Section 2

Digestion of Nutrients

The digestive process is essential because it breaks large food molecules into smaller molecules that can be absorbed into the villi of the small intestine and eventually travel through the blood. Simple molecules can then dissolve in blood and go into circulation to reach every part of the body. There are two types of digestion, physical and chemical.

Physical Digestion

Physical digestion is the breaking down of food into small particles without the use of any chemicals such as digestive enzymes. Physical digestion occurs in the mouth (the chewing of food by the teeth and tongue), and the stomach (the continual contractions and relaxations of the stomach muscles causes a churning action, breaking down the food particles and mixing them with digestive enzymes). Physical digestion helps with chemical digestion as it provides a larger surface area for the digestive enzymes to work on, thus speeding up the digestion process. It can also be called "mechanical digestion".

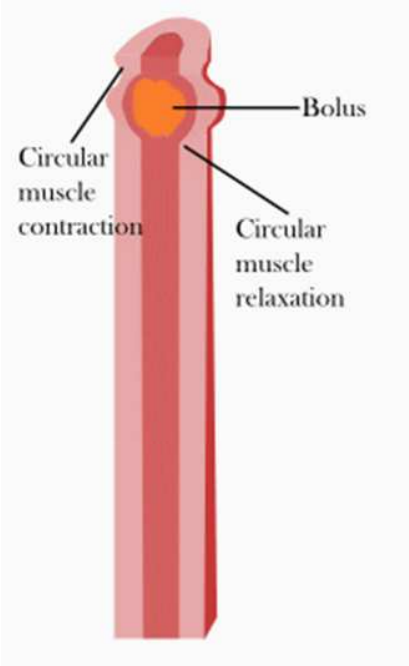
Peristalsis

Peristalsis is the contraction of muscles that propel food down the digestive tract. The word is derived from the Greek word *peristaltikos*, which means "to wrap around", and "to place".

In the gastrointestinal tract, smooth muscles contract in sequence to produce a peristaltic wave which forces a ball of food (called a bolus while in the esophagus and gastrointestinal tract and chyme in the stomach) along the gastrointestinal tract. Peristaltic movement is initiated by circular smooth muscles contracting behind the chewed material to prevent it from moving back into the mouth, followed by a contraction of longitudinal smooth muscles which pushes the digested food forward.

Peristalsis in the esophagus

In the esophagus, two types of peristalsis occur.



A simplified image showing peristalsis

First, there is a **primary peristaltic wave**; once the bolus enters the esophagus during swallowing. The primary peristaltic wave forces the bolus down the esophagus and into the stomach in a wave lasting about 8–9 seconds. The wave travels down to the stomach even if the bolus of food descends at a greater rate than the wave itself, and will continue even if for some reason the bolus gets stuck further up the esophagus.

In the event that the bolus gets stuck or moves slower than the primary peristaltic wave (as can happen when it is poorly lubricated), stretch receptors in the esophageal lining are stimulated and a local reflex response causes a **secondary peristaltic wave** around the bolus, forcing it further down the esophagus, and these secondary waves will continue indefinitely until the bolus enters the stomach.

Peristalsis in the small intestine:

Once processed and digested by the stomach, the milky chyme is squeezed through the pyloric valve into the small intestine. Once past the stomach a typical peristaltic wave will only last for a few seconds, traveling at only a few centimeters per second. Its primary purpose is to mix the chyme in the intestine rather than to move it forward in the intestine. Through this process of mixing and continued digestion

and absorption of nutrients, the chyme gradually works its way through the small intestine to the large intestine.[1]

