CHAPTER 3

Organic Chemistry

The Chemistry of Life

3

Chapter Outline

Key Concepts	Applications
Understand carbon atoms and their chemical nature.	• Distinguish between molecules that are organic and inorganic. • Understand how the large organic molecules that are found in living things are formed. • Learn how these same molecules are split apart by living things. • Draw diagrams of organic molecules.
Recognize different molecular structures common to organic molecules.	• Recognize how organic molecules differ from one another.
Know the various categories of organic molecules.	• Learn what roles each category of organic molecules play in living things.

Figure 3.1

Some Common Synthetic Organic Materials
These items are examples of useful organic compounds invented by chemists. The words *organism, organ, organize,* and *organic* are all related. Organized objects have parts that fit together in a meaningful way. Organisms are separate living things that are organized. Animals have within their organization organs, and the unique kinds of molecules they contain are called organic. Therefore, organisms consist of organized systems of organs containing organic molecules.

3.1 Molecules Containing Carbon

The principles and concepts discussed in chapter 2 apply to all types of matter—nonliving as well as living. Living systems are composed of various types of molecules. Most of the things we described in the previous chapter did not contain carbon atoms and so are classified as **inorganic molecules.** This chapter is mainly concerned with more complex structures, **organic molecules,** which contain carbon atoms arranged in rings or chains.

The original meanings of the terms *inorganic* and *organic* came from the fact that organic materials were thought to be either alive or produced only by living things. The words *organism, organ, organize,* and *organic* are all related. Organized objects have parts that fit together in a meaningful way. Organisms are separate living things that are organized. Animals have within their organization organs, and the unique kinds of molecules they contain are called organic. Therefore, organisms consist of organized systems of organs containing organic molecules. A very strong link exists between organic chemistry and the chemistry of living things, which is called **biochemistry,** or biological chemistry. Modern chemistry has considerably altered the original meanings of the terms organic and inorganic, because it is now possible to manufacture unique organic molecules that cannot be produced by living things. Many of the materials we use daily are the result of the organic chemist's art. Nylon, aspirin, polyurethane varnish, silicones, Plexiglas, food wrap, Teflon, and insecticides are just a few of the unique molecules that have been invented by organic chemists (figure 3.1).

In many instances, organic chemists have taken their lead from living organisms and have been able to produce organic molecules more efficiently, or in forms that are slightly different from the original natural molecule. Some examples of these are rubber, penicillin, some vitamins, insulin, and alcohol (figure 3.2). Another example is the insecticide Pyethrin, which is based on a natural insecticide that is widely used in agriculture and for domestic purposes, and is from the chrysanthemum plant *Pyrethrum cinerariaefolium.*

3.2 Carbon: The Central Atom

All organic molecules, whether they are natural or synthetic, have certain common characteristics. The carbon atom, which is the central atom in all organic molecules, has some unusual properties. Carbon is unique in that it can combine

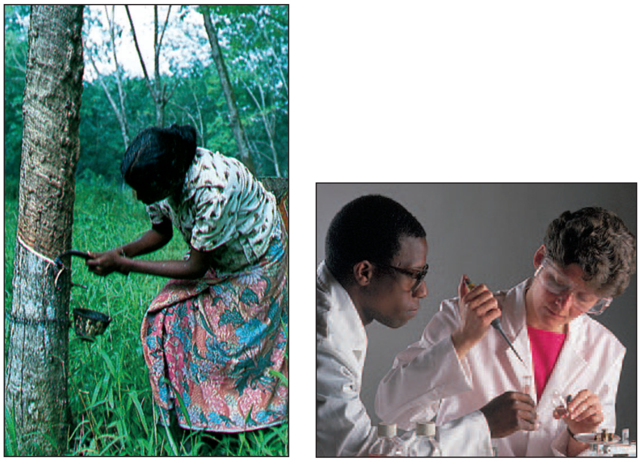


Figure 3.2

Natural and Synthetic Organic Compounds
Some organic materials, such as rubber, were originally produced by plants but are now synthesized in industry. The photograph on the left shows the collection of latex from the rubber tree. After processing, this naturally occurring organic material will be converted into products such as gloves, condoms, and tubing. The other photograph shows an organic chemist testing one of the steps in a manufacturing process.

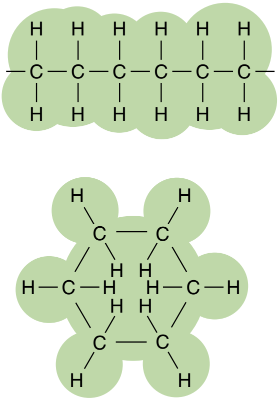


Figure 3.3

A Chain or Ring Structure
The ring structure shown on the bottom is formed by joining the two ends of a chain of carbon atoms.

Figure 3.4

Bonding Sites of a Carbon Atom
The arrangement of bonding sites around the carbon is similar to a ball with four equally spaced nails in it. Each of the four bondable electrons inhabits an area as far away from the other three as possible. Each can share its electron with another. Carbon can share with four other atoms at each of these sites.

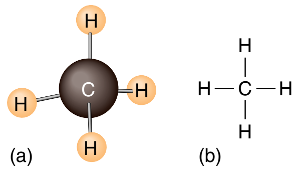


Figure 3.5

A Methane Molecule
A methane molecule is composed of one carbon atom bonded with four hydrogen atoms. (*a*) These bonds are formed at the four bonding sites of the carbon. For the sake of simplicity, all future diagrams of molecules will be two-dimensional drawings, although in reality they are three-dimensional molecules. (*b*) Each line in the diagram represents a covalent bond between the two atoms where a pair of electrons is being shared. This is a shorthand way of drawing the pair of shared electrons.

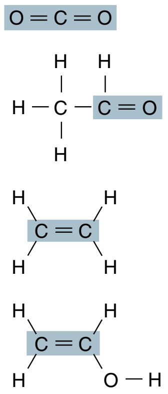
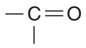


Figure 3.6

Double Bonds
These diagrams show several molecules that contain double bonds. A double bond is formed when two atoms share two pairs of electrons with each other.

with other carbon atoms to form long chains. In many cases the ends of these chains may join together to form ring structures (figure 3.3). Only a few other atoms have this ability. What is really unusual is that these bonding sites are all located at equal distances from one another. If you were to take a rubber ball and stick four nails into it so that they were equally distributed around the ball, you would have a good idea of the geometry involved. These bonding sites are arranged this way because in the carbon atom there are four electrons in the second energy level. These four electrons do not stay in the standard positions described in chapter 2. They distribute themselves differently, that is, into four propeller-shaped orbitals. This allows them to be as far away from each other as possible (figure 3.4). Carbon atoms are usually involved in covalent bonds. Because carbon has four places it can bond, the carbon atom can combine with four other atoms by forming four separate *single* covalent bonds with other atoms. This is the case with the methane molecule, which has four hydrogen atoms attached to a single carbon atom. Pure methane is a colorless and odorless gas that makes up 95% of natural gas (figure 3.5). The aroma of natural gas is the result of mercaptan (and trimethyl disulfide) added to let consumers know when a leak occurs. Outlooks 3.1 explains how chemists and biologists diagram the kinds of bonds formed in organic molecules.

Some atoms may be bonded to a single atom more than once. This results in a slightly different arrangement of bonds around the carbon atom. An example of this type of bonding occurs when oxygen is attracted to a carbon. Oxygen has two bondable electrons. If it shares one of these with a carbon and then shares the other with the same carbon, it forms a *double bond.* A **double bond** is two covalent bonds formed between two atoms that share two pairs of electrons. Oxygen is not the only atom that can form double bonds, but double bonds are common between it and carbon. The double bond is denoted by two lines between the two atoms:



$$-\underset{|}{C}=O$$

Two carbon atoms might form double bonds between each other and then bond to other atoms at the remaining bonding sites. Figure 3.6 shows several compounds that contain double bonds. Some organic molecules contain *triple covalent bonds;* the flammable gas acetylene, HC≡CH, is one example. Others, like hydrogen cyanide, HC≡N, have biological significance. This molecule inhibits the production of energy and results in death.

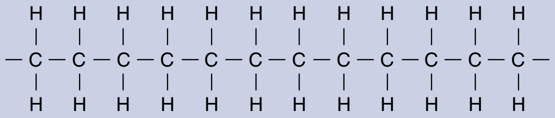
Although most atoms can be involved in the structure of an organic molecule, only a few are commonly found. Hydrogen (H) and oxygen (O) are almost always present. Nitrogen (N), sulfur (S), and phosphorus (P) are also very important in specific types of organic molecules.

An enormous variety of organic molecules is possible because carbon is able to bond at four different sites, form long chains, and combine with many other kinds of atoms. The types of atoms in the molecule are important in determining the properties of the molecule. The three-dimensional arrangement of the atoms within the molecule is also important.

OUTLOOKS 3.1

Chemical Shorthand

You have probably noticed that sketching the entire structural formula of a large organic molecule takes a great deal of time. If you know the structure of the major functional groups, you can use several shortcuts to more quickly describe chemical structures. When multiple carbons with two hydrogens are bonded to each other in a chain, we sometimes write it as follows:

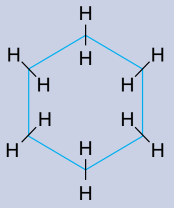


$$-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{\mathrm{C}}}-$$

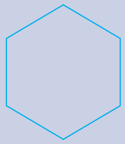
Or we might write it this way:

$$-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-$$

or more simply, we may write it as follows $(-CH_2-)_{12}$. If the 12 carbons were in a pair of two rings, we probably would not label the carbons or hydrogens unless we wished to focus on a particular group or point. We would probably draw the two six-carbon rings with only hydrogen attached as follows:

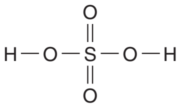


Or



Don't let these shortcuts throw you. You will soon find that you will be putting an –OH group onto a carbon skeleton and neglecting to show the bond between the oxygen and hydrogen, just like a professional. Structural formulas are regularly included in the package insert information of most medications.

