Colorized scanning electron micrograph (SEM) of a mitochondrion in the cytoplasm of an intestinal epithelial cell. The mitochondrion has an outer and inner membrane. The inner membrane has numerous folds that project into the interior of the mitochondrion. Enzymes, necessary for producing ATP, are located in these folds.

Nutrition, Metabolism, and Temperature Regulation

CHAPTER

25

We are usually more concerned with the taste of food than with its nutritional value when choosing from a menu or when selecting food to prepare. Knowing about nutrition is important, however, because we literally are what we eat. Food provides us with energy and the building blocks necessary to synthesize new molecules. What happens if we don't obtain enough vitamins, or if we eat too much sugar and fats? Health claims about foods and food supplements bombard us every day. Which ones are ridiculous, and which ones have merit? A basic understanding of nutrition can help us to answer these and other questions so that we can develop a healthy diet.

This chapter explains *nutrition* (912), *metabolism* (920), *carbohydrate metabolism* (922), *lipid metabolism* (929), *protein metabolism* (930), *interconversion of nutrient molecules* (931), *metabolic states* (932), *metabolic rate* (934), and *body temperature regulation* (935).

Nutrition

Objectives

- *Define nutrients, and describe the food guide pyramid.*
- *Describe for carbohydrates, lipids, and proteins their dietary sources, their uses in the body, and the daily recommended amounts of each in the diet.*
- *List the vitamins and minerals, and indicate the function of each. Define the terms Daily Values and % Daily Value.*

Nutrition is the process by which certain components of food are obtained and used by the body. The process includes digestion, absorption, transportation, and cell metabolism. Nutrition is also defined as the evaluation of food and drink requirements for normal body function.

Nutrients

Nutrients are the chemicals taken into the body that are used to produce energy, provide building blocks for new molecules, or function in other chemical reactions. Some important substances in food, such as nondigestible plant fibers, are not nutrients. Nutrients are divided into six major classes: carbohydrates, proteins, lipids, vitamins, minerals, and water. Carbohydrates, proteins, and lipids are the major organic nutrients and are broken down by enzymes into their individual components during digestion. Many of these subunits are broken down further to supply energy, whereas others are used as building blocks for other macromolecules. Carbohydrates, proteins, lipids, and water are required in fairly substantial quantities, whereas vitamins and minerals are required in only small amounts. Vitamins, minerals, and water are taken into the body without being digested.

Essential nutrients are nutrients that must be ingested because the body cannot manufacture them or is unable to manufacture adequate amounts of them. The essential nutrients include certain amino acids, certain fatty acids, most vitamins, minerals, water, and a minimum amount of carbohydrates. The term *essential* doesn't mean, however, that only the essential nutrients are required by the body. Other nutrients are necessary, but, if they are not part of the diet, they can be synthesized from other ingested nutrients. Most of this synthesis takes place in the liver, which has a remarkable ability to transform and manufacture molecules.

The U.S. Department of Agriculture provides recommendations for obtaining the proper amounts of carbohydrates, lipids, proteins, vitamins, minerals, and fiber in the form of a "food guide pyramid" (figure 25.1). The six food groups shown in the pyramid are (1) bread, cereal, rice, and pasta; (2) vegetables; (3) fruits; (4) milk, yogurt, and cheese; (5) meat, poultry, fish, dry beans, eggs, and nuts; and (6) fats, oils, and sweets. The shape of the pyramid suggests that grains, vegetables, and fruits should be the main part of the diet. Fats, oils, and sweets can be used in moderation to improve the flavor of foods. A balanced diet includes a variety of foods from each of the major food groups. Variety is necessary because no one food contains all the nutrients necessary for good health.

Benefits of a Healthy Diet

Two studies completed in 2000 compared the eating habits of 67,272 women and 51,529 men to the government's Healthy Eating Index, a measure of how well a diet conforms to dietary guidelines and the food pyramid. Those who ate best, according to the index, were compared to those who ate the worst. Men who ate best had a 28% reduction in heart disease and a 11% decrease in chronic diseases compared to men who ate worst. Women who ate best had a 14% reduction in heart disease but no significant decrease in chronic diseases compared to women who ate worst. There was no significant difference in cancer between the men and women who ate best compared to those who ate worst.

1. *Define the terms nutrient and essential nutrient, and list the six major classes of nutrients.*
2. *List the six food groups shown in a food guide pyramid. What food groups are at the bottom and top of the pyramid?*

Kilocalories

The energy stored within the chemical bonds of certain nutrients is used by the body. A **calorie** (kal′ō-rē; **cal**) is the amount of energy (heat) necessary to raise the temperature of 1 g of water 1°C. A **kilocalorie** (kil′ō-kal-ō-rē; **kcal**) is 1000 calories and is used to express the larger amounts of energy supplied by foods and released through metabolism.

What Is a Calorie?

A kilocalorie is often called a Calorie (with a capital *C*). Unfortunately, this usage has resulted in confusion between the terms *calorie* (with a lowercase *c*) and *Calorie* (with a capital *C*). It's common practice on food labels and in nutrition books to use calorie when Calorie (kilocalorie) is the proper term.

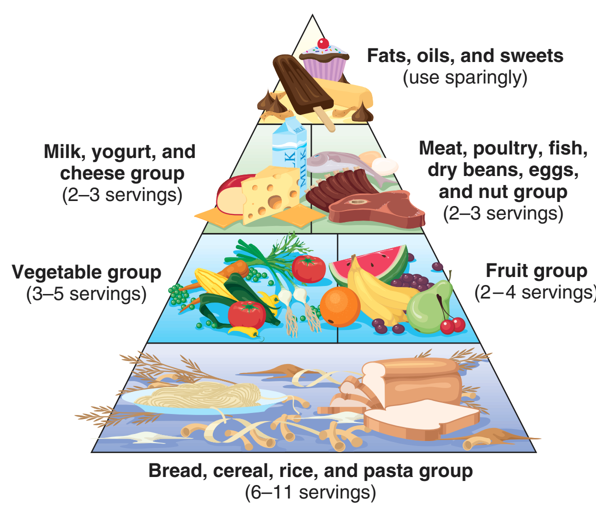


Figure 25.1 Food Guide Pyramid

The pyramid suggests three approaches to a healthy diet: eat different amounts of foods from each basic food group, use fats and sugars sparingly, and choose variety by eating the indicated number of servings per day of the different foods from each major food group.

Almost all of the kilocalories supplied by food come from carbohydrates, proteins, or fats. For each gram of carbohydrate or protein that the body metabolizes, about 4 kcal of energy is released. Fats contain more energy per unit of weight than carbohydrates and proteins and yield about 9 kcal/g. Table 25.1 lists the kilocalories supplied by some typical foods. A typical diet in the United States consists of 50%–60% carbohydrates, 35%–45% fats, and 10%–15% protein. Table 25.1 also lists the carbohydrate, fat, and protein composition of some foods.

3. Define the term kilocalorie, and state the number of kilocalories supplied by a gram of carbohydrate, lipid, and protein.

Carbohydrates

Sources in the Diet

Carbohydrates include monosaccharides, disaccharides, and polysaccharides (see chapter 2). Most of the carbohydrates humans ingest come from plants. An exception is lactose (milk sugar), which is found in animal and human milk.

The most common monosaccharides in the diet are glucose and fructose. Plants capture the energy in sunlight and use the energy to produce glucose which can be found in vegetables. Fructose (fruit sugar) and galactose are isomers of glucose (see figure 2.14). Glucose is found in vegetables and fructose is found in fruits, berries, honey, and high-fructose corn syrup, which is used to sweeten soft drinks and desserts. Galactose is usually found in milk.

The disaccharide sucrose (table sugar) is what most people think of when they use the term *sugar.* Sucrose is a glucose and a fructose molecule joined together, and its principal sources are sugarcane, sugar beets, maple sugar, and honey. Maltose (malt sugar), derived from germinating cereals, is a combination of two glucose molecules, and lactose (in milk) consists of a glucose and a galactose molecule (see figure 2.14).

The **complex carbohydrates** are the polysaccharides: starch, glycogen, and cellulose. These polysaccharides consist of many glucose molecules bound together to form long chains. Starch is an energy storage molecule in plants and is found primarily in vegetables, fruits, and grains. Glycogen is an energy storage molecule in animals and is located in muscle and in the liver. By the time meats

Table 25.1 Food Consumption

Food	Quantity	Food Energy (kcal)	Carbohydrate (g)	Fat (g)	Protein (g)
Dairy Products					
Whole milk (3.3% fat)	1 cup	150	11	8	8
Low fat milk (2% fat)	1 cup	120	12	5	8
Butter	1 tablespoon	100	—	12	—
Grain					
Bread, white enriched	1 slice	75	24	1	2
Bread, whole wheat	1 slice	65	14	1	3
Fruit					
Apple	1	80	20	1	—
Banana	1	100	26	—	1
Orange	1	65	16	—	1
Vegetables					
Corn, canned	1 cup	140	33	1	4
Peas, canned	1 cup	150	29	1	8
Lettuce	1 cup	5	2	—	—
Celery	1 cup	20	5	—	1
Potato, baked	1 large	145	33	—	4
Meat, Fish, and Poultry					
Lean ground beef (10% fat)	3 ounces	185	—	10	23
Shrimp, french fried	3 ounces	190	9	9	17
Tuna, canned	3 ounces	170	—	7	24
Chicken breast, fried	3 ounces	160	1	5	26
Bacon	2 slices	85	—	8	4
Hot dog	1	170	1	15	7

continued

Table 25.1 *continued*

Food	Quantity	Food Energy (kcal)	Carbohydrate (g)	Fat (g)	Protein (g)
Fast Foods					
McDonald's Egg McMuffin	1	327	31	15	19
McDonald's Big Mac	1	563	41	33	26
Taco Bell's beef burrito	1	466	37	21	30
Arby's roast beef	1	350	32	15	22
Pizza Hut Super Supreme	1 slice	260	23	13	15
Long John Silver's fish	2 pieces	366	21	22	22
McDonald's fish fillet	1	432	37	25	14
Dairy Queen malt, large	1	840	125	28	22
Desserts					
Cupcake with icing	1	130	21	5	2
Chocolate chip cookie	4	200	29	9	2
Apple pie	1 piece	345	51	15	3
Dairy Queen cone, large	1	340	52	10	10
Beverage					
Cola soft drink	12 ounces	145	37	—	—
Beer	12 ounces	144	13	—	1
Wine	31/2 ounces	73	2	—	—
Hard liquor (86 proof)	11/2 ounces	105	—	—	—
Miscellaneous					
Egg	1	80	1	6	6
Mayonnaise	1 tablespoon	100	—	11	—
Sugar	1 tablespoon	45	12	—	—

are processed and cooked, they contain little, if any, glycogen. Cellulose forms cell walls, which surround plant cells.

Uses in the Body

During digestion, polysaccharides and disaccharides are split into monosaccharides, which are absorbed into the blood (see chapter 24). Humans can digest starch and glycogen because they can break the bonds between the glucose molecules of starch and glycogen. Humans are unable to digest cellulose because they can't break the bonds between its glucose molecules. Instead, cellulose provides fiber, or "roughage," thereby increasing the bulk of feces and promoting defecation.

The liver converts fructose, galactose, and other monosaccharides absorbed by the blood into glucose. Glucose, whether absorbed from the digestive tract or produced by the liver, is a primary energy source for most cells, which use it to produce **adenosine triphosphate (ATP)** molecules (see "Anaerobic Respiration" on p. 923 and "Aerobic Respiration" on p. 925). Because the brain relies almost entirely on glucose for its energy, blood glucose levels are carefully regulated (see chapter 18).

If excess amounts of glucose are present, the glucose is converted into glycogen, which is stored in muscle and in the liver. Glycogen can be rapidly converted back to glucose when energy is needed. Because cells can store only a limited amount of glycogen, any additional glucose is converted into fat, which is stored in adipose tissue.

In addition to being used as a source of energy, sugars have other functions. They form part of deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and ATP molecules (see chapter 2); and they combine with proteins to form glycoproteins, such as the glycoprotein receptor molecules on the outer surface of the plasma membrane (see chapter 3).

Recommended Amounts

It's recommended that 60% of the daily intake of kilocalories be from carbohydrates. Although a minimum acceptable level of carbohydrate ingestion is unknown, consumption of too few carbohydrates per day results in overuse of proteins and fats for energy sources. Because muscles are primarily protein, the use of proteins for energy can result in the breakdown of muscle tissue, and the use of fats can result in acidosis (see chapter 27).

Complex carbohydrates are recommended because starchy foods often contain other valuable nutrients like vitamins and minerals. Although foods like soft drinks and candy are rich in carbohydrates, they are mostly sugar and they may have little other nutritive value. For example, a typical soft drink contains 9 teaspoons of sugar. In excess, the consumption of foods high in sugar content can result in obesity and tooth decay.

4. What are the most common monosaccharides in the diet? What are sucrose, maltose, and lactose?
5. Give three examples of complex carbohydrates. How are they used by the body?
6. How does the body use glucose and other monosaccharides?
7. What quantities of carbohydrate should be ingested daily?

Lipids

Sources in the Diet

About 95% of the lipids in the human diet are **triglycerides** (trī-glis′er-īdz). Triglycerides, which are sometimes called **triacylglycerols** (trī-as′il-glis′er-olz), consist of three fatty acids attached to a glycerol molecule (see chapter 2). Triglycerides are often referred to as fats, which are divided into saturated and unsaturated fats. **Saturated fats** have only single covalent bonds between the carbon atoms of their fatty acids (see figure 2.17). They are found in the fats of meats (e.g., beef, pork), dairy products (e.g., whole milk, cheese, butter), eggs, coconut oil, and palm oil. **Unsaturated fats** have one (monounsaturated) or more (polyunsaturated) double covalent bonds between the carbon atoms of their fatty acids (see figure 2.17). Monounsaturated fats include olive and peanut oils; and polyunsaturated fats occur in fish, safflower, sunflower, and corn oil.

Saturating Fats

Solid fats, such as shortening and margarine, work better than liquid oils do for preparing some foods, such as pastries. Polyunsaturated vegetable oils can be changed from a liquid to a solid by making them more saturated, that is, by decreasing the number of double covalent bonds in their polyunsaturated fatty acids. Hydrogen gas is bubbled through the oil. As hydrogen binds to the fatty acids, double covalent bonds are converted to single covalent bonds to produce a change in molecular shape that solidifies the oil. The more saturated the product, the harder it becomes at room temperature.

The remaining 5% of lipids include cholesterol and phospholipids like **lecithin** (les′i-thin). Cholesterol is a steroid (see chapter 2) found in high concentrations in liver and egg yolks, but it's also present in whole milk, cheese, butter, and meats. Cholesterol is not found in plants. Phospholipids are major components of plasma membranes, and they are found in a variety of foods. A good source of lecithin is egg yolks.

Uses in the Body

Triglycerides are important sources of energy that are used to produce ATP molecules. A gram of triglyceride delivers more than twice as many kilocalories as a gram of carbohydrate. Some cells, such as skeletal muscle cells, derive most of their energy from triglycerides.

After a meal, excess triglycerides that are not immediately used are stored in adipose tissue or the liver. Later, when energy is required, the triglycerides are broken down, and their fatty acids are released into the blood, where they are taken up and used by various tissues. In addition to storing energy, adipose tissue surrounds and pads organs, and under the skin adipose tissue is an insulator, which prevents heat loss.

Cholesterol is an important molecule with many functions in the body. It can either be obtained in food or manufactured by the liver and most other tissues. Cholesterol is a component of the plasma membrane, and it can be modified to form other useful molecules, such as bile salts and steroid hormones. Bile salts are necessary for fat digestion and absorption. Steroid hormones include the sex hormones estrogen, progesterone, and testosterone, which regulate the reproductive system.

The eicosanoids (ī′kō-să-noydz), which include prostaglandins and leukotrienes, are derived from fatty acids. The molecules are involved in activities like inflammation, blood clotting, tissue repair, and smooth muscle contraction. Phospholipids, such as lecithin, are part of the plasma membrane and are used to construct the myelin sheath around the axons of nerve cells. Lecithin is also found in bile and helps to emulsify fats.

Recommended Amounts

The American Heart Association recommends that fats account for 30% or less of the total daily kilocaloric intake, with 8%–10% coming from saturated fats, up to 10% from polyunsaturated fats, and up to 15% from monounsaturated fats. Furthermore, saturated fats should contribute no more than 10% of total fat intake, and cholesterol should be limited to 300 mg (the amount in an egg yolk) or less per day. These guidelines reflect the belief that excess amounts of fats, especially saturated fats and cholesterol, contribute to cardiovascular disease. Evidence also suggests that high-fat intake is associated with colon cancer. The typical U.S. diet derives 35%–45% of its kilocalories from fats, indicating that most Americans need to reduce fat consumption. On the other hand, fat intake may account for as little as 10% of the kilocalories in a healthy person's diet.

Most of the lecithin consumed in the diet is broken down in the digestive tract. The liver has the ability to manufacture all of the lecithin necessary to meet the body's needs, and it's not necessary to consume lecithin supplements.

Linoleic (lin-ō-lē′ik) **acid** and **α-linolenic** (lin-ō-len′ik) **acid** are **essential fatty acids** because the body cannot synthesize them and they must be ingested. They are found in plant oils, such as canola or soybean oils.

Fatty Acids and Blood Clotting

The essential fatty acids are used to synthesize prostaglandins that affect blood clotting. Linoleic acid can be converted to **arachidonic** (ă-rak-i-don′ik) **acid,** which is used to produce prostaglandins that increase blood clotting. Alpha-linolenic acid can be converted to **eicosapentaenoic** (ī′kō-să-pen-tă-nō′ik) **acid (EPA),** which is used to produce prostaglandins that decrease blood clotting. Normally, most prostaglandins are synthesized from linoleic acid because it's more plentiful in the body. Individuals who consume foods rich in EPA, however, such as herring, salmon, tuna, and sardines, increase the synthesis of prostaglandins from EPA. Individuals who eat these fish twice or more times per week have a lower risk of heart attack than those who don't, possibly because of reduced blood clotting. Although EPA can be obtained using fish oil supplements, this is not currently recommended because fish oil supplements contain high amounts of cholesterol, vitamins A and D, and uncommon fatty acids, all of which can cause health problems when taken in large amounts.

