CHAPTER 5
CELL RESPIRATION AND METABOLISM

CHAPTER SCOPE

To place this chapter in perspective, we must realize that all living cells have a continuous need for **energy (ATP**) to perform routine functions. These include such vital functions as the transport of materials across cell membranes; generating membrane potentials (chapter 6) and transmitting these electrical impulses (chapters 7-10); the synthesis and secretion of hormones (chapter 11); and muscle contraction (chapters 12-14).

Ultimately, the energy for these cellular activities comes from the fuel foods we consume, digest, and absorb (digestion: chapter 17); deliver to our cells (circulation: chapters 13 and 14); and combust or metabolize along enzyme-catalyzed pathways. As we learned in the previous chapter, much of this chemical energy is lost as heat energy (measured in *calories*) as the residual energy is transferred to the synthesis of ATP. The ATP then serves to drive or "energize" cellular functions. We are prepared now to ask questions about the processes that comprise cell respiration and to analyze the combustion reactions that occur continuously in all living cells. In this way, food consumption provides the high-energy raw materials that active cells require to produce the ATP that drives the cell's activities and that ultimately maintains overall body homeostasis.

When we breathe in, where in the body does the *oxygen* go? And, where does the *carbon dioxide* come from that we exhale? And how does this exchange of gases relate to the combustion of fuel food molecules such as **glucose**, **fat** (triglycerides), and **amino acids;** and to the subsequent transfer of energy to ATP? Answers to these questions and others regarding **cell respiration** are discussed here.

Finally, this chapter illustrates how the metabolic demands for ATP can be met by exercising skeletal muscles and other active tissues. For example, a continuous supply of glucose in the blood as fuel for ATP synthesis in the brain and nerve tissue is primarily obtained from glucose stored as **glycogen** within the *liver*. In most muscle tissue, however, glucose cannot only be extracted from the blood but also obtained from glycogen stores within the muscles themselves. Chemical messengers in the blood such as hormones work to maintain the concentration of glucose in the blood within normal limits so that brain and tissue function can continue normally (homeostasis).

I. GLYCOLYSIS AND THE LACTIC ACID PATHWAY

In cellular respiration, energy is released by the stepwise breakdown of glucose and other molecules, and some of this energy is used to produce ATP. The complete combustion of glucose requires the presence of oxygen and yields thirty ATP for each molecule of glucose. However, some energy can be obtained in the absence of oxygen by the pathway that leads to the production of lactic acid. This process results in the net gain of two ATP per glucose.

A. Multiple Choice

___ 1. Synthesis of larger, energy storage molecules from smaller molecules, best describes
   a. anabolism.
   b. metabolism.
   c. catabolism.

___ 2. Which of the following molecules is *not* used as a primary source of energy for the cellular synthesis of ATP?
   a. glucose
   b. fatty acids
   c. nucleic acids
   d. amino acids
   e. All of these molecules are used for ATP synthesis.

___ 3. Which of these is *not* a final product of aerobic cell respiration?
   a. carbon dioxide
   b. water
   c. oxygen
   d. energy (ATP)

___ 4. In the aerobic respiration of glucose to form two molecules of pyruvic acid, four atoms of _____ are removed.
   a. carbon
   b. hydrogen
   c. oxygen
   d. carbon dioxide

___ 5. Which of the following statements about glycolysis is *false*?
   a. It results in the ultimate formation of two molecules of pyruvic acid.
   b. It results in the net gain of two ATP molecules.
   c. It can occur with or without oxygen present.
   d. It is exergonic.
   e. All of these statements about glycolysis are true.

___ 6. As a result of anaerobic respiration or lactic acid fermentation, glucose is converted to
   a. pyruvic acid.
   b. lactic acid.
   c. citric acid.
   d. acetyl CoA.

___ 7. The organ most responsible for extracting and converting lactic acid to pyruvic acid, and which ultimately reforms and releases free glucose into the bloodstream, is the
   a. liver.
   b. brain.
   c. cardiac muscle.
   d. skeletal muscle.
   e. kidney.

___ 8. The process in question 7, which describes the conversion of noncarbohydrate molecules into glucose, is known as
   a. glycogenolysis.
   b. glycogenesis.
   c. gluconeogenesis.
   d. glycolysis.

