BSC 5TH SEM MAJOR

OXIDATION- REDUCTION POTENTIAL WITH SPECIAL REFERRENCE TO MITOCHONDRIAL ELECTRON TRANSPORT SYSTEM ATP IN METABOLISM AND FREE ENERGY PRODUCTION

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Oxidation-Reduction Potential or Radox potential

- In acid-base systems, one compound acts as the proton (H+) donor and the other as the proton acceptor, the donor being the acid and the acceptor the base.
- The two form a conjugate acid-base pair. In a similar manner, oxidizing and reducing agents function in pairs.
- In this case, they are called redox pairs or redox couples. The member of the pair that donates the electron is called the reducing agent or reductant and the electron acceptor is called the oxidizing agent or oxidant.

The terms donating and accepting fail to convey the nature of the amounts or energy change involved in the reaction. In effect, the reducing agent has a certain capability to retain electrons, as does the oxidizing agent. In a redox couple, one member attracts electrons more strongly than the other, and in effect the oxidizing agent can pull the electrons away from the reducing agent. This capability to gain (or lose) electrons can be measured and is called the oxidation- reduction potential or redox potential and is ex-pressed in volts.

The redox potential is used to describe a system's overall reducing or oxidizing capacity. The redox potential is measured in millivolts (mV)

- Reactions that involve the movement of electrons between reductant and oxidant are called redox reactions.

- Different chemical substances have different potentials for donating or accepting electrons. The tendency of hydrogen to dissociate

- $H_2 \leftrightarrows 2H^+ + 2e^-$

Electron transport chain

The electron transport chain (ETC) is a series of complexes that transfer electrons from electron donors to electron acceptors via redox (both reduction and oxidation occurring simultaneously) reactions, and couples this electron transfer with the transfer of protons (H+ ions) across a membrane. The electron transport chain is built up of peptides, enzymes, and other molecules.

Electron transport is a series of redox reactions that resemble a relay race or bucket brigade in that electrons are passed rapidly from one component to the next, to the endpoint of the chain where the electrons reduce molecular oxygen, producing water. There are four complexes composed of proteins, labeled I through IV in Figure 1, and the aggregation of these four complexes, together with associated mobile, accessory electron carriers, is called the electron transport chain. The electron transport chain is present in multiple copies in the inner mitochondrial membrane of eukaryotes and the plasma membrane of prokaryotes. Note, however, that the electron transport chain of prokaryotes may not require oxygen as some live in anaerobic conditions. The common feature of all electron transport chains is the presence of a proton pump to create a proton gradient across a membrane.

