Nutrition and Metabolism

OUTLINE

Role of the Liver
Nutrient Metabolism
- Carbohydrate Metabolism
- Fat Metabolism
- Protein Metabolism

Vitamins and Minerals
Metabolic Rates
Metabolic and Eating Disorders
Body Temperature
- Abnormal Body Temperature

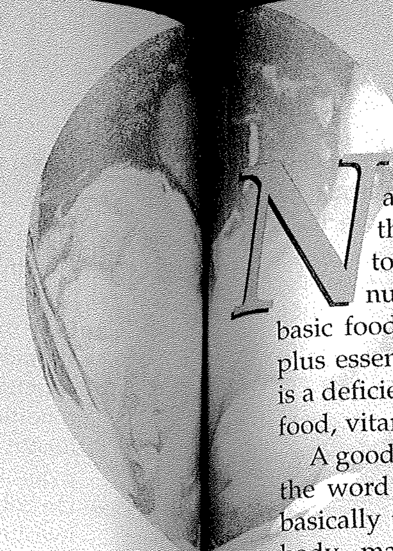
OBJECTIVES

After you have completed this chapter, you should be able to:

1. Define and contrast *catabolism* and *anabolism.*
2. Describe the metabolic roles of carbohydrates, fats, proteins, vitamins, and minerals.
3. Define basal metabolic rate and list some factors that affect it.
4. Describe three disorders associated with eating or metabolism.
5. Discuss the physiological mechanisms that regulate body temperature.

BOXED ESSAYS

Cholesterol
Vitamin Supplements for Athletes



Nutrition and *metabolism* are words that are often used together—but what do they mean? *Nutrition* is a term that refers to the food (nutrients) that we eat. Proper nutrition requires a balance of the three basic food types, *carbohydrates, fats,* and *proteins,* plus essential *vitamins* and *minerals.* Malnutrition is a deficiency or imbalance in the consumption of food, vitamins, and minerals.

A good phrase to remember in connection with the word metabolism is "use of foods" because basically this is what metabolism is—the use the body makes of foods after they have been digested, absorbed, and circulated to cells. It uses them in two ways: as an energy source and as building blocks for making complex chemical compounds. Before they can be used in these two ways, foods have to be *assimilated.* Assimilation occurs when food molecules enter cells and undergo many chemical changes there. All the chemical reactions that release energy from food molecules make up the process of catabolism, a vital process because it is the only way that the body has of supplying itself with energy for doing any work. The many chemical reactions that build food molecules into more complex chemical compounds constitute the process of anabolism. Catabolism and anabolism make up the process of metabolism.

This chapter explores many of the basic ideas about why certain nutrients are necessary for survival, how they are used by the body, and what can go wrong in metabolic and eating disorders.

Role of the Liver

As we discussed in Chapter 16, the liver plays an important role in the mechanical digestion of lipids because it secretes *bile.* As you recall, bile breaks large fat globules into smaller droplets of fat that are more easily broken down. In addition, liver cells perform other functions necessary for healthy survival. They play a major role in the metabolism of all three kinds of foods. They help maintain a normal blood glucose concentration by carrying on complex and essential chemical reactions. Liver cells also carry on the first steps of protein and fat metabolism and synthesize several kinds of protein compounds. They release them into the blood, where they are called the *blood proteins* or *plasma proteins.* Prothrombin and fibrinogen, two of the plasma proteins formed by liver cells, play essential parts in blood clotting (see pp. 301 and 302). Another protein made by liver cells, albumin, helps maintain normal blood volume. Liver cells detoxify various poisonous substances such as bacterial products and certain drugs. Liver cells store several substances, notably iron and vitamins A and D.

The liver is assisted by an interesting structural feature of the blood vessels that supply it. As you may recall from Chapter 13, the hepatic portal vein delivers blood directly from the gastrointestinal tract to the liver (see Figure 13-9). This arrangement allows blood that has just absorbed nutrients and other substances to be processed by the liver before being distributed throughout the body. Thus excess nutrients and vitamins can be stored and toxins can be removed from the bloodstream.

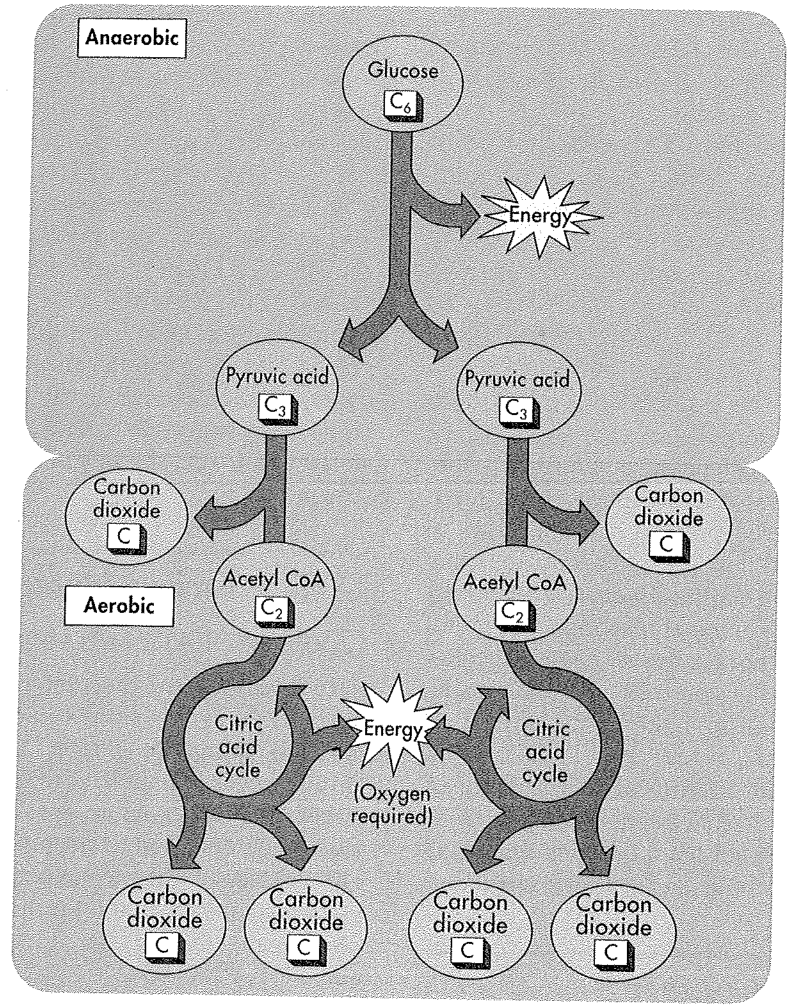
Nutrient Metabolism

CARBOHYDRATE METABOLISM

Carbohydrates are the preferred energy food of the body. They are composed of smaller "building blocks"—primarily *glucose.* (See Appendix A). Human cells catabolize (break down) glucose rather than other substances as long as enough glucose enters them to supply their energy needs. Three series of chemical reactions, occurring in a precise sequence, make up the process of glucose catabolism. **Glycolysis** (glye-KOL-i-sis) is the name given the first series of reactions; **citric acid cycle** is the name of the second series, and **electron transfer system** is the third. Glycolysis, as Figure 17-1 shows, changes glucose to pyruvic acid. The citric acid cycle changes the pyruvic acid to carbon dioxide. Glycolysis takes place in the cytoplasm of a cell, whereas the citric acid cycle goes on in the mitochondria, the cell's miniature power plants. Glycolysis uses no oxygen; it is an **anaerobic** (an-er-O-bik) process. The citric acid cycle, in contrast, is an oxygen-using or **aerobic** (aer-O-bik) process.