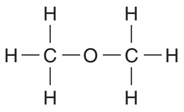
Because most inorganic molecules are small and involve few atoms, a group of atoms can be usually arranged in only one way to form a molecule. There is only one arrangement for a single oxygen atom and two hydrogen atoms in a molecule of water. In a molecule of sulfuric acid, there is only one arrangement for the sulfur atom, the two hydrogen atoms, and the four oxygen atoms.



$$H-O-\overset{\overset{\mathrm{O}}{\|}}{\underset{\underset{\mathrm{O}}{\|}}{S}}-O-H$$

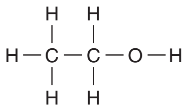
Sulfuric (battery) acid

However, consider these two organic molecules:



$$H-\overset{\mathrm{H}}{\underset{\mathrm{H}}{C}}-O-\overset{\mathrm{H}}{\underset{\mathrm{H}}{C}}-H$$

Dimethyl ether



$$H-\overset{\mathrm{H}}{\underset{\mathrm{H}}{C}}-\overset{\mathrm{H}}{\underset{\mathrm{H}}{C}}-O-H$$

Ethyl alcohol
(as found in alcoholic beverages)

Both the dimethyl ether and the ethyl alcohol contain two carbon atoms, six hydrogen atoms, and one oxygen atom, but they are quite different in their arrangement of atoms and in the chemical properties of the molecules. The first is an ether; the second is an alcohol. Because the ether and the alcohol have the same number and kinds of atoms, they are said to have the same empirical formula, which in this case is written C_2H_6O. An empirical formula simply indicates the number of each kind of atom within the molecule. When the arrangement of the atoms and their bonding within the molecule is indicated, we call this a structural formula. Figure 3.7 shows several structural formulas for the empirical formula $C_6H_{12}O_6$. Molecules that have the same empirical formula but different structural formulas are called **isomers** (How Science Works 3.1).

3.3 The Carbon Skeleton and Functional Groups

To help us understand organic molecules a little better, let's consider some of their similarities. All organic molecules have a **carbon skeleton,** which is composed of rings or chains of carbons. It is this carbon skeleton that determines the overall shape of the molecule. The differences between various organic molecules depend on the length and arrangement of the carbon skeleton. In addition, the kinds of atoms that are bonded to this carbon skeleton determine the way the organic compound acts. Attached to the carbon skeleton are specific combinations of atoms called **functional groups.** Functional groups determine specific chemical properties. By learning to recognize some of the functional groups, it is possible to identify an organic molecule and to predict something about its activity. Figure 3.8 shows some of the functional groups that are important in biological activity. Remember that a functional group does not exist by itself; it must be a part of an organic molecule (Outlooks 3.1).

3.4 Common Organic Molecules

One way to make organic chemistry more manageable is to organize different kinds of compounds into groups on the basis of their similarity of structure or the chemical properties

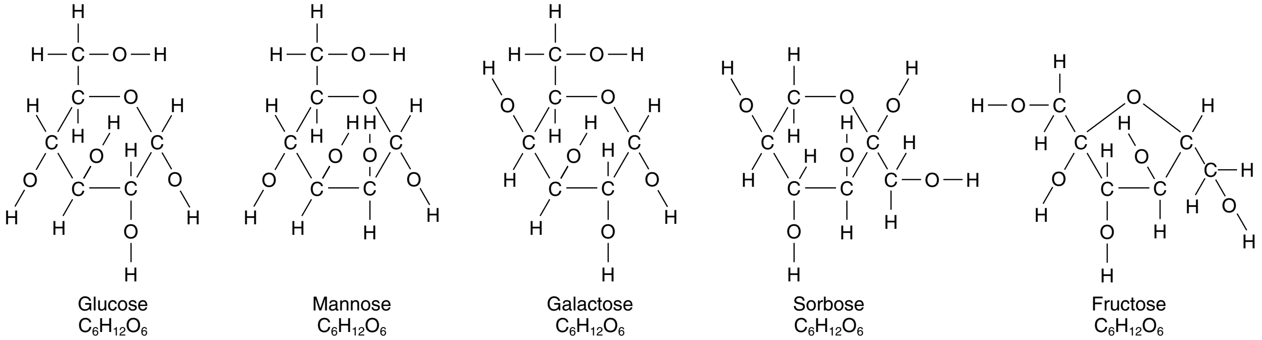


Figure 3.7

Structural Formulas for Several Hexoses
Several 6-carbon sugars, hexoses (*hex* = 6; *-ose* = sugar) are represented here. Each has the same empirical formula, but each has a different structural formula. They will also act differently from each other.

of the molecules. Frequently you will find that organic molecules are composed of subunits that are attached to each other. If you recognize the subunit, then the whole organic molecule is much easier to identify. It is similar to distinguishing among the units of a pearl necklace, boat's anchor chain, and beaded key chain. They are all constructed of individual pieces hooked together. Each is distinctly different because the repeating units are not the same, that is, pearls are not anchor links. In all these examples, individual pieces are called *monomers* (*mono* = single; *mer* = segment or piece). The entire finished piece composed of all the units hooked together is called a *polymer* (*poly* = many; *mer* = segments). The plastics industry has polymer chemistry as its foundation.

The monomers in a polymer are usually combined by a **dehydration synthesis reaction** (*de* = remove; *hydro* = water; *synthesis* = combine). This reaction results in the synthesis or formation of a macromolecule when water is removed from between the two smaller component parts. For example, when a monomer with an –OH group attached to its carbon skeleton approaches another monomer with an available hydrogen, dehydration synthesis can occur. Figure 3.9 shows the removal of water from between two such subunits. Notice that in this case, the structural formulas are used to help identify just what is occurring. However, the chemical equation also indicates the removal of the water. You can easily recognize a dehydration synthesis reaction because the reactant side of the equation shows numerous small molecules, whereas the product side lists fewer, larger products and water.

The reverse of a dehydration synthesis reaction is known as *hydrolysis* (*hydro* = water; *lyse* = to split or break). **Hydrolysis** is the process of splitting a larger organic molecule into two or more component parts by the addition of water. Digestion of food molecules in the stomach is an important example of hydrolysis.

Table 3.1

THE RELATIVE SWEETNESS OF VARIOUS SUGARS AND SUGAR SUBSTITUTES

Type of Sugar or Artificial Sweetener	Relative Sweetness
Lactose (milk sugar)	0.16
Galactose	0.30
Maltose (malt sugar)	0.33
Glucose	0.75
Sucrose (table sugar)	**1.00**
Fructose (fruit sugar)	1.75
Cyclamate	30.00
Aspartame	150.00
Saccharin	350.00

Carbohydrates

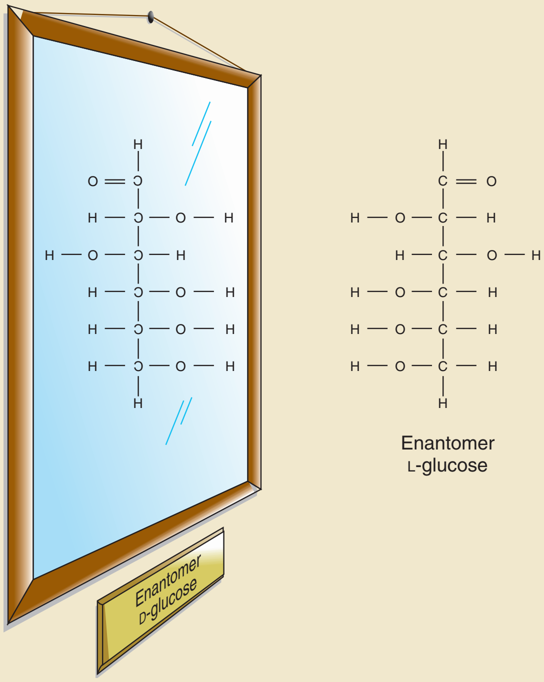
One class of organic molecules, **carbohydrates,** is composed of carbon, hydrogen, and oxygen atoms linked together to form monomers called *simple sugars* or *monosaccharides* (*mono* = single; *saccharine* = sweet, sugar) (table 3.1). Carbohydrates play a number of roles in living things. They serve as an immediate source of energy (sugars), provide shape to certain cells (cellulose in plant cell walls), are components of many antibiotics and coenymes, and are an essential part of genes (DNA). The empirical formula for a simple sugar is easy to recognize because there are equal numbers of carbons and oxygens and twice as many hydrogens—for example, $C_3H_6O_3$ or $C_5H_{10}O_5$. We usually describe simple sugars by the number of carbons in the molecule. The ending *-ose* indicates that you are dealing with a carbohydrate. A tri*ose* has three carbons, a pent*ose* has five, and a hex*ose* has six. If you remember that the number of carbons equals the number of oxygen atoms and that the number of hydrogens

HOW SCIENCE WORKS 3.1

Generic Drugs and Mirror Image Isomers

Isomers that are mirror images of each other are called *mirror image isomers, stereo isomers, enantomers* or *chiral compounds.* The difference among stereo isomers is demonstrated by shining polarized light through the two types of sugar. The light coming out the other side of a test tube containing D-glucose will be turned to the right, that is, *dextro*rotated. When a solution of L-glucose has polarized light shown through it, the light coming out the other side will be rotated to the left, that is, *levo*rotated.

The results of this basic research has been utilized in the pharmaceutical and health care industries. When drugs are synthesized in large batches in the lab many contain 50% "D" and 50% "L" enantomers. Various so-called "generic drugs" are less expensive because they are a mixture of the two enantomers and have not undergone the more thorough and expensive chemical processes involved in isolating only the "D" or "L" form of the drug.



is double that number, these names tell you the empirical formula for the simple sugar.

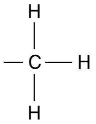
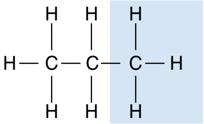
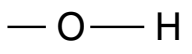
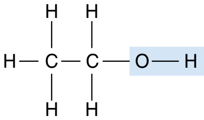
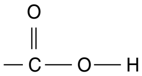
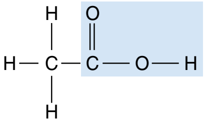
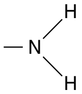
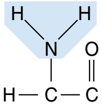
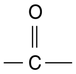
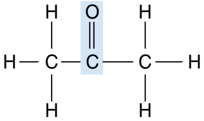
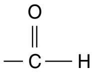
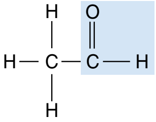
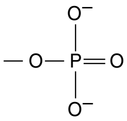
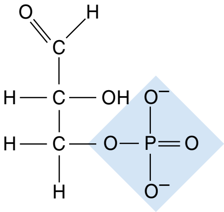
Simple sugars, such as glucose, fructose, and galactose, provide the chemical energy necessary to keep organisms alive. These simple sugars combine with each other by dehydration synthesis to form **complex carbohydrates** (figure 3.10). When two simple sugars bond to each other, a *disaccharide* (*di-* = two) is formed; when three bond together, a *trisaccharide* (*tri-* = three) is formed. Generally we call a complex carbohydrate that is larger than this a *polysaccharide* (many sugar units). In all cases, the complex carbohydrates are formed by the removal of water from between the sugars. Some common examples of polysaccharides are starch and glycogen. Cellulose is an important polysaccharide used in constructing the cell walls of plant cells. Humans cannot digest (*hydrolyze*) this complex carbohydrate, so we are not able to use it as an energy source. On the other hand, animals known as ruminants (e.g., cows and sheep) and termites have microorganisms within their digestive tracts that do digest cellulose, making it an energy source for them. Plant cell walls add bulk or fiber to our diet, but no calories. Fiber is an important addition to the diet because it helps control weight, reduce the risk of colon cancer, and control constipation and diarrhea.

