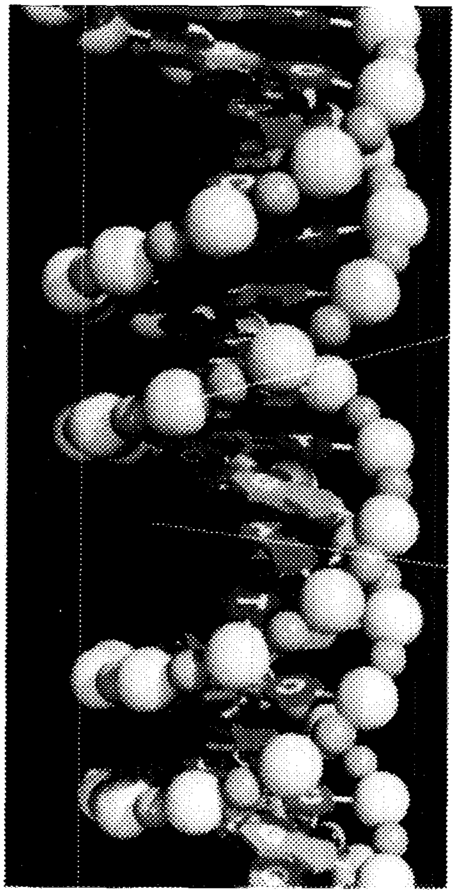
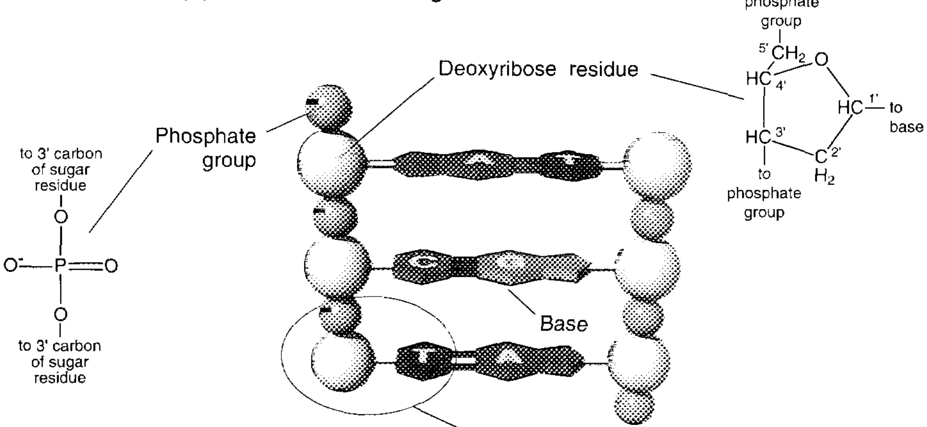
DNA: its structure and components



(a) Computer-generated Image of DNA (by Mel Prueitt)

(b) Uncoiled DNA Fragment



The usual configuration of DNA is shown in (a). Two chains, or strands, of repeated chemical units are coiled together into a double helix. Each strand has a "backbone" of alternating deoxyribose residues (larger spheres) and phosphate groups (smaller spheres). Free deoxyribose, $C_5O_4H_{10}$, is one of a class of organic compounds known as sugars; the phosphate group, $(PO_4)^{-3}$, is a component of many other biochemicals.

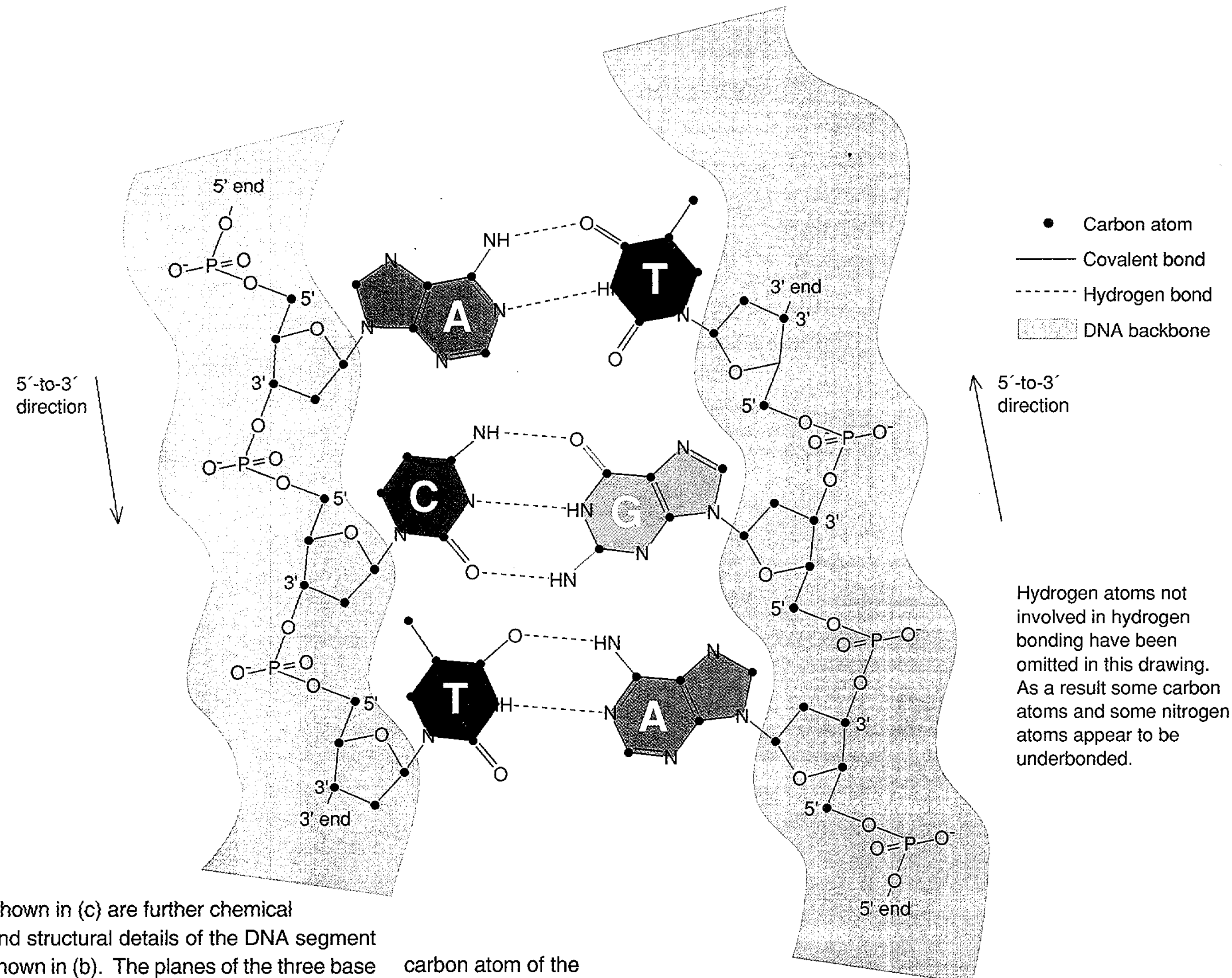
Attached to each sugar residue is one of four essentially planar nitrogenous organic bases: adenine (A), cytosine (C), guanine (G), or thymine (T). The plane of each base is essentially perpendicular to the helix axis. *Encoded in the order of the bases along a strand is the hereditary information that distinguishes, say, a robin from a human and one robin from another.*

