Study Guide - Cellular Respiration

In the previous lesson we talked of photosynthesis and how it produced glucose and oxygen. Glucose (and carbohydrates in general) are ways in which energy is stored. All organisms take the energy that is stored in glucose or the other organic compounds and release that energy through **energy releasing pathways** that convert the stored energy into energy that the cell can use to carry out its processes. There are two different pathways involved in this, **aerobic** and **anaerobic**. While the two processes are different in their final output of total energy they both have one common starting place - **glycolysis** - the splitting of the glucose molecule.

Lets talk about these two types - well start first with the **aerobic pathway** - commonly called **aerobic respiration**.

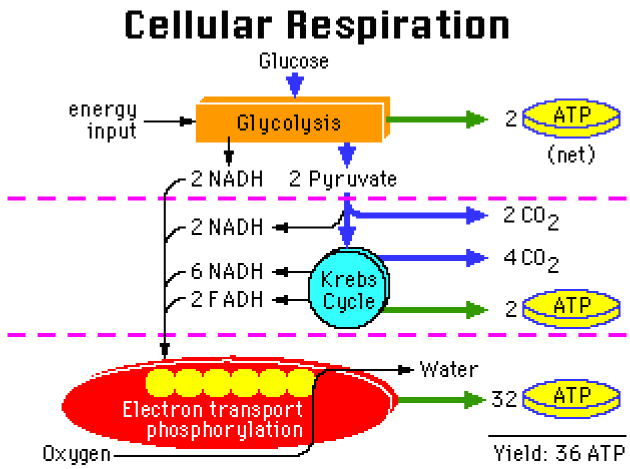
Aerobic Respiration

As we can see by the name of this type of respiration (aerobic), it requires the presence of oxygen for the process to be completed. Aerobic respiration has three stages: **glycolysis**, the **Krebs cycle**, and the **electron transport system**. All stages produce **ATP**, however the first two stages dont produce that much. The big producer of ATP comes from the third stage which uses coenzymes and drains energy from electrons that have been stripped from hydrogen atoms in the previous two steps. Well talk later about each of these stages in detail. The whole process can be summed up in a simple equation:

$$C6H12O6 + 6O2 \quad 6CO2 + 6H2O$$

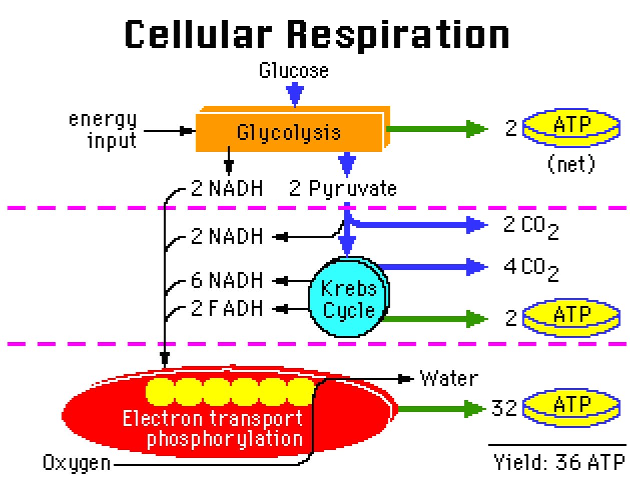
Do some elements from this equation look familiar to an equation from our previous lesson? Well, you will notice that the glucose molecule and the 6 oxygen molecules are both products of **photosynthesis**, and, as we will see in this lesson, the products of cellular respiration are some of the elements that are used in photosynthesis - so once again we are reminded of how all organisms rely on each other.

Glycolysis



As the word itself indicates, this a splitting (lysis) of sugar - or some other carbohydrate (glyco). This process occurs in the **cytoplasm** of the cell and does not necessarily require the presence of oxygen - that is why it is a common factor of both **aerobic respiration** and the **anaerobic pathway**. Remember that a product that goes into the pathway is glucose, a 6 carbon sugar. Glycolysis splits the 6 carbon sugar in two, thus producing two 3 carbon molecules known as **pyruvate** (**pyruvic acid**). The splitting process requires energy in the form of ATP, but at the same time the process produces energy. The hydrogen that is part of the original glucose molecule are stripped of some of their electrons and the hydrogen and electrons bind to the coenzyme **NAD** and it becomes **NADH** (because of the hydrogen). The NADH is then carried over into the next stage of the pathway. The results of glycolysis can be summarized by saying that for one molecule of glucose that goes in a total of 4 molecules of ATP are produced (but 2 are used in the splitting process - so the net yield is 2 molecules of ATP), 2 coenzymes of NADH are produced, and 2 - 3 carbon molecules of pyruvate are all passed on.

