Chapter 9 - Cellular Respiration

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Food provides living things with the chemical building blocks they need to grow and reproduce. Most importantly, food serves as a source of energy.

Overview of Cellular Respiration

Cellular respiration is the process that releases energy by breaking down glucose and other food molecules in the presence of oxygen. It occurs in both ***prokaryotic*** and ***eukaryotic*** cells.

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Word Equation

oxygen + glucose ⟶ carbon dioxide + water + energy

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Balanced Chemical Equation

$$6O_2 + C_6H_{12}O_6 \longrightarrow 6CO_2 + 6\,H_2O + \text{energy}$$

** Respiration does **not** take place in one step. The energy in food must be released a little bit at a time.

Glycolysis - Page 223

Greek: *glukus* -> sweet
Latin: *lysis* -> process of decomposing

glycolysis -> "breaking glucose"

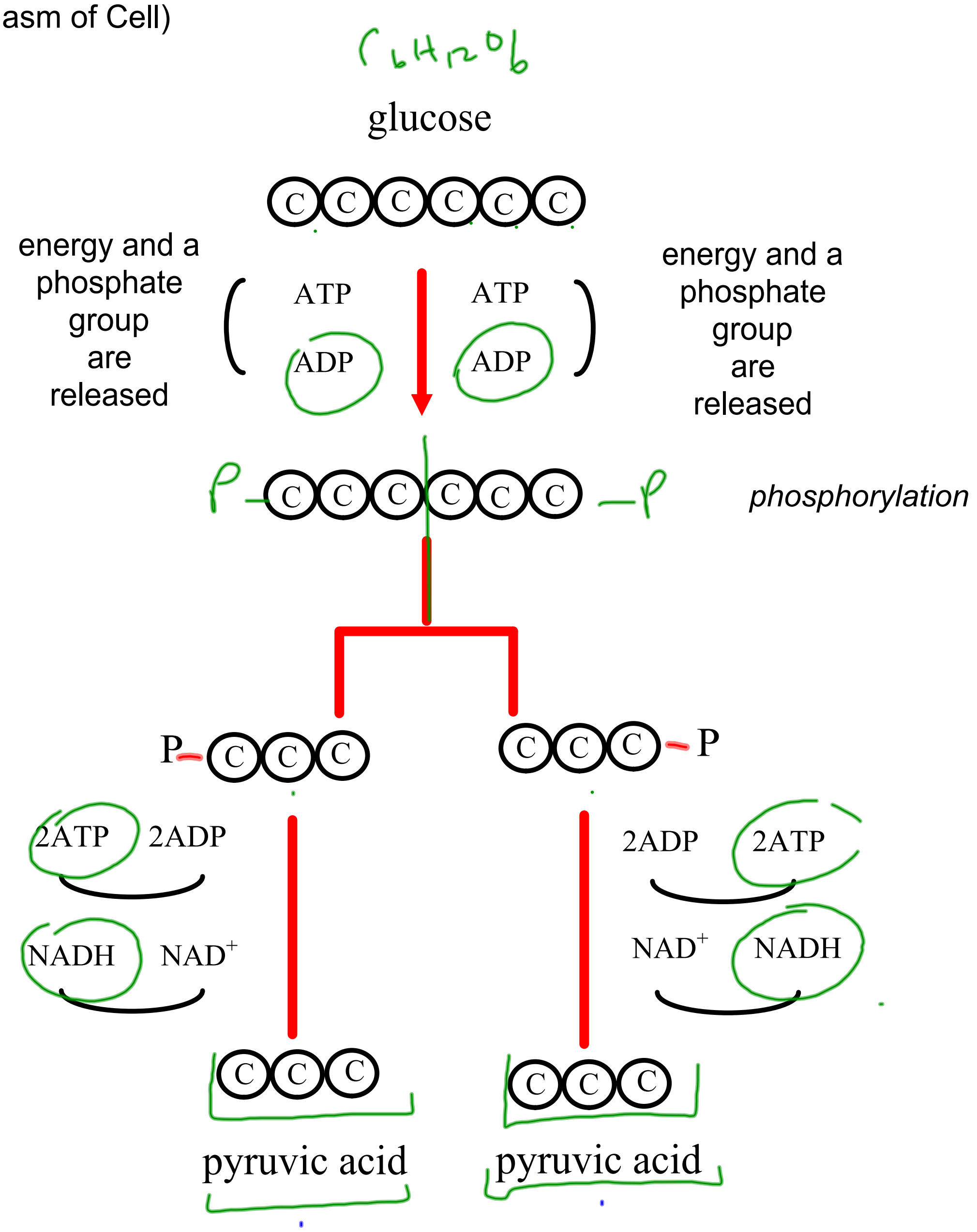
pyruvate

Glycolysis is the first set of reactions in cellular respiration and is a fast, energy-releasing process in which one molecule of glucose is broken in half, producing two molecules of pyruvic acid (a 3-carbon compound). Glycolysis takes place in the cytoplasm of the cell.

