Name______________________________ Class__________________ Date ______________

Summary

9–1 Chemical Pathways

Food serves as the source of energy for cells. Quite a lot of energy is stored in food. For instance, 1 gram of the sugar glucose releases 3811 calories of heat energy when burned in the presence of oxygen. A calorie is the amount of energy needed to raise the temperature of 1 gram of water 1 degree Celsius. Cells don't burn glucose and other food compounds. They gradually release the energy. The process begins with a pathway called glycolysis. In the presence of oxygen, glycolysis is followed by the Krebs cycle and the electron transport chain. Together, these three pathways make up cellular respiration. Cellular respiration is the process that releases energy by breaking down glucose and other food molecules in the presence of oxygen. The equation for cellular respiration is:

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

$$\text{oxygen} + \text{glucose} \rightarrow \text{carbon dioxide} + \text{water} + \text{energy}$$

There are three main stages of cellular respiration: (1) glycolysis, (2) the Krebs cycle, and (3) electron transport.

Glycolysis is the process in which one molecule of glucose is broken in half, producing two molecules of pyruvic acid, a 3-carbon compound. Through glycolysis, the cell gains 2 ATP molecules. In one of the reactions of glycolysis, the electron carrier NAD^+ accepts a pair of high-energy electrons, producing NADH. By doing this, NAD^+ helps pass energy from glucose to other pathways in the cell.

When oxygen is not present, glycolysis is followed by another pathway. This pathway is called fermentation. Fermentation releases energy from food molecules by producing ATP. Because fermentation does not require oxygen, it is said to be anaerobic. During fermentation, cells convert NADH back into the electron carrier NAD^+, which is needed for glycolysis. This action allows glycolysis to continue producing a steady supply of ATP. The two main types of fermentation are alcoholic fermentation and lactic acid fermentation. Yeasts and a few other microorganisms carry out alcoholic fermentation. The equation for alcoholic fermentation after glycolysis is:

$$\text{pyruvic acid} + \text{NADH} \rightarrow \text{alcohol} + CO_2 + NAD^+$$

Lactic acid fermentation occurs in your muscles during rapid exercise. The equation for lactic acid fermentation after glycolysis is:

$$\text{pyruvic acid} + \text{NADH} \rightarrow \text{lactic acid} + NAD^+$$

9–2 The Krebs Cycle and Electron Transport

When oxygen is available, glycolysis is followed by the Krebs cycle and the electron transport chain. The three pathways together make up the process of cellular respiration. Because the pathways of cellular respiration require oxygen, they are said to be aerobic.

The Krebs cycle is the second stage of cellular respiration. In eukaryotes, the Krebs cycle takes place in the mitochondrion. During the Krebs cycle, pyruvic acid is broken down into carbon dioxide in a series of energy-extracting reactions. The Krebs cycle is also known as the citric acid cycle, because citric acid is one of the first products. The Krebs cycle begins when pyruvic acid produced by glycolysis enters the mitochondrion. One carbon atom from pyruvic acid becomes part of a molecule of carbon dioxide, which is eventually released into the air. The carbon dioxide released during the Krebs cycle is the source of much of the carbon dioxide in air.

The other two carbon atoms from pyruvic acid are used in a series of reactions. During these reactions, two energy carriers accept high-energy electrons. NAD^+ is changed to NADH, and FAD is changed to $FADH_2$. These molecules carry the high-energy electrons to the electron transport chain.

Electron transport is the third stage of cellular respiration. The electron transport chain uses the high-energy electrons from the Krebs cycle to convert ADP into ATP. In eukaryotes, the electron transport chain is composed of a series of carrier proteins located in the inner membrane of the mitochondrion. In prokaryotes, the same chain is in the cell membrane. In this pathway, high-energy electrons move from one carrier protein to the next. Their energy is used to move hydrogen ions across the membrane through a protein sphere called ATP synthase. Each time an ATP synthase spins, a phosphate group is added to an ADP molecule, producing an ATP molecule.

In the absence of oxygen, all the energy that a cell can extract from a single molecule of glucose is 2 ATP molecules—the product of glycolysis.

In the presence of oxygen, though, the cell can extract many more ATP molecules. The Krebs cycle and the electron transport chain enable the cell to produce 34 more ATP molecules per glucose molecule. The total, then, for cellular respiration—glycolysis plus the Krebs cycle plus electron transport—is 36 ATP molecules per glucose molecule.

Human body cells normally contain small amounts of ATP produced during cellular respiration. When the body needs energy in a hurry, muscle cells produce ATP by lactic acid fermentation. For long-term energy needs, the body must use cellular respiration.

The energy flows in photosynthesis and cellular respiration take place in opposite directions. On a global level, photosynthesis and cellular respiration are also opposites. Photosynthesis removes carbon dioxide from the atmosphere and puts back oxygen. Cellular respiration removes oxygen from the atmosphere and puts back carbon dioxide.