8. *What is the major source of lipids in the diet? What are other sources?*
9. *Define saturated and unsaturated fats.*
10. *How are triglycerides, cholesterol, prostaglandins, and lecithin used by the body?*
11. *Describe the recommended dietary intake of lipids. List the essential fatty acids.*

Proteins

Sources in the Diet

Proteins are chains of amino acids (see chapter 2). Proteins in the human body are constructed of 20 different kinds of amino acids, which are divided into two groups: essential and nonessential amino acids. The body cannot synthesize **essential amino acids,** so they must be obtained in the diet. The nine essential amino acids are histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. The body can synthesize **nonessential amino acids** from other molecules. If adequate amounts of the essential amino acids are ingested, they can be converted to the nonessential amino acids. Like the essential amino acids, the nonessential amino acids are necessary for good health.

A **complete protein** food contains adequate amounts of all nine essential amino acids, whereas an **incomplete protein** food does not. Examples of complete proteins are meat, fish, poultry, milk, cheese, and eggs, and examples of incomplete proteins are leafy green vegetables, grains, and legumes (peas and beans).

Uses in the Body

Essential and nonessential amino acids are used to synthesize proteins. Proteins perform numerous functions in the human body as the following examples illustrate. Collagen provides structural strength in connective tissue as does keratin in the skin, and the combination of actin and myosin makes muscle contraction possible. Enzymes are responsible for regulating the rate of chemical reactions, and protein hormones regulate many physiologic processes (see chapter 18). Proteins in the blood act as buffers to prevent changes in pH, and hemoglobin transports oxygen and carbon dioxide in the blood. Proteins also function as carrier molecules to move materials across plasma membranes, and other proteins in the plasma membrane function as receptor molecules and ion channels. Antibodies, lymphokines, and complement are part of the immune system response that protects against microorganisms and other foreign substances.

Proteins are also used as a source of energy, yielding the same amount of energy as carbohydrates. If excess proteins are ingested, the energy in the proteins can be stored by converting their amino acids into glycogen or fats.

Recommended Amounts

The recommended daily consumption of protein for a healthy adult is 0.8 g/kg of body weight, or about 10% of total kilocalories (55 g protein/day for a 2000 kcal/day intake). A cup of skim milk contains 8 g protein, 1 ounce of meat contains 7 g protein, and a slice of bread provides 2 g protein. If two incomplete proteins, such as rice and beans are ingested, each can provide amino acids lacking in the other. Thus, a correctly balanced vegetarian diet can provide all of the essential amino acids.

When protein intake is adequate, the synthesis and breakdown of proteins in a healthy adult occurs at the same rate. The amino acids of proteins contain nitrogen; so saying that a person is in **nitrogen balance** means that the nitrogen content of ingested protein is equal to the nitrogen excreted in urine and feces. A starving person is in negative nitrogen balance because the nitrogen gained in the diet is less than that lost by excretion. In other words, when proteins are broken down for energy, more nitrogen is lost than is replaced in the diet. A growing child or a healthy pregnant woman, on the other hand, is in positive nitrogen balance because more nitrogen is going into the body to produce new tissues than is lost by excretion.

12. *Distinguish between essential and nonessential amino acids. Between complete and incomplete protein foods.*
13. *Describe some of the functions performed by proteins in the body.*
14. *What is the recommended daily consumption of proteins? Define the term nitrogen balance.*

Vitamins

Vitamins (vīt′ă-minz; life-giving chemicals) are organic molecules that exist in minute quantities in food and are essential to normal metabolism (table 25.2). **Essential vitamins** cannot be produced by the body and must be obtained through the diet. Because no single food item or nutrient class provides all the essential vitamins, it's necessary to maintain a balanced diet by eating a variety of foods. The absence of an essential vitamin in the diet can result in a specific deficiency disease. A few vitamins, such as vitamin K, are produced by intestinal bacteria, and a few can be formed by the body from substances called provitamins. A **provitamin** is a part of a vitamin that can be assembled or modified by the body into a functional vitamin. Beta carotene is an example of a provitamin that can be modified by the body to form vitamin A. The other provitamins are **7-dehydrocholesterol** (dē-hī′dro-kō-les′ter-ol), which can be converted to vitamin D, and **tryptophan** (trip′tō-fan), which can be converted to niacin.

Vitamins are not broken down by catabolism but are used by the body in their original or slightly modified forms. After the chemical structure of a vitamin is destroyed, its function is usually lost. The chemical structure of many vitamins is destroyed by heat, such as when food is overcooked.

Many vitamins function as **coenzymes,** which combine with enzymes to make the enzymes functional (see chapter 2). Without coenzymes and their enzymes, many chemical reactions would occur too slowly to support good health and even life. For example, vitamins B_2 and B_3, biotin (bī′ō-tin), and pantothenic (pan-tō-then′ik) acid are critical for the chemical reactions necessary to produce energy. Folate (fō′lāt) and vitamin B_{12} are involved in nucleic acid synthesis. Vitamins A, B_1, B_6, B_{12}, C, and D are necessary for growth. Vitamin K is necessary for the synthesis of proteins involved in blood clotting (see table 25.2).

Vitamins are either fat-soluble or water-soluble. **Fat-soluble vitamins,** such as vitamins A, D, E, and K, dissolve in lipids. They are absorbed from the intestine along with lipids. Some of them can be stored in the body for a long time. Because they can be stored, it's possible to accumulate these vitamins in the body to the

Table 25.2 The Principal Vitamins

Vitamin	Fat (F)– or Water (W)–Soluble	Source	Function	Symptoms of Deficiency	Reference Daily Intake (RDIs)*
A (retinol)	F	From provitamin carotene found in yellow and green vegetables: preformed in liver, egg yolk, butter, and milk	Necessary for rhodopsin synthesis, normal health of epithelial cells, and bone and tooth growth	Rhodopsin defiency, night blindness, retarded growth, skin disorders and increase in infection risk	1000 RE†
B_1 (thiamine)	W	Yeast, grains, and milk	Involved in carbohydrate and amino acid metabolism, necessary for growth	Beriberi—muscle weakness (including cardiac muscle), neuritis, and paralysis	1.5 mg
B_2 (riboflavin)	W	Green vegetables, liver, wheat germ, milk, and eggs	Component of flavin adenine dinucleotide; involved in citric acid cycle	Eye disorders and skin cracking, especially at corners of the mouth	1.7 mg
B_3 (niacin)	W	Fish, liver, red meat, yeast, grains, peas, beans, and nuts	Component of nicotinamide adenine dinucleotide; involved in glycolysis and citric acid cycle	Pellagra—diarrhea, dermatitis, and nervous system disorder	20 mg
Pantothenic acid	W	Liver, yeast, green vegetables, grains, and intestinal bacteria	Constituent of coenzyme-A, glucose production from lipids and amino acids, and steriod hormone synthesis	Neuromuscular dysfunction and fatigue	10 mg
Biotin	W	Liver, yeast, eggs, and intestinal bacteria	Fatty acid and nucleic acid synthesis; movement of pyruvic acid into citric acid cycle	Mental and muscle dysfunction, fatigue, and nausea	0.3 mg
B_6 (pyridoxine)	W	Fish, liver, yeast, tomatoes, and intestinal bacteria	Involved in amino acid metabolism	Dermatitis, retarded growth, and nausea	2.0 mg
Folate	W	Liver, green leafy vegetables, and intestinal bacteria	Nucleic acid synthesis, hematopoiesis; prevents birth defects	Macrocytic anemia (enlarged red blood cells) and spina bifida	0.4 mg
B_{12} (cobalamins)	W	Liver, red meat, milk, and eggs	Necessary for red blood cell production, some nucleic acid and amino acid metabolism	Pernicious anemia and nervous system disorders	6 µg
C (ascorbic acid)	W	Citrus fruit, tomatoes, and green vegetables	Collagen synthesis; general protein metabolism	Scurvy—defective bone formation and poor wound healing	60 mg
D (cholecalciferol, ergosterol)	F	Fish liver oil, enriched milk, and eggs; provitamin D converted by sunlight to cholecalciferol in the skin	Promotes calcium and phosphorus use; normal growth and bone and teeth formation	Rickets—poorly developed, weak bones, osteomalacia; bone reabsorption	400 IU‡
E (tocopherol, tocotrienols)	F	Wheat germ, cotton seed, palm, and rice oils; grain, liver, and lettuce	Prevents the oxidation of plasma membranes and DNA	Hemolysis of red blood cells	30 IU
K (phylloquinone)	F	Alfalfa, liver, spinach, vegetable oils, cabbage, and intestinal bacteria	Required for synthesis of a number of clotting factors	Excessive bleeding due to retarded blood clotting	80µg

* RDIs for people over 4 years of age; IU = international units.
† Retinol equivalents (RE). 1 retinol equivalent = 1 µg retinol or 6 µg beta carotene.
‡ As cholecalciferol. 1 µg cholecalciferol = 40 IU (international units) vitamin D.

point of toxicity. **Water-soluble vitamins,** such as the B vitamins and vitamin C, dissolve in water. They are absorbed from the water in the intestinal tract and remain in the body only a short time before being excreted.

Vitamins were discovered at the beginning of the twentieth century. They were found to be associated with certain foods that were known to protect people from diseases like rickets and beriberi. In 1941, the first Food and Nutrition Board established the **Recommended Dietary Allowances (RDAs),** which are the nutrient intakes sufficient to meet the needs of nearly all people in certain age and gender groups. RDAs have been established for different-aged males and females, starting with infants and continuing on to adults. RDAs are also set for pregnant and lactating women. The RDAs have been reevaluated every 4–5 years and updated, when necessary, on the basis of new information.

The RDAs establish a minimum intake of vitamins and minerals that should protect almost everyone (97%) in a given group from diseases caused by vitamin or mineral deficiencies. Although personal requirements can vary, the RDAs are a good benchmark. The further dietary intake is below the RDAs, the more likely a nutritional deficiency can occur. On the other hand, the consumption of too large a quantity of some vitamins and minerals can have harmful effects. For example, the long-term ingestion of 3–10 times the RDA for vitamin A can cause bone and muscle pain, skin disorders, hair loss, and increased liver size. The long-term consumption of 5–10 times the RDA of vitamin D can result in the deposition of calcium in the kidneys, heart, and blood vessels, and the regular consumption of more than 2 g of vitamin C daily can cause stomach inflammation and diarrhea.

Free Radicals and Antioxidants

Damage from free radicals may contribute to aging and certain diseases, such as atherosclerosis and cancer. **Free radicals** are molecules, produced as part of normal metabolism, that are missing an electron. Free radicals can replace the missing electron by taking an electron from cell molecules, such as fats, proteins, or DNA, resulting in damage to the cell. The loss of an electron from a molecule is called oxidation. **Antioxidants** are substances that prevent oxidation of cell components by donating an electron to free radicals. Examples of antioxidants include beta carotene (provitamin A), vitamin C, and vitamin E.

Many studies have been done to determine whether or not taking large doses of antioxidants is beneficial. Although future research may suggest otherwise, the consensus among scientists establishing the RDAs is that the best evidence presently available doesn't support the claims that taking large doses of antioxidants prevents chronic disease or otherwise improves health. On the other hand, the amount of antioxidants normally found in a balanced diet that includes fruits and vegetables rich in antioxidants, combined with the complex mix of other chemicals found in food, can be beneficial.

15. What are vitamins, essential vitamins, and provitamins? Name the water-soluble vitamins and the fat-soluble vitamins.
16. List some of the functions of vitamins.
17. What are Recommended Dietary Allowances (RDAs)? Why are they useful?

P R E D I C T 1

What would happen if vitamins were broken down during the process of digestion rather than being absorbed intact into the circulation?

Minerals

Minerals (min′er-ălz) are inorganic nutrients that are necessary for normal metabolic functions. They constitute about 4%–5% of the total body weight and are components of coenzymes, a few vitamins, hemoglobin, and other organic molecules. Minerals are involved in a number of important functions, such as establishing resting membrane potentials and generating action potentials, adding mechanical strength to bones and teeth, combining with organic molecules, or acting as coenzymes, buffers, or regulators of osmotic pressure. Table 25.3 lists important minerals and their functions.

Minerals are ingested by themselves or in combination with organic molecules. Minerals are obtained from animal and plant sources. Mineral absorption from plants, however, can be limited because the minerals tend to bind to plant fibers. Refined breads and cereals have hardly any minerals or vitamins because they are lost in the processing of the seeds used to make them. The seeds are crushed and the outer parts of the seeds, which contains most of their minerals and vitamins, are removed. The inner part of the seeds, which has few minerals and vitamins, is used to make the refined breads and cereals. Minerals and vitamins are often added to refined breads and cereals to compensate for their loss during the refinement process. A balanced diet can provide all the necessary minerals, with a few possible exceptions. For example, women who suffer from excessive menstrual bleeding may need an iron supplement.

18. What are minerals? List some of the important functions of minerals.

Caloric Intake and Life Span

Studies in mice, rats, and other animals indicate that life span can be increased by approximately one-third by decreasing normal caloric intake 30%–50%, provided the diet includes enough protein, fat, vitamins, and minerals. Why life span increases is not understood, but one proposed explanation for this phenomenon is that decreased caloric intake in some way reduces free radical damage to mitochondria. It has been suggested that humans might derive a similar benefit by reducing caloric input, starting at age 20. Unlike laboratory animals, however, humans would have to voluntarily restrict their caloric intake by 30%–50%, which is an unlikely behavioral change for most humans. Much more needs to be learned before it will be known if the restriction of caloric intake to increase longevity is beneficial to humans.

Daily Values

Daily Values are dietary reference values now appearing on food labels to help consumers plan a healthy diet. Daily Values are based on two other sets of reference values: Reference Daily Intakes and Daily Reference Values. The **Reference Daily Intakes (RDIs)** are based on the 1968 RDAs for certain vitamins and minerals. RDIs have been set for four categories of people: infants, toddlers, people over 4 years of age, and pregnant or lactating women. Generally, the RDIs are set to the highest 1968 RDA value of an age category.

Table 25.3 Important Minerals

Mineral	Function	Symptoms of Deficiency	Reference Daily Intake (RDIs)*
Calcium	Bone and teeth formation, blood clotting, muscle activity, and nerve function	Spontaneous action potential generation in neurons and tetany	1 g
Chloride	Blood acid–base balance; hydrochloric acid production in stomach	Acid–base imbalance	3.4 g
Chromium	Associated with enzymes in glucose metabolism	Unknown	120 µg
Cobalt	Component of vitamin B_{12}; red blood cell production	Anemia	Unknown
Copper	Hemoglobin and melanin production, electron-transport system	Anemia and loss of energy	2.0 mg
Fluorine	Provides extra strength in teeth; prevents dental caries	No real pathology	2.5 mg
Iodine	Thyroid hormone production, maintenance of normal metabolic rate	Goiter and decrease in normal metabolism	150 µg
Iron	Component of hemoglobin; ATP production in electron-transport system	Anemia, decreased oxygen transport, and energy loss	18 mg
Magnesium	Coenzyme constituent; bone formation; muscle and nerve function	Increased nervous system irritability, vasodilation, and arrhythmias	400 mg
Manganese	Hemoglobin synthesis; growth; activation of several enzymes	Tremors and convulsions	3.5 mg
Molybdenum	Enzyme component	Unknown	75µg
Phosphorus	Bone and teeth formation; important in energy transfer (ATP); component of nucleic acids	Loss of energy and cellular function	1 g
Potassium	Muscle and nerve function	Muscle weakness, abnormal electrocardiogram, and alkaline urine	2 g
Selenium	Component of many enzymes	Unknown	55 µg
Sodium	Osmotic pressure regulation; nerve and muscle function	Nausea, vomiting, exhaustion, and dizziness	500 mg†
Sulfur	Component of hormones; several vitamins, and proteins	Unknown	Unknown
Zinc	Component of several enzymes; carbon dioxide transport and metabolism; necessary for protein metabolism	Deficient carbon dioxide transport and deficient protein metabolism	15 mg

* RDIs for people over 4 years of age, except for sodium.
† The estimated minimum for people over 10 years of age. The maximum Daily Value for sodium is 2400 mg.

For example, the highest RDA for iron in males over 4 years of age is 10 mg/day and for females over 4 years of age is 18 mg/day. Thus, the RDI for iron is set at 18 mg/day. The **Daily Reference Values (DRVs)** are set for total fat, saturated fat, cholesterol, total carbohydrate, dietary fiber, sodium, potassium, and protein.

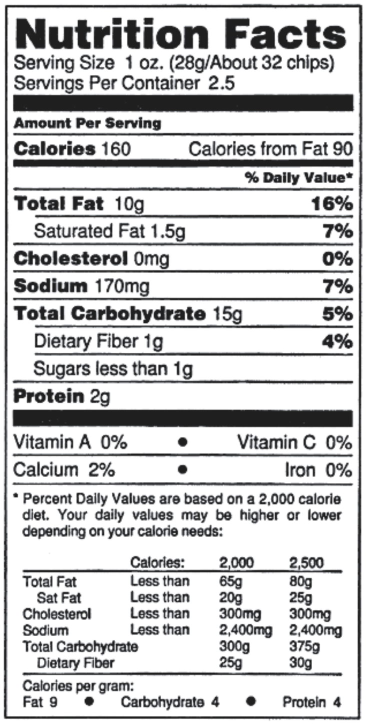
Having two standards on food labels, RDIs for vitamins and minerals and DRVs for other nutrients, was thought to be more confusing for consumers than having one standard.Therefore, the RDIs and DRVs are combined to form the Daily Values. In addition, not all possible Daily Values are required to be listed.

The Daily Values appearing on food labels are based on a 2000 kcal reference diet, which approximates the weight maintenance requirements of postmenopausal women, women who exercise moderately, teenage girls, and sedentary men (figure 25.2). On large food labels, additional information is listed based on a daily intake of 2500 kcal, which is adequate for young men.

The Daily Values for energy-producing nutrients are determined as a percentage of daily kilocaloric intake: 60% for carbohydrates, 30% for total fats, 10% for saturated fats, and 10% for proteins. The Daily Value for fiber is 11.5 g for each 1000 kcal of intake. The Daily Values for a nutrient in a 2000 kcal/day diet can be calculated on the basis of the recommended daily percentage of the nutrient and the kilocalories in a gram of the nutrient. For example, carbohydrates should be 60% of a 2000 kcal/day diet, or 1200 kcal/day (0.60×2000). Since there are 4 kcal in a gram of carbohydrate, the Daily Value for carbohydrate is 300 g/day (1200/4).