NAD^+ (nicotinamide adenine nucleotide) is an electron carrier involved in glycolysis. NAD^+ can accept a pair of high-energy electrons and a H^+ to form NADH which holds the electrons until they can be transferred to other molecules.

hydrogen ion

Glycolysis - Page 223
(Cyotoplasm of Cell)



Products: 2 ATP
2 NADH
2 pyruvic acid

http://biology.about.com/od/cellularprocesses/a/aa082704a.htm

The energy yield from glycolysis is small, but very fast. Since glycolysis does not require oxygen, this process can supply chemical energy to cells when oxygen is not available.

When NAD^+ molecules are filled up with electrons, ATP production stops.

Fermentation - Page 224

When oxygen is not present, glycolysis is followed by a particular chemical pathway. The combination of glycolysis and this pathway is called fermentation. This process releases energy from food molecules by producing ATP in the absence of oxygen.

Fermentation does not require oxygen so it is said to be anaerobic which means "not in air".

There are two main types of fermentation: alcoholic fermentation and lactic acid fermentation.

Alcoholic Fermentation

pyruvic acid + NADH ⟶ ______ + ______ + ______

The production of NAD^+ allows glycolysis to continue.

This type of fermentation causes bread to rise. When yeast in dough runs out of oxygen, it begins to ferment, giving off bubbles of carbon dioxide that form the air spaces you see in bread. The small amount of alcohol produced in the dough evaporates when the bread is baked.

Lactic Acid Fermentation

pyruvic acid + NADH ⟶ ______ + ______

The production of NAD^+ allows glycolysis to continue.

Lactic acid is produced in your muscles during rapid exercise when the body cannot supply enough oxygen to the tissues. Your muscle cells rapidly begin to produce ATP by lactic acid fermentation. The build-up of lactic acid causes a painful, burning sensation. This is why muscles may feel sore after only a few seconds of intense activity.

Some unicellular organisms produce lactic acid as a waste product. Prokaryotes are used in the production of cheese, yogurt, buttermilk, sour cream, pickles and sauerkraut (fermented cabbage).

At the end of glycolysis, 90% of the chemical energy stored in glucose is still unused, locked in the high-energy electrons of pyruvic acid.

Oxygen, the most powerful electron acceptor, is required for the final steps of cellular respiration. Because the next pathways require oxygen they are said to be aerobic meaning "in air".

The Krebs Cycle - Page 226

In the presence of oxygen, pyruvic acid produced in glycolysis passes to the second stage of cellular respiration, Krebs cycle (named for British biochemist Hans Krebs).

The Krebs cycle begins when pyruvic acid enters the mitochondria.

Mitochondria Structural Features

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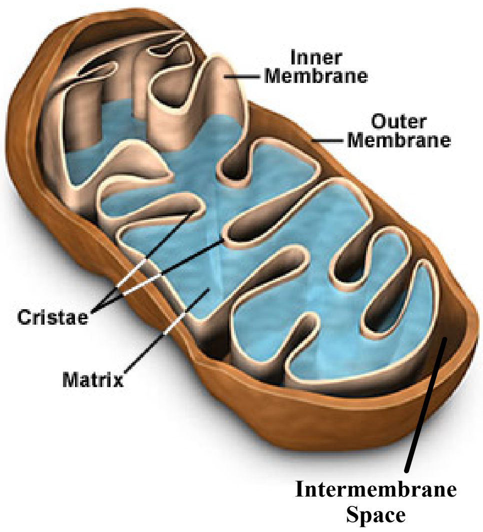

*two membranes
smooth outer membrane
folding inner membrane

cristae - fingerlike projections of the inner membrane
- increase surface area
- there are enzymes on the cristae that assist in the breakdown of sugar molecules in the mitochondrion

matrix - fluid inside the mitochondrion
- contains enzymes responsible for Krebs cycle reactions

During the Krebs cycle, pyruvic acid is broken down into carbon dioxide in a series of ***energy-extracting reactions*** that occur in the matrix of a mitochondrion.