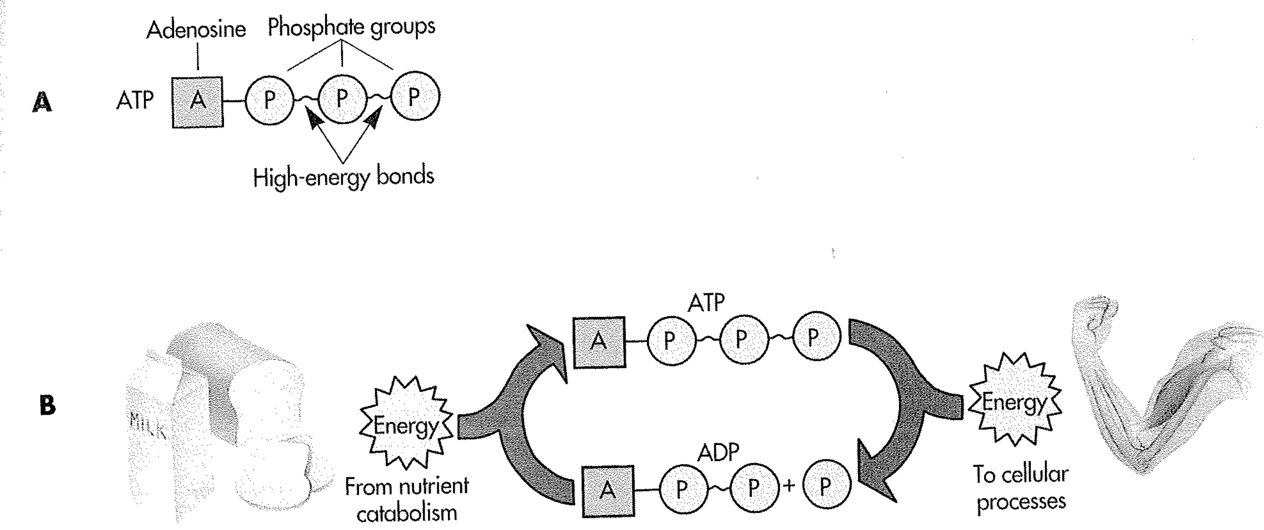
While the chemical reactions of glycolysis and the citric acid cycle occur, energy stored in the glucose molecule is being released. Over half the

FIGURE 17-1 ***Catabolism of Glucose.*** Glycolysis splits one molecule of glucose (six carbon atoms) into two molecules of pyruvic acid (three carbon atoms each). The citric acid cycle converts each pyruvic acid molecule into three carbon dioxide molecules (one carbon atom each).



released energy is in the form of high-energy electrons. The electron transport system, located in the mitochondria, almost immediately transfers the energy to molecules of adenosine triphosphate (ATP). The rest of the energy originally stored in the glucose molecule is released as heat. ATP serves as the direct source of energy for doing cellular work in all kinds of living organisms from one-cell plants to billion-cell animals, including man. Among biological compounds, therefore, ATP ranks as one of the most important. The energy transferred to ATP molecules differs in two ways from the energy stored in food molecules; the energy in ATP molecules is not stored but is released almost instantaneously, and it can be used directly to do cellular work. Release of energy from food molecules occurs much more slowly because it accompanies the long series of chemical reactions that make up the process of catabolism. Energy released from food molecules

FIGURE 17-2 ***ATP.*** **A,** The structure of ATP. A single adenosine group *(A)* has three attached phosphate groups *(P)*. The high-energy bonds between the phosphate groups can release chemical energy to do cellular work. **B,** ATP energy cycle. ATP stores energy in its last high-energy phosphate bond. When that bond is later broken, energy is released to do cellular work. The ADP and phosphate groups that result can be resynthesized into ATP, capturing additional energy from nutrient catabolism.



cannot be used directly for doing cellular work. It must first be transferred to ATP molecules and be released explosively from them.

As Figure 17-2 shows, ATP comprises an adenosine group and three phosphate groups. The capacity of ATP to store large amounts of energy is found in the high-energy bonds that hold the phosphate groups together, illustrated as curvy lines. When a phosphate group breaks off the molecule, an adenosine diphosphate (ADP) molecule and free phosphate group result. Energy that had been holding the phosphate bond together is freed to do cellular work (muscle fiber contractions, for example). As you can see in Figure 17-2, the ADP and phosphate are reunited by the energy produced by carbohydrate catabolism, making ATP a reusable energy-storage molecule. Only enough ATP for immediate cellular requirements is made at any one time. Glucose that is not needed is anabolized into larger molecules that are stored for later use.

Glucose anabolism is called **glycogenesis** (glye-ko-JEN-e-sis). Carried on chiefly by liver and muscle cells, glycogenesis consists of a series of reactions that join glucose molecules together, like many beads in a necklace, to form *glycogen*, a compound sometimes called *animal starch*.

Something worth noticing is that the amount of nutrients in the blood normally does not change very much, not even when we go without food for many hours, when we exercise and use a lot of food for energy, or when we sleep and use little food for energy. The amount of glucose in our blood, for example, usually stays at about 80 to 120 mg in 100 ml of blood.

