Electron Carriers

In redox reactions in living systems some molecules function as electron shuttles, binding and carrying high-energy electrons between molecules in different metabolic pathways. Nicotinamide adenine dinucleotide (NAD) is a major electron carrier derived from vitamin B3 (Figure 6.5). NAD^+ is the oxidized form of the molecule. When NAD^+ accepts two electrons and a proton (hydrogen ion) it is reduced to NADH.

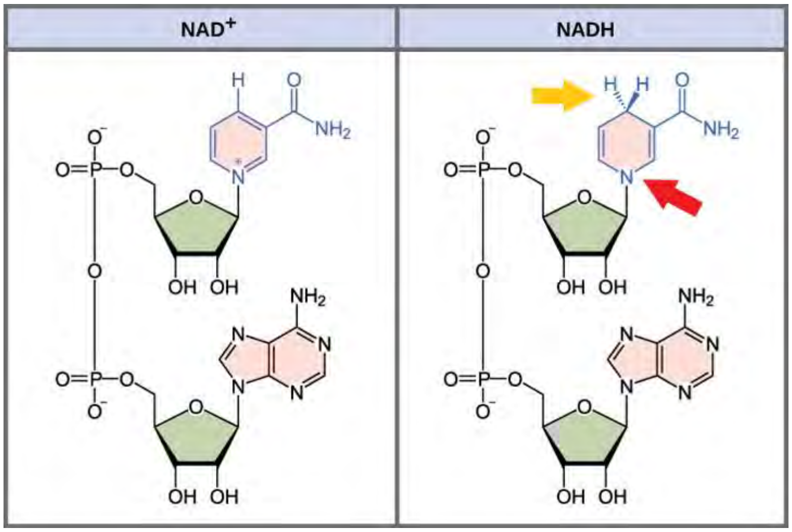

Figure 6.5 The oxidized form of the electron carrier (NAD+) is shown on the left, and the reduced form (NADH) is shown on the right. The red arrow points to where an electron is being carried and the orange arrowpoints to where an electron and a proton are being carried. (credit: Modified by Jason Cashmore original work by Clark et al. / Biology 2E OpenStax)

In Figure 6.6 below, the organic substrate, CH_2O, is being oxidized. An enzyme helps to remove the two hydrogen atoms from the organic substrate. The two hydrogen atoms transfer their two electrons along with one hydrogen ion to the electron carrier, NAD^+. When NAD^+ accepts the electrons and hydrogen ion, it is reduced to NADH. In eukaryotic cells, the NADH can now shuttle the electrons to the inner membrane of the mitochondria, where they will be used to synthesize large quantities of ATP.

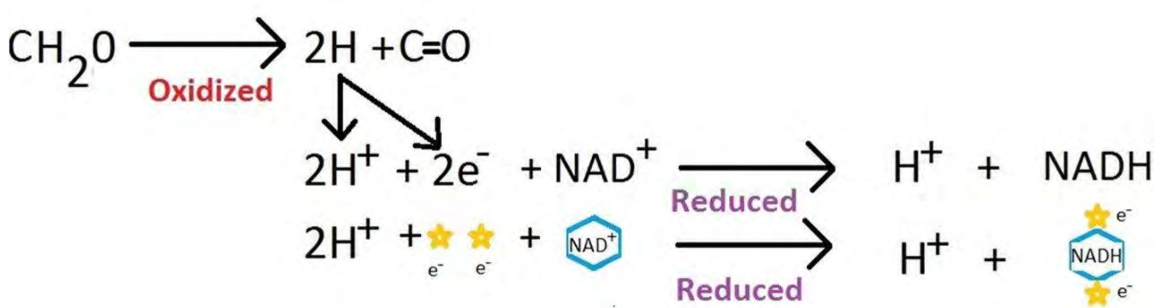

Figure 6.6 shows a redox reaction where an organic molecule is oxidized NAD^+ is reduced. (credit: Elizabeth O'Grady)

Similarly, flavin adenine dinucleotide (FAD), derived from vitamin B_2, also functions as an electron carrier. Its reduced form is $FADH_2$. Both NAD^+ and FAD are extensively used to shuttle electrons into the mitochondria and will be discussed throughout the next several sections.

ATP in Living Systems

ATP is often called the “energy currency" of a cell because it provides much of the energy needed to carry out cellular processes. ATP is classified as a high energy molecule because the covalent bonds that link the phosphate groups contain large quantities of potential energy (Figure 6.7). Phosphate groups are negatively charged and as a result, repel one another. To bring them together and form the covalent bonds large amounts of energy are necessary. Therefore, when the bonds are broken, the stored potential energy is released and can be used to power any number of different cell activities.