___ 9. The Cori cycle is the process by which
   a. liver glycogen is exchanged for muscle glycogen.
   b. blood glucose is stored as liver glycogen.
   c. muscle lactic acid is stored as muscle glycogen.
   d. blood lactic acid is converted to glucose by the liver.
   e. liver glucose is converted to lactic acid and released into the bloodstream.

B. True or False/Edit

___ 10. Aerobic respiration and ventilation describe two different processes.
___ 11. During aerobic respiration the oxygen we breathe in is converted into carbon dioxide we breathe out.
___ 12. Glycolysis can take place both inside and outside the mitochondrion organelles of the cell.
___ 13. Anaerobic respiration (or lactic acid fermentation) yields a net gain of two ATP molecules.
___ 14. Anaerobic respiration (or lactic acid fermentation) in the cell does not require the presence of oxygen in the conversion of one glucose molecule to two molecules of lactic acid.
___ 15. It is common for certain tissues like skeletal muscle to derive energy (ATP) from anaerobic respiration without permanent injury or damage to the tissue.

II. AEROBIC RESPIRATION

In the aerobic respiration of glucose, pyruvic acid is formed by glycolysis and then converted into acetyl coenzyme A. This begins a cyclic metabolic pathway called the Krebs cycle. As a result of these pathways, a large amount of reduced NAD and FAD (NADH and $FADH_2$)is generated. These reduced coenzymes provide electrons for an energy-generating process that drives the formation of ATP.

A. Multiple Choice

___ 16. In addition to energy (ATP), what is (are) the final product(s) of aerobic respiration?
a. O_2 and CO_2
b. CO_2 and H_2O
c. O_2 and H_2O
d. CO_2 only

___ 17. Following aerobic respiration, approximately what percent of the chemical bond energy present in a glucose molecule is captured in high-energy bonds of ATP?
a. 40%
b. 50%
c. 60%
d. 70%
e. 80%

___ 18. The vitamin from the diet that is converted into coenzyme A and that combines with acetic acid in the mitochondrion is
a. niacin (B_3).
b. pantothenic acid.
c. riboflavin (B_2).
d. pyridoxine (B_6).
e. vitamin C.

___ 19. Which of the following processes does *not* occur during the completion of one circuit around the Krebs cycle?
a. One GTP molecule is converted to one ATP molecule.
b. Three NAD molecules are reduced by electrons (H's).
c. One molecule of oxygen is combined with hydrogen to form water.
d. One molecule of FAD is reduced by electrons (H's).

___ 20. Which of the following molecules is *not* part of the electron transport chain?
a. cytochrome
b. flavoprotein
c. coenzyme Q
d. coenzyme A
e. All of these are part of the electron transport chain.

___ 21. All of the following are formed as a result of the electron transport system, or chain, *except*
a. carbon dioxide.
b. oxidized NAD.
c. water.
d. ATP.
e. oxidized FAD.

___ 22. Molecules with unpaired electrons, such as an oxygen molecule with an extra, unpaired electron, may be involved in disease processes and are collectively known as
a. antioxidants.
b. free radicals.
c. coenzymes.
d. cytochromes.

___ 23. Which of the following is usually *not* considered an antioxidant molecule?
a. vitamin E (alpha-tocopherol)
b. glutathione
c. hydrogen peroxide
d. superoxide dismutase
e. vitamin C (ascorbic acid)

___ 24. The **chemiosmotic theory** involves the participation of proton (H^+) pumps that are found within the
a. nuclear membrane.
b. plasma (cellular) membrane.
c. mitochondrial inner membrane.
d. mitochondrial outer membrane.
e. lysosomal membrane.

___ 25. Cyanide is a poison that blocks the electron transfer from cytochrome a_3 to oxygen, therefore *directly* interrupting
a. glycolysis.
b. Krebs cycle.
c. oxidative phosphorylation.
d. gluconeogenesis.

___ 26. The actual (not theoretical) number of ATP molecules generated by the complete aerobic respiration of glucose is
a. twelve.
b. twenty-four.
c. thirty.
d. thirty-eight.
e. forty-six.