Because the first compound formed in this series of reactions is citric acid, the Krebs cycle is also known as the citric acid cycle.

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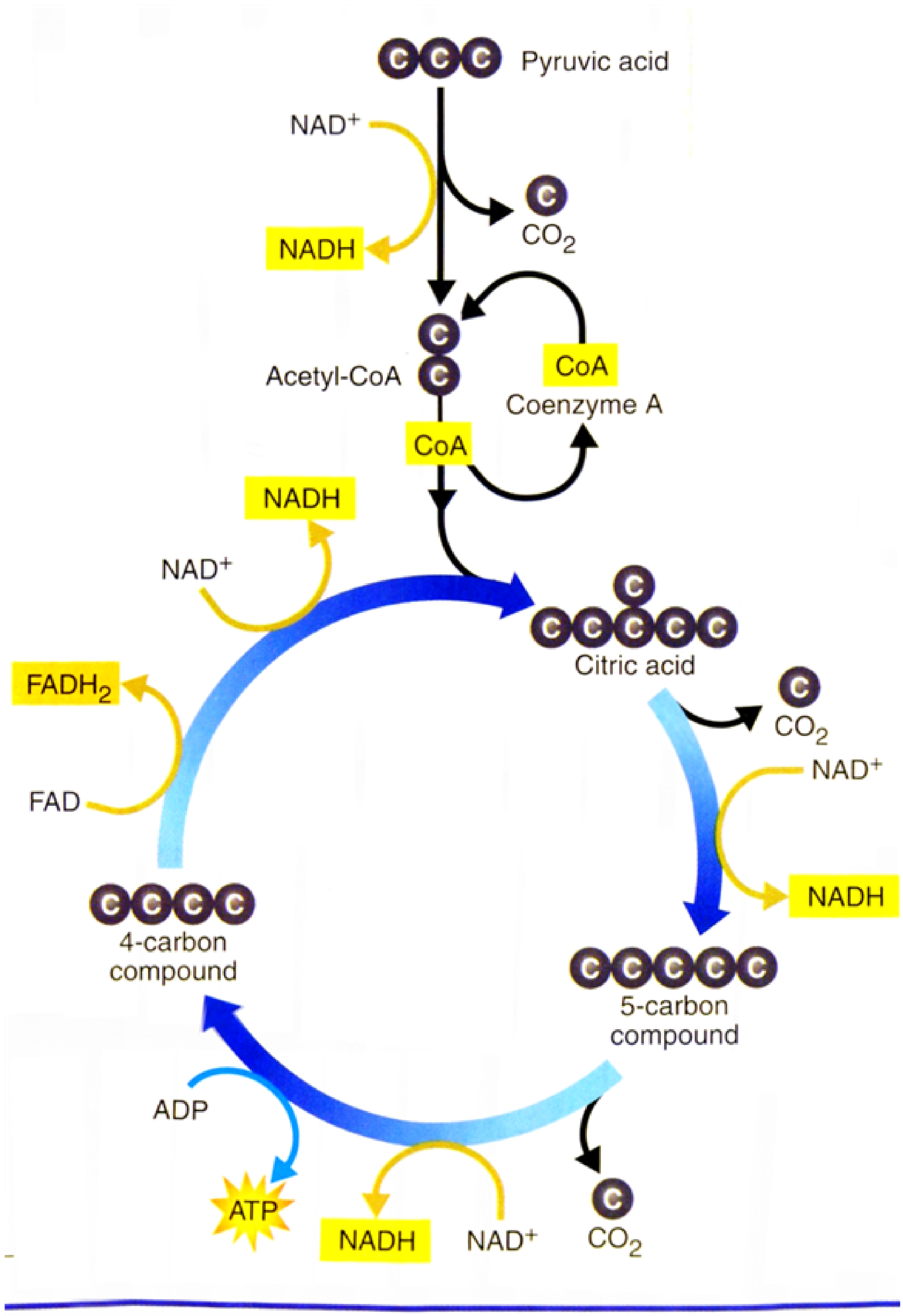
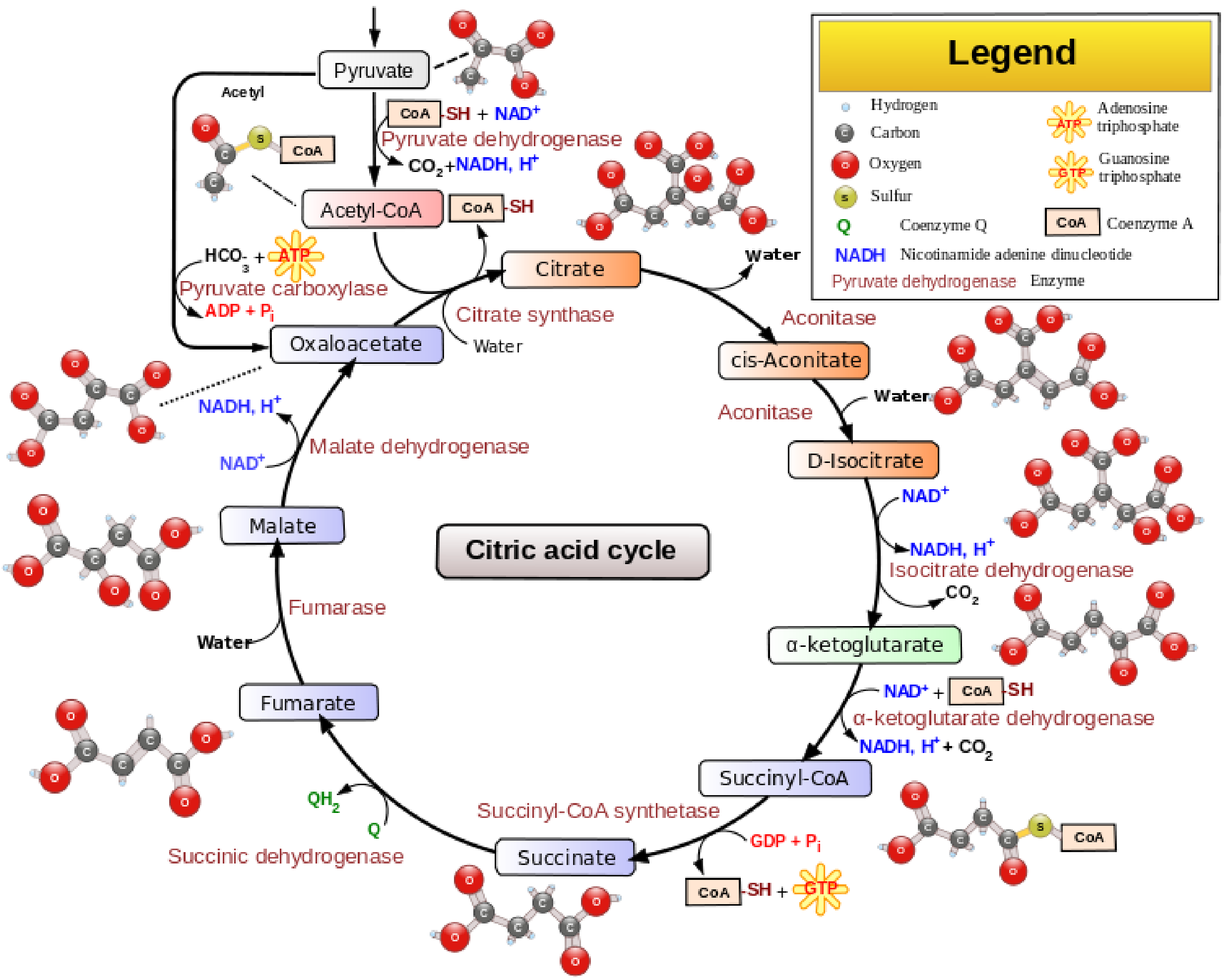
Krebs Cycle - Page 227
(Matrix of Mitochondria)