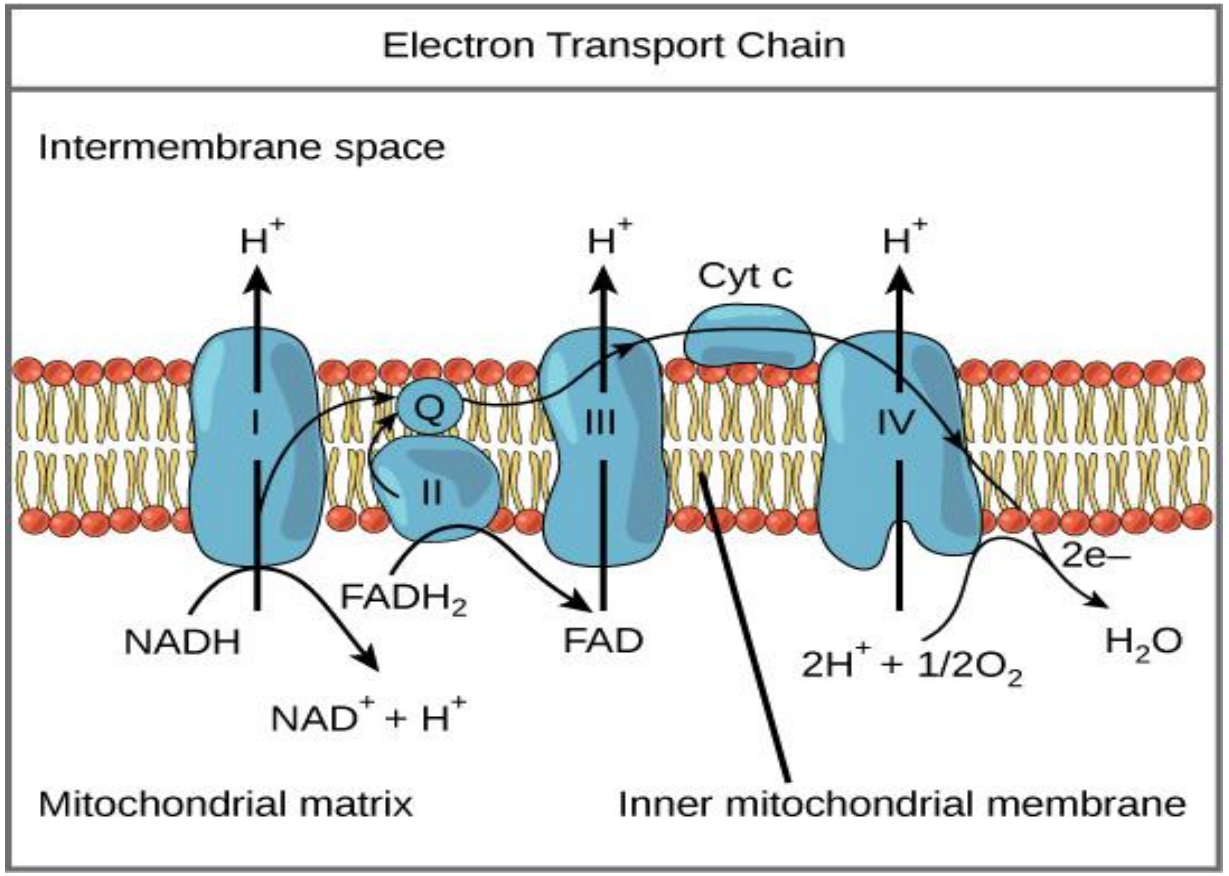


Figure 1. The electron transport chain is a series of electron transporters embedded in the inner mitochondrial membrane that shuttles electrons from NADH and FADH2 to molecular oxygen. In the process, protons are pumped from the mitochondrial matrix to the intermembrane space, and oxygen is reduced to form water.

Complex I

To start, two electrons are carried to the first complex aboard NADH. This complex, labeled I, is composed of flavin mononucleotide (FMN) and an iron-sulfur (Fe-S)-containing protein. FMN, which is derived from vitamin B2, also called riboflavin, is one of several prosthetic groups or co-factors in the electron transport chain. A prosthetic group is a non-protein molecule required for the activity of a protein. Prosthetic groups are organic or inorganic, non-peptide molecules bound to a protein that facilitate its function; prosthetic groups include co-enzymes, which are the prosthetic groups of enzymes. The enzyme in complex I is NADH dehydrogenase and is a very large protein, containing 45 amino acid chains. Complex I can pump four hydrogen ions across the membrane from the matrix into the intermembrane space, and it is in this way that the hydrogen ion gradient is established and maintained between the two compartments separated by the inner mitochondrial membrane.

Q and Complex II

Complex II directly receives FADH2, which does not pass through complex I. The compound connecting the first and second complexes to the third is ubiquinone (Q). The Q molecule is lipid soluble and freely moves through the hydrophobic core of the membrane. Once it is reduced, (QH2), ubiquinone delivers its electrons to the next complex in the electron transport chain. Q receives the electrons derived from NADH from complex I and the electrons derived from FADH2 from complex II, including succinate dehydrogenase. This enzyme and FADH2 form a small complex that delivers electrons directly to the electron transport chain, bypassing the first complex. Since these electrons bypass and thus do not energize the proton pump in the first complex, fewer ATP molecules are made from the FADH2 electrons. The number of ATP molecules ultimately obtained is directly proportional to the number of protons pumped across the inner mitochondrial membrane.

