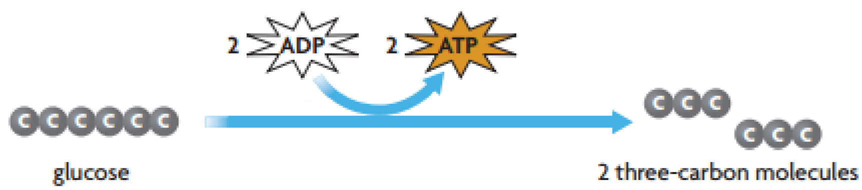
7.14 – Cellular Respiration

How Organisms Get Energy

Through **cellular respiration** plants, animals, and other eukaryotes get energy through chemical reactions that make ATP. This is an **aerobic** process which means that it needs oxygen gas to take place. This aerobic process takes place in the mitochondria or the "powerhouses" of the cell.

The mitochondria cannot directly make ATP form food because the food must be broken down into smaller molecules such as glucose. Then a process called **glycolysis** breaks glucose down into 2 three-carbon molecules and makes two molecules of ATP. The term glukus means "sweet" and lysis means "to split." This glycolysis takes place in the cell's cytoplasm and does not need oxygen gas, so we call that an **anaerobic** process. These 2 three-carbon molecules break down further in the mitochondria to make many more molecules of ATP.



Where the Action Happens

The two parts involved in cellar respiration in the mitochondria are the matrix and the inner mitochondrial membrane.

(Stage 1) The **Krebs cycle** takes place in the interior space, or the matrix, of the mitochondria and is anaerobic.

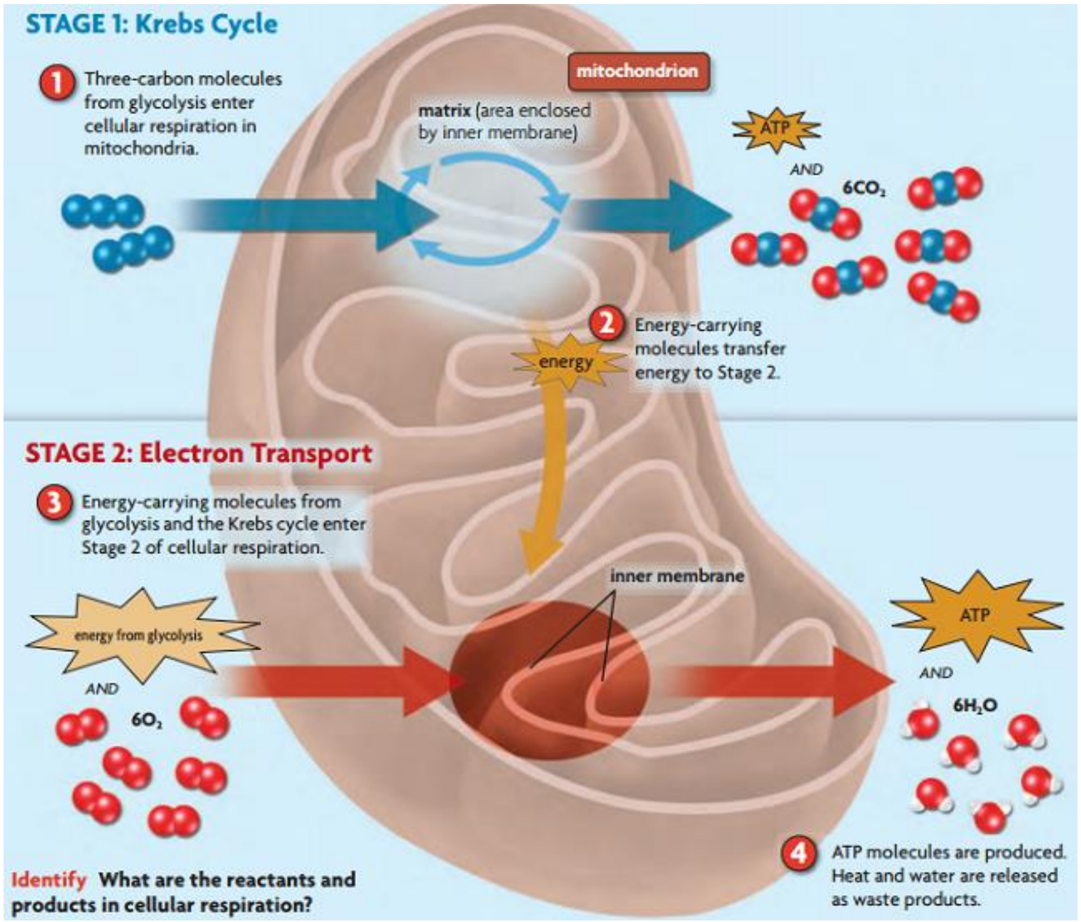
1. 2 moles of three-carbon molecules from glycolysis are broken down in a series of chemical reaction. A small number of ATP molecules (2 molecules) are made as well as six moles of carbon dioxide is given off as a waste product.
2. Energy is transferred to the second stage.