Chemical Digestion

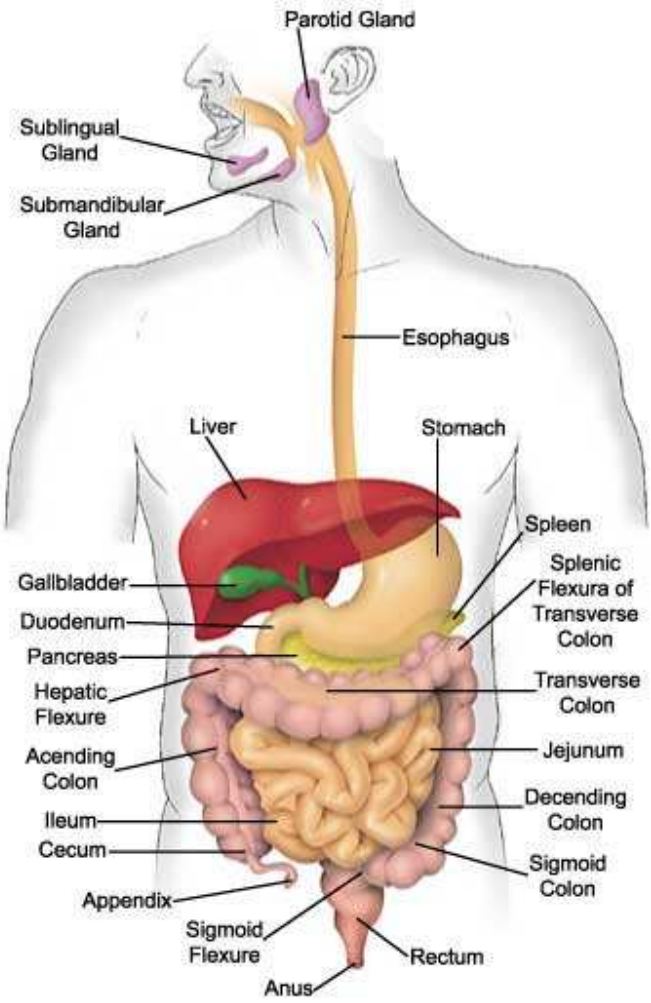
Chemical digestion is the breaking down of particles of food produced by physical digestion into smaller molecules of food which could be absorbed into the bloodstream. Unlike physical digestion, chemical digestion makes use of digestive enzymes. Chemical digestion takes place in the mouth (salivary amylase), stomach (proteases), and small intestines (amylases, proteases, and lipases).

The digestive enzymes include the following:

Amylase: source is salivary glands in the mouth; substrate is starch; product is maltose; and optimum pH is about 7 (balanced). Amylase digests carbohydrates.

Protease (a.k.a. pepsin): source is glands in stomach wall; substrate is proteins; product is polypeptides; optimum pH is 2 (acidic). Proteases digest proteins.

Lipase: source is the pancreas; substrate is lipids; product is glycerol and fatty acids; optimum pH is basic (higher than 7). Lipases digest fats.



The stomach is where the protein digestion process begins. Pepsin breaks the proteins down into small polypeptides. The small intestine is the site where most of the breaking down of food occurs, and also where absorption of nutrients occurs. This is where fats begin to be broken down. Starch, glycogen, and smaller polysaccharides are hydrolyzed into disaccharides such as maltose. Maltose is split into two simpler molecules of maltase. The lining of the small intestine is made of small villi, which absorb small molecules, putting them in the circulatory system(sugars & peptides) or the lymphatic system(fats). In the large intestine water is reabsorbed and the wastes of the digestive tract, feces, are taken up. They become more solid by the removal of water, and then pass out of the rectum.

Absorption is the passage of digested substances through the wall of the intestine into the blood capillaries in bodies. Assimilation is a process by which food becomes incorporated within the body without being broken down. [2]

Metabolic Pathways

Metabolic pathways are the sequences of biochemical steps through which substances in living things change from one form to another. Each reaction in a metabolic pathway is dependent on a specific precursor: a chemical, an enzyme, or the transfer of energy. One of the first studies of metabolic pathways was carried out in 1909 by the British physician Archibald Garrod (1857-1936). His study suggested a link between the inability to make a particular enzyme and inherited disease. The disease was alkaptonuria, a condition in which urine darkens upon exposure to air, due to the presence of the chemical alkapton. Garrod's discovery was one of the first incidents of a physical manifestation being tied to a specific metabolic disorder. [3]

The human body contains chemical compounds, such as water, carbohydrates (sugar, starch, and fiber), amino acids (in proteins), fatty acids (in lipids), and nucleic acids (DNA and RNA). These compounds in turn consist of elements such as carbon, hydrogen, oxygen, nitrogen, phosphorus, calcium, iron, zinc, magnesium, manganese, and so on. All of these chemical compounds and elements occur in various forms and combinations.

The human body consists of elements and compounds ingested, digested, absorbed, and circulated through the bloodstream to feed the cells of the body. Except in the unborn fetus, the digestive system is the first system involved. In a typical adult, about seven liters of digestive juices enter the lumen of the digestive tract. These break chemical bonds in ingested molecules, and modulate their conformations and energy states. [4]

The Conversion of Digested Nutrients into Energy

Cellular Respiration

Cellular respiration begins with the raw materials glucose and oxygen and yields carbon dioxide and water (both waste products) and free energy, some of which is captured and stored in a usable form as ATP. The chemical equation for this conversion is $C_6H_{12}O_6 + 6\ O_2$ --- > $6\ CO_2 + 6\ H_2O$ + energy (ATP).

The foundation of the process is glucose, a simple sugar molecule made up of 6 atoms each of carbon and oxygen and 12 atoms of hydrogen. Glucose can be found in varying amounts in the carbohydrates, fats, and proteins that we consume.

