Nucleic Acids 2.6

DNA, the well-known abbreviation for **deoxyribonucleic acid**, is vital for cell function and reproduction. Its task is to direct the synthesis of proteins. As you learned in Section 2.4, each protein is a polymer of amino acids in a unique sequence. The role of DNA, therefore, is to put amino acids in the desired sequence *before* peptide bonds form between each pair of amino acids.

There are 20 different amino acids that are incorporated into proteins; so the DNA molecules must be able to "write code" for at least 20 amino acids. The coding system of DNA is created from only four different **nucleotides** that are the monomers of the large DNA polymer.

Another type of nucleic acid, **ribonucleic acid** (**RNA**), is similar to DNA and also serves important roles in protein synthesis. Messenger RNAs carry the genetic code from the DNA to the sites of protein synthesis in the cell, and transfer RNAs are relatively small molecules that bring the amino acids to the site where they are aligned in proper sequence.

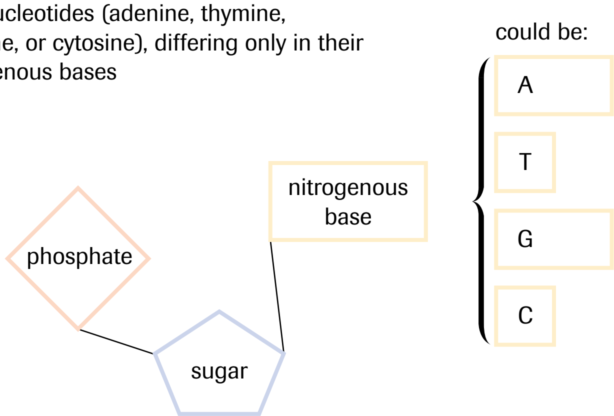
deoxyribonucleic acid (DNA) a polynucleotide that carries genetic information; the cellular instructions for making proteins

ribonucleic acid a polynucleotide involved as an intermediary in protein synthesis

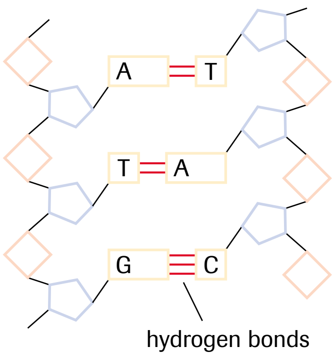
nucleotide a monomer of DNA, consisting of a ribose sugar, a phosphate group, and one of four possible nitrogenous bases

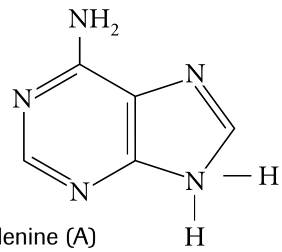
DNA Structure

monomers:
- four nucleotides (adenine, thymine, guanine, or cytosine), differing only in their nitrogenous bases

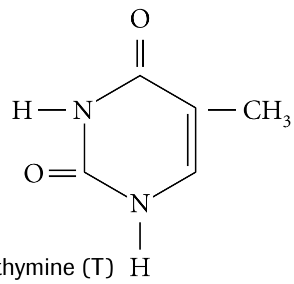


polymer:
- double helix with backbones of alternating sugar and phosphate groups
- opposite strands held together by hydrogen bonding between pairs of nitrogenous bases (A–T and G–C)

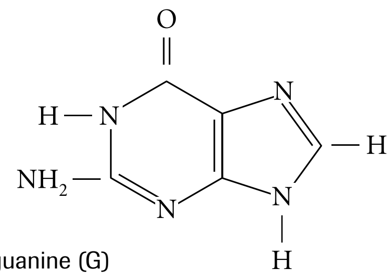




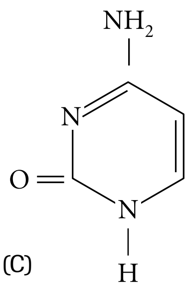
adenine (A)



thymine (T)



guanine (G)



cytosine (C)

Figure 1
The structure of DNA

DID YOU KNOW?