___ 27. The breakdown of stored glycogen into individual molecules of glucose 6-phosphate occurs during the process known as
a. glycolysis.
b. gluconeogenesis.
c. glycogenolysis.
d. glycogenesis.

___ 28. The enzyme, found *only* in the liver, that removes phosphate groups and, thus, can release free glucose into the blood, is
a. glycogen synthetase.
b. glucose 6-phosphatase.
c. glycogen phosphorylase.
d. glucose isomerase.

___ 29. Glucose molecules entering skeletal muscle fibers from the blood are “trapped” when quickly converted to
a. pyruvic acid.
b. glucose 1 phosphate.
c. glucose 6-phosphate.
d. glycogen.

B. True or False/Edit

___ 30. In aerobic respiration, the catabolism of a glucose molecule forms pyruvic acid, not lactic acid.

___ 31. The conversion of pyruvic acid to acetyl CoA occurs in the cytoplasm.

___ 32. Glycolysis occurs in the mitochondrion.

___ 33. Iron is the crucial atom within the cytochromes of the mitochondrion that participates in the electron transport chain.

___ 34. Electron transport molecules are fixed within the inner membrane of the mitochondrion and are not part of the matrix.

___ 35. The transfer of energy from the electrons of hydrogen atoms to ATP is an example of an endergonic reaction.

___ 36. The formation of ATP along the electron transport chain, which requires the presence of O_2, is called oxidative phosphorylation.

___ 37. The production of free radicals and other molecules classified as reactive oxygen species by cells of the body are always implicated in disease processes.

___ 38. Antioxidants are molecules that scavenge free radicals and protect the body from the damaging effects of certain reactive oxygen species.

___ 39. The consumption of a diet high in fruits and vegetables would provide the body with an abundant supply of antioxidant molecules.

___ 40. Oxygen is the final electron acceptor of the electron transport chain.
___ 41. The oxygen (O_2) we breathe in is ultimately converted to carbon dioxide (CO_2).
___ 42. In oxidative phosphorylation, each electron pair from $FADH_2$ forms two molecules of ATP, while each electron pair from NADH forms three molecules of ATP.
___ 43. Organic molecules with phosphate groups, such as glucose 6-phosphate, are intracellular "prisoners" and cannot "escape" the cell by crossing the cell membrane.
___ 44. Skeletal muscle can supply the liver with energy in the form of free glucose but the opposite is not true.
___ 45. To maintain a steady supply of ATP, more glucose molecules would have to be burned in tissues that are anaerobic than if the tissues are supplied with oxygen.
___ 46. During exercise, the liver can supply free glucose to many tissues of the body that may have depleted glycogen stores, including the exercising muscles.
___ 47. To summarize aerobic cell respiration: the combustion of one glucose molecule has a theoretical yield of about 30-32 ATP, whereas, the actual yield is 36-38 ATP per glucose molecule.
___ 48. The estimates of the actual number of ATP obtained by the cell are lower than originally thought because the costs of transporting ATP out of the mitochondria and into the cytoplasm were not included.

III. METABOLISM OF LIPIDS AND PROTEINS

Triglycerides can be hydrolyzed into glycerol and fatty acids. The latter are of particular importance because they can be converted into numerous molecules of acetyl CoA that can enter Krebs cycles and generate a large amount of ATP. Amino acids derived from proteins may also be used for energy. This involves deamination (removal of the amine group) and the conversion of the remaining molecule into either pyruvic acid or one of the Krebs cycle molecules.

A. Multiple Choice

___ 49. *Acetyl CoA* is an important metabolic intersection that can lead to the formation of all of the following substances, *except*
a. CO_2 via Krebs cycle.
b. cholesterol and steroids.
c. ketone bodies.
d. fatty acids and triglycerides.
e. All of these substances are formed from acetyl CoA.

___ 50. The two intermediates of the glucose combustion pathway that directly link glucose metabolism to fat metabolism are
a. pyruvic acid and phosphoglyceraldehyde.
b. acetyl CoA and pyruvic acid.
c. phosphoglyceraldehyde and acetyl CoA.
d. glucose and pyruvic acid.

