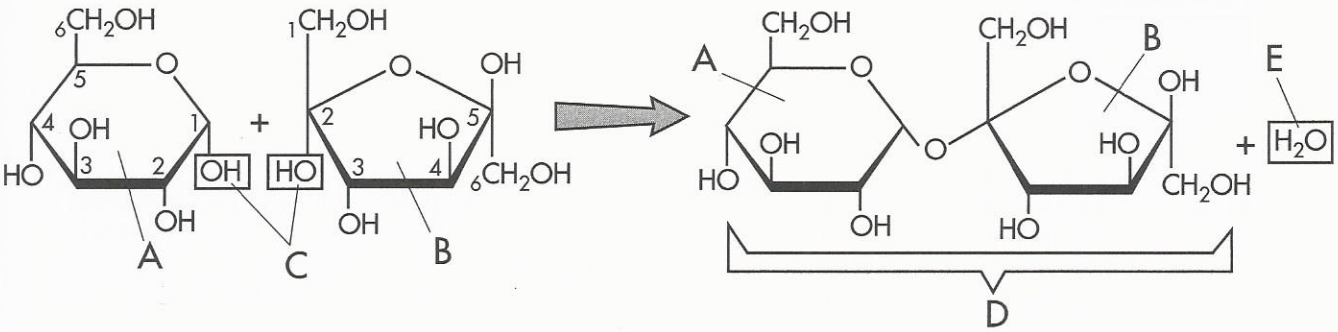
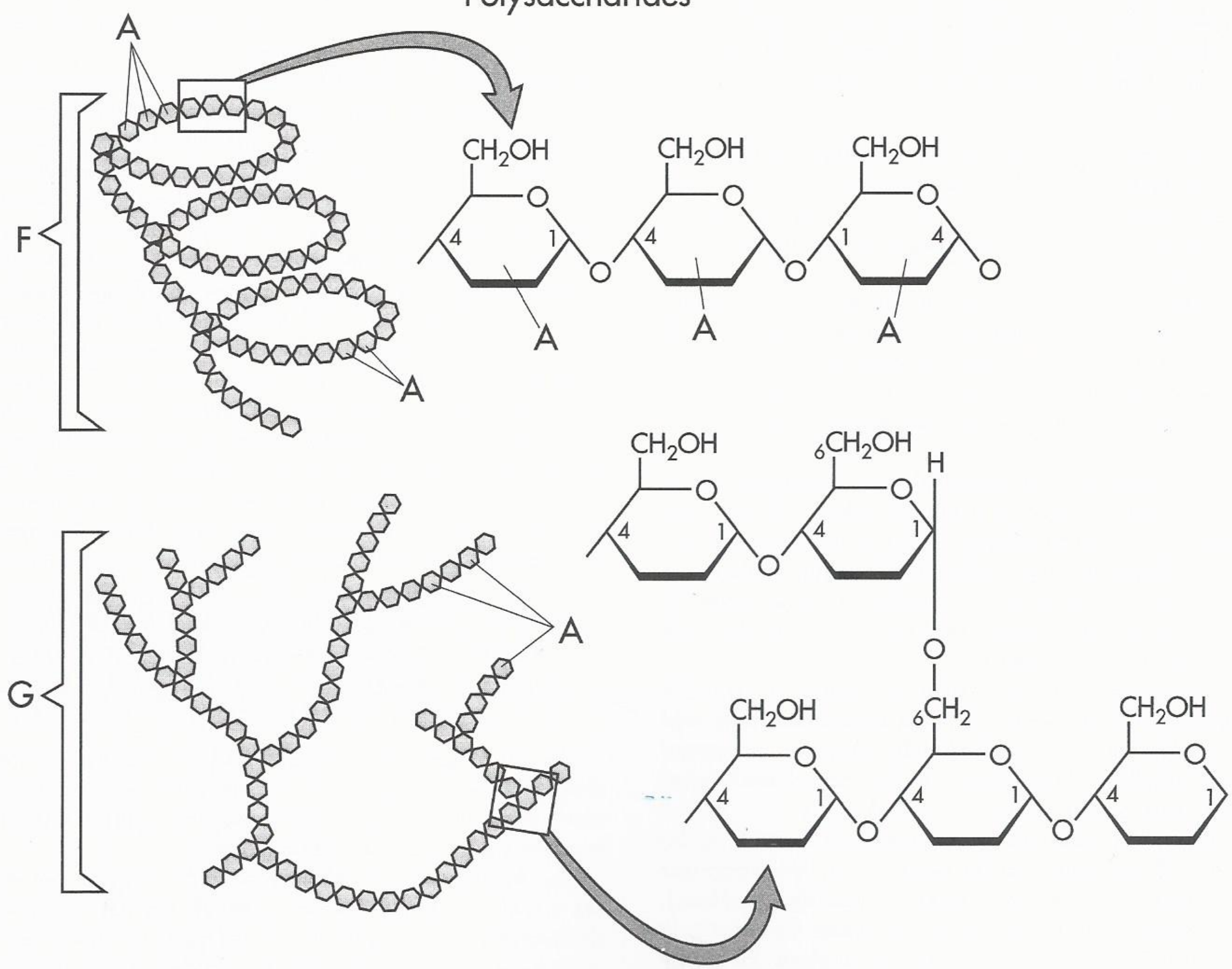
Simple Sugars