(Stage 2) Electron transport takes place in and across the inner mitochondrial membrane and is aerobic.

3. Energy is transferred to a chain of proteins.
4. Six moles of oxygen gas molecules are broken using the energy and six moles of water are formed along with a large number of ATP molecules (34 or 36 molecules).

Up to 38 molecules of ATP are formed from the breakdown of just one mole of glucose. The equation for cellular respiration is shown below but it again has many intermediate reactions including many enzymes.

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow \rightarrow \rightarrow \rightarrow 6\ CO_2 + 6\ H_2O$$

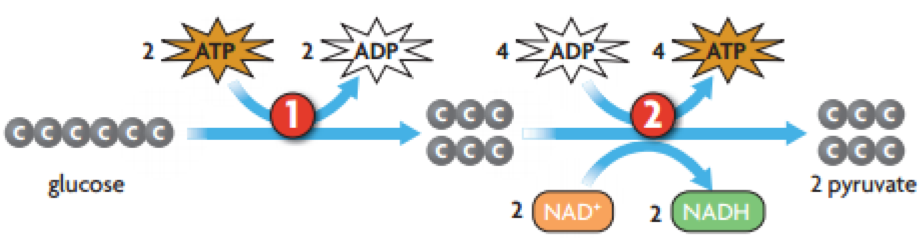


Glycolysis in Detail

Glycolysis is an ongoing process in all cells and takes place in the cytoplasm before cellular respiration. The process of glycolysis is as follows:

1. One mole of glucose (six-carbon sugar molecule) is broken by the energy provided by two moles of ATP. The glucose splits into 2 three-carbon molecules. A series of enzymes and chemical reactions rearrange the three-carbon molecules. The two moles of ATP produce two moles of ADP.
2. High energy electrons from the three-carbon molecules are transferred to two molecules of NAD^+ which form two molecules of NADH. A series of reactions change the 2 three-carbon molecules into 2 **pyruvate** molecules. In the process energy and phosphates are released to 4 ADP molecules to produce 4 molecules of ATP.

The net result of glycolysis is 2 pyruvate molecules, overall 2 ATP molecules, and 2 molecules of NADH (an electron carrier).