Several hormones help regulate carbohydrate metabolism to keep blood glucose normal. **Insulin** is one of the most important of these. It acts in some way not yet definitely known to make glucose leave the blood and enter the cells at a more rapid rate. As insulin secretion increases, more glucose leaves the blood and enters the cells. The amount of glucose in the blood therefore decreases as the rate of glucose metabolism in cells increases (see p. 283). Too little insulin secretion, such as that which occurs

Cholesterol

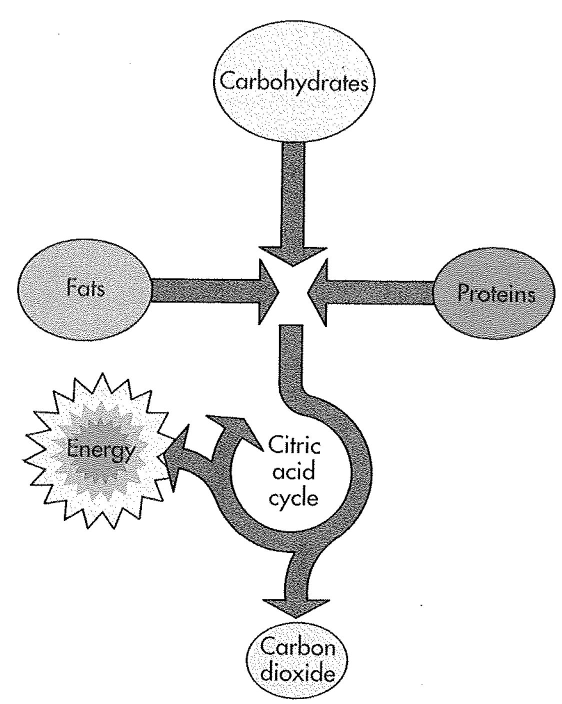
Cholesterol is a type of lipid that has many uses in the body (see Appendix A). The body derives steroid hormones from cholesterol (see Chapter 10) and uses cholesterol to stabilize the phospholipid bilayer that forms the plasma membrane and membranous organelles of the cells. So why does such a useful substance have such a bad reputation? The reason lies in the fact that an *excess* of cholesterol in the blood, a condition called **hypercholesterolemia** (hye-per-kol-es-ter-ol-EE-me-ah), increases the risk of developing atherosclerosis. You may recall from Chapter 13 that *atherosclerosis* develops into a type of arteriosclerosis or "hardening of the arteries" that can lead to heart disease, stroke, and other problems. Hypercholesterolemia occurs most often in people with a genetic predisposition but is certainly affected by other factors such as diet and exercise. People with hypercholesterolemia are encouraged to switch to diets low in cholesterol and saturated fats and to participate in aerobic exercise, both of which tend to lower blood cholesterol levels. Appendix A discusses different types of cholesterol and their roles in health and disease.

with diabetes mellitus, produces the opposite effects. Less glucose leaves the blood and enters the cells; more glucose therefore remains in the blood, and less glucose is metabolized by cells. In other words, high blood glucose (hyperglycemia) and a low rate of glucose metabolism characterize insulin deficiency. Insulin is the only hormone that lowers the blood glucose level. Several other hormones, on the other hand, increase it. Growth hormone secreted by the anterior pituitary gland, hydrocortisone secreted by the adrenal cortex, epinephrine secreted by the adrenal medulla, and glucagon secreted by the pancreatic islets are four of the most important hormones that increase blood glucose. More information about these hormones appears in Chapter 10.

FAT METABOLISM

Fats, like carbohydrates, are primarily energy foods. If cells have inadequate amounts of glucose to catabolize, they immediately shift to the catabolism of fats for energy. They are simply converted into a form of glucose that can enter the citric acid cycle. This happens normally when a person goes without food for many hours. It happens abnormally in diabetic individuals. Because of an insulin deficiency, too little glucose enters the cells of a diabetic person to supply all energy needs. Result? The cells catabolize fats to make up the difference (Figure 17-3). In all persons, fats not needed for catabolism are anabolized to form triglycerides and stored in adipose tissue.

FIGURE 17–3 ***Catabolism of Nutrients.*** Fats, carbohydrates, and proteins can be converted to products that enter the citric acid cycle to yield energy.



PROTEIN METABOLISM

In a healthy person, proteins are catabolized to release energy to a very small extent. When fat reserves are low, as they are in the starvation that accompanies certain eating disorders such as anorexia nervosa, the body can start to use its protein molecules as an energy source. Specifically, the amino acids that make up proteins are each broken apart to yield an amine group that is converted to a form of glucose that can enter the citric acid cycle. After a shift to reliance on protein catabolism as a major energy source occurs, death may quickly follow because vital proteins in the muscles and nerves are catabolized (Figure 17-3).

A more common situation in normal bodies is protein anabolism, the process by which the body builds amino acids into complex protein compounds (for example, enzymes and proteins that form the structure of the cell). Proteins are assembled from a pool of 20 different kinds of amino acids. If any one type of amino acid is deficient, vital proteins cannot be synthesized—a serious health threat. One way your body maintains a constant supply of amino acids is by making them from other compounds already present in the body. Only about half of the required 20 types of amino acids can be made by the body, however. The remaining types of amino acids must be supplied in the diet. **Essential amino acids** are those that must be in the diet. **Nonessential amino acids** can be missing from the diet because they can be made by the body. See Table 17-1.

TABLE 17–1 Amino Acids

ESSENTIAL (INDISPENSABLE)	NONESSENTIAL (DISPENSABLE)
Histidine*	Alanine
Isoleucine	Arginine
Leucine	Asparagine
Lysine	Aspartic acid
Methionine	Cysteine
Phenylalanine	Glutamic acid
Threonine	Glutamine
Tryptophan	Glycine
Valine	Proline
	Serine
	Tyrosine†

*Essential in infants and, perhaps, adult males.
†Can be synthesized from phenylalanine; therefore is nonessential as long as phenylalanine is in the diet.

Vitamins and Minerals

One glance at the label of any packaged food product reveals the importance we place on vitamins and minerals. We know that carbohydrates, fats, and proteins are used by our bodies to build important molecules and to provide energy. So why do we need vitamins and minerals?

First, let's discuss the importance of vitamins. Vitamins are organic molecules needed in small quantities for normal metabolism throughout the body. Vitamin molecules attach to enzymes and help them work properly. Many enzymes are totally useless without the appropriate vitamins to activate them. Most vitamins cannot be made by the body, so we must eat them in our food. The

Vitamin Supplements for Athletes

Because a deficiency of vitamins **(avitaminosis)** can cause poor athletic performance, many athletes regularly consume vitamin supplements. However, research suggests that vitamin supplementation has little or no effect on athletic performance. A reasonably well-balanced diet supplies more than enough vitamins for even the elite athlete. The use of vitamin supplements therefore has fueled somewhat of a controversy among exercise experts. Opponents of vitamin supplements cite the cost and the possibility of liver damage associated with some forms of **hypervitaminosis,** whereas supporters cite the benefit of protecting against vitamin deficiency.

