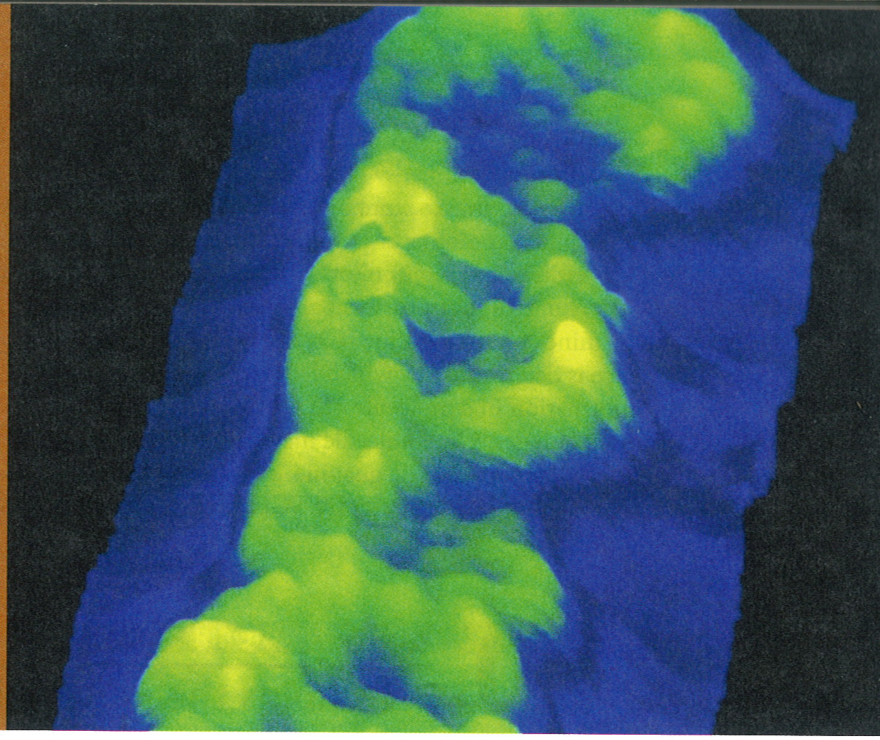
2·19–2·21 Nucleic acids store information on how to build and run a body.



Three turns of the DNA double helix (from a scanning tunneling micrograph).

2·19 Nucleic acids are macromolecules that store information.

We have examined three of life's macromolecules: carbohydrates, lipids, and proteins. We turn our attention now to the fourth: **nucleic acids,** macromolecules that store information and are made up of individual units called **nucleotides.** All nucleotides have three components: a molecule of sugar, a phosphate group (containing a phosphorus atom bound to four oxygen atoms), and a nitrogen-containing molecule (**FIGURE 2-45**). There are two types of nucleic acids: **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA).** Both play central roles in directing the production of proteins in living organisms, and by doing so play a central role in determining all of the inherited characteristics of an individual. In both types of nucleic acids, the molecule has the same type of backbone: a sugar molecule attached to a phosphate group attached to another sugar, then another phosphate, and so on. Attached to each sugar is one of the nitrogen-containing molecules called DNA **bases** (so named because of their chemical structure). A 10-unit nucleic acid therefore would have 10 bases, one attached to each sugar within the sugar-phosphate-sugar-phosphate backbone. But the base attached to each sugar is not always the same. It can be one of several different bases. For this reason, a nucleic acid