Polysaccharides



Carbohydrates

- ○ Glucose Molecule ......A
- ○ Fructose Molecule......B
- ○ Hydroxyl Group C
- ○ Sucrose Molecule ......D
- ○ Water Molecule ....E
- ○ Starch Molecule........F
- ○ Glycogen Molecule......G

Chapter 1-4: Carbohydrates

A thorough understanding of biology requires that one have an understanding of the fundamentals of chemistry, because life is basically a chemical process.

Many of the chemical substances associated with living things are referred to as organic substances; organic substances are substances that contain carbon. (All other substances are called inorganic.) Four classes of organic compounds are studied in depth in this book: carbohydrates, lipids, proteins, and nucleic acids. This plate centers on the first group, the carbohydrates. Carbohydrates are primarily used as sources of energy in living things.

Looking over this plate, you will notice that we discuss two types of carbohydrates; the simple sugars and the polysaccharides. We will note what these substances are composed of and what some of their functions are in living things. Continue to read as you color the plate.

All plants, animals, and microorganisms use carbohydrates as sources of energy. Carbohydrates are also used as structural building blocks. For instance, the cellulose of plant cell walls is composed of carbohydrates. Carbohydrates are made up of carbon, hydrogen, and oxygen atoms. In the upper portion of the plate, we show a **glucose molecule (A)**. This is a basic carbohydrate known as a monosaccharide, or simple sugar. It consists of six carbon atoms located at the positions that are designated one through six. Carbon 1 and carbon 5 are connected by an oxygen molecule, as the diagram shows.

A second monosaccharide is the **fructose molecule (B)**. This molecule also consists of six carbon atoms, but they are arranged differently than the carbons in glucose. Notice that the oxygen atom joins carbons 2 and 5, and that fructose is a five-membered ring, while glucose's ring contains six members.

Extending from both glucose and fructose molecules are a number of –OH groups, or **hydroxyl groups (C)**. When the molecules combine, an –OH group leaves the glucose molecule and an –H atom leaves the fructose. They unite to form a **water molecule (E)**. The two monosaccharides then bond with one another to form a molecule of **sucrose (D)**, and this double sugar is called a disaccharide.

Other disaccharides include maltose (two glucose units combined) and lactose (one glucose unit and one galactose unit). When disaccharides are used for energy, they are digested by enzymes that break them up into monosaccharides, and the monosaccharides are metabolized in the process of cellular respiration (as shown in the plate on Glycolysis). The process of the digestion of the disaccharide lactose (milk) requires the enzyme lactase. Lactose intolerant persons cannot produce lactase and therefore experience gastric difficulties from the ingestion of milk.

We now turn to complex carbohydrates known as polysaccharides. Continue your coloring as before, using the same colors as used previously. Two polysaccharides will be discussed in the paragraphs below. Each is essential for the maintenance and structure of biological organisms.

Polysaccharides are molecules that can consist of hundreds or thousands of monosaccharide units. The first polysaccharide molecule we will look at (in the bracket) is a starch molecule (F), which is found in plants such as corn and wheat.

Starch molecules represent a storage form of glucose; as the diagram shows, a starch molecule is composed of many glucose molecules (A) (we left off the hydroxyl groups of glucose here for simplicity). As you can see, the glucose molecules are bound to one another through an oxygen atom that unites carbons 1 and 4. The starch molecule is extensively twisted to form the final molecule.

When starch from food is taken into the body, the enzyme amylase (present in the mouth and small intestine) breaks it down into smaller units. After further digestion, glucose units are liberated, and these glucose units are absorbed into the blood stream, and taken up by cells. Cells use them in the metabolic process of respiration, which yields high-energy molecules necessary for the life of the cell.