TABLE 17-2 Major Vitamins

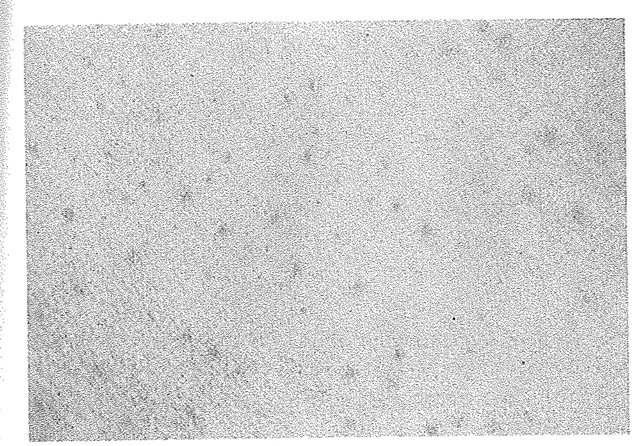
VITAMIN	DIETARY SOURCE	FUNCTIONS	SYMPTOMS OF DEFICIENCY
Vitamin A	Green and yellow vegetables, dairy products, and liver	Maintains epithelial tissue and produces visual pigments	Night blindness and flaking skin
B-complex vitamins			
B_1 (thiamine)	Grains, meat, and legumes	Helps enzymes in the citric acid cycle	Nerve problems (beriberi), heart muscle weakness, and edema
B_2 (riboflavin)	Green vegetables, organ meat, eggs, and dairy products	Aids enzymes in the citric acid cycle	Inflammation of skin and eyes
B_3 (niacin)	Meat and grains	Helps enzymes in the citric acid cycle	Pellagra (scaly dermatitis and mental disturbances) and nervous disorders
B_5 (pantothenic acid)	Organ meat, eggs, and liver	Aids enzymes that connect fat and carbohydrate metabolism	Loss of coordination (rare)
B_6 (pyridoxine)	Vegetables, meat, and grains	Helps enzymes that catabolize amino acids	Convulsions, irritability, and anemia
B_{12} (cyanocobalamin)	Meat and dairy products	Involved in blood production and other processes	Pernicious anemia
Biotin	Vegetables, meat, and eggs	Helps enzymes in amino acid catabolism and fat and glycogen synthesis	Mental and muscle problems (rare)
Folic acid	Vegetables	Aids enzymes in amino acid catabolism and blood production	Digestive disorders and anemia
Vitamin C (ascorbic acid)	Fruits and green vegetables	Helps in manufacture of collagen fibers	Scurvy and degeneration of skin, bone, and blood vessels
Vitamin D (calciferol)	Dairy products and fish liver oil	Aids in calcium absorption	Rickets and skeletal deformity
Vitamin E (tocopherol)	Green vegetables and seeds	Protects cell membranes from being catabolized	Muscle and reproductive disorders (rare)

body can store fat-soluble vitamins—A, D, E, and K—in the liver for later use. Because the body cannot store water-soluble vitamins such as B vitamins and vitamin C, they must be continually supplied in the diet. Vitamin deficiencies can lead to severe metabolic problems. Table 17-2 lists some of the more well-known vitamins, their sources, functions, and symptoms of deficiency.

Vitamin deficiency or **avitaminosis** (a-vye-tah-min-OS-is) can lead to severe metabolic problems. For example, *avitaminosis C* (vitamin C deficiency) can lead to **scurvy** (SKER-vee) (Figure 17-4). Scurvy results from the inability of the body to manufacture and maintain collagen fibers. As you may have gathered from your studies thus far, collagen fibers compose the connective tissues that hold most of the body together. In scurvy, the body literally falls apart in the same way that a neglected house eventually falls apart. More details about scurvy and other types of avitaminosis are given in Appendix B.

Some forms of **hypervitaminosis** (hye-per-vye-tah-min-OS-is)—or vitamin excess—can be just as serious as a deficiency of vitamins. For example,

FIGURE 17-4 *Scurvy.* Scurvy impairs the normal maintenance of collagen-containing connective tissues, causing bleeding and ulceration of the skin, gums, and other tissues.



chronic *hypervitaminosis A* can occur if large amounts of vitamin A (over 10 times the U.S. Recommended Daily Allowance) are consumed daily over a period of 3 months or more. This condition first manifests itself with dry skin, hair loss, anorexia (appetite loss), and vomiting, but may progress to severe headaches and mental disturbances, liver enlargement, and occasionally cirrhosis. Acute hypervitaminosis A, characterized by vomiting, abdominal pain, and headache, can occur if a massive overdose is ingested. Excesses of the fat-soluble vitamins (A, D, E, and K) are generally more serious than excesses of the water-soluble vitamins (B complex and C).

Minerals are just as important as vitamins. Minerals are inorganic elements or salts found naturally in the earth. Like vitamins, mineral ions can attach to enzymes and help them work. Minerals also function in a variety of other vital chemical reactions. For example, sodium, calcium, and other minerals are required for nerve conduction and for contraction in muscle fibers. Without these minerals, the brain, heart, and respiratory tract would cease to function. Information about some of the more important minerals is summarized in Table 17-3.

Like vitamins, minerals are beneficial only when taken in the proper amounts. Many of the minerals listed in Table 17-3 are required in trace amounts. Any intake of such minerals beyond the recommended trace amount may become toxic—perhaps even life threatening.

Metabolic Rates

The **basal metabolic rate (BMR)** is the rate at which food is catabolized under basal conditions (that is, when the individual is resting but awake, is not digesting food, and is not adjusting to a cold external temperature). Or, stated differently, the BMR is the number of calories of heat that must be produced per hour by catabolism just to keep the body alive, awake, and comfortably warm. To provide energy for muscular work and digestion and absorption of food, an additional amount of food must be catabolized. The amount of additional food depends mainly on how much work the individual does. The more active he or she is, the more food the body must catabolize and the higher the total metabolic rate will be. The **total metabolic rate (TMR)** is the total amount of energy used by the body per day (Figure 17-5).

When the number of calories in your food intake equals your TMR, your weight remains constant (except for possible variations resulting from water retention or water loss). When your food intake provides more calories than your TMR, you gain weight; when your food intake provides fewer calories than your TMR, you lose weight. These weight control principles rarely fail to operate. Nature does not forget to count calories. Reducing diets make use of this knowledge. They contain fewer calories than the TMR of the individual eating the diet.

