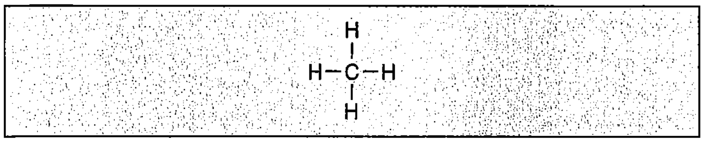
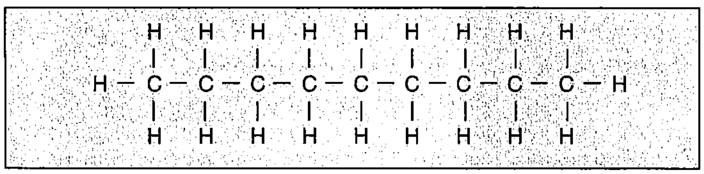
2.3 Organic Molecules

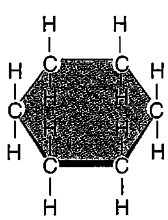
Inorganic molecules constitute nonliving matter, but even so, inorganic molecules such as salts (e.g., NaCl) and water play important roles in living things. The molecules of life are organic molecules. **Organic molecules** always contain carbon (C) and hydrogen (H). The chemistry of carbon accounts for the formation of the very large variety of organic molecules found in living things. A carbon atom has four electrons in the outer shell. In order to achieve eight electrons in the outer shell, a carbon atom shares electrons covalently with as many as four other atoms, as in methane (CH_4):



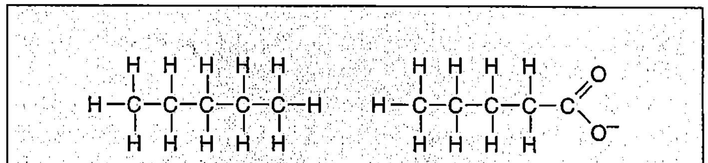
A carbon atom can share with another carbon atom, and in so doing, a long hydrocarbon chain can result:



A hydrocarbon chain can also turn back on itself to form a ring compound:



So-called functional groups can be attached to carbon chains. A **functional group** is a particular cluster of atoms that always behaves in a certain way. One functional group of interest is the acidic (carboxyl) group —COOH because it can give up a hydrogen (H^+) and ionize to —COO^-:



Whereas a hydrocarbon chain is *hydrophobic* (does not interact with water) because it is nonpolar, a hydrocarbon chain with an attached ionized group is *hydrophilic* (does interact with water) because it is polar.

Many molecules of life are macromolecules. Just as atoms can join to form a molecule, so molecules can join to form a macromolecule. When the same type of molecule, called a **monomer,** joins repeatedly, the macromolecule is called a **polymer.** The polymers in cells are these:

Polymer	Monomer
carbohydrate	monosaccharide
protein	amino acid
nucleic acid	nucleotide

Aside from carbohydrates, proteins, and nucleic acids, lipids are also macromolecules in cells. You are very familiar with carbohydrates, lipids, and proteins because certain foods are known to be rich in these molecules, as illustrated in Figures 2.14–2.16. The nucleic acid DNA makes up our genes, which are hereditary units that control our cells and the structure of our bodies.

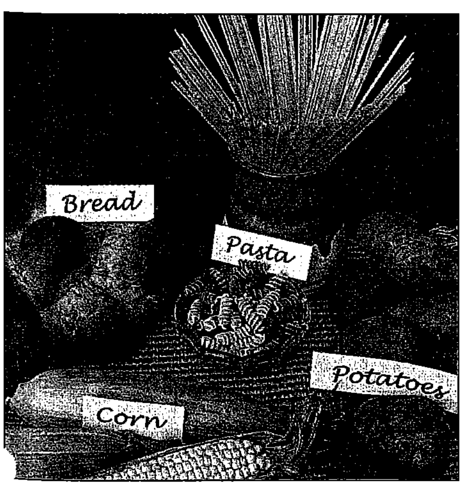


Figure 2.14 Carbohydrate foods. Breads, pasta, rice, corn, and oats all contain complex carbohydrates.

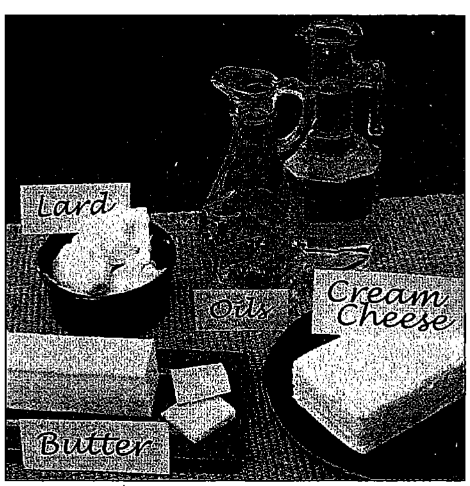


Figure 2.15 Lipid foods. Butter and oils contain fat, the most familiar of the lipids.

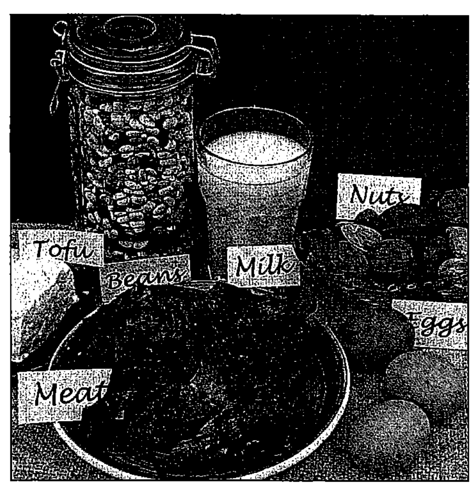


Figure 2.16 Protein foods. Meat, eggs, cheese, and beans have a high content of protein.

2.4 Carbohydrates

Carbohydrates first and foremost function for quick and short-term energy storage in all organisms, including humans. Carbohydrates play a structural role in woody plants, bacteria, and animals such as insects. In addition, carbohydrates on cell surfaces play a role in cell-to-cell recognition, as we learn in the next chapter.

Carbohydrate molecules are characterized by the presence of the atomic grouping H—C—OH, in which the ratio of hydrogen atoms (H) to oxygen atoms (O) is approximately 2:1. Since this ratio is the same as the ratio in water, the name "hydrates of carbon" seems appropriate.

Simple Carbohydrates

If the number of carbon atoms in a molecule is low (from three to seven), then the carbohydrate is a simple sugar, or **monosaccharide.** The designation **pentose** means a 5-carbon sugar, and the designation **hexose** means a 6-carbon sugar. **Glucose,** a hexose, is blood sugar (Fig. 2.17); our bodies use glucose as an immediate source of energy. Other common hexoses are fructose, found in fruits, and galactose, a constituent of milk.

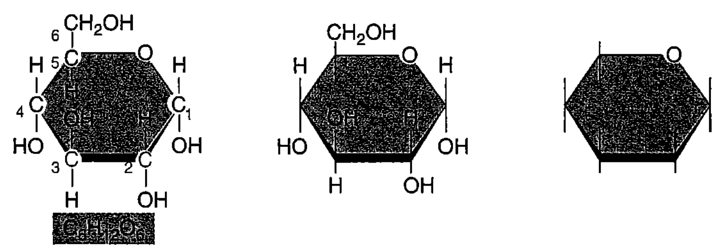


Figure 2.17 Three ways to represent the structure of glucose.
The *far left* structure shows the carbon atoms; $C_6H_{12}O_6$ is the molecular formula for glucose. The *far right* structure is the simplest way to represent glucose.

