Using Chemical Energy

One way that organisms maintain homeostasis is through cellular respiration, which releases energy to carry out cell processes and helps maintain body temperature. Bonds in food molecules and oxygen molecules are broken and new molecules are formed that transfer energy in forms that the organism can use. Cellular respiration transfers chemical energy stored in the bonds of glucose and other molecules to ATP.

Analyze Identify the inputs and outputs of glycolysis and the two stages of cellular respiration.

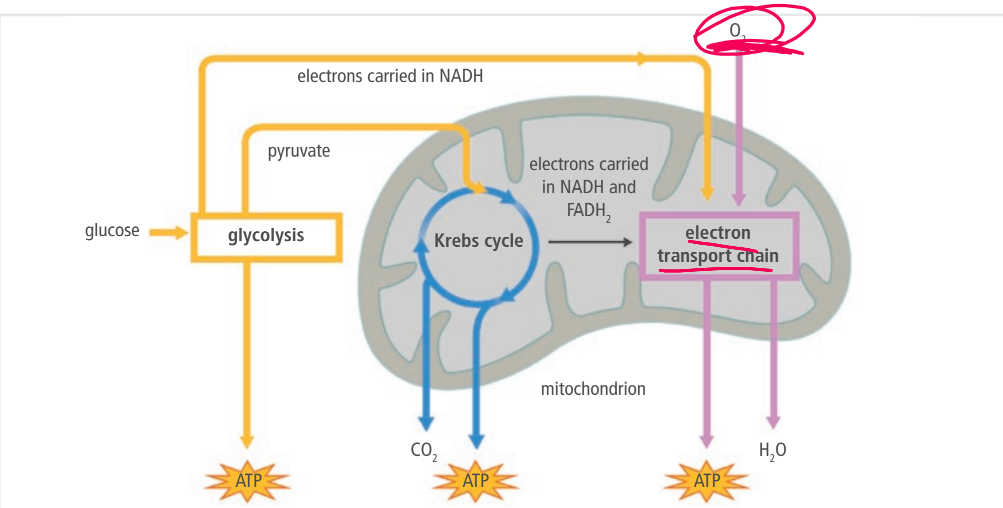


FIGURE 8: The process of glycolysis occurs before the two main stages of cellular respiration: the Krebs cycle and the electron transport chain.

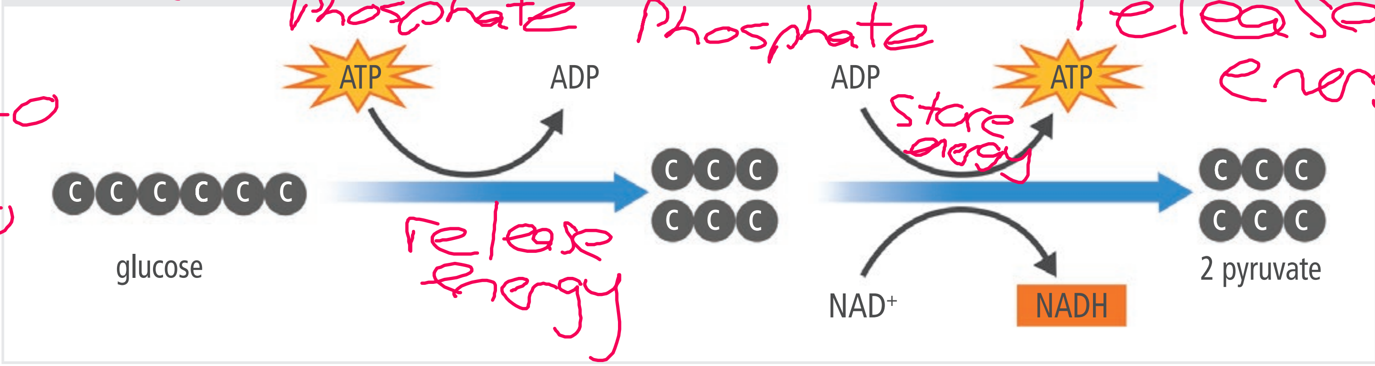
Glycolysis and the Stages of Cellular Respiration

Bonds store energy

Cellular respiration occurs in mitochondria. Before it can take place, however, glucose must be broken down into compounds the mitochondria can use. This process occurs in the cytoplasm of the cell. Glycolysis, shown in Figure 9, is an anaerobic process that uses a series of enzyme-catalyzed reactions to break glucose into two three-carbon molecules, called pyruvate. Mitochondria use the pyruvate molecules to fuel cellular respiration.

