

## Introduction

As you read through the steps that happen in cellular respiration, draw models of the molecules involved (just include the carbons, which is called a carbon skeleton) and create a flow chart showing the steps. Keep track of the major molecules involved. It helps to keep track of the number of carbons in each molecule.

Make note of when ATP is used or formed. It is helpful to actually count the number of ATP involved, making note of the net amount (the amount you have after subtracting what was needed to make the reaction happen in the first place).

Also keep track of the electron acceptors, molecules that accept electrons from glucose through the acceptance of H. Glucose is oxidized and the electron carriers are reduced. There are two major types of electron acceptors involved in cellular respiration, NAD<sup>+</sup> and FAD<sup>+</sup>.

### Step 1

1. The first thing that happens in cellular respiration is that glucose is broken up into two pieces. This process is called glycolysis (lysis means splitting). Glycolysis takes place in the cytoplasm of the cell.

It takes energy to split the *glucose* molecule in glycolysis, so two ATPs are needed. Phosphates are added to the glucose before it splits, making the glucose a sugar-phosphate molecule. This then splits into two smaller *sugar-phosphate molecules*. How many carbons are in each of these smaller molecules? Enzymes will act on each of these molecules to rearrange their atoms. They will lose the phosphate and some electrons (oxidized) to make two molecules of *pyruvate* (also called pyruvic acid). During this process, two NAD<sup>+</sup> become NADH by accepting a H and the electrons. Four ATP are also created through this process of glycolysis.

This process really has nine steps. It does not require oxygen so it is called anaerobic.

### Step 2

2. The pyruvic molecules enter the matrix of the mitochondria by going through the outer and inner membranes. The matrix is inner space of the mitochondria. The pyruvic are not quite ready to participate in the process that generates ATP, though. Each pyruvic has to undergo "grooming" – this is where the pyruvic becomes a two carbon molecule called Acetyl CoA. At this stage two CO<sub>2</sub> are produced and two NAD<sup>+</sup> becomes NADH.

Fatty acids from fats and lipids can also enter the mitochondria matrix and become acetyl CoA.

### Step 3

3. The next stage is called the Krebs Cycle or the citric acid cycle. This process was figured out in 1937. It also happens in the matrix of the mitochondria.

First, an Acetyl CoA joins a 4 carbon molecule, called oxaloacetate, to become a 6 carbon molecule called citric acid. Seven more steps happen, each involving different enzymes. Both acetyl CoA from the two pyruvates will go through this cycle.

During this process, two carbon atoms are removed to become CO<sub>2</sub> while two H<sub>2</sub>O molecules are needed for the reactions. Besides CO<sub>2</sub>, six NAD<sup>+</sup> become NADHs. Another receiver of H involved in this process is a molecule called FAD<sup>+</sup>. Two FAD<sup>+</sup> will become FADH. Two ATP are also made. At the end, oxaloacetate is regenerated and the process, or cycle, will start again with a new acetyl CoA. Is this an anaerobic or aerobic process?

### Step 4

4. Think back to our equation that describes the Big Idea of cellular respiration. How much of the equation have we used or created? Has anything not been used or created yet?

### Step 5

5. The final process of cellular respiration takes place on the inner membrane of the mitochondria. This inner membrane is much larger than the mitochondria's outer membrane. In mitochondria that are in the liver, the inner membrane is nearly five times the area of the outer membrane. In mitochondria in cardiac cells, the inner membrane is three times that of liver mitochondria!

This final process is called the electron transport chain (ETC). The ETC needs oxygen so it is called an aerobic reaction. To start, a NADH moves to the inner membrane and removes a H (the H is really a hydride ion, H<sup>-</sup>, having 2 electrons). The hydride ion breaks apart and the two electrons are picked up by electron carrier protein molecules embedded in the inner membrane. The electrons get passed down to different electron carrier molecules in the membrane (there are more than 15 of them!) and as they do, they lose a little energy each time, dropping in their energy state. At the end of the chain, oxygen accepts the electrons and combines with H<sup>+</sup> to create water. Six H<sub>2</sub>O are created per glucose.

#### Step 6

6. The energy that is transferred in the movement of the electrons through the chain, is used to pump  $H^+$  from the matrix across the inner membrane to the space between the inner and outer membranes of the mitochondria (the intra-membrane space). This is an active transport process, building up the concentration of  $H^+$  in the intra-membrane space. This concentration is a way to storage energy.

#### Step 7

7. Other proteins in the inner membrane use this stored energy in the concentration of  $H^+$  to make ATP. The large enzyme complex, ATP synthetase, allows  $H^+$  to flow back through the inner membrane to the matrix. As  $H^+$  flows through this enzyme at one location, ADP picks up a phosphate at another location, causing ATP to be made. This enzyme is often thought of as a turbine, since it transfers energy from one storage form to another. What are the different storage forms involved?

The average number of ATP created through this process is 34, though some current research shows 29 are made.