These three hexoses (glucose, fructose, and galactose) all occur as ring structures with the molecular formula $C_6H_{12}O_6$, but the exact shape of the ring differs, as does the arrangement of the hydrogen (—H) and hydroxyl (—OH) groups attached to the ring. A **disaccharide** (*di*, two; *saccharide*, sugar) is made by linking two monosaccharides together. Maltose is a disaccharide that contains two glucose molecules (Fig. 2.18). When glucose and fructose join, the disaccharide sucrose forms. Sucrose, which is ordinarily derived from sugarcane and sugar beets, is commonly known as table sugar.

Polysaccharides

Long polymers such as starch, glycogen, and cellulose are **polysaccharides** that contain many glucose units. Organisms have a common way of joining monomers to build polymers. **Condensation synthesis** of a larger molecule is so called because synthesis means "making of" and condensation means that water has been removed as monomers are joined. Breakdown of the larger molecule is a **hydrolysis** reaction because water is used to split bonds between monomers. Polymers are synthesized and hydrolyzed (broken down) in this manner:

$$\text{monomers} \rightleftharpoons \text{polymer} + H_2O \text{ molecules}$$

For convenience, Figure 2.18 shows how condensation synthesis results in a disaccharide called maltose and how hydrolysis of the maltose results in two glucose molecules again.

Starch and Glycogen

Starch and **glycogen** are ready storage forms of glucose in plants and animals, respectively. Some of the polymers in starch are long chains of up to 4,000 glucose units. Starch has fewer side branches, or chains of glucose that branch off from the main chain, than does glycogen, as shown in Figures 2.19 and 2.20. Flour, which we usually acquire by grinding wheat and use for baking, is high in starch, and so are potatoes.

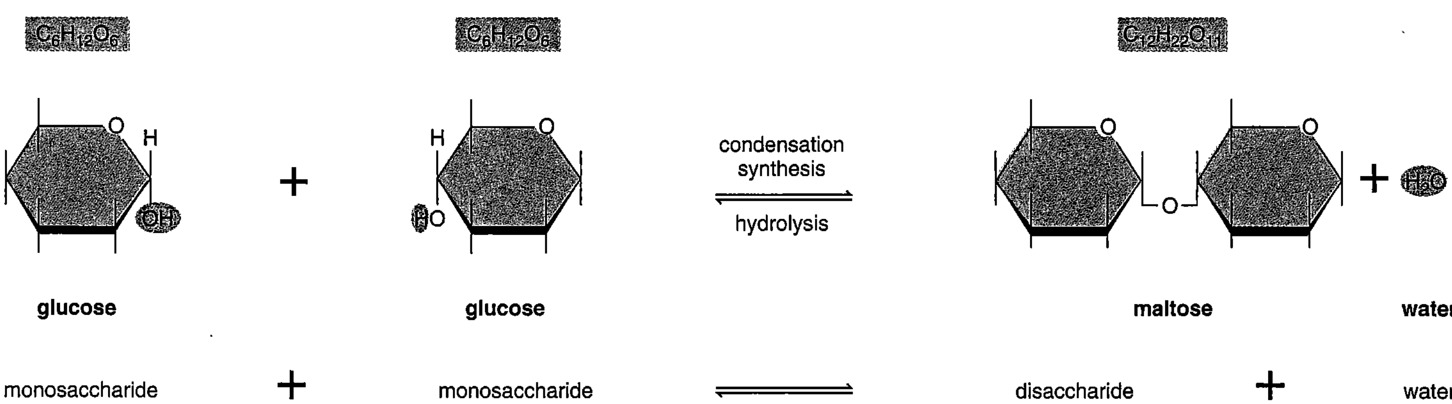


Figure 2.18 Condensation synthesis and hydrolysis of maltose, a disaccharide.
During condensation synthesis of maltose, a bond forms between the two glucose molecules, and the components of water are removed. During hydrolysis, the components of water are added, and the bond is broken.

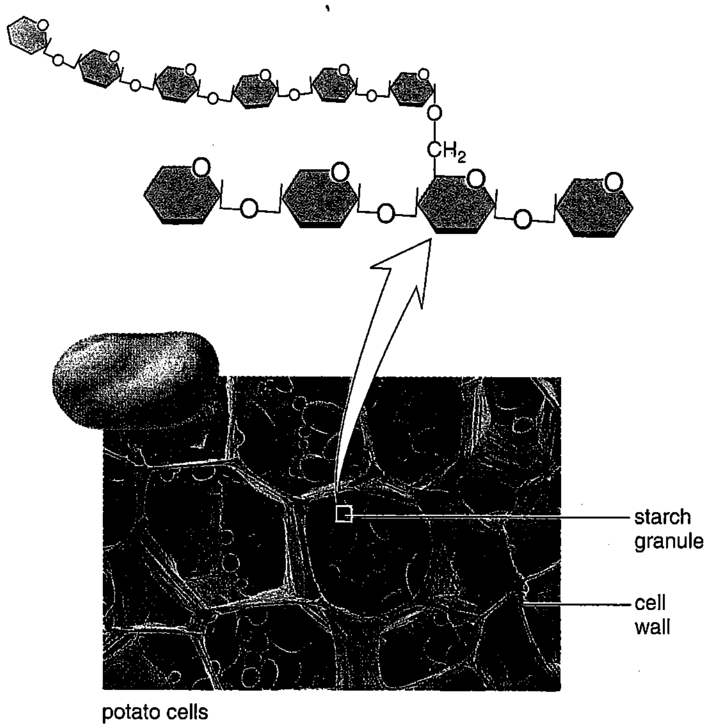


Figure 2.19 Starch structure and function.
Starch has straight chains of glucose molecules. Some chains are also branched, as indicated. The electron micrograph shows starch granules in potato cells. Starch is the storage form of glucose in plants.

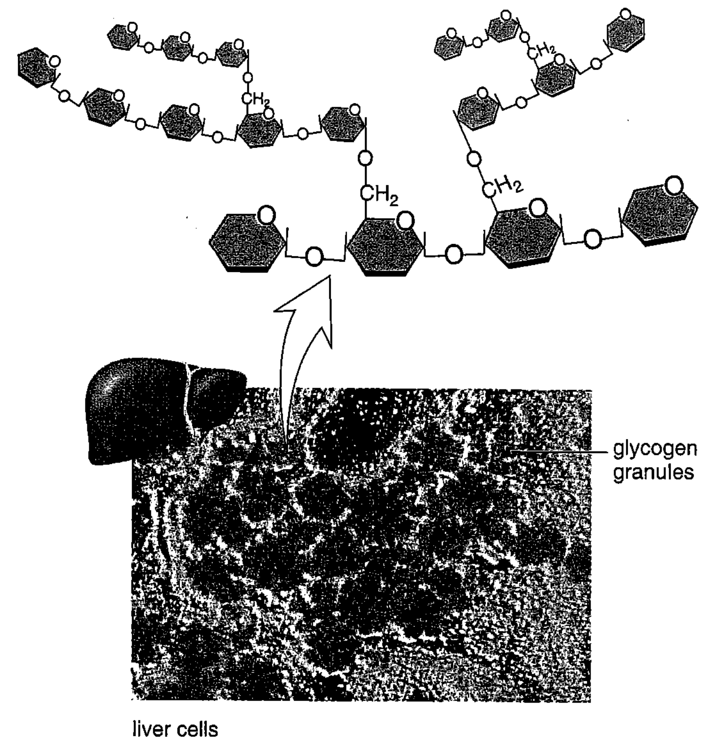


Figure 2.20 Glycogen structure and function.
Glycogen is a highly branched polymer of glucose molecules. The electron micrograph shows glycogen granules in liver cells. Glycogen is the storage form of glucose in animals.