___ 51. Ranking the following stored energy forms from highest to lowest number of total calories available for the energy needs of the body, the proper sequence is:
1. glycogen (skeletal muscle); 2. glycogen (liver); 3. fat.
a. 1—2—3.
b. 3—2—1.
c. 3—1—2.
d. 2—3—1.
e. 1—3—2.

___ 52. In the cytoplasm, the removal of two-carbon acetic acid molecules from the acid end of fatty acids is an important enzymatic process known as
a. lipogenesis.
b. lipolysis.
c. ß-oxidation.
d. ketosis.

___ 53. The primary purpose for stored fuel in the form of *brown fat* is to
a. increase the metabolism of fatty acids, thereby generating heat.
b. protect the internal organs from damage, particularly in the newborn.
c. spare the excessive combustion of carbohydrates during starvation.
d. add pigmentation to adipose tissue as one ages.

___ 54. In the liver, fatty acid metabolism can result in the formation of excess acetyl CoA molecules; this "overflow" pathway ultimately results in the formation of
a. lactic acid.
b. ketone bodies.
c. cholesterol.
d. bile.

___ 55. The formation of nonessential amino acids from essential amino acids and carbohydrates is known as
a. transamination.
b. ß-oxidation.
c. oxidative deamination.
d. urea cycle.
e. ketosis.

___ 56. The vitamin that serves as the required coenzyme for the successful activity of transaminase enzymes is
a. niacin (B_3).
b. riboflavin (B_2).
c. pyridoxine (B_6).
d. vitamin C.
e. pantothenic acid.

___ 57. The enzymatic removal of the amine group from one amino acid, forming ammonia (later converted to urea), and leaving behind a ketone acid, is called
a. ketosis.
b. ß-oxidation.
c. transamination.
d. oxidative deamination.
e. urea cycle.

___ 58. The catabolism (breakdown) of this energy source can require the liver to convert toxic ammonia molecules into urea molecules.
a. carbohydrates
b. proteins
c. ketone bodies
d. fats

___ 59. Which of the following is *not* an energy source that can be found circulating in the bloodstream?
a. glycogen
b. glucose
c. ketone bodies
d. fatty acids
e. amino acids

___ 60. The organ with an absolute requirement for blood glucose as its primary energy source is the
a. brain.
b. heart.
c. skeletal muscle.
d. liver.
e. All of these organs require glucose as its primary energy source.

___ 61. The oxygen debt following strenuous exercise is due, in part, to the *extra* oxygen required for the metabolism of
a. carbon dioxide.
b. lactic acid.
c. glycogen.
d. fatty acid.
e. None of these require extra oxygen.

B. True or False/Edit

___ 62. Fatty acids are formed by the condensation of many two-carbon acetyl CoA molecules, resulting in the formation of long hydrocarbon chains.
___ 63. Protein accounts for 15% to 20% of the stored calories in the body and is used extensively as an energy source.
___ 64. Lipase enzymes specialize in catalyzing the hydrolysis of triglycerides into glycogen and free fatty acids.
___ 65. Like glucose metabolism, ß-oxidation of fatty acids requires coenzymes NAD and FAD for the transfer of hydrogen atoms and the subsequent release of energy for ATP synthesis.
___ 66. The rationale behind the popular low-carbohydrate (higher protein) diet stems from the concept that such diets lower the secretion of insulin from the pancreas that will promote the breakdown of fat with subsequent weight loss.
___ 67. Brown fat accumulates as one ages especially in the skin and abdominal regions of the body.
___ 68. Many peripheral tissues can use ketone bodies as an energy source.
___ 69. Growing children excrete less nitrogen than they ingest, therefore they are in a state of *negative* nitrogen balance.
___ 70. Excess amino acids, not used for energy, can be converted to carbohydrate and/or to fat.
___ 71. Of the twenty amino acids required to synthesize protein, about twelve are essential, which means the body must make them.
___ 72. Ketone acids can be used in the Krebs cycle as a source of energy, or converted to fat or glucose.

IV. CHAPTER REVIEW

A. Completion—Metabolism Terms

Complete the sentences below by writing in the space or spaces the correct metabolic process or term related to metabolism. Notice that the number of blank spaces corresponds to the number of words in the process or term. The same process may be written more than once.

