Steps of cellular respiration

Cellular respiration is a metabolic pathway that breaks down glucose and produces ATP. The stages of cellular respiration include glycolysis, pyruvate oxidation, the citric acid or Krebs cycle, and oxidative phosphorylation.

Introduction

Cellular respiration is one of the most elegant, majestic, and fascinating metabolic pathways on earth. At the same time, it's also one of the most complicated. When I learned about it for the first time, I felt like I had tripped and fallen into a can of organic-chemistry-flavoured alphabet soup! Luckily, cellular respiration is not so scary once you get to know it. Let's start by looking at cellular respiration at a high level, walking through the four major stages and tracing how they connect up to one another.

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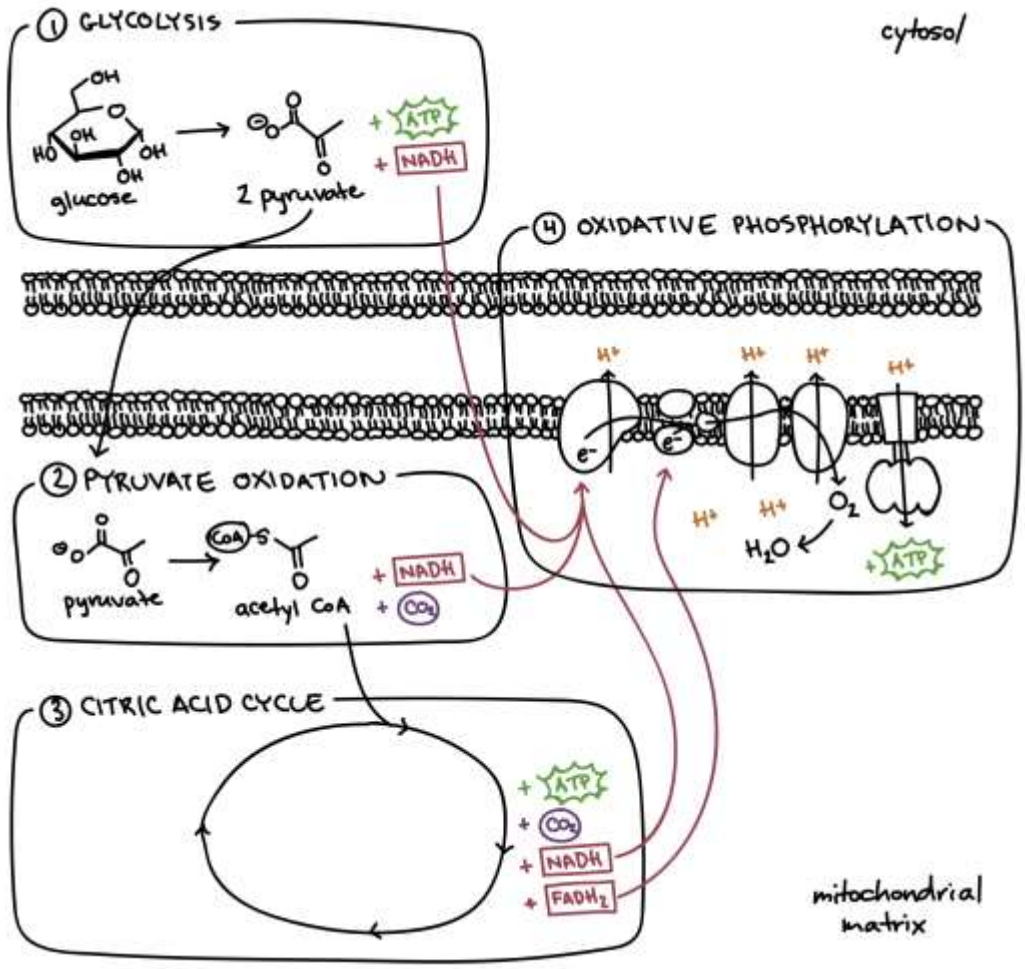

Overview of the steps of cellular respiration.

1. Glycolysis. Six-carbon glucose is converted into two pyruvates (three carbons each). ATP and NADH are made. These reactions take place in the cytosol.

2. Pyruvate oxidation. Pyruvate travels into the mitochondrial matrix and is converted to a two-carbon molecule bound to coenzyme A, called acetyl CoA. Carbon dioxide is released and NADH is made.
3. Citric acid cycle. The acetyl CoA combines with a four-carbon molecule and goes through a cycle of reactions, ultimately regenerating the four-carbon starting molecule. ATP (or, in some cases, GTP), NADH, and FADH_2 are made, and carbon dioxide is released. These reactions take place in the mitochondrial matrix.
4. Oxidative phosphorylation. The NADH and FADH_2 produced in other steps deposit their electrons in the electron transport chain in the inner mitochondrial membrane. As electrons move down the chain, energy is released and used to pump protons out of the matrix and into the inter-membrane space, forming a gradient. The protons flow back into the matrix through an enzyme called ATP synthase, making ATP. At the end of the electron transport chain, oxygen accepts electrons and takes up protons to form water.

During cellular respiration, a glucose molecule is gradually broken down into carbon dioxide and water. Along the way, some ATP is produced directly in the reactions that transform glucose. Much more ATP, however, is produced later in a process called oxidative phosphorylation. Oxidative phosphorylation is powered by the movement of electrons through the electron transport chain, a series of proteins embedded in the inner membrane of the mitochondrion. These electrons come originally from glucose and are shuttled to the electron transport chain by electron carriers NAD^+ and FAD which become $NADH$ and $FADH_2$ when they gain electrons. To be clear, this is what's happening in the diagram above when it says plus NADH FADH2. The molecule isn't appearing from scratch, it's just being converted to its electron-carrying form:

$$NAD+ 2e^{-2} + 2H+2 \rightarrow + H+FAD+ 2e^{-+} 2H+2 \rightarrow FADH_2$$

To see how a glucose molecule is converted into carbon dioxide and how its energy is harvested as ATP and $NADH/FADH_2$ in one of your body's cells, let's walk step by step through the four stages of cellular respiration.

1. **Glycolysis.** In glycolysis, glucose—a six-carbon sugar—undergoes a series of chemical transformations. In the end, it gets converted into two molecules of pyruvate, a three-carbon organic molecule. In these reactions, ATP is made, and NAD^+ is converted to $NADH$.
2. **Pyruvate oxidation.** Each pyruvate from glycolysis goes into the mitochondrial matrix—the innermost compartment of mitochondria. There, it's converted into a two-carbon molecule bound to Coenzyme A, known as acetyl CoA. Carbon dioxide is released and $NADH$ is generated.
3. **Citric acid cycle.** The acetyl CoA made in the last step combines with a four-carbon molecule and goes through a cycle of reactions, ultimately regenerating the four-carbon starting molecule. ATP, $NADH$ and $FADH_2$ are produced, and carbon dioxide is released.
4. **Oxidative phosphorylation.** The $NADH$ and $FADH_2$ made in other steps deposit their electrons in the electron transport chain, turning back into their "empty" forms (NAD^+ and $FADH_2$). As electrons move down the chain, energy is released and used to pump protons out of the matrix, forming a gradient. Protons flow back into the matrix through an enzyme called ATP synthase, making ATP. At the end of the electron transport chain, oxygen accepts electrons and takes up protons to form water.

Glycolysis can take place without oxygen in a process called fermentation. The other three stages of cellular respiration—pyruvate oxidation, the citric acid cycle, and oxidative phosphorylation—require oxygen in order to occur. Only oxidative phosphorylation uses oxygen directly, but the other two stages can't run without oxidative phosphorylation.