After we eat starchy foods such as potatoes, bread, and cake, glucose enters the bloodstream, and the liver stores glucose as glycogen. In between eating, the liver releases glucose so that the blood glucose concentration is always about 0.1%.

Cellulose

The polysaccharide **cellulose** is found in plant cell walls, and this accounts, in part, for the strong nature of these walls. In cellulose (Fig. 2.21), the glucose units are joined by a slightly different type of linkage than that in starch or glycogen. (Observe the alternating position of the oxygen atoms in the linked glucose units.) While this might seem to be a technicality, actually it is important because we are unable to digest foods containing this type of linkage; therefore, cellulose largely passes through our digestive tract as fiber, or roughage. It is believed that fiber in the diet is necessary to good health, and some have suggested it may even help prevent colon cancer.

> Cells usually use the monosaccharide glucose as an energy source. The polysaccharides starch and glycogen are storage compounds in plant and animal cells, respectively, and the polysaccharide cellulose is found in plant cell walls.

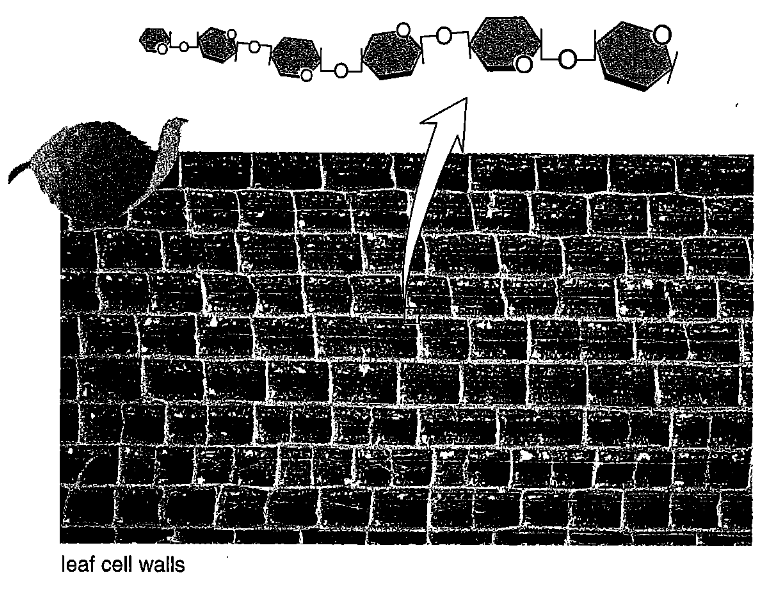


Figure 2.21 Cellulose structure and function.
Cellulose contains a slightly different type of linkage between glucose molecules than that in starch or glycogen. Plant cell walls contain cellulose, and the rigidity of the cell walls permits nonwoody plants to stand upright as long as they receive an adequate supply of water.

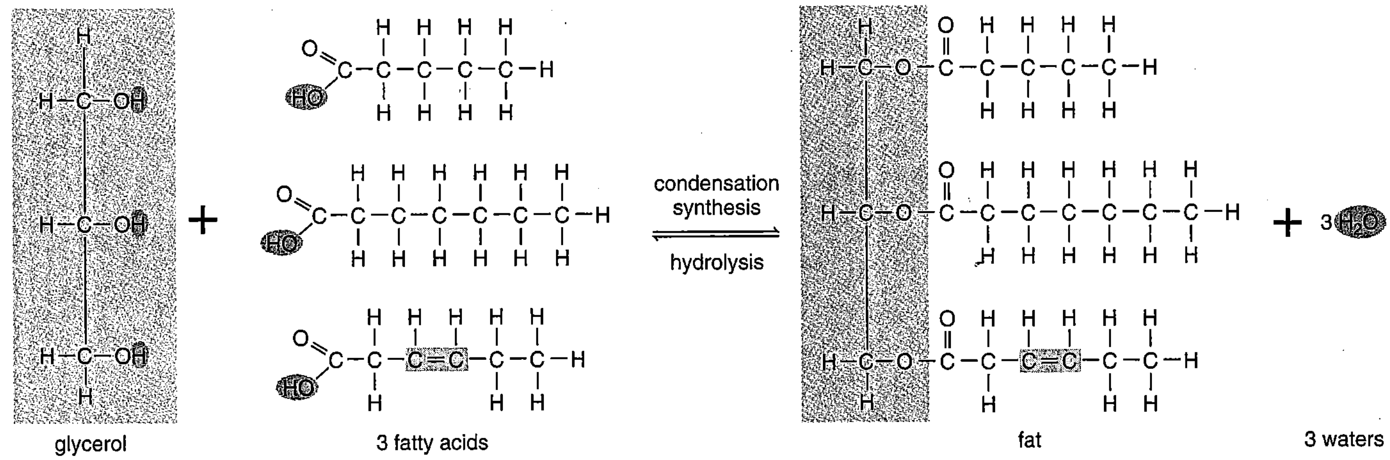


Figure 2.22 Condensation synthesis and hydrolysis of a fat molecule.
Fatty acids can be saturated (no double bonds between carbon atoms) or unsaturated (have double bonds, colored gray, between carbon atoms). When a fat molecule forms, three fatty acids combine with glycerol, and three water molecules are produced.

2.5 Lipids

Lipids contain more energy per gram than other biological molecules, and some function well as energy storage molecules in organisms. Others form a membrane so that the cell is separated from its environment and has inner compartments as well. The steroids are a large class of lipids that includes, among others, the sex hormones.

Lipids are diverse in structure and function, but they have a common characteristic: they do not dissolve in water. Their low solubility in water is due to an absence of polar groups. They contain little oxygen and consist mostly of carbon and hydrogen atoms.

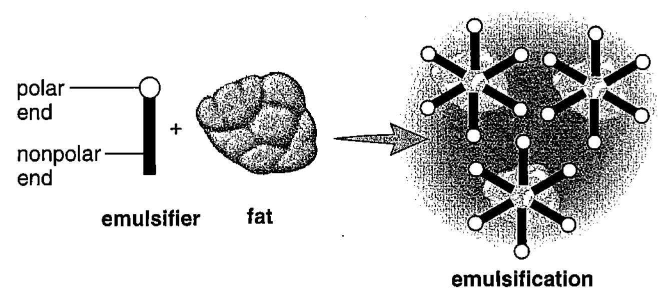
Fats and Oils

The most familiar lipids are those found in fats and oils. **Fats,** which are usually of animal origin (e.g., lard and butter), are solid at room temperature. **Oils,** which are usually of plant origin (e.g., corn oil and soybean oil), are liquid at room temperature. Fat has several functions in the body: it is used for long-term energy storage, it insulates against heat loss, and it forms a protective cushion around major organs.

Fats and oils form when one glycerol molecule reacts with three fatty acid molecules (Fig. 2.22). A fat is sometimes called a **triglyceride** because of its three-part structure, and the term neutral fat is sometimes used because the molecule is nonpolar.