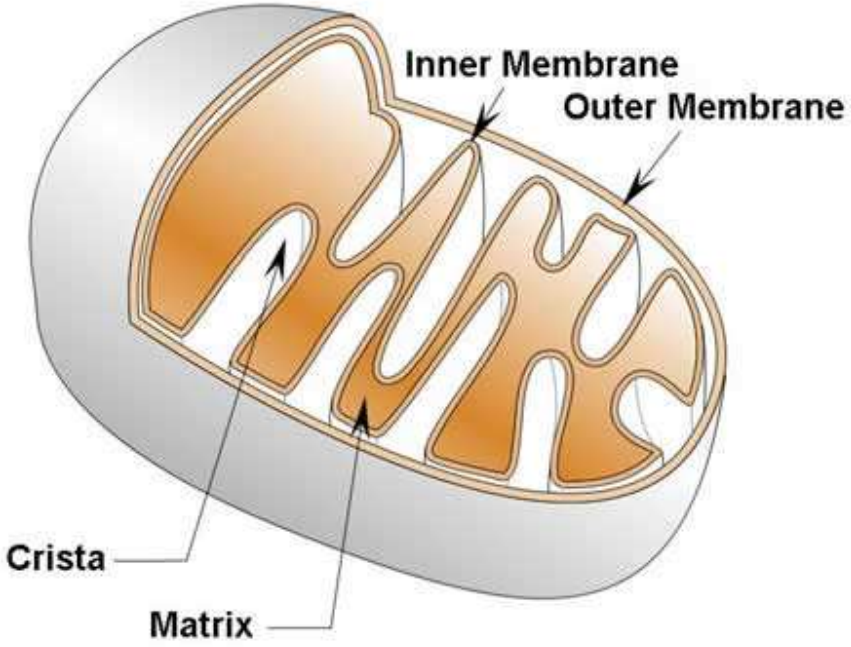
The food we eat must be broken down before it ever enters the cell's mitochondria, where cellular respiration takes place. Breaking down complex carbohydrates into glucose is a relatively simple process. Complex carbohydrate molecules are made up primarily of multiple glucose molecules linked together. Enzymes in the stomach and intestines separate individual glucose molecules from one another early in the digestive process. In contrast, fats and amino acids, the molecules that make up proteins, have chemical structures that only vaguely resemble glucose. They contain carbon, hydrogen, and oxygen atoms, just like glucose, but in dramatically different ratios.

The liver is responsible for converting carbohydrate, protein and fat molecules into glucose. It is also the place where excess carbohydrates are converted into a readily available but storable carbohydrate molecule called glycogen and into fat. The direction of these conversions depends on the level of glucose in the blood. When the concentration of glucose in the blood is low, the liver converts glycogen and fat (and in their absence, protein) into glucose. When blood glucose levels are high, the liver reverses the process, storing carbohydrates and maintaining fat and protein stores.

Cells obtain glucose from the blood, through the walls of capillaries nearby. These capillaries carry not only glucose but also oxygen and many other important nutrients. Once inside the cell glucose is absorbed by organelles called mitochondria. These important structures play host to the two stages of cellular respiration: the Krebs cycle and the electron transport chain. Combined, these chemical conversions and the raw material glucose that feeds them, produce the energy that drives nearly every cellular process in your body. [5]

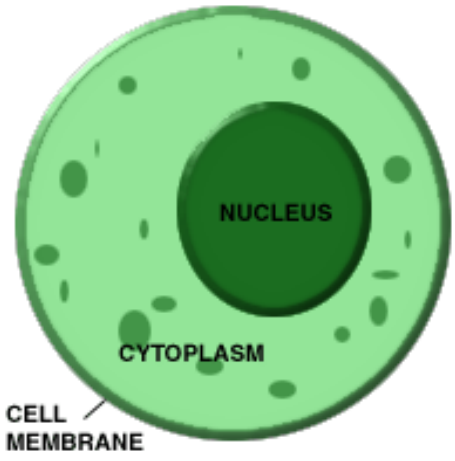
Components of Cellular Respiration:

Mitochondria- The mitochondria is an organelle found in human cells. The mitochondria is said to be the power house of the cell and creates almost all of the ATP (adenosine tri-phosphate which is made up of adenosine and three phosphates) required for the daily functions of the cell. Cells that would require more energy like muscle cells, would have a larger amount of mitochondria.



A single cell can contain several thousand mitochondria, and cells with especially high energy demands generally have the largest number of mitochondria.