The Daily Value for some nutrients is the uppermost limit considered desirable because of the link between these nutrients and certain diseases. Thus, the Daily Values for total fats is less than 65 g, saturated fats is less than 20 g, and cholesterol is less than 300 mg because of their association with increased risk of heart disease. The Daily Value for sodium is less than 2400 mg because of its association with high blood pressure in some people.

For a particular food, the Daily Value is used to calculate the **Percent Daily Value (% Daily Value)** for some of the nutrients in one serving of the food (see figure 25.2). For example, if a serving of food has 3 g of fat and the Daily Value for total fat is 65 g, then the % Daily Value is 5% ($3/65 = 0.05$, or 5%). The Food and Drug Administration (FDA) requires % Daily Values to be on food labels so that the public has useful and accurate dietary information.



Nutrition Facts

Serving Size 1 oz. (28g/About 32 chips)
Servings Per Container 2.5

Amount Per Serving	
Calories 160	Calories from Fat 90
	% Daily Value*
Total Fat 10g	**16%**
Saturated Fat 1.5g	**7%**
Cholesterol 0mg	**0%**
Sodium 170mg	**7%**
Total Carbohydrate 15g	**5%**
Dietary Fiber 1g	**4%**
Sugars less than 1g	
Protein 2g	
Vitamin A 0% •	Vitamin C 0%
Calcium 2% •	Iron 0%

* Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4

Figure 25.2 Food Label

PREDICT 2

One serving of a food has 30 g of carbohydrate. What % Daily Value for carbohydrate is on the food label for this food?

The % Daily Values for nutrients related to energy consumption are based on a 2000 kcal/day diet. For people who maintain their weight on a 2000 kcal/day diet, the total of the % Daily Values for each of these nutrients should add up to no more than 100%. For individuals consuming more or fewer kilocalories per day than 2000 kcal, however, the total of the % Daily Values can be more or fewer than 100%. For example, for a person consuming 2200 kcal/day, the total of the % Daily Values for each of these nutrients should add up to no more than 110% because 2200/2000 = 1.10, or 110%.

PREDICT 3

Suppose a person consumes 1800 kcal/day. What total % Daily Values for energy-producing nutrients is recommended?

When using the % Daily Values of a food to determine how the amounts of certain nutrients in the food fit into the overall diet, the number of servings in a container or package needs to be considered. For example, suppose a small (2.25-ounce) bag of corn chips has a % Daily Value of 16% for total fat. One might suppose that eating the bag of chips accounts for 16% of total fat for the day. The bag, however, contains 2.5 servings. Therefore, if all the chips in the bag are consumed, they account for 40% (16% × 2.5) of the maximum recommended total fat.

19. What are the Reference Daily Intakes and the Daily Reference Values? When combined, what reference set of values is established?

20. Define % Daily Values. The % Daily Values appearing on food labels are based on how many kilocalories per day?

Metabolism

Objective

- *Describe the energy changes that take place in metabolism.*

Metabolism (mĕ-tab′ō-lizm; change) is the total of all the chemical changes that occur in the body. It consists of **anabolism** (ă-nab′ō-lizm), the energy-requiring process by which small molecules are joined to form larger molecules, and **catabolism** (kă-tab′ō-lizm), the energy-releasing process by which large molecules are broken down into smaller molecules. Anabolism occurs in all cells of the body as they divide to form new cells, maintain their own intracellular structure, and produce molecules like hormones, neurotransmitters, or extracellular matrix molecules for export. Catabolism begins during the process of digestion and is concluded within individual cells. The energy derived from catabolism is used to drive anabolic reactions and processes such as active transport and muscle contraction.

The cellular metabolic processes are often referred to as cellular metabolism or cellular respiration. The digestive products of carbohydrates, proteins, and lipids taken into body cells are catabolized, and the released energy is used to combine adenosine diphosphate (ADP) and an inorganic phosphate group (P_i) to form ATP (figure 25.3).

$$ADP + P_i + Energy \rightarrow ATP$$

ATP is often called the energy currency of the cell because when it is spent, or broken down to ADP, energy becomes available for use by the cell.

The chemical reactions responsible for the transfer of energy from the chemical bonds of nutrient molecules to ATP molecules involve oxidation–reduction reactions (see chapter 2). A molecule is reduced when it gains electrons and is oxidized when it loses electrons. A nutrient molecule has many hydrogen atoms covalently bonded to the carbon atoms that form the "backbone" of the molecule. Because a hydrogen atom is a hydrogen ion (proton) and an electron, the nutrient molecule has many electrons and is, therefore, highly reduced. When a hydrogen ion and an associated electron are lost from the nutrient molecule, the molecule loses energy and becomes oxidized. The energy in the electron is used to synthesize ATP. The major events of cellular metabolism are summarized in figure 25.4.

21. Define metabolism, anabolism, and catabolism. How is the energy derived from catabolism used to drive anabolic reactions?

22. How does the removal of hydrogen atoms from nutrient molecules result in a loss of energy from the nutrient molecule?

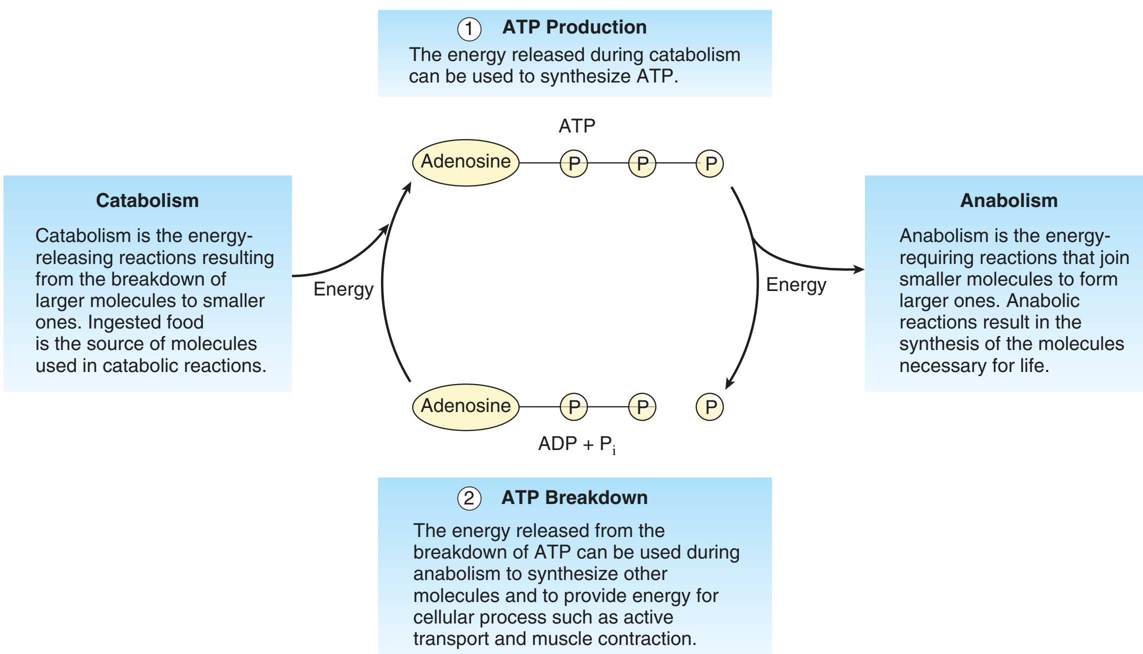


Figure 25.3 ATP Coupling of Catabolic and Anabolic Reactions

Energy released by catabolic reactions is used to form ATP, which releases the energy for use in anabolic reactions.

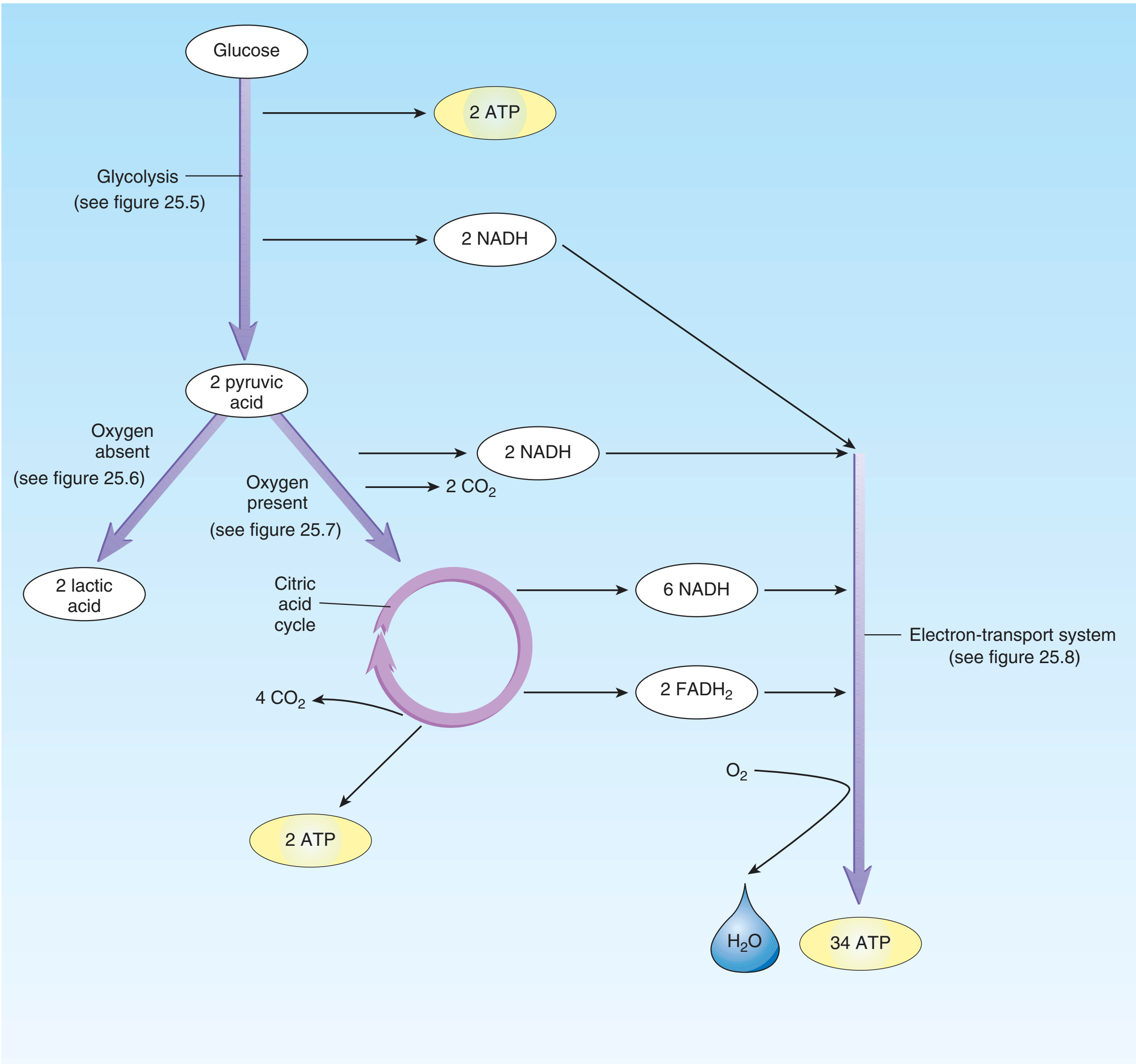


Figure 25.4 Cellular Metabolism

Overview of cellular metabolism, including glycolysis, citric acid cycle, and electron-transport system.

Carbohydrate Metabolism

Objectives

- ***Describe the use of glucose to produce ATP without oxygen and with oxygen.***
- ***Describe the chemical reactions occurring in glycolysis, acetyl-CoA formation, and the citric acid cycle.***
- ***Describe the electron-transport chain and how ATP is produced in the process.***

Glycolysis

Carbohydrate metabolism begins with **glycolysis** (glī-kol′i-sis), which is a series of chemical reactions in the cytosol that results in the breakdown of glucose into two **pyruvic** (pī-roo′vik) **acid** molecules (figure 25.5).

Glycolysis is divided into four phases.

1. *Input of ATP.* The first steps in glycolysis require the input of energy in the form of two ATP molecules. A phosphate

group is transferred from ATP to the glucose molecule, a process called **phosphorylation** (fos′fōr-i-lā′shŭn), to form glucose-6-phosphate. The glucose-6-phosphate atoms are rearranged to form fructose-6-phosphate, which is then converted to fructose-1,6-bisphosphate by the addition of another phosphate group from another ATP.

2. *Sugar cleavage.* Fructose-1,6-bisphosphate is cleaved into two three-carbon molecules, glyceraldehyde (glis-er-al′dĕ-hīd)-3-phosphate and dihydroxyacetone (dī′hī-drok-sē-as′e-tōn) phosphate. Dihydroxyactone phosphate is rearranged to form glyceraldehyde-3-phosphate; consequently, two molecules of glyceraldehyde-3-phosphate result.
3. *NADH production.* Each glyceraldehyde-3-phosphate molecule is oxidized (loses two electrons) to form 1,3-bisphosphoglyceric (biz′phos-fo-gli′sēr′ik) acid, and **nicotinamide adenine** (nik-ō-tin′ă-mīd ad′ĕ-nēn) **dinucleotide (NAD^+)** is reduced (gains two electrons) to **NADH.** Glyceraldehyde-3-phosphate also loses two hydrogen ions, one of which binds to NAD^+.

$$NAD^+ + 2\,e^- + 2\,H^+ \rightarrow NADH + H^+$$

NAD^+ is the oxidized form of nicotinamide adenine dinucleotide, and NADH is the reduced form. NADH is a carrier molecule with two high-energy electrons (e^-) that can be used to produce ATP molecules through the electron-transport chain (see "Electron-Transport Chain" on p. 926).

4. *ATP and pyruvic acid production.* The last four steps of glycolysis produce two ATP molecules and one pyruvic acid molecule from each 1,3-bisphosphoglyceric acid molecule.

Table 25.4 ATP Production from One Glucose Molecule

Process	Product	Total ATP Produced*
Glycolysis	4 ATP	2 ATP (4 ATP produced minus 2 ATP to start)
	2 NADH	6 ATP (or 4 ATP; see text)
Acetyl-CoA production	2 NADH	6 ATP
Citric acid cycle	2 ATP	2 ATP
	6 NADH	18 ATP
	2 $FADH_2$	4 ATP
Total		38 ATP (or 36 ATP; see text)

*NADH and $FADH_2$ are used in the production of ATP in the electron-transport chain.
Abbreviations: ATP = adenosine triphosphate, NADH = reduced nicotinamide adenine dinucleotide, $FADH_2$ = reduced flavin adenine diphosphate, acetyl-CoA = acetyl coenzyme A.

The events of glycolysis are summarized in table 25.4. Each glucose molecule that enters glycolysis forms two glyceraldehyde-3-phosphate molecules at the sugar cleavage phase. Each glyceraldehyde-3-phosphate molecule produces two ATP molecules, one NADH molecule, and one pyruvic acid molecule. Each glucose molecule, therefore, forms four ATP, two NADH, and two pyruvic acid molecules. Because the start of glycolysis requires the input of two ATP molecules, however, the final yield of each glucose molecule is two ATP, two NADH, and two pyruvic acid molecules (see figure 25.4).

If the cell has adequate amounts of oxygen, the NADH and pyruvic acid molecules are used in aerobic respiration to produce ATP. In the absence of sufficient oxygen, they are used in anaerobic respiration.

23. Describe the four phases of glycolysis. What are the products of glycolysis?

24. What determines whether the pyruvic acid produced in glycolysis is used in aerobic or anaerobic respiration?

Anaerobic Respiration

Anaerobic (an-ār-ō′bik) **respiration** is the breakdown of glucose in the absence of oxygen to produce two molecules of **lactic** (lak′tik) **acid** and two molecules of ATP (figure 25.6). The ATP thus produced is a source of energy during activities such as intense exercise, when insufficient oxygen is delivered to tissues. Anaerobic respiration can be divided into two phases.

1. *Glycolysis.* The first phase of anaerobic respiration is glycolysis, in which glucose undergoes several reactions to produce two pyruvic acid molecules and two NADH. There's also a net gain of two ATP molecules.
2. *Lactic acid formation.* The second phase is the conversion of pyruvic acid to lactic acid, a reaction that requires the input of energy from the NADH produced in phase 1 of anaerobic respiration.

Lactic acid is released from the cells that produce it and is transported by the blood to the liver. When oxygen becomes available, the lactic acid in the liver can be converted through a series of chemical reactions into glucose. The glucose then can be released from the liver and transported in the blood to cells that use glucose as an energy source. This process of converting lactic acid to glucose is called the **Cori cycle.** Some of the reactions involved in converting lactic acid into glucose require the input of ATP (energy) produced by aerobic respiration. The oxygen necessary for the synthesis of the ATP is part of the **oxygen debt** (see chapter 9).

