

7.6: Biological Oxidation

Before the concept of biological oxidation can be understood and explored, the fundamental chemical process through which oxidation and reduction take place should be first established.

Foundation

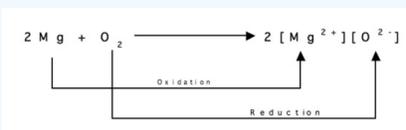
All reactions which involve electron flow are considered oxidation-reduction reactions. The basic definition can be defined as: One reactant is oxidized (loses electrons), while another is reduced (gains electrons). A couple of basic oxidation-reduction or "redox" example's are given here.

✓ Example 1

The reaction of magnesium metal with oxygen, involves the oxidation of magnesium



Since the magnesium solid is oxidized, we expect to see a loss of electrons. Similarly, since oxygen must therefore be reduced, we should see a gain of electrons.



As the magnesium is oxidized there is a loss of 2 electrons while simultaneously, oxygen gains those two electrons. Another example of a redox reaction is with the two gasses CO_2 and H_2 . This redox reaction also demonstrates the importance of implementing "oxidation numbers" in the methodology of redox reactions, allowing for the determination of which reactant is being reduced and which reactant is being oxidized.

✓ Example 2

The reaction of carbon dioxide gas with hydrogen gas, involving the oxidation of hydrogen



Since the hydrogen gas is being oxidized (reductant), we expect to see an overall loss of electrons for the resulting molecule. Similarly, we expect to see a gain in the overall number of electrons for the resulting molecule of the oxidant (CO_2).



Here it is possible to infer that the carbon of CO_2 is being reduced by review of its unique oxidation number. Such that, C (of CO_2) goes from an oxidation number of +4 to C (of CO) having an oxidation number of +2, representing a loss of two electrons. Similarly, H_2 is noted as going from an oxidation number of 0 to +1, or gaining one electron in a reduction process. For more information on oxidation numbers, review the following link: [Oxidation-Reduction Reactions](#)

A Basic Biological Model

The flow of electrons is a vital process that provides the necessary energy for the survival of all organisms. The primary source of energy that drives the electron flow in nearly all of these organisms is the radiant energy of the sun, in the form of electromagnetic radiation or Light. Through a series of nuclear reactions, the sun is able to generate thermal energy (which we can feel as warmth) from [electromagnetic radiation](#) (which we perceive as light). However, the particular wavelength of the electromagnetic spectrum we are able to detect with the human eye is only between 400 and 700 nm in wavelength. It should therefore be noted that the visible part of the electromagnetic spectrum is actually a small percentage of the whole; where a much greater percentage remains undetectable for the human eye.

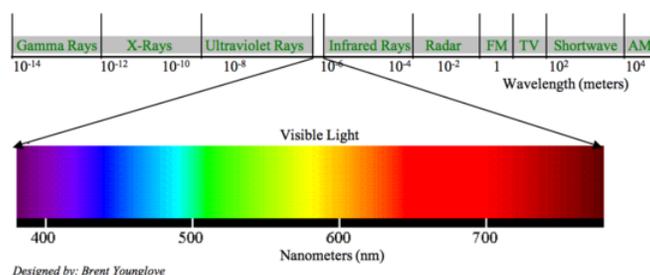


Figure 1: The electromagnetic spectrum with an emphasis on the visible light region

In physics, the use of the term "light" refers to electromagnetic radiation of any wavelength, independent of its detectability for the human eye. For plants, the upper and lower ends of the visible spectrum are the wavelengths that help drive the process of splitting water (H_2O) during photosynthesis, to release its electrons for the biological reduction of carbon dioxide (CO_2) and the release of diatomic oxygen (O_2) to the atmosphere. It is through the process of photosynthesis that plants are able to use the energy from light to convert carbon dioxide and water into the chemical energy storage form called glucose.

Plants represent one of the most basic examples of biological oxidation and reduction. The chemical conversion of carbon dioxide and water into sugar (glucose) and oxygen is a light-driven reduction process:



The process by which non photosynthetic organisms and cells obtain energy, is through the consumption of the energy rich products of photosynthesis. By oxidizing these products, electrons are passed along to make the products carbon dioxide, and water, in an environmental recycling process. The process of oxidizing glucose and atmospheric oxygen allowed energy to be captured for use by the organism that consumes these products of the plant. The following reaction represents this process:



It is therefore through this process that heterotrophs (most generally "animals" which consume other organisms obtain energy) and autotrophs (plants which are able to produce their own energy) participate in an environmental cycle of exchanging carbon dioxide and water to produce energy containing glucose for organismal oxidation and energy production, and subsequently allowing the regeneration of the byproducts carbon dioxide and water, to begin the cycle again. Therefore, these two groups of organisms have been allowed to diverge interdependently through this natural life cycle.