All of the reactions in the body that involve energy transformation are collectively called 73. _____; which, in turn is divided into two categories: reactions that release energy when breaking down larger molecules called 74. _____, and 75. _____, reactions that require energy while building larger molecules. The metabolic pathway that converts glucose or fatty acid molecules into carbon dioxide and water (transferring some energy to ATP) is called aerobic 76. _____ _____ . The metabolic process by which glucose is broken down into two molecules of pyruvic acid, or pyruvate, is called 77. _____.

The reactions that simply add a phosphate group to a molecule (such as glucose, thereby trapping glucose in the cell) is called 78. _____. The metabolic pathway by which glucose is converted to lactic acid without the need for oxygen, is referred to as 79. _____ _____, or alternatively called lactic acid 80. _____.

The formation of glycogen storage molecules from excess glucose molecules during feasting is called 81. _____. The reverse reactions that occur during fasting, is known as 82. _____. Because muscular exercise uses glucose for fuel, athletes are very interested in this next very important process. This pathway involves the conversion of noncarbohydrate molecules (not just lactic acid, but also amino acids and glycerol) through pyruvic acid to make glucose, is called 83. _____. When this process specifically occurs only in the liver, during which lactic acid made by skeletal muscle metabolism is reformed into glucose, the pathway is known as the 84. _____ cycle.

Once an acetyl COA molecule has been formed following glycolysis in the cytoplasm, it enters the mitochondria to bind with oxaloacetic acid to form citric acid along a sequence called the citric acid cycle (or TCA cycle), or most commonly known as the 85. _____. As the last of the original glucose molecule remnants are broken down in the citric acid cycle, high-energy hydrogen atoms are removed and transported by NADH and $FADH_2$ the foldings or cristae of the inner mitochondria. Here, aerobic respiration is completed as high-energy hydrogen atoms (actually, paired electrons) are transferred along a series of molecules built into the mitochondrial cristae forming water as the final product. However, along the way energy was released and transferred to form ATP molecules, a process known as 86. _____ _____.

In adipose tissue or the liver, the formation of fat from triglyceride or triacylglycerol molecules, is known as 87. _____; whereas the reverse reaction that occurs during the breakdown of stored fat for energy is called 88. _____. During the latter process, fatty acid molecules are hydrolyzed by enzymes into two-carbon acetic acid molecules that eventually become acetyl CoA molecules, entering the mitochondria for the production of ATP. Since oxygen is required, the pathway just described is called beta-89. _____.

Proteins may also be used as a source of energy, especially when carbohydrate or fat molecules are in limited supply. The building blocks of proteins are called amino acids, with 9 of the 20 amino acids called 90. _____. The synthesis of the amino acids required by the body involves a transfer of an amine group from one amino acid to form another amino acid - a process called 91. _____. However, when time comes to combust amino acids for energy production, the amine group needs to be removed and made into ammonia, leaving a keto acid - a process called 92. _____ _____.

B. Label the Figure — Cell Metabolic Pathways

Your understanding of the most important metabolic pathways in living cells is very important. Study the incomplete figure below and test yourself by attempting to name as many intermediates as possible. When you are finished, compare your answers with the text figure 5.17. As a post-test, erase your work and come back later (before your next exam!) and try it again. Don't expect to completely accurate the first time — these concepts are difficult.

