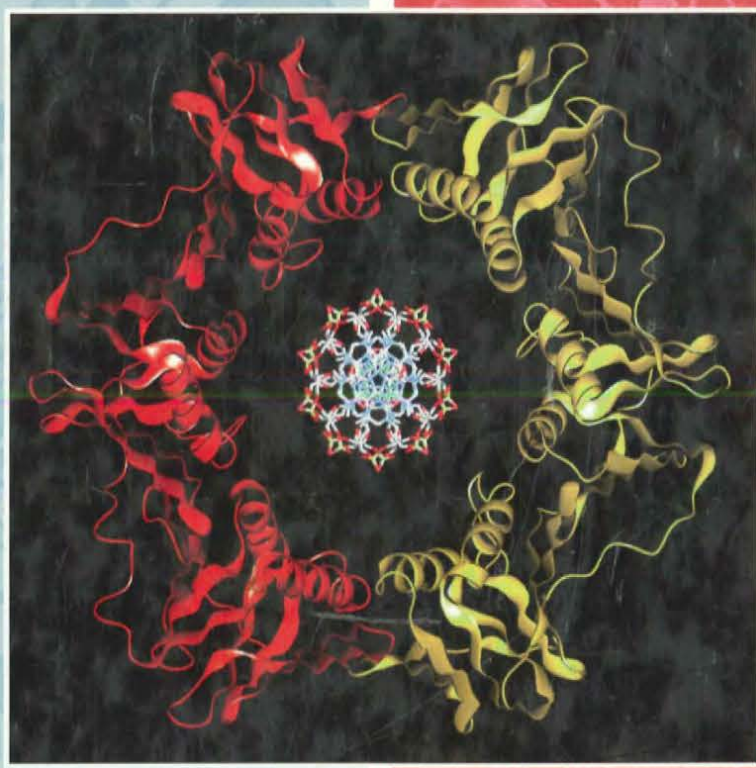
Biochemistry

Second Edition



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NUCLEIC ACIDS

In the next several chapters we introduce three major classes of biomolecules—nucleic acids, proteins, and carbohydrates. Together, they make up a large part of all living matter. As we saw in Chapter 1, these substances exist as macromolecules, some of them giant. We shall find all of these macromolecules to be polymers; each type is made by the linking of a limited number of kinds of monomer units. However, these classes of macromolecules play entirely different roles in the life of the cell.

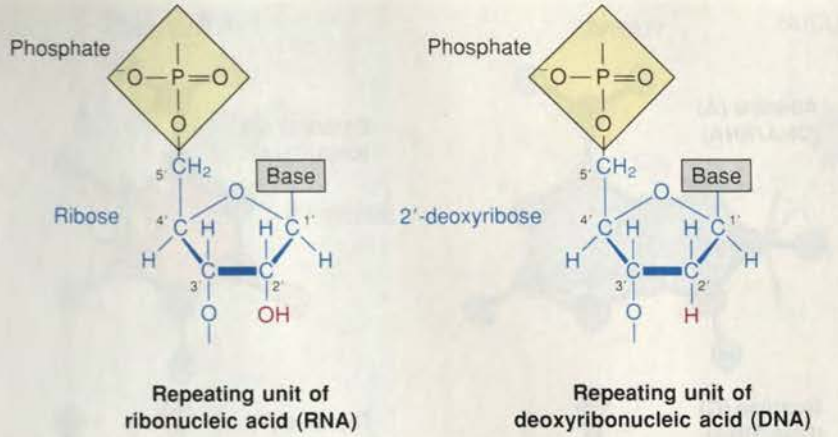
THE NATURE OF NUCLEIC ACIDS

It is appropriate to begin this section with the **nucleic acids,** for in a certain sense they are the most fundamental and important constituents of the living cell. It seems probable that life itself began its evolution with nucleic acids, for only they, of all biological substances, carry the remarkable potential for self-duplication. Today, nucleic acids act as the repositories and transmitters of genetic information for every cell, tissue, and organism. The blueprint for an organism is encoded in its nucleic acid, in gigantic molecules like that shown in Figure 1.5 (page 9). Much of an organism's physical development throughout life is programmed in these molecules. The proteins that its cells will make and the functions that they will perform are all recorded on this molecular tape.

In this chapter, and in the several that follow, we first describe the nucleic acids and then provide a brief introduction to the ways in which they preserve and transmit genetic information. The details of these processes will be covered in Part V of this book, but it is important that we consider, at the beginning, the role that nucleic acids play in the formation of proteins and cellular structure.