Cytoplasm- The cytoplasm is a gelatin like substance found in all cells. The cytoplasm is the site of many chemical reactions. The sum all of these chemical reactions is called metabolism. The cytoplasm is made up of about 70 percent water and 30 percent proteins, carbohydrates, ions, fats, and nucleic acids. The cytoplasm houses all of the organelles inside of the cells.



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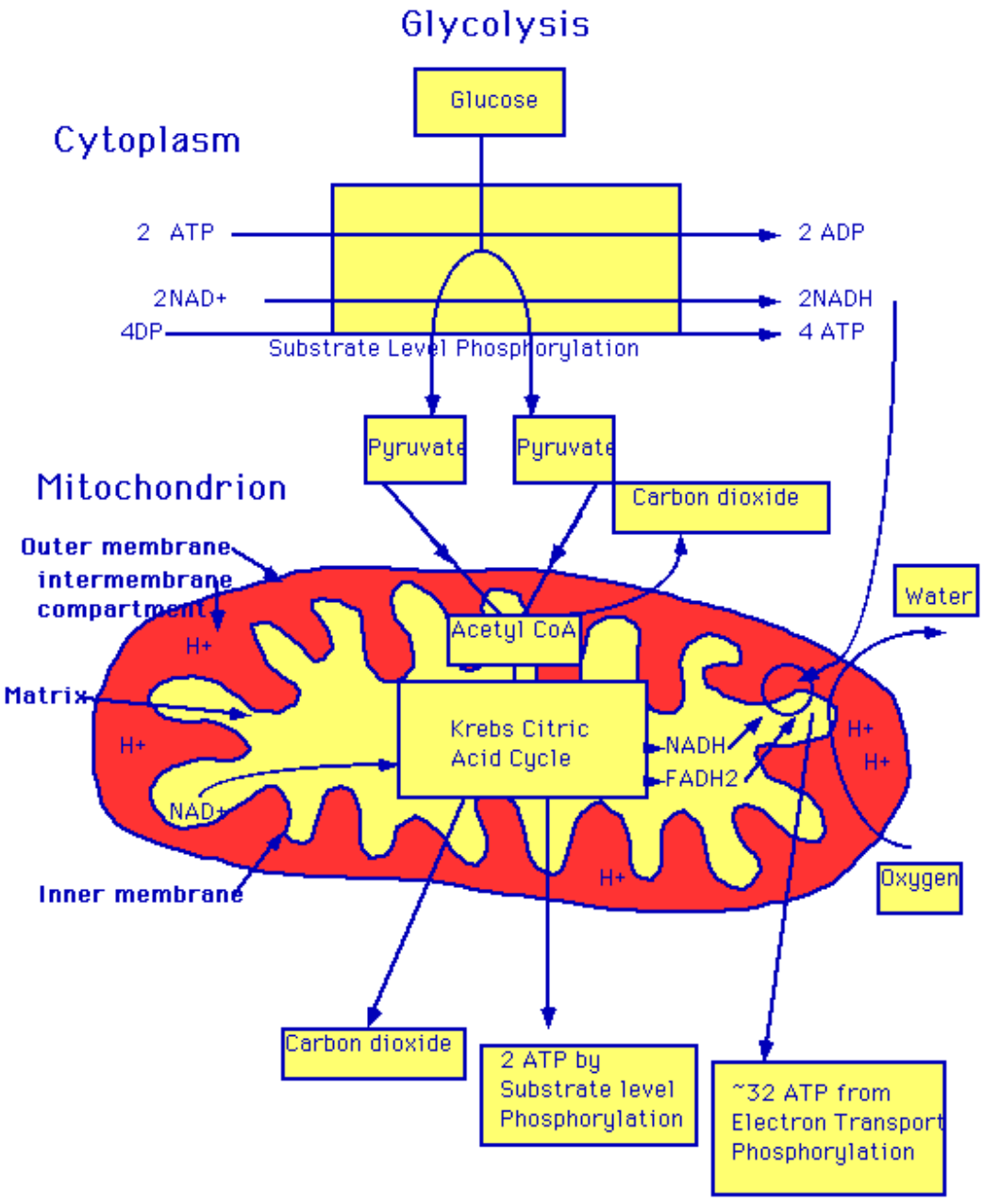
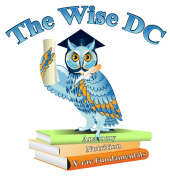
Three Stages of Cellular Respiration

The three stages of cellular respiration include glycolysis, the Krebs Cycle and the electron transport system.