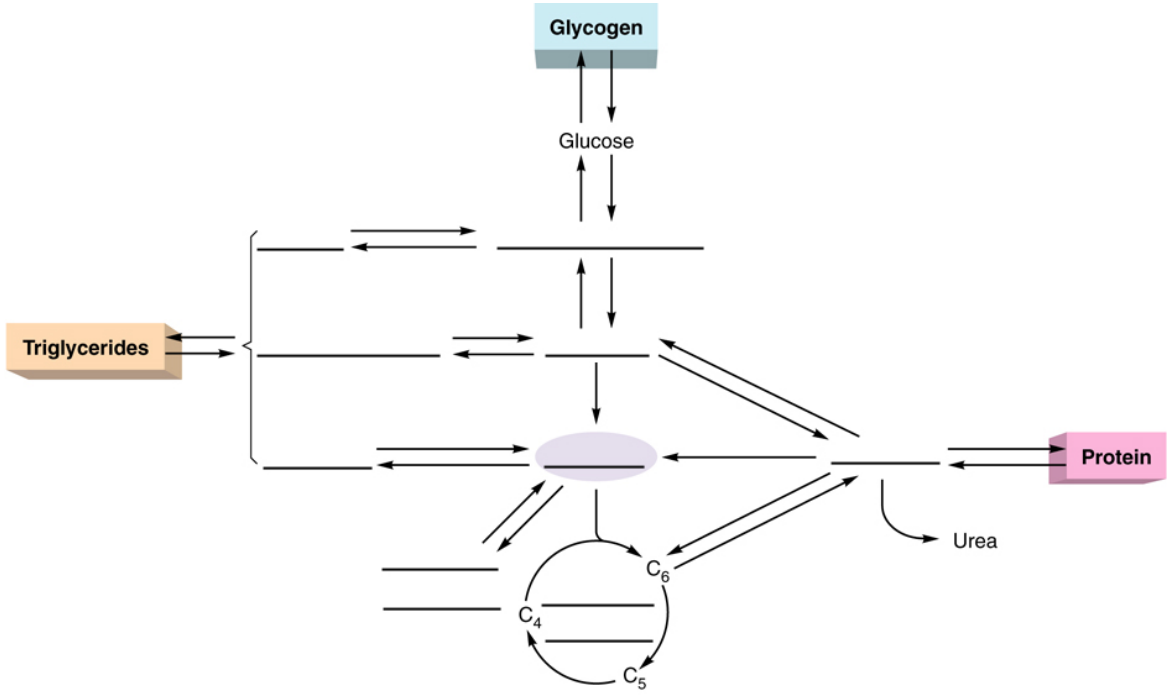

Figure 5.1 The interconversion of glycogen, fat, and protein.

C. Metabolism Compartments

So far in this text we have learned many processes that take place in specific parts of the cell, such as the cytoplasm, plasma membrane, and organelles (ribosomes, mitochondria, among others). These locations can be thought of as "**compartments.**" In this exercise, select the letter of the compartment listed a. – e. on the right that relates to the process described by the numbered phrases on the left. Write that letter in the space provided.

(*Note*: An answer may be used more than once.)

___ 93. Electron transport chain chemiosmotic "hydrogen pumps"
___ 94. Protein synthesis (translation) of enzymes for metabolism
___ 95. Krebs cycle
___ 96. ß-oxidation of fatty acids to acetyl CoA
___ 97. Blocks transport of phosphorylated molecules
___ 98. Glucose conversion to pyruvic acid molecules
___ 99. Formation of acetyl CoA from pyruvic acid, linking glycolysis to the Krebs cycle
___ 100. Conversion of glycerol to phosphoglyceraldehyde
___ 101. Conversion of O_2 gas to water in the electron transport system
___ 102. Formation of CO_2 gas from carboxyl groups
___ 103. Formation of lactic acid from glucose

a. cytoplasm
b. plasma membrane
c. ribosome
d. mitochondrion (membranes)
e. mitochondrion (matrix)

D. Essay

Essay Tutorial

This essay tutorial will answer the first essay question found under "**Review Activities**" of your *Human Physiology* textbook. Read question 1 located in the **"Test Your Understanding of Concepts and Principles"** section at the end of chapter 5, read it carefully, and let me guide you through one possible answer. Watch for key terms in boldface type, helpful tips and general suggestions on writing the essay or short-answer questions. Enjoy!

104. **State** the advantages and disadvantages of **anaerobic respiration**.

Note: "**State**" does not necessarily mean to simply "list" or "outline". Rather, it means to describe first the advantages, then the disadvantages, using phrases or complete sentences. Numbering your points may help to organize your answer and assist the reader/instructor in separating each statement. Your discussion then becomes more than just a numbered list. Also notice that by defining the key word "anaerobic" at the start, we help establish a foundation for the rest of the answer. When finished, try a couple of my essay questions that follow, OK?

Answer. Anaerobic respiration refers to the conversion of glucose in the cytoplasm of living cells to pyruvic acid and then to lactic acid, when there exists a temporary absence of oxygen.