THE TWO TYPES OF NUCLEIC ACID: DNA AND RNA

There are two types of nucleic acid, **ribonucleic acid** (RNA) and **deoxyribonu-**



Both DNA and RNA are polynucleotides. RNA has the sugar ribose; DNA has deoxyribose. RNA contains the base uracil instead of thymine.

In each case the monomer unit contains a five-carbon sugar, **ribose** in RNA and **2′-deoxyribose** in DNA (shown in blue in the structures). The difference between the two sugars lies solely in the 2′ hydroxyl group on ribose. The connection between successive monomer units in nucleic acids is through a phosphate residue attached to the hydroxyl on the 5′ carbon of one unit and the 3′ hydroxyl of the next one. This forms a **phosphodiester link** between two sugar residues (Figure 4.1). In this way, long nucleic acid chains, sometimes containing hundreds of millions of units, are built up. The phosphate group is a strong acid, with a pK_a of about 1; this is why DNA and RNA are called nucleic *acids*. Every residue in a DNA or RNA molecule carries a negative charge at physiological pH.

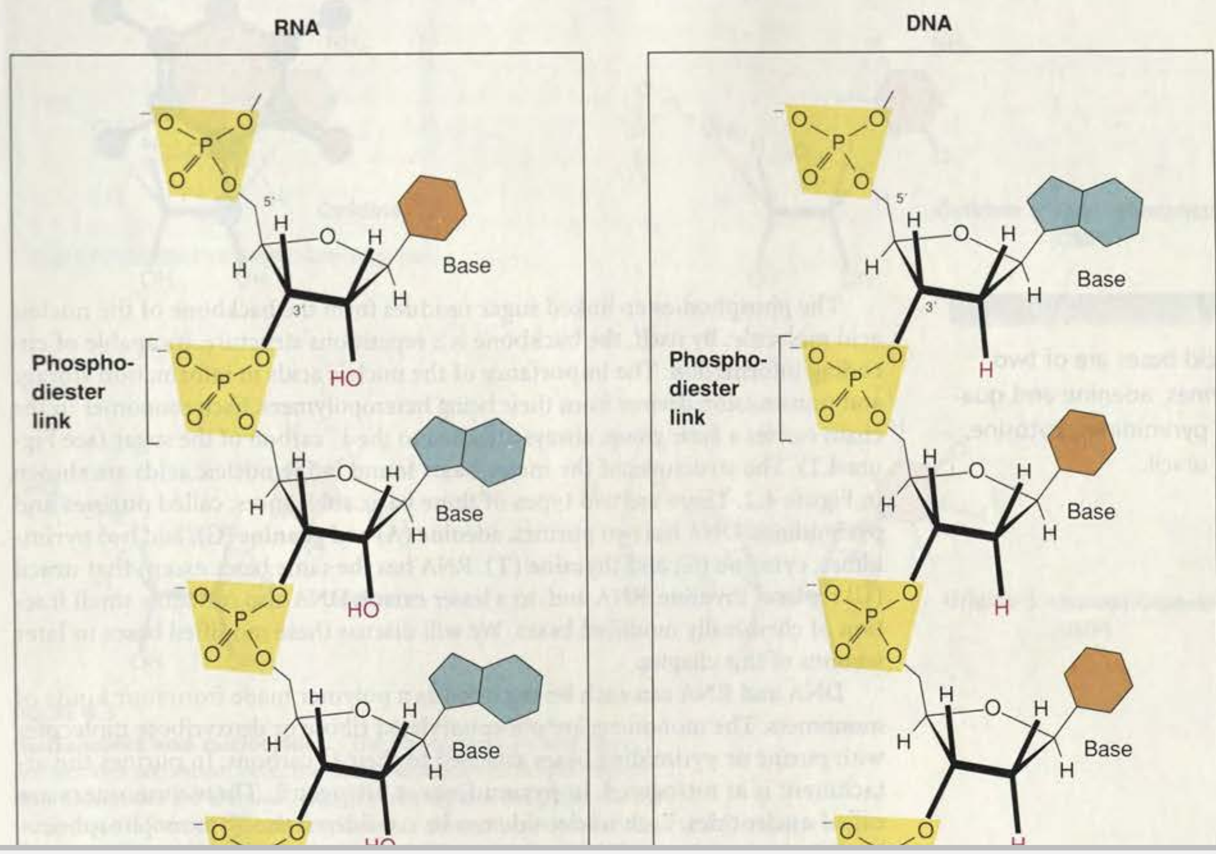
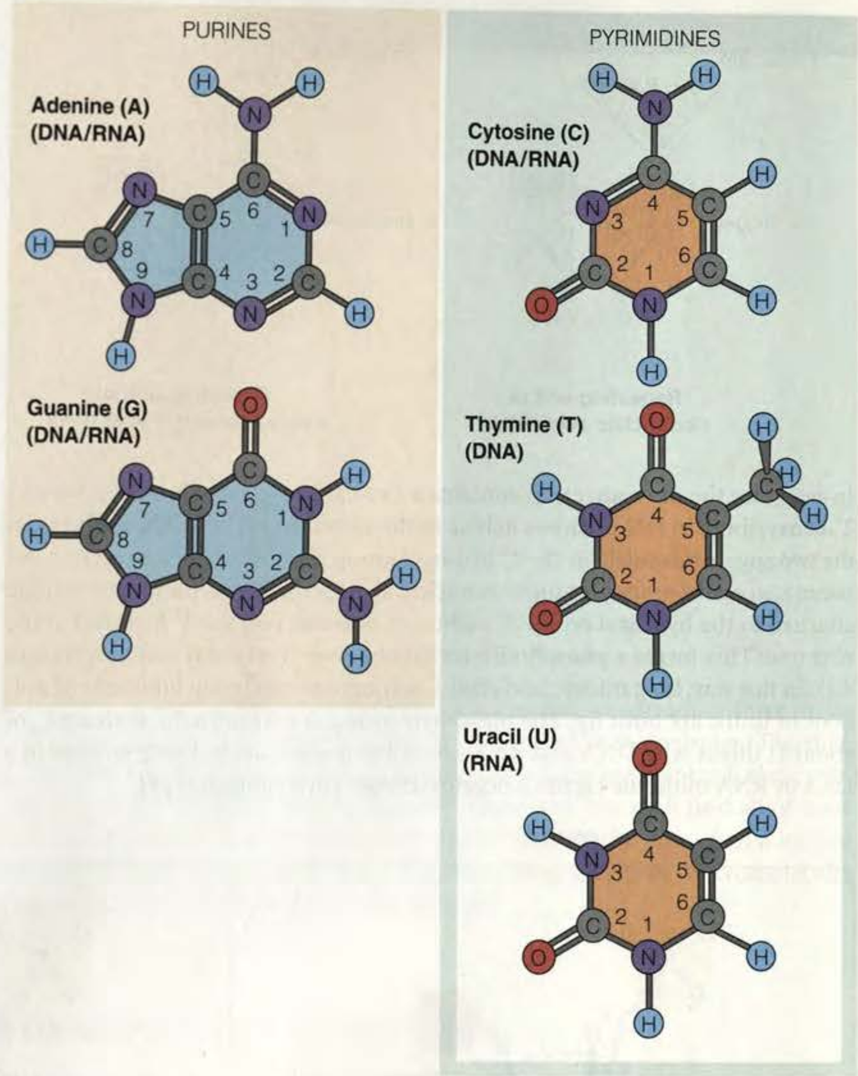