Simple sugars can be used by the cell as components in other, more complex molecules. Sugar molecules are a part of other, larger molecules such as DNA, RNA, or ATP. The ATP molecule is important in energy transfer. It has a simple sugar (ribose) as part of its structural makeup. The building blocks of the genetic material (DNA) also have a sugar component.

Lipids

We generally call molecules in this group fats. However, there are three different types of **lipids:** *true fats* (pork chop fat or olive oil), **phospholipids** (the primary component of cell membranes), and **steroids** (most hormones). In general, lipids are large, nonpolar, organic molecules that do not easily dissolve in polar solvents such as water. They are soluble in nonpolar substances such as ether or acetone. Just like carbohydrates, the lipids are composed of carbon, hydrogen, and oxygen. They do not, however, have the same ratio of carbon, hydrogen, and oxygen in their empirical formulas. Lipids generally have very small amounts of oxygen in comparison to the amounts of carbon and hydrogen. *Simple lipids* such as steroids and prostaglandins are not able to be hydrolyzed into smaller, similar subunits. *Complex lipids* such as true fats and phospholipids can be hydrolyzed into smaller, similar units.

Classification of Small Molecules by Functional Groups

Group	Name of Group	Example of Group in Biologically Important Molecule	Name of Compound	Class of Molecule Found in
	Methyl		Propane	Numerous
	Alcohol		Ethanol (ethyl alcohol)	Alcohols
	Carboxyl		Acetic acid	Acids
	Amine		Glycine	Amines and amino acids
	Ketone		Acetone	Ketones
	Aldehyde		Acetaldehyde	Aldehydes
	Phosphate		Glyceraldehyde 3-phosphate	Phosphorylated compounds

Key functional groups are shaded.

Figure 3.8

Functional Groups
These are some of the groups of atoms that frequently attach to a carbon skeleton. Notice how the nature of the organic compound changes as the nature of the functional group changes from one molecule to another.

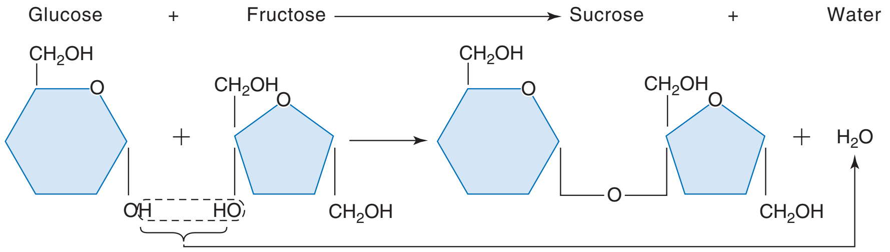


Figure 3.9

The Dehydration Synthesis Reaction
In the reaction illustrated here, the two –OH groups line up next to each other so that the –OH groups can be broken from the molecules to form water, and the oxygen that remains acts as an attachment site between the two larger sugar molecules. Many structural formulas appear to be complex at first glance, but if you look for the points where subunits are attached and dissect each subunit, they become much simpler to deal with.

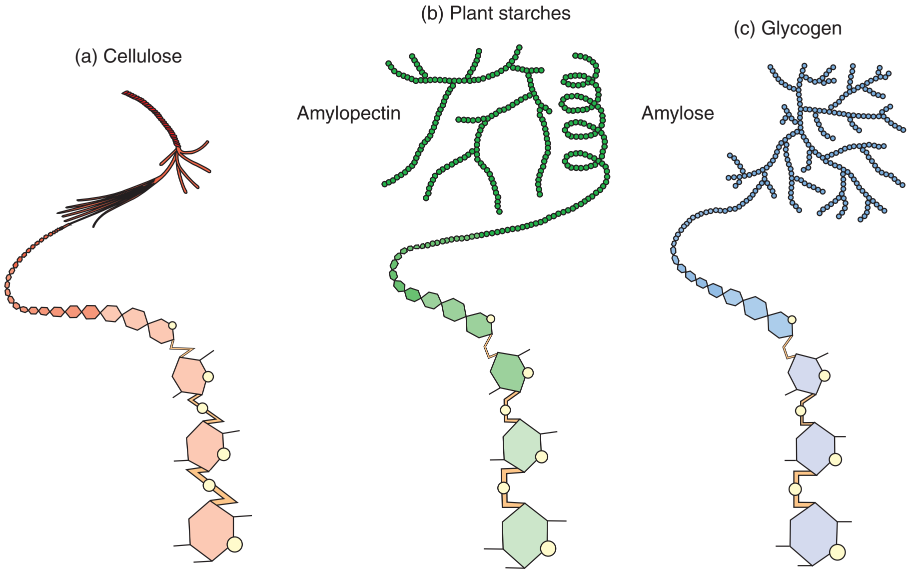
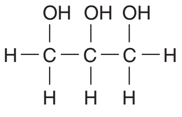


Figure 3.10

A Complex Carbohydrate
Simple sugars are attached to each other by the removal of water from between them. Three common complex carbohydrates are (*a*) cellulose (wood fibers), (*b*) plant starch (amylose and amylopectin), and (*c*) glycogen (sometimes called animal starch). Glycogen is found in muscle cells. Notice how each is similar in that they are all polymers of simple sugars, but differ from one another in how they are joined together. While many organisms are capable of digesting (hydrolyzing) the bonds that are found in glycogen and plant starch molecules, few are able to break those that link the monosaccharides of cellulose together.

True (Neutral) Fats

True (neutral) fats are important, complex organic molecules that are used to provide, among other things, energy. The building blocks of a fat are a glycerol molecule and fatty acids. The **glycerol** is a carbon skeleton that has three alcohol groups attached to it. Its chemical formula is $C_3H_5(OH)_3$. At room temperature, glycerol looks like clear, lightweight oil. It is used under the name glycerin as an additive to many cosmetics to make them smooth and easy to spread.



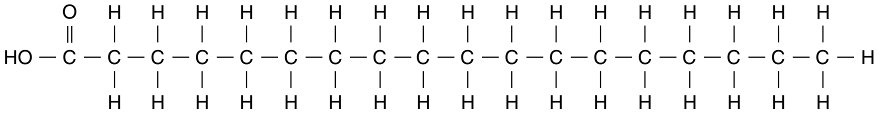
Glycerol

A **fatty acid** is a long-chain carbon skeleton that has a carboxylic acid functional group. If the carbon skeleton has as much hydrogen bonded to it as possible, we call it **saturated.** The saturated fatty acid in figure 3.11*a* is stearic acid, a component of solid meat fats such as mutton tallow. Notice that at every point in this structure the carbon has as much hydrogen as it can hold. Saturated fats are generally found in animal tissues—they tend to be solids at room temperatures. Some examples of saturated fats are butter, whale blubber, suet, lard, and fats associated with such meats as steak or pork chops.

If the carbons are double-bonded to each other at one or more points, the fatty acid is said to be **unsaturated.** The occurrence of a double bond in a fatty acid is indicated by the Greek letter ω (omega) followed by a number

Figure 3.11

Structure of Saturated and Unsaturated Fatty Acids
(*a*) Stearic acid is an example of a saturated fatty acid. (*b*) Linoleic acid is an example of an unsaturated fatty acid.



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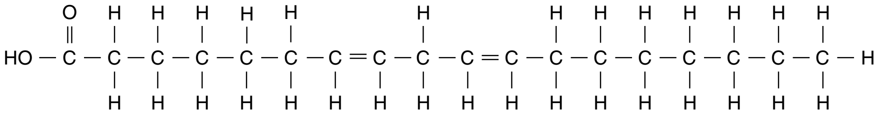
(a) Stearic acid



$$HO-\overset{\overset{O}{\|}}{C}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\underset{H}{C}=\underset{H}{C}-\overset{H}{\underset{H}{C}}-\underset{H}{C}=\underset{H}{C}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H$$

(b) Linoleic acid

indicating the location of the first double bond in the molecule. Oleic acid, one of the fatty acids found in olive oil, is comprised of 18 carbons with a single double bond between carbons 9 and 10. Therefore, it is chemically designated C18:Iω9 and is a monounsaturated fatty acid. This fatty acid is commonly referred to as an omega-9 fatty acid. The unsaturated fatty acid in figure 3.11*b* is linoleic acid, a component of sunflower and safflower oils. Notice that there are two double bonds between the carbons and fewer hydrogens than in the saturated fatty acid. Linoleic acid is chemically a polyunsaturated fatty acid with two double bonds and is designated C18:2ω6, an omega-6 fatty acid. This indicates that the first double bond of this 18-carbon molecule is between carbons 6 and 7. Since the human body cannot make this fatty acid, it is called an *essential fatty acid* and must be taken in as a part of the diet. The other essential fatty acid, linoleic acid, is C18:3ω3 and has three double bonds. These two fatty acids are commonly referred to as omega-3 fatty acids. One key function of these essential fatty acids is the synthesis of prostaglandin hormones that are necessary in controlling cell growth and specialization.

Sources of Omega-3 Fatty Acids	**Sources of Omega-6 Fatty Acids**
Certain fish oil (salmon, sardines, herring)	Corn oil
	Peanut oil
Flaxseed oil	Cottonseed oil
Soybeans	Soybean oil
Soybean oil	Sesame oil
Walnuts	Safflower oil
Walnut oil	Sunflower oil

Unsaturated fats are frequently plant fats or oils—they are usually liquids at room temperature. Peanut, corn, and olive oil are mixtures of different triglycerides and are considered unsaturated because they have double bonds between the carbons of the carbon skeleton. A polyunsaturated fatty acid is one that has a great number of double bonds in the carbon skeleton. When glycerol and three fatty acids are combined by three dehydration synthesis reactions, a fat is formed. Notice that dehydration synthesis is almost exactly the same as the reaction that causes simple sugars to bond together.

Fats are important molecules for storing energy. There is more than twice as much energy in a gram of fat as in a gram of sugar, 9 calories versus 4 calories. This is important to an organism because fats can be stored in a relatively small space and still yield a high amount of energy. Fats in animals also provide protection from heat loss. Some animals have a layer of fat under the skin that serves as an insulating layer. The thick layer of blubber in whales, walruses, and seals prevents the loss of internal body heat to the cold, watery environment in which they live. This same layer of fat, together with the fat deposits around some internal organs—such as the kidneys and heart—serve as a cushion that protects these organs from physical damage. If a fat is formed from a glycerol molecule and three attached fatty acids, it is called a *triglyceride;* if two, a *diglyceride;* and if one, a *monoglyceride* (figure 3.12). Triglycerides account for about 95% of the fat stored in human tissue.