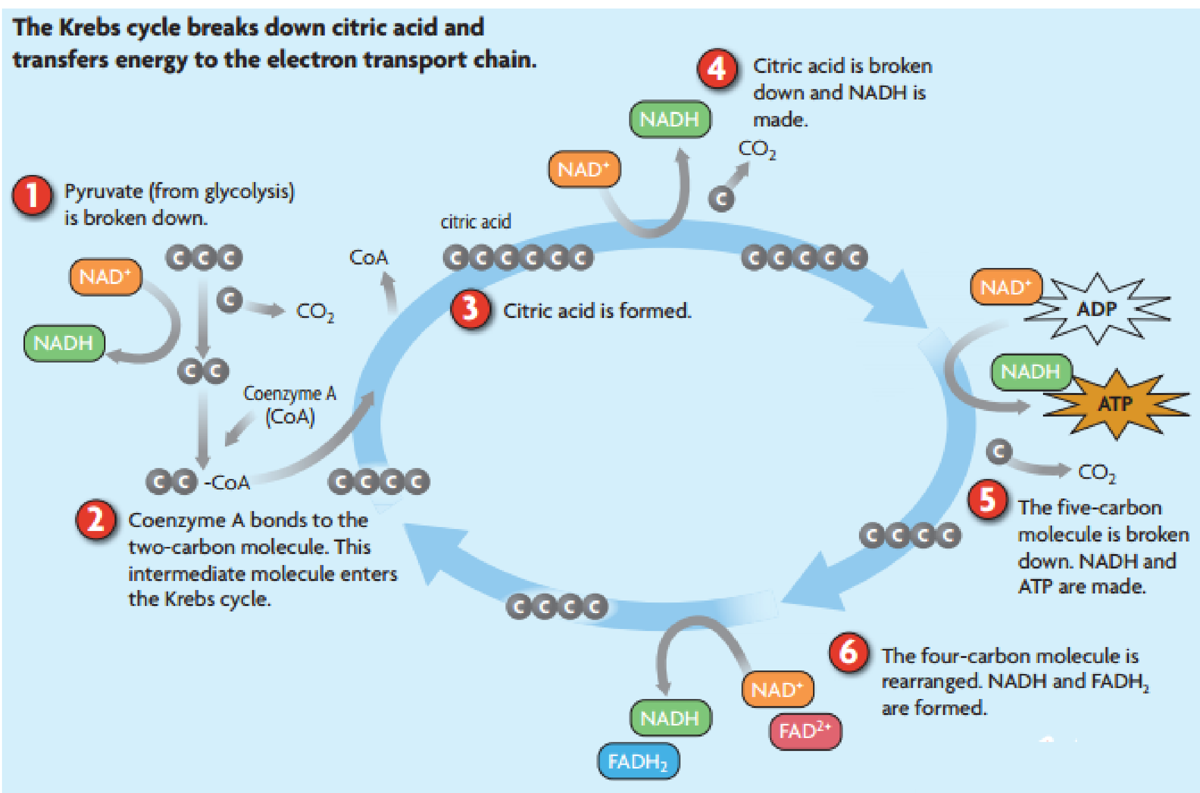


Krebs Cycle in Detail

The Krebs cycle or what is often called the citric acid cycle is the first main part of cellular respiration. The process is as follows:

1. A pyruvate molecule (three-carbon molecule) from glycolysis is broken down into a two-carbon molecule and a molecule of carbon dioxide. High-energy electrons are transferred from the two-carbon molecule to NAD^+ forming a molecule of NADH which in turn moves to the electron transport chain.
2. A molecule called coenzyme A or (CoA) bonds to the two-carbon molecule (this is often called **acetyl-CoA**).
3. Acetyl-CoA then moves into the Krebs cycle and adds to a four-carbon molecule. A six-carbon molecule called **citric acid** is now formed.
4. Citric acid (six-carbon molecule) is broken down by an enzyme into a five-carbon molecule and carbon dioxide. Another electron is transferred to a NAD^+ molecule to form an NADH molecule.
5. The five-carbon molecule is broken down by an enzyme into a four-carbon molecule and carbon dioxide. Another electron is transferred to a NAD^+ molecule to form an NADH molecule. ADP also reacts to form ATP in this step.
6. The four-carbon molecule is rearranged by enzymes. High-energy electrons are released and transferred to a NAD^+ molecule and FAD^+ molecule to form an NADH molecule and a $FADH_2$ molecule.

The net result of the Krebs cycle from two pyruvate molecules are six CO_2 molecules, two molecules of ATP, eight molecules of NADH to the electron transport chain, and two molecules of $FADH_2$ to the electron transport chain.