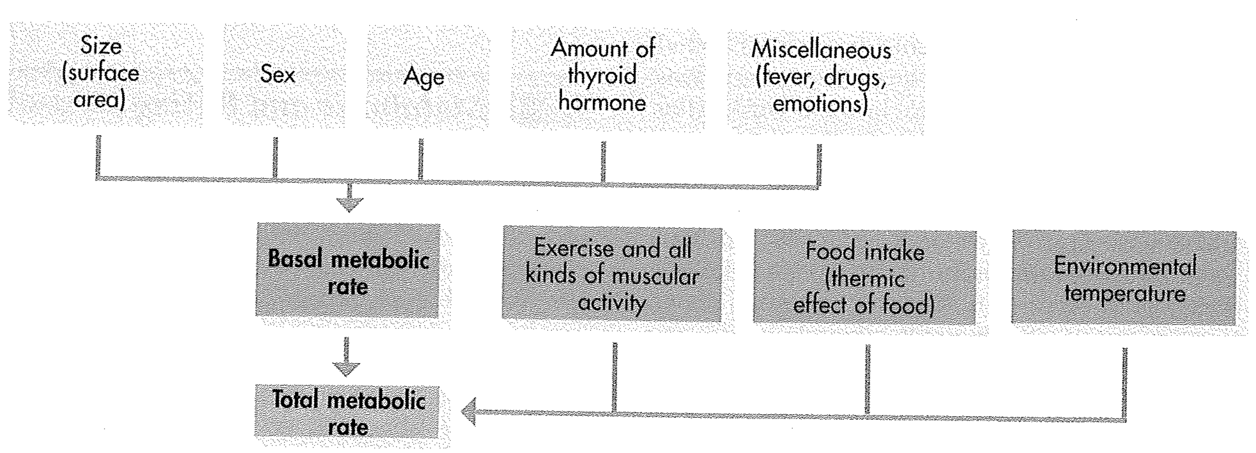
Metabolic and Eating Disorders

Disorders characterized by a disruption or imbalance of normal metabolism can be caused by several different factors. For example, *inborn errors of metabolism* are a group of genetic conditions involving a deficiency or absence of a particular enzyme. Specific enzymes are required by cells to carry out each step of every metabolic reaction. Although an abnormal genetic code may affect

TABLE 17-3 Major Minerals

MINERAL	DIETARY SOURCE	FUNCTIONS	SYMPTOMS OF DEFICIENCY
Calcium (Ca)	Dairy products, legumes, and vegetables	Helps blood clotting, bone formation, and nerve and muscle function	Bone degeneration and nerve and muscle malfunction
Chlorine (Cl)	Salty foods	Aids in stomach acid production and acid-base balance	Acid-base imbalance
Cobalt (Co)	Meat	Helps vitamin B_{12} in blood cell production	Pernicious anemia
Copper (Cu)	Seafood, organ meats, and legumes	Involved in extracting energy from the citric acid cycle and in blood production	Fatigue and anemia
Iodine (I)	Seafood and iodized salt	Aids in thyroid hormone synthesis	Goiter (thyroid enlargement) and decrease of metabolic rate
Iron (Fe)	Meat, eggs, vegetables, and legumes	Involved in extracting energy from the citric acid cycle and in blood production	Fatigue and anemia
Magnesium (Mg)	Vegetables and grains	Helps many enzymes	Nerve disorders, blood vessel dilation, and heart rhythm problems
Manganese (Mn)	Vegetables, legumes, and grains	Helps many enzymes	Muscle and nerve disorders
Phosphorus (P)	Dairy products and meat	Aids in bone formation and is used to make ATP, DNA, RNA, and phospholipids	Bone degeneration and metabolic problems
Potassium (K)	Seafood, milk, fruit, and meat	Helps muscle and nerve function	Muscle weakness, heart problems, and nerve problems
Sodium (Na)	Salty foods	Aids in muscle and nerve function and fluid balance	Weakness and digestive upset
Zinc (Zn)	Many foods	Helps many enzymes	Metabolic problems

FIGURE 17–5 *Factors That Determine the Basal and Total Metabolic Rates.*



the production of only a single enzyme, the resulting abnormal metabolism may have widespread effects. Specific diseases resulting from inborn errors of metabolism, such as *phenylketonuria (PKU)*, are discussed in Chapter 23.

A number of metabolic disorders are complications of other conditions. For example, you may recall from Chapter 10 that both hyperthyroidism and hypothyroidism have profound effects on the basal metabolic rate (BMR). Diabetes mellitus affects metabolism throughout the body when an insulin deficiency limits the amount of glucose available for use by the cells.

Some metabolic disorders result from normal mechanisms in the body that maintain homeostasis. For example, the body has several mechanisms that maintain a relatively constant level of glucose in the blood—glucose required by cells for life-sustaining catabolism. As mentioned earlier in this chapter, during *starvation* or in certain *eating disorders*, these mechanisms are taken to the extreme as they attempt to maintain blood glucose homeostasis. A few of the more well-known eating and nutrition disorders are briefly described here:

1. Anorexia nervosa is a behavioral disorder characterized by chronic refusal to eat, often because of an abnormal fear of becoming obese. This condition is most commonly seen in teenage girls and young adult women and is often linked to emotional stress. Treatment is usually directed at solving the resulting nutritional deficit first, then dealing with the underlying behavioral problem.

2. Bulimia (bu-LEE-me-ah) is a behavioral disorder characterized by insatiable craving for food alternating with periods of self-deprivation. The self-deprivation that follows a "food binge" is often accompanied by depression. People with a form of this disorder called *bulimarexia* (bu-lee-mah-REK-see-ah) purposely induce the vomiting reflex to purge themselves of the food they just ate. Excessive vomiting in this way can have a variety of consequences, including damage to the esophagus, pharynx, mouth, and teeth by stomach acid.

3. Obesity is not an eating disorder itself but may be a symptom of chronic overeating behavior. Like anorexia nervosa and bulimia, eating disorders characterized by chronic overeating usually have an underlying emotional cause. Obesity is defined as an abnormal increase in the proportion of fat in the body. Most of the excess fat is stored in the subcutaneous tissue and around the viscera. Obesity is a risk factor for a variety of life-threatening diseases, including many forms of cancer and heart disease.

4. Protein-calorie malnutrition (PCM) is an abnormal condition resulting from a deficiency of calories in general and protein in particular. PCM is likely to result from reduced intake of food but may also be caused by increased nutrient loss or increased use of nutrients by the body. Table 17-4 summarizes a few of the many conditions that may lead to PCM. Mild cases occur frequently in illness; as many as one in five patients admitted to the hospital are significantly malnourished. More severe cases of PCM are likely to occur in parts of the world where food, especially protein-rich food, is relatively unavailable. There are two forms of advanced PCM: *marasmus* and *kwashiorkor* (kwah-shee-OR-kor) (Figure 17-6). Maras-

FIGURE 17-6 *Protein-calorie malnutrition (PCM).* Marasmus results from starvation. Kwashiorkor results from a diet sufficient in calories but deficient in protein. Note the abdominal bloating typical of kwashiorkor.