Phospholipids

Phospholipids are a class of complex water-insoluble organic molecules that resemble fats but contain a phosphate group (PO_4) in their structure (figure 3.13). One of the reasons phospholipids are important is that they are a major component of membranes in cells. Without these lipids in our membranes, the cell contents would not be separated from the exterior environment. Some of the phospholipids are better known as the *lecithins*. Lecithins are found in cell membranes and also help in the emulsification of fats. They help separate large portions of fat into smaller units. This allows the fat to mix with other materials. Lecithins are added to many types of food for this purpose (chocolate bars, for example). Some people take lecithin as nutritional supplements because they believe it leads to healthier hair and better reasoning ability. But once inside your intestines, lecithins are destroyed by enzymes, just like any other phospholipid (Outlooks 3.2). Phospholipids are essential components of the membranes of all cells and will be described again in chapter 4.

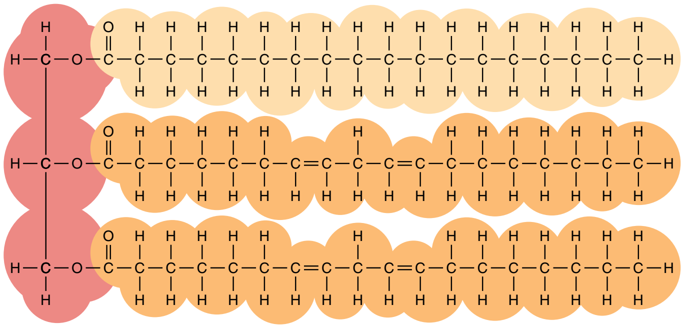


Figure 3.12

A Fat Molecule
The arrangement of the three fatty acids attached to a glycerol molecule is typical of the formation of a fat. The structural formula of the fat appears to be very cluttered until you dissect the fatty acids from the glycerol; then it becomes much more manageable. This example of a triglyceride contains a glycerol molecule, two unsaturated fatty acids (linoleic acid), and a third saturated fatty acid (stearic acid).

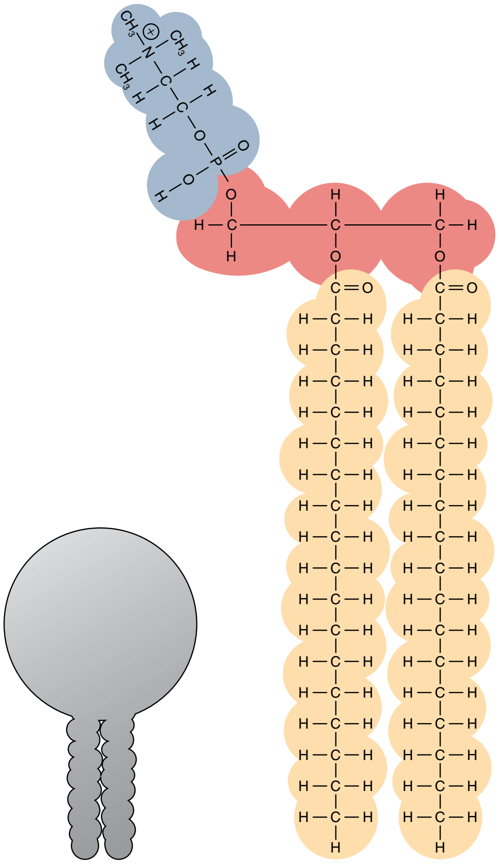


Figure 3.13

A Phospholipid Molecule
This molecule is similar to a fat but has a phosphate group in its structure. The phosphate group and two fatty acids are bonded to the glycerol by a dehydration synthesis reaction. Molecules like these are also known as lecithin. The diagram of phospholipid molecules are shown as a balloon with two strings. The balloon portion is the glycerol and phosphate group while the strings are the fatty acid segments of the molecule.

Steroids

Steroids, another group of lipid molecules, are characterized by their arrangement of interlocking rings of carbon. They often serve as hormones that aid in regulating body processes. We have already mentioned one steroid molecule that you are probably familiar with: cholesterol. Although serum cholesterol (the kind found in your blood associated with lipoproteins) has been implicated in many cases of atherosclerosis, this steroid is made by your body for use as a component of cell membranes. It is also used by your body to make bile acids. These products of your liver are channeled into your intestine to emulsify fats. Cholesterol is also necessary for the manufacture of vitamin D. Cholesterol molecules in the skin react with ultraviolet light to produce vitamin D, which assists in the proper development of bones and teeth. Figure 3.14 illustrates some of the steroid compounds that are typically manufactured by organisms.

A large number of steroid molecules are hormones. Some of them regulate reproductive processes such as egg and sperm production (see chapter 21); others regulate such things as salt concentration in the blood.

Proteins

Proteins play many important roles. As catalysts (enzymes) they speed the rate of chemical reactions. They also serve as carriers of other molecules such as oxygen (hemoglobin), provide shape and support (collagen), and cause movement (muscle fibers). Proteins also act as chemical messengers (certain hormones) and help defend the body against dangerous microbes and chemicals (antibodies). Chemically, proteins are polymers made up of monomers known as *amino acids*. An **amino acid** is a short carbon skeleton that contains an amino group (a nitrogen and two hydrogens) on one end of the skeleton and a carboxylic acid group at the other end (figure 3.15). In addition, the carbon skeleton may have one of several different side chains on it. These vary in their composition and are generally noted as the amino acid's R-group. About 20 common amino acids are important to cells and each differs from one another in the nature of its attached R-group.

OUTLOOKS 3.2

Fat and Your Diet

When triglycerides are eaten in fat-containing foods, digestive enzymes hydrolyze them into glycerol and fatty acids. These molecules are absorbed by the intestinal tract and coated with protein to form lipoprotein, as shown in the accompanying diagram.

The five types of lipoproteins found in the body are: (1) chylomicrons, (2) very-low-density lipoproteins (VLDL), (3) low-density lipoproteins (LDL), (4) high-density lipoproteins (HDL), and (5) lipoprotein a–Lp(a). Chylomicrons are very large particles formed in the intestine and are between 80% and 95% triglycerides. As the chylomicrons circulate through the body, cells remove the triglycerides in order to make hormones, store energy, and build new cell parts. When most of the triglycerides have been removed, the remaining portions of the chylomicrons are harmlessly destroyed.

The VLDLs and LDLs are formed in the liver. VLDLs contain all types of lipid, protein, and 10% to 15% cholesterol, while the LDLs are about 50% cholesterol. As with the chylomicrons, the body uses these molecules for fats they contain. However, in some people, high levels of LDLs and Lp(a) in the blood are associated with the diseases atherosclerosis, stroke, and heart attack. While in the blood, LDLs may stick to the insides of the vessels, forming deposits that restrict blood flow and contribute to high blood pressure, strokes, and heart attacks. Even though they are 30% cholesterol, a high level of HDLs (made in the intestine) in comparison to LDLs and Lp(a) is associated with a lower risk of atherosclerosis. One way to reduce the risk of this disease is to lower your intake of LDLs and Lp(a). Reducing your consumption of saturated fats can do this since the presence of saturated fats disrupts the removal of LDLs from the bloodstream. An easy way to remember the association between LDLs and HDLs is "L = lethal" and "H = Healthy" or "Low = Bad" and "High = Good." The federal government's new cholesterol guidelines recommend that all adults get a full lipoprotein profile (total cholesterol, HDL, and LDL and triglycerides) once every five years. They also recommend a sliding scale for desirable LDL levels. The higher your heart attack risk, the lower your LDL should be.

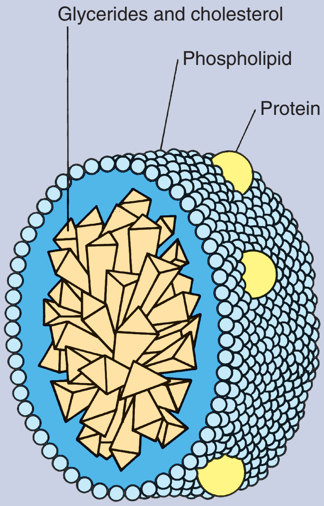


Diagram of a Lipoprotein

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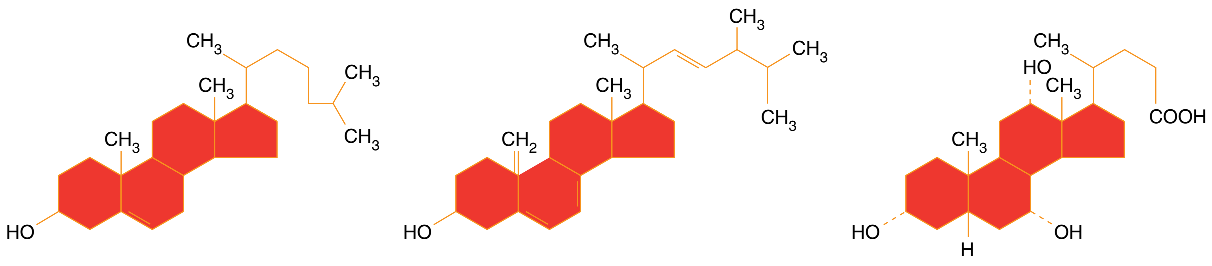
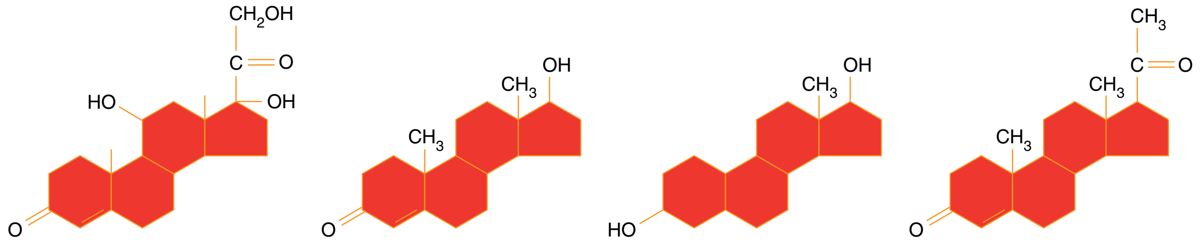
Normal HDL Values	Normal LDL Values	Normal VLDL Values
Men: 40–70 mg/dL Women: 40–85 mg/dL Children: 30–65 mg/dL	Men: 91–100 mg/dL Women: 69–100 mg/dL	Men: 0–40 mg/dL Women: 0–40 mg/dL
Minimum desirable: 40 mg/dL	High risk: no higher than100 mg/dL	Desirable: below 40 mg/dL
	Moderate risk: no higher than 130 mg/dL Low risk: at or below 160 mg/dL	
For Total Cholesterol Levels		
Desirable: Below 200 mg/dL	Borderline: 200–240	Undesirable: Above 240

The amino acids can bond together by dehydration synthesis reactions. When two amino acids form a bond by removal of water, the nitrogen of the amino group of one is bonded, or linked, to the carbon of the acid group of another. This covalent bond is termed a **peptide bond** (figure 3.16).