The second polysaccharide we will mention is glycogen. A **glycogen molecule (G)** is indicated by the bracket at the bottom of the page. Glycogen is often referred to as animal starch. It is stored in the liver and muscles when the body has to store excess glucose molecules. Note that the glycogen molecule is composed of glucose units, but that glycogen is highly branched—this distinguishes glycogen from starch.

As we mentioned previously, one example of a structural polysaccharide is cellulose. Cellulose is very similar to starch except that the units are combined such that they cannot be digested by any of our digestive enzymes. For this reason, the cellulose in plant cells remains undigested and acts as roughage—which is essential to our diet.

A polysaccharide is an example of a macromolecule, also called a polymer. Polysaccharides may be branched or they may be long and linear. The types of linkages in polysaccharides determine which chemical reactions they take part in.

Chapter 1-5: Lipids

The four types of organic molecules that are associated with life are carbohydrates, lipids, proteins, and nucleic acids.

In the preceding plate, carbohydrates were considered, and in this plate, we will focus our attention on lipids. Lipids are a group of organic molecules that dissolve in oils, but not water.

In this plate, we will discuss fats, phospholipids, and cholesterol, all important lipids. They consist solely of carbon, hydrogen, and oxygen. Focus on the top portion of the plate, where we consider fats.

Fats are very efficient energy-storage molecules that yield about twice the amount of chemical energy per gram as do carbohydrates. Fats are important in the construction of plasma membranes, and they also provide physical and thermal insulation to animals.

In the upper portion of the plate, we consider two types of fats: a saturated fat and an unsaturated fat. The saturated fat is built from two types of subunits: a **glycerol molecule (A)**, which contains three atoms of carbon and numerous oxygen and hydrogen atoms. The box containing the molecule should be shaded in a pale color.

In the saturated fat, three **saturated fatty acid chains (B)** are chemically bound to the glycerol subunit. A fatty acid is a long hydrocarbon chain, as the diagram shows. A saturated fatty acid contains its maximum number of hydrogen atoms; single bonds are represented by straight lines in the diagram. When three saturated fatty acids are connected to glycerol as shown, the result is a saturated fat, or triglyceride.

In the unsaturated fatty acid, there are fewer than the maximum number of hydrogen atoms in the **unsaturated fatty acid chains (C)**; there are some double bonds, which are represented by two parallel lines. Three unsaturated fatty acid chains bonded to glycerol form an unsaturated fat, or triglyceride.

Saturated and unsaturated fats are extremely important to the metabolism of organisms. Fats are broken down into two-carbon units, and these units are used in the Krebs cycle (discussed later). They undergo a series of conversions and release their energy in the form of ATP molecules. Fats serve as a supplemental energy source when carbohydrate stores are exhausted.

Having discussed fats, we turn to another important lipid, the phospholipid. Read about this organic compound as you color the diagram.

One of the key uses of phospholipids is in the formation of the cell (plasma) membrane. The cell membrane consists of two layers of phospholipids with associated proteins. We will discuss membranes in depth in a later plate.

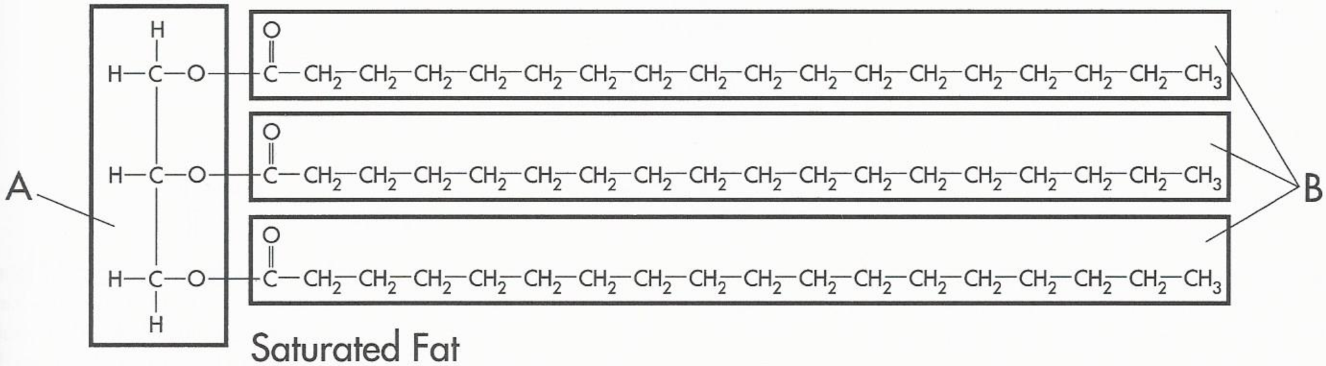
Phospholipids are basically made up of a glycerol molecule (A) with a **phosphate group (D)** attached to the first carbon at the extreme right. This phosphate group consists of a phosphorus atom and four oxygen atoms, and you should use a light color for it. The second and third carbons of the glycerol molecule bear fatty acid chains. Note that the fatty acid on the left is a saturated fatty acid (B), while the fatty acid on the right is unsaturated (C).

