonic reactions occur spontaneously, but usually some bonds are first broken which takes energy. The energy required to get an exergonic reaction going is called the **energy of activation (E_A)**. The **rates of reactions** depend upon the required E_A for the reaction, the greater the E_A for the reaction, the slower the rate. If the E_A can be reduced, the reaction will proceed much more quickly. **Catalysis** is the process of influencing chemical bonds in a way that lowers E_A. **Catalysts** are substances that lower E_A, and therefore speed up the rates of reactions. Catalysts can only increase the rates of exergonic reactions. They cannot make an endergonic reaction proceed spontaneously.

Enzymes perform catalysis in living organisms. They catalyze biochemical reactions **without being consumed**. They have shapes that **specially** fit the reactant molecules. They become associated with the reactants and put stress on particular chemical bonds that lower the amount of energy required for new bonds to form. The enzyme binds with the substrate forming an **enzyme-substrate complex**. The place on the enzyme where the substrate becomes associated with the enzyme is called the enzyme's **active site**. The shape and chemical nature of the active site determines what substrate the enzyme will work on. Most enzymes are **very picky** and will catalyze only one reaction. The enzyme-substrate complex breaks down to form the **products**. The enzyme itself is not permanently altered. After it has catalyzed one transformation, it is free to do another one.

Factors Affecting Enzyme Activity: The activity of enzymes is affected by any change in the conditions of the environment of the enzyme that alters its 3-dimentional shape. 1. **Temperature**: If the environment is too cold, there is not enough random energy in the system to allow the reaction to occur. As temperature increases, the rate of reaction will increase until, at very high temperatures, the enzyme denatures so the rate becomes zero. Different enzymes have different optimal temperatures. 2. **pH**: The pH is the measure of the concentration of H+ in a solution. A change in pH changes the H^+ bonding within the molecule, thus changing its effectiveness. Different enzymes have different optimal pH's. 3. **Chemical inhibitors and activators**: Activators and inhibitors are separate chemicals that bind to the enzyme and either speed up or slow down that reaction. Inhibitors can be **reversible** changing the action of the enzyme for only as long as it reacts with the enzyme. When it releases the enzyme, the enzyme is free to continue to work. Reversible inhibitors may be **competitive** (which means that they bind to the active site so they compete with the substrate for the active site) or **non-competitive** which means that they inhibit by binding to someplace other than the active site – an **allosteric site**. Inhibitors can also be **irreversible** and permanently inactivates an enzyme. 4. **Cofactors**: Additional chemical components (metal ions or organic molecules) that facilitate the activity of enzymes. A cofactor that is a nonprotein organic molecule is called a **coenzyme**.

Enzymes are organized into teams in metabolic pathways. The products of one reaction go straight to another enzyme to be reactants in that reaction. Often, these enzymes will be found in the same membrane, or same small space in a cell so that they are more efficient. A→B→C→D→E. At the end, then, the final product will be an inhibitor at the first reaction – something called **feedback inhibition**, or **end product inhibition**.

AEROBIC RESPIRATION AND OXIDATION-REDUCTION REACTIONS:

In some reactions, electrons pass from one atom or molecule to another. This class of chemical reaction is called and **oxidation-reduction reaction (redox)**. When an atom or molecule *loses* an electron it is **oxidized** and the process is called **oxidation**. When an atom or molecule *gains* an electron it is **reduced**, and the process is called **reduction**. Redox reactions always occur together because, every electron that is lost by one atom is gained by some other atom. There are a couple of molecules, **coenzymes**, that are commonly used in redox reactions: NAD+ to **NADH** (nicotinamide adenine dinucleotide) and FAD to **FADH2** (flavin adenine dinucleotide). NADH to NAD+ is highly exergonic and gives off 52.4 kcal/mol. The breakdown of glucose is essentially a series of redox reactions. **Glucose becomes oxidized and oxygen becomes reduced**.

$$C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O \rightarrow 6\ CO_2 + 12\ H_2O + \text{energy (in ATP)}$$

CARBOHYDRATES – CHAPTER 3 – another macromolecule

Structure - Made up of the elements C, O, and H, some are very large molecules but are made up of smaller building blocks. Functions - Energy and energy storage, some are structural. Types:

