Instructor’s Answer Key

Chapter 5: Cell Respiration and Metabolism

Answers to Test Your Understanding of Concepts and Principles

1. The primary advantage of anaerobic respiration is that it serves as a source of new ATP formation at times when there is not an adequate supply of oxygen available to sustain aerobic respiration. Without a constant generation of at least a minimal number of ATP (a net gain of two ATP molecules per glucose molecule) a cell would die. For example, red blood cells (RBCs) have no mitochondria and are responsible for the delivery of oxygen to other cells. The RBCs however, only use the lactic acid pathway (anaerobic) and thus spare the oxygen molecules they carry. Skeletal muscle that is deprived of blood and oxygen is also adapted to survive for a limited period of time anaerobically. The disadvantages of anaerobic respiration are that it supplies less ATP per glucose molecule (or per other fuel source molecule such as protein or fat) than is the case with aerobic respiration. Another disadvantage is that it produces lactic acid as a final product. Accumulation of lactic acid can cause a lowering of pH that has a number of undesirable side effects (such as the promotion of muscle pain and fatigue). [Note: This question is also answered in the Student Study Guide.]

2. The reduction of pyruvic acid to lactic acid in anaerobic respiration is accomplished with the oxidation of NADH to NAD and yields a net gain of two ATP molecules per glucose molecule. In this way lactic acid serves as the last electron acceptor in this pathway. This oxidation of NADH is required for the continuation of glucose metabolism (anaerobic respiration or lactic acid fermentation). During aerobic respiration however, the oxidation of NAD is achieved in the mitochondrion when the electrons from NADH are transferred to the electron-transport chain and ultimately to oxygen as the last electron acceptor in the formation of water.

3. By blocking the transfer of electrons from the last cytochrome to oxygen, cyanide causes the last cytochrome to remain in a reduced state. Since it is in a reduced state, it is unable to accept more electrons from the next-to-last cytochrome, so the latter must also remain in a reduced state. This ultimately results in the fact that all of the cytochromes in the electron-transport chain remain reduced, and electron transport ceases. Production of ATP by oxidative phosphorylation thus stops, and the Krebs cycle stops as a result of the accumulation of reduced NAD (which cannot become oxidized by donating their electrons to the cytochromes). Cyanide is deadly because it blocks oxidative phosphorylation and by this means results in the depletion of cellular ATP.

4. In the process of glycolysis and aerobic respiration, glucose is converted into phosphoglyceraldehyde (3C) and then into acetyl CoA (2C). The phosphoglyceraldehyde can be converted to glycerol; and the acetyl CoA can serve as substrates for the formation of fatty acids. Condensation of three fatty acids with glycerol yields triglycerides (fats). If glucose is plentiful, so that ATP concentration within an adipose cell is high, the reactions of the Krebs cycle are inhibited by allosteric interactions between ATP and key Krebs cycle enzymes. This results in the accumulation of the intermediates of glycolysis

and of acetyl CoA that provides more substrates favoring the conversion of phosphoglyceraldehyde and acetyl CoA into triglycerides.

5. Enzymes can hydrolyze triglycerides into glycerol and fatty acids. The glycerol can be changed to 2,3-diphosphoglyceraldehyde, which is an intermediate of glycolysis (essentially the reverse of the answer to question 4). Beta-oxidation converts fatty acids into acetyl CoA. These acetyl CoA units can enter the Krebs cycle in the same manner as does the acetyl CoA derived from pyruvic acid. However, since each triglyceride molecule has three fatty acids and each fatty acid molecule can yield 20 or 22 acetyl CoA molecules, the beta-oxidation of a triglyceride can yield hundreds of ATP when compared to the 30 ATP produced by the glycolysis of glucose. With fat metabolism more Krebs cycles are thus generated, leading to more reduced NAD and FAD formation and more oxidative phosphorylation of ATP.

6. Amino acids can undergo oxidative deamination to form ketone acid products, including pyruvic acid and certain Krebs cycle acid intermediates. These products contribute substrates that can enter the pathways of cell respiration and in this way result in the increased production of ATP by oxidative phosphorylation. The oxidative deamination of amino acids also yields the amino group that can be used by the liver as substrate in the formation of urea (urea cycle). Since starving people rely increasingly on the breakdown of proteins and amino acids for energy, they will have a corresponding increase in urea production and release into the blood.