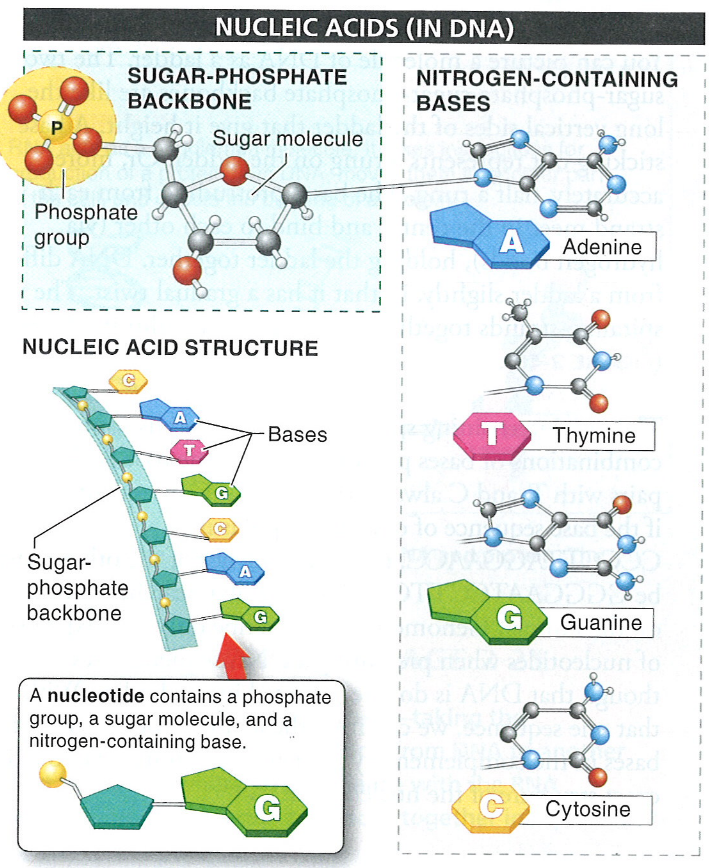


FIGURE 2-45 The molecules that carry genetic information. The structure of nucleic acids.

is often described by the sequence of bases attached to the sugar-phosphate-sugar-phosphate backbone.

Nucleic acids are able to store information by varying which base is attached at each position in the molecule's backbone. At each position in a molecule of DNA, for example, the base can be any one of four possible bases: adenine (A), thymine (T), guanine (G), or cytosine (C). Just as the meaning of a sentence is determined by which letters are strung together, the information in a molecule of DNA is determined by its sequence of bases. One molecule may have the sequence adenine, adenine, adenine, guanine, cytosine, thymine, guanine—abbreviated as AAAGCTG. Another molecule may have the sequence CGATTACCCGAT. Because the information differs in each case, so, too, does the protein for which the sequence codes, as we'll see.

TAKE-HOME MESSAGE 2·19

The nucleic acids DNA and RNA are macromolecules that store information in their unique sequences of bases contained in nucleotides, their building-block molecules. Both nucleic acids play central roles in directing protein production in organisms.

2·20 DNA holds the genetic information to build an organism.

A molecule of DNA has two strands, each a sugar-phosphate-sugar-phosphate backbone with a base sticking out from each sugar molecule. The two strands wrap around each other, each turning in a spiral. Although each strand has its own sugar-phosphate-sugar-phosphate backbone and sequence of bases, the two strands are connected by the bases protruding from them.

You can picture a molecule of DNA as a ladder. The two sugar-phosphate-sugar-phosphate backbones are like the long vertical sides of the ladder that give it height. A base sticking out represents a rung on the ladder. Or, more accurately, half a rung. The bases protruding from each strand meet in the center and bind to each other (via hydrogen bonds), holding the ladder together. DNA differs from a ladder slightly, in that it has a gradual twist. The two spiraling strands together are said to form a **double helix** (FIGURE 2-46).

The two intertwining spirals fit together because only two combinations of bases pair up together. The base A always pairs with T, and C always pairs with G. Consequently, if the base sequence of one of the spirals is CCCCTTAGGAACC, the base sequence of the other must be GGGGAATCCTTGG. That is why researchers working on the Human Genome Project describe only one sequence of nucleotides when presenting a DNA sequence—even though that DNA is double-stranded in our bodies. With that one sequence, we can infer the identity and order of the bases in the complementary sequence, and thus we know the exact structure of the nucleic acid.

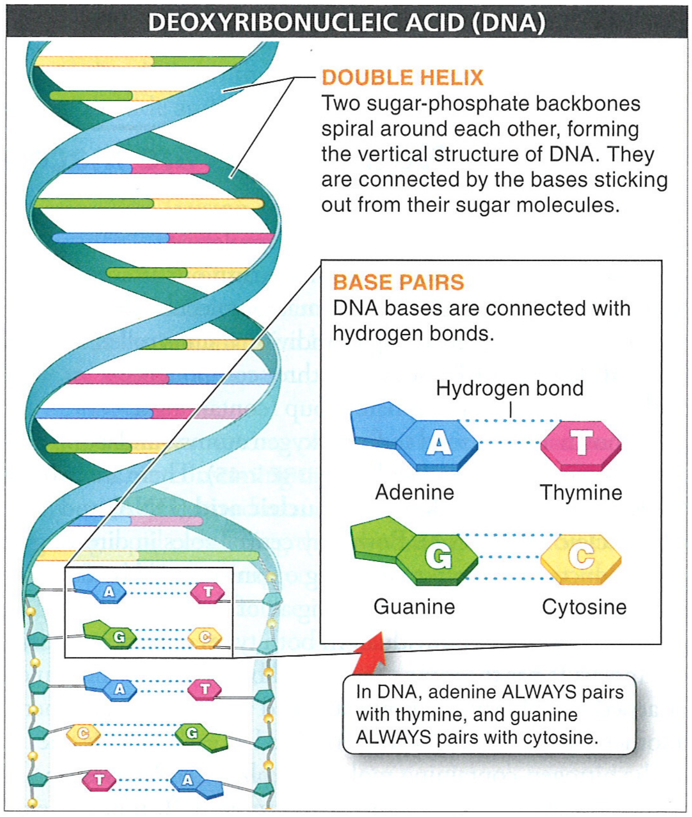


FIGURE 2-46 A gradually twisting ladder. The rungs of the DNA ladder are nucleotide base pairs, and the sides of the ladder are made up of two sugar-phosphate backbones.

