UNIT 1: METABOLIC PROCESSES

Metabolism and Cellular Energy

- the basic characteristics of any living organism is that it grows, repair itself, reproduces, respires, and eventually dies
- to do those things, an organism requires energy
- energy is defined as the ability to do work
- the work from the energy coming from an organism is observed on a macroscopic level when we notice them move, grow, and reproduce – however, living tings do all their work on a molecular level, at the cellular level
- in order to acquire the appropriate amount and form of energy that organisms require to perform their every day metabolic processes, they must break down large molecules at the cellular level, such as amylase, into glucose, and then into CO_2 and water, in a series of complex catabolic reactions
- the energy that comes from such reactions is then used to build materials at the cellular level, that are essential to the organism's survival – such as DNA from nucleotide units, or proteins from amino acids – these reactions are called anabolic reactions
- two types of energy that exist are **potential energy** and **kinetic energy**
- potential energy is the energy of position, whereas kinetic energy is the energy of motion
- Figure 1, p. 59 shows a skydiver converting the potential energy that she gained in the flight up into kinetic energy on the way down
- **The First Law of Thermodynamics** states that "the total amount of energy in the universe is constant, and that energy cannot be created nor destroyed but only converted from one form into another" – this means that if a certain substance or matter gains energy it does so at the expense of a loss in energy in another substance or form of matter
- Nature provides various forms of energy – electric, chemical, light, sound, heat, etc.
- cells are constantly converting energy to forms that are readily usable
- for example, plants convert sunlight (photonic) energy into chemical potential energy in the bonds of glucose molecules in a process called photosynthesis
- through reactions of cellular respiration, cells convert the chemical potential energy stored in the bonds of glucose into another usable, and practical from of potential energy called ATP – the gasoline of a cell
- chemical potential energy is an important form of energy in living systems
- any molecule's energy is stored in its covalent bonds and is therefore called **bond energy** – it is the measure of the stability of a covalent bond
- Table 1, p. 59 lists the average bond energies of the most common types of chemical bonds found in biologically important
- the assumption is that the energy required to break the bond represents its relative stability

- if the total amount of energy to break bonds in reactant molecules is greater than the amount of bond energy gained in the making of the bonds in the products, then the reaction is **endothermic**
- if the total amount of energy to break bonds in reactant molecules is less than the total amount of bond energy gained in the making of the bonds in the products, then the reaction is **exothermic**
- Figure 2, p. 60 is a **potential energy diagram** that shows the changes in chemical potential energy that take place during a chemical reaction
- the placement on the diagram of the reactant molecules and product molecules reflects the relative stability of the bonds that make them up – for example, if the reactants have covalent bonds in them that are more stable than those found in the products, then they are placed higher up on the diagram, thus going from reactants to products means energy is lost or released in the process
- the amount of energy needed to strain and break the reactants' bonds, called the **activation energy**, is provided by the difference between the energy level of the transition and the potential energy of the reactants
- if enough reactant molecules possess the necessary amount of energy to react, the molecules will reach the **transition state** – the temporary condition in which the bonds within reactants are breaking and bonds between products age forming
- when bonds form in the products, a certain amount of energy is released – if more is released than went into breaking the bonds in the reactants, then a net energy output results
- Figure 2 and 3, p. 60 demonstrate both outcomes that are possible for any chemical reaction
- combustion is a common exothermic reaction that occurs in living organisms: $C_6H_{12}O_6$ (s) + $6O_2$ (g) $\rightarrow$ $6CO_2$ (g) + $6H_2O$ (l)
- fireflies undergo exothermic reactions when they light up – they possess chemicals in their abdomens that are mixed at will and release light (not heat) energy
- energy requirements are not the only factors that determine whether a reaction is spontaneous or not
- a physical property called **entropy** – a measure of the randomness or disorder of matter – also must be taken into consideration
- the universe favours an increase in entropy

- examples of an *increase* in entropy are:
  - solid reactants going to liquids, then to gases
  - more moles of product are formed than present as reactants
  - complex molecules are broken down into simpler subunits
  - solutes move from high concentration to low concentration
- Table 2 explains when reactions would be spontaneous or when they would not be spontaneous, based on both entropy and energy factors