25. Describe the two phases of anaerobic respiration. How many ATP molecules are produced by anaerobic respiration?

26. What happens to the lactic acid produced in anaerobic respiration when oxygen becomes available?

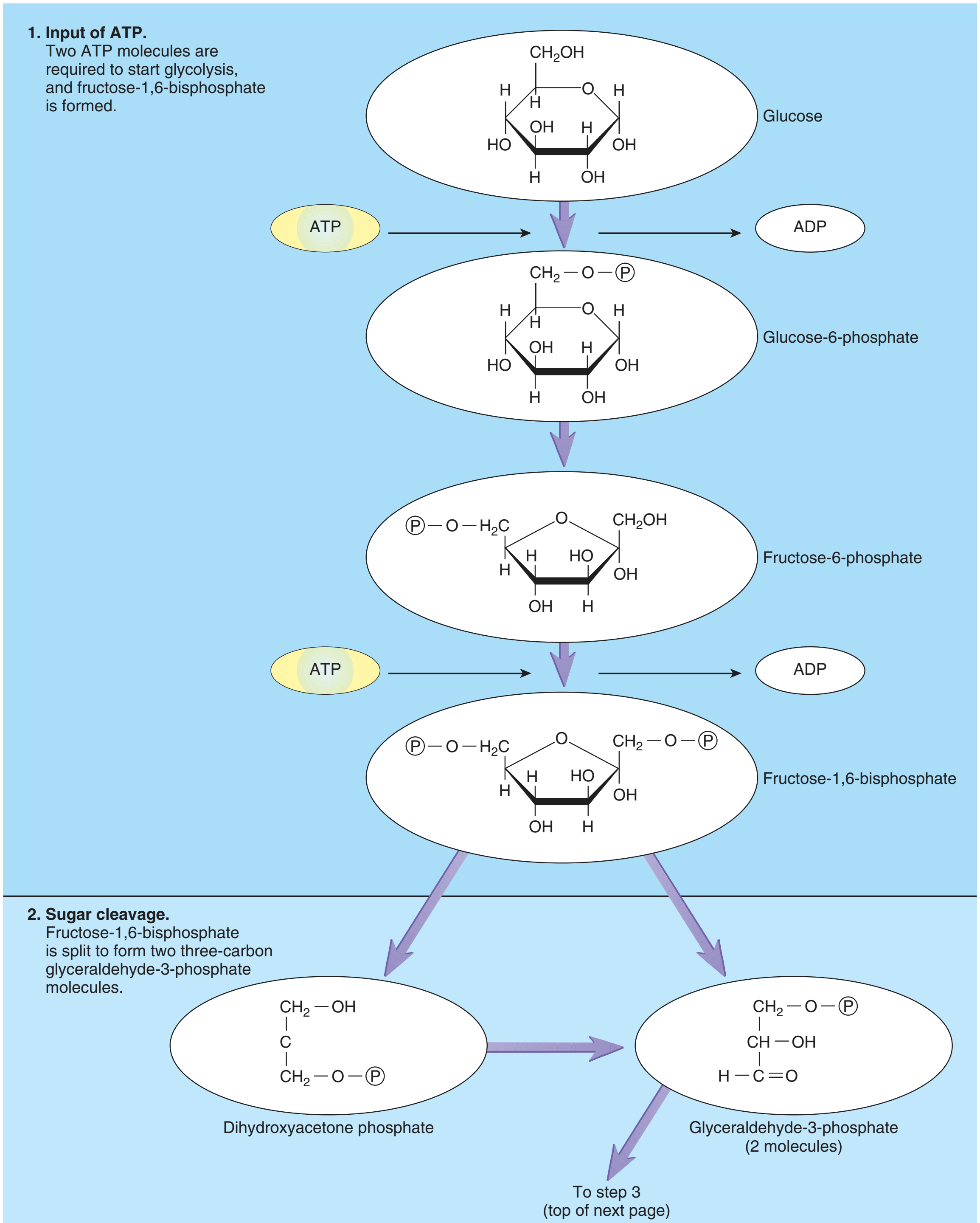


Figure 25.5 Glycolysis

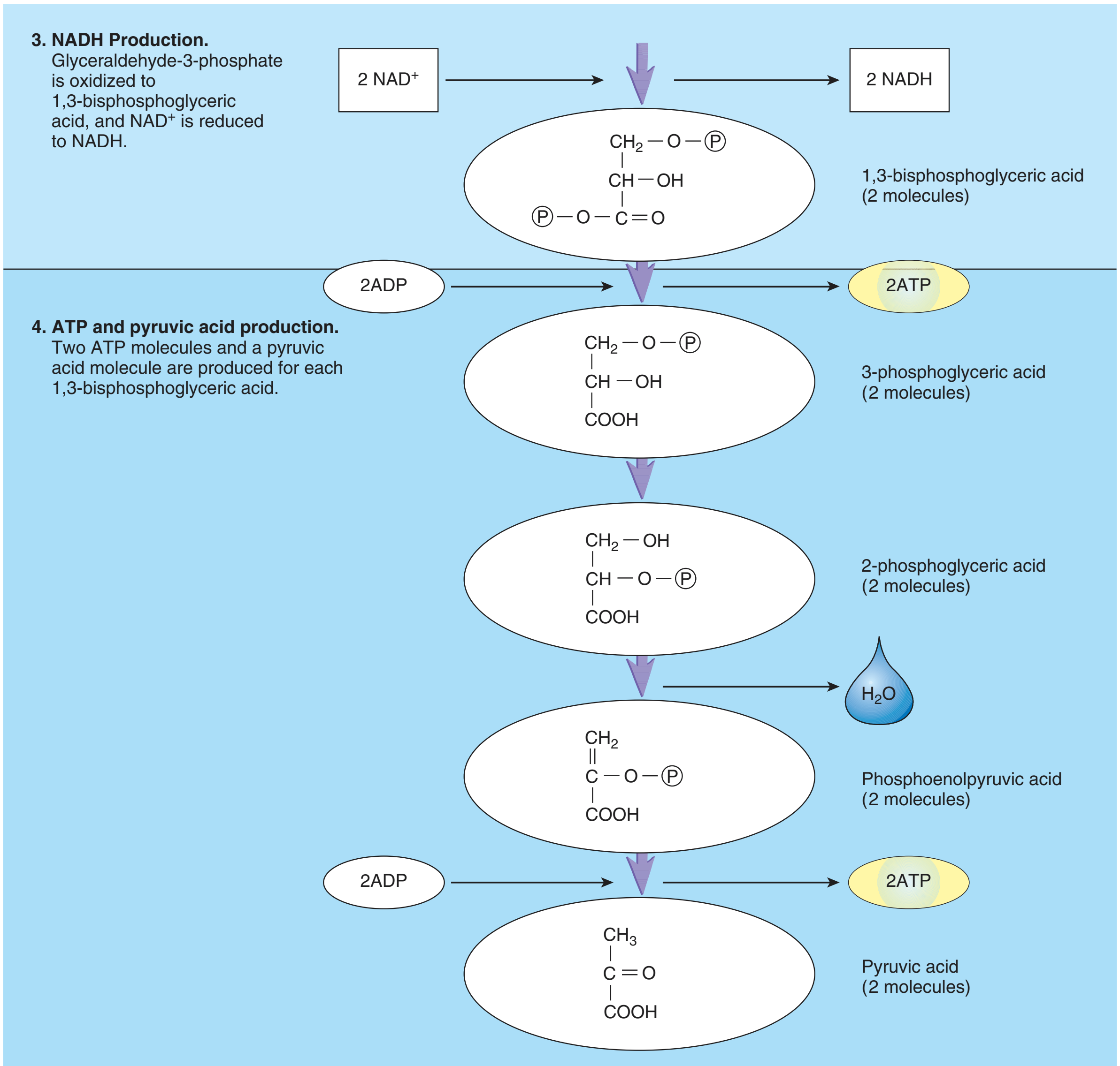


Figure 25.5 *(continued)*

Aerobic Respiration

Aerobic (ār-ō′bik) **respiration** is the breakdown of glucose in the presence of oxygen to produce carbon dioxide, water, and 38 ATP molecules. Most of the ATP molecules required to sustain life are produced through aerobic respiration, which can be considered in four phases: glycolysis, acetyl-CoA formation, the citric acid cycle, and the electron-transport chain. The first phase of aerobic respiration, as in anaerobic respiration, is glycolysis. The remaining phases are acetyl-CoA formation, the citric acid cycle, and the electron-transport chain.

Acetyl-CoA Formation

In the second phase of aerobic respiration, pyruvic acid moves from the cytosol into a mitochondrion, which is separated into an inner and outer compartment by the inner mitochondrial membrane. Within the inner compartment, enzymes remove a carbon and two oxygen atoms from the three-carbon pyruvic acid molecule to form carbon dioxide and a two-carbon acetyl (as′e-til) group (figure 25.7). Energy is released in the reaction and is used to reduce NAD^+ to NADH. The acetyl group combines with coenzyme A (CoA) to form acetyl-CoA. For each two pyruvic acid

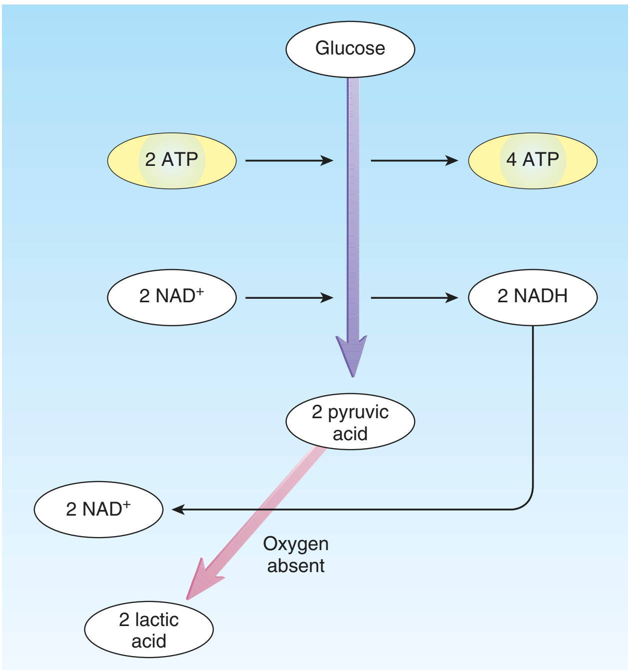


Figure 25.6 Anaerobic Respiration

In the absence of oxygen, the pyruvic acid produced in glycolysis is converted to lactic acid. The NADH produced in glycolysis is converted back to NAD^+.

molecules from glycolysis, two acetyl-CoA molecules, two carbon dioxide molecules, and two NADH are formed (see figure 25.4).

Citric Acid Cycle

The third phase of aerobic respiration is the **citric acid cycle,** which is named after the six-carbon citric acid molecule formed in the first step of the cycle (see figure 25.7). It is also called the Krebs' cycle after its discoverer, the British biochemist Sir Hans Krebs. The citric acid cycle begins with the production of citric acid from the combination of acetyl-CoA and a four-carbon molecule called oxaloacetic (ok′să-lō-ă-sē′tik) acid. A series of reactions occurs, resulting in the formation of another oxaloacetic acid, which can start the cycle again by combining with another acetyl-CoA. During the reactions of the citric acid cycle, three important events occur.

1. *ATP production.* For each citric acid molecule, one ATP is formed.
2. *NADH and $FADH_2$ production.* For each citric acid molecule, three NAD^+ molecules are converted to NADH molecules, and one flavin (flā′vin) adenine dinucleotide (FAD) molecule is converted to $FADH_2$. The NADH and $FADH_2$ molecules are electron carriers that enter the electron-transport chain and are used to produce ATP.
3. *Carbon dioxide production.* Each six-carbon citric acid molecule at the start of the cycle becomes a four-carbon oxaloacetic acid molecule at the end of the cycle. Two carbon and four oxygen atoms from the citric acid molecule are used to form two carbon dioxide molecules. Thus, some of the carbon and oxygen atoms that make up food molecules like glucose are eventually eliminated from the body as carbon dioxide. We literally breathe out part of the food we eat!

For each glucose molecule that begins aerobic respiration, two pyruvic acid molecules are produced in glycolysis, and they are converted into two acetyl-CoA molecules that enter the citric acid cycle. To determine the number of molecules produced from glucose by the citric acid cycle, two "turns" of the cycle must, therefore, be counted; the results are two ATP, six NADH, two $FADH_2$, and four carbon dioxide molecules (see figure 25.4).

Electron-Transport Chain

The fourth phase of aerobic respiration involves the **electron-transport chain** (figure 25.8), which is a series of electron carriers in the inner mitochondrial membrane. Electrons are transferred from NADH and $FADH_2$ to the electron-transport carriers, and hydrogen ions are released from NADH and $FADH_2$. After the loss of the electrons and the hydrogen ions, the oxidized NAD^+ and FAD are reused to transport additional electrons from the citric acid cycle to the electron-transport chain.

The electrons released from NADH and $FADH_2$ pass from one electron carrier to the next through a series of oxidation–reduction reactions. Three of the electron carriers also function as proton pumps that move the hydrogen ions from the inner mitochondrial compartment into the outer mitochondrial compartment. Each proton pump accepts an electron, uses some of the electron's energy to export a hydrogen ion, and passes the electron to the next electron carrier. The last electron carrier in the series collects the electrons and combines them with oxygen and hydrogen ions to form water.

$$1/2\ O_2 + 2\ H^+ + 2\ e^- \rightarrow H_2O$$

Without oxygen to accept the electrons, the reactions of the electron-transport chain cease, effectively stopping aerobic respiration.

The hydrogen ions released from NADH and $FADH_2$ are moved from the inner mitochondrial compartment to the outer mitochondrial compartment by active transport. As a result, the concentration of hydrogen ions in the outer compartment exceeds that of the inner compartment, and hydrogen ions diffuse back into the inner compartment. The hydrogen ions pass through certain channels formed by an enzyme called **ATP synthase.** As the hydrogen ions diffuse down their concentration gradient they lose energy that is used to produce ATP. This process is called the **chemiosmotic** (kem-ē-os-mot′ik) **model** because the chemical formation of ATP is coupled to a diffusion force similar to osmosis.

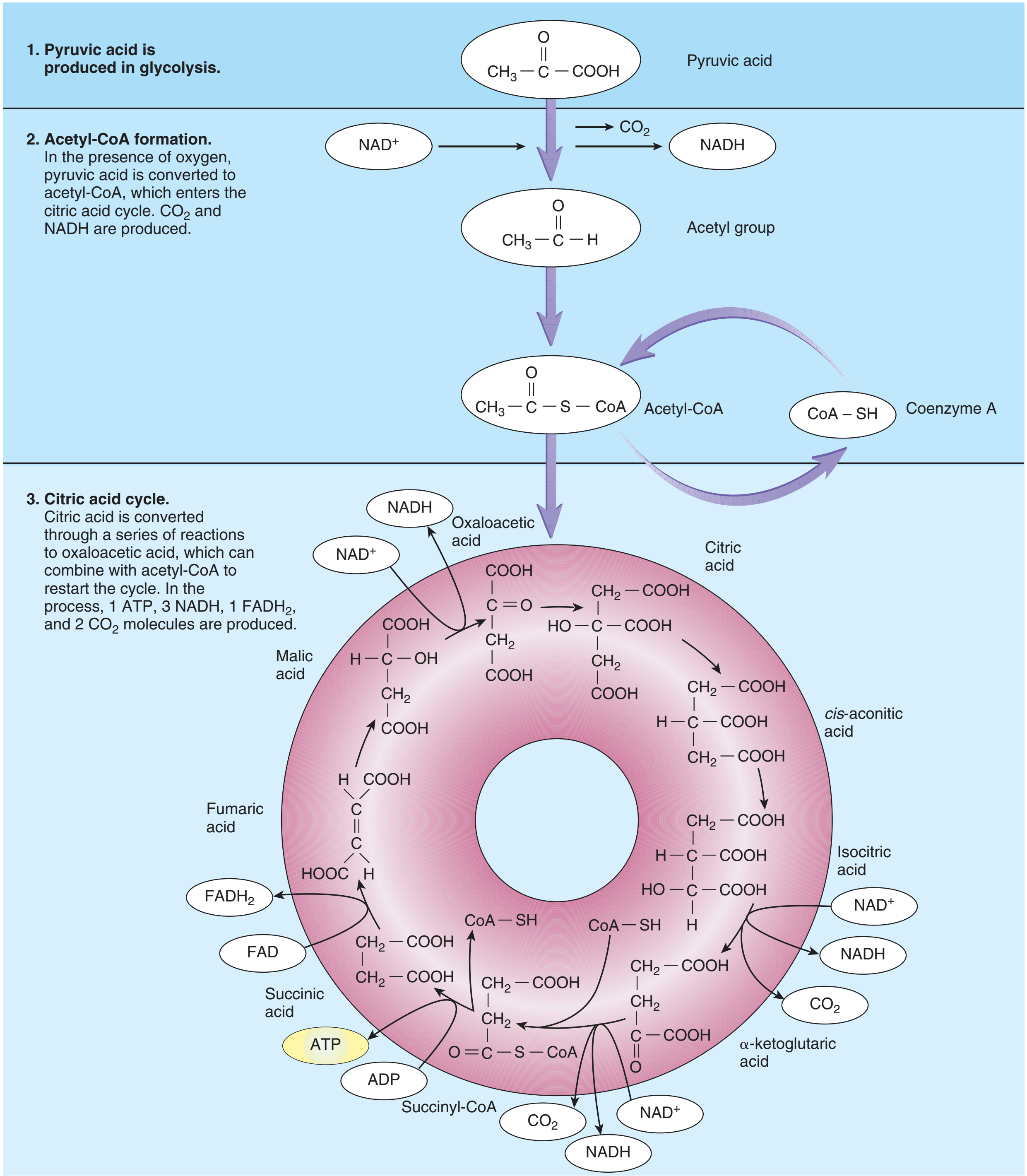
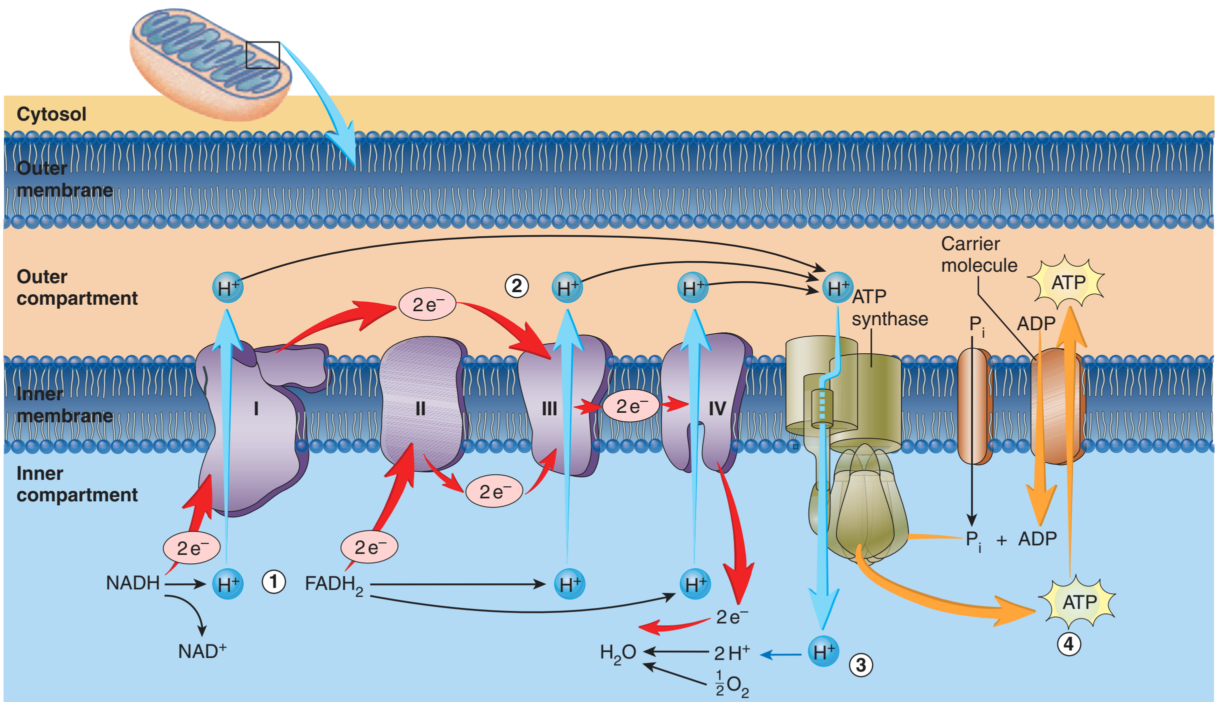


Figure 25.7 Aerobic Respiration



1. NADH or FADH$_2$ transfer their electrons to the electron-transport chain.

2. As the electrons move through the electron-transport chain, some of their energy is used to pump hydrogen ions into the outer compartment, resulting in a higher concentration of hydrogen ions in the outer than in the inner compartment.