Products: __4__ NADH
__1__ $FADH_2$
__1__ ATP

} store energy

--__3__ CO_2


Legend
Hydrogen
Carbon
Oxygen
Sulfur
Q Coenzyme Q
NADH Nicotinamide adenine dinucleotide
Pyruvate dehydrogenase Enzyme
ATP Adenosine triphosphate
GTP Guanosine triphosphate
CoA Coenzyme A
Pyruvate
Acetyl
CoA-SH + NAD+
Pyruvate dehydrogenase
CO2 + NADH, H+
Acetyl-CoA
CoA-SH
Citrate
Water
HCO3- + ATP
Pyruvate carboxylase
ADP + Pi
Oxaloacetate
Citrate synthase
Water
Aconitase
cis-Aconitate
Water
Aconitase
D-Isocitrate
NAD+
NADH, H+
Isocitrate dehydrogenase
CO2
α-ketoglutarate
NAD+ + CoA-SH
α-ketoglutarate dehydrogenase
NADH, H+ + CO2
Succinyl-CoA
Succinyl-CoA synthetase
GDP + Pi
CoA-SH + GTP
Succinate
Succinic dehydrogenase
QH2
Q
Fumarate
Fumarase
Water
Malate
Malate dehydrogenase
NAD+
NADH, H+
Citric acid cycle

The ATP directly produced from the Krebs cycle can be used for cellular activities.

What happens to the high-energy electrons stored in NADH and $FADH_2$?

Electron Transport - Figure 9-7
(Page 228)

The third stage of cellular respiration takes place within the inner mitochondrial membrane.

The electron transport chain uses the high-energy electrons from the Krebs cycle to convert ADP into ATP.

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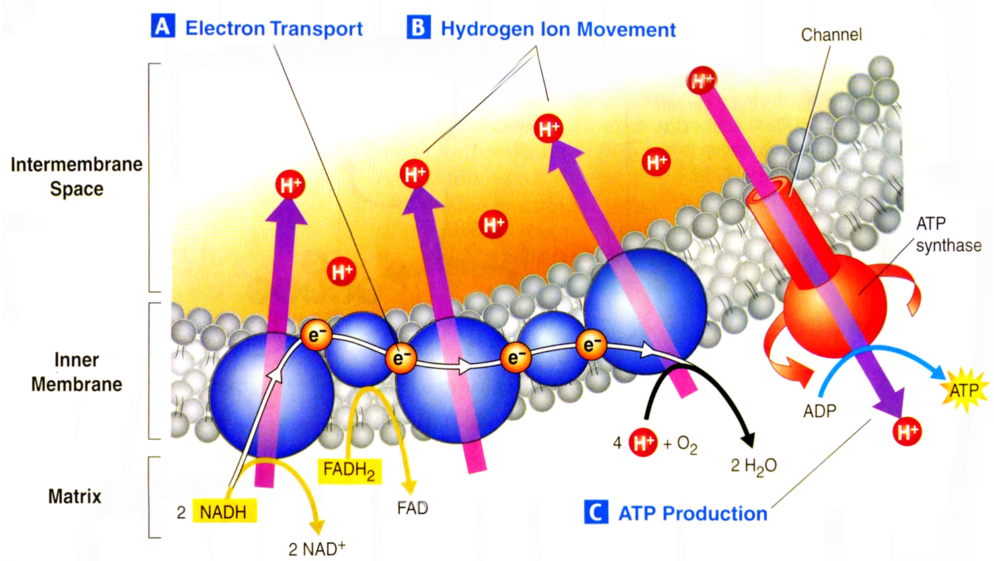
High-energy electrons from NADH and $FADH_2$ are passed along the electron transport chain. At the end of the chain is an enzyme that combines these electrons with hydrogen ions and oxygen to form water. ***Oxygen*** is the final electron acceptor of the electron transport chain.

Every time 2 high-energy electrons transport down the electron transport chain, their energy is used to transport hydrogen ions across the membrane into the intermembrane space making it positively charged. The other side of the membrane becomes negatively charged.

H^+ ions escape from the intermembrane space through channels in ATP synthase. ATP synthase spins. Each time it does, it grabs a low-energy ADP and attaches a phosphate forming high-energy ATP.



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Cellular Respiration - ATP Production

Glycolysis	2 ATP per glucose molecule
Krebs Cycle + Electron Transport	34 ATP per glucose molecule
Total	36 ATP per glucose molecule

Comparing Photosynthesis and Cellular Respiration

Figure 9-10

(Page 232)

	Photosynthesis	Cellular Respiration
Function	Energy capture	Energy release
Location	Chloroplasts	Mitochondria
Reactants	CO_2 and H_2O	$C_6H_{12}O_6$ and O_2
Products	$C_6H_{12}O_6$ and O_2	CO_2 and H_2O
Equation	$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ (↑ Energy)	$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ (↓ Energy)