Emulsification

Emulsifiers can cause fats to mix with water. They contain molecules with a nonpolar end and a polar end. The molecules position themselves about an oil droplet so that their nonpolar ends project. Now the droplet disperses in water, which means that **emulsification** has occurred.



Emulsification occurs when dirty clothes are washed with soaps or detergents. Also, prior to the digestion of fatty foods, fats are emulsified by bile. A person who has had the gallbladder removed may have trouble digesting fatty foods because this organ stores bile for emulsifying fats prior to the digestive process.

Saturated and Unsaturated Fatty Acids

A **fatty acid** is a hydrocarbon chain that ends with the acidic group —COOH (Fig. 2.22). Most of the fatty acids in cells contain 16 or 18 carbon atoms per molecule, although smaller ones with fewer carbons are also known.

Fatty acids are either saturated or unsaturated. **Saturated fatty acids** have no double covalent bonds between carbon atoms. The carbon chain is saturated, so to speak, with all the hydrogens it can hold. Saturated fatty acids account for the solid nature at room temperature of fats such as lard and butter. **Unsaturated fatty acids** have double bonds between carbon atoms wherever the number of hydrogens is less than two per carbon atom. Unsaturated fatty acids account for the liquid nature of vegetable oils at room temperature. Hydrogenation of vegetable oils can convert them to margarine and products such as Crisco.

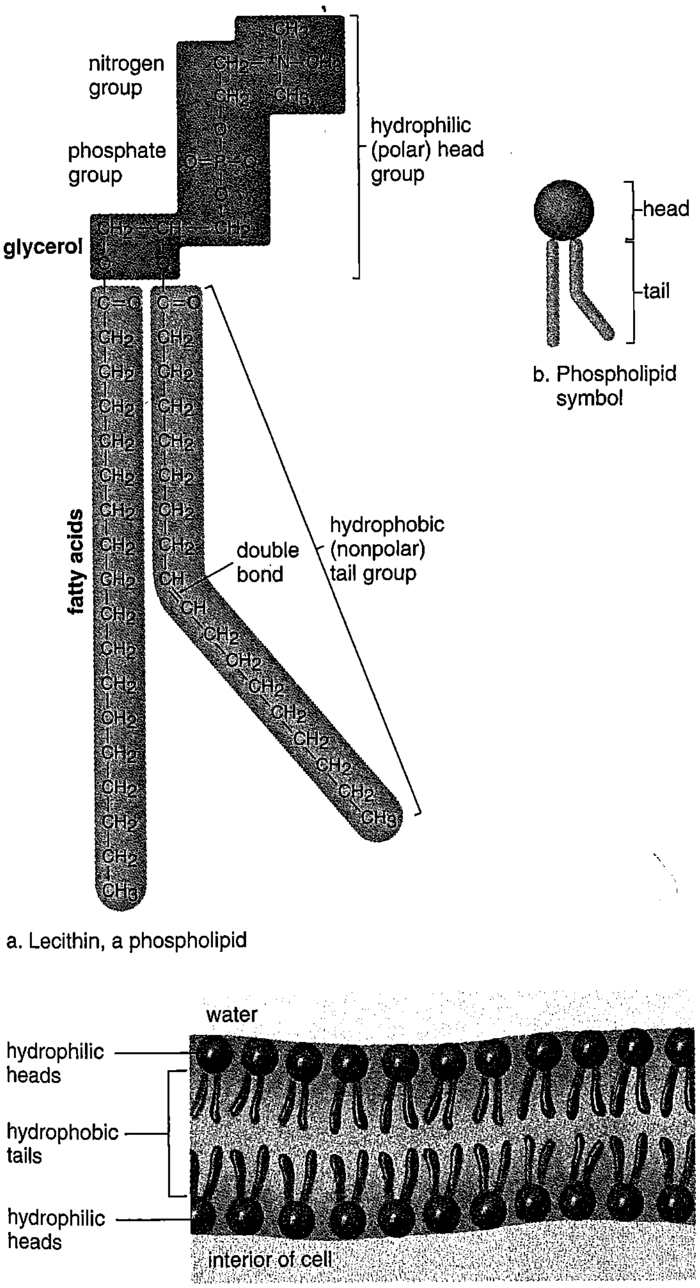


Figure 2.23 Phospholipid structure and shape.
a. Phospholipids are constructed like fats, except that they contain a phosphate group. This phospholipid also includes an organic group that contains nitrogen. **b.** The hydrophilic portion of the phospholipid molecule (head) is soluble in water, whereas the two hydrocarbon chains (tails) are not. **c.** This structure causes the molecules to arrange themselves within a plasma membrane as shown because the exterior and interior of a cell are mostly water.

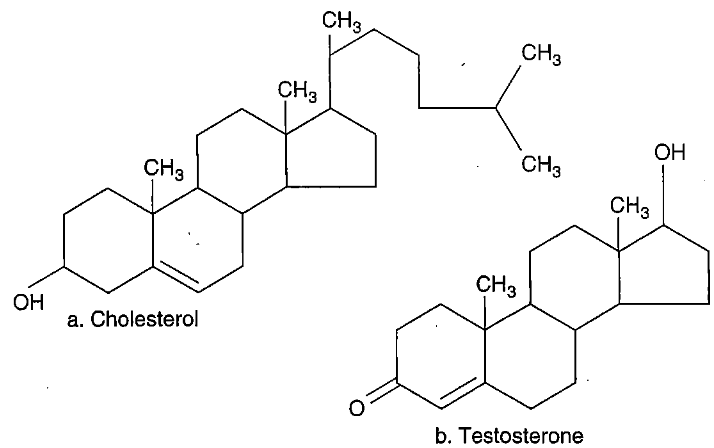


Figure 2.24 Steroid diversity.
a. Cholesterol, like all steroid molecules, has four adjacent rings, but the effects of steroids on the body largely depend on the attached groups indicated in red. **b.** Testosterone is the male sex hormone.

Phospholipids

Phospholipids, as their name implies, contain a phosphate group (Fig. 2.23). Essentially, they are constructed like fats, except that in place of the third fatty acid, there is a phosphate group or a grouping that contains both phosphate and nitrogen. These molecules are not electrically neutral, as are fats, because the phosphate and nitrogen-containing groups are ionized. They form the so-called hydrophilic head of the molecule, while the rest of the molecule becomes the hydrophobic tails. Phospholipids are the backbone of cellular membranes; they spontaneously form a bilayer in which the hydrophilic heads face outward toward watery solutions and the tails form the hydrophobic interior.

Steroids

Steroids have a backbone of four fused carbon rings. Each one differs primarily by the arrangement of the atoms in the rings and the type of functional groups attached to them. Cholesterol is a component of an animal cell's plasma membrane and is the precursor of several other steroids, such as the sex hormones estrogen and testosterone (Fig. 2.24).

We know that a diet high in saturated fats and cholesterol can cause fatty material to accumulate inside the lining of blood vessels, thereby reducing blood flow. As discussed in the Science Focus on page 36, nutrition labels are now required to list the calories from fat per serving and the percent daily value from saturated fat and cholesterol.

Lipids include fats and oils (for long-term energy storage) and steroids. Phospholipids, unlike other lipids, are soluble in water because they have a hydrophilic group.