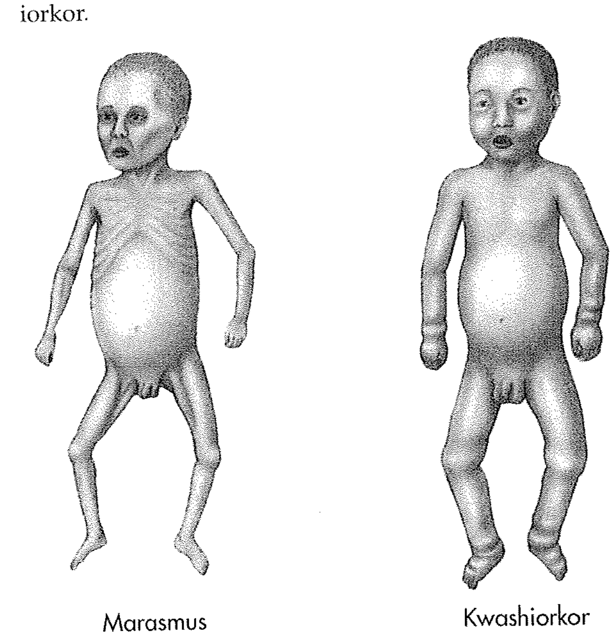


TABLE 17-4 Some Causes of Protein-Calorie Malnutrition

CONDITION	IMPACT ON NUTRIENTS
Conditions That Reduce Nutrient Intake	
Anorexia	Absence of appetite; reduced motivation to eat
Dysphagia	Difficulty in swallowing; inhibition of normal eating
Gastrointestinal obstruction	Inability of food to be digested or absorbed
Nausea	Upset stomach; discomfort, which inhibits appetite
Pain	Discomfort, which discourages eating
Poverty	Inability to acquire proper nutrients
Social isolation	Absence of social cues or motivation for eating
Substance abuse	Reduction or replacement of the motivation to eat
Tooth problems	Difficulty in chewing, which discourages or prevents eating
Conditions That Increase Loss of Nutrients	
Diarrhea	Increased intestinal motility, which reduces absorption of nutrients
Glycosuria	Loss of glucose in the urine
Hemorrhage	Loss of blood and the nutrients it contains
Malabsorption	Failure to properly absorb nutrients, which causes nutrients to pass unabsorbed
Conditions That Increase the Use of Nutrients by the Body	
Burns	Loss of nutrients from damaged tissues
Fever	Increased temperature and metabolic rate, which increase rate of nutrient catabolism
Infection	Increased immune activity and tissue repair, which increase the rate of nutrient use
Trauma and surgery	Increased immune activity, tissue repair, and homeostatic-compensating mechanisms, which increase the rate of nutrient use
Tumors	Increased tissue growth, which increases the rate of nutrient use

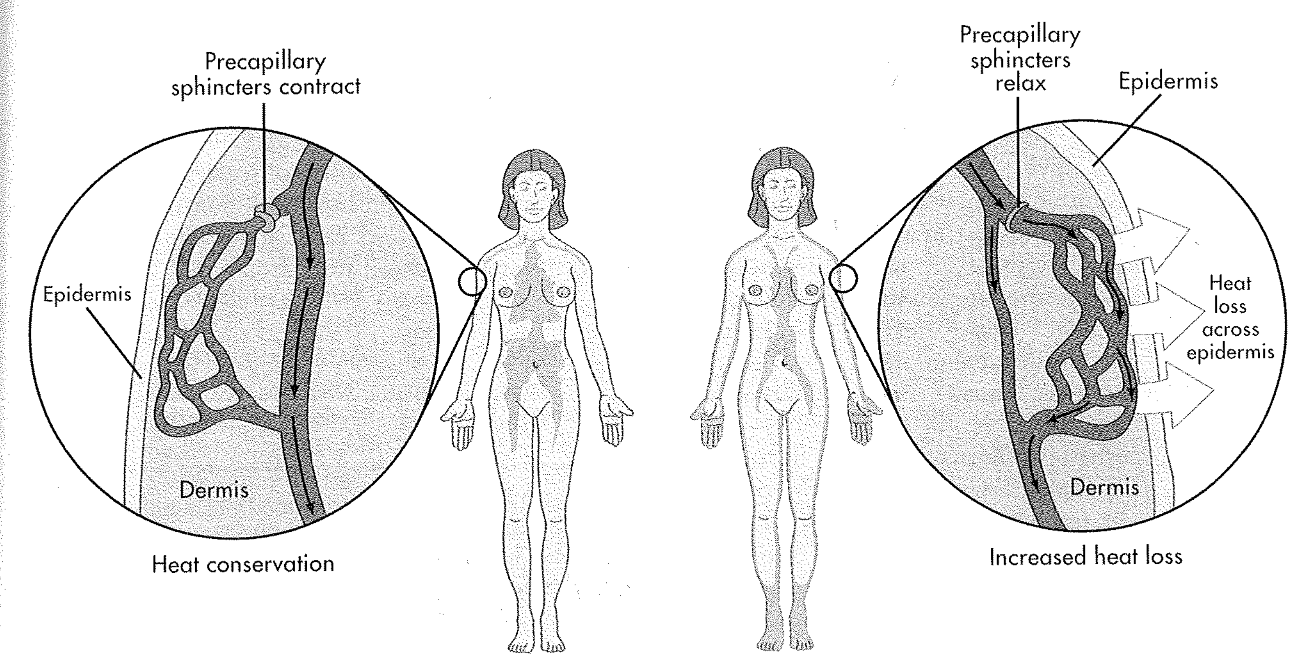
mus results from an overall lack of calories and proteins, such as when sufficient quantities of food are not available. Marasmus is characterized by progressive wasting of muscle and subcutaneous tissue accompanied by fluid and electrolyte imbalances. Kwashiorkor results from a protein deficiency in the presence of sufficient calories, as when a child is weaned from milk to low-protein foods. Kwashiorkor also causes wasting of tissues, but unlike marasmus, it also causes pronounced ascites (abdominal bloating) and flaking dermatitis. The ascites results from a deficiency of plasma proteins, which changes the osmotic balance of the blood and thus promotes osmosis of water from the blood into the peritoneal space (see Figure 16-17).

Nutrition disorders, including many specific deficiency diseases, are summarized in Appendix B.

Body Temperature

Considering the fact that over 60% of the energy released from food molecules during catabolism is converted to heat rather than being transferred to ATP, it is no wonder that maintaining a constant body temperature is a challenge. Maintaining homeostasis of body temperature or thermoregulation is the function of the hypothalamus. The hypothalamus operates a variety of negative-feedback mechanisms that keep body temperature in its normal range (36.2° to 37.6° C or 97° to 100° F).

FIGURE 17–7 ***The Skin as a Thermoregulatory Organ.*** When homeostasis requires that the body conserve heat, blood flow in the warm organs of the body's core increases *(left)*. When heat must be lost to maintain the stability of the internal environment, flow of warm blood to the skin increases *(right)*. Heat can be lost from the blood and skin by means of radiation, conduction, convection, and evaporation.



The skin is often involved in negative-feedback loops that maintain body temperature. When the body is overheated, blood flow to the skin increases (Figure 17-7). Warm blood from the body's core can then be cooled by the skin, which acts as a radiator. At the skin, heat can be lost from blood by the following mechanisms:

1. Radiation—flow of heat waves away from the blood
2. Conduction—transfer of heat energy to the skin and then the external environment
3. Convection—transfer of heat energy to air that is continually flowing away from the skin
4. Evaporation—absorption of heat by water (sweat) vaporization

When necessary, heat can be conserved by reducing blood flow in the skin (Figure 17-7).