FREE ENERGY

- the relationship between the energy change, entropy change, and the temperature of a reaction predicts whether a reaction proceed spontaneously or not
- the difference between free energy and energy was determined by an American physicist, Willard Gibbs
- the energy that can do useful work is actually called **Gibbs free energy**
- Figure 6, p. 62 explains how Gibbs free energy and energy are in fact different
- if the change in Gibbs free energy of the reactants to products increases, then the reaction is not spontaneous
- if the change in Gibbs free energy of the reactants going to products decreases, then the reaction is spontaneous
- the **Second Law of Thermodynamics** states that "the entropy of the universe increases with any change that occurs"
- by this time you should have realized that living things actually violate this law – any anabolic process, or process that involves organization, compartmentalization, etc, goes against randomness
- however, it is important to note that all anabolic (decrease in randomness) processes are followed by even greater disordering processes caused by energy-yielding catabolic reactions
- basically, "nothing comes from nothing" – free energy is required to do the work so that more free energy can be achieved
- Figure 7, p. 64, summarizes the relationship between free energy, spontaneous change, and work
- photosynthesis is an example where the product ($C_6H_{12}O_6$ and O_2) contain more free energy than the reactants (CO_2 and water), resulting in an increase in Gibbs free energy and a reduction in randomness, therefore an absorption of energy – **endergonic rx**
- respiration is the reverse – Gibbs free energy decreases and energy is released – **exergonic rx**
- all metabolic reactions (like photosynthesis and respiration) are reversible
- when theses reactions have achieved no change in Gibbs free energy, the cell is dead
- the way that cells prevent this from happening is that as soon as a process makes a specific product, thus resulting in a ΔG that is not zero, the product is removed in the solution by excretion or precipitation
- for example, at the end of photosynthesis, glucose is removed, polymerized and stored as soluble starch granules – at the end of cellular respiration, the carbon dioxide and water are expelled as waste

ADENOSINE TRIPHOSPHATE ACTION

- known as ATP, it is the cell's "gasoline", and the source of any cell's Gibbs free energy
- Figure 8a, p. 65 illustrates its structure: adenine base (a purine) + pentose, ribose sugar + three phosphate tails
- when the cell requires Gibbs free energy to do work (i.e. to activate an enzyme, or energize molecules so they can react and lead to products), an enzyme called ATPase hydrolyzes the third phosphate and removes it from the tail
- the result is the release of 54 kJ/mol of free energy (in vivo) – the perfect amount of energy necessary to drive almost all of the cells processes that require work to proceed
- Figure 8b, p. 65 illustrates ATPase action
- ATP is a highly energized molecule mainly because of its tail
- the high degree of electronegativity of each phosphate group in the tail creates a large repulsive force among this group
- the instability of the terminal phosphate bond results, and the bond holding it in ATP breaks
- the inorganic phosphate actually attaches to the molecule that is to be energized, thus becoming phosphorylated
- **phosphorylation** of any molecule results in it becoming modified (sometimes in shape) into a more reactive molecule (see Figure 9, p. 66)
- Figure 10, p. 66 demonstrates how ADP is phosphorylated and becomes ATP in the recycling process
- ATP molecules exist in all cells, but some cells possess more than others
- for example, a single muscle cells uses 600 million ATP molecules per minute, sperm cells and nerve cells contain a lot of ATP
- the average human consumes his/her own mass in ATP molecules in one day

REDUCTION-OXIDATION REACTIONS

- when biochemical reactions involve the transferring of electrons from one molecule to another, it is called a **reduction-oxidation** or **redox rx**
- the process of losing electrons is called oxidation, and the process of gaining electrons is called reduction (remember….LEO THE LION SAYS GER, or OIL RIG)
- the substance that gains the electrons is called the oxidizing agent (usually a very electronegative species), whereas the substance that loses electrons is called the reducing agent

- Figure 11, p. 66 shows a simple redox rx between sodium and chlorine to form sodium chloride
- in some biochemical reactions a series of redox rxs occur where electrons are lost, gained, lost, gained, lost, gained, etc., until the final product is reduced – its sort of like “hot potato”, where the electron is the potato, and each successive oxidation agent in the series of rxs possesses a stronger pull for it than the previous one
- Figure 12, p. 67 shows this coupled redox process
- any burning or combustion is categorized as a redox rx
- this is because oxygen (a good oxidizing agent – thus the name), steals electrons from fuel that it burns
- the result is a decrease in potential energy of the transferred electrons, thus a release of free energy – heat, light
- for example, Figure 13, p. 67 illustrates how oxygen removes methane’s electrons, causing them to lose potential energy and release it as heat
- cellular respiration is a slow, controlled redox reaction

Homework: p. 68, 1-10.