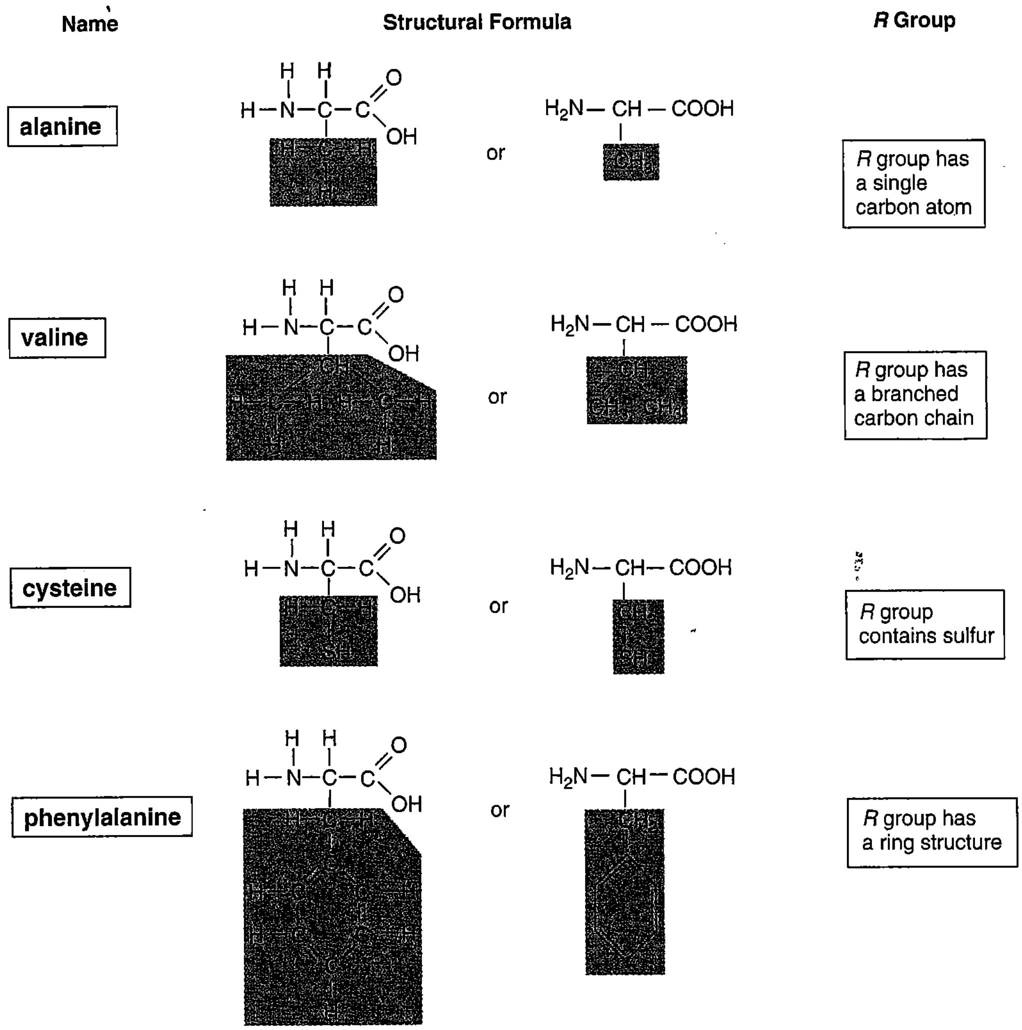


Figure 2.25 Representative amino acids.
Amino acids differ from one another by their *R* group; the simplest *R* group is a single hydrogen atom (H). The *R* groups (blue) that contain carbon vary as shown.

2.6 Proteins

Proteins perform many functions. Proteins such as keratin, which makes up hair and nails, and collagen, which lends support to ligaments, tendons, and skin, are structural proteins. Many hormones, which are messengers that influence cellular metabolism, are also proteins. The proteins actin and myosin account for the movement of cells and the ability of our muscles to contract. Some proteins transport molecules in the blood; hemoglobin is a complex protein in our blood that transports oxygen. Antibodies in blood and other body fluids are proteins that combine with foreign substances, preventing them from destroying cells and upsetting homeostasis.

Proteins in the plasma membrane of our cells have various functions: some form channels that allow substances to enter and exit cells; some are carriers that transport molecules into and out of the cell; and some are enzymes. Enzymes are necessary contributors to the chemical workings of the cell, and therefore of the body. **Enzymes** speed chemical reactions; they work so quickly that a reaction that normally takes several hours or days without an enzyme takes only a fraction of a second with an enzyme.

Proteins are polymers with amino acid monomers. An **amino acid** has a central carbon atom bonded to a hydrogen atom and three groups. The name of the molecule is appropriate because one of these groups is an amino group ($—NH_2$) and another is an acidic group ($—COOH$). The other group is called an *R* group because it is the *Remainder* of the molecule. Amino acids differ from one another by their *R* group; the *R* group varies from having a single carbon to being a complicated ring structure (Fig. 2.25).

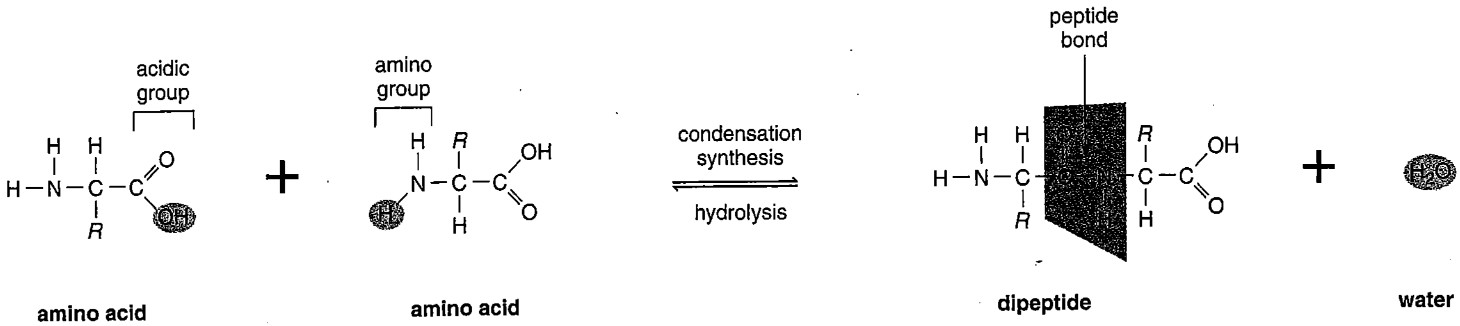
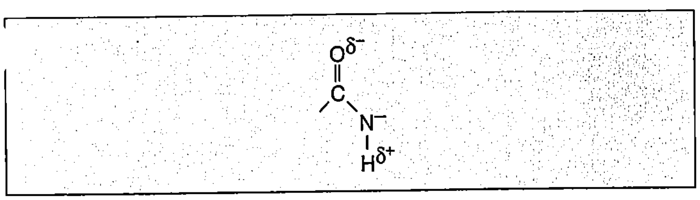


Figure 2.26 Condensation synthesis and hydrolysis of a dipeptide.
The two amino acids on the left-hand side of the equation differ by their *R* groups. As these amino acids join, a peptide bond forms, and a water molecule is produced. During hydrolysis, water is added, and the peptide bond is broken.

