9-2 The Krebs Cycle and Electron Transport

Oxygen is required for the final steps of cellular respiration.
Because the pathways of cellular respiration require oxygen, they are **aerobic**.

The Krebs Cycle

In the presence of oxygen, pyruvic acid produced in glycolysis passes to the second stage of cellular respiration, the **Krebs cycle**.
During the Krebs cycle, pyruvic acid is broken down into carbon dioxide in a series of energy-extracting reactions.
The Krebs cycle begins when pyruvic acid produced by glycolysis enters the mitochondrion.
One carbon molecule is removed, forming CO2, and electrons are removed, changing NAD+ to NADH.
Coenzyme A joins the 2-carbon molecule, forming acetyl-CoA.
Acetyl-CoA then adds the 2-carbon acetyl group to a 4-carbon compound, forming citric acid.
Citric acid is broken down into a 5-carbon compound, then into a 4-carbon compound.
Two more molecules of CO2 are released and electrons join NAD+ and FAD, forming NADH and FADH2
In addition, one molecule of ATP is generated.
The energy tally from 1 molecule of pyruvic acid is

- 4 NADH
- 1 FADH2
- 1 ATP

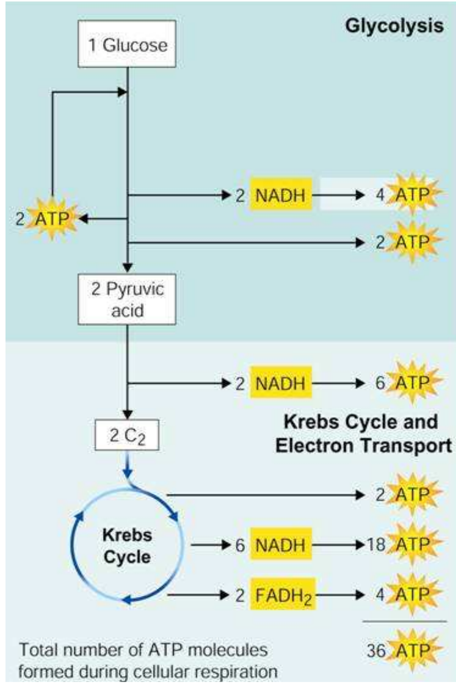
What does the cell do with all those high-energy electrons in carriers like NADH?
In the presence of oxygen, those high-energy electrons can be used to generate huge amounts of ATP.

Electron Transport

The electron transport chain uses the high-energy electrons from the Krebs cycle to convert ADP into ATP.
High-energy electrons from NADH and FADH2 are passed along the electron transport chain from one carrier protein to the next.
At the end of the chain, an enzyme combines these electrons with hydrogen ions and oxygen to form water.
As the final electron acceptor of the electron transport chain, oxygen gets rid of the low-energy electrons and hydrogen ions.
When 2 high-energy electrons move down the electron transport chain, their energy is used to move hydrogen ions (H+) across the membrane.
During electron transport, H+ ions build up in the intermembrane space, so it is positively charged.
The other side of the membrane, from which those H+ ions are taken, is now negatively charged.
The inner membranes of the mitochondria contain protein spheres called ATP synthases.
As H+ ions escape through channels into these proteins, the ATP synthase spins.
As it rotates, the enzyme grabs a low-energy ADP, attaching a phosphate, forming high-energy ATP.
On average, each pair of high-energy electrons that moves down the electron transport chain provides enough energy to produce three molecules of ATP from ADP.

The Totals

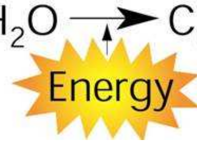
Glycolysis produces just 2 ATP molecules per molecule of glucose.
The complete breakdown of glucose through cellular respiration, including glycolysis, results in the production of 36 molecules of ATP.



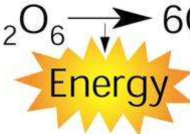
Comparing Photosynthesis and Cellular Respiration

The energy flows in photosynthesis and cellular respiration take place in opposite directions.

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



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



On a global level, photosynthesis and cellular respiration are also opposites.

- Photosynthesis removes carbon dioxide from the atmosphere and cellular respiration puts it back.
- Photosynthesis releases oxygen into the atmosphere and cellular respiration uses that oxygen to release energy from food.