3. The hydrogen ions diffuse back into the inner compartment through special channels (ATP synthase) that couple the hydrogen ion movement with the production of ATP. The electrons, hydrogen ions, and oxygen combine to form water.

4. ATP is transported out of the inner compartment by a carrier molecule that exchanges ATP for ADP. A different carrier molecule moves phosphate into the inner compartment.

Process Figure 25.8 Electron-Transport Chain

27. Define the term aerobic respiration, and list the products produced by it. Describe the four phases of aerobic respiration.

28. Why is the citric acid cycle a cycle? What molecules are produced as a result of the citric acid cycle?

29. What is the function of the electron-transport chain? Describe the chemiosmotic model of ATP production.

PREDICT 4

Many poisons function by blocking certain steps in the metabolic pathways. For example, cyanide blocks the last step in the electron-transport chain. Explain why this blockage would cause death.

Summary of ATP Production

For each glucose molecule, aerobic respiration produces a net gain of 38 ATP molecules: 2 from glycolysis, 2 from the citric acid cycle, and 34 from the NADH molecules and FADH$_2$ molecules that pass through the electron-transport chain (see table 25.4). For each NADH molecule formed, three ATP molecules are produced by the electron-transport chain, and for each FADH$_2$ molecule, two ATP molecules are produced.

The number of ATP molecules produced is also reported as 36 ATP molecules. The two NADH molecules produced by glycolysis in the cytosol cannot cross the inner mitochondrial membrane; thus, their electrons are donated to a shuttle molecule that carries the electrons to the electron-transport chain. Depending on the shuttle molecule, each glycolytic NADH molecule can produce 2 or 3 ATP molecules. In skeletal muscle and the brain, 2 ATP molecules are produced for each NADH molecule, resulting in a total number of 36 ATP molecules; but in the liver, kidneys, and heart, 3 ATP molecules are produced for each NADH molecule, and the total number of ATP molecules formed is 38.

Six carbon dioxide molecules are produced in aerobic respiration. Water molecules are reactants in some of the chemical reactions of aerobic respiration and products in others. Six water molecules are used, but 12 are formed, for a net gain of 6 water molecules. Thus, aerobic respiration can be summarized as follows:

$$C_6H_{12}O_6 + 6\,O_2 + 6H_2O + 38\,ADP + 38\,P_i \rightarrow 6\,CO_2 + 12\,H_2O + 38\,ATP$$

30. In aerobic respiration, how many ATP molecules are produced from one molecule of glucose through glycolysis, the citric acid cycle, and the electron-transport chain?

31. Why is the total number of ATP produced in aerobic respiration listed as 38 or 36?

The Quantity of ATP Produced from Glucose

The number of ATP molecules produced per glucose molecule is a theoretical number that assumes two hydrogen ions are necessary for the formation of each ATP. If the number required is more than two, the efficiency of aerobic respiration decreases. In addition, it's now understood that it costs energy to get ADP and phosphates into the mitochondria and to get ATP out. Considering all these factors, it's estimated that each glucose molecule yields about 25 ATP molecules instead of 38 ATP molecules.

Lipid Metabolism

Objective

- *Describe the basic steps involved in using lipids as an energy source.*

Lipids are the body's main energy-storage molecules. In a healthy person, lipids are responsible for about 99% of the body's energy storage, and glycogen accounts for about 1%. Although proteins are used as an energy source, they are not considered storage molecules because the breakdown of proteins normally involves the loss of molecules that perform other functions.

Lipids are stored primarily as triglycerides in adipose tissue. There is constant synthesis and breakdown of triglycerides; thus, the fat present in adipose tissue today isn't the same fat that was there a few weeks ago. Between meals when triglycerides are broken down in adipose tissue, some of the fatty acids produced are released into the blood, where they are called **free fatty acids.** Other tissues, especially skeletal muscle and the liver, use the free fatty acids as a source of energy.

The metabolism of fatty acids occurs by **beta-oxidation,** a series of reactions in which two carbon atoms at a time are removed from the end of a fatty acid chain to form acetyl-CoA. The process of beta-oxidation continues to remove two carbon atoms at a time until the entire fatty acid chain is converted into acetyl-CoA molecules. Acetyl-CoA can enter the citric acid cycle and be used to generate ATP (figure 25.9).

Acetyl-CoA is also used in **ketogenesis** (kē-tō-jen′ĕ-sis), the formation of ketone bodies. In the liver when large amounts of acetyl-CoA are produced, not all of the acetyl-CoA enters the citric acid cycle. Instead, two acetyl-CoA molecules combine to form a molecule of acetoacetic (as′e-tō-a-sē′tik) acid, which is converted mainly into β-hydroxybutyric (hī-drōk′sē-bū-tir′ik) acid and a smaller amount of acetone (as′e-tōn). Acetoacetic acid, β-hydroxybutyric acid, and acetone are called **ketone** (kē′tōn) **bodies** and are released into the blood, where they travel to other tissues, especially skeletal muscle. In these tissues, the ketone bodies are converted back into acetyl-CoA that enters the citric acid cycle to produce ATP.

32. Define the term beta-oxidation, and explain how it results in ATP production.

33. What are ketone bodies, how are they produced, and for what are they used?

The Danger of Excessive Amounts of Ketones

Normally, blood contains only small amounts of ketone bodies. During starvation (see "Clinical Focus: Starvation" on p. 934), however, or in patients with diabetes mellitus, the rate of fat metabolism increases. As a result, the quantity of ketone bodies increases to produce the condition called **ketosis.** The increased number of ketone bodies can exceed the capacity of the body's buffering system, resulting in acidosis, a decrease in blood pH (see chapter 27).

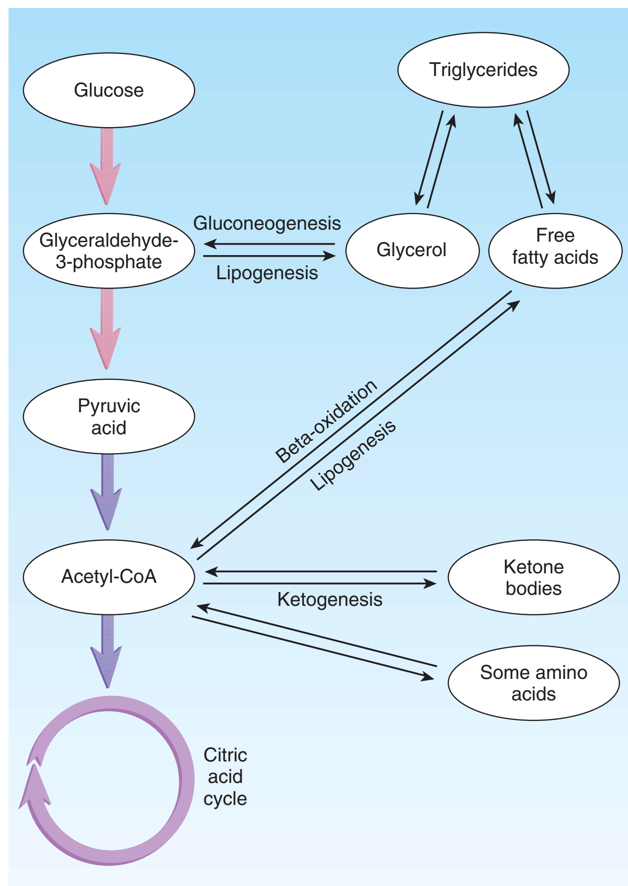


Figure 25.9 Lipid Metabolism

Triglyceride is broken down into glycerol and fatty acids. Glycerol enters glycolysis to produce ATP. The fatty acids are broken down by beta-oxidation into acetyl-CoA, which enters the citric acid cycle to produce ATP. Acetyl-CoA can also be used to produce ketone bodies (ketogenesis). Lipogenesis is the production of lipids. Glucose is converted to glycerol, and amino acids are converted to acetyl-CoA molecules. Acetyl-CoA molecules can combine to form fatty acids. Glycerol and fatty acids join to form triglycerides.

Protein Metabolism

Objective

- ***Describe the metabolism of amino acids in the body.***

Once absorbed into the body, amino acids are quickly taken up by cells, especially in the liver. Amino acids are used to synthesize needed proteins (see chapter 3) or as a source of energy (figure 25.10). Unlike glycogen and triglycerides, amino acids are not stored in the body.

The synthesis of nonessential amino acids usually begins with keto acids (figure 25.11). A keto acid can be converted into an amino acid by replacing its oxygen with an amine group. Usually this conversion is accomplished by transferring an amine group from an amino acid to the keto acid, a reaction called **transamination** (trans-am′i-nā′shŭn). For example, α-ketoglutaric acid (a keto acid) reacts with an amino acid to form glutamic acid (an amino acid; figure 25.12*a*). Most amino acids can undergo transamination to produce glutamic acid. The glutamic acid is used as a source of an amine group to construct most of the nonessential amino acids. A few nonessential amino acids are formed in other ways from the essential amino acids.

Amino acids can be used as a source of energy. In **oxidative deamination** (dē-am-i-nā′shŭn; deaminization, dē-am′i-ni-zā′shŭn), an amine group is removed from an amino acid (usually glutamic acid), leaving ammonia and a keto acid (figure 25.12*b*). In the process, NAD^+ is reduced to NADH, which can enter the

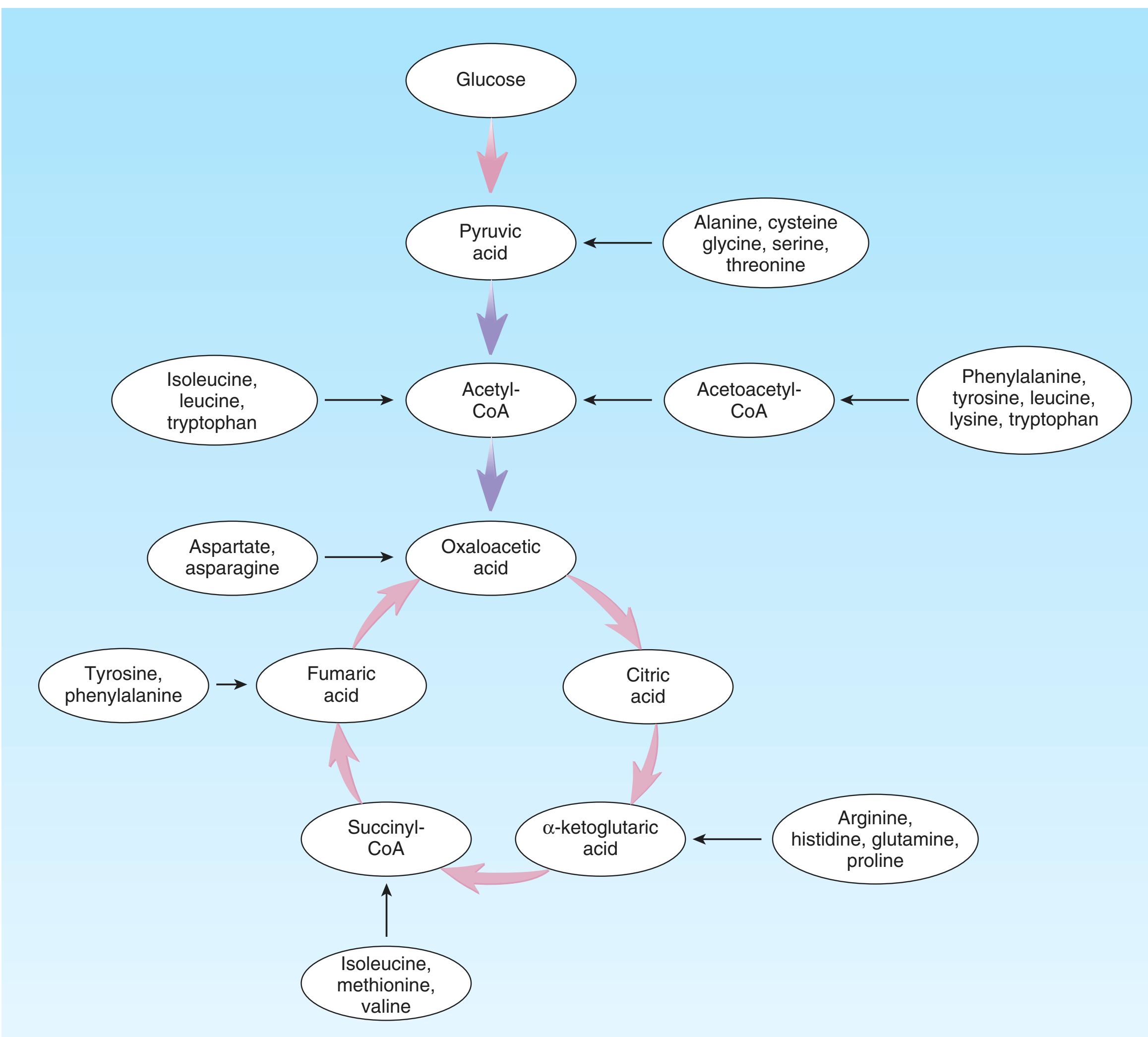


Figure 25.10 Amino Acid Metabolism
Various entry points for amino acids into carbohydrate metabolism.

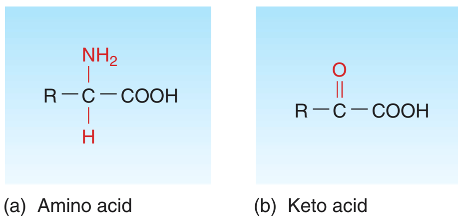


Figure 25.11 **General Formulas of an Amino Acid and a Keto Acid**

(*a*) Amino acid with a carboxyl group (—COOH), an amine group (NH_2), a hydrogen atom (H), and a group called "R" that represents the rest of the molecule. (*b*) Keto acid with a double-bonded oxygen replacing the amine group and the hydrogen atom of the amino acid.

electron-transport chain to produce ATP. Ammonia is toxic to cells. An accumulation of ammonia to toxic levels is prevented because the liver converts it into urea, which is carried by the blood to the kidneys, where the urea is eliminated (figure 25.12*c*; see chapter 26).

Amino acids are also used as a source of energy by converting them into the intermediate molecules of carbohydrate metabolism (see figure 25.10). These molecules are then metabolized to yield ATP. The conversion of an amino acid often begins with a transamination or oxidative deamination reaction, in which the amino acid is converted into a keto acid (see figure 25.12). The keto acid enters the citric acid cycle or is converted into pyruvic acid or acetyl-CoA.

34. What is accomplished by transamination and oxidative deamination?

35. How are proteins (amino acids) used to produce energy?

Interconversion of Nutrient Molecules

Objective

- ***Describe the processes by which nutrients are changed from one type of nutrient into another type.***

Blood glucose enters most cells by facilitated diffusion and is immediately converted to glucose-6-phosphate, which cannot recross the plasma membrane (figure 25.13*a*). Glucose-6-phosphate then continues through glycolysis to produce ATP. If, however, excess glucose is present (e.g., after a meal), it's used to form glycogen through a process called **glycogenesis** (glī-kō-jen′ĕ-sis). Most of the body's glycogen is contained in skeletal muscle and the liver.

Once glycogen stores, which are quite limited, are filled, glucose and amino acids are used to synthesize lipids, a process called **lipogenesis** (lip-ō-jen′ĕ-sis; see figure 25.9). Glucose molecules can be used to form glyceraldehyde-3-phosphate and acetyl-CoA. Amino acids can also be converted to acetyl-CoA. Glyceraldehyde-3-phosphate is converted to glycerol, and the two-carbon acetyl-CoA molecules are joined together to form fatty acid chains. Glycerol and three fatty acids then combine to form triglycerides.

