Definition and Phases of Cellular Respiration

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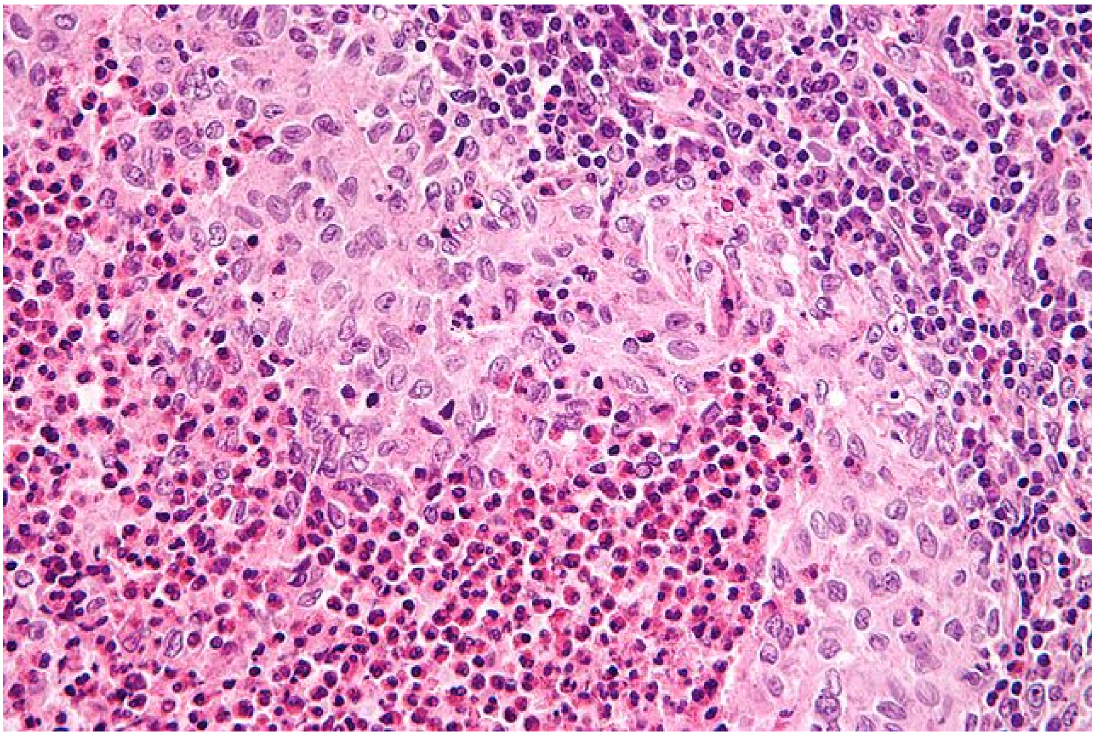
A number of process in the human body involves oxidation and reduction processes. These processes involve the transfer of electrons from one compound to another. These types of reactions are very important in body metabolism as some of these reactions are involved in the production of ATP, the energy unit of the cell. In this article, the whole process of cellular respiration will be discussed. The structural features of the cell and the reactions occurring in it will be given emphasis.



Redox Reactions in Living Systems

A lot of chemical reactions occurring in nature involve the transfer of electrons from one compound to another. In the process, the compound that received the electron will be reduced while the compound losing the electron will be oxidized. The **processes of reduction and oxidation always occur in tandem**

“OIL RIG” — **o**xidation **i**s **l**oss of electrons, **r**eduction **i**s **g**ain of electrons.
In biological systems, redox reactions occur with the aid of enzymes. Enzymes are efficient catalysts for biochemical reactions. They are protein structures that **provide pathways for reactions that would otherwise not take place at all** because the energy required is too high, or liberate energy in an explosive reaction and all the energy would be lost (combustion) and none stored.

In biological redox reactions, the process is called **cellular respiration**. During this process, the enzyme, NAD+ acts as an intermediary, oxidizing the food molecules in a much more controlled fashion than combustion. By using NAD+ and the electron transport chain the oxidation of organic molecules can be linked to the production of ATP rather than just the generation of heat.

For cellular respiration to work, the **enzyme must be able to collide with the substrate** (the reacting molecule that binds to the enzyme) **in the correct orientation**. Enzymes have a specific part in their structure that selectively binds with the substrate. This part is called the **active site**.

Co-enzymes are sometimes required to complete the reaction. They are small molecules that link to enzymes and are essential in enzymatic activity.

In the process shown above, an energy rich molecule attaches itself to the active site of the enzyme. Also the coenzyme NAD+ attaches itself to another site in the enzyme surface. The whole process involves oxidation of the substrate and the reduction of the coenzyme NAD+ to NADH.

Inside the cells, similar types of reactions occur that involve **breaking down energy-rich molecules producing Adenosine Triphosphate** (ATP) in the process. These reactions are part of the process called cellular respiration.

Cellular Respiration

Breaking down of carbohydrates and combustion of paper both involves the release of energy. In ordinary combustion, **energy is released in the form of heat**. On the other hand, when carbohydrates are broken down inside the cells, the energy is retained in the form of ATP. This is harvested and stored for later use. The whole process of ATP synthesis inside the cells is called **cellular respiration**.