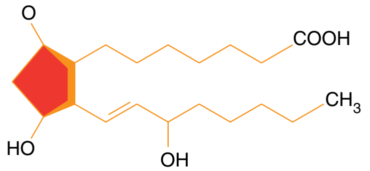
Any amino acid can form a peptide bond with any other amino acid. They fit together in a specific way, with the amino group of one bonding to the acid group of the next. You can imagine that by using 20 different amino acids as building blocks, you can construct millions of different com-



(a) Cholesterol (b) Vitamin D_2 (c) Cholic acid



(d) Cortisol (e) Testosterone (f) Estradiol (g) Progesterone



(h) Prostaglandin E_1 (PGE_1)

Figure 3.14

Steroids

(*a*) Cholesterol is produced by the human body and is found in your cells' membranes. (*b*) Vitamin D_2 is important to the normal growth of teeth and bones. (*c*) Cholic acid is a bile salt produced by the liver and used to break down fats. (*d*) Cortisol controls the metabolism of food and helps control inflammation. Excess amount of cortisol can also be responsible for a person's feelings of sadness, stress, and anxiety. (*e*) Testosterone increases during puberty, causing the male sex organs to mature. (*f*) Estradiol, a form of estrogen, is a female sex hormone necessary for many processes in the body. (*g*) Progesterone is a female sex hormone produced by the ovaries and placenta. (*h*) Prostaglandin E_1 (PGE_1) is a chemical messenger in the body and is associated with the immune system.

binations. Each of these combinations is termed a **polypeptide chain.** A specific polypeptide is composed of a specific sequence of amino acids bonded end to end. There are four levels or degrees of protein structure. A listing of the amino acids in their proper order within a particular polypeptide constitutes its *primary* structure. The specific sequence of amino acids in a polypeptide is controlled by the genetic information of an organism. Genes are specific messages that tell the cell to link particular amino acids in a specific order; that is, they determine a polypeptide's primary structure. The kinds of side chains on these amino acids influence the shape that the polypeptide forms. Many polypeptides fold into globular shapes after they have been made as the molecule bends. Some of the amino acids in the chain can form bonds with their neighbors.

The string of amino acids in a polypeptide is likely to twist into particular shapes (a coil or a pleated sheet), whereas other portions remain straight. These twisted forms are referred to as the *secondary structure* of polypeptides.

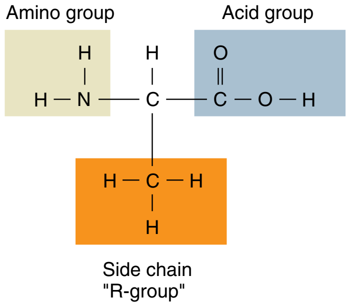


Figure 3.15

The Structure of an Amino Acid

An amino acid is composed of a short carbon skeleton with three functional groups attached: an amino group, a carboxylic acid group (acid group), and an additional variable group (R-group). It is the variable group that determines which specific amino acid is constructed.

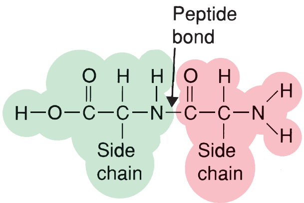


Figure 3.16

A Peptide Bond
The bond that results from a dehydration synthesis reaction between two amino acids is called a peptide bond. This bond forms as a result of the removal of the hydrogen and hydroxyl groups. In the formation of this bond, the nitrogen is bonded directly to the carbon.

For example, at this secondary level some proteins (e.g., hair) take the form of an *alpha helix:* a shape like that of a coiled telephone cord. The helical shape is maintained by hydrogen bonds formed between different amino acid side chains at different locations in the polypeptide. Remember from chapter 2 that these forces of attraction do not form molecules but result in the orientation of one part of a molecule to another part within the same molecule. Other polypeptides form hydrogen bonds that cause them to make several flat folds that resemble a pleated skirt. This is called a *beta pleated sheet.* The way a particular protein folds is important to its function. In Alzheimer's, Bovine spongiform encephalitis (mad cow disease), and Creutzfeldt-Jakob's diseases, protein structures are not formed correctly resulting in characteristic nervous system symptoms.

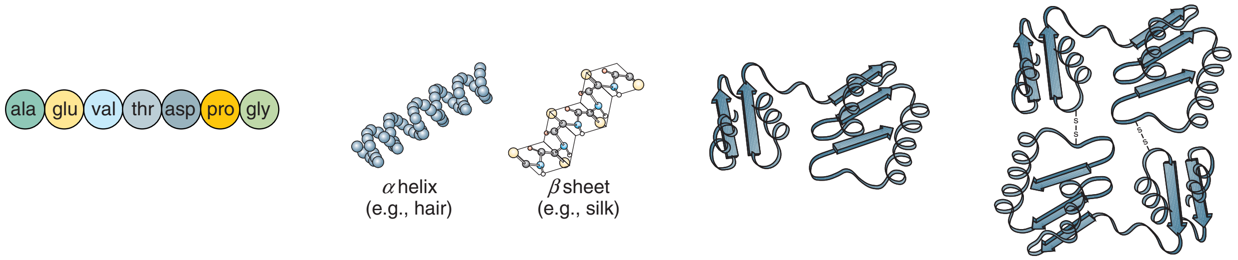
It is also possible for a single polypeptide to contain one or more coils and pleated sheets along its length. As a result, these different portions of the molecule can interact to form an even more complex globular structure. This occurs when the coils and pleated sheets twist and combine with each other. The complex three-dimensional structure formed in this manner is the polypeptide's *tertiary* (third-degree) *structure.* A good example of tertiary structure can be seen when a coiled phone cord becomes so twisted that it folds around and back on itself in several places. The oxygen-holding protein found in muscle cells, myoglobin, displays tertiary structure: it is composed of a single (153 amino acids) helical molecule folded back and bonded to itself in several places.

Frequently several different polypeptides, each with its own tertiary structure, twist around each other and chemically combine. The larger, globular structure formed by these interacting polypeptides is referred to as the protein's *quaternary* (fourth-degree) *structure.* The individual polypeptide chains are bonded to each other by the interactions of certain side chains, which can form disulfide covalent bonds (figure 3.17). Quaternary structure is displayed by the protein molecules called immunoglobulins or *antibodies,* which are involved in fighting diseases such as mumps and chicken pox (Outlooks 3.3). The protein portion of the hemoglobin molecule (globin is globular in shape) also demonstrates quaternary structure.

Individual polypeptide chains or groups of chains forming a particular configuration are proteins. The structure of a protein is closely related to its function. Any changes in the arrangement of amino acids within a protein can have far-reaching effects on its function. For example, normal hemoglobin found in red blood cells consists of two kinds of polypeptide chains called the alpha and beta chains. The beta chain is 146 amino acids long. If just one of these amino acids is replaced by a different one, the hemoglobin molecule may not function properly. A classic example of this results in a condition known as *sickle-cell anemia.* In this case, the sixth amino acid in the beta chain, which is normally glutamic acid, is replaced by valine. This minor change causes the hemoglobin to fold differently, and the red blood cells that contain this altered hemoglobin assume a sickle shape when the body is deprived of an adequate supply of oxygen.

When a particular sequence of amino acids forms a polypeptide, the stage is set for that particular arrangement to bond with another polypeptide in a certain way. Think of a telephone cord that has curled up and formed a helix (its secondary structure). Now imagine that you have attached magnets at several irregular intervals along that cord. You can see that the magnets at the various points along the cord will attract each other, and the curled cord will form a particular three-dimensional shape. You can more closely approximate the complex structure of a protein (its tertiary structure) if you imagine several curled cords, each with magnets attached at several points. Now imagine these magnets as bonding the individual cords together. The globs or ropes of telephone cords approximate the quaternary structure of a protein. This shape can be compared to the shape of a key. In order for a key to do its job effectively, it has to have particular bumps and grooves on its surface. Similarly, if a particular protein is to do its job effectively, it must have a particular shape. The protein's shape can be altered by changing the order of the amino acids, which causes different cross-linkages to form. Changing environmental conditions also influences the shape of the protein. Figure 3.18 shows the importance of the three-dimensional shape of the protein (Outlooks 3.4).

Energy in the form of heat or light may break the hydrogen bonds within protein molecules. When this occurs, the chemical and physical properties of the protein are changed and the protein is said to be **denatured.** (Keep in mind, a protein is a molecule, not a living thing, and therefore cannot be "killed.") A common example of this occurs when the gelatinous, clear portion of an egg is cooked and the protein changes to a white solid. Some medications are proteins and must be protected from denaturation so as not to lose their effectiveness. Insulin is an example. For protec-

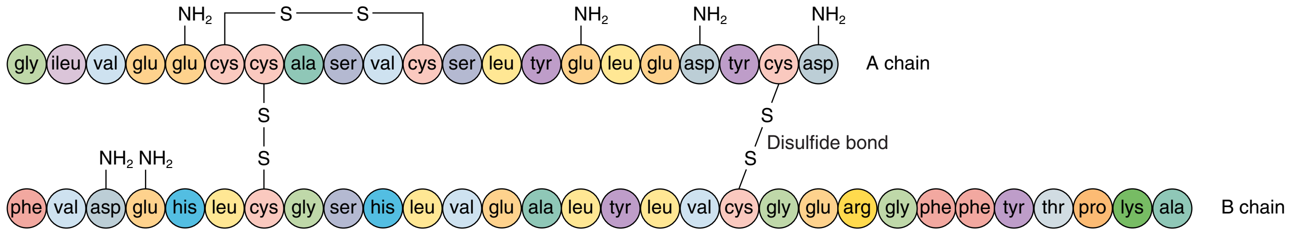


(a) Primary structure

(b) Secondary structure

(c) Tertiary structure
(e.g., myoglobin)

(d) Quaternary structure
(e.g., antibody)



(e) Structure of insulin

Figure 3.17

Levels of Protein Structure

(*a*) The primary structure of a molecule is simply a list of its component amino acids in the order in which they occur. (*b*) This figure illustrates the secondary structure of protein molecules or how one part of the molecule initially attached to another part of the same molecule. (*c*) If already folded parts of a single molecule attach at other places, the molecule is said to display tertiary (third-degree) structure. (*d*) Quaternary (fourth-degree) structure is displayed by molecules that are the result of two separate molecules (each with its own tertiary structure) combining into one large macromolecule. (*e*) The protein insulin is composed of two polypeptide chains bonded together at specific points by reactions between the side chains of particular sulfur-containing amino acids. The side chains of one interact with the side chains of the other and form a particular three-dimensional shape. The bonds that form between the polypeptide chains are called disulfide bonds.

tion, such medications may be stored in brown-colored bottles or kept under refrigeration.