Complex III

The third complex is composed of cytochrome b, another Fe-S protein, Rieske center (2Fe-2S center), and cytochrome c proteins; this complex is also called cytochrome oxidoreductase. Cytochrome proteins have a prosthetic group of heme. The heme molecule is similar to the heme in hemoglobin, but it carries electrons, not oxygen. As a result, the iron ion at its core is reduced and oxidized as it passes the electrons, fluctuating between different oxidation states: Fe++ (reduced) and Fe+++ (oxidized). The heme molecules in the cytochromes have slightly different characteristics due to the effects of the different proteins binding them, giving slightly different characteristics to each complex. Complex III pumps protons through the membrane and passes its electrons to cytochrome c for transport to the fourth complex of proteins and enzymes (cytochrome c is the acceptor of electrons from Q; however, whereas Q carries pairs of electrons, cytochrome c can accept only one at a time).

Complex IV

The fourth complex is composed of cytochrome proteins c, a, and a3. This complex contains two heme groups (one in each of the two cytochromes, a, and a3) and three copper ions (a pair of CuA and one CuB in cytochrome a3). The cytochromes hold an oxygen molecule very tightly between the iron and copper ions until the oxygen is completely reduced. The reduced oxygen then picks up two hydrogen ions from the surrounding medium to make water (H_2O). The removal of the hydrogen ions from the system contributes to the ion gradient used in the process of chemiosmosis.

Chemiosmosis

In chemiosmosis, the free energy from the series of redox reactions just described is used to pump hydrogen ions (protons) across the membrane. The uneven distribution of H+ ions across the membrane establishes both concentration and electrical gradients (thus, an electrochemical gradient), owing to the hydrogen ions' positive charge and their aggregation on one side of the membrane.

If the membrane were open to diffusion by the hydrogen ions, the ions would tend to diffuse back across into the matrix, driven by their electrochemical gradient. Recall that many ions cannot diffuse through the nonpolar regions of phospholipid membranes without the aid of ion channels

Similarly, hydrogen ions in the matrix space can only pass through the inner mitochondrial membrane through an integral membrane protein called ATP synthase (Figure 2). This complex protein acts as a tiny generator, turned by the force of the hydrogen ions diffusing through it, down their electrochemical gradient. The turning of parts of this molecular machine facilitates the addition of a phosphate to ADP, forming ATP, using the potential energy of the hydrogen ion gradient.

Chemiosmosis (Figure 3) is used to generate 90 percent of the ATP made during aerobic glucose catabolism; it is also the method used in the light reactions of photosynthesis to harness the energy of sunlight in the process of photophosphorylation. Recall that the production of ATP using the process of chemiosmosis in mitochondria is called oxidative phosphorylation. The overall result of these reactions is the production of ATP from the energy of the electrons removed from hydrogen atoms. These atoms were originally part of a glucose molecule. At the end of the pathway, the electrons are used to reduce an oxygen molecule to oxygen ions. The extra electrons on the oxygen attract hydrogen ions (protons) from the surrounding medium, and water is formed.