Adenosine Tri(3) Phosphate Adenosine Di(2) Phosphate Break bonds releases energy

FIGURE 9: Glycolysis



PO4

store energy

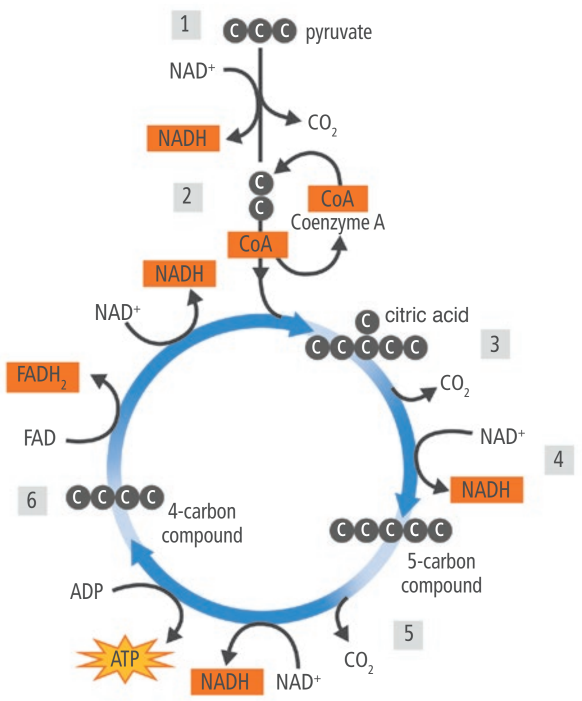
release energy

Gather Evidence Summarize evidence that bonds are broken and new bonds are formed in glycolysis.

Krebs Cycle

The Krebs cycle, sometimes called the citric acid cycle, is the first set of reactions in cellular respiration. The function of the Krebs cycle is to complete the breakdown of glucose started in glycolysis and fuel the production of ATP. This is done by transferring high-energy electrons to the electron transport chain.

FIGURE 10: The Krebs Cycle



The Krebs cycle is summarized in the steps below.

1. **Pyruvate is broken down** A 3-carbon pyruvate molecule is split into a 2-carbon molecule and a carbon dioxide molecule, which is given off as waste. High-energy electrons are transferred to NAD^+, forming a molecule of NADH. The NADH moves to the second stage of cellular respiration, the electron transport chain.
2. **Coenzyme A is added** A molecule called coenzyme A bonds to the 2-carbon molecule, forming an intermediate molecule.
3. **Citric acid is formed** The 2-carbon part of the intermediate molecule is added to a 4-carbon molecule to form the 6-carbon molecule called citric acid.
4. **Citric acid is broken down** The citric acid molecule is broken down by an enzyme, and a 5-carbon molecule is formed. A molecule of NADH is made, which moves out of the Krebs cycle. A molecule of carbon dioxide is given off as a waste product.
5. **Five-carbon molecule is broken down** The 5-carbon molecule is broken down by an enzyme. A 4-carbon molecule, a molecule of NADH, and one ATP are formed. Carbon dioxide is given off as a waste product.
6. **Four-carbon molecule is rearranged** Enzymes rearrange the 4-carbon molecule, releasing high-energy electrons. Molecules of NADH and $FADH_2$, another electron carrier, are made. They leave the Krebs cycle, and the 4-carbon molecule remains.

Analyze How is the Krebs cycle a bridge between the energy in sugars and energy-carrying molecules?

Explain During the hands-on lab, which product of the Krebs cycle caused the bromothymol blue solution to change color?

The Krebs cycle is a continual series of reactions. All the carbon atoms in glucose eventually end up as carbon dioxide, a waste product expelled from the cell. The role of the electron carriers NADH and $FADH_2$ is to transfer electrons to the electron transport chain in the next stage of respiration. The transferred electrons will fuel the formation of ATP.