In the phospholipid bilayer of the cell membrane, the phosphate groups point toward the outside of the cell and the fatty acid chains extend toward each other. The phosphate end is the **polar end (E)** because it bears a negative charge. The opposite end of the molecule is the **nonpolar end (F)**, and this section of the molecule lacks an electrical charge. In the construction of the cell membrane, millions of these molecules stand next to one another to form a structure similar to a picket fence. Molecules entering or leaving the cell must pass through this double layer of lipids, and the membrane acts as a selective barrier for the cell.

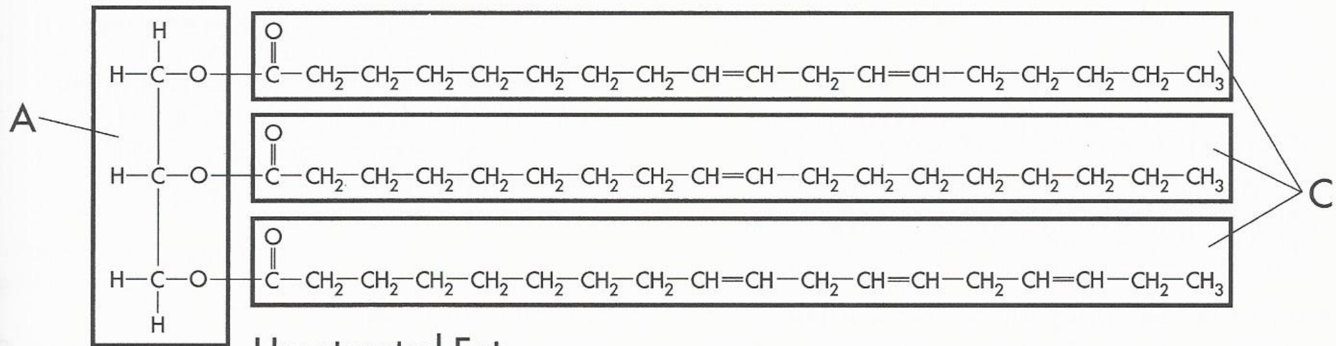
We now turn our attention to the final type of lipid, cholesterol. This molecule should be colored as you read about it below.

Steroids comprise an important group of lipids that are insoluble in water and consist of carbon, hydrogen, and oxygen atoms arranged in rings. Estrogen and androgens, the sex hormones in humans, are steroid hormones.

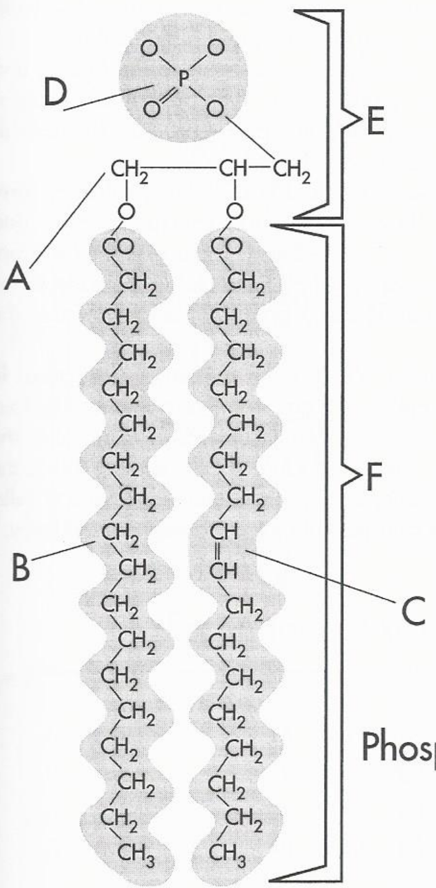
One familiar steroid is cholesterol. In the diagram, we show this complex molecule that has a **sterol ring (G)**. In humans, cholesterol is used as a precursor to sex hormones, but an excess of cholesterol is a problem because it can clog arteries and veins, which results in restricted blood flow. The liver synthesizes cholesterol for the body, but the diet also provides some, and if this intake is high, excessive cholesterol accumulates.