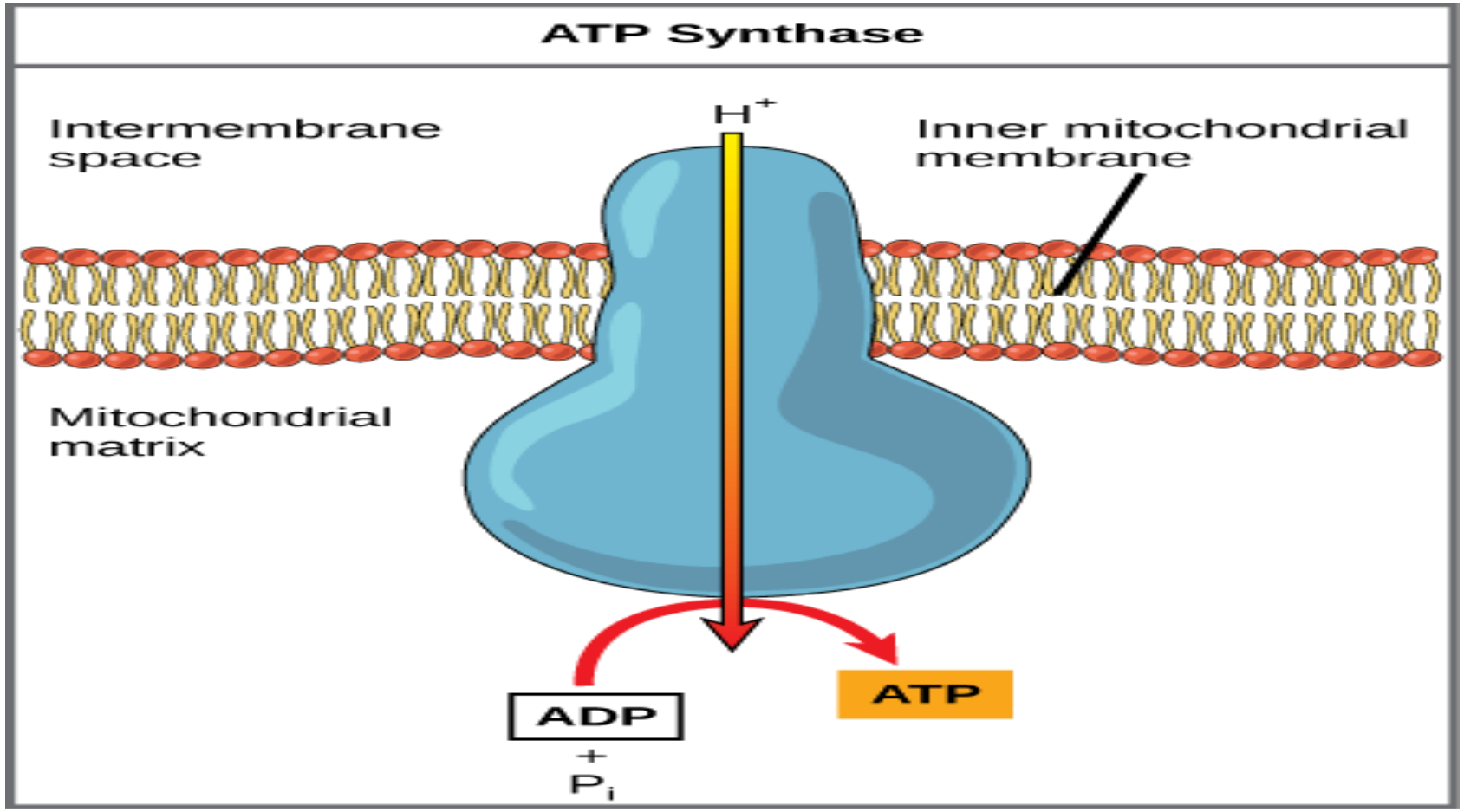


Figure 2. ATP synthase is a complex, molecular machine that uses a proton (H+) gradient to form ATP from ADP and inorganic phosphate (Pi). (Credit: modification of work by Klaus Hoffmeier)