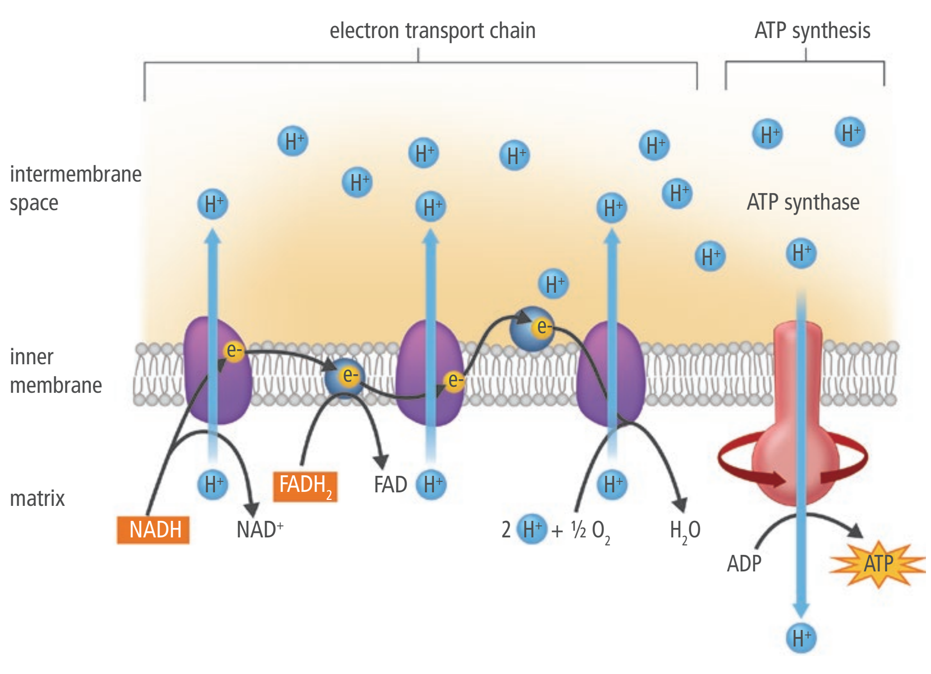
The Electron Transport Chain

The second stage of cellular respiration, the electron transport chain, uses proteins embedded in the inner membrane of the mitochondrion. It is similar to the electron transport chain stage of photosynthesis. The energy carried by the NADH and $FADH_2$ molecules produced in the Krebs cycle is used to make ATP. A number of enzymes are involved in this process.

Model Make a simple flow chart to summarize the energy transfer from energy-carrying molecules to ATP.

FIGURE 11: The Electron Transport Chain

Explore Online



The electron transport chain is summarized in the steps below.

1. **Electrons are transferred** Proteins inside the inner membrane of the mitochondrion take high-energy electrons from NADH and $FADH_2$.
2. **Hydrogen ions are transported** High-energy electrons travel from protein to protein in the electron transport chain. The proteins use energy from the electrons to pump hydrogen ions across the inner membrane to produce a gradient, just as in photosynthesis. The hydrogen ions build up in the intermembrane space.
3. **ATP is produced** Like in photosynthesis, the flow of hydrogen ions is used to make ATP. Hydrogen ions diffuse through a protein channel in the inner membrane of the mitochondrion. The channel is part of the ATP synthase enzyme. ATP synthase adds phosphate groups to ADP to make ATP molecules.
4. **Water is formed** Oxygen picks up electrons and hydrogen ions to form water. The water molecules are given off as a waste product.

Together, glycolysis and cellular respiration produce up to 38 ATP molecules for every glucose molecule.

Collaborate With a partner, discuss how the electron transport chain depends on the Krebs cycle. Consider the role of energy in your discussion.

Fermentation

The cells in your body cannot store large amounts of oxygen for cellular respiration. The amount of oxygen that is provided by breathing is enough for your cells during normal activities. When you are doing high levels of activity, such as playing a game of basketball as shown in Figure 12, your body cannot bring in enough oxygen for your cells, even though you breathe faster. How do your cells function without oxygen to keep cellular respiration going?

The production of ATP without oxygen continues through the anaerobic processes of glycolysis and fermentation. Fermentation does not make ATP, but it allows glycolysis to continue. Fermentation removes electrons from NADH molecules and recycles NAD^+ molecules for glycolysis. Why is this process important? Because glycolysis, just like cellular respiration, needs a molecule that picks up electrons. It needs molecules of NAD^+.

The role of fermentation is simply to provide the process of glycolysis with a steady supply of NAD^+. If you've ever felt your muscles "burn" during hard exercise, that is a result of fermentation. Lactic acid is a waste product of fermentation that builds up in muscle cells and causes that burning feeling. Once oxygen is available again, your cells return to using cellular respiration. The lactic acid is quickly broken down and removed from the cells.

Analyze What is the role of anaerobic respiration in organisms? What is the role in ecosystems?

FIGURE 12: During strenuous or prolonged activity, athletes may not be able to sustain the oxygen levels their bodies need. If not enough oxygen is supplied to the cells, anaerobic respiration takes over.

FIGURE 13: Bifidobacteria live in the digestive tracts of animals, including humans.

Not all organisms rely on oxygen for respiration. Organisms that use anaerobic respiration have an important role in an ecosystem, because they can live in places where most other organisms cannot. For example, microorganisms, such as the bifidobacteria shown in Figure 13, live in the digestive tracts of animals and help in the process of digestion. They must get their ATP from anaerobic processes because oxygen is not available.

Explain Summarize the evidence that you have gathered to explain how molecules are rearranged and energy is transferred in the process of cellular respiration.

1. Cite evidence to support the claim that bonds are broken and new bonds are formed in each stage of cellular respiration.
2. Explain how energy is transferred from the bonds of food molecules to cellular processes.