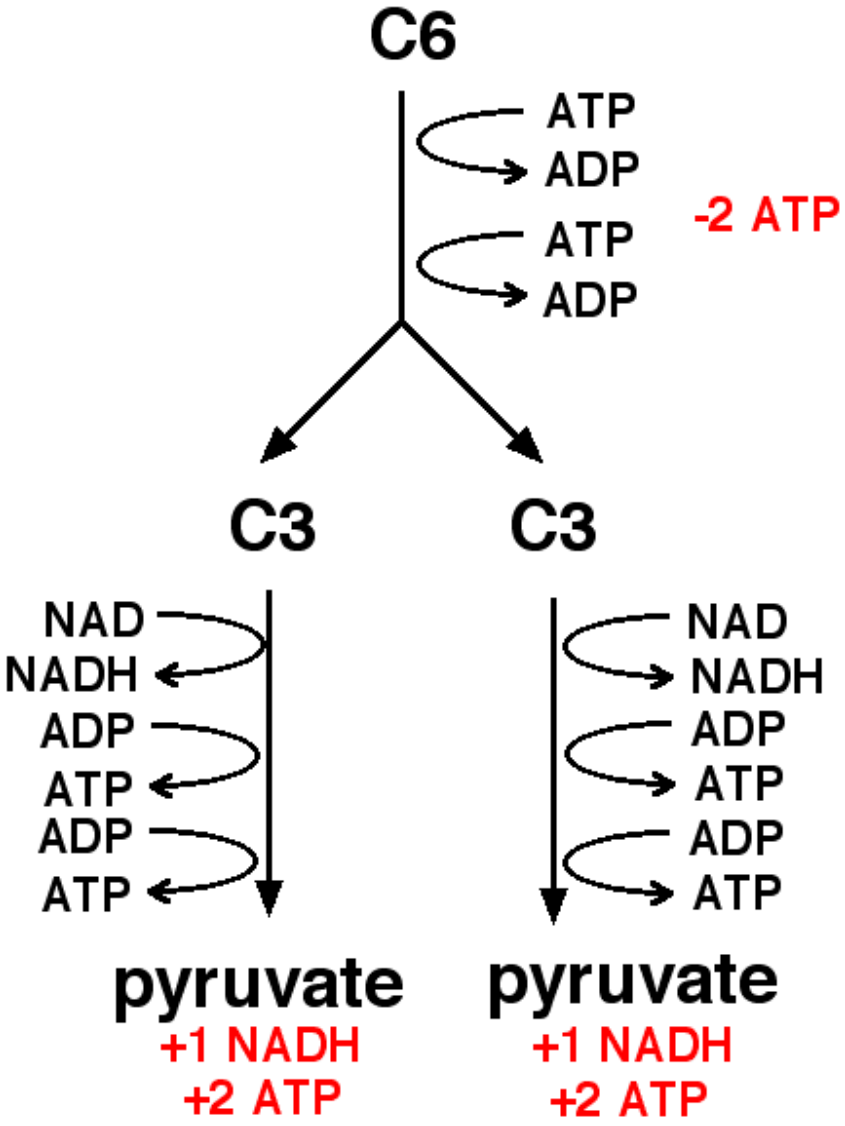
Glycolysis is the first stage of cellular respiration which begins in the cytoplasm of a cell, when a glucose molecule is split into two negatively- charged ions of *pyruvate*. G*lycolysis*, does not require oxygen and is a form of anaerobic respiration. The energy released during glycolysis is used by the cell to generate 2 ATP molecules by adding a single phosphate group to each of 2 ADP molecules.

The splitting of glucose during glycolysis also produces high-energy hydrogen ions (H^+). A pyruvate ($C_3H_3O_3^-$) ion is negatively-charged because it is missing a hydrogen ion, and so it has an extra electron that isn't paired with a proton. The uncharged hydrogen atoms that are liberated when glucose is split into pyruvate ultimately combine with oxygen to form water molecules.

The highly energetic H^+ ions would do damage if they were left unpaired. They are gotten rid of by combining them with the coenzyme *NAD* (**N**icotinamide **A**denine **D**inucleotide), to form NADH. Therefore, glycolysis produces 2 molecules of ATP that store and transport energy, plus two molecules of NADH, which get rid of the energetic and therefore potentially dangerous H^+ ions.

Of course, the fact that the H^+ ions are so energetic means that it is possible to extract energy from them, and the cell does exactly that. Energy stored in the NADH molecules is used to generate an additional 4 molecules of ATP. (Cardiac muscle cells and liver cells are more efficient at this, and can generate not 4 but *6* ATP molecules in this way.)