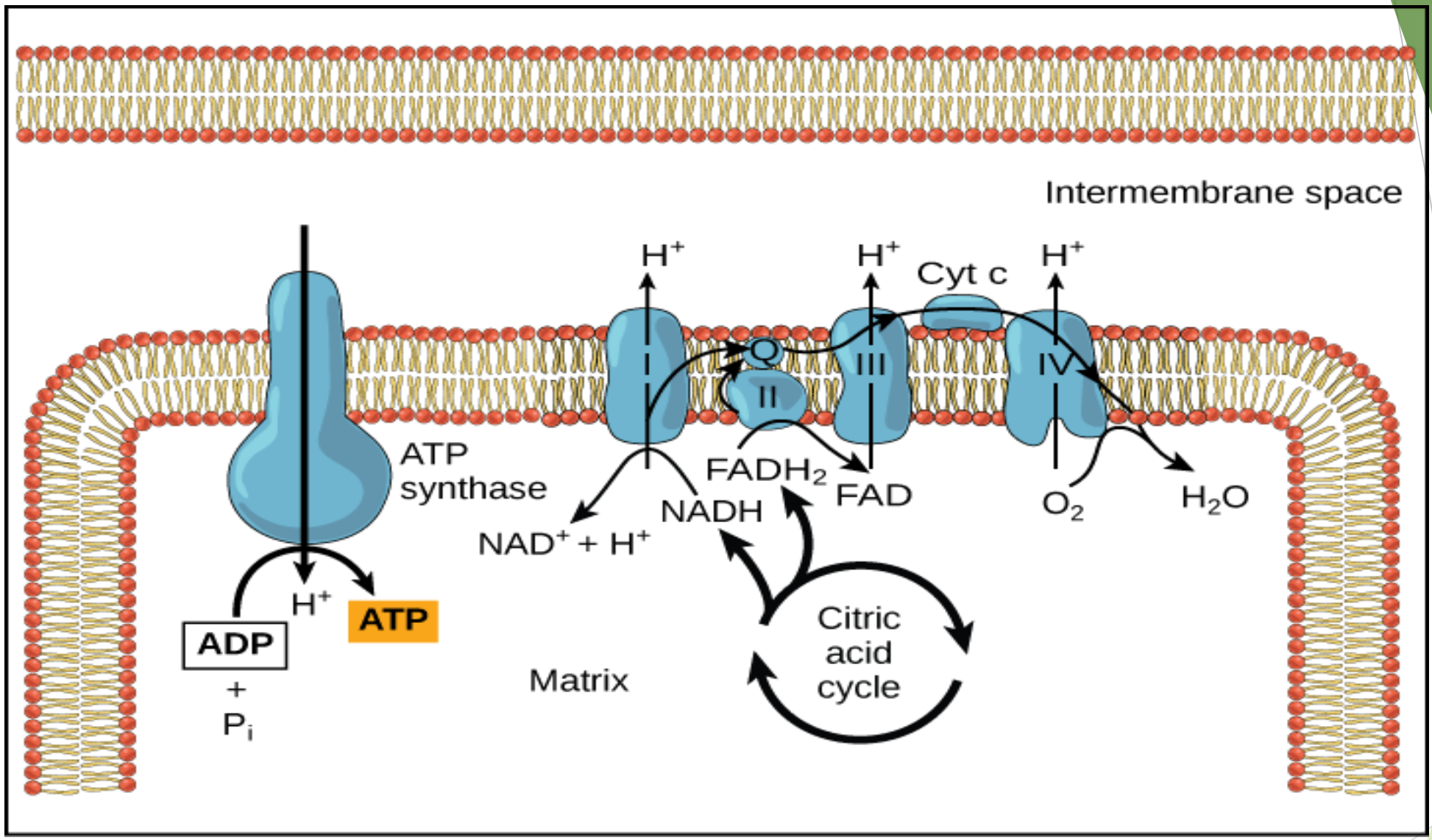


Figure 3. In oxidative phosphorylation, the pH gradient formed by the electron transport chain is used by ATP synthase to form ATP.

ATP IN METABOLISM AND FREE ENERGY PRODUCTION

The breaking down of food particles we consume and derive energy from is called metabolism. ... Thus, ATP production in cells stores Gibbs free energy which can then be used for other processes with the help of the reverse reaction which converts ATP to ADP and, in the process, releases 30.5 kJ of energy per ATP molecule.