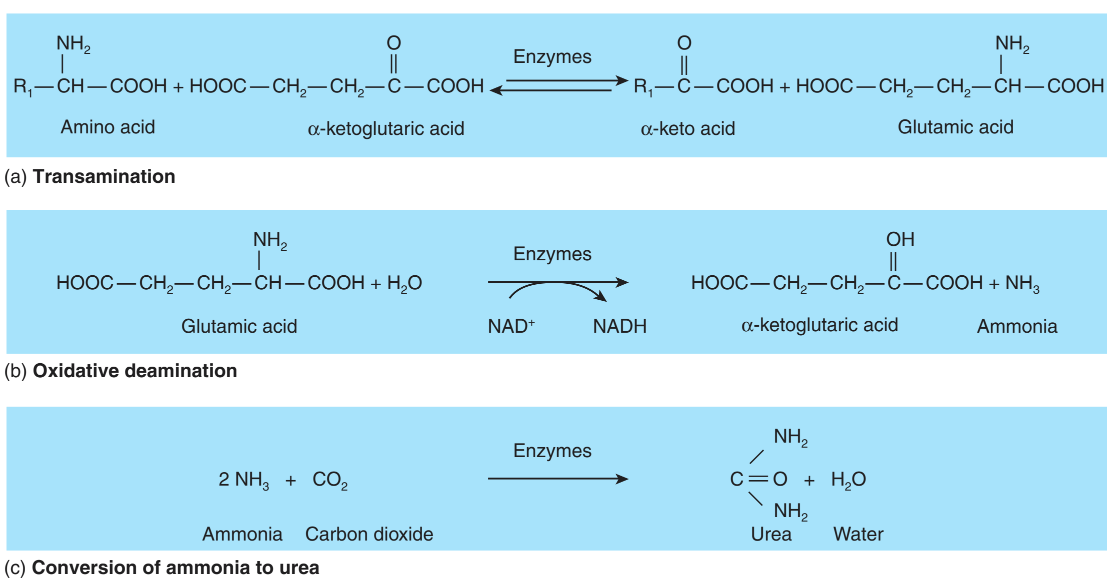
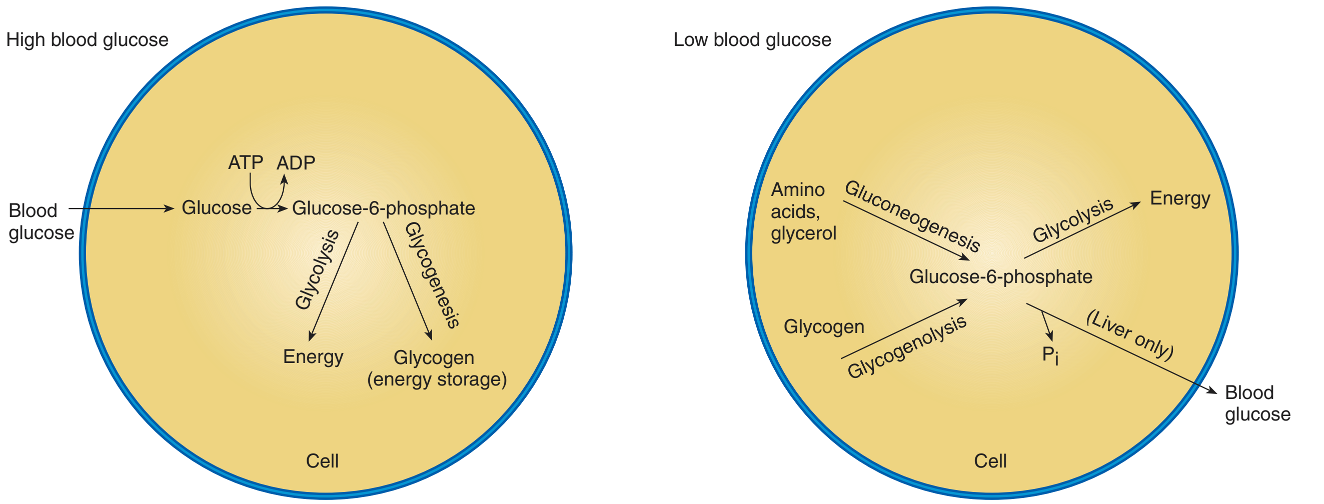


Figure 25.12 **Amino Acid Reactions**

(*a*) Transamination reaction in which an amine group is transferred from an amino acid to a keto acid to form a different amino acid. (*b*) Oxidative deamination reaction in which an amino acid loses an amine group to become a keto acid and to form ammonia. In the process, NADH, which can be used to generate ATP, is formed. (*c*) Ammonia is converted to urea in the liver. The actual conversion of ammonia to urea is more complex, involving a number of intermediate reactions that constitute the urea cycle.



(a) When blood glucose levels are high, glucose enters the cell and is phosphorylated to form glucose-6-phosphate, which can enter glycolysis or glycogenesis.

(b) When blood glucose levels drop, glucose-6-phosphate can be produced through glycogenolysis or gluconeogenesis. Glucose-6-phosphate can enter glycolysis, or the phosphate group can be removed in liver tissue and glucose released into the blood.

Figure 25.13 Interconversion of Nutrient Molecules

Alcoholism and Cirrhosis of the Liver

Enzymes in the liver convert ethanol (beverage alcohol) into acetyl-CoA, and in the process two NADH molecules are produced. The NADH molecules enter the electron-transport chain and are used to produce ATP molecules. Each gram of ethanol provides 7 kcal of energy. Because of the high level of NADH in the cell that results from the metabolism of ethanol, the production of NADH by glycolysis and by the citric acid cycle is inhibited. Consequently, sugars and amino acids are not broken down but are converted into fats that accumulate in the liver. Chronic alcohol abuse can, therefore, result in **cirrhosis** (sir-rō′sis) **of the liver,** which involves fat deposition, cell death, inflammation, and scar tissue formation. Death can occur because the liver is unable to carry out its normal functions.

When glucose is needed, glycogen can be broken down into glucose-6-phosphate through a set of reactions called **glycogenolysis** (glī′kō-jĕ-nol′i-sis; figure 25.13*b*). In skeletal muscle, glucose-6-phosphate continues through glycolysis to produce ATP. The liver can use glucose-6-phosphate for energy or can convert it to glucose, which diffuses into the blood. The liver can release glucose, but skeletal muscle cannot because it lacks the necessary enzymes to convert glucose-6-phosphate into glucose.

Release of glucose from the liver is necessary to maintain blood glucose levels between meals. Maintaining these levels is especially important to the brain, which normally uses only glucose for an energy source and consumes about two-thirds of the total glucose used each day. When liver glycogen levels are inadequate to supply glucose, amino acids from proteins and glycerol from triglycerides are used to produce glucose in a process called **gluconeogenesis** (gloo′kō-nē-ō-jen′ĕ-sis). Most amino acids can be converted into citric acid cycle molecules, acetyl-CoA, or pyruvic acid (see figure 25.10). Through a series of chemical reactions, these molecules are converted into glucose. Glycerol enters glycolysis by becoming glyceraldehyde-3-phosphate.

36. Define the terms glycogenesis, lipogenesis, glycogenolysis, and gluconeogenesis.

Metabolic States

Objective

- ***Differentiate between the absorptive and postabsorptive metabolic states.***

Two major metabolic states have been described in the body. The first is the **absorptive state,** the period immediately after a meal when nutrients are being absorbed through the intestinal wall into the circulatory and lymphatic systems (figure 25.14). The absorptive state usually lasts about 4 hours after each meal, and most of the glucose that enters the circulation is used by cells to provide the energy they require. The remainder of the glucose is converted into glycogen or fats. Most of the absorbed fats are deposited in adipose tissue. Many of the absorbed amino acids are used by cells in protein synthesis, some are used for energy, and others enter the liver and are converted into fats or carbohydrates.

The second state, the **postabsorptive state,** occurs late in the morning, late in the afternoon, or during the night after each absorptive state is concluded (figure 25.15). Normal blood glucose levels range between 70 and 110 mg/100 mL, and it's vital to the body's homeostasis that this range be maintained, especially for

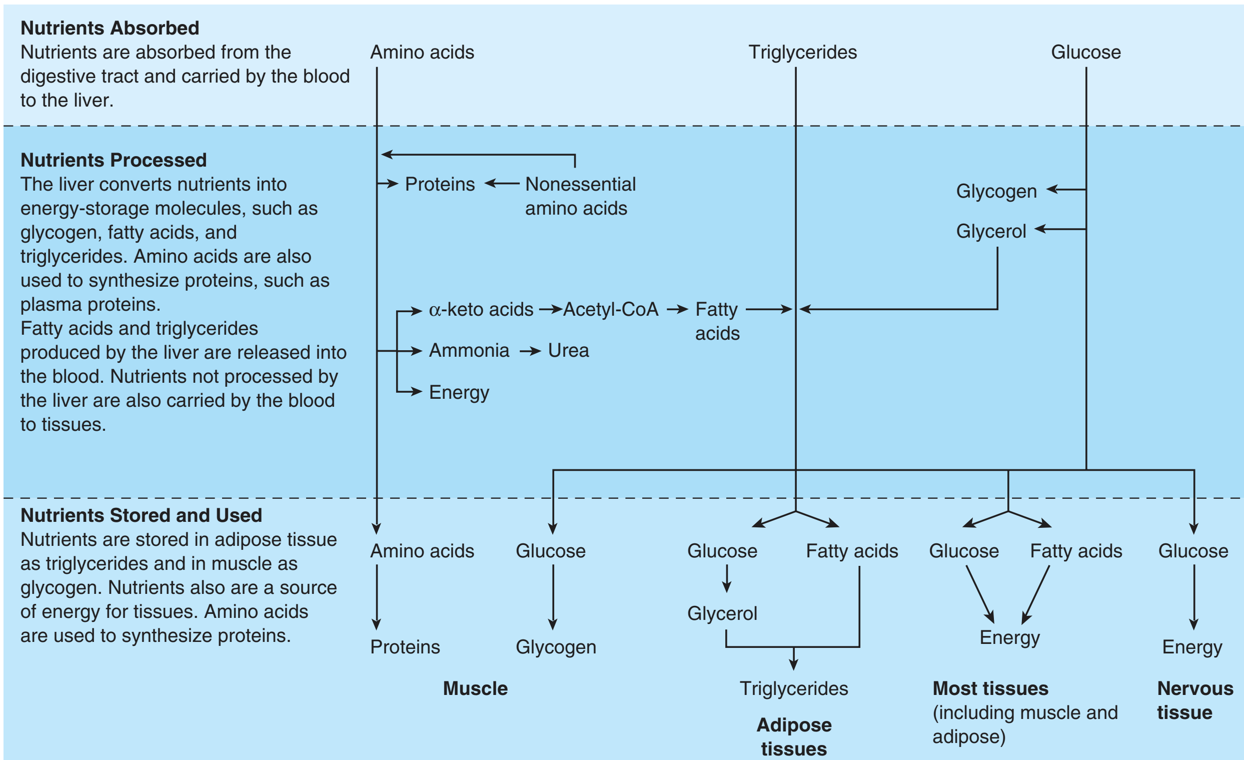


Figure 25.14 Events of the Absorptive State

Absorbed molecules, especially glucose, are used as sources of energy. Molecules not immediately needed for energy are stored: glucose is converted to glycogen or triglycerides, triglycerides are deposited in adipose tissue, and amino acids are converted to triglycerides or carbohydrates.

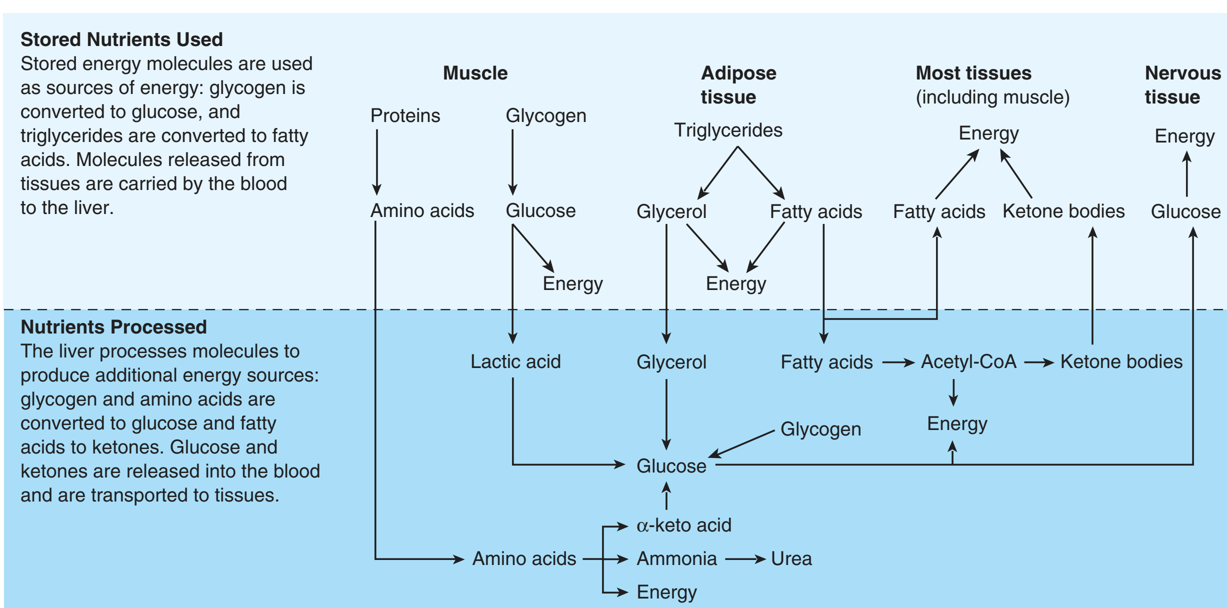


Figure 25.15 Events of the Postabsorptive State

Stored energy molecules are used as sources of energy: glycogen is converted to glucose; triglycerides are broken down to fatty acids, some of which are converted to ketones; and proteins are converted to glucose.

Clinical Focus Starvation

Starvation results from the inadequate intake of nutrients or the inability to metabolize or absorb nutrients. It can have a number of causes, such as prolonged fasting, anorexia, deprivation, or disease. No matter what the cause, starvation follows the same course and consists of three phases. The events of the first two phases occur even during relatively short periods of fasting or dieting, but the third phase occurs only in prolonged starvation and can end in death.

During the first phase of starvation, blood glucose levels are maintained through the production of glucose from glycogen, proteins, and fats. At first, glycogen is broken down into glucose; however, only enough glycogen is stored in the liver to last a few hours. Thereafter, blood glucose levels are maintained by the breakdown of proteins and fats. Fats are decomposed into fatty acids and glycerol. Fatty acids can be used as a source of energy, especially by skeletal muscle, thus decreasing the use of glucose by tissues other than the brain. Glycerol can be used to make a small amount of glucose, but most of the glucose is formed from the amino acids of proteins. In addition, some amino acids can be used directly for energy.

In the second stage, which can last for several weeks, fats are the primary energy source. The liver metabolizes fatty acids into ketone bodies that can be used as a source of energy. After about a week of fasting, the brain begins to use ketone bodies, as well as glucose, for energy. This usage decreases the demand for glucose, and the rate of protein breakdown diminishes but doesn’t stop. In addition, the proteins not essential for survival are used first.

The third stage of starvation begins when the fat reserves are depleted and a switch to proteins as the major energy source takes place. Muscles, the largest source of protein in the body, are rapidly depleted. At the end of this stage, proteins essential for cellular functions are broken down, and cell function degenerates.

In addition to weight loss, symptoms of starvation include apathy, listlessness, withdrawal, and increased susceptibility to infectious disease. Few people die directly from starvation because they usually die of some infectious disease first. Other signs of starvation include changes in hair color, flaky skin, and massive edema in the abdomen and lower limbs, causing the abdomen to appear bloated.

During the process of starvation, the ability of the body to consume normal volumes of food also decreases. Foods high in bulk but low in protein content often cannot reverse the process of starvation. Intervention involves feeding the starving person low-bulk food that provides ample proteins and kilocalories and is fortified with vitamins and minerals. The process of starvation also results in dehydration, and rehydration is an important part of intervention. Even with intervention, a victim may be so affected by disease or weakness that he or she cannot recover.

normal functioning of the brain. During the postabsorptive state, blood glucose levels are maintained by the conversion of other molecules to glucose. The first source of blood glucose during the postabsorptive state is the glycogen stored in the liver. This glycogen supply, however, can provide glucose for only about 4 hours. The glycogen stored in skeletal muscles can also be used during times of vigorous exercise. As glycogen stores are depleted, fats are used as an energy source. The glycerol from triglycerides can be converted to glucose. The fatty acids from fat can be converted to acetyl-CoA, moved into the citric acid cycle, and used as a source of energy to produce ATP. In the liver, acetyl-CoA is used to produce ketone bodies that other tissues use for energy. The use of fatty acids as an energy source partly eliminates the need to use glucose for energy, resulting in reduced glucose removal from the blood and maintenance of blood glucose levels at homeostatic levels. Proteins can also be used as a source of glucose or can be used for energy production, again sparing the use of blood glucose.

37. *What happens to glucose, fats, and amino acids during the absorptive state?*
38. *Why is it important to maintain blood glucose levels during the postabsorptive state? Name three sources for this glucose.*

Metabolic Rate

Objective

- ***Define the term metabolic rate, and explain the three ways metabolic energy is used.***

Metabolic rate is the total amount of energy produced and used by the body per unit of time. A molecule of ATP exists for less than 1 minute before it’s degraded back to ADP and inorganic phosphate. For this reason, ATP is produced in cells at about the same rate as it’s used. Thus, in examining metabolic rate, ATP production and use can be roughly equated. Metabolic rate is usually estimated by measuring the amount of oxygen used per minute because most ATP production involves the use of oxygen. One liter of oxygen consumed by the body is assumed to produce 4.825 kcal of energy.

The daily input of energy should equal the metabolic expenditure of energy; otherwise, a person will gain or lose weight. For a typical 23-year-old, 70 kg (154-pound) male to maintain his weight, the daily input should be 2700 kcal/day; for a typical 58 kg (128-pound) female of the same age 2000 kcal/day is necessary. A pound of body fat provides about 3500 kcal. Reducing kilocaloric intake by 500 kcal/day can result in the loss of 1 pound of fat per week. Clearly, adjusting kilocaloric input is an important way to control body weight.

The Proportion of Fat in the Diet and Body Weight

Not only the number of kilocalories ingested but also the proportion of fat in the diet has an effect on body weight. To convert dietary fat into body fat, 3% of the energy in the dietary fat is used, leaving 97% for storage as fat deposits. On the other hand, the conversion of dietary carbohydrate to fat requires 23% of the energy in the carbohydrate, leaving just 77% as body fat. If two people have the same kilocaloric intake, the one with the higher proportion of fat in his or her diet is more likely to gain weight because fewer kilocalories are used to convert the dietary fat into body fat.

Metabolic energy is used in three ways: for basal metabolism, for the thermic effect of food, and for muscular activity.

Basal Metabolic Rate

The **basal metabolic rate (BMR)** is the metabolic rate calculated in expended kilocalories per square meter of body surface area per hour. It's determined by measuring the oxygen consumption of a person who is awake but restful and has not eaten for 12 hours. The liters of oxygen consumed are then multiplied by 4.825 because each liter of oxygen used results in the production of 4.825 kcal of energy. A typical BMR for a 70 kg (154-pound) male is 38 kcal/m^2/h.