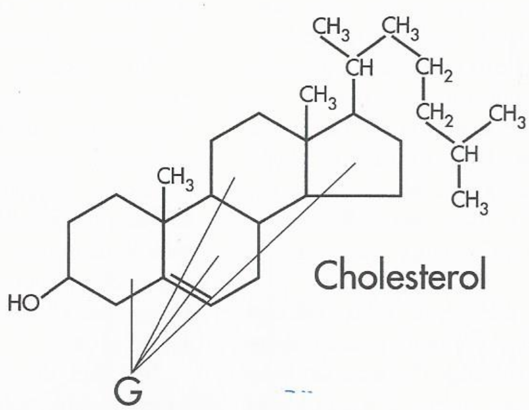
Saturated Fat



Unsaturated Fat



Phospholipid



Cholesterol

Lipids

- ○ Glycerol Molecule......A
- ○ Saturated Fatty Acid Chains............B
- ○ Unsaturated Fatty Acid Chains............C
- ○ Phosphate Group........D
- ○ Polar End.............E
- ○ Nonpolar End ....F
- ○ Sterol Ring...........G

Chapter 1-6: Proteins

Organic molecules provide the body with structural materials to form cells, tissues, and organs; regulatory substances to direct and govern the interactions of molecules; and energy to fuel the chemical operations of cells.

In previous plates, we discussed the structure and function of carbohydrates and lipids, and here we will examine proteins. Proteins> are vital to the formation and function of many cellular structures and processes. They are also among the most diverse organic molecules in the living organism.

> This plate shows how amino acid subunits are joined to form protein molecules. Once formed, proteins can assume a number of shapes, as the remainder of the plate will illustrate.

Proteins are molecules that are formed from units called amino acids. A protein may contain as few as ten amino acids, or it may contain thousands. The sequence of amino acids in proteins gives them unique functional characteristics.

In this plate, we show how amino acids combine with one another to form a linear protein called a peptide. The upper portion of the plate shows **two amino acids (A)** outlined by brackets. Each amino acid contains a **carboxyl group (B)** (shaded on the left amino acid and outlined on the right one). Amino acids also contain **amino groups (C)**. In the left amino acid, the amino group is outlined, and in the right one, it has been shaded. Light colors are recommended to color these groups. The amino group contains nitrogen and hydrogen atoms. The –R stands for a general alkyl group, and each of the twenty amino acids bear a distinct alkyl sidechain.

In the synthesis of a peptide, the –OH group of the carboxyl group of one amino acid and the –H of the amino group of the next amino acid are enzymatically removed. The nitrogen from one amino acid bonds with the carboxyl carbon of the adjacent amino acid, and this bond is called the **peptide bond (D)**. We have now formed a dipeptide, the smallest protein. In the course of the formation of the peptide bond, a molecule of water (H_2O) is given off.

Notice the far right side of the dipeptide, where it could join with the carboxyl group of an adjacent amino acid, and the far left of the dipeptide, where it could also be extended. Additional amino acids are added to the growing chain of peptides, and when the final amino acid has been added, a polypeptide results.

> The order and number of amino acids in the peptide chain is determined by the cell's genes; this is discussed in a future plate. Once the peptide has formed, additional modifications occur, as the following diagrams illustrate. Continue your coloring as you read below.

As amino acids are added to the growing peptide, a polypeptide results, and when the polypeptide is modified to its working structure, it is called a protein.

The linear sequence of amino acids in a protein is referred to as a protein's primary structure. In the diagram entitled Primary Structure, we show six amino acids (A) linked together by peptide bonds (D). You may choose to color the six amino acids different colors. The amino acids in this peptide are valine (val), leucine (leu), lysine (lys), tyrosine (tyr), and histidine (his).