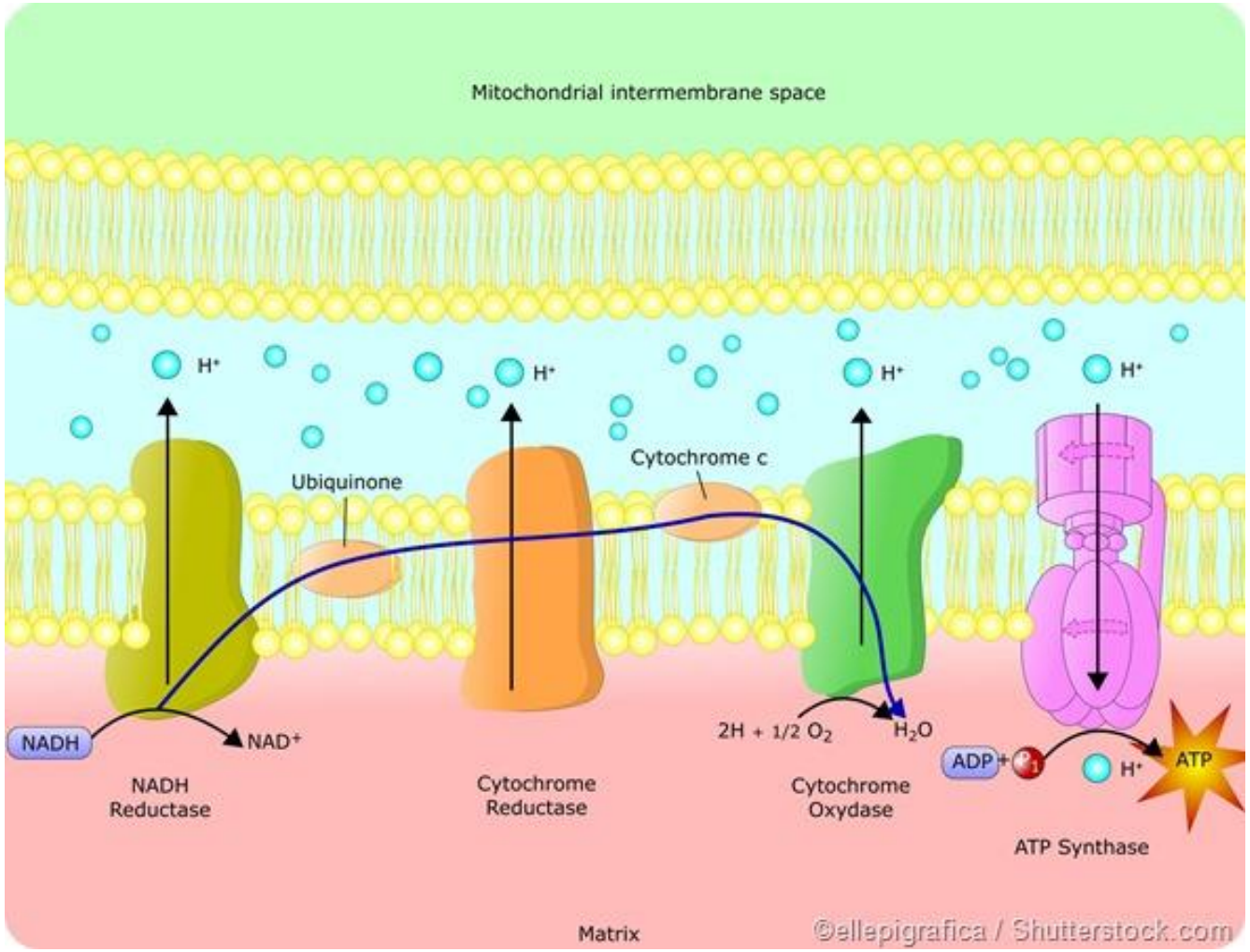
ATP Yield

The number of ATP molecules generated from the catabolism of glucose varies. For example, the number of hydrogen ions that the electron transport chain complexes can pump through the membrane varies between species. Another source of variance stems from the shuttle of electrons across the membranes of the mitochondria. (The NADH generated from glycolysis cannot easily enter mitochondria.) Thus, electrons are picked up on the inside of mitochondria by either NAD+ or FAD+. As you have learned earlier, these FAD+ molecules can transport fewer ions; consequently, fewer ATP molecules are generated when FAD+ acts as a carrier. NAD+ is used as the electron transporter in the liver and FAD+ acts in the brain.

Another factor that affects the yield of ATP molecules generated from glucose is the fact that intermediate compounds in these pathways are used for other purposes. Glucose catabolism connects with the pathways that build or break down all other biochemical compounds in cells, and the result is somewhat messier than the ideal situations described thus far. For example, sugars other than glucose are fed into the glycolytic pathway for energy extraction. Moreover, the five-carbon sugars that form nucleic acids are made from intermediates in glycolysis. Certain nonessential amino acids can be made from intermediates of both glycolysis and the citric acid cycle. Lipids, such as cholesterol and triglycerides, are also made from intermediates in these pathways, and both amino acids and triglycerides are broken down for energy through these pathways. Overall, in living systems, these pathways of glucose catabolism extract about 34 percent of the energy contained in glucose.

ATP and free energy

Under standard conditions, glucose reacts with oxygen during glycolysis to release Gibbs free energy. This is an exergonic reaction, which means energy is released. In order to use up this free energy, this reaction is coupled to other reactions in our body. One main way in which this free energy is captured in our body is by producing adenosine triphosphate (ATP) from adenosine diphosphate (ADP) by the addition of an inorganic phosphate group.


Mitochondrial intermembrane space
H+