BMR is the energy needed to keep the resting body functional. In the average person, basal metabolism accounts for about 60% of energy expenditure. Basal metabolism supports active-transport mechanisms, muscle tone, maintenance of body temperature, beating of the heart, and other activities. A number of factors can affect the BMR. Muscle tissue is metabolically more active than adipose tissue, even at rest. Younger people have a higher BMR than older people because of increased cell activity, especially during growth. Fever can increase BMR 7% for each degree Fahrenheit increase in body temperature. During dieting or fasting, greatly reduced kilocaloric input can depress BMR, which apparently is a protective mechanism to prevent weight loss. Thyroid hormones can increase BMR on a long-term basis, and epinephrine can increase BMR on a short-term basis (see chapter 18). Males have a greater BMR than females because men have proportionately more muscle tissue and less adipose tissue than women do. During pregnancy, a woman's BMR can increase 20% because of the metabolic activity of the fetus.

Thermic Effect of Food

The second component of metabolic energy concerns the assimilation of food. When food is ingested, the accessory digestive organs and the intestinal lining produce secretions, the motility of the digestive tract increases, active transport increases, and the liver is involved in the synthesis of new molecules. The energy cost of these events is called the **thermic effect of food** and accounts for about 10% of the body's energy expenditure.

Muscular Activity

Muscular activity consumes about 30% of the body's energy. Physical activity resulting from skeletal muscle movement requires the expenditure of energy. In addition, energy must be provided for increased contraction of the heart and of the muscles of respiration. The number of kilocalories used in an activity depends almost entirely on the amount of muscular work performed and on the duration of the activity. Despite the fact that studying can make a person feel tired, intense mental concentration produces little change in the BMR.

Energy loss through muscular activity is the only component of energy expenditure that a person can reasonably control. A comparison of the number of kilocalories gained from food versus the number of kilocalories lost in exercise reveals why losing weight can be difficult. For example, walking (3 mph) for 20 minutes burns the kilocalories supplied by one slice of bread, whereas jogging (5 mph) for the same time eliminates the kilocalories obtained from a soft drink or a beer (see table 25.1). Nonetheless, weight loss through exercise and dieting is possible.

39. Define the term metabolic rate.
40. What is BMR? What factors can alter BMR?
41. What is the thermic effect of food?
42. BMR, thermic effect of food, and muscular activity each account for what percent of total energy expenditure?
43. How are kilocalorie input and output adjusted to maintain body weight?

Body Temperature Regulation

Objective

- *Describe heat production and regulation in the body.*

Humans are **homeotherms** (hō′mē-ō-thermz; uniform warming), or **warm-blooded animals,** and can regulate body temperature rather than have it adjusted by the external environment. Maintenance of a constant body temperature is very important to homeostasis. Most enzymes are very temperature sensitive and function only in narrow temperature ranges. Environmental temperatures are too low for normal enzyme function, and the heat produced by metabolism helps maintain the body temperature at a steady, elevated level that is high enough for normal enzyme function.

Free energy is the total amount of energy liberated by the complete catabolism of food. It's usually expressed in terms of kilocalories (kcal) per mole of food consumed. For example, the complete catabolism of 1 mole of glucose (168 g; see chapter 2) releases 686 kcal of free energy. About 43% of the total energy released by catabolism is used to produce ATP and to accomplish biologic work, such as anabolism, muscular contraction, and other cellular activities. The remaining energy is lost as **heat.**

PREDICT 5

Explain why we become warm during exercise and why we shiver when it's cold.

Clinical Focus Obesity

Obesity is the presence of excess fat, and it results from the ingestion of more food than is necessary for the body's energy needs. Obesity can be defined on the basis of body weight, body mass index, or percent body fat. "Desirable body weight" is listed in the Metropolitan Life Insurance Table and indicates, for any height, the weight that is associated with a maximum life span. Overweight is defined as weighing 10% more than the "desirable weight," and obesity is weighing 20% more than the "desirable weight." Body mass index (BMI) can be calculated by dividing a person's weight (Wt) in kilograms by the square of his or her height (Ht) in meters: $BMI = Wt/Ht^2$. A BMI greater than 25–27 is overweight, and a value greater than 30 is defined as obese. About 10% of people in the United States have a BMI of 30 or greater. In terms of the percent of the total body weight contributed by fat, 15% body fat or less in men and 25% body fat or less in women is associated with reduced health risks. Obesity is defined to be more than 25% body fat in men and 30%–35% in women.

Obesity is classified according to the number and size of fat cells. The greater the amount of lipids stored in the fat cells, the larger their size. In **hyperplastic obesity,** a greater-than-normal number of fat cells occur that are also larger than normal. This type of obesity is associated with massive obesity and begins at an early age. In nonobese children, the number of fat cells triples or quadruples between birth and 2 years of age and then remains relatively stable until puberty, when a further increase in the number occurs. In obese children, however, between 2 years of age and puberty, an increase also occurs in the number of fat cells. **Hypertrophic obesity** results from a normal number of fat cells that have increased in size. This type of obesity is more common, is associated with moderate obesity or being "overweight," and typically develops in adults. People who were thin or of average weight and quite active when they were young become less active as they become older. They begin to gain weight between age 20 and 40, and, although they no longer use as many kilocalories, they still take in the same amount of food as when they were younger. The unused kilocalories are turned into fat, causing fat cells to increase in size. At one time, it was believed that the number of fat cells did not increase after adulthood. It's now known that the number of fat cells can increase in adults. Apparently, if all the existing fat cells are filled to capacity with lipids, new fat cells are formed to store the excess lipids. Once fat cells are formed, however, dieting and weight loss don't result in a decrease in the number of fat cells—instead, they become smaller in size as their lipid content decreases.

The distribution of fat in obese individuals varies. Fat can be found mainly in the upper body, such as in the abdominal region, or it can be associated with the hips and buttocks. These distribution differences are clinically significant because upper body obesity is associated with an increased likelihood of diabetes mellitus, cardiovascular disease, stroke, and death.

In some cases, a specific cause of obesity can be identified. For example, a tumor in the hypothalamus can stimulate overeating. In most cases, however, no specific cause is apparent. In fact, obesity occurs for many reasons, and obesity in an individual can have more than one cause. A genetic component to obesity seems to exist, and, if one or both parents are obese, their children are more likely to also be obese. Environmental factors, such as eating habits, however, can also play an important role. For example, adopted children can exhibit similarities in obesity to their adoptive parents. In addition, psychologic factors, such as overeating as a means for dealing with stress, can contribute to obesity.

Regulation of body weight is actually a matter of regulating body fat because most changes in body weight reflect changes in the amount of fat in the body. According to the "set point" theory of weight control, the body maintains a certain amount of body fat. If the amount decreases below or increases above this level, mechanisms are activated to return the amount of body fat to its normal value.

The two factors that affect the amount of adipose tissue in the body are energy intake and energy expenditure. The regulation of energy intake is poorly understood. Apparently, neurons originating in or passing through the hypothalamus continually and spontaneously stimulate appetite and food-seeking behaviors. After food is consumed, several mechanisms are responsible for decreasing further food intake. Neural mechanisms, such as distension of the stomach, are known to inhibit feeding, and a number of hormones released from the gastrointestinal tract or pancreas also decrease appetite. For example, somatostatin, cholecystokinin, glucagon, insulin, and other hormones have been shown to reduce food intake. The level of fatty acids, glucose, or amino acids in the blood also provides the brain with information necessary to adjust appetite. Low levels of fatty acids, glucose, and amino acids stimulate appetite, whereas high levels of these substances inhibit appetite.

Some scientists believe that the number of fat cells in the body also affects appetite. According to this line of reasoning, fat cells maintain their size, and, once a "fat plateau" is attained, the body stays at that plateau. Fat cells accomplish this by effectively taking up triglycerides and converting them to fat. Consequently, less energy is available for muscle and body organs, and, to compensate, appetite increases to provide needed energy. In support of this hypothesis, it's known that obese individuals have an increased amount of the enzyme lipoprotein lipase, which is responsible for the uptake and storage of triglycerides in fat cells. Furthermore, in obese individuals who have lost weight, the levels of lipoprotein lipase increase even more.

It's a common belief that the main cause of obesity is overeating. Certainly for obesity to occur, at some time, energy intake must have exceeded energy expenditure. A comparison of the kilocaloric intake of obese and lean individuals at their usual weights, however, reveals that on a per kilogram basis, obese people consume fewer kilocalories than lean people.

When people lose a large amount of weight, their feeding behavior changes. They become hyperresponsive to external food cues, think of food often, and cannot get enough to eat without gaining weight. It's now understood that this behavior is typical of both lean and obese individuals who are below their relative set point for weight. Other changes, such as a decrease in basal metabolic rate, take place in a person who has lost a large amount of weight. Most of this decrease in BMR probably results from a decrease in muscle mass associated with weight loss. In addition, some evidence exists that energy lost through exercise and the thermic effect of food are also reduced.

Thus, a person who has lost a large amount of weight is a person with an increased appetite and a decreased ability to expend energy. It's no surprise that only a small percentage of obese people maintain weight loss over the long term. Instead, the typical pattern is one of repeated cycles of weight loss followed by a rapid regain of the lost weight.

Current research is attempting to find ways to help manage obesity. Unfortunately, most appetite suppressants can only be used for a short time. Dexfenfluramine (deks-fen-flū′ră-mēn), which had been approved by the FDA for long-term use, was recalled because of harmful side effects.

Humans have an *obese (ob)* gene that codes for a protein called **leptin** (lep′tin), which is mainly produced by adipose cells. Leptin is released into the blood and affects appetite and body weight regulation. When energy stores in adipose tissue decrease, leptin levels decrease, resulting in an increased appetite and a decreased metabolism. Decreased leptin levels may be a signal that helps the body to adjust to fasting or starvation by increasing food intake and reducing energy expenditure. Two populations of obese individuals provide supporting evidence for this hypothesis. In some obese people, leptin is inappropriately low as a function of the amount of body fat present. Thus, there is a mismatch between the leptin signal and the amount of energy stored in adipose tissue. Most obesity, however, occurs in the presence of elevated levels of leptin. This observation seems contradictory, because high leptin levels should cause decreased appetite, increased metabolism, and weight loss. It turns out, however, that these obese individuals are leptin-resistant. They may have defective receptors for leptin or in some other way don't respond appropriately to leptin. This is analogous to people with noninsulin-dependent diabetes mellitus (see chapter 18), who have increased levels of insulin but don't respond to it. Future research may determine the mechanism of leptin resistance and the role of leptin in obesity.

The message emerging from current research is that body weight results from many complicated genetic and metabolic factors that go awry in many different ways. Obesity is being regarded as a chronic condition that may someday respond to medication in much the same way that diabetes does. Nonetheless, medication will only be part of the story. Drugs can help, but eating less and exercising more will still be necessary for optimal health.

The average normal body temperature usually is considered 37°C (98.6°F) when measured orally and 37.6°C (99.7°F) when measured rectally. Rectal temperature comes closer to the true core body temperature, but an oral temperature is more easily obtained in older children and adults and, therefore, is the preferred measure.

Heat can be exchanged with the environment in a number of ways (figure 25.16). **Radiation** is the loss of heat as infrared radiation, a type of electromagnetic radiation. For example, the coals in a fire give off radiant heat that can be felt some distance away from the fire. **Conduction** is the exchange of heat between objects in direct contact with each other, such as the bottom of the feet and the floor. **Convection** is a transfer of heat between the body and the air. A cool breeze results in the movement of air over the body and loss of heat from the body. **Evaporation** is the conversion of water from a liquid to a gaseous form, a process that requires heat. The evaporation of 1 g of water from the body's surface results in the loss of 580 cal of heat.

Body temperature is maintained by balancing heat gain with heat loss. When heat gain equals heat loss, body temperature is maintained. If heat gain exceeds heat loss, body temperature increases, and if heat loss exceeds heat gain, body temperature decreases. Heat gain occurs through metabolism and the muscular contractions of shivering, whereas heat loss occurs through evaporation. Heat gain or loss can occur by radiation, conduction, or convection depending on the skin temperature and the environmental temperature. If the skin temperature is lower than the environmental temperature, heat is gained, but if the skin temperature is higher than the environmental temperature, heat is lost.

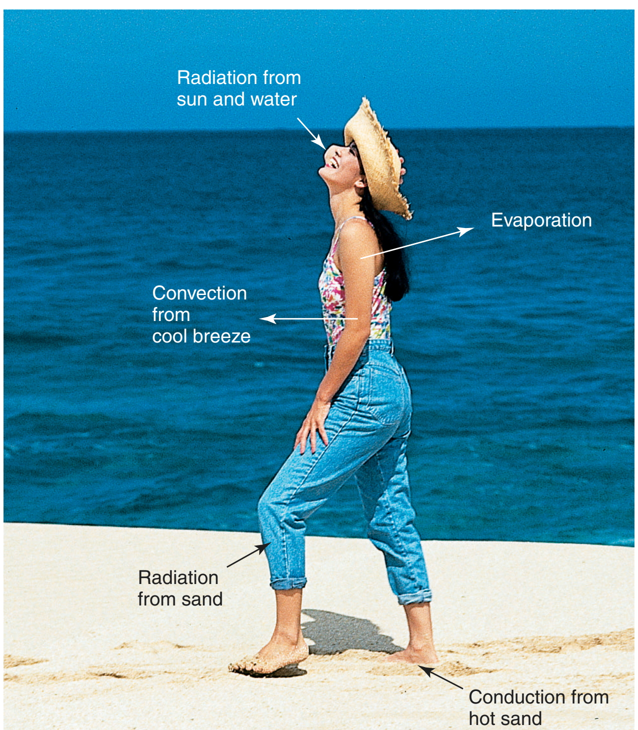


Figure 25.16 Heat Exchange

Heat exchange between a person and the environment occurs by convection, radiation, evaporation, and conduction. *Arrows* show the direction of net heat gain or loss in this environment.

The difference in temperature between the body and the environment determines the amount of heat exchanged between the environment and the body. The greater the temperature difference, the greater the rate of heat exchange. Control of the temperature difference is used to regulate body temperature. For example, if environmental temperature is very cold, like on a cold winter day, a large temperature difference exists between the body and the environment, and a large loss of heat occurs. The loss of heat can be decreased by behaviorally selecting a warmer environment, for example, by going inside a heated house. Heat loss can also be decreased by insulating the exchange surface, such as by putting on extra clothes. Physiologically, temperature difference can be controlled through dilation and constriction of blood vessels in the skin. When these blood vessels dilate, they bring warm blood to the surface of the body, raising skin temperature; conversely, vasoconstriction decreases blood flow and lowers skin temperature.

PREDICT 6

Explain why vasoconstriction of the skin's blood vessels on a cool day is beneficial.

When environmental temperature is greater than body temperature, vasodilation brings warm blood to the skin, causing an increase in skin temperature that decreases heat gain from the environment. At the same time, evaporation carries away excess heat to prevent heat gain and overheating.

Body temperature regulation is an example of a negative-feedback system that is controlled by a "set point." A small area in the anterior part of the hypothalamus detects slight increases in body temperature through changes in blood temperature (figure 25.17). As a result, mechanisms are activated that cause heat loss, such as vasodilation and sweating, and body temperature decreases. A small area in the posterior hypothalamus can detect slight decreases in body temperature and can initiate heat gain by increasing muscular activity (shivering) and vasoconstriction.

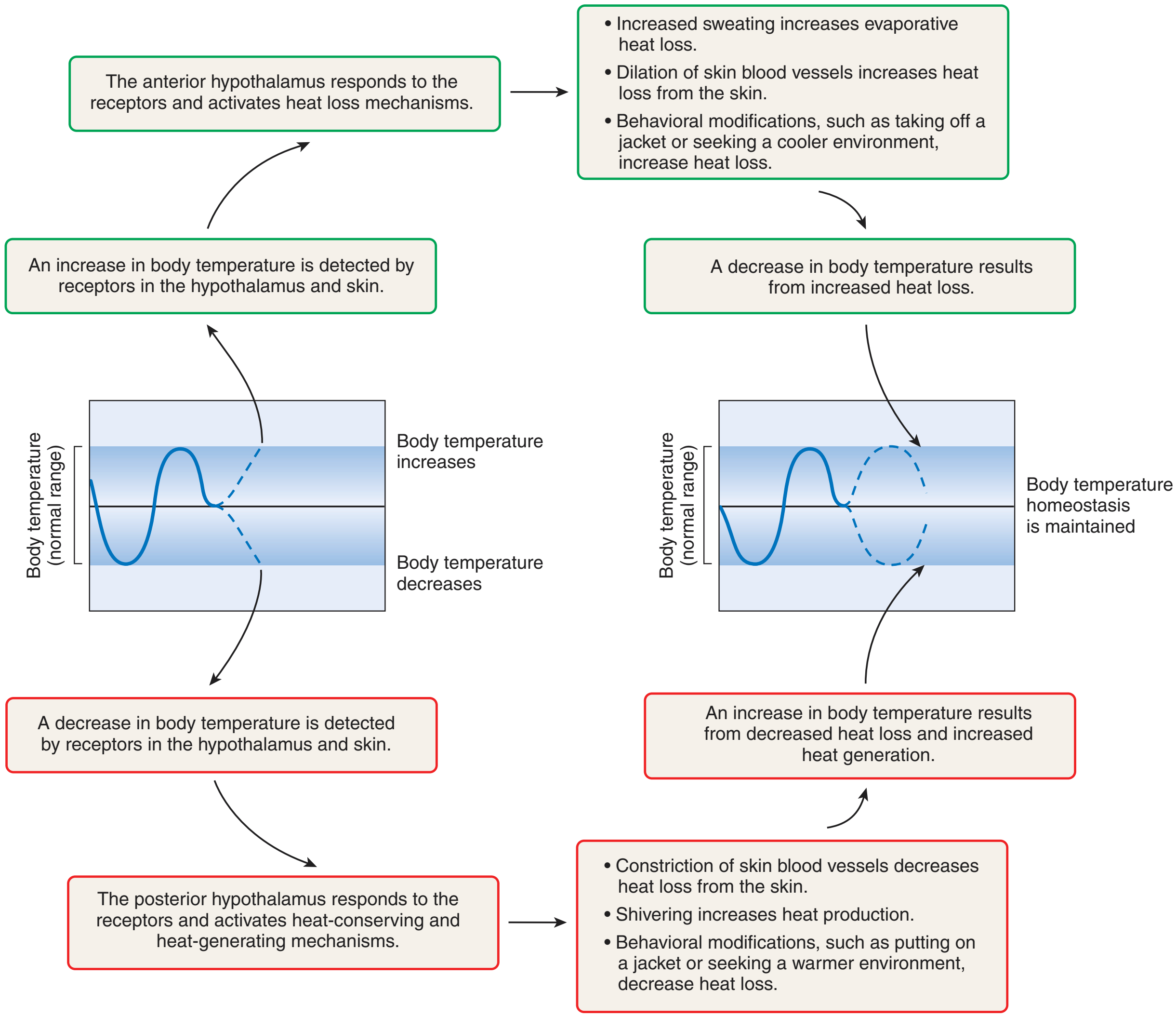
Under some conditions, the set point of the hypothalamus is actually changed. For example, during a fever, the set point is raised, heat-conserving and heat-producing mechanisms are stimulated, and body temperature increases. In recovery from a fever, the set point is lowered to normal, heat loss mechanisms are initiated, and body temperature decreases.