The sequences of nucleotide bases containing the information about how to produce a particular protein have anywhere from a hundred to several thousand bases. In a human, all of the DNA in a cell, containing all of the instructions for every protein that a human must produce, contains about three billion base pairs. Almost all of this DNA is in the cell's nucleus.

TAKE-HOME MESSAGE 2·20

DNA is shaped like a ladder in which the long vertical sides of the ladder are made from a sequence of sugar-phosphate-sugar-phosphate molecules and the rungs are pairs of nucleotide bases. The sequence of nucleotide bases contains the information about how to produce a particular protein.

2·21 RNA is a universal translator, reading DNA and directing protein production.

The process of building a protein from a DNA sequence is not a direct one. Rather, it incorporates a middleman, RNA, that is also a nucleic acid (**FIGURE 2-47**). Segments of the DNA are read off, directing the production of short strips of RNA that contain the information, taken from the DNA, about the amino acid sequence in a protein. The RNA moves to another part of the cell and then directs the piecing together of amino acids into a three-dimensional protein. We explore this in greater detail in Chapter 5.

RNA differs from DNA in three important ways. First, the sugar molecule of the sugar-phosphate-sugar-phosphate backbone differs slightly, containing an extra atom of oxygen. Second, RNA is single stranded. The sugar-phosphate-sugar-phosphate backbone is still there, as are the bases that protrude from each sugar. The bases, however, do not bind with anything else and do not form base pairs with another RNA strand. And third, while RNA has the bases A, G, and C, it replaces the thymine with a similar base called uracil (U).

Whether we're looking at the nucleotides that make up RNA and DNA or the lipids used to build sex hormones and cell membranes, we see a recurring theme in the construction of biological macromolecules: from relatively simple sets of building blocks linked together, infinitely complex molecules can be formed. Complex webs of one simple sugar, bonded together as glycogen, for instance, provide fuel for organisms. Similarly, sequences of amino acids of 20 different types, joined together, specify the structure of all the proteins found in every species on earth.

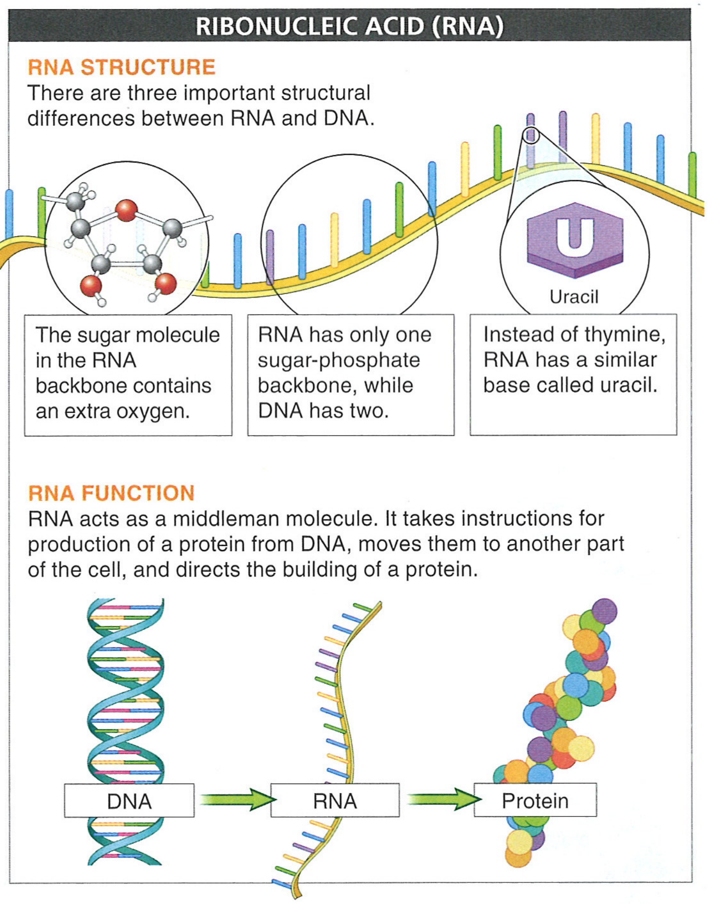


FIGURE 2-47 The middleman between DNA and protein. The structure of RNA.

TAKE-HOME MESSAGE 2·21

RNA acts as a middleman molecule—taking the instructions for protein production from DNA to another part of the cell where, in accordance with the RNA instructions, amino acids are pieced together into proteins.