H+
H+
H+
Ubiquinone
Cytochrome c
NADH
NAD+
2H + 1/2 O2
H2O
ADP
+
P
H+
ATP
NADH Reductase
Cytochrome Reductase
Cytochrome Oxydase
ATP Synthase
Matrix
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The formation of ATP from ADP is an endergonic reaction, which means energy is used up in the reaction. So by coupling this reaction with the exergonic glycolysis reaction, ATP can be produced.

The oxidation of glucose and the production of ATP in humans results in the storage of large amounts of Gibbs free energy in the phosphate bonds of ATP, which can be released when ATP is hydrolyzed and its phosphate group is removed to form ADP in the cells. This released energy is used up by the body for several cellular processes.

Free energy and metabolism

The breaking down of food particles we consume and derive energy from is called metabolism. It covers various processes that use nutrients in food to release Gibbs free energy, which is stored during the formation of ATP from ADP. This stored energy in ATP is captured and used for various purposes in the body by converting ATP back to ADP.

Nutrient metabolism in the human body occurs via a complex series of enzyme-mediated reactions. According to Hans Krebs, there are three stages in metabolism:

Digestion

The breaking down of large biomolecules such as carbohydrates, lipids, and proteins to less complex, smaller molecules such as glucose, fatty acids, and amino acids, respectively. These simpler molecules can easily travel from the digestive tract and enter the bloodstream.

Conversion to acetyl CoA

The smaller molecules of glucose, fatty acids, and amino acids are converted to acetyl groups which get linked to coenzyme A forming acetyl coenzyme A, or acetyl CoA.

Oxidation of acetyl groups

The acetyl CoA is oxidized during the citric acid cycle or Krebs cycle. This oxidation reaction, which converts acetyl CoA to CO_2 and H_2O, is coupled with other reactions that produce ATP from ADP by a process called oxidative phosphorylation.

Thus, ATP production in cells stores Gibbs free energy which can then be used for other processes with the help of the reverse reaction which converts ATP to ADP and, in the process, releases 30.5 kJ of energy per ATP molecule.

THANK YOU