Cellular respiration is the process by which **cells produce energy through the breakdown of biomolecules like carbohydrates and proteins**. The whole process requires oxygen (O2) molecules to occur. In the process, carbon dioxide is released. The most common source of energy in animals is glucose. **Glucose can be completely broken down to carbon dioxide** and water in a series of redox reactions in the cell.

C6H12O6 + 6 O2	**→ 6 CO2 + 6 H2O + ATP (energy)**

In this specific reaction, the glucose molecules are oxidized while the oxygen molecules are reduced. To maximize the production of ATP, energy from the structure of the glucose molecules must be **released slowly** and so what occurs in the cell is a series of breakdown reactions instead of a one-step complete breakdown. The amount of energy that can be harvested during cellular respiration is only equivalent to 39 % of the energy stored in a glucose molecule. **This is equivalent to about 36 or 38 molecules of ATP.**

In cellular respiration, each step is catalyzed by a specific enzyme. Enzymes that are useful in cellular respiration work with the redox coenzyme NAD+. NAD+ serves as the electron acceptor during cellular respiration. It accepts two electrons and a proton to produce NADH. The electrons obtained by the NAD+ molecule are carried later to the electron transport chain. Another co-enzyme used in some biological redox reaction is FAD which is converted to FADH2 when it accepts two electrons and two hydrogen atoms.

Phases of Cellular Respiration

The whole process of cellular respiration is divided into four phases, namely:

1. glycolysis
2. preparatory reaction
3. citric acid cycle
4. the electron transport chain

Glycolysis

Glycolysis is the first phase of cellular respiration and **occurs outside the mitochondria** while the other phases occur inside the mitochondria. Glycolysis comes from the Greek words *glyco* which means sugar and *lysis* which means splitting.

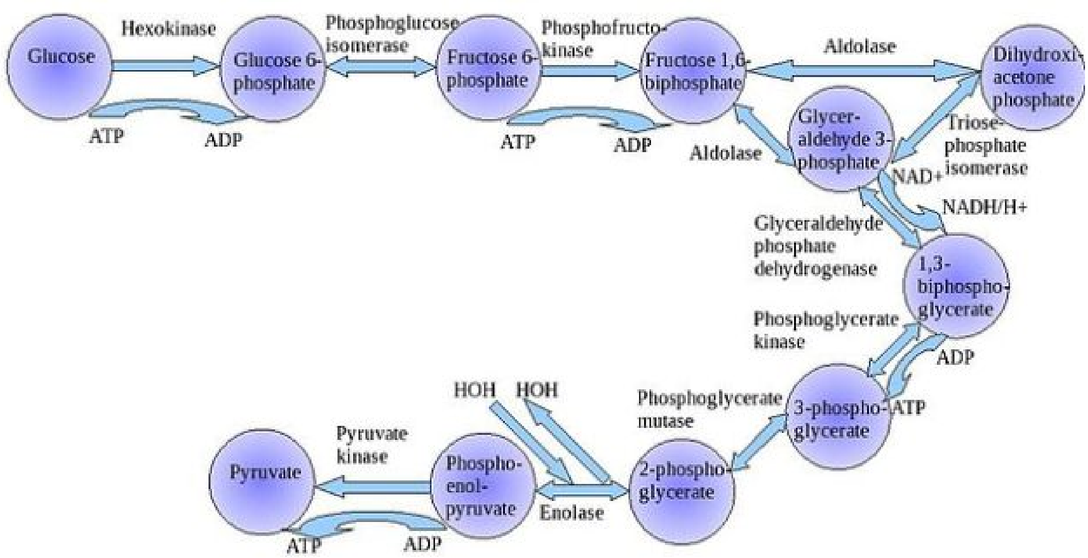


Image: “Glycolysis diagram.” by Tekks. License: CC BY-SA 3.0

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. Glycolysis is a ten-step reaction where a total of 4 ATP molecules are produced. However, to activate the glucose molecule, 2 ATP molecules are needed thereby giving a net production of 2 ATP molecules only after glycolysis. Aside from the ATP produced during glycolysis, 2 NAD+ molecules are reduced to 2 molecules of NADH.

Preparatory reaction phase

The second phase is the preparatory reaction phase. This phase is called so because it prepares the substrate molecule that will enter the citric acid cycle. Here, each of the two **pyruvate molecules is broken down from a 3-carbon molecule to a 2-carbon acetyl molecule**. In the process, a carbon dioxide molecule is released. Each pyruvate molecule binds with co-enzyme A to produce acetyl CoA. Carbon dioxide is released, an NAD+ is again reduced to **NADH**.

Citric acid cycle

The third phase is the citric acid cycle also known as the Krebs Cycle. This involves

matching the 2-carbon acetyl CoA to a 4-carbon molecule to produce the 6-carbon molecule, citrate. The series of reactions involves four oxidation steps where three NAD+ and one FAD are used as the electron acceptor. Each of the acetyl groups from the acetyl CoA is oxidized to produce two CO2 molecules each. In the process, each acetyl CoA molecule produces one ATP molecule each giving the net ATP production of 2 per glucose molecule for this phase.