44. Define the terms homeotherm and free energy. How much of the free energy is lost as heat from the body?

45. What are four ways that heat is exchanged between the body and the environment?

46. How is body temperature behaviorally and physiologically maintained in a cold and in a hot environment?

47. How does the hypothalamus regulate body temperature?



Homeostasis Figure 25.17 Temperature Regulation

Clinical Focus Hyperthermia and Hypothermia

Hyperthermia

If heat gain exceeds the ability of the body to lose heat, body temperature increases above normal levels, a condition called **hyperthermia.** Hyperthermia can result from exercise, exposure to hot environments, fever, and anesthesia.

Exercise increases body temperature because of the heat produced as a by-product of muscle activity (see chapter 9). Normally, vasodilation and increased sweating prevent body temperature increases that are harmful. In a hot, humid environment, the evaporation of sweat is decreased, and exercise levels have to be reduced to prevent overheating.

Exposure to a hot environment normally results in the activation of heat loss mechanisms, and body temperature is maintained at normal levels. This is an excellent example of a negative-feedback mechanism. Prolonged exposure to a hot environment, however, can result in **heat exhaustion.** The normal negative-feedback mechanisms for controlling body temperature are operating, but they are unable to prevent an increase in body temperature above normal levels. Heavy sweating results in dehydration, decreased blood volume, decreased blood pressure, and increased heart rate. Individuals suffering from heat exhaustion have a wet, cool skin because of the heavy sweating. They usually feel weak, dizzy, and nauseated. Treatment includes reducing heat gain by moving to a cooler environment, ceasing activity to reduce heat produced by muscle metabolism, and restoring blood volume by drinking fluids.

Heat stroke is more severe than heat exhaustion because it results from a breakdown in the normal negative-feedback mechanisms of temperature regulation. If the temperature of the hypothalamus becomes too high, it no longer functions appropriately. Sweating stops, and the skin becomes dry and flushed. The person becomes confused, irritable, or even comatose. In addition to the treatment for heat exhaustion, heat loss from the skin should be increased. This can be accomplished by increasing evaporation from the skin by applying wet cloths or by increasing conductive heat loss by immersing the person in a cool bath.

Fever is the development of a higher-than-normal body temperature following the invasion of the body by microorganisms or foreign substances. Lymphocytes, neutrophils, and macrophages release chemicals called **pyrogens** (pī′rō-jenz) that raise the temperature set point of the hypothalamus. Consequently, body temperature and metabolic rate increase. Fever is believed to be beneficial because it speeds up the chemical reactions of the immune system (see chapter 22) and inhibits the growth of some microorganisms. Although beneficial, body temperatures greater than 41°C (106°F) can be harmful. Aspirin lowers body temperature by inhibiting the synthesis of pyrogens (prostaglandins).

Malignant hyperthermia is an inherited muscle disorder. Certain drugs used to induce general anesthesia for surgery cause sustained, uncoordinated muscle contractions in individuals with this disorder. Consequently, body temperature increases.

Therapeutic hyperthermia is an induced local or general body increase in temperature. It's a treatment sometimes used on tumors and infections.

Hypothermia

If heat loss exceeds the ability of the body to produce heat, body temperature decreases below normal levels. **Hypothermia** is a decrease in body temperature to 35°C (95°F) or below. Hypothermia usually results from prolonged exposure to cold environments. At first, normal negative-feedback mechanisms maintain body temperature. Heat loss is decreased by constricting blood vessels in the skin, and heat production is increased by shivering. If body temperature decreases despite these mechanisms, hypothermia develops. The individual's thinking becomes sluggish, and movements are uncoordinated. Heart, respiratory, and metabolic rates decline, and death results unless body temperature is restored to normal. Rewarming should occur at a rate of a few degrees per hour.

Frostbite is damage to the skin and deeper tissues resulting from prolonged exposure to the cold. Damage results from direct cold injury to cells, injury from ice crystal formation, and reduced blood flow to affected tissues. The fingers, toes, ears, nose, and cheeks are most commonly affected. Damage from frostbite can range from redness and discomfort to loss of the affected part. The best treatment is immersion in a warm water bath. Rubbing the affected area and local, dry heat should be avoided.

Therapeutic hypothermia is sometimes used to slow metabolic rate during surgical procedures like heart surgery. Because metabolic rate is decreased, tissues don't require as much oxygen as normal and are less likely to be damaged.

SUMMARY

Nutrition (p. 912)

Nutrition is the taking in and use of food.

Nutrients

1. Nutrients are the chemicals used by the body and consist of carbohydrates, lipids, proteins, vitamins, minerals, and water.
2. Essential nutrients are nutrients that must be ingested because the body cannot manufacture them or is unable to manufacture adequate amounts of them.

Kilocalories

1. A calorie (cal) is the heat (energy) necessary to raise the temperature of 1 g of water 1°C. A kilocalorie (kcal) or Calorie (Cal) is 1000 calories.

2. A gram of carbohydrate or protein yields 4 kcal, and a gram of fat yields 9 kcal.

Carbohydrates

1. Carbohydrates are ingested as monosaccharides (glucose, fructose), disaccharides (sucrose, maltose, lactose), and polysaccharides (starch, glycogen, cellulose).
2. Polysaccharides and disaccharides are converted to glucose. Glucose can be used for energy or stored as glycogen or fats.
3. About 125–175 g of carbohydrates should be ingested each day.

Lipids

1. Lipids are ingested as triglycerides (95%) or cholesterol and phospholipids (5%).
2. Triglycerides are used for energy or are stored in adipose tissue. Cholesterol forms other molecules, such as steroid hormones. Cholesterol and phospholipids are part of the plasma membrane.
3. The recommended daily diet should derive no more than 30% of its kilocalories from lipids, and no more than 300 mg should be in the form of cholesterol.

Proteins

1. Proteins are ingested and broken down into amino acids.
2. Proteins perform many functions: protection (antibodies), regulation (enzymes, hormones), structure (collagen), muscle contraction (actin and myosin), and transportation (hemoglobin, carrier molecules, ion channels).
3. An adult should consume 0.8 g of protein per kilogram of body weight each day.

Vitamins

1. Many vitamins function as coenzymes or as parts of coenzymes.
2. Most vitamins are not produced by the body and must be obtained in the diet. Some vitamins can be formed from provitamins.
3. Vitamins are classified as either fat-soluble or water-soluble.
4. Recommended Dietary Allowances (RDAs) are a guide for estimating the nutritional needs of groups of people based on their age, sex, and other factors.

Minerals

Minerals are necessary for normal metabolism, add mechanical strength to bones and teeth, function as buffers, and are involved in osmotic balance.

Daily Values

1. Daily Values are dietary references that can be used to help plan a healthy diet.
2. Daily Values for vitamins and minerals are based on Reference Daily Intakes, which are generally the highest 1968 RDA value of an age category.
3. Daily Values are based on Daily Reference Values.
   - The Daily Reference Values for energy-producing nutrients (carbohydrates, total fat, saturated fat, and proteins) and dietary fiber are recommended percentages of the total kilocalories ingested daily for each nutrient.
   - The Daily Reference Values for total fats, saturated fats, cholesterol, and sodium are the uppermost limit considered desirable because of their link to diseases.
4. The % Daily Value is the percent of the recommended Daily Value of a nutrient found in one serving of a particular food.

Metabolism (p. 920)

1. Metabolism consists of anabolism and catabolism. Anabolism is the building up of molecules and requires energy. Catabolism is the breaking down of molecules and gives off energy.
2. The energy in carbohydrates, lipids, and proteins is used to produce ATP through oxidation–reduction reactions.

Carbohydrate Metabolism (p. 922)

Glycolysis

Glycolysis is the breakdown of glucose into two pyruvic acid molecules. Also produced are two NADH molecules and two ATP molecules.

Anaerobic Respiration

1. Anaerobic respiration is the breakdown of glucose in the absence of oxygen into two lactic acid and two ATP molecules.
2. Lactic acid can be converted to glucose (Cori cycle) using aerobically produced ATP (oxygen debt).

Aerobic Respiration

1. Aerobic respiration is the breakdown of glucose in the presence of oxygen to produce carbon dioxide, water, and 38 (or 36) ATP molecules.
2. The first phase is glycolysis, which produces two ATP, two NADH, and two pyruvic acid molecules.
3. The second phase is the conversion of the two pyruvic acid molecules into two molecules of acetyl-CoA. These reactions also produce two NADH and two carbon dioxide molecules.
4. The third phase is the citric acid cycle, which produces two ATP, six NADH, two FADH2, and four carbon dioxide molecules.
5. The fourth phase is the electron-transport chain. The high-energy electrons in NADH and FADH2 enter the electron-transport chain and are used in the synthesis of ATP and water.

Lipid Metabolism (p. 929)

1. Adipose triglycerides are broken down and released as free fatty acids.
2. Free fatty acids are taken up by cells and broken down by beta-oxidation into acetyl-CoA.
   - Acetyl-CoA can enter the citric acid cycle.
   - Acetyl-CoA can be converted into ketone bodies.

Protein Metabolism (p. 930)

1. New amino acids are formed by transamination, the transfer of an amine group to a keto acid.
2. Amino acids are used to synthesize proteins. If used for energy, ammonia is produced as a by-product of oxidative deamination. Ammonia is converted to urea and is excreted.

Interconversion of Nutrient Molecules (p. 931)

1. Glycogenesis is the formation of glycogen from glucose.
2. Lipogenesis is the formation of lipids from glucose and amino acids.
3. Glycogenolysis is the breakdown of glycogen to glucose.
4. Gluconeogenesis is the formation of glucose from amino acids and glycerol.

Metabolic States (p. 932)

1. In the absorptive state, nutrients are used as energy or stored.
2. In the postabsorptive state, stored nutrients are used for energy.

Metabolic Rate (p. 934)

Metabolic rate is the total energy expenditure per unit of time, and it has three components.

Basal Metabolic Rate

Basal metabolic rate is the energy used at rest. It is 60% of the metabolic rate.

Thermic Effect of Food

The thermic effect of food is the energy used to digest and absorb food. It is 10% of the metabolic rate.

Muscular Activity

Muscular energy is used for muscle contraction. It is 30% of the metabolic rate.

Body Temperature Regulation (p. 935)

1. Body temperature is a balance between heat gain and heat loss.
   • Heat is produced through metabolism.
   • Heat is exchanged through radiation, conduction, convection, and evaporation.
2. The greater the temperature difference between the body and the environment, the greater the rate of heat exchange.
3. Body temperature is regulated by a "set point" in the hypothalamus.

R E V I E W A N D C O M P R E H E N S I O N

1. Which of these statements concerning kilocalories is true?
   a. A kilocalorie is the amount of energy required to raise the temperature of 1 g of water 1°C.
   b. There are 9 kcal in a gram of protein.
   c. There are 4 kcal in a gram of fat.
   d. A pound of body fat contains 3500 kcal.
2. Complex carbohydrates include
   a. sucrose.
   b. milk sugar (lactose).
   c. starch, an energy storage molecule in plants.
   d. all of the above.
3. What type of nutrient is recommended as the primary energy source in the diet?
   a. carbohydrates
   b. fats
   c. proteins
   d. cellulose
4. A good source of monounsaturated fats is
   a. fat associated with meat.
   b. egg yolks.
   c. whole milk.
   d. fish oil.
   e. olive oil.
5. A complete protein food
   a. provides the daily amount (grams) of protein recommended in a healthy diet.
   b. can be used to synthesize the nonessential amino acids.
   c. contains all 20 amino acids.
   d. includes beans, peas, and leafy green vegetables.
6. Concerning vitamins,
   a. most can be synthesized by the body.
   b. they are normally broken down before they can be used by the body.
   c. A, D, E, and K are water-soluble vitamins.
   d. many function as coenzymes.
7. Minerals
   a. are inorganic nutrients.
   b. compose about 4%–5% of total body weight.
   c. act as buffers and osmotic regulators.
   d. are components of enzymes.
   e. all of the above.
8. Glycolysis
   a. is the breakdown of glucose to two pyruvic acid molecules.
   b. requires the input of two ATP molecules.
   c. produces two NADH molecules.
   d. does not require oxygen.
   e. all of the above.
9. Anaerobic respiration occurs in the ____________ of oxygen and produces ____________ energy (ATP) for the cell than aerobic respiration.
   a. absence, more
   b. absence, less
   c. presence, more
   d. presence, less
10. Which of these reactions take place in both anaerobic and aerobic respiration?
    a. glycolysis
    b. citric acid cycle
    c. electron-transport chain
    d. acetyl-CoA formation
    e. all of the above
11. A molecule that moves electrons from the citric acid cycle to the electron-transport chain is
    a. tRNA.
    b. mRNA.
    c. ADP.
    d. NADH.
    e. pyruvic acid.
12. The production of ATP molecules by the electron-transport chain is accompanied by the synthesis of
    a. alcohol.
    b. water.
    c. oxygen.
    d. lactic acid.
    e. glucose.
13. The carbon dioxide you breathe out comes from
    a. glycolysis.
    b. the electron-transport chain.
    c. anaerobic respiration.
    d. the food you eat.
14. Lipids are
    a. stored primarily as triglycerides.
    b. synthesized by beta-oxidation.
    c. broken down by oxidative deamination.
    d. all of the above.
15. Amino acids
    a. are classified as essential or nonessential.
    b. can be synthesized in a transamination reaction.
    c. can be used as a source of energy.
    d. can be converted to keto acids.
    e. all of the above.
16. Ammonia is
    a. a by-product of lipid metabolism.
    b. formed during ketogenesis.
    c. converted into urea in the liver.
    d. produced during lipogenesis.
    e. converted to keto acids.
17. The conversion of amino acids and glycerol into glucose is called
    a. gluconeogenesis.
    b. glycogenolysis.
    c. glycogenesis.
    d. ketogenesis.
18. Which of these events takes place during the absorptive state?
    a. Glycogen is converted into glucose.
    b. Glucose is converted into fats.
    c. Ketones are produced.
    d. Proteins are converted into glucose.

19. The major use of energy by the body is in
    a. basal metabolism.
    b. physical activity.
    c. the thermic effect of food.
20. The loss of heat resulting from the loss of water from the body's surface is
    a. radiation.
    b. evaporation.
    c. conduction.
    d. convection.

Answers in Appendix F

C R I T I C A L T H I N K I N G

1. One serving of a food has 2 g of saturated fat. What % Daily Value for saturated fat would appear on a food label for this food? (See bottom of figure 25.2 for information needed to answer this question.)
2. An active teenage boy has a daily intake of 3000 kcal/day. What is the maximum amount (weight) of total fats he should consume according to the Daily Values?
3. If the teenager in question 2 eats a serving of food that has a total fat content of 10 g/serving, what is his % Daily Value for total fat?
4. Suppose the food in question 3 is in a package that lists a serving size of 1/2 cup with 4 servings in the package. If the teenager eats half of the contents of the package (1 cup), how much of his % Daily Value does he consume?
5. Why does a vegetarian usually have to be more careful about his or her diet than a person who includes meat in the diet?
6. Explain why a person suffering from copper deficiency feels tired all the time.
7. Some people claim that occasionally fasting for short periods can be beneficial. How can fasts be damaging?
8. Why can some people lose weight on a 1200 kcal/day diet and others cannot?
9. Lotta Bulk, a muscle builder, wanted to increase her muscle mass. Knowing that proteins are the main components of muscle, she began a high-protein diet in which most of her daily kilocalories were supplied by proteins. She also exercised regularly with heavy weights. After 3 months of this diet and exercise program, Lotta increased her muscle mass, but not any more than her friend, who did the same exercises but did not have a high-protein diet. Explain what happened. Was Lotta in positive or negative nitrogen balance?
10. On learning that sweat evaporation results in the loss of calories, an anatomy and physiology student enters a sauna in an attempt to lose weight. He reasons that a liter (about a quart) of water weighs 1000 g, which is equivalent to 580,000 cal or 580 kcal of heat when lost as sweat. Instead of reducing his diet by 580 kcal/day, if he loses a liter of sweat every day in the sauna, he believes he will lose about a pound of fat a week. Will this approach work? Explain.

Answers in Appendix G

A N S W E R S T O P R E D I C T Q U E S T I O N S

1. If vitamins were broken down during the process of digestion, their structures would be destroyed, and, as a result, their ability to function would be lost.
2. The Daily Value for carbohydrate is 300 g/day. One serving of food with 30 g of carbohydrate has a % Daily Value of 10% (30/300 = .10, or 10%).
3. On a 1800 kcal/day diet, the total percentage of Daily Values for energy-producing nutrients should add up to no more than 90%, because 1800/2000 = 0.9, or 90%.
4. If the electron of the electron-transport chain cannot be donated to oxygen, the entire electron-transport chain stops, no ATP can be produced aerobically, and the patient dies because too little energy is available for the body to perform vital functions. Anaerobic respiration is not adequate to provide all the energy needed to maintain human life, except for a short time.
5. When muscles contract, they use ATP. As a result of the chemical reactions necessary to synthesize ATP, heat is also produced. During exercise the large amounts of heat can raise body temperature, and we feel warm. Shivering consists of small, rapid muscle contractions that produce heat in an effort to prevent a decrease in body temperature in the cold.
6. Vasoconstriction reduces blood flow to the skin, which reduces skin temperature because less warm blood from the deeper parts of the body reaches the skin. As the difference in temperature between the skin and the environment decreases, less loss of heat occurs.

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