7. The liver is the only organ that contains the enzyme glucose 6-phosphatase, which can remove the phosphate group from glucose 6-phosphate and produce free glucose for release from hepatocytes. Since all glucose formed within a cell by glycogenolysis and gluconeogenesis has a phosphate group attached to it, and since organic molecules that have phosphate groups attached cannot freely cross the plasma membrane, only the liver can secrete glucose into the blood. This liver glucose may be derived from stored glycogen, or it may be produced by gluconeogenesis using lactic acid (Cori cycle), glycerol, or amino acids as initial substrates.

8. Anaerobic respiration can refer to respiration that occurs in the absence of oxygen, or to the metabolic pathway in certain bacteria in which sulfur or iron serves as a final electron acceptor in place of oxygen. The production of lactic acid is sometimes termed a "lactic acid fermentation" pathway because the metabolic pathway is analogous to that used by yeast cells to produce ethyl alcohol from glucose.

9. Brown fat functions in thermogenesis, or heat production in the newborn. In response to regulation by thyroid hormone and norepinephrine from sympathetic nerves, brown fat produces a unique uncoupling protein. This protein causes H^+ to leak out of the inner mitochondrial membrane, so that less H^+ passes through the respiratory assemblies to drive ATP synthetase activity. Therefore, less ATP is made by the electron-transport system than would otherwise be the case. This causes the electron-transport system to be more active and generate more heat derived primarily from the respiration of fatty acids. As ATP concentration decreases, the rate of cell respiration increases.

10. The three major molecules used as substrates for gluconeogenesis are lactic acid, amino acids, and glycerol. During exercise some of the lactic acid produced by skeletal muscles may be transformed through gluconeogenesis in the liver to blood glucose (Cori cycle). During starvation, glycerol and amino acids can be converted to new glucose through gluconeogenesis in the liver. Fatty acids cannot be used as a substrate for gluconeogenesis because they contain too many carbons.

Answers to Test Your Ability to Analyze and Apply Your Knowledge

1. Elimination of all fat from her diet would sharply reduce her total calorie intake and help her lose weight since fats, with nine kcal/gram, have a greater calorie density than carbohydrates or proteins, each at three kcal/gram. Yes, because weight gain occurs when there is greater total calorie consumption with lesser total calorie expenditure. Any replacement of fat calories with excessive amounts of either carbohydrate or protein calorie foods could cause weight gain. The health consequences of a no fat diet could be severe since some organs preferentially use lipids, such as ketone bodies, as an energy source. Lipid derivatives are also essential precursors of pyruvic acid, acetyl CoA, and serve as common intermediates of the Krebs cycle. Furthermore, members of the lipid family such as steroids and prostaglandins become hormones and other physiological regulators, respectively, that are vital to the body.

2. The chemiosmotic theory depends on the steep H^+ gradient across the inner mitochondrial membrane for the directed H^+ passage through the respiratory assemblies that couples electron transport to ATP production. The inner mitochondrial membrane is impermeable to H^+ diffusion except through the respiratory assemblies. If a drug promoted the inward channeling of H^+ from the intermembrane space into the matrix of the mitochondria of adipose cells, then the existing diffusion gradient into the matrix would be weakened and ATP production would be severely reduced. Analogous to the uncoupling protein found in brown fat, this drug would cause stimulation of the electron-transport system that would generate more heat from the respiration of fatty acids and body temperature would rise. The increase in fuel consumption would deplete fat stores and result in weight loss.

3. The primary factor that must be considered in estimating the yield of ATP molecules from a single glucose is the metabolic cost of cell respiration. For years the theoretical yield of 36 to 38 did not take into consideration the costs of transport across the mitochondrial membranes. The first two proton pumps of the electron transport system transport four protons each producing one ATP per pump. The third proton pump transports only two protons forming one-half ATP – for a grand total of 2.5 ATP per pair of NADH donated electrons. FADH donated electrons bypass the first pump, activating only the second and third pumps to transport six protons forming 1.5 ATP each. Furthermore, the "shuttle" of cytoplasmic NADH into the mitochondria occurs slightly differently in different tissues resulting in varying amounts of ATP formed. Since these factors surprised scientists and since controversy still exists, the more recent numbers are considered approximate values.