The thousands of kinds of proteins can be placed into three categories. Some proteins are important for maintaining the shape of cells and organisms—they are usually referred to as **structural proteins.** The proteins that make up the cell membrane, muscle cells, tendons, and blood cells are examples of structural proteins. The protein collagen is found throughout the human body and gives tissues shape, support, and strength. The second category of proteins, **regulator proteins,** help determine what activities will occur in the organism. These regulator proteins include enzymes and some hormones. These molecules help control the chemical activities of cells and organisms. Enzymes are important, and they are dealt with in detail in chapter 5. Some examples of enzymes are the digestive enzymes in the stomach. Two hormones that are regulator proteins are insulin and oxytocin. Insulin is produced by the pancreas and controls the amount of glucose in the blood. If insulin production is too low, or if the molecule is improperly constructed, glucose molecules are not removed from the bloodstream at a fast enough rate. The excess sugar is then eliminated in the urine. Other symptoms of excess sugar in the blood include excessive thirst and even loss of consciousness. The disease caused by improperly functioning insulin is known as *diabetes*. Oxytocin, a second protein hormone, stimulates the contraction of the uterus during childbirth. It is also an example of an organic molecule that has been produced artificially (e.g., pitocin) and is used by physicians to induce labor. The third category of proteins is **carrier proteins.** Proteins in this category pick up and deliver molecules at one place and transport them to another. For example, proteins regularly attach to cholesterol entering the system from the diet-forming molecules called lipoproteins, which are transported through the circulatory system. The cholesterol is released at a distance from the digestive tract and the proteins return to pick up more entering dietary cholesterol.

Nucleic Acids

The last group of organic molecules that we will consider are the *nucleic acids*. **Nucleic acids** are complex polymeric

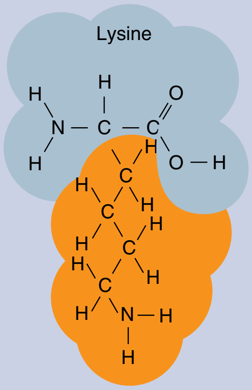
OUTLOOKS 3.3

Some Interesting Amino Acid Information

Nine Essential Amino Acids (those not able to be manufactured by the body and required in the diet)

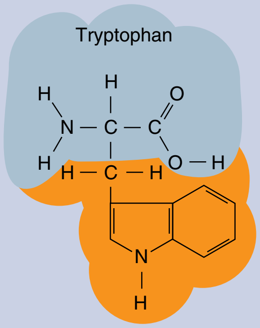
Threonine
Lysine
Valine
Leucine
Methionine
Tryptophan
Phenylalanine
Histidine
Isoleucine

The Structure and Function of Four of the Essential Amino Acids



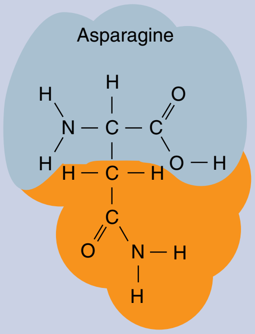
Lysine

Found in such foods as yogurt, fish, chicken, brewer's yeast, cheese, wheat germ, pork, and other meats; improves calcium uptake; in concentrations higher than arginine helps to control cold sores (herpes virus infection).



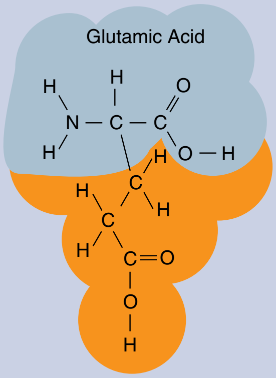
Tryptophan

Found in turkey, dairy products, eggs, fish, and nuts; required for the manufacture of hormones such as serotonin, prolactin, and growth hormone; has been shown to be of value in controlling depression, PMS (premenstrual syndrome), insomnia, migraine headaches, and immune function disorders.



Asparagine

Found in asparagus—some individuals excrete this amino acid in aromatically noticeable amount after eating asparagus.



Glutamic Acid

Found in animal and vegetable proteins; used in monosodium glutamate (MSG), a flavor-enhancing salt; required for the synthesis of folic acid; found to accumulate in and damage brain cells following stroke; the only amino acid metabolized in the brain.

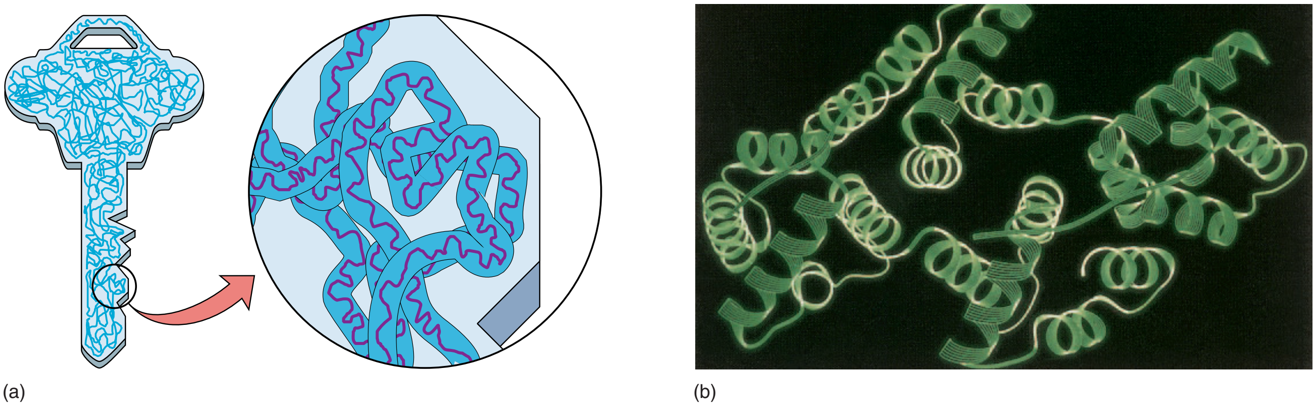


Figure 3.18

The Three-Dimensional Shape of Proteins
(*a*) The specific arrangement of amino acids results in side chains that are available to bond with other side chains. The results are specific three-dimensional proteins that have a specific surface geometry. We frequently compare this three-dimensional shape to the three-dimensional shape of a specific key. (*b*) This is the structure of the protein annexin as determined by X-ray diffraction. This molecule is located just inside cell membranes and is involved in the transport of materials through the membrane. The surface of this molecule has the shape required to attach to the molecule being transported.

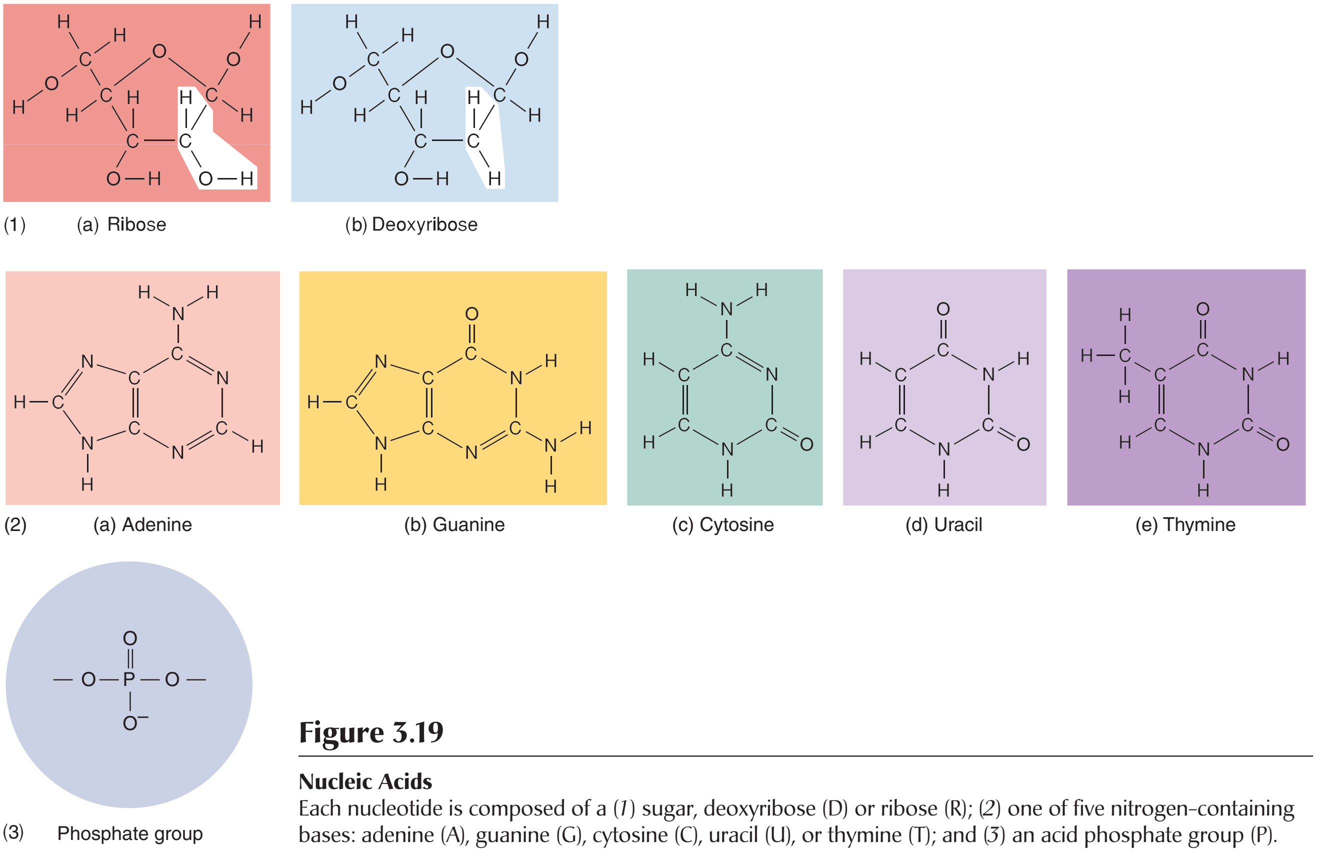
OUTLOOKS 3.4

Antibody Molecules: Defenders of the Body

Globular proteins that function as antibodies are known as immunoglobulins or antibodies. These proteins are manufactured by cells known as B-cells and plasma cells in response to the presence of dangerous molecules known as immunogens or antigens. Antigens may be such things as bacteria, viruses, pollen, plant oils, insect venoms, or toxic molecules. They are also protein-containing molecules. The basic structure of most antibodies is that of a slingshot, either a **Y** or a **T** configuration. The antibody takes the T shape when not combined with an antigen. After combining, the antibody changes its shape and assumes a shape that better resembles the letter Y. Antibodies are composed of two long "heavy" polypeptide chains and two short "light" chains attached to one another by covalent bonds giving it quarternary structure. The unit is able to spread apart, or flex, at the "hinge," making the space between the top of the Y larger or smaller. The portion of the antibody that combines with the antigen is located at the tips of the Y arms. The bonds that hold the two together are hydrogen forces. When a person is *vaccinated,* they are given a solution of disease-causing organisms, or their products that have been specially treated so that they will not cause harm. However, the *vaccine* does cause the body's immune system to produce antibody proteins that protect them against that danger.