At the end of this first stage in cellular respiration, the cell will typically have generated a total of 6 molecules of ATP from the splitting of a glucose molecule – 2 ATP molecules from glycolysis and 4 more from processing of electrons temporarily stored in molecules of NADH. If the 2 pyruvates produced by the splitting of the original glucose molecule are to be broken down any further, however, oxygen is required. Otherwise, the pyruvate is processed into less-dangerous substances and excreted.



Complete breakdown of pyruvate into CO_2 and H_2O can only take place inside the mitochondria, so after glycolysis has been completed, the pyruvate is normally transported into mitochondria for further breakdown. A few cells in the body lack mitochondria (notably, red blood cells), and therefore they are capable *only* of anaerobic respiration. This would account for the short life span of RBCs.

During heavy exercise, skeletal muscle cells can find themselves in an anaerobic condition, because their metabolic rates are so high that they use up all the oxygen that can be delivered to them by the blood. They can survive and continue to function for a time by producing energy through glycolysis. Because the end-products of glycolysis are poisonous to cells, there is a sharp limit to how long skeletal muscles can

function anaerobically. One of the major effects of repeated exercise is that the circulatory system becomes more efficient at delivering oxygen to skeletal muscles, and so they can function for longer periods of time before running out of oxygen.

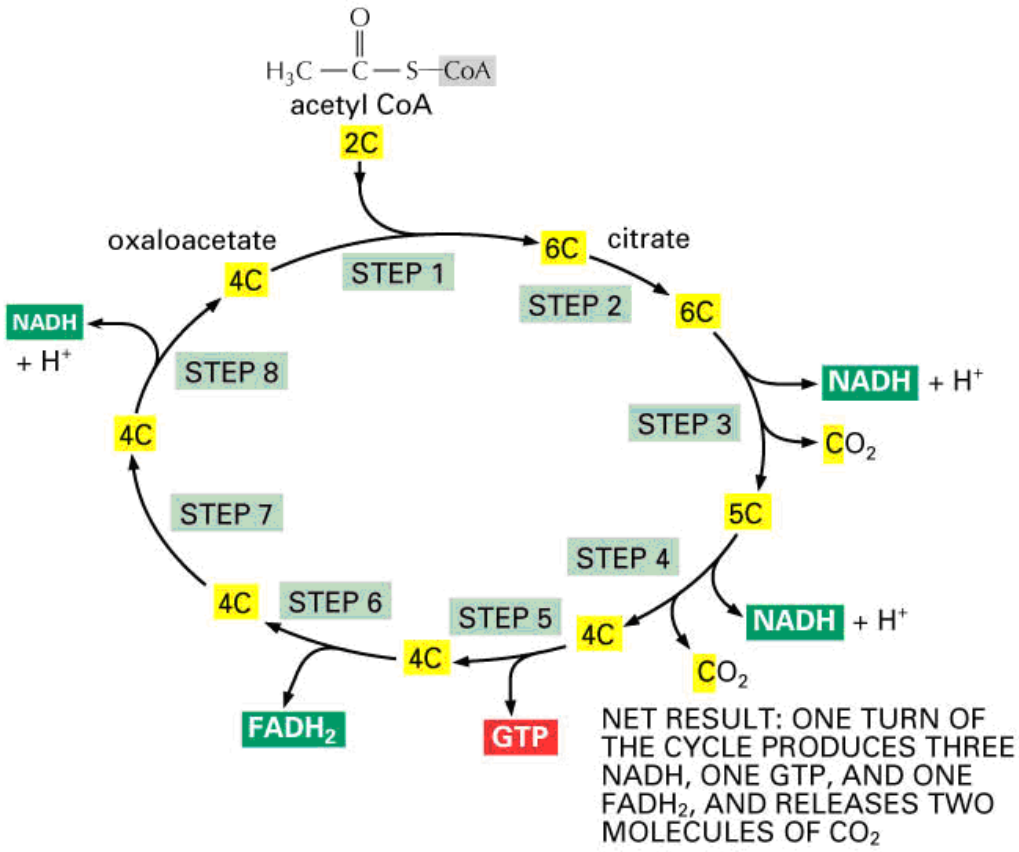
The TCA/Krebs/Citric Acid Cycle

The second stage of cellular respiration is the TCA/ Krebs/Citric Acid Cycle. When oxygen is available, the 2 pyruvate ions produced during glycolysis are transported into a mitochondrion. Inside the mitochondrion, the pyruvates are completely broken down in the TCA Cycle (the Tricarboxylic Acid Cycle), also known as the Krebs Cycle(named after the chemist, Hans Krebs), or the Citric Acid Cycle. This Cycle produces 2 more ATP molecules, plus 8 NADH and 2 FADH2 molecules. (FADH2, or flavin adenine dinucleotide, like NADH is a coenzyme.)