Antibiotics

Bacterial cells are quite different from animal cells such as our own. However, protein synthesis is essential to survival in all types of cells. Many antibiotics take effect by specifically blocking protein syntheses in bacterial cells. For example, tetracyclines inhibit protein synthesis in a bacterial cell by interfering with the binding of nucleic acids that align the amino acids. Streptomycin disrupts bacterial protein synthesis because it causes the DNA sequence to be "misread."

There are three main parts to each nucleotide: a phosphate group, a 5-carbon sugar called ribose (**Figure 2(a)**), and a nitrogenous base, which contains an amino group. The four different nucleotides differ only in the composition of the bases: adenine, thymine, cytosine, and guanine (**Figure 1**). In DNA, the ribose is "deoxy," meaning that it is "lacking an oxygen," a result of an –OH group being replaced by an H atom (**Figure 2(b)**).

(**a**) Ribose (in RNA)　　(**b**) Deoxyribose (in DNA)

Figure 2
The sugar part of monomers of RNA and DNA

These nucleotide monomers are linked to form polynucleotides—called nucleic acids—by condensation reactions involving hydroxyl groups of the phosphate on one monomer and the ribose of another monomer. The resulting ribose–phosphate–ribose–phosphate backbone is staggered rather than linear, giving the polymer chain a helical shape. Attached to this spiral backbone are the different bases with their amino groups.

double helix the coiled structure of two complementary, antiparallel DNA chains

As it turns out, not only is deoxyribonucleic acid helical in structure, it in fact occurs as two strands coiled together in a **double helix** (**Figure 3**). The ribose–phosphate backbone of the two DNA chains is held together by pairs of amine bases, one from each DNA chain. As shown in **Figure 1**, the bases contain –NH groups and C=O groups, between which hydrogen bonds can form. The helical structure of the long DNA strands allows the genetic material to be flexible and easily stored in the nucleus of the cell.

The double-stranded arrangement is also an ingenious design for cell replication, ensuring that exact copies of DNA can be made. Each strand in the DNA double helix is an exact "opposite" match of the other strand. When needed, each of the two strands makes its own new "opposite" partner, and so two new double-stranded DNA pairs are produced. How is one strand an exact "opposite" of the other? The maximum hydrogen bonding between DNA strands occurs only when adenine is paired with thymine, and when cytosine is paired with guanine; that is, only A–T pairs and C–G pairs are formed.

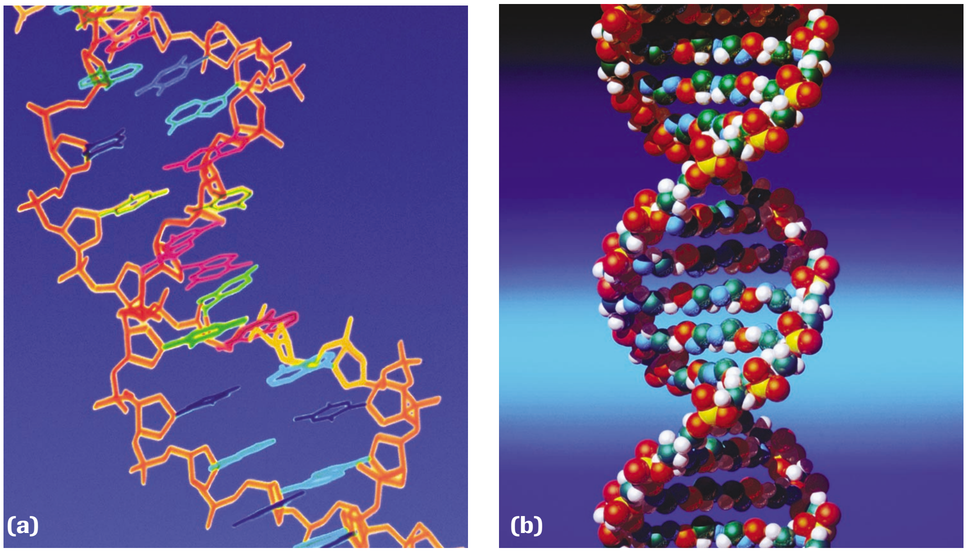


Figure 3
(a) The two DNA chains are held together by hydrogen bonding between the nitrogenous bases on each chain, A pairing with T, and C pairing with G.
(b) The double-helical structure of a DNA molecule

This restriction is dictated by the shape and size of the amine side chains (**Figure 3**). Thus, if one DNA strand has a sequence of AACC, its "opposite" partner has to be TTGG.

