Cellular respiration:
A pathway to provide energy to the cell

All cells need energy to function (biosynthesis, molecule transport, cellular movements, etc.). ATP is a molecule that plays a key role in the cellular energy transfers involved. This molecule can be produced during various chemical reactions; In most eukaryotic cells, it is respiration that provides ATP.

What is respiration about?

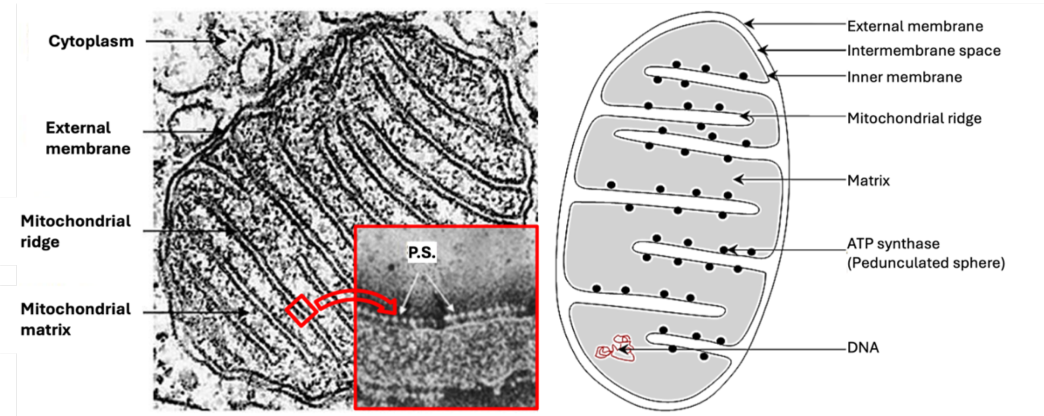
In the presence of glucose and oxygen gas (i.e., in aerobic conditions), a cell consumes these 2 reactants to produce CO_2 and water: this is called cellular respiration.
It is accompanied by the production of energy, which is the real purpose of this process.
This can be expressed by an equation showing the balance of transformations from a glucose molecule:

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{Energy\nearrow} 6CO_2 + 6H_2O$$

Note: *All carbon atoms are oxidized: cellular respiration is therefore a complete oxidation of organic matter; carbonaceous matter is said to be completely mineralized in the form of CO_2.*

Where(s) does cellular respiration take place?

Mitochondria are the key organelles for cellular respiration: without them, respiration cannot take place in a cell.



The mitochondrial matrix is surrounded by 2 membranes:

- The external membrane separates the mitochondrion from the cytoplasm of the cell.
- The inner membrane features invaginations called mitochondrial ridges. These are covered by granular, spherical structures known as pedunculated spheres (PS). Analysis of these spheres reveals that they are ATP synthase enzyme complexes.

Note: *A mitochondrion is partially autonomous, due to the presence of mitochondrial DNA. This is evidence for the origin of cells through endosymbiosis.*

A mechanism in 3 steps

1. A first step in the cytoplasm: oxidation of glucose into pyruvate ions.

The glucose contained in the extracellular medium enters the cell cytoplasm. There, it undergoes an initial stage of partial oxidation, known as GLYCOLYSIS, which results in the formation of pyruvate ions. This oxidation is accompanied by the production of reduced compounds NADH.

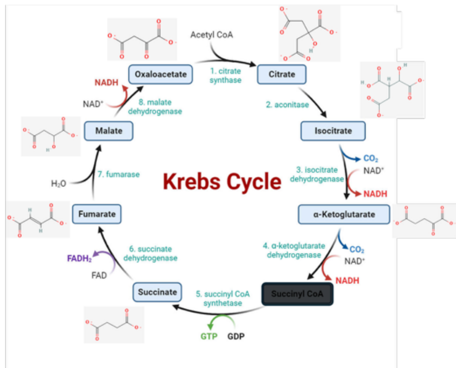
Note: NADH stands for Nicotinamide Adenine Dicnucleotide Hydride. Its structure is similar to NADPH, produced during photosynthesis.

The redox reaction releases energy that is used by energy coupling to synthesize 2 ATP molecules per molecule of oxidized glucose.

$$\overbrace{C_6H_{12}O_6}^{glucose} + 2NAD^+ \longrightarrow 2\,\overbrace{CH_3COCOO^-}^{pyruvate} + 4H^+ + 2NADH$$

ADP+P_i → ATP

2. A second step in the mitochondrial matrix: the Krebs cycle



The pyruvate ions formed by glycolysis enter the mitochondria and undergoes complete oxidation in the matrix during a series of reactions forming the Krebs cycle.

These reactions are accompanied by the production of reduced compounds and the synthesis of ATP. Pyruvate is completely oxidized: CO_2 is produced, which is the "waste product" of cellular respiration.

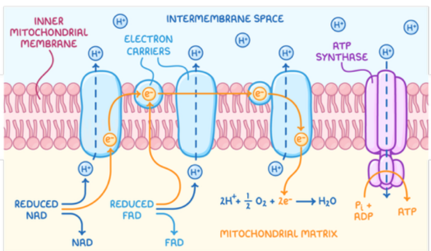
$$CH_3COCOO^- + 5NAD^+ + 3H_2O \longrightarrow 3CO_2 + 5NADH + 4H^+$$

ADP+P_i → ATP

Note: It is not pyruvate that is involved in the Krebs cycle, but Acetyl-CoA, which is the result of the interaction of pyruvate ions with Co-enzyme A after it entered the mitochondrion.

3. A third step in the crests of the internal membrane of mitochondria: phosphorylation of ADP into ATP

The reduced compounds produced in the matrix during glycolysis and the Krebs cycle are used to produce ATP. They transfer their electrons (oxidation) to a chain of transporters (respiratory chain): the electrons are transported across the inner membrane of the mitochondrion to the final acceptor O_2, which is then reduced to H_2O, another waste product of respiration. The reduction of oxygen gas is accompanied by a consumption of H^+ ion, thus creating a concentration gradient between the mitochondrial matrix and the intermembrane space. The passage of H^+ ions through ATP-synthase proteins, embedded in the inner mitochondrial membrane, leads to the end goal of the respiratory chain: a very large production of ATP.



$$2NADH + O_2 + 2H^+ \longrightarrow 2NAD^+ + 2H_2O$$

ADP+P_i → ATP

Note: Respiration is not the only process to produce energy. Procaryotic cells, and in some situations also eukaryotic cells use fermentation to produce ATP. However, in these anaerobic conditions, the incomplete breakdown of glucose into ethanol or lactic acid allows the synthesis of only 2 ATP molecules (through glycolysis at the start of fermentation). This difference results in a slower growth of organisms depending on fermentation, with a higher organic matter requirement. However, fermentation is advantageous under certain conditions, as it allows cellular life in the absence of O_2.

A diagram to summarize all this