molecules that store and transfer information within a cell. There are two types of nucleic acids, DNA and RNA. DNA serves as genetic material while RNA plays a vital role in the manufacture of proteins. All nucleic acids are constructed of fundamental monomers known as **nucleotides.** Each nucleotide is composed of three parts: (1) a 5-carbon simple sugar molecule that may be ribose or deoxyribose, (2) a phosphate group, and (3) a nitrogenous base. The nitrogenous bases may be one of five types. Two of the bases are the larger, double ring molecules *A*denine and *G*uanine. The smaller bases are the single ring bases *T*hymine, *C*ytosine, and *U*racil (figure 3.19). Nucleotides (monomers) are linked together in long sequences (polymers) so that the sugar and phosphate sequence forms a "backbone" and the nitrogenous bases stick out to the side. DNA has deoxyribose sugar and the bases A, T, G, and C, while RNA has ribose sugar and the bases A, U, G, and C (figure 3.20). (Nucleotides are also components of molecules used to transfer chemical-bond energy. One, ATP and its role in metabolism, will be discussed in chapter 6.)

DNA (***d**eoxyribo **n**ucleic **a**cid*) is composed of two strands to form a ladderlike structure thousands of bases long. The two strands are attached between their protruding bases according to *the base pair rule,* that is, *A*denine protruding


(1) (a) Ribose (b) Deoxyribose

(2) (a) Adenine (b) Guanine (c) Cytosine (d) Uracil (e) Thymine

(3) Phosphate group

Figure 3.19

Nucleic Acids

Each nucleotide is composed of a (*1*) sugar, deoxyribose (D) or ribose (R); (*2*) one of five nitrogen-containing bases: adenine (A), guanine (G), cytosine (C), uracil (U), or thymine (T); and (*3*) an acid phosphate group (P).

from one strand always pairs with *T*hymine protruding from the other (in the case of RNA, *A*denine always pairs with *U*racil). *G*uanine always pairs with *C*ytosine.

A T (or A U) and G C

One strand of DNA is called the *coding strand* because it has a meaningful genetic message written using the nitrogenous bases as letters (e.g., the base sequence CATTAGACT) (figure 3.21). If these bases are read in groups of three, they make sense to us (i.e., "cat," "tag," and "act"). This is the basis of the genetic code for all organisms. The opposite strand is called *non-coding* since it makes no "sense" but protects the coding strand from chemical and physical damage. Both strands are twisted into a helix—that is, a molecule turned around a tubular space. Strands of helical DNA may contain tens or thousands of base pairs (AT and GC combinations) that an organism reads as a sequence of chapters in a book. Each chapter is a gene. Just as chapters in a book are identified by beginning and ending statements, different genes along a DNA strand have beginning and ending signals. They tell when to start and when to stop reading a particular gene. Human body cells contain 46 strands (books) of helical DNA, each containing thousands of genes (chapters). These strands are called **chromosomes** when they become super coiled in preparation for cellular reproduction. Before cell reproduction, the DNA makes copies of the coding and non-coding strands ensuring that the offspring or *daughter cells* will each receive a full complement of the genes required for their survival (figure 3.22).

RNA (*r*ibo*n*ucleic *a*cid) is found in three forms. **Messenger RNA (mRNA)** is a single strand copy of a portion of the coding strand of DNA for a specific gene. When mRNA is formed on the surface of the DNA, the base pair rule (A pairs with U and G pairs with C) applies. After mRNA is formed and peeled off, it moves to a cellular structure called the *ribosome* where the genetic message can be translated into a protein molecule. Ribosomes contain another type of RNA, **ribosomal RNA (rRNA).** rRNA is also an RNA copy of DNA, but after being formed it becomes twisted and covered in protein to form a ribosome. The third form of RNA, **transfer RNA (tRNA),** are also copies of different segments of DNA, but when peeled off the surface, each takes the form of a cloverleaf. tRNA molecules are responsible for transferring or carrying specific amino acids to the ribosome where all three forms of RNA come together and cooperate in the manufacture of protein molecules (figure 3.23).

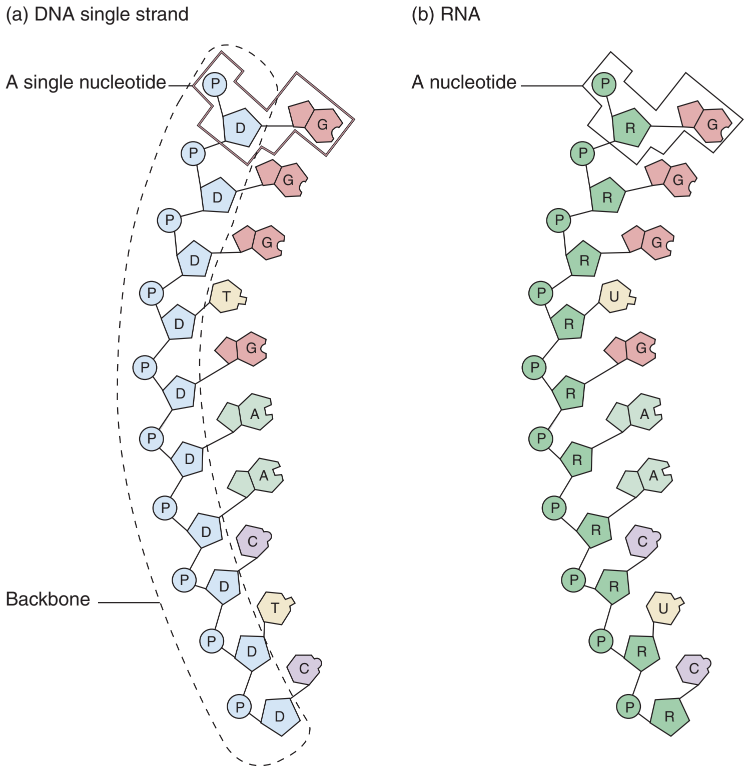


Figure 3.20

DNA and RNA
(*a*) A single strand of DNA is a polymer composed of nucleotides. Each nucleotide consists of deoxyribose sugar, phosphate, and one of four nitrogenous bases: A, T, G, or C. Notice the backbone of sugar and phosphate. (*b*) RNA is also a polymer but each nucleotide is composed of ribose sugar, phosphate, and one of four nitrogenous bases: A, U, G, or C.

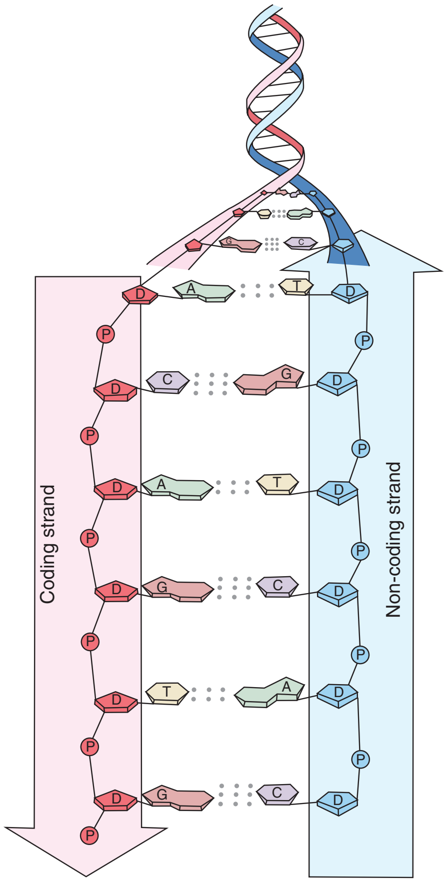


Figure 3.21

DNA
The generic material is really double-stranded DNA molecules comprised of sequences of nucleotides that spell out an organism's genetic code. The coding strand of the double molecule is the side that can be translated by the cell into meaningful information. The genetic code has the information for telling the cell what proteins to make, which in turn become the major structural and functional components of the cell. The non-coding is unable to code for such proteins.