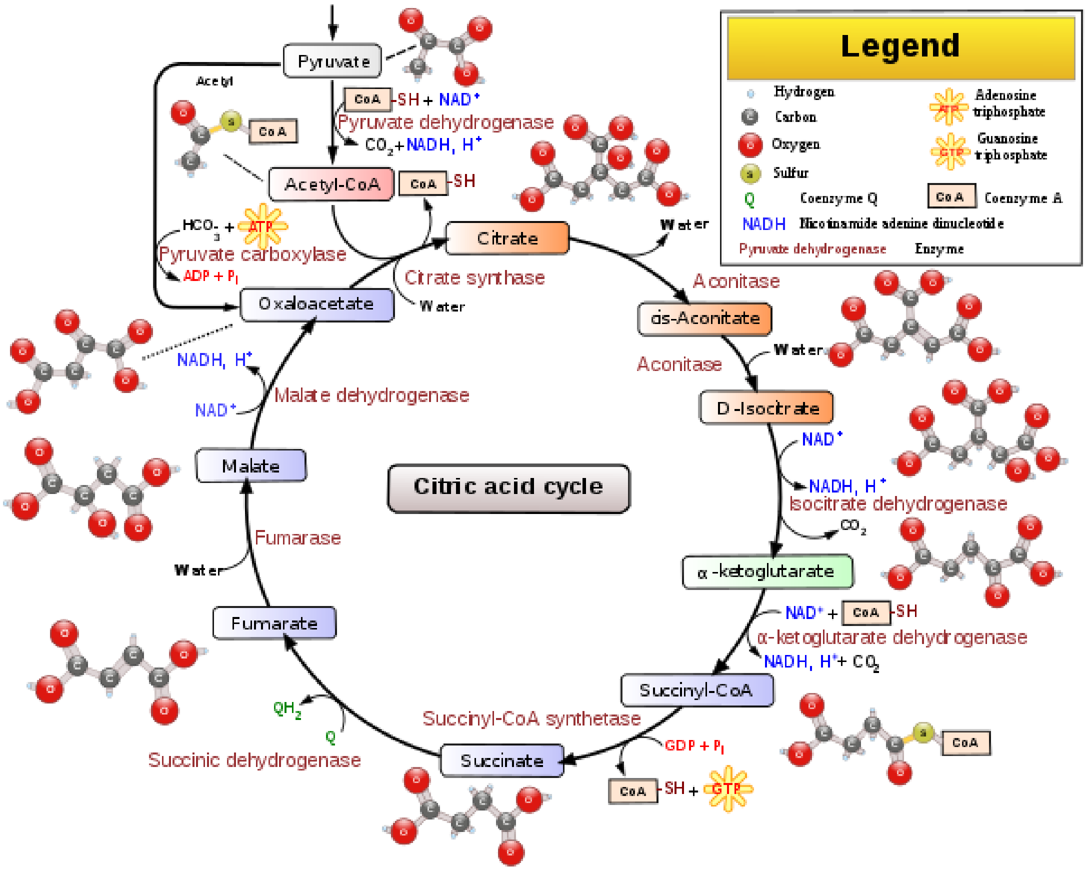


Image: “Overview of the citric acid cycle” by Narayanese, WikiUserPedia, YassineMrabet, TotoBaggins. License: CC BY-SA 3.0

Electron transport chain

The last phase of the cellular respiration is the electron transport chain. Here, the NADH and FADH2 produced in the **previous phases enter the electron transport chain**. Each NADH molecule that enter the chain results in the production of three ATP molecules while each FADH2 can produce two ATP molecules.

The two NADH molecules produced in the cytosol during glycolysis sometimes do not account for the production of ATP, as NADH cannot enter the mitochondria. It requires a transport system. Instead of NADH directly entering the mitochondria, there are **electron shuttle systems** that accept electrons from cytosolic NADH, enter the mitochondria, and give up the electrons to electron acceptors in the mitochondrial matrix. This requires the use of one ATP molecule, thus reducing the net output of the process.

Image: “The electron transport chain in the mitochondrion is the site of oxidative phosphorylation in eukaryotes. The NADH and succinate generated in the citric acid cycle are oxidized, providing energy to power ATP synthase." by Fvasconcellos. License: Public Domain

Summary of the four phases

The whole process of cellular respiration can produce a total of 36—38 ATP molecules per glucose molecule. For the glycolysis, 2 ATP molecules are produced plus two moles of NADH which when they enter the electron transport chain produces 4 or 6 ATP molecules.

The preparatory stage produces 2 NADH molecules that enter the electron transport chain and produce a total of six more ATP molecules. The citric acid cycle produces 2 ATP molecules plus 6 NADH and 2 FADH2 molecules. When the NADH and FADH2 produced in the citric acid cycle enter the electron transport chain, 22 more ATP molecules are produced.

References

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