Chapter 20

The Role of Hydrogen Bonding in the Structure and Function of the Nucleic Acids

In the form of deoxyribonucleic acid (DNA), the macromolecular nucleic acids are of prime importance in biology because they carry the building plan for each living individual. They are identically reduplicated and inherited from one generation to the next, be it bacterium, plant, animal, or man. The information about every feature of and about every molecule contained in a living being is encoded in the nucleotide sequence of its DNA, which is read out and translated into the amino acid sequences of its proteins. In the many different steps involved in this protein biosynthesis, information transfer takes place which would be impossible without the weak hydrogen bonds. Because they can easily and rapidly be formed and broken, they are ideally suited for these dynamic processes which are so important for life.

20.1 Hydrogen Bonding in the Nucleic Acids is Essential for Life

There are two types of nucleic acids – the genetic material deoxyribonucleic acid (DNA), and the ribonucleic acids (RNA) –, which are involved in protein biosynthesis. DNA and RNA have very different functions in biology, but are similar in chemical terms. As illustrated in Fig. 20.1, both nucleic acids are linear polymers, DNA being formed by the four deoxyribonucleosides (see Fig. 17.1) and RNA by the four ribonucleosides. The nucleosides are connected at their 3′- and 5′-hydroxyl groups by phosphodiester linkages. DNA, which is 10^7 to several 10^9 nucleotides long, can be compared with computer magnetic tapes: the tape material, a plastic ribbon, is the "inert" sugar-phosphate backbone, and the information contained on the tapes in the form of bits (letters) and bytes (words) is encoded in the nucleic acids in the sequence of the four bases (bits), with three of them (a triplet) being the equivalent of the byte.

Base-pair hydrogen bonding of the Watson-Crick type is fundamental in all biological processes where nucleic acids are involved. These processes, which are chiefly DNA replication and protein biosynthesis [650, 651], were understood only at the molecular level when Watson and Crick discovered the three-dimensional structure of DNA [27, 527]. This structure consists of two polynucleotide chains running in opposite directions (antiparallel), and twisted into a right-handed double helix. The hydrophobic purine and pyrimidine bases are stacked in the center

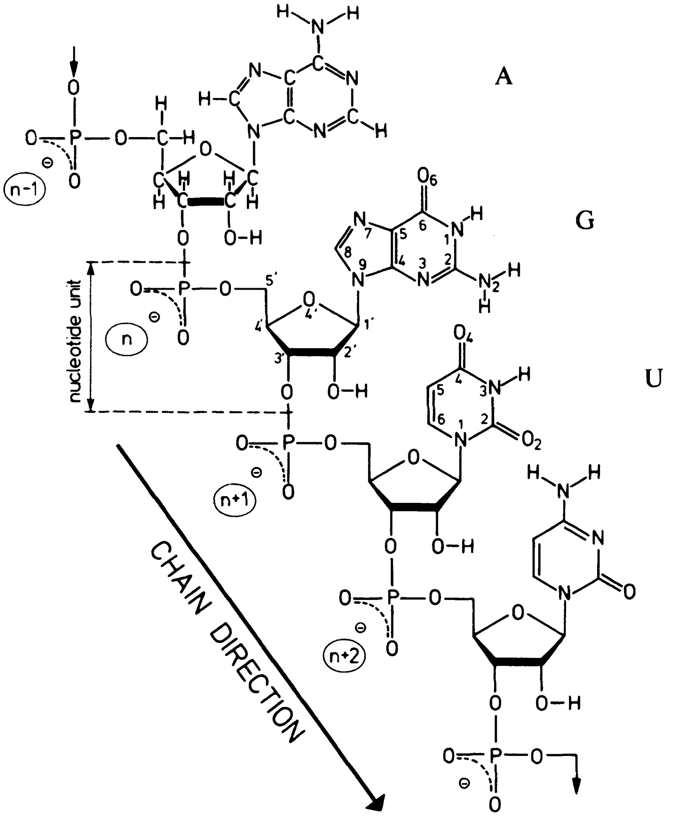

Fig. 20.1. Chemical structure of RNA with sequence ...pApGpUpCp... or, in short, AGUC. All hydrogen atoms are drawn in adenosine, and only functional hydrogen atoms are given in the other nucleotide units. In DNA, hydroxyl groups in sugar 2'-position are replaced by hydrogen atoms, and uridine is methylated in 5-position and called thymidine [522]

of the helix and the hydrophilic sugar-phosphate backbones are at the periphery. The bases are linked by hydrogen bonds in the base pairs such that adenine (A) in one strand opposes thymine (T) in the other strand, and guanine (G) opposes cytosine (C), so that one strand of DNA is said to be *complementary* to the other (Part II, Chap. 16, Figs. 16.10, 16.11, 16.13).

For *reduplication*, the chains are separated and on each a new, complementary strand is synthesized by enzymes called DNA polymerases [652]. For *protein biosynthesis*, the DNA is copied (transcribed) into the "messenger" ribonucleic acid (mRNA) by the enzyme RNA polymerase (Fig. 20.2) where, in contrast to DNA, the deoxyribose is replaced by ribose and thymine by the equivalent uracil. Here again, the Watson-Crick base pair plays the crucial role so that the mRNA sequence is complementary to the DNA sequence.

In order to read the sequence of nucleotides in the mRNA and to *translate* it into the protein sequence, the complicated multi-protein-subunit machinery called