A number of other mechanisms can be called on to help maintain the homeostasis of body temperature. Heat-generating muscle activity such as shivering and secretion of metabolism-regulating hormones are two of the body's processes that can be altered to adjust the body's temperature. The concept of using feedback control loops in homeostatic mechanisms was introduced in Chapter 1.

ABNORMAL BODY TEMPERATURE

Maintenance of a body temperature within a narrow range is necessary for normal functioning of the body. As Figure 17-8 shows, straying too far out of the normal range of body temperatures can have very serious physiological consequences. A few important conditions related to body temperature are listed on p. 452.

1. Fever—As explained in Chapter 4, a fever or *febrile* state is an unusually high body temperature associated with a systemic inflammation response. In the case of infections, chemicals called *pyrogens* (literally "fire-makers") cause the thermostatic control centers of the hypothalamus to produce a fever. Because the body's "thermostat" is reset to a higher setting, a person feels a need to warm up to this new temperature and often experiences "chills" as the febrile state begins. The high body temperature associated with infectious fever is thought to enhance the body's immune responses, eliminating the pathogen. Strategies aimed at reducing the temperature of a febrile person are normally counteracted by the body's heat-generating mechanisms and have the effect of further weakening the infected person. Under ordinary circumstances, it is best to let the fever "break" on its own after the pathogen is destroyed.

2. Malignant hyperthermia (MH) is an inherited condition characterized by an abnormally increased body temperature (hyperthermia) and muscle rigidity when exposed to certain anesthetics (succinylcholine, for example). The drug *dantrolene (Dantrium)*, which inhibits heat-producing muscle contractions, has been used to prevent or relieve effects of this condition.

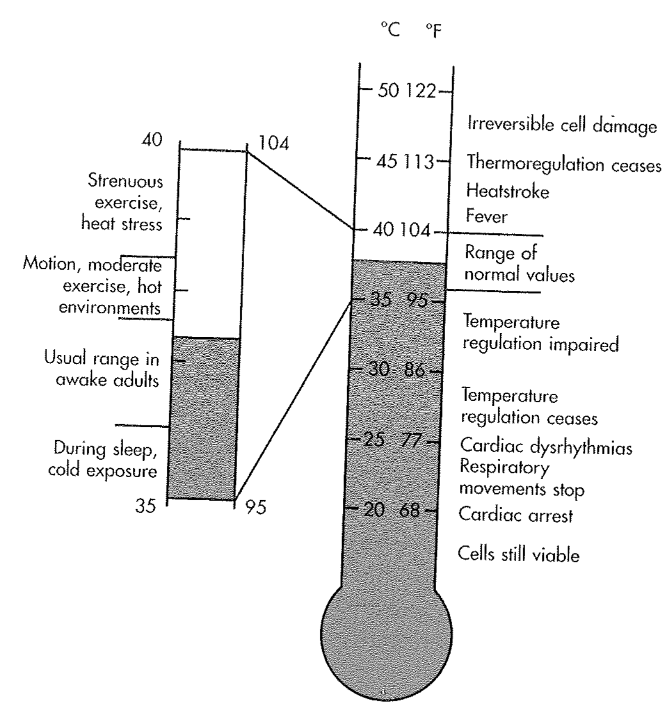
3. Heat exhaustion occurs when the body loses a large amount of fluid resulting from heat-loss mechanisms. This usually happens when environmental temperatures are high. Although a normal body temperature is maintained, the loss of water and electrolytes can cause weakness, vertigo, nausea, and possibly loss of consciousness. Heat exhaustion may also be accompanied by skeletal muscle cramps that are often called *heat cramps*. Heat exhaustion is treated with rest (in a cool environment) accompanied by fluid replacement.

4. Heat stroke or *sunstroke* is a severe, sometimes fatal condition resulting from the inability of the body to maintain a normal temperature in an extremely warm environment. Such thermoregulatory failure may result from factors such as old age, disease, drugs that impair thermoregulation, or simply overwhelming elevated environmental temperatures. Heat stroke is characterized by body temperatures of 41° C (105° F) or higher, tachycardia, headache, and hot, dry skin. Confusion, convulsions, or loss of consciousness may occur. Unless the body is cooled and body fluids replaced immediately, death may result.

5. Hypothermia (hye-po-THER-me-ah) is the inability to maintain a normal body temperature in extremely cold environments. Hypothermia is characterized by body temperatures lower than 35° C (95° F), shallow and slow respirations, and a faint, slow pulse. Hypothermia is usually treated by slowly warming the affected person's body.

6. Frostbite is local damage to tissues caused by extremely low temperatures. Damage to tissues results from formation of ice crystals accompanied by a reduction in local blood flow. Necrosis (tissue death) and even gangrene (decay of dead tissue) can result from frostbite.

FIGURE 17-8 *Body Temperature.* This diagram, modeled after a thermometer, shows some of the physiological consequences of abnormal body temperature. The normal range of body temperature under a variety of conditions is shown in the inset.



OUTLINE SUMMARY

DEFINITIONS

A Nutrition—food, vitamins, and minerals that are ingested and assimilated into the body
B Metabolism—process of using food molecules as energy sources and as building blocks for our own molecules
C Catabolism—breaks food molecules down, releasing their stored energy; oxygen used in catabolism
D Anabolism—builds food molecules into complex substances

ROLE OF THE LIVER

A Processes blood immediately after it leaves the gastrointestinal tract
  1 Helps maintain normal blood glucose level
  2 Site of protein and fat metabolism
  3 Removes toxins from the blood

NUTRIENT METABOLISM

A Carbohydrates are primarily catabolized for energy (Figure 17-1), but small amounts are anabolized by glycogenesis (a series of chemical reactions that changes glucose to glycogen—occurs mainly in liver cells where glycogen is stored)
B Blood glucose (imprecisely, blood sugar)—normally stays between about 80 and 120 mg per 100 ml of blood; insulin accelerates the movement of glucose out of the blood into cells, therefore decreases blood glucose and increases glucose catabolism
C Adenosine triphosphate (ATP)—molecule in which energy obtained from breakdown of foods is stored; serves as a direct source of energy for cellular work (Figure 17-2)
D Fats catabolized to yield energy and anabolized to form adipose tissue (Figure 17-3)
E Proteins primarily anabolized and secondarily catabolized

VITAMINS AND MINERALS

A Vitamins—organic molecules that are needed in small amounts for normal metabolism (Table 17-2)
  1 Avitaminosis—deficiency of a vitamin, such as avitaminosis C (vitamin C deficiency)
  2 Hypervitaminosis—excess of a vitamin, such as hypervitaminosis A (excess of vitamin A)
B Minerals—inorganic molecules required by the body for normal function (Table 17-3)