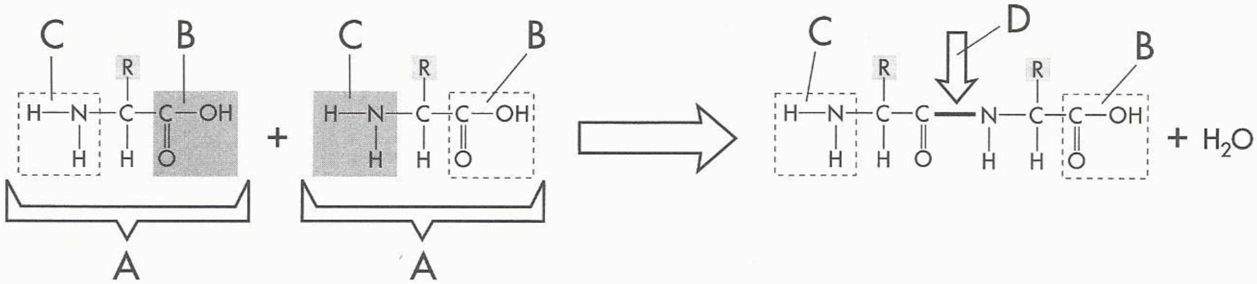
The secondary structure of proteins refers to the folding and twisting patterns of the protein chain. One pattern that proteins can assume is a **helix (E)**, indicated by the bracket. The individual amino acids in the helix can be seen.

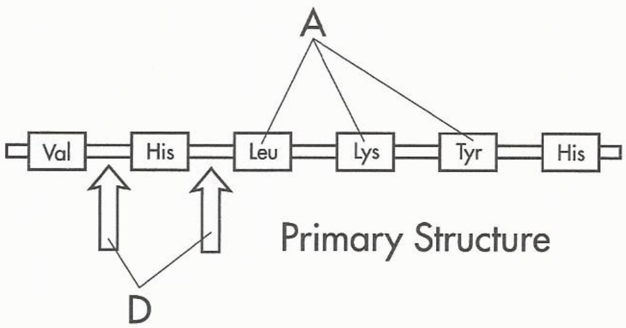
Certain polypeptide chains fold back on themselves to form **folded proteins (F)**. These proteins are globular proteins, and their three dimensional shape is shown. The protein in the figure is one of the four polypeptides in a hemoglobin molecule of the human blood cell, and the **heme group (G)** is found within the folded protein.

The final structure we show is the quaternary structure, in which **multiple polypeptides (H)** are organized together. The **four chains (H_1, H_2, H_3, H_4)** are different, but one is identical to the folded protein of the tertiary structure shown earlier. This is the final structure of the hemoglobin protein found in red blood cells. It is important for the transport of oxygen throughout the body.

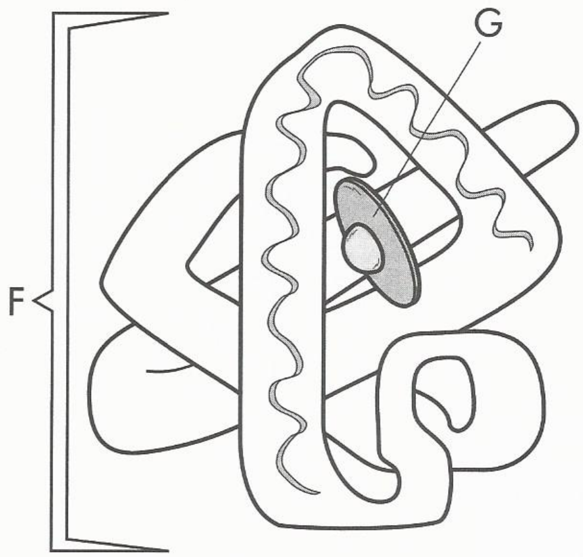
Proteins

○ Amino Acids .... A	○ Helix .... E	○ Chain #1 .... H_1
○ Carboxyl Group .... B	○ Folded Protein .... F	○ Chain #2 .... H_2
○ Amino Groups C	○ Heme Group .... G	○ Chain #3 .... H_3
○ Peptide Bond .... D	○ Multiple Polypeptides .... H	○ Chain #4 .... H_4