Advantages

1. Glycolysis of glucose to pyruvic acid is allowed to continue, despite the fact that fewer ATP (two) are synthesized. This provides cells with a backup or emergency source of ATP.
2. Some peripheral tissues such as skeletal muscles commonly function anaerobically without injury or cell damage for short periods of time.
3. Red blood cells (RBCs) respire anaerobically, thus conserving the hemoglobin-bound O_2 for the tissues.

Disadvantages

1. The potential to make twenty-eight more ATP from glucose is lost.
2. The accumulation of lactic acid in tissues such as skeletal muscle leads to an overall acidosis. By altering the active sites of enzymes, acidosis can interrupt metabolism and lead to the inadequate production of ATP and fatigue.
3. The extra lactic acid produced may place a burden on the liver, that may already be overworked with the Cori Cycle and glycogenesis reactions.
4. Anaerobic respiration is only a temporary backup system for periods of intermittent lack of oxygen and cannot be used as a primary source of energy.

105. You have just consumed a delicious bowl of sugary cereal! In outline form, trace the metabolic pathways taken by the extra glucose molecules as they are converted to triglycerides.

106. So far, you have been introduced to many vitamins that play important roles in metabolism. Briefly, describe the function and physiologic importance of niacin (B_3), riboflavin (B_2), pantothenic acid, and pyridoxine (B_6).

107. We inhale to supply cells with oxygen, and we exhale to exhaust the carbon dioxide by-products of metabolism. In your own words, describe the specific metabolic process in the cell in which O_2 is consumed, as well as the three specific metabolic processes in which CO_2 is produced.

Answers — Chapter 5

I. Glycolysis and the Lactic Acid Pathway
   A. 1. a, 2. c, 3. c, 4. b, 5. e, 6. b, 7. a, 8. c, 9. d
   B. 10. T, 11. F—Replace “carbon dioxide” with “water,” 12. F—Glycolysis occurs only in the cytoplasm, 13. T, 14. T, 15. T

II. Aerobic Respiration
   A. 16. b, 17. a, 18. b, 19. c, 20. d, 21. a, 22. b, 23. c, 24. c, 25. c, 26. c, 27. c, 28. b, 29. c
   B. 30. T, 31. F—Replace “cytoplasm” with “mitochondrial membrane,” 32. F—Replace “mitochondrion” with “cytoplasm,” 33. T, 34. T, 35. F—Replace “endergonic” with “exergonic,” 36. T, 37. F—Some “reactive oxygen species” are needed by WBC’s to help destroy bacteria, 38. T, 39. T, 40. T, 41. F—Replace “carbon dioxide (CO_2)” with “water,” 42. T, 43. T, 44. F—Switch “skeletal muscle” and “liver,” 45. T, 46. T, 47. F— Switch “30-32” with “36-38”, 48. T
   C. Brown fat is most abundant at birth; produces heat, 68. T, 69. F—Replace “negative” with “positive,” 70. T, 71. F—There are eight (nine in children [histidine]) essential amino acids which must be included in the adult diet; cells make nonessential amino acids through transamination, 72. T

III. Metabolism of Lipids and Proteins
   A. 49. e, 50. c, 51. c, 52. c, 53. a, 54. b, 55. a, 56. c, 57. d, 58. b, 59. a, 60. a, 61. b
   B. 62. T, 63. F—Proteins are <u>not</u> used daily for energy, 64. F—Replace “glycogen” with “glycerol,” 65. T, 66. T, 67. F—
   80. fermentation, 81. glycogenesis, 82. glycogenolysis, 83. gluconeogenesis, 84. Cori, 85. Krebs, 86. oxidative phosphorylation, 87. lipogenesis, 88. lipolysis, 89. oxidation, 90. essential, 91. transamination, 92. oxidative deamination.
   B. See figure 5.17 in the text
   C. 93. d, 94. c, 95. e, 96. a, 97. b, 98. a, 99. d, 100. a, 101. d, 102. d and e, 103. a

IV. Chapter Review
   A. 73. metabolism, 74. catabolism, 75. anabolism, 76. cell respiration, 77. glycolysis, 78. phosphorylation, 79. anaerobic respiration,