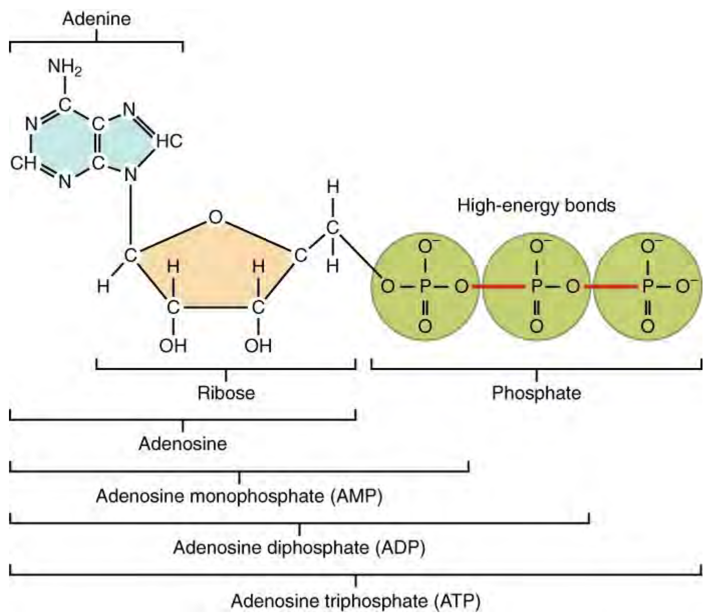

Figure 6.7 Structure of Adenosine Triphosphate (ATP) (credit: Betts et al. / Anatomy and Physiology OpenStax)

Phosphorylation

ATP can be regenerated when an inorganic phosphate (P_i) is covalently bound to ADP (adenosine diphosphate) through the process of **phosphorylation**. Phosphorylation requires energy and can be done using three separate mechanisms. Where does this energy for phosphorylation come from? In almost all living organisms, the energy comes from the metabolism of simple sugars such as glucose, fructose, or galactose. Let's now take a closer look at the different types of phosphorylation.

Substrate Phosphorylation

In substrate phosphorylation, a few ATP molecules are generated when a phosphate group is removed from an intermediate reactant in the cellular respiration pathway. The free energy of the reaction is used to add the removed phosphate directly to ADP producing ATP (Figure 6.8). This direct method of phosphorylation is called **substrate-level phosphorylation** and does not require oxygen.

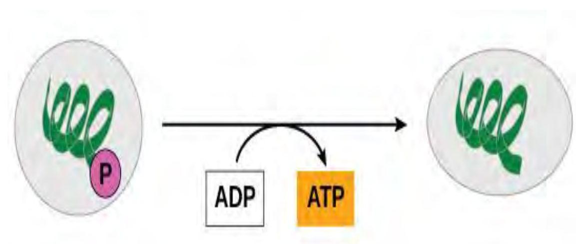

Figure 6.8 shows substrate-level phosphorylation reactions, where a phosphate is removed from a substrate and attached to ADP to make ATP. (credit: Clark et al. / Biology 2E OpenStax)

Oxidative Phosphorylation

Most of the ATP generated during glucose catabolism is synthesized during oxidative phosphorylation, a complex process that takes place in the mitochondria (Figure 6.9) of eukaryotic cells or the plasma membrane of some prokaryotic cells. **Oxidative phosphorylation** is made up of two steps: the electron transfer chain and chemiosmosis. Chemiosmosis is used to generate 90 percent of the ATP made during glucose catabolism. It is also used in photosynthesis to convert light energy from the sun to chemical energy found in the bonds of ATP. Chemiosmosis yields ATP as long as oxygen is present. The details of oxidative phosphorylation will be discussed in section 6.4.

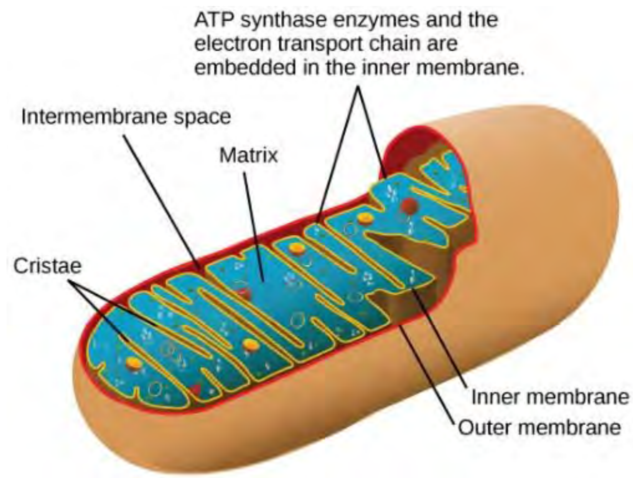

Figure 6.9 In eukaryotes, oxidative phosphorylation takes place in mitochondria. (credit: modification of work by Mariana Ruiz Villareal / [Biology 2E OpenStax](#))

Check your knowledge

How many electrons will NAD+ carry?

When NAD+ picks up those electrons, is it oxidized or reduced?

Answers: NAD+ will pick up 2 electrons (and one hydrogen ion).

It will be reduced.