Peptides

Figure 2.26 shows that a condensation synthesis reaction between two amino acids results in a dipeptide and a molecule of water. A bond that joins two amino acids is called a **peptide bond.** The atoms associated with a peptide bond—oxygen (O), carbon (C), nitrogen (N), and hydrogen (H)—share electrons in such a way that the oxygen has a partial negative charge (δ^-) and the hydrogen has a partial positive charge (δ^+).



Therefore, the peptide bond is polar, and hydrogen bonding is possible between the C=O of one amino acid and the N—H of another amino acid in a polypeptide. A **polypeptide** is a single chain of amino acids.

Levels of Protein Organization

The structure of a protein has at least three levels of organization and can have four levels (Fig. 2.27). The first level, called the *primary structure,* is the linear sequence of the amino acids joined by peptide bonds. Polypeptides can be quite different from one another. If you likened a polysaccharide to a necklace that contains a single type of "bead," namely, glucose, then polypeptides make use of 20 different possible types of "beads," namely amino acids. Each particular polypeptide has its own sequence of amino acids. Therefore, each polypeptide differs by the sequence of its *R* groups.

The *secondary structure* of a protein comes about when the polypeptide takes on a certain orientation in space. A coiling of the chain results in an alpha (α) helix, or a right-handed spiral, and a folding of the chain results in a pleated sheet. Hydrogen bonding between peptide bonds holds the shape in place.

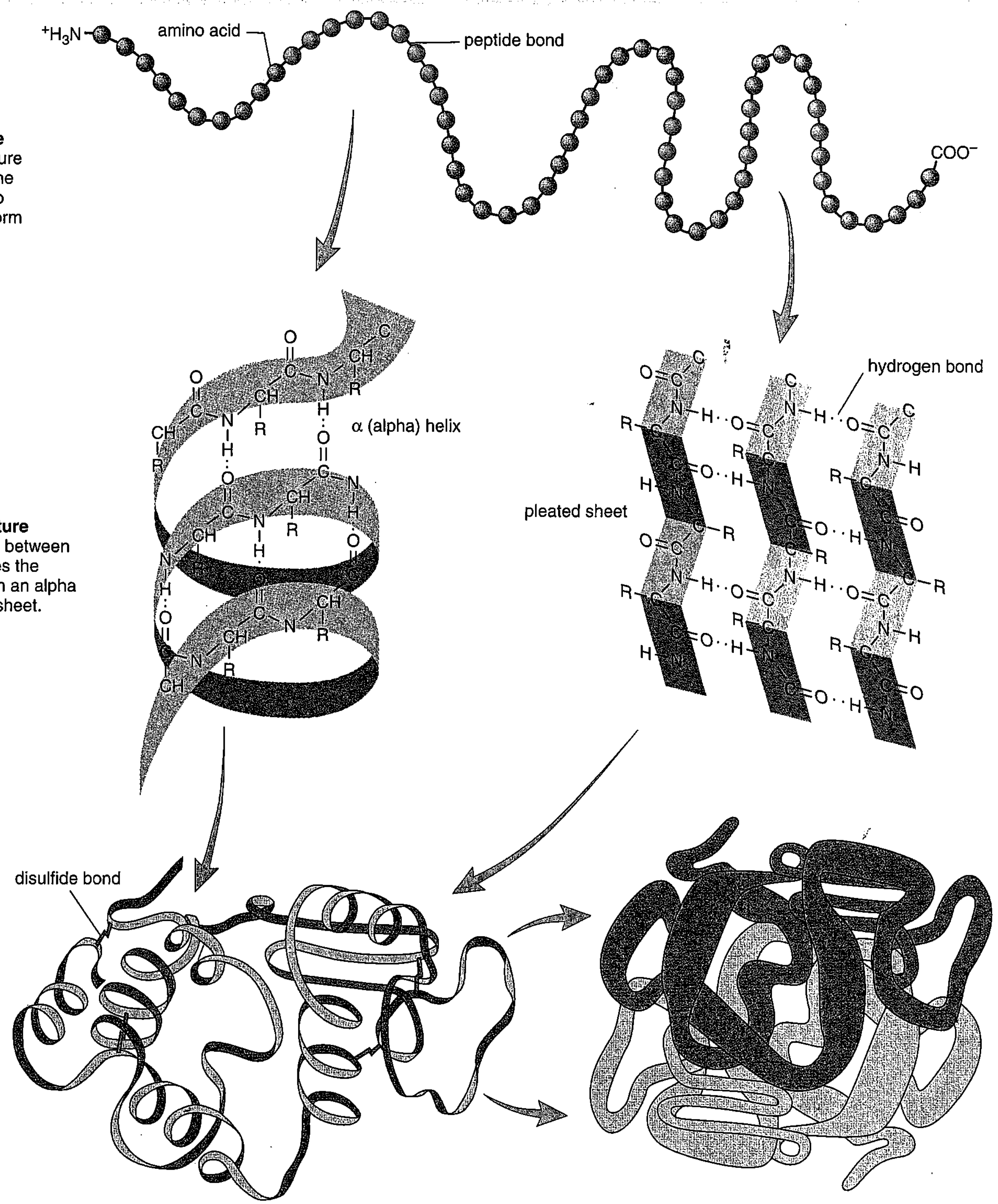
The *tertiary structure* of a protein is its final three-dimensional shape. In muscles, myosin molecules have a rod shape ending in globular (globe-shaped) heads. In enzymes, the polypeptide bends and twists in different ways. Invariably, the hydrophobic portions are packed mostly on the inside, and the hydrophilic portions are on the outside where they can make contact with water. The tertiary shape of a polypeptide is maintained by various types of bonding between the *R* groups; covalent, ionic, and hydrogen bonding all occur. One common form of covalent bonding between *R* groups is disulfide (S—S) linkages between two cysteine amino acids.

Some proteins have only one polypeptide, and others have more than one polypeptide, each with its own primary, secondary, and tertiary structures. These separate polypeptides are arranged to give some proteins a fourth level of structure, termed the *quaternary structure.* Hemoglobin is a complex protein having a quaternary structure; most enzymes also have a quaternary structure.

The final shape of a protein is very important to its function. As we will discuss in Chapter 6, for example, enzymes cannot function unless they have their usual shape. When proteins are exposed to extremes in heat and pH, they undergo an irreversible change in shape called **denaturation.** For example, we are all aware that the addition of acid to milk causes curdling and that heating causes egg white, which contains a protein called albumin, to coagulate. Denaturation occurs because the normal bonding between the *R* groups has been disturbed. Once a protein loses its normal shape, it is no longer able to perform its usual function. Researchers hypothesize that an alternation in protein organization has occurred when Alzheimer disease and Creutzfeldt-Jakob disease (the human form of "mad cow" disease) develop.

Proteins, which have levels of organization, are important in the structure and the function of cells. Some proteins are enzymes, which speed chemical reactions.

Visual Focus



Primary Structure
This level of structure is determined by the sequence of amino acids that join to form a polypeptide.

Secondary Structure
Hydrogen bonding between amino acids causes the polypeptide to form an alpha helix or a pleated sheet.

Tertiary Structure
The helix folds into a characteristic globular shape due in part to covalent bonding between *R* groups.

Quaternary Structure
This level of structure occurs when two or more polypeptides join to form a single protein.

Figure 2.27 Levels of protein organization.