As shown, the two strands coil about each other in a fashion such that all the bases project inward toward the helix axis. The two strands are held together by hydrogen bonds (pink rods) linking each base projecting from one backbone to its so-called complementary base projecting from the other backbone. The base A *always bonds to T (A and T are complementary bases)*, and C is always linked to G (C and G are complementary bases). Thus the order of the bases along one strand is dictated by and can be inferred from the order of the bases along the other strand. (The two strands are said to be complementary.) The pairing of A only with T and of C only with G is the feature of DNA that allows it to serve as a template not only for its own replication but also for the synthesis of proteins (see "DNA Replication" and "Protein Synthesis"). Note that the members of a base pair are essentially coplanar.

All available evidence indicates that each eukaryotic chromosome contains a single long molecule of DNA, only a small portion of which is shown here. Furthermore, the ends of each DNA molecule, called telomeres, have a special base sequence and a somewhat different structure.

Shown in (b) is an uncoiled fragment of (a) containing three complementary base pairs. From the chemist's viewpoint, each strand of DNA is a polymer made up of four repeated units called deoxyribonucleotides, or simply nucleotides. The four nucleotides are regarded as the monomers of DNA (rather than the sugar residue, the phosphate group, and the four base residues) because the *nucleotides are the units added as a strand* of DNA is being synthesized (see "DNA Replication").

A particular nucleotide is commonly designated by the symbol for the base it contains. Thus T is a symbol not only for the base thymine (more precisely, the thymine residue) but also for the indicated nucleotide. Also shown are chemical and structural details of the backbone components. Note that four carbon atoms of the sugar residue and its one oxygen atom form a pentagon in a plane parallel to the helix axis, and that the fifth carbon atom of the sugar residue projects out of that plane.



Shown in (c) are further chemical and structural details of the DNA segment shown in (b). The planes of the three base pairs have been rotated into the plane of the sugar residues. Details of particular note include the following.

Linking any two neighboring sugar residues is an -O–P–O- "bridge" between the 3´ carbon atom of one of the sugars and the 5´ carbon atom of the other sugar. (The designations 3´ (three prime) and 5´ (five prime) arise from a standard system for numbering atoms in organic molecules.) When a DNA molecule is broken into fragments, as it must be before it can be studied, the breaks usually occur at one of the four covalent bonds in each bridge.

Because deoxyribose has an asymmetric structure, the ends of each strand of a DNA fragment are different. At one end the terminal carbon atom in the backbone is the 5´ carbon atom of the terminal sugar (the carbon atom that lies outside the planar portion of the sugar), whereas at the other end the terminal carbon atom is the 3´ carbon atom of the terminal sugar (a carbon atom that lies within the planar portion of the sugar).

The two complementary strands of DNA are antiparallel. In other words, arrows drawn from, say, the 5´ end to the 3´ end of each strand have opposite directions. Most of the enzymes that move along a backbone in the course of catalyzing chemical reactions move in the 5´-to-3´ direction. The composition of a DNA fragment is represented symbolically in a variety of ways. However, all of the representations focus on the order, or sequence, of the nucleotides (and hence the bases) along the strands of the fragment. For example, the most complete representation for the fragment shown above is

5´-ACT-3´
3´-TGA-5´.

The most abbreviated representation, ACT (or, equivalently, AGT), gives the sequence of only one strand (since the sequence of the complementary strand can be inferred from the given sequence) and follows the convention that the left-to-right direction corresponds to the 5´-to 3´ direction.