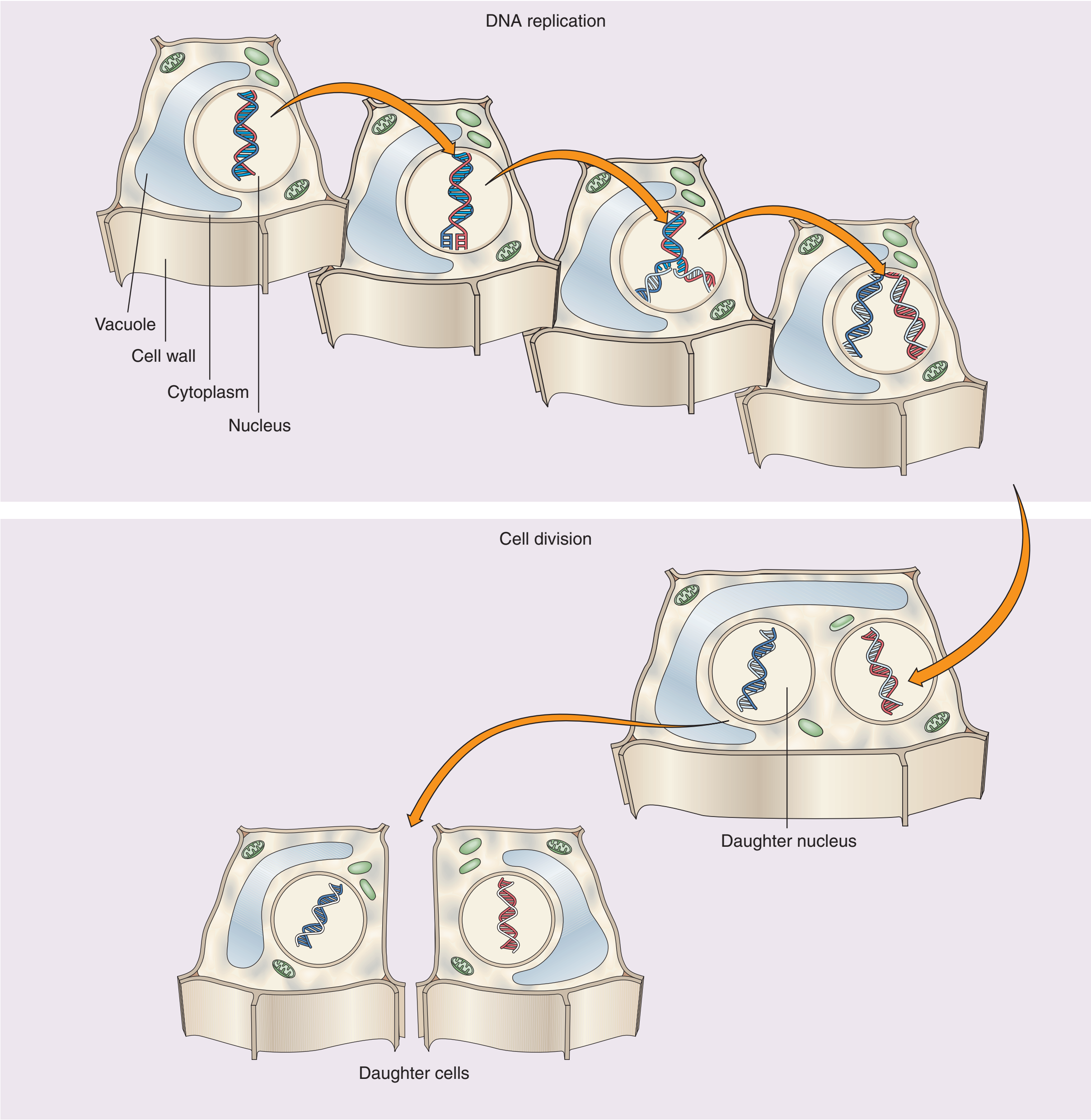


Figure 3.22

Passing the Information on to the Next Generation
These are the generalized events in DNA replication and do not show how the DNA supercoils into chromosomes. Notice that the daughter cells each receive double helices; they are identical to each other and identical to the original double strands of the parent cell.

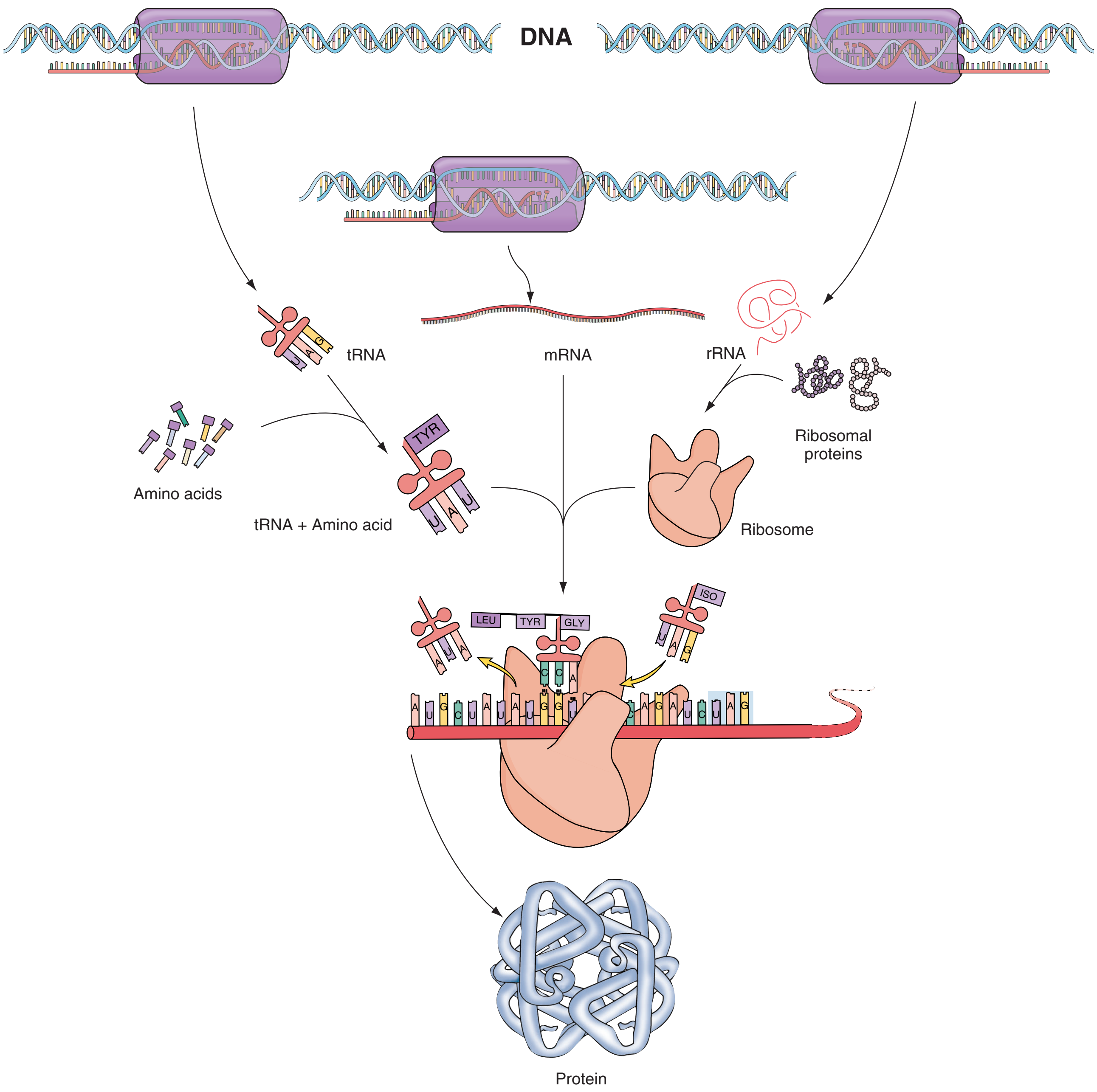


Figure 3.23

The Role of RNA
All forms of RNA (messenger, transfer, and ribosomal) are copies of different sequences of coding strand DNA. However, each plays a different role in the manufacture of proteins. When the protein synthesis process is complete, the RNA can be reused to make more of the same protein coded for by the mRNA. This is similar to replaying a cassette in a tape machine. The tape is like the mRNA and the tape machine is like the ribosome. Eventually the tape and machine will wear out and must be replaced. In a cell, this involves the synthesis of new RNA molecules from food.

Table 3.2

A SUMMARY OF THE TYPES OF ORGANIC MOLECULES FOUND IN LIVING THINGS

Type of Organic Molecule	Basic Subunit	Function	Examples
Carbohydrates	Simple sugar; monosaccharides	Provide energy Provide support	Glucose Cellulose
Lipids			
1. Fats	Glycerol and fatty acids	Provide energy Provide insulation Serve as shock absorber	Lard Olive oil Linseed oil Tallow
2. Steroids and prostaglandins	Structure of interlocking carbon rings	Often serve as hormones that control the body processes	Testosterone Vitamin D Cholesterol
3. Phospholipids	Glycerol, fatty acids, and phosphorus compounds	Form a major component of the structure of the cell membrane	Cell membrane
Proteins	Amino acid	Maintain the shape of cells and parts of organisms	Cell membrane Hair Antibodies Clotting factors Enzymes Muscle
		As enzymes, regulate the rate of cell reactions	Ptyalin in the mouth
		As hormones, effect physiological activity, such as growth or metabolism	Insulin
Nucleic acids	Nucleotide	Store and transfer genetic information that controls the cell Involved in protein synthesis	DNA RNA

SUMMARY

The chemistry of living things involves a variety of large and complex molecules. This chemistry is based on the carbon atom and the fact that carbon atoms can connect to form long chains or rings. This results in a vast array of molecules. The structure of each molecule is related to its function. Changes in the structure may result in abnormal functions, which we call disease. Some of the most common types of organic molecules found in living things are carbohydrates, lipids, proteins, and nucleic acids. Table 3.2 summarizes the major types of biologically important organic molecules and how they function in living things.

THINKING CRITICALLY

Both amino acids and fatty acids are organic acids. What property must they have in common with inorganic acids such as sulfuric acid? How do they differ? Consider such aspects as structure of molecules, size, bonding, and pH.

CONCEPT MAP TERMINOLOGY

Construct a concept map to show relationships among the following concepts.

amino acid
dehydration synthesis
denature
hydrolysis
monomer
polymer
polypeptide
primary structure
side chain

KEY TERMS

amino acid
biochemistry
carbohydrate
carbon skeleton
carrier proteins
chromosomes
complex carbohydrates
dehydration synthesis reaction
denature
DNA (deoxyribonucleic acid)
double bond
fat

fatty acid
functional groups
glycerol
hydrolysis
inorganic molecules
isomers
lipids
messenger RNA (mRNA)
nucleic acids
nucleotide
organic molecules
peptide bond
phospholipid
polypeptide chain
protein
regulator proteins
ribosomal RNA (rRNA)
RNA (ribonucleic acid)
saturated
steroid
structural proteins
transfer RNA (tRNA)
true (neutral) fats
unsaturated

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Topics	Questions	Media Resources
3.1 Molecules Containing Carbon	1. What is the difference between inorganic and organic molecules?	**Quick Overview** • Inorganic vs. organic **Key Points** • Molecules containing carbon
3.2 Carbon: The Central Atom	2. What two characteristics of the carbon molecule make it unique?	**Quick Overview** • Carbon is unusual **Key Points** • Carbon: The central atom **Interactive Concept Maps** • Characteristics of carbon
3.3 The Carbon Skeleton and Functional Groups	3. Diagram an example of each of the following: amino acid, simple sugar, glycerol, fatty acid. 4. Describe five functional groups. 5. List three monomers and the polymers that can be constructed from them.	**Quick Overview** • Similarities between complex organic molecules **Key Points** • The carbon skeleton and functional groups
3.4 Common Organic Molecules	6. Give an example of each of the following classes of organic molecules: carbohydrate, protein, lipid, nucleic acid. 7. Describe three different kinds of lipids. 8. What is meant by HDL, LDL, and VLDL? Where are they found? How do they relate to disease? 9. How do the primary, secondary, tertiary, and quaternary structures of proteins differ?	**Quick Overview** • Biologically important polymers **Key Points** • Common organic molecules **Animations and Review** • Organic chemistry • Carbohydrates • Lipids • Proteins • Nucleic acids • Concept quiz **Interactive Concept Maps** • Text concept map **Experience This!** • Polymers and monomers **Review Questions** • Organic chemistry: The chemistry of life