The deduction of this double helix structure was made in 1953 and won James Watson, Francis Crick, and Maurice Wilkins the 1962 Nobel Prize in Physiology and Medicine. Rosalind Franklin was credited for her contribution of X-ray diffraction work in the study.

Denaturation of DNA

Just as heat and changes in pH can denature globular proteins, they can also denature or "melt" double-helical DNA. Hydrogen bonds between the paired bases are disrupted, causing the two strands in the double helix to unwind and separate. This "melting" process is reversible on cooling, however, and if the two separated strands are partially attached, or come into contact, the remaining portions of the strands quickly "zip" together into the double-helical structure once again.

Some changes to DNA structure *mutations* occur spontaneously, others are accelerated by chemical agents. For example, the nitrogen bases of the nucleotides can lose an amino group; this reaction is accelerated by the presence of nitrites and nitrates, often found in small amounts as preservatives in meats such as hot dogs and sausages. High-energy radiation such as gamma rays, beta rays, X rays, and UV light can also cause chemical changes in DNA. For example, UV radiation can lead to the joining of two adjacent nitrogen bases, introducing a bend or a kink in the DNA chain.

Since the DNA sequence dictates the amino acid sequence in proteins synthesized by the cell, even a minor error can cause the wrong protein or no protein to be synthesized, leading to major malfunctions in an organism.

Practice

Understanding Concepts

1. What do the letters DNA stand for, and what is its main function in an organism?
2. Describe the three main components of a monomer of a nucleic acid.
3. What type of linkage joins the nucleotides
   (a) within a single DNA strand?
   (b) between two single DNA strands?
4. Write a balanced chemical equation for the condensation reaction between deoxyribose and phosphoric acid.
5. In what ways does the double-helical structure of DNA serve its function as a carrier of genetic information in a cell?
6. (a) Describe three causes of chemical alterations to DNA.
   (b) Explain briefly why a minor alteration in a DNA sequence can cause a change in cell function.

Section 2.6 Questions

Understanding Concepts

1. (a) Name the four nucleotides that make up deoxyribonucleic acid.
   (b) In what ways are these four nucleotides similar, and in what way are they different?
2. What is RNA and how is it similar to or different from DNA?
3. Discuss the advantage of a helical structure over a linear fibrous structure, in view of DNA's cellular function.
4. Discuss the role of hydrogen bonding in the structure of
   (a) single-stranded DNA
   (b) double-stranded DNA
5. Alterations in DNA structure, however minor, can have serious consequences for the organism. Explain what the consequences are and why they result.
6. An experiment was performed in which DNA molecules were extracted and completely hydrolyzed into their component nucleotides. The nucleotides were analyzed and it was found that the number of adenine bases was the same as the number of thymine bases, and the number of cytosine bases was the same as the number of guanine bases. What conclusions might you draw about the structure of DNA, based on the evidence obtained?

Applying Inquiry Skills

7. There are only four nucleotides in DNA to code for 20 amino acids in proteins. Each amino acid must have its own unique DNA code. Design and perform a numerical test to find out the minimum number of nucleotides that would be needed in order to assign a different code to each of the 20 amino acids. Show calculations to support your answer.

Making Connections

8. In this chapter, we have discussed the helical structure of three natural polymers: proteins, carbohydrates, and nucleic acids. For the three polymers,
   (a) compare the functional groups on their monomers;
   (b) compare the types of interchain interactions; and
   (c) compare the properties and function of the polymers.
9. Canadian biochemist Dr. Michael Smith won a Nobel Prize in Chemistry in 1993 for an ingenious technique he developed called "site-specific mutagenesis." Simply, he "knocked out" specific sites in a DNA sequence, and observed the effects on protein and cell function. Using the analogy of an unlabelled electrical fuse box or circuit-breaker box in a home, describe how Dr. Smith's technique can be used to decipher the circuitry and wiring in the home.
10. List and describe as many ways as possible in which you can reduce the risk of mutation of DNA in your skin cells from UV exposure.