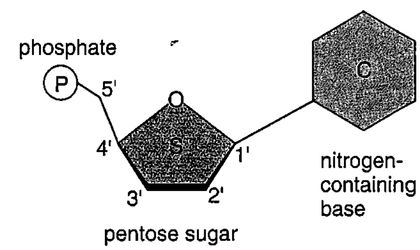
2.7 Nucleic Acids

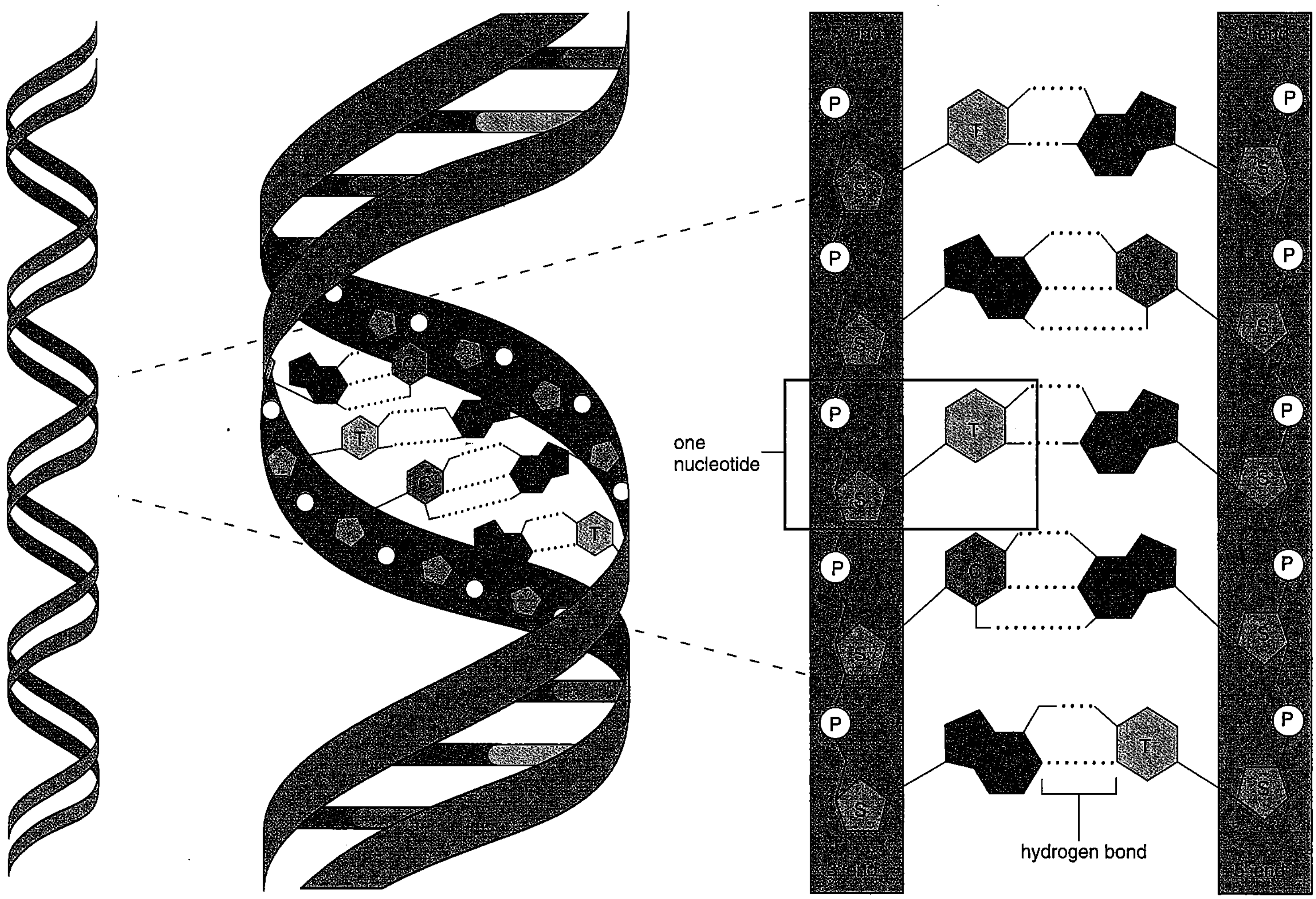
The two types of nucleic acids are **DNA (deoxyribonucleic acid)** and **RNA (ribonucleic acid)**. The discovery of the structure of DNA has had an enormous influence on biology and on society in general. DNA stores genetic information in the cell and in the organism. Further, it replicates and transmits this information when a cell reproduces and when an organism reproduces. We now not only know how genes work, but we can manipulate them. The science of biotechnology is largely devoted to altering the genes in living organisms.

DNA codes for the order in which amino acids are to be joined to form a protein. RNA is an intermediary that conveys DNA's instructions regarding the amino acid sequence in a protein.

Structure of DNA and RNA

Both DNA and RNA are polymers of nucleotides. Every **nucleotide** is a molecular complex of three types of subunit molecules—phosphate (phosphoric acid), a pentose sugar, and a nitrogen-containing base:





a. DNA double helix b. Complementary base pairing c. Ladder configuration

Figure 2.28 Overview of DNA structure.
a. Double helix. **b.** Complementary base pairing between strands. **c.** Ladder configuration. Notice that the uprights are composed of phosphate and sugar molecules and that the rungs are complementary paired bases.

The nucleotides in DNA contain the sugar deoxyribose, and the nucleotides in RNA contain the sugar ribose; this difference accounts for their respective names (Table 2.3). There are four different types of bases in DNA: A = **adenine,** T = **thymine,** G = **guanine,** and C = **cytosine.** The base can have two rings (adenine or guanine) or one ring (thymine or cytosine). These structures are called bases because their presence raises the pH of a solution. In RNA, the base **uracil** replaces the base thymine.

The nucleotides form a linear molecule called a strand, which has a backbone made up of phosphate-sugar-phosphate-sugar, with the bases projecting to one side of the backbone. Since the nucleotides occur in a definite order, so do the bases. After many years of work, researchers now know the sequence of bases along all the genes in human DNA—the human genome. This breakthrough is expected to lead to improved genetic counseling, gene therapy, and medicines to treat the cause of many human illnesses.

DNA is double stranded, with the two strands twisted about each other in the form of a double helix (Fig. 2.28). In DNA, the two strands are held together by hydrogen bonds between the bases. When unwound, DNA resembles a stepladder. The uprights (sides) of the ladder are made entirely of phosphate and sugar molecules, and the rungs of the ladder are made only of complementary paired bases. Thymine (T) always pairs with adenine (A), and guanine (G) always pairs with cytosine (C). Complementary bases have shapes that fit together.

Complementary base pairing allows DNA to replicate in a way that ensures the sequence of bases will remain the same. This sequence of the DNA bases contains a code that specifies the sequence of amino acids in the proteins of the cell. RNA is single stranded, and when it forms, complementary base pairing with one DNA strand passes this information on to RNA.

DNA has a structure like a twisted ladder: sugar and phosphate molecules make up the uprights of the ladder, and hydrogen-bonded bases make up the rungs.

Table 2.3 DNA Structure Compared to RNA Structure

	DNA	RNA
Sugar	Deoxyribose	Ribose
Bases	Adenine, guanine, thymine, cytosine	Adenine, guanine, uracil, cytosine
Strands	Double stranded with base pairing	Single stranded
Helix	Yes	No

ATP (Adenosine Triphosphate)

In addition to being the monomers of nucleic acids, nucleotides have other metabolic functions in cells. When adenosine (adenine plus ribose) is modified by the addition of three phosphate groups instead of one, it becomes **ATP (adenosine triphosphate),** an energy carrier in cells. A glucose molecule contains too much energy to be used as a direct energy source in cellular reactions. Instead, the energy of glucose is converted to that of ATP molecules. ATP contains an amount of energy that makes it usable to supply energy for chemical reactions in cells.