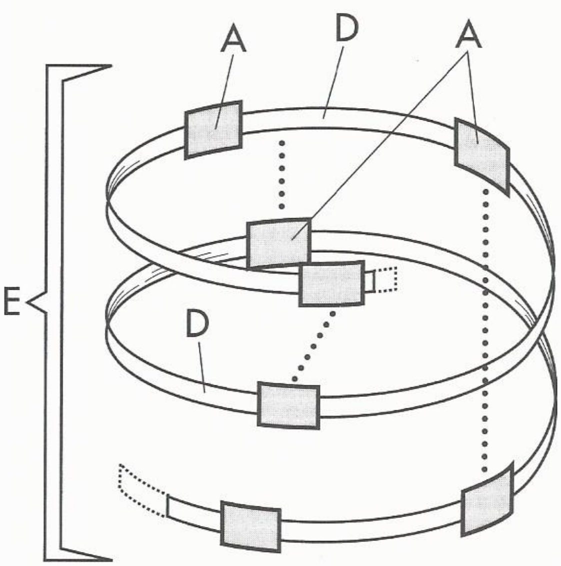




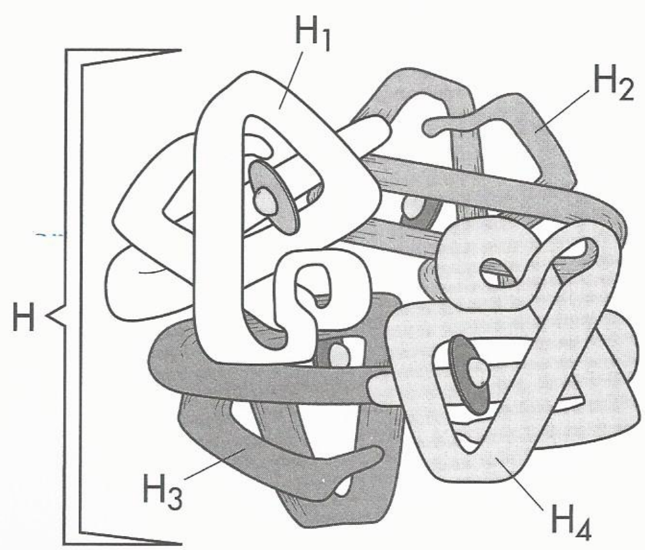
Primary Structure



Tertiary Structure



Secondary Structure



Quaternary Structure

Chapter 4-1: Structure of DNA

Two types of nucleic acids exist: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). DNA is the genetic material of organisms, while RNA is used during the construction of proteins. This plate will examine the structure of DNA. RNA's structure is studied in a succeeding plate in this chapter.

This plate illustrates the components of a molecule of DNA. Letters have been correlated with the names of some of the components; most textbooks use these letter abbreviations. Light colors such as grays and yellows should be used for the first part of the plate.

DNA exists in the chromosome of the living eukaryotic cell, and in the cytoplasm of prokaryotic cells. DNA is composed of repeating units known as nucleotides. Each nucleotide has three components: a molecule of the carbohydrate deoxyribose, a phosphate group, and a nitrogenous base. At the upper portion of the plate, two nucleotides are shown. At the left is a nucleotide composed of a **phosphate group (P)**, a **deoxyribose molecule (D)**, and a nitrogenous base called **adenine (A)**. The three components should be lightly shaded to avoid obscuring their individual atoms.

The deoxyribose molecule contains a five-carbon carbohydrate ring bound to the phosphate group at its $-CH_2$ group. On its opposite side, the deoxyribose molecule is bonded to the adenine molecule. The adenine contains five nitrogen atoms, which is why it is called a nitrogenous base.

A second nucleotide is shown at the right. It consists of a nitrogenous base called **thymine (T)**, bonded to a deoxyribose molecule (D) which is inverted here. The deoxyribose is in turn bonded to a phosphate group (P). As before, light shading should be used to denote the three portions of the nucleotide.

Adenine and thymine nucleotides are held to one another by two **hydrogen bonds (H)**, one of which is indicated by an arrow, which should be colored boldly. Hydrogen bonds are weak chemical bonds formed between hydrogen and nearby electronegative atoms. In DNA, two hydrogen bonds exist between A and T, and three exist between G and C.

We will now examine how the nucleotides bind to one another to form DNA. Continue your coloring as you read, and use the same colors in the DNA molecule that you used for the nucleotides.