Physical Chemistry's Understanding

Biological oxidation-reduction reactions, or simply *biological oxidations* utilize multiple stages or processes of oxidation to produce large amounts of **Gibbs energy**, which is used to synthesize the energy unit called adenosine triphosphate or ATP. To efficiently produce ATP, the process of glycolysis must be near an abundance of oxygen. Since glycolysis by nature is not an efficient process, if it lacks sufficient amounts of oxygen the end product pyruvate, is reduced to lactate with NADH as the reducing agent. However, in a more favorable aerobic process, the degradation of glucose through glycolysis proceeds with two additional processes known as the *citric acid cycle* and the terminal *respiratory chain*; yielding the end products carbon dioxide and water, which we exhale with each breath.



Figure 2: The three main processes for the breakdown of glucose into carbon dioxide and water

The products NADH and $FADH_2$ formed during glycolysis and the citric acid cycle are able to reduce molecular oxygen (O_2) thereby releasing large amounts of Gibbs energy used to make ATP. The process by which electrons are transferred from NADH or $FADH_2$ to O_2 by a series of electron transfer carriers, is known as *oxidative phosphorylation*. It is through this process that ATP is able to form as a result of the transfer of electrons.

Three specific examples of redox reactions that are used in biological processes, involving the transfer of electrons and hydrogen ions as follows. During some biological oxidation reactions, there is a simultaneous transfer of hydrogen ions with electrons (1). In other instances, hydrogen ions may be lost by the substance being oxidized while transferring only its electrons to the substance being reduced (2). A third type of biological oxidation might involve only a transfer of electrons (3). It should be noted that biological oxidation rarely proceeds in a direct manner, and generally involves complex mechanisms of several enzymes. The outline below recaps the three processes of biological oxidation stated above, in descending order.

Table 1: Transfer of hydrogen ions and electrons for the general reaction scheme of A + B with intermediate stage shown

Reactants	Intermediate Stage	Products
$AH_2 + B$	$[A + 2H^+ + 2e^- + B]$	$A + BH_2$
$AH_2 + B$	$[A + 2H^+ + 2e^- + B]$	$A + B^{2-} + 2H^+$
$A^{2-} + B$	$[A + 2e^- + B]$	$A + B^{2-}$

In the last stage of the metabolic process (the terminal respiratory chain), the sequence by which electrons are carried is determined by relative redox potentials. The carrier molecules used to transfer electrons in this stage are called cytochromes, which are an electron-carrying protein containing a heme group. The iron atom of each cytochrome molecule can exist either in the oxidized (Fe^{3+}) or reduced (Fe^{2+}) form. Within the terminal respiratory chain, each carrier molecule alternates between the reduced state and the oxidized state, with molecular oxygen as the final electron acceptor at the end.

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Figure 3. The terminal respiratory chain showing electron transport and phosphorylation. Electrons from the citric acid cycle are transferred from one carrier to another, where each carrier alternates between the reduced and oxidized state. Molecular oxygen represents the final electron acceptor.

It is through the knowledge of redox potentials, that the knowledge of biological processes can be further expanded. The standard reduction potential is denoted as E° and is often based on the hydrogen electrode scale of pH 7, rather than pH 0, a common reference point for listed values. Moreover, the superscript symbol ($^{\circ}$) denotes standard-state conditions, while the adjacent superscript symbol ($'$) denotes the pH scale of 7 for biochemical processes.

It therefore becomes possible to trace the energy transfer in cells back to the fundamental flow of electrons from one particular molecule to another. Where this electron flow occurs via the physics principle of higher potential to lower potential; similar to a ball rolling down a hill, as opposed to the opposite direction. All of these reactions involving electron flow can be attributed to the basic definition of the oxidation-reduction pathway stated above.

References

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2. Nelson, David, and Michael Cox. *LEHNINGER PRINCIPLES OF BIOCHEMISTRY*. 5th. New York, NY: Freeman and Company, 22. Print.

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