Krebs Cycle

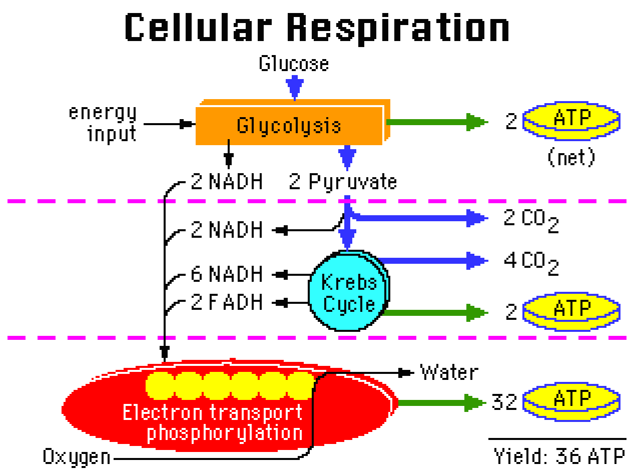


This and the following stage take place ***only*** in the mitochondrion. Once the **pyruvate** molecules have entered the **mitochondrion**, they go through a preparatory cycle before entering the actual Krebs cycle. As a result of this preparatory cycle the pyruvate molecules are stripped of their carbon and oxygen atoms and these end up being expelled in the form of carbon dioxide molecules (what we breathe out). The remaining group (which happens to be an acetyl group) binds with a coenzyme called coenzyme A, and the resulting molecule is called **acetyl-CoA**. Acetyl-CoA binds to another coenzyme and enters the Krebs cycle. The results of the preparatory cycle of the pyruvate molecules include expulsion of carbon dioxide and the production of 2 NADH molecules (because the hydrogen and electrons were stripped from the carbon and oxygen).

The actual **Krebs cycle** has a couple of functions. The first is that hydrogen and electrons are transferred and bound to the coenzymes **NAD** and **FAD**, which become **NADH** and **FADH2**. The second is that **phosphorylation** produces two more molecules of ATP. Another important part of the cycle is that it generates the coenzyme that binds with acetyl-CoA so the cycle can continue.

The results of the Krebs cycle arent that great as far as ATP is concerned, only two molecules are produced. But the cycle does produce a lot of coenzymes with hydrogen and electrons that are passed on to the next stage. Those totals are 2 molecules of FADH2, 8 molecules of NADH (2 of which came from the preparatory cycle), and 2 molecules of ATP.

Electron Transport System



This is the **high energy production** portion of the aerobic pathway. All of the **coenzymes** (a total of 10 molecules of NADH and 2 of FADH2) from the previous stages are introduced to the electron transport system. The transport system is made up of a sequence of enzymes and other molecules that transport the hydrogen and electrons from the **NADH** and **FADH2** coenzymes across the membrane that divides the mitochondrion into two compartments (inner and outer). As the hydrogen and electrons pass through the system, the hydrogen is ”tossed“ to the outer compartment where it binds with oxygen atoms and forms water molecules. As all the hydrogen and electrons are passed through the system, **phosphorylation** again takes place and 32 molecules of ATP are produced. So from start to finish, the aerobic pathway commonly produces 36 molecules of ATP - all available for use by the cell to carry out its functions.

So, to see the ”bookkeeping“ of the aerobic pathway we get:

2 ATP	2 NADH		from glycolysis
	2 NADH		from pyruvate prep
2 ATP	6 NADH	2 FADH2	from Krebs cycle
32 ATP			from the electron transport system, which converted the NADH and FADH2 into ATP.

36 ATP and 0 molecules of NADH and FADH2

Anaerobic Pathways

Some organisms actually thrive in places that dont have oxygen - places like mud, canned foods, sewage treatment ponds, and others - all anaerobic environments because of the lack of oxygen. In fact, some organisms actually die if they come in contact with oxygen. But that doesnt mean they dont need energy to survive and carry out their purposes. Most of these organisms are bacteria. The anaerobic pathways they use to produce ATP are called **fermentation** and it occurs within the cytoplasm. Well talk about two types here.

Alcoholic Fermentation

As we mentioned earlier, both aerobic and anaerobic pathways begin with **glycolysis**, so that is the first stage of alcoholic fermentation. Glucose is split into two molecules of **pyruvate** - and we get 2 ATP molecules and 2 NADH molecules. These are all passed on to the fermentation stage.

In the fermentation stage the pyruvate is rearranged and releases carbon dioxide, and the NADH gives up its electrons and forms a product called **ethanol**. This is the process by which beer and wine receive the alcoholic content.

Yeasts (a single-celled fungi) use this pathway. Yeast is a product that is used widely, particularly by bakers. Its what makes the bread dough rise. Yeast is blended into the mixture of sugar, the yeasts use the sugar and release carbon dioxide - which causes the dough to expand and ”rise“.

Lactate Fermentation

Another form of fermentation is lactate fermentation. Again, **glycolysis** produces 2 molecules of **pyruvate** and the **2 ATP** and **2 NADH** molecules. But thats about it. The pyruvate is the final acceptor of the hydrogen and electrons of NADH and the combination forms **lactic acid**.

This type of fermentation is common with bacteria that live in milk. When they produce lactate, the milk turns sour. Another use of this type of fermentation is when your demands for energy are intense but brief - like when you are running a short race or have a quick burst. The muscle cells actually switch to lactate fermentation for a quick ATP fix - but they cant do it for long.

A final note on the fermentation pathways - they do not completely break down the glucose molecule - so no more ATP is produced beyond what we get from glycolysis.

The Circle Continues

Remember, as we mentioned at the beginning of this lesson, that the products of cellular respiration (particularly the aerobic respiration) use what photosynthesis produces - and the process produces what photosynthesis uses.