BIOL 300 – Foundations of Biology
Summer 2017 – Telleen
Lecture Outline

Energy, Enzymes, and ATP

I. Chemical Reactions, Energy, and Thermodynamics

A. We define **energy** as the ability to do work.
B. There are two types of energy:
   1. **Kinetic energy** is the energy of motion
   2. **Potential energy** is energy contained in objects that are not moving, but that have the potential to do so
   3. A boulder on a hill has potential energy, but some of that potential energy is converted into kinetic energy when it begins to roll down the hill
C. There are many forms of energy: mechanical energy, heat, sound, electric current, light, and radiation. This also means that there are numerous ways to measure energy.
D. For convenience, we will use heat because all other forms of energy can be converted into heat. The study of energy is called **thermodynamics** (meaning heat changes)
E. All energy in the biological sphere originally comes from the sun, which is captured by photosynthetic organisms, which use the energy to combine small molecules into larger ones that can store potential energy. This potential energy stored as chemical energy is responsible for doing work in cells. It is stored in the chemical bonds between atoms. Thus, a **chemical reaction** is the breakage or formation of chemical bonds.
F. All chemical activities in cells are just a series of chemical reactions forming and breaking down molecules
G. The Laws of Thermodynamics are a set of universal rules that describe the changes in energy in the universe
H. The **First Law of Thermodynamics** states that the amount of energy in the universe remains constant. Energy can change form, but it cannot be created or destroyed. In the context of biology, this means that energy can be transferred from one molecule to another or from one organism to another, but this energy is not created or destroyed. In living organisms, chemical potential energy is shifted between molecules and bonds. In this process there is a net loss of usable energy, but the energy is not destroyed; instead it is dissipated as heat (so the 1st Law isn't violated!). Heat energy can only be used to do work if there is a heat gradient. Cells, however, are too small to generate and use heat gradients, so heat energy isn't useful for cells.
I. The **Second Law of Thermodynamics** describes transformation of potential energy into heat (which is random molecular motion as we saw in the previous lecture/lab). It states that in a closed system, the disorder, or **entropy**, is constantly increasing. Another way to state this is that disorder is more likely

than order, or energy transformations proceed to convert matter in a more ordered, less stable form into a less ordered, more stable form.

J. How can cells order themselves if the entropy must always increase? It turns out that cells organize themselves at the expense of the outside. That is, while the entropy inside a cell may decrease, it is accompanied by a corresponding increase in entropy somewhere else (through the dissipation of heat, for example) which either equals or exceeds the decrease, but we have to look at the entire system (not just the cell itself) to notice it.

II. Chemical Reactions and Enzymes

A. We need to get through a few more chemistry terms before we move on to enzymes:
    1. Chemical reactions can be written as equations (though we won't do this very much) showing the **reactants**, or **substrates**, (i.e. the molecules we start with) on the left and the **products** of a reaction on the right.
    2. However, not all chemical reactions are equally likely to occur. Some, called **exergonic**, release energy and can occur spontaneously, while others, called **endergonic**, require an input of energy to occur. The simplest way to think about this is that the reactants have more energy than the reactants in exergonic reactions, while in endergonic reactions the products have more energy than the reactants
    3. Not all exergonic reactions occur spontaneously (think about the burning of gasoline as an example). It turns out that most chemical reactions (even if the products have lower energy than the reactants) require a little bit of extra input energy to get started (e.g. a kick in the butt to get them going). This is referred to as the **activation energy**. Going back to the boulder on a hill example, to convert the potential energy into kinetic energy we need to give the boulder a little push to get it rolling. Activation energy is analogous to this.
    4. One way to make a chemical reaction more likely to occur is lower the required activation energy, which we refer to as **catalysis**. Catalysis can make reactions occur much more quickly

B. A class of proteins, called **enzymes**, are catalysts used by cells to facilitate particular chemical reactions. Cells can control which chemical reactions occur by altering the types, locations, and activities of enzymes.

C. Enzymes work by binding to specific molecules in a way that makes them more likely to react in certain ways (essentially lowering the activation energy required to kick-start a particular reaction). This can occur is several ways (such as weakening bonds by interacting with electrons or holding two reactants in close proximity so they are more likely to react, etc.).

D. The shapes of enzymes are critical, and each enzyme can only bind one (or a few) specific molecules. The site on an enzyme that binds to the reactants in called the **active site**. There is corresponding **binding site** on the particular molecule that fits into the enzyme's active site. The binding of reactants causes enzymes to change shape.

E. The binding to reactants and catalysis of chemical reactions does not affect an enzyme, which can release the reaction products and catalyze the same reaction over and over again
F. There are many things that can influence the activity of enzymes. These include temperature, pH, concentration of reactants and/or products, etc. Each enzyme has an optimal set of conditions for maximum activity
G. Enzymes can also be regulated in several different ways.
    1. One such mechanism is called **allosteric regulation**, in which a signal molecule (not a reactant!) binds to an **allosteric site** on the enzyme and affects it's activity. Some of these signals inhibit the enzyme and are called **repressors**. Others are **activators**.
    2. Enzymes can also be regulated in a process called **feedback inhibition**, in which the product of a reaction acts as a repressor. This can occur in two ways: **competitive inhibition**, where a non-reactant molecule can occupy the active site on the enzyme and block the reactant(s) from binding; or **noncompetitive inhibition**, where the inhibitor binds to an allosteric site, which makes the enzyme change shape so the reactants cannot bind.

III. Adenosine Triphosphate (ATP)

A. ATP is chief energy molecule in cells (though there are some others that are not as ubiquitous) and the primary energy currency
B. Each ATP molecule is composed of three parts: a sugar (ribose), a nitrogenous base (adenine), and a chain of three phosphates. This should sound familiar: ATP is one of the nucleotide that is used in RNA!
C. The key to energy storage is the group of phosphates. Each phosphate is negatively charged, so it takes lots of energy to hold them close together. This is why the bonds between them store so much energy and are so reactive
D. When the most distant phosphate is removed, a significant amount of energy is released. This reaction converts ATP into ADP (adenosine diphosphate). Usually only the one bond is broken for energy, though occasionally ADP is also broken down into AMP (adenosine monophosphate). Note that each of these conversions also yields and inorganic phosphate (P_i).
E. We can write this equation as:

$$ATP \rightarrow ADP + P_i + Energy$$

F. Cells break these phosphate bonds and use the energy to activate chemical reactions in the cell. Some of the energy released is dissipated as heat. Most cellular work is fueled by ATP.
G. As we'll see, there are two major mechanisms to convert energy (from the sun or food) into ATP. One is photosynthesis, in which light energy is used to make ATP and sugar (which can be broken down to make more ATP!). The other is cellular respiration (which occurs in mitochondria) which breaks down sugars to make ATP.

A. Oxidation-Reduction

1. During many chemical reactions, electrons are transferred from one atom or molecule to another. We have specific terms for these **redox** reactions (redox stands for reduction-oxidation).
2. When an atom or molecule loses an electron, it is **oxidized**. The name comes from oxygen, which strongly attracts and steals electrons.
3. When an atom or molecule gains an electron, it is **reduced**. The name comes from the fact that the charge to the molecule is reduced since electrons are negatively charged
4. Oxidation and reduction always occur together (One molecule has to lose an electron for another to gain one!)
5. Reduced forms of molecules have more electrons and thus more energy than oxidized forms, so redox reactions play a key role in the transfer of energy through biological systems as the electrons transfer energy from molecule to molecule.