METABOLIC RATES

A Basal metabolic rate (BMR)—rate of metabolism when a person is lying down but awake and not digesting food and when the environment is comfortably warm
B Total metabolic rate (TMR)—the total amounts of energy, expressed in calories, used by the body per day (Figure 17-5)

METABOLIC AND EATING DISORDERS

A Inborn errors of metabolism—genetic conditions involving deficient or abnormal metabolic enzymes
B Hormonal imbalances may cause metabolic problems
C Eating disorders usually have an underlying emotional cause
D Examples of eating and nutritional disorders
  1 Anorexia nervosa is characterized by chronic refusal to eat
  2 Bulimia involves an alternating pattern of craving of food followed by a period of self-denial; in bulimarexia, the self-denial triggers self-induced vomiting
  3 Obesity—abnormally high proportion of fat in the body; may be a symptom of an eating disorder
  4 Protein-calorie malnutrition (PCM)—results from a deficiency of calories in general and proteins in particular (Figure 17-6)
    a May be a complication of a preexisting condition (Table 17-4)
    b Marasmus—type of advanced PCM caused by an overall lack of calories and protein, characterized by tissue wasting and fluid and electrolyte imbalances
    c Kwashiorkor—type of advanced PCM caused by a lack of protein in the presence of sufficient calories; similar to marasmus but distinguished by ascites and flaking dermatitis

BODY TEMPERATURE

A Hypothalamus—regulates the homeostasis of body temperature through a variety of processes
B Skin—can cool the body by losing heat from the blood through four processes: radiation, conduction, convection, evaporation (Figure 17-7)
C Abnormal body temperature can have serious physiological consequences
  1 Fever (febrile state)—unusually high body temperature associated with systemic imflammation response
  2 Malignant hyperthermia—inherited condition that causes increased body temperature (hyperthermia) and muscle rigidity when exposed to certain anesthetics
  3 Heat exhaustion—results from loss of fluid as the body tries to cool itself; may be accompanied by heat cramps
  4 Heat stroke (sunstroke)—overheating of body resulting from failure of thermoregulatory mechanisms in a warm environment
  5 Hypothermia—reduced body temperature resulting from failure of thermoregulatory mechanisms in a cold environment
  6 Frostbite—local tissue damage caused by extreme cold; may result in necrosis or gangrene

NEW WORDS

anabolism
basal metabolic rate (BMR)
calorie
catabolism
citric acid cycle
glycogenesis
glycolysis
kilocalorie
thermoregulation
total metabolic rate (TMR)
vitamin

Diseases and Other Clinical Terms

anorexia nervosa
avitaminosis
bulimarexia
bulimia
frostbite
heat exhaustion
heat stroke
hypercholesterolemia
hypervitaminosis
hypothermia
malignant hyperthermia
obesity
phenylketonuria (PKU)
protein-calorie malnutrition (PCM)
scurvy

CHAPTER TEST

1. The type of metabolism that involves the breakdown of food molecules is called ______________.
2. The type of metabolism that involves the synthesis of large molecules is called ______________.
3. *Nutrition* refers to the food that we eat, whereas ______________ refers to the use of foods after they have entered the cells.
4. The ______________ vein delivers blood from the gastrointestinal tract directly to the liver.
5. The chemical process that changes glucose into pyruvic acid, producing energy, is called ______________.
6. The series of reactions in liver cells that joins glucose molecules together to form glycogen is called ______________.
7. When the body runs low on carbohydrates several hours after a meal, it begins catabolizing ______________ instead.
8. ______________ are organic molecules needed in small quantities for normal metabolism throughout the body.
9. The molecule in which energy from catabolism is stored until it is used by the cell is called ______________.
10. The rate at which food is catabolized in a resting individual who is not digesting a meal is called the ______________.
11. Thermoregulation is controlled mainly by the ______________ in the brain.
12. Heat exhaustion may progress to become ______________ ______________ if the body's thermoregulatory mechanisms fail.
13. ______________ occurs when tissue in local areas is damaged by extreme or prolonged cold temperatures.

Circle the T before each true statement and the F before each false statement.

T F 14. The citric acid cycle changes glucose into pyruvic acid, releasing energy for the cell's use.
T F 15. Insulin promotes the entry of glucose into body cells.
T F 16. Anorexia nervosa can result in death.
T F 17. Minerals can also be called *vitamins*.
T F 18. Sodium is a mineral that is found in only a few types of food.
T F 19. Basal metabolic rate (BMR) and total metabolic rate (TMR) for a particular individual are always the same.
T F 20. The skin is an important organ for maintaining the body's temperature homeostasis.

REVIEW QUESTIONS

1. Briefly and clearly explain anabolism, catabolism, metabolism, and nutrition.
2. In words or in a sketched diagram, describe the metabolic pathway taken by a glucose molecule when energy is extracted from it.
3. Liver cells perform a process that prevents the blood glucose level from getting too high just after a large meal. What is it?
4. How are fats used by the body? Proteins?
5. What is the difference between essential and nonessential amino acids?
6. Explain the metabolic roles of vitamins and minerals.
7. Explain what is meant by the term *metabolic rate.* What is the difference between basal metabolic rate and total metabolic rate.
8. What is protein-calorie malnutrition? What factors or conditions may lead to this nutritional disorder?
9. How does the body maintain the body temperature within a normal range?
10. Name the four mechanisms by which the skin removes heat from the body.
11. Briefly explain the mechanisms for each of these abnormalities: fever, malignant hyperthermia, heat exhaustion, heat stroke, hypothermia, frostbite.

CRITICAL THINKING

12. What adaptive advantage is gained by detouring blood from the gastrointestinal tract to the liver before returning it to the heart?
13. How does the body get energy during fasting?
14. Explain why you think the following statement is true or false: "If you do not want to gain or lose weight but just stay the same, you must eat just enough food to supply the kilocalories of your BMR. If you eat more than this, you will gain; if you eat less than this, you will lose."
15. Compare and contrast anorexia nervosa and bulimia.

CLINICAL APPLICATIONS

1. A friend of yours is helping you chop firewood on a hot day. She complains of muscle cramps and nausea but has a normal body temperature. What has happened to her? How would you help your friend?
2. While looking through an old family album, you can't help but notice that your great-great-great-grandfather's smile reveals that he has no teeth. When asked why this ancestor lost his teeth at an early age, your grandmother replies that he suffered from scurvy as a merchant marine and lost all his teeth as a result. Is this possible? Can you explain how scurvy can cause the loss of teeth?
3. Andrea is planning to adopt a totally vegetarian diet—a diet that includes no meats or animal products. Her friends have voiced some concern that her new diet may not contain certain essential amino acids. What is an essential amino acid? Why must her diet contain these nutrients?