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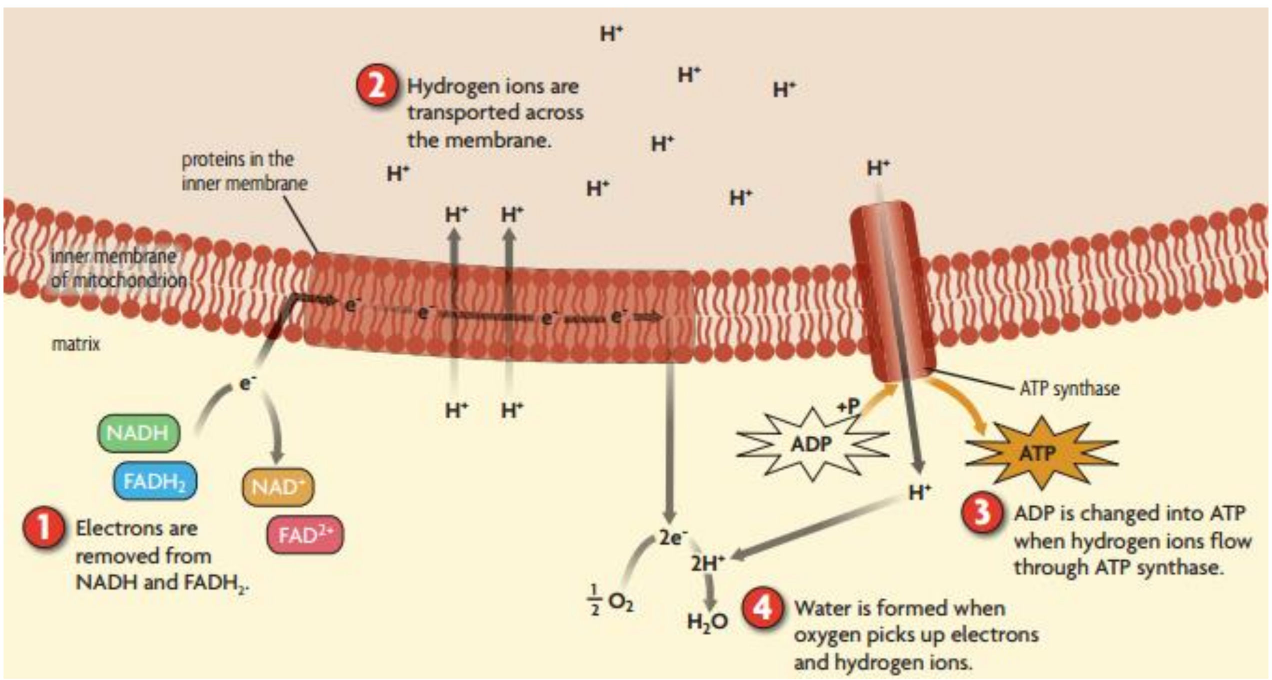
Electron Transport Chain in Detail

The electron transport chain is the second main part of cellular respiration. The process is as follows:

1. Proteins from the inner membrane of the mitochondria remove the high-energy electrons from NADH and $FADH_2$. NAD^+ and FAD^{2+} molecules are produced.
2. The high-energy electrons move through the proteins in the **electron transport chain**. The proteins use the energy to pump **hydrogen ions (H^+)** across the inner membrane to produce a gradient.
3. Hydrogen ions diffuse through a protein channel which is part of the **ATP synthase enzyme** in the inner membrane of the mitochondria. ATP synthase adds phosphate groups to ADP to make **ATP molecules**. Each pair of electrons that pass through the chain produces three ATP molecules.
4. **Oxygen gas molecules** finally enter in the process and reacts with the electrons and hydrogen ions to form water.

The net result of the electron transport chain is six water molecules and up to 34 ATP molecules.



PHOTOSYNTHESIS AND CELLULAR RESPIRATION		
	PHOTOSYNTHESIS	CELLULAR RESPIRATION
Organelle for process	chloroplast	mitochondrion
Reactants	CO_2 and H_2O	sugars ($C_6H_{12}O_6$) and O_2
Electron transport chain	proteins within thylakoid membrane	proteins within inner mitochondrial membrane
Cycle of chemical reactions	Calvin cycle in stroma of chloroplasts builds sugar molecules	Krebs cycle in matrix of mitochondria breaks down carbon-based molecules
Products	sugars ($C_6H_{12}O_6$) and O_2	CO_2 and H_2O