FIGURE **4.1**

Chemical structures of ribonucleic acid (RNA) and deoxyribonucleic acid (DNA). The ribose–phosphate or deoxyribose–phosphate backbone of each chain is shown in detail. The bases shown schematically here are detailed in Figure 4.2.

FIGURE **4.2**

Purine and pyrimidine bases found in DNA and RNA. A major difference between the two types of nucleic acids is that RNA has uracil (U) instead of the thymine (T) found in DNA.



The nucleic acid bases are of two kinds: the purines, adenine and guanine, and the pyrimidines, cytosine, thymine, and uracil.

The phosphodiester-linked sugar residues form the backbone of the nucleic acid molecule. By itself, the backbone is a repetitious structure, incapable of encoding information. The importance of the nucleic acids in information storage and transmission derives from their being **heteropolymers.** Each monomer in the chain carries a *basic group,* always attached to the 1′ carbon of the sugar (see Figure 4.1). The structures of the major bases found in the nucleic acids are shown in Figure 4.2. There are two types of these basic substances, called **purines** and **pyrimidines.** DNA has two purines, **adenine** (A) and **guanine** (G), and two pyrimidines, **cytosine** (C) and **thymine** (T). RNA has the same bases except that **uracil** (U) replaces thymine. RNA and, to a lesser extent, DNA also contain a small fraction of chemically modified bases. We will discuss these modified bases in later sections of this chapter.

DNA and RNA can each be regarded as a polymer made from four kinds of monomers. The monomers are phosphorylated ribose or deoxyribose molecules with purine or pyrimidine bases attached to their 1′ carbons. In purines the attachment is at nitrogen 9, in pyrimidines at nitrogen 1. These monomers are called **nucleotides.** Each nucleotide can be considered the 5′-monophosphory-

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