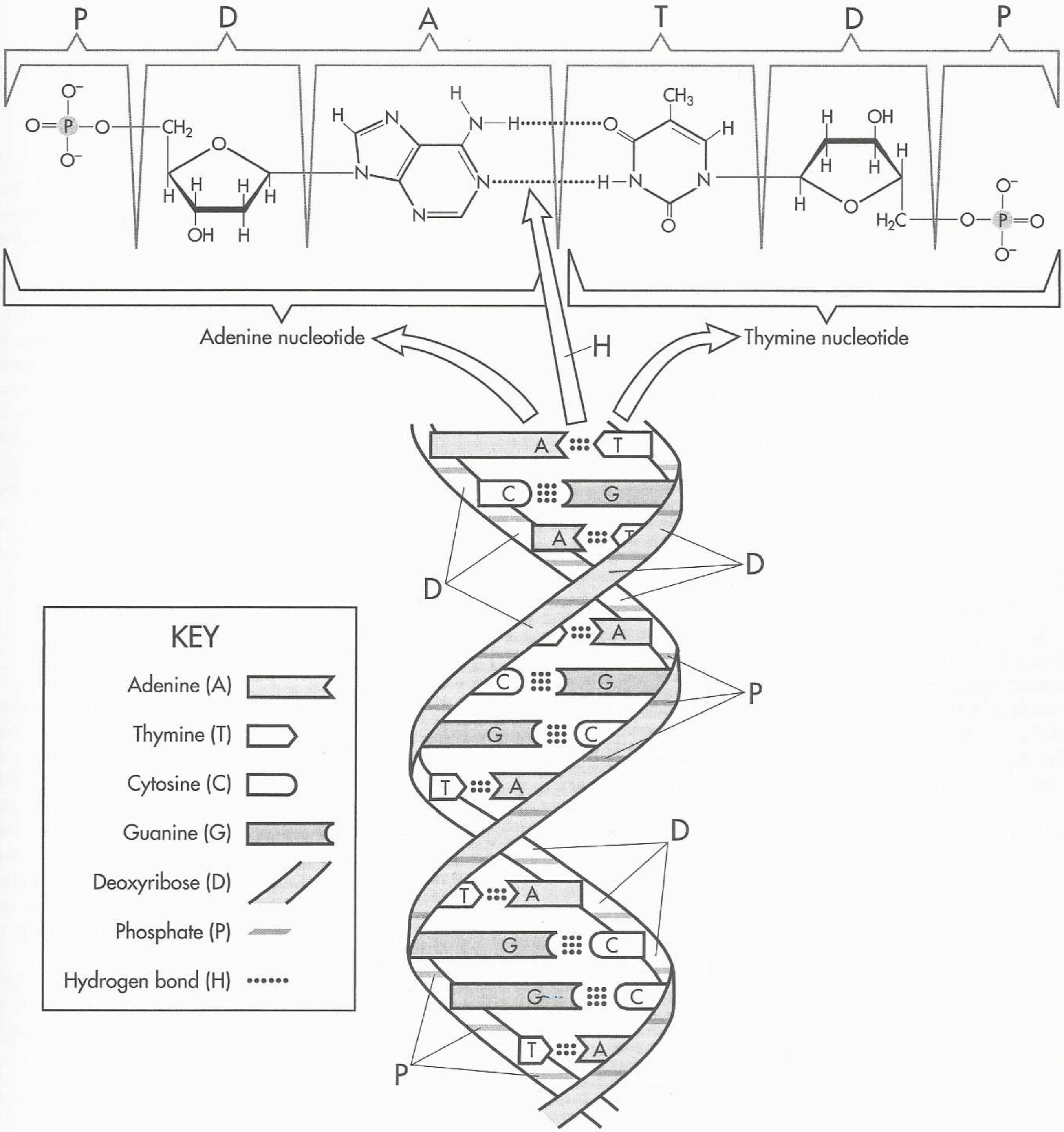
The four nitrogenous bases that make up DNA are thymine, adenine, **cytosine (C)**, and **guanine (G)**. Let's take a look at the DNA double helix.

Begin at the top of the molecule, and note that the first nucleotide contains adenine (A), and that it is attached to deoxyribose (D). The deoxyribose is connected to a phosphate group (P) which in turn is connected to another deoxyribose molecule. The latter is connected to a cytosine (C) molecule, as well as another phosphate group (P). A deoxyribose molecule (D) follows, which is connected to an adenine (A). This pattern continues with alternating deoxyribose molecules and phosphate groups as the ribbon-like strand continues and curves. Each deoxyribose molecule is connected to one of the four nitrogenous bases.

Now move to the right side of the molecule and follow the ribbon, beginning at the upper right. As you follow it, note that it contains deoxyribose molecules that alternate with phosphate groups, and that again, connected to each deoxyribose molecule is one of the four nitrogenous bases. The second strand of DNA is very similar to the first strand.

We will complete the plate by noting how the two strands of DNA unite to form the double-stranded DNA molecule. If you have not yet completed your coloring of all the parts of the two strands, do so at this point. Then read below.

In the complete DNA molecule, two single strands oppose one another in a ladder-like arrangement, in which the nitrogenous bases line up opposite one another according to the principle of complementary base pairing. Adenine always lines up opposite thymine, and cytosine always lines up opposite guanine. As we mentioned earlier, hydrogen bonds then hold the bases together. The nitrogenous bases thus form rungs of a ladder.



Structure of DNA

- ○ Phosphate Group........P
- ○ Deoxyribose...........D
- ○ Adenine...............A
- ○ Thymine...............T
- ○ Hydrogen Bond.........H
- ○ Cytosine C
- ○ Guanine...............G