ATP is a high-energy molecule because the last two phosphate bonds are unstable and easily broken. Usually in cells, the terminal phosphate bond is hydrolyzed, leaving the molecule **ADP (adenosine diphosphate)** and a molecule of inorganic phosphate Ⓟ (Fig. 2.29). The energy released by ATP breakdown is used by the cell to synthesize macromolecules such as carbohydrates and proteins. In muscle cells, the energy is used for muscle contraction, and in nerve cells, it is used for the conduction of nerve impulses. After ATP breaks down, it is rebuilt by the addition of Ⓟ to ADP (Fig. 2.29).

ATP is a high-energy molecule. ATP breaks down to ADP + Ⓟ, releasing energy, which is used for all metabolic work done in a cell.

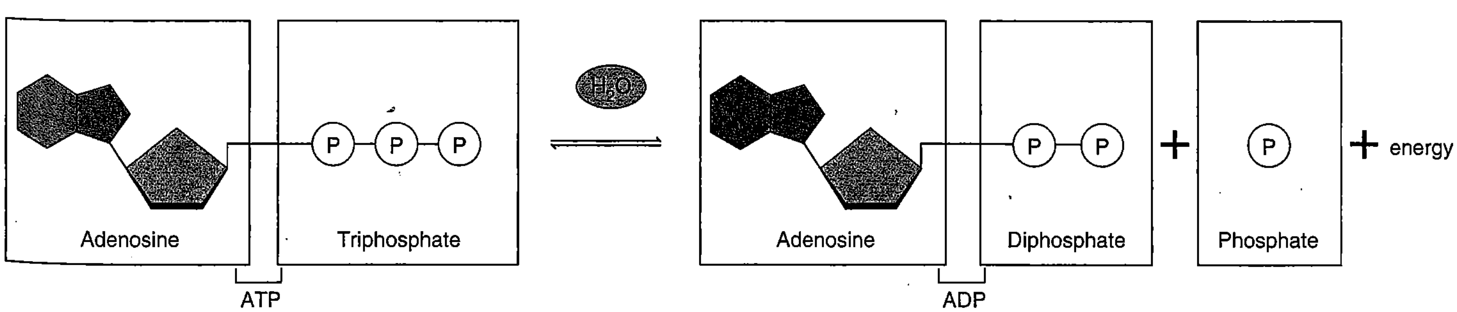


Figure 2.29 ATP reaction.
ATP, the universal energy currency of cells, is composed of adenosine and three phosphate groups. When cells require energy, ATP undergoes hydrolysis, producing ADP + Ⓟ, with the release of energy.

Bioethical Focus Organic Pollutants

Organic compounds include the carbohydrates, proteins, lipids, and nucleic acids that make up our bodies. Modern industry also uses all sorts of organic compounds that are synthetically produced. Indeed, our modern way of life wouldn't be possible without synthetic organic compounds.

Pesticides, herbicides, disinfectants, plastics, and textiles contain organic substances that are termed pollutants when they enter the natural environment and cause harm to living things. Global use of pesticides has increased dramatically since the 1950s, and modern pesticides are ten times more toxic than those of the 1950s. The Centers for Disease Control and Prevention in Atlanta report that 40% of children working in agricultural fields now show signs of pesticide poisoning. The U.S. Geological Survey estimates that 32 million people in urban areas and 10 million people in rural areas are using groundwater that contains organic pollutants. J. Charles Fox, an official of the Environmental Protection Agency, says that "over the life of a person ingestion of these chemicals has been shown to have adverse health effects such as cancer, reproductive problems, and developmental effects."

At one time, people failed to realize that everything in the environment is connected to everything else. In other words, they didn't know that an organic chemical can wander far from the site of its entry into the environment and that eventually these chemicals can enter our own bodies and cause harm. Now that we are aware of this outcome, we have to decide as a society how to proceed. We might decide to do nothing if the percentage of people dying from exposure to organic pollutants is small. Or we might decide to regulate the use of industrial compounds more strictly than has been done in the past. We could also decide that we need better ways of purifying public and private water supplies so that they do not contain organic pollutants.

Decide Your Opinion

1. Are you in favor of reducing the level of organic pollutants in the environment? Would you favor this even if it reduced productivity and had adverse economic consequences? Explain.
2. Are you willing to stop using pesticides on your own lawn in order to prevent pollution of the water supply? Discuss.
3. Are you willing to devote time and energy to support government regulation of organic pollutants?

Summarizing the Concepts

2.1 Basic Chemistry

All matter is composed of some 92 elements. Each element is made up of just one type atom. An atom has a mass, which is dependent on the number of protons and neutrons in the nucleus, and its chemical properties are dependent on the number of electrons in the outer shell. Atoms react with one another by forming ionic bonds or covalent bonds. Ionic bonds are an attraction between charged ions. In covalent bonds, which can be single, double, or triple bonds, atoms share electrons.

2.2 Water and Living Things

Water, acids, and bases are important inorganic molecules. The polarity of water accounts for it being the universal solvent; hydrogen bonding accounts for it boiling at 100°C and freezing at 0°C. Because it is slow to heat up and slow to freeze, water is liquid at the temperature of living things.

Pure water has a neutral pH; acids increase the hydrogen ion concentration $[H^+]$ but decrease the pH of water, and bases decrease the hydrogen ion concentration $[H^+]$ but increase the pH.

2.3 Organic Molecules

The chemistry of carbon accounts for the chemistry of organic compounds. Carbohydrates, lipids, proteins, and nucleic acids are macromolecules with specific functions in cells.

2.4 Carbohydrates

Glucose is the 6-carbon sugar most utilized by cells for "quick" energy. Like the rest of the macromolecules to be studied, condensation synthesis joins two or more sugars, and hydrolysis splits the bond. Plants store glucose as starch, and animals store glucose as glycogen. Humans cannot digest cellulose, which forms plant cell walls.

2.5 Lipids

Lipids are varied in structure and function. Fats and oils, which function in long-term energy storage, contain glycerol and three fatty acids. Fatty acids can be saturated or unsaturated. Plasma membranes contain phospholipids that have a polarized end. Certain hormones are derived from cholesterol, a complex ring compound.

2.6 Proteins

Proteins have numerous functions in cells; some are enzymes that speed chemical reactions. The primary structure of a polypeptide is its own particular sequence of the possible 20 types of amino acids. The secondary structure is often an alpha (α) helix. The tertiary structure occurs when a polypeptide bends and twists into a three-dimensional shape. A protein can contain several polypeptides, and this accounts for a possible quaternary structure.

2.7 Nucleic Acids

Nucleic acids are polymers of nucleotides. Each nucleotide has three components: a sugar, a base, and phosphate (phosphoric acid). DNA, which contains the sugar deoxyribose, is the genetic material that stores information for its own replication and for the order in which amino acids are to be sequenced in proteins. DNA, with the help of RNA, specifies protein synthesis.

ATP, with its unstable phosphate bonds, is the energy currency of cells. Hydrolysis of ATP to ADP + Ⓟ releases energy that is used by the cell to do metabolic work.