1. **Monosaccharides** are simple sugars. The most common ones, and the ones that play the most central roles in energy storage, have 6 carbons ($C_6H_{12}O_6$) or 5 C. The O's are in the form of -OH (hydroxyl groups) so the molecule is polar and they are soluble in water. 2. **Disaccharides** are made up of two monosaccharides linked together. The condensation reaction forms a **glycosidic linkage** between two monosaccharides. 3. **Polysaccharides** are long polymers composed of monosaccharide sugar subunits. Energy stored as carbohydrates is usually stored as polysaccharides. Polysaccharides can be unbranched or branched chains of sugars. A branched polysaccharide is called a **pectin**. **Starch** is a plant polysaccharide made up entirely of glucose subunits. Used for energy storage. **Glycogen** is the principle carbohydrate of storage in animals. Glycogen is stored in liver cells and in muscle. **Cellulose** is also a plant polysaccharide made up entirely of glucose. It is the major support material in plants as the chief component in plant cell walls so it is structural in function. The link in starches is an alpha-link and that in cellulose is a beta-link. This makes it impossible for most animals to break down cellulose, because we do not possess the enzymes necessary to break down cellulose. **Chitin** is a structural polysaccharide. It is found in animals - in the exoskeleton of insects - and in the cell walls of fungi.

BACK TO CELLULAR RESPIRATION There are four stages in the process of breaking down glucose to produce energy. 1. **Glycolysis** – this takes place in the cytosol of ALL living organisms. The 6-carbon sugar (glucose) is broken down into two 3-carbon sugars (pyruvate), with production of 2 ATP and 2 NADH. 2. **Formation of Acetyl Coenzyme A** – Each pyruvate from #1 enters the mitochondrion (in eukaryotes) and is oxidized to a 2-carbon molecule (acetate) that combines with CoA, forming **acetyl CoA**, NADH is produced and CO_2 is given off as waste.

An Aside About Mitochondria: They have two membranes, the outer is smooth whereas the inner folds to give it a large surface area. The large folds are called **cristae**. The area between the two membranes is called the **intermembrane space**. The area enclosed by the inner membrane is called the **mitochondrial matrix**. They are found in virtually all eukaryotic cells (including in plants).

3. **The citric acid cycle** (also known as the **Krebs cycle** and the **tricarboxylic acid (TCA) cycle)**. This series of reactions begins with **acetyl-CoA** binding to oxaloacetate (a 4-c molecule) to form citrate (a 6-C molecule), and ends with the production of oxaloacetate. Through this series of enzymatic reactions the 2 carbons of the acetyl-CoA are oxidized to CO_2 and H_2O, and the electrons that are removed are given to NAD^+ to form NADH and to FAD to $FADH_2$. There is also one ATP made. This occurs in the mitochondrial matrix. 4. **Electron transport and chemiosmosis**: the NADH and FADH2 need to be recycled to NAD+ and FAD so that they can accept more electrons. This means they have to donate the electrons they picked up to something else. The NADH and FADH2 donate their electrons to the **electron transport chain**, a series of membrane-bound proteins in the inner mitochondrial membrane. These **enzyme complexes** pass the donated electrons from one to another. As these electrons are passed to lower energy levels, energy is given off that is used to generate a **proton concentration gradient**. Lots of H^+ is sequestered in the intermembrane space. The last enzyme in the electron transport chain is **cytochrome c oxidase** which saves up 4 electrons, to reduce oxygen to produce H_2O.

Then, protons are allowed to go through the membrane through specific channels. These channels couple the energy of the protons going down their concentration and charge gradients (**chemiosmosis**) to the production of ATP. These channels are enzymes called **ATP synthases**. This type of production of ATP is called **chemiosmosis or oxidative phosphorylation**. The total number of ATP's that are produced during aerobic respiration is about 36 - 38 ATP.

ANAEROBIC RESPIRATION: **Glycolysis** can be performed in the absence of oxygen. All cells undergo glycolysis, but some organisms or cells do not use oxygen as their final electron acceptor. They can use an inorganic compound such as nitrate or sulfate. They have electron transport and chemiosmosis but just don't use O_2.

FERMENTATION: Fermentation is the process by which cells donate the H atoms generated by glycolysis to organic molecules derived from the original nutrient, and in the absence of O_2. There is no electron transport chain used in fermentation. ATP synthesis is by **substrate level phosphorylation**. A common type of fermentation are alcohol fermentation

$$\text{Carbohydrate} + \text{NADH} \dashrightarrow \text{Reduced carbohydrate} + NAD^+$$

The NAD^+ is then free to cycle back to glycolysis and accept more electrons so that ATP production can continue. In organisms such as yeasts, the reduced compound is an alcohol. **Facultative anaerobes** are those organisms that can switch back and forth between aerobic respiration and fermentation, depending upon whether or not oxygen is available and survive. You are not a facultative anaerobe. Fermentation is not efficient. There is a net gain of only 2 ATP per glucose as opposed to the 36 - 38 from aerobic respiration.