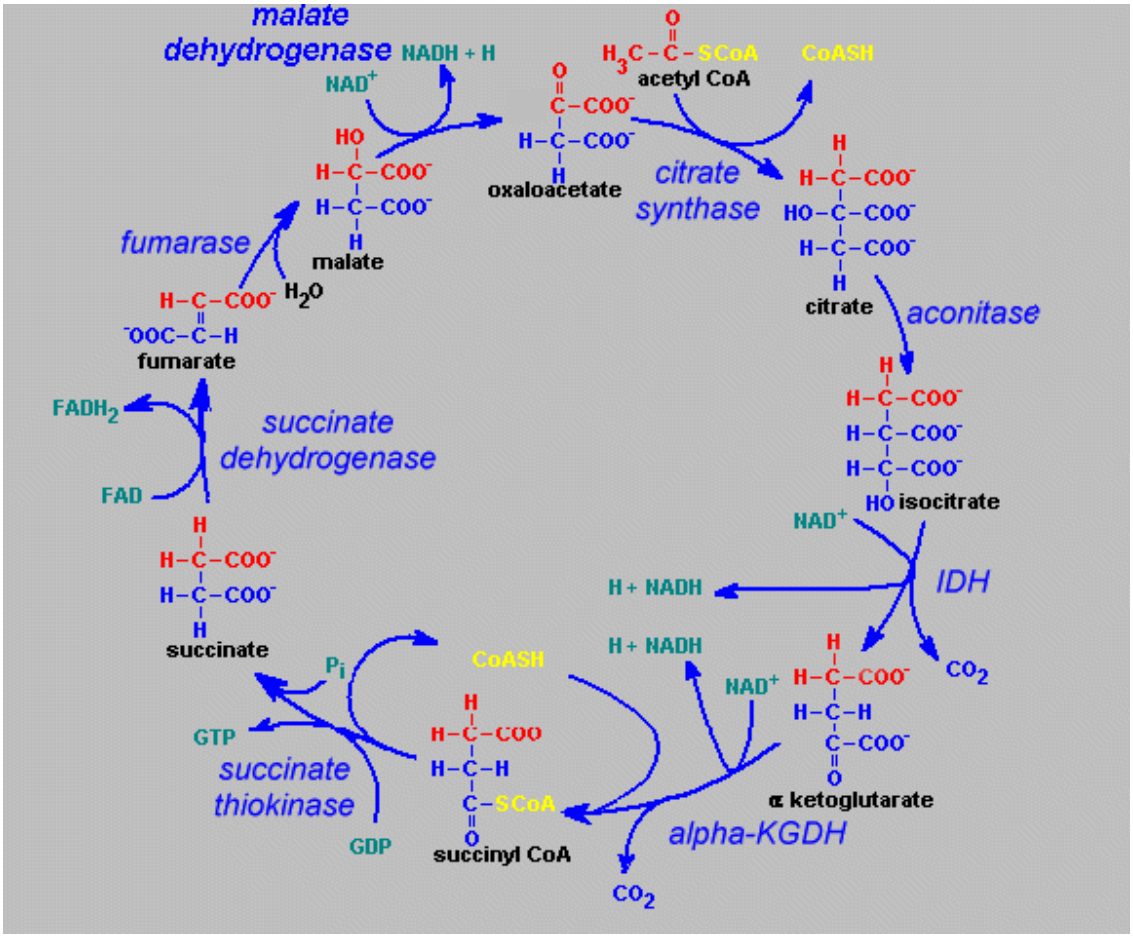
The Krebs cycle is the key to turning food into energy. During the Krebs Cycle acetlyl co-A (manufactured from glucose) and oxaloacetate form citric acid (aka citrate), which is very high in energy.

The citric acid gradually loses that energy, partly as CO2 (a waste product) and partly as GTP and NADH and FADH2, which go on to produce ATP, which is used to power many of the actual operations in the body.

The remaining bits are then used to reconstruct the oxaloacetate molecule, waiting to get another acetyl co-A to begin the whole cycle over again. The following is simplified diagram:



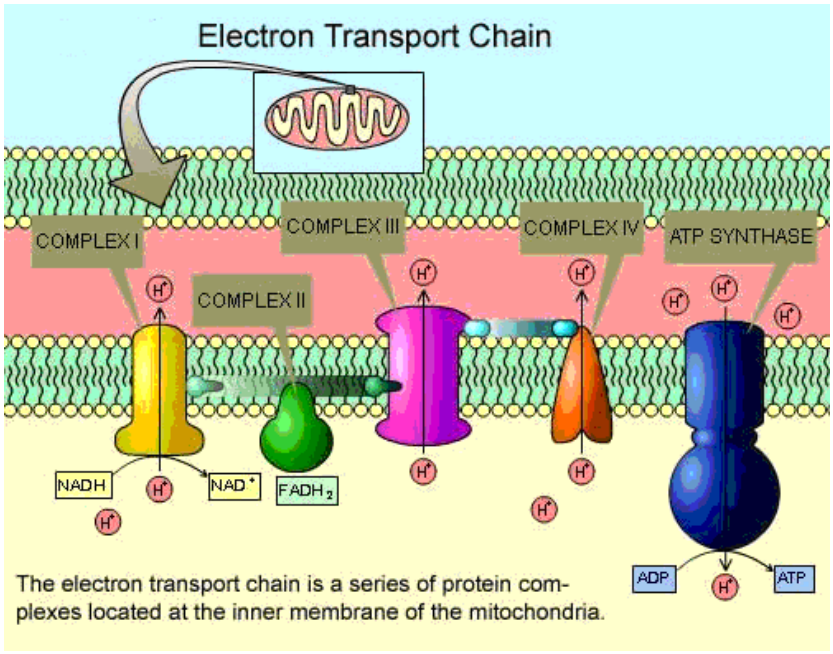
The acetyl co-A can also come from fats and proteins as well as carbohydrates, which is why this cycle is so important: every calorie you take in is transformed via this cycle into something you can use to power your body.



The TCA/Krebs/Citric Acid Cycle begins when a 2-carbon acetyl-CoA molecule binds to a 4-carbon oxaloacetate molecule to form a 6-carbon molecule of citrate (citric acid). Two of the carbon atoms are stripped off the citrate, one at a time, and combined with oxygen to form CO_2, which is excreted. Ultimately, the stripping of 2 carbons from citrate regenerates oxaloacetate, which can then combine with another molecule of acetyl-CoA.

The Electron Transport System

The electron transport system is composed of four enzymes (Complexes I, II, III, and IV). These enzymes are all located in the inner mitochondrial membrane.



Complex I: NADH Dehydrogenase: Complex I is responsible for removing two electrons from NADH and transferring them to the electron carrier, ubiquinone (Q). The reduced product is called ubiquinol (QH_2) and can freely move about the membrane. NADH dehydrogenase also moves four protons from the mitochondrial matrix to the intermembrane space, beginning the production of a proton gradient.

Complex II: Succinate Dehydrogenase: Complex II removes electrons from succinate and transfers them to ubiquinone via FAD. Succinate dehydrogenase does not contribute to the proton gradient.

Complex III: Cytochrome bc_1 Complex: Complex III removes two electrons form QH_2 and transfers them to two molecules of the electron carrier, cytochrome c. The cytochrome bc_1 complex also moves four protons across the inner mitochondrial membrane, further contributing to the proton gradient.

Complex IV: Cytochrome c Oxidase: Complex IV removes two electrons from the two molecules of cytochrome c and transfers them to molecular oxygen (O_2), producing water. Cytochrome c oxidase also moves two electrons

across the inner mitochondrial membrane, adding to the proton gradient.

Electrons from NADH (Complex I) and $FADH_2$ (Complex II) are passed through the electron transport chain to oxygen (Complex IV), which is reduced to water. During electron transport, the enzymes of the electron transport chain create a proton gradient across the inner mitochondrial membrane. This proton gradient is subsequently used by the enzyme ATP synthase to produce ATP.[7]

The NADH and $FADH_2$ molecules feed the energetic electrons they've captured into *electron transport chains*, which strip energy from the electrons. Ultimately, the energetic electrons and H^+ ions are eliminated by combining them with oxygen to form water (H_2O). The *electron transport system* produces an additional 28 ATP molecules.

The Advantages of Aerobic Respiration:

Anaerobic respiration can produce only 2 molecules of ATP for each glucose molecule broken down. Additionally, it produces highly toxic waste products. Even under the best of conditions, anaerobic respiration produces only 6 molecules of ATP for each molecule of glucose consumed.

Aerobic respiration can produce up to 38 molecules of ATP for each molecule of glucose consumed and its waste products (water and carbon dioxide) are much less toxic.

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[1] http://en.wikipedia.org/wiki/Peristalsis
[2] http://www.cic-caracas.org/departments/science/Topic5.php
[3] http://www.answers.com/topic/metabolic-pathway
[4] http://www.answers.com/library/Wikipedia-cid-56389
[5] http://www.teachersdomain.org/resource/tdc02.sci.life.cell.krebs/
[6] http://shortie894.tripod.com/id1.html
[7] http://www.google.